Practical Math Calculations Training Resource

Contents

PRACTICAL MATHS

(Material courtesy of A.N.T.A. publications)

Section 1: Basic Mathematical Calculations
1.1 Fractions

A fraction is part of a whole number or unit of measurement. Represented as $\frac{a}{b}$, each fraction is made up of the;

Numerator - The figure positioned above the line which represents the parts of a whole number or unit of measurement. Eg.

$\frac{a}{\ }$

Denominator - The figure positioned below the line, the denominator is the number of units that make one whole.Eg.

$\frac{\ }{b}$

Addition

When adding together fractions it is essential that the denominators, the figure below the line in the equation, are the same. This allows you to operate with equivalent units.

When the denominators are the same for all of the fractions the process is simply to add together the numerators for each of the respective fractions, (the value above the line).

Example: $\frac{1}{7}+\frac{3}{7}+\frac{4}{7}=\frac{8}{7}$

$\frac{8}{7}$ is an **improper** fraction because the numerator is greater than the denominator. This improper fraction needs to be converted to a proper fraction.

To convert to a proper fraction divide the numerator by the denominator.

In this case 8 is divided by 7. As $\frac{7}{7}=$ 1, then the whole the fraction $\frac{8}{7}$ becomes 1 $\frac{1}{7}$.

When the denominators for each individual fraction are not the same and you still want to add them together, you need to identify the **lowest common denominator.**

The lowest common denominator is the lowest possible number that all of the existing denominators will divide into. Once you have found the lowest common denominator, you will then convert the fractions to this format.
To find the lowest common denominator follow these few steps.

1. Multiply the denominators of the individual fractions to find a common denominator.
2. Reduce the common denominator to the lowest number that all the original denominators will divide into.
3. Multiply each numerator by same amount its denominator was multiplied by when determining the lowest common denominator.
4. Add together all of the numerators and present the answer in its simplest form.

Example: $\frac{3}{8}+\frac{1}{10}+\frac{2}{5}$

Step 1. Common denominator = 8 x 10 x 5 =400

Step 2. Lowest common denominator = 40
(8, 10 and 5 will all divide into 40).

Step 3. Having found the lowest common denominator, each fraction in the example can now be thought of in another way:

$$\frac{3}{8} x \frac{5}{5} = \frac{15}{40} \qquad \frac{1}{10} x \frac{4}{4} = \frac{4}{40} \qquad \frac{2}{5} x \frac{8}{8} = \frac{16}{40}$$

Step 4. Similarly, when reducing a fraction to its simplest form following addition.

$$\frac{15}{40} + \frac{4}{40} + \frac{16}{40} = \frac{35}{40}$$

$\frac{35}{40}$ is not the simplest form of the fraction because 5 will divide exactly into both the numerator and the denominator.

Now divide numerator and denominator by 5.

Therefore: $\frac{35}{40} = \frac{7}{8}$

Subtraction

The principles used for adding fractions also apply when subtracting fractions. When subtracting the denominators of each individual fraction must be the same. In the event that they are not, as with addition, the **lowest common denominator** must be found.

Some ***Examples:***.

i). $2\frac{1}{4}-1\frac{3}{4}$ *converting to improper fractions this becomes*: $\frac{9}{4}-\frac{7}{4}=\frac{2}{4}=\frac{1}{2}$

ii). $\frac{2}{5}-\frac{1}{4}=\frac{8}{20}-\frac{5}{20}=\frac{3}{20}$

Multiplication

When multiplying fractions the denominators **DO NOT** have to be the same.

ie. $\frac{a}{b}\times\frac{c}{d}=\frac{ac}{bd}$

Example: $\frac{9}{11}\times\frac{3}{10}=\frac{27}{110}$

Division

Dividing fractions by fractions appears slightly more complex than addition, subtraction and multiplication.

ie. $\frac{a}{b} \div \frac{c}{d}$

The easiest method is to invert the second fraction

(in this case $\frac{c}{d}$ changes to $\frac{d}{c}$) and now multiply the two fractions together.

ie. $\frac{a}{b}\div\frac{c}{d}$ = $\frac{a}{b}$ x $\frac{d}{c}$ = $\frac{ad}{bc}$

Example: $\frac{1}{2}\div\frac{3}{4}=\frac{1\times 4}{2\times 3}=\frac{4}{6}\Rightarrow$ in its simplest form = $\frac{2}{3}$.

This process can be applied to all situations when dividing a fraction by a fraction.

1.2 Decimals

Decimals are another way of representing parts of numbers or units of measurement. A decimal, like a fraction, is part of a whole unit.

Adding and subtracting

When adding and subtracting decimals it is recommended that you use the column format, allowing you to keep the decimal places in line and correctly position them in the answer.

For example;

3.26 + 6.9 and 10.13 - 2.02 are best calculated using the column format where the decimal places can be carried down and the numbers added and subtracted respectively.

$$\begin{array}{r} 3.26 \\ +\underline{6.90} \\ 10.16 \end{array} \qquad \begin{array}{r} 10.13 \\ -\underline{2.02} \\ 8.11 \end{array}$$

Multiplying

When multiplying decimals you can follow this four step procedure:

1) Temporarily disregard or ignore the decimal place and treat the numbers as whole.
2) Multiply the numbers from step 1 to arrive at a total.
3) Count how many numbers in the original problem fell after a decimal place
4) Counting this number of spaces back from the right hand side insert the decimal place.

Example: 10.02 × 2.10

Step 1. Temporarily ignoring the decimal place the problem becomes 1002 × 210.

Step 2. 1002 x 210 = 210420.

Step 3. There were four numbers after the decimal places in the original equation.

Step 4. Counting back four places from the right hand side of the total figure 210420 from Step 2 gives the answer 21.042.

Tip

It also helps if you have some idea of the size of your answer. In this question we are multiplying a number close to 10 by a second number close to 2. Therefore, the answer should be near 20, not 2 or 200.

Division

The division of decimals by whole numbers is best calculated using the following procedure:

Example: $\frac{0.85}{5} = \begin{array}{r} 0.17 \\ 5\overline{)0.85} \end{array}$

When dividing a decimal by another decimal, the common practice is to make a whole number. To make a decimal a whole number you need to multiply the decimal by 10, 100, 1000 until you achieve a whole number:

ie 0.4 x 10 = 4.0

0.04 x 100 = 4.0

Once you have made the “dividing” decimal a whole number, you must multiply the other decimal in the equation by the same amount (ie 10, 100, 1000).

Example: 3.48 ÷ 0.4

0.4 is the “dividing” decimal

To make 0.4 a whole number multiply by 10 and do the same to the other decimal in the equation. So 0.4 becomes 4 and 3.48 becomes 34.8.

Now divide 34.8 by 4

$$\Rightarrow \quad \begin{array}{r} 8.7 \\ 4\overline{)34.8} \end{array}$$

So 3.48 ÷ 0.4 = 8.7

Tip

In this problem it is necessary to move the decimal “one place to the right” to convert 0.4 to 4. Use the same movement of “one place to the right” with 3.48 to get 34.8.

1.3 Converting Fractions to Decimals

When converting fractions to decimals without using a calculator, the numerator is divided by the denominator.

Example: $\frac{7}{8}$ converted to a decimal

= $8\overline{)7}$ $\Rightarrow$now since 7 is not wholly divisible by 8 it must be fractionally, so therefore the decimal point must be inserted.

= $8\overline{)7.000}$ $\Rightarrow$applying the principles of short division the conversion is calculated.

= $\begin{array}{r} 0.875 \\ 8\overline{)7.000} \end{array}$

The hard work is taken out of this process if you use a scientific calculator (see section 1.4).

1.4 Operating a Scientific Calculator

Addition, subtraction, multiplication and division of fractions and decimals, as well as conversions from fraction form to decimal form, can all be undertaken on a standard scientific calculator. Whilst the location of specific keys may differ from one calculator to another, the keys used to solve these mathematical problems are basically the same.

To enter a fraction into your calculator use the key with the symbol $\boxed{a\,{}^{b}\!/_{c}}$ or similar. This key, when pressed after each number in the fraction enables the user to carry out fractional calculations.

Example:

Stuart wants to calculate how much fuel he has left in the tank if he started his trip with $\frac{2}{3}$ of a full tank of fuel and consumed $\frac{1}{2}$ of the available fuel.

Calculation:

Manually:

$$\frac{2}{3} - \left(\frac{1}{2} \times \frac{2}{3}\right) = \frac{1}{3}$$

This is, the (Amount at start) - (amount consumed)

On the calculator press the following sequence of buttons;

2 $\boxed{a\,{}^{b}\!/_{c}}$ 3 - 1 $\boxed{a\,{}^{b}\!/_{c}}$ 2 × 2 $\boxed{a\,{}^{b}\!/_{c}}$ 3 $\boxed{=}$ $\frac{1}{3}$ (as given by the calculator).

When using a scientific calculator to tally figures with decimal points, simply input the figures using the $\boxed{\bullet}$ decimal point key.

Calculation:

Manually:

2.13 + 17.98 + 2.87 = 22.98

On the calculator press the following sequence of buttons;

2 $\boxed{\bullet}$ 13 + 17 $\boxed{\bullet}$ 98 + 2 $\boxed{\bullet}$ 87 $\boxed{=}$ 22.98

Written Activity 1

Use a scientific calculator or mental arithmetic to solve these short problems.

a) Calculate $\frac{4}{7} + \frac{3}{4} + \frac{1}{2}$

b) Add $2\frac{1}{3} + 3\frac{3}{7}$ and give the answers in its simplest form.

c) Calculate $3\frac{3}{4} + \frac{1}{5} + 1\frac{3}{8}$. Give your answer as an improper fraction and in its simplest form.

d) Subtract $\frac{3}{7}$ from $\frac{3}{4}$. What is your answer?

e) Calculate $2\frac{1}{8} - \frac{11}{4}$ Give your answer in its simplest form.

f) Multiply $\frac{3}{7}$ by $\frac{2}{5}$

g) Calculate $2\frac{1}{7} \times \frac{1}{4}$ Give your answer in its simplest form.

h) Divide $\frac{2}{5}$ by .$\frac{3}{7}$

i) Calculate $3\frac{2}{3} \times \frac{5}{7}$ (Give your answer in its simplest form).

j) Add 2.7 and 6.27

k) Multiply 10.65 by 7.4

l) Calculate 6.25 divided by 0.37 (Show the method you have used to obtain your answer).

m) Convert $2\frac{4}{5}$ into a decimal figure.

n) A fresh water tank holds 100 litres. If the tank is filled to $\frac{1}{5}$ capacity - how many litres of fresh water are in the tank?

o) If $\frac{1}{2}$ of the tank's full capacity is now added to the existing $\frac{1}{5}$ (from question n), how much fresh water is in the tank? Give your answer in litres and as a fraction of the tank capacity.

p) Water is pumped out at a rate of $8\frac{1}{4}$ litres per minute. A cavity holds 132 litres of water that needs to be pumped out. If the pump is in operation for a total period of 12 minutes;

i) Calculate how many litres are pumped out of the cavity in the given time.

ii) After finding your answer to part (i), what fraction of the cavity capacity still needs to be pumped out if it were to be emptied?

iii) How long would the pump need to operate to empty the cavity?

Check your answers at the rear of this workbook.

1.5 Transpose Formulae

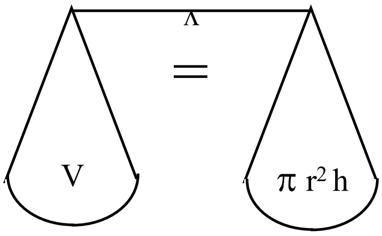
The formula for the volume of a cylindrical tank is given by:

$$\boxed{V = \pi r^2 h}$$

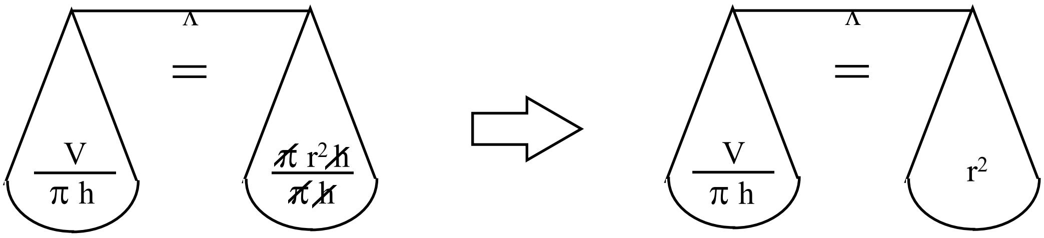
where V = volume of tank.
r = radius of circular end.
h = height or length of
tank
π = 3.14.

If the value of the radius must be found and all other information is known we make **r** the subject of the formula. ie. r =_______

But how do we determine the right hand side of the equation? First we must consider what an equation is. An equation can be best thought of as a balance arrangement like a set of scales. To keep things equal and balanced we must always do the same to both sides of the scales. In the above situation we have:



To get to the value of **r** we must remove all of the other symbols attached to it. Notice that $\mathbf{r^2}$ is multiplied by π and **h**. To remove this we must use the complimentary process to multiplication which is division. The equation must be divided by π and **h** on both sides to keep the balance:



We now have $\mathbf{r^2}$ (r squared) by itself on the right hand side of the equation. This is a good time to change the sides of the equation in order to get $\mathbf{r^2}$ on the left hand side, by swapping the information on either side of the **=** sign.

But $\mathbf{r^2}$ was achieved by squaring the radius. To undo this process we use the complimentary process of finding the square root of both sides of the equation.

$$\sqrt{r2} = \frac{\sqrt{v}}{\pi\ h}$$

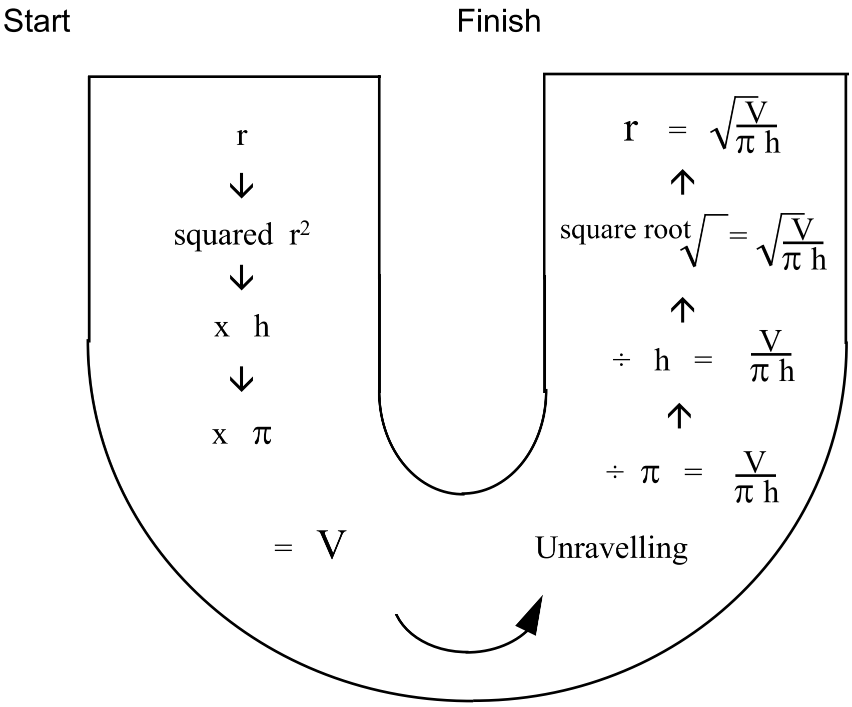
ie. **r** = $\sqrt{\dfrac{V}{\pi x h}}$

Now it is a simple matter of substituting (replacing) the values for **V**, π and **h** into the equation and calculating **r**.

In general, you would not draw up sets of scales on a mathematics page! But you will need to keep all the complimentary processes in mind.

Process	Complimentary Process
+	-
-	+
x	÷
÷	x
x^2	$\sqrt{\ }$
$\sqrt{\ }$	x^2

A second technique is to “unravel” the equation. Using the same example, start determining how the equation was put together by considering the unknown value **r**.



equation development

r	
r2	$\sqrt{\frac{V}{\pi x h}}$
x h	$\frac{v}{\pi x h}$
x π	$\frac{v}{\pi}$
= V	V

complimentary process to get “r” by itself

Assessment Checklist

Can you now:

☐ undertake basic mathematical calculations for addition, subtraction, multiplication and division of common fractions

☐ undertake basic calculations such as addition, subtraction, multiplication and division of decimal fractions

☐ convert common fractions to decimal fractions

☐ correctly operate a scientific calculator to mathematical order of operation

☐ transpose formula relevant to Marine Engine Driver Grade 1 mathematics

Section 2: Engineering Units and the Metric System

2.1 International System of Units

The International System of Units (SI Units) are standard measurements adopted for use throughout the world.

As different countries had varying systems of measurement (for example: imperial and metric) it was necessary to develop a system of units which could represent standard measurements for international trade.

This section deals with those SI units which are relevant to engineering and maritime. However, it is useful to first to look at the basic physical measurements that are generally sub-measurement of the SI units commonly found in engineering and maritime.

Common base measurements:

- **METRES** are the measuring scale for **DISTANCE (LENGTH)**
- **TONNES** are the measurement for **MASS**
- **SECONDS** are the measurement for **TIME**
- **TEMPERATURE** is measured in **KELVIN**

Many of the SI Units commonly used in engineering and maritime measure are derived from the base units mentioned above. This means that often a derived SI Unit is expressed as a combination of two or more base measurements.

Example:
Density is measured an object’s Mass per unit of Volume.

SI Units common to engineering and maritime:

- **DENSITY** is the measurement of a subject’s **MASS** per unit of **VOLUME**
- **NEWTONS** are the measurement for **FORCE**

One Newton of force is required to accelerate a Mass of one kilogram by one metre per second per second.

- **PASCALS** are the measurement for **PRESSURE**
- **JOULES** are the measuring for **ENERGY**
- **WATTS** are the measurement for **POWER**
- **METRES / SECOND** is a measurement for **SPEED**
- **METRES / SECOND** in a specific direction measures **VELOCITY**
- **TORQUE** is measured in **NEWTON/METRES**

It is important to note that some measurements in common use are not SI units eg. nautical miles. You will need to be cautious that the measurement you are using correctly defines the SI unit. Similarly if you are using a formula, you need to ensure that the measurements are consistent for all variables in the formula.

Example A: The measurement for **SPEED** in SI units is metres per second. But generally we refer to **SPEED** as kilometres per hour and in maritime we refer to **SPEED** as nautical miles per hour.

Example B: **SPEED** (kilometres/hour) =

$$\frac{\textit{DISTANCE (kilometres)}}{\textit{TIME (hours)}}$$

Tip

When calculating, you must also remember to always convert information into units that are compatible.

Example:

3m, 27.8 cm, 1010 mm

can be used in metres (3, 0.278, 1.01)

or in cm (300, 27.8, 101)

or in mm (3000, 278, 1010)

You decide the most appropriate, however be sure that the units used are the correct units for the formula and that they relate to the other variables in the formula.

From above:

$$\text{Speed (km/h)} = \frac{\textit{Distance}}{\textit{Time}} \quad \frac{\textit{km}}{\textit{(h)}}$$

Do not use:

$$\text{Speed (m/sec)} = \frac{\textit{Distance}}{\textit{Time}} \qquad \frac{\textit{km}}{\textit{(minutes)}}$$

2.2 Multiples of Units

The following are SI units. You will need to differentiate between these units and the more commonly used measurements which may either be multiple or a fraction of the SI unit.

THE METRIC SYSTEM

MEASURE OF:	UNIT NAME ABBREVIATION	EQUAL VALUE
Mass	1 Tonne (T)	= 1000 kilograms
Force	1 Newton (N)	Not applicable
Pressure	1 Megapascal (mPa)	= 100000 pascals
Energy	1 Kilojoule (kj)	= 1000 joules
Power	1 Kilowatt (kW)	= 1000 Watts
Distance	1 metre (m)	= 100 centimetres

2.3 Units of Measurement

Below are two measurement conversions that are useful to remember.

These conversions can be used to calculate:

- the speed at which you are travelling
- the time taken to complete a voyage
- the fuel consumed at a theoretical hourly rate or the total voyage consumption, and
- the distance covered.

NAUTICAL UNIT	SI UNIT
1 nautical mile	= 1852 metres
NAUTICAL SPEED	**METRIC SPEED**
1 nautical mile/hour = 1 knot	= 1852 metres/hour = 1.852 kilometres/hour

***Example A*.**

If a vessel travels 20 nautical miles, what distance would have been covered in metres?

Calculation: 1 nautical mile (nm) = 1852 metres

20 nm = 20 x 1852 m

= 37040 metres

***Example B*.**

A cruiser travels 23.15 kilometres per hour. What is the equivalent speed of the vessel in knots?

Calculation: 1 knot = 1.852 kilometres/hour

knot = 23.15/1.852

= 12.50

2.4 Converting Quantity and Volume to Mass using Relative Density

THE RELATIVE DENSITY, also known as the SPECIFIC GRAVITY, of a substance as a ratio measurement comparing the mass of a volume of one substance to the mass of an equal volume of fresh/pure water.

Formula:

$$\textbf{Relative Density} = \frac{\text{Density of the Substance}}{\text{Density of Fresh Water}}$$

RELATIVE DENSITY IS A RATIO AND AS SUCH HAS NO UNITS. ALL UNITS ARE COMMON AND THEREFORE CANCEL EACH OTHER OUT.

DEFINED VARIABLES

METRIC:

$1m^3$ = 1000 Litres Fluid Capacity

STANDARD FRESH WATER:

$1m^3$ = 1 Tonne

= 1000 Kilograms

THEREFORE:

1000 Litres = 1000 Kilograms

1 Litre = 1 Kilogram

To convert quantity and volume to mass it is useful to categorise mass on the basis of kilograms and tonnes, as these are recognised standard terms of measurement.

We know that **DENSITY =** $\frac{Mass\ (tonnes)}{Volume\ (cubic\ metres)}$

Note: In this formula Density of the substance can be replaced by Relative Density as defined earlier in this section (since density of fresh water = 1).

This formula can also be converted to:

MASS (tonnes) **= VOLUME** (cubic metres) × **RELATIVE DENSITY**

OR

MASS (kilograms) **= VOLUME** (litres) × **RELATIVE DENSITY**

When converting to mass follow the steps outlined in the example below.

- ***Problem: Conversion to Mass***

  What is the Mass of fuel in a rectangular prism tank that measures 2 metres in length, 8 metres wide and 1.5 metres deep if the fuel has a Relative Density of 80% of an equivalent volume of fresh water.

Volume **= Length × Width × Depth**
= 2 metres × 8 metres × 1.5 metres
= 24m^3 (cubic metres)

Mass (tonnes) **= Volume (cubic metres) × Relative Density**
= 24 × 0.8
= 19.2

The mass of fuel in the rectangular prism tank is 19.2 tonnes.

Problem: Given Mass calculate Relative Density

If oil weighs 900 kgs/m^3, what is its Relative Density?

Relative Density = $\frac{\text{Density of the Substance}}{\text{Density of Fresh Water}} \Rightarrow$ (*for the same volumes).*

Where: 1000kgs = 1m^3 of fresh water

Therefore: RD = $\frac{900 \text{ kgs / m3}}{1000 \text{ kg / m3}}$

RD of oil = 0.9

Interpretation: 0.9 means that for one cubic metre this sample of oil weighs 90% of an equivalent volume of fresh water.

Written Activity 2.4

a) Convert 27 nautical miles into the equivalent SI unit for distance.
Show your calculations.

b) If a vessel is travelling at 5 metres per second, how fast is this in kilometres per hour and knots. Show your calculations.

c) If a liquid has a mass of 2 tonnes and a volume of 4000 litres, what is its density?

d) A liquid has a relative density of 0.76. Explain what this means.

e) If a fuel tank measures 8m x 5m x 0.75m, what is the volume of the tank?

f) If a fuel tank has a capacity of 5750 litres and fuel has a relative density of 0.85, what is the fuel mass? Express your answer in tonnes.

Assessment Checklist

Can you now:

☐ identify SI units such as Kilograms, Tonnes, Newton, Newton metres, Pascals, Joules, Watts, Metres

☐ convert these units to multiples of base units (eg. grams to kilograms, pascals to megaPascals, watts to kiloWatts)

☐ convert the SI units of measurement to nautical units (eg metres to nautical miles)

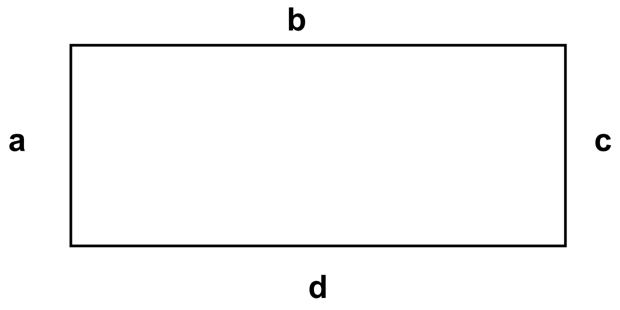
☐ convert metric speed to nautical speed (eg km/hour to knots)

☐ use relative density/specific gravity to convert quantity and volume to mass

Section 3: Calculating Tank Dimensions

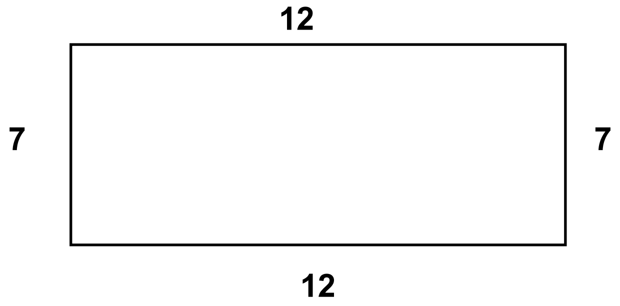
3.1 Perimeter

THE PERIMETER OF A RECTANGLE is the distance around the outside or boundary, calculated by adding the Lengths and the Widths.



Perimeter = a + b + c + d

Example: Find the perimeter of the rectangle below.



Perimeter = 7 + 12 + 7 + 12

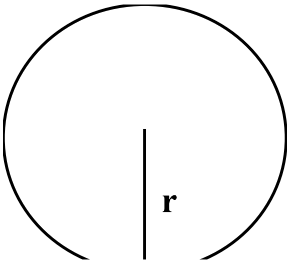
THE PERIMETER OF A CIRCLE, KNOWN AS THE CIRCUMFERENCE, is the distance around the outside of the circle and is calculated by applying the formula:

$$\boxed{\textbf{Circumference} = 2 \times \pi \times r}$$

Note: π or Pi is the ratio of the circumference to the diameter of a circle and is equal to 3.141592654, as given by a calculator, or approximately 3.14.

When using fractions π is approximately equal to $\frac{22}{7}$.

r is the radius of the circle (the distance from the centre of the circle to the circumference).



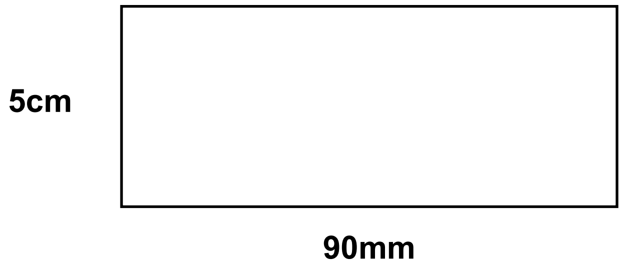
If r = 8 the circumference is:
= 2 x π x 8
= 50.26548246
= 50.27 units

Note:When using a calculator the number of decimal places shown on the screen will depend on the capacity of the calculator. For ease, it is common practice to round the value off to 2 decimal places.

In the example above, the answer was rounded to 50.27 because the third decimal place was equal to 5 or greater.

Written Activity 3.1- Perimeters and Circumference

a)



If each opposing side is of equal length, what is the perimeter of this rectangle in centimetres?

b) Calculate the circumference of a circle with a diameter of 18cm.

(Using the π function key on your calculator give your answer correct to 2 decimal places)

3.2 Areas of Common Shapes

Area is the measurement for two dimensional objects.

CIRCLES:

The **area of a circle** is given by using the formula:

$$\boxed{\text{Area} = \pi \times r^2}$$

Where: π = approximately 3.14, or as given by your calculator.

r = the radius of the circle, or half of the diameter.

Example:

Find the area of a circle with a diameter of 2.6cm. Give your answer to 2 decimal places.

$\text{Area} = \pi \times \left(\frac{1}{2} \times 2.6\right)^2$

$= \pi \times 1.3^2$

$= 5.309291585$

$= 5.31\ \text{cm}^2$

Written Activity 3.2 - Area

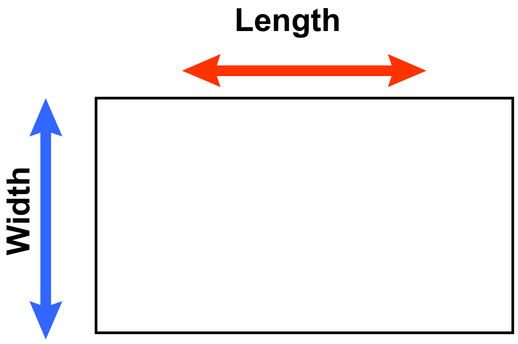
(A)Find the area of a circle with a diameter of 4.12 metres. Give your answer in square metres, correct to 2 decimal places.

(B)Calculate the area of a circle that has a radius of 55cm. Give your answer in square metres correct to 2 decimal places.

RECTANGLES:

The area of a rectangle is measured by multiplying the Length by the Width.

Area = Length (L) x Width (W)



Area = Length x Width

Example:

Find the area of a rectangle measuring 10.2 metres long and 6 metres wide.

AREA = L × W

= 10.2 × 6

= 61.2m ^{2} (square metres)

Written Activity 3.2 - Area

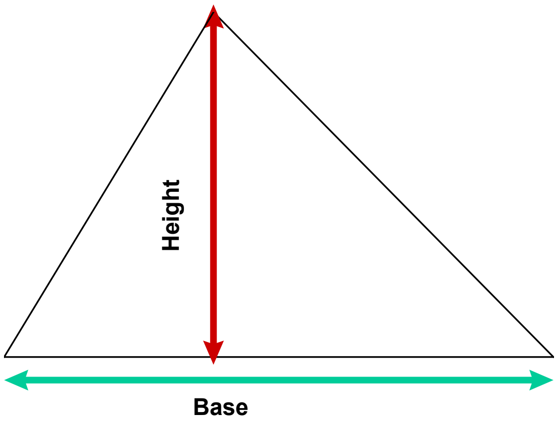
(C)Find the area of a rectangle that has one side 6.2m long and one 4700mm wide. Give you answer in square metres to 2 decimal places.

(D)What is the area of a rectangle measuring 870cm long and 3.7m wide. Answer in square metres to 2 decimal places.

TRIANGLES:

The area of a triangle is calculated by multiplying half of the base of the triangle by the height of the triangle. Or equivalently, the base can be multiplied by the height and the result then divided by two.

Area (A) = $\frac{1}{2}$ x base (b) x height (h)



Example:

What is the area of a triangle with a base of 3.8m and 1.1m high?

Area (A) = $\frac{1}{2}$bh

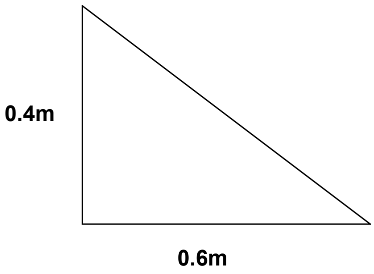
A = $\frac{1}{2}$ x 3.8 × 1.1

= 2.09m ^{2} (square metres).

Written Activity 3.2 - Area

e) Find the area of a triangle with a base of 260cm and a height of 0.85m. Give your answer in square metres correct to 3 decimal places.

f) What is the area of the triangle illustrated? Give your answer in cm^2.



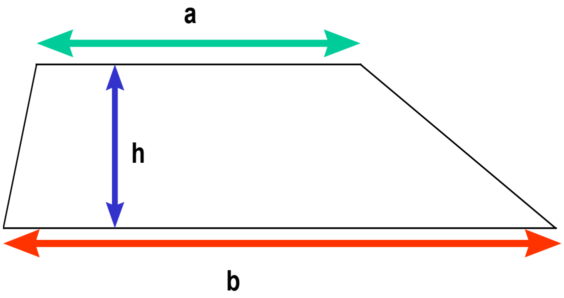
TRAPEZIUMS:

A trapezium is a four sided figure that has TWO parallel sides.

The area of a trapezium can be calculated by multiplying half its height by the sum of the two parallel sides.

Area = $\frac{1}{2}$ x height x (sum of the two parallel sides (a + b))

Diagram below – Where a & b are the parallel sides and h is the perpendicular (shortest) distance between them, the height.



Note:

Do not measure up one of the sides.

Example:

What is the area of a trapezium having parallel sides of 2.12m and 3.1m which are 1.2m apart ?

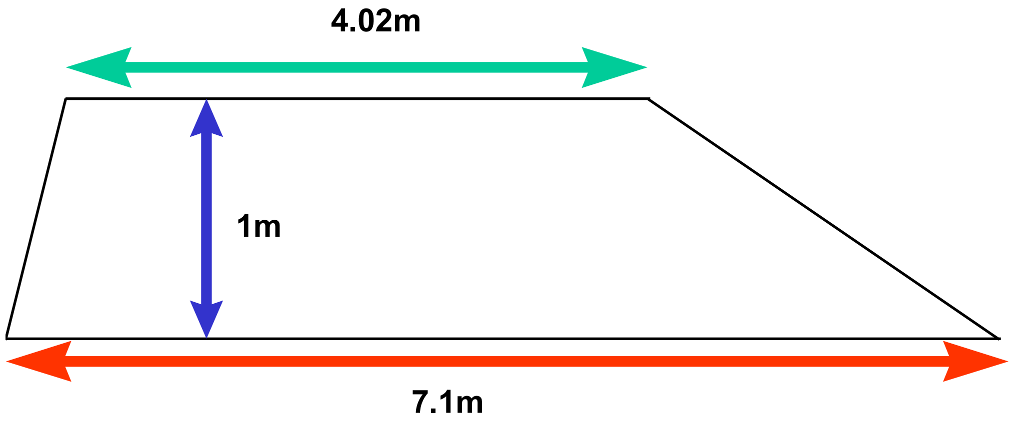
Area (A) $= \frac{1}{2} h\ (a + b)$

A $= \frac{1}{2} \times 1.2 \times (2.12 + 3.1)$

$= 3.132 m^2$ (square metres)

Written Activity 3.2 - Areas

g) Calculate the area of the trapezium below.



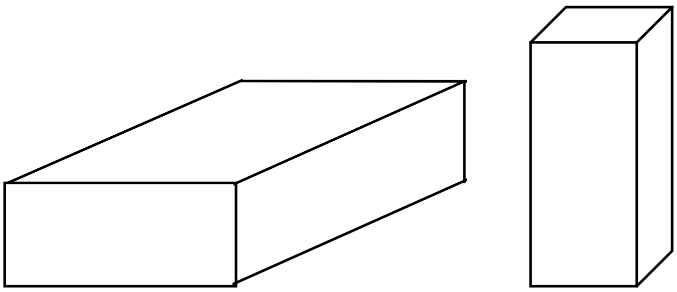
h) Find the area of a trapezium having parallel sides 600mm apart if these sides are 1.23 and 2.32 metres long respectively. Answer in square metres.

3.3 Tank Volumes

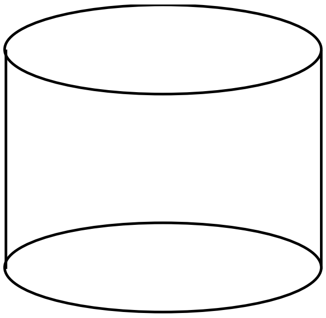
VOLUME is the capacity measurement for three dimensional objects, in this case, tanks.

For the purpose of calculations, the following tanks are defined as “regular” or “irregular” in shape:

Regular shaped tanks

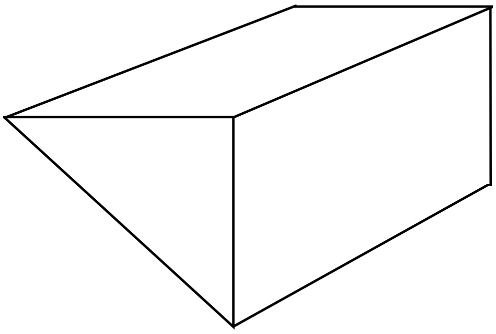


Rectangular Tanks

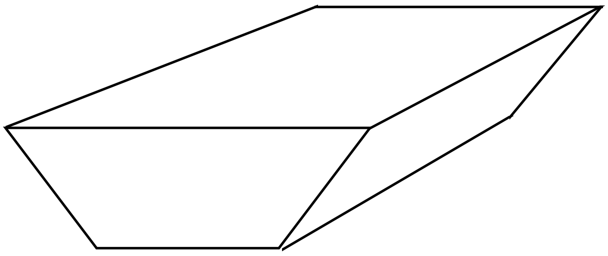


Cylindrical Tanks

Irregular shaped tanks

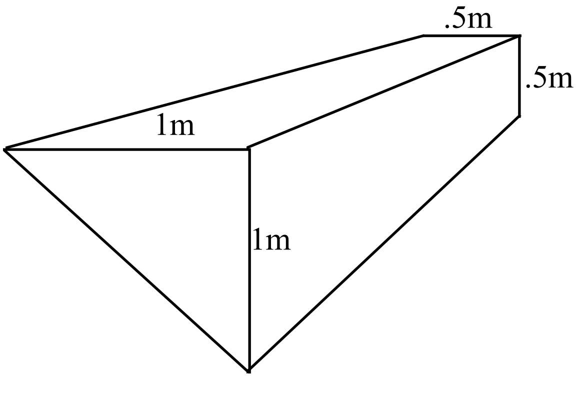


Triangular Tank

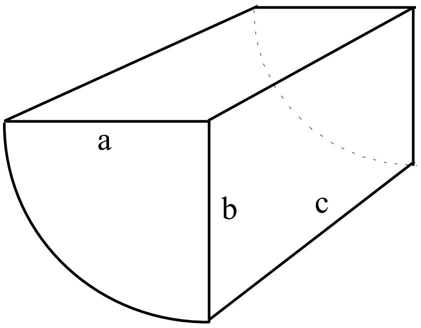


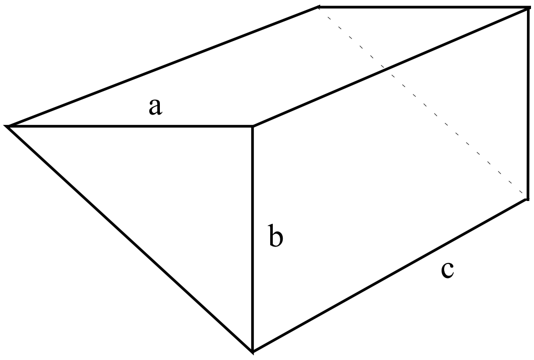
Trapezoidal Tank

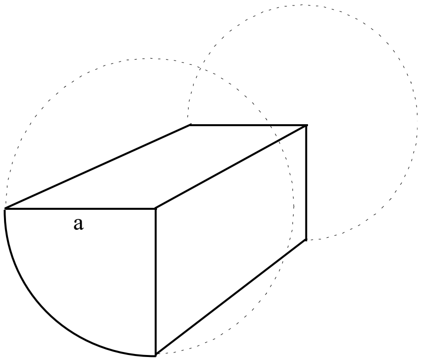
Also tanks that taper fit into this category.



In practical situations you may need to make calculations based on an approximate shape. For example, this curved tank can be approximated either to a triangular tank or a quarter of a cylinder depending on the lengths of **a** and **b** and the curvature of the side.







CAUTION:
When accurately calculating the volume of tanks you need to use the internal measurements of the tank (ie, excluding the thickness of the material which the tank is made from).

For example, if you are given the external measurements of a rectangular tank, you need to subtract the material thickness of each side off each external measurement.

Eg. Length - 2 x (material thickness)
Width - 2 x (material thickness)
Depth - 2 x (material thickness)

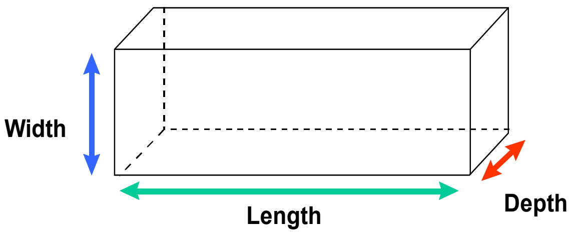
This calculation becomes more complex as the tanks take on irregular shape.

For ease, this workbook does not consider material thickness in examples or activities, however in practice you need to be aware of using internal tank measurements when calculating volumes.

RECTANGULAR TANKS:

To calculate the volume of rectangular tanks or prisms the formula to use is Length multiplied by the Width multiplied by the Depth of the tank.

Volume = Length (L) × Width (W) × Depth (D)



Example:
If a tank is 3.1m long and 2.24m wide, what would be its volume if the depth of the tank is 1.1m. Give your answer to 2 decimal places.

Volume (V) = L x W x D

$= 3.1 \times 2.24 \times 1.1$

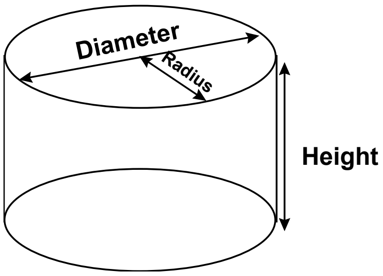
$= 7.6384\text{m}^3$

$= 7.64\text{m}^3$ (in cubed meters to 2 decimal places)

CYLINDRICAL TANKS:

The volume of a cylindrical tank is measured by multiplying the area of the circle by the height or length of the tank.

Volume = $\pi \times \text{radius } (r)^2 \times \text{height } (h)$



Example:
A cylinder has a circular base of 1.8m in radius and stands 2.2m high. What is the capacity of the cylindrical prism?

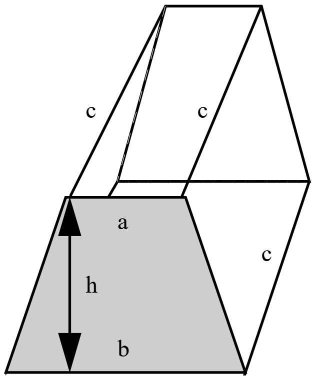
Volume = $\pi r^2 \times h$

$V = \pi \times 0.9^2 \times 2.2$

$= 5.598318109\text{m}^3$

Trapezoidal tanks

Given the shape of some vessels and the limited space available below decks, it is often necessary to make fuel tanks in an irregular shape.



The area of a trapezium (grey shaded shape) is calculated by multiplying half its height **h** by the sum of the two parallel sides **a** and **b**.

$$\textbf{Area} = \frac{1}{2} \times h \times (a+b)$$

$$= \frac{1}{2} h(a+b)$$

Once you have calculated the area of the base, you can calculate the volume of the tank by multiplying the area of the base by the depth **c**.

Volume = Area of base x c

Example:
Referring to the above shape, calculate the volume if the dimensions of the tank are:

a = 1.5, b = 3, c = 4 and h = 2

Area $= \frac{1}{2} \times h \times (a+b)$

$= \frac{1}{2} \times 2 \times (1.5 + 3)$

$4.5\ m^2$

Volume = Area x c

= 4.5 x 4

=$18m^3$ or the tank has a volume of 18 cubic metres

Written Activity 3.3 - Volume

a) What is the volume of a tank measuring 7.1m long, 3m wide and 4500mm deep? Give you answer in m^3.

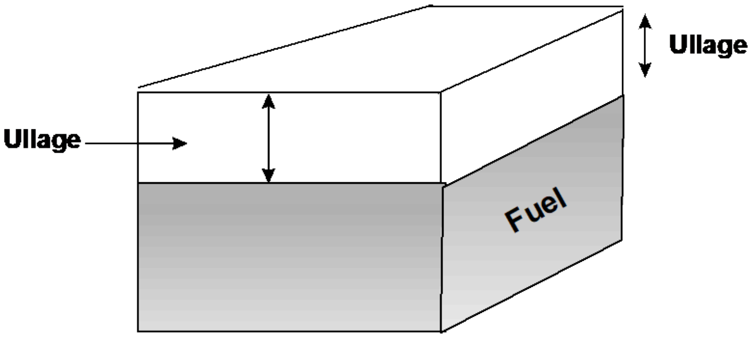
b) What is the volume of a ballast tank measuring 3080mm long, 1420mm wide and 64cm deep? Give your answer in m^3. What is this tank's capacity in litres, to 3 decimal places.

HINT: 1 Litre = 0.001m3 OR 1000 Litres = 1m3

c) Find the volume of this cylindrical fresh water tank if the tank has a diameter of 6.2m and a length of 424.2cm. Give your answer to 2 decimal places. What is the capacity of this fresh water tank in litres?

3.4 Ullages or Sounding of Fuel

Ullages or sounding of fuel are the amount by which the fuel falls short of filling the tank.



The volume of this tank is calculated by multiplying its Length by its Width by its Depth.

If the tank is 2.4m long, 1.84m wide and 1250mm deep, calculate the volume of the tank in cubic metres.

Calculation:

Volume = Length (L) × Width (W) × Depth (D)

Volume = 2.4m × 1.84m × 1.25m

=5.52m^3

Having found the tank's volume, you can next calculate the volume of fuel or the tillage by determining the depth of fuel in the tank.

Tip

The fuel will cover the length and width of the tank and only the depth will change when the volume changes.

Ie if the volume of fuel in the tank increases, the depth of fuel will increase and the ullage will decrease proportionately.

Once you have found the depth of fuel in the tank you can calculate the volume of fuel using the formula:

V = L x **W** x **D**

By subtracting the volume of fuel from the total volume of the tank, you will have calculated the ullage.

Example:

If a fuel tank has internal dimensions of :

L = 2.1m

W = 1.6m

D = 1.0m

but the fuel depth is only 0.2m, what is the ullage?

Calculation:

Step 1: Calculate the tank volume

V = L x W x D

V = 2.1 x 1.6 x 1.0

= $3.36m^3$

Step 2: Calculate the fuel volume

V = L x W x D

= 2.1 x 1.6 x 0.2

= $0.67m^3$

Step 3: Subtract the fuel volume from the tank volume to calculate the ullage.

Ullage = 3.36 – 0.67

= $2.69m^3$

Alternatively, if you know the depth of fuel, subtract this measurement from the depth of the tank. Use this answer to calculate the volume of empty space (the ullage) left in the tank.

Example:

If a fuel tank has internal dimensions of:

L = 2.5m
W = 1.75m
D = 1.25m

and the fuel reaches a depth of 0.8m, what is the ullage?

Give your answer in cubic metres.

Calculation:

Step 1:Depth of tank - depth of fuel

1.25 – 0.8 = 0.45m

Step 2: V = L x W x D

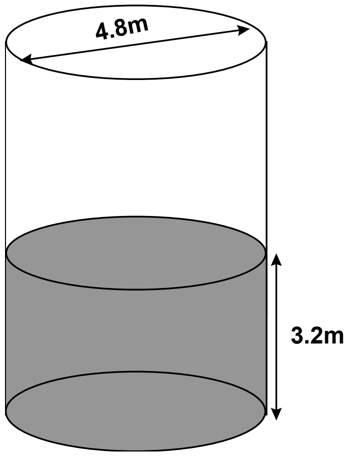
V = 2.5 x 1.75 x 0.45

= 1.97m^3

The ullage is 1.97m^3

Written Activity 3.4 - Volume

Calculate the volume of liquid in the illustrated cylindrical tank. Give your answer in cubic metres and litres. Calculate, in cubic metres and litres, the ullage given the total height of the tank is 6 metres. Give your answers to 2 decimal places.



3.5 Tank Height

When attempting to calculate the height of a tank given its volume, use the formula for volume.

For example, when calculating the volume of a rectangular prism shaped tank that is 4m long, 2.7m wide and 4200 mm deep we use:

$$
\begin{aligned}
\text{Volume} &= L \times W \times D \\
&= 4\text{m} \times 2.7\text{m} \times 4.2\text{m} \\
&= 45.36\text{m}^3
\end{aligned}
$$

Working with this same example to find the depth of the above rectangular fuel tank, given its capacity, we first write down the information we have:

Volume = 45.36m^3

Length = 4m

Width = 2.7m

Calculation:

Method 1 - substitute into the formula

$$\text{Volume} = L \text{ x } W \text{ x } D$$

$$45.36\text{m}^3 = 4\text{m} \times 2.7\text{m} \times D$$

$$\frac{45.36}{4 \text{ x } 2.7} = D$$

$$\frac{45.36}{10.8} = D$$

$$D = 4.2\text{m}$$

Method 2 - Rearrange the formula and then substitute values

V = L x W x D

Therefore $D = \frac{V}{LxW}$

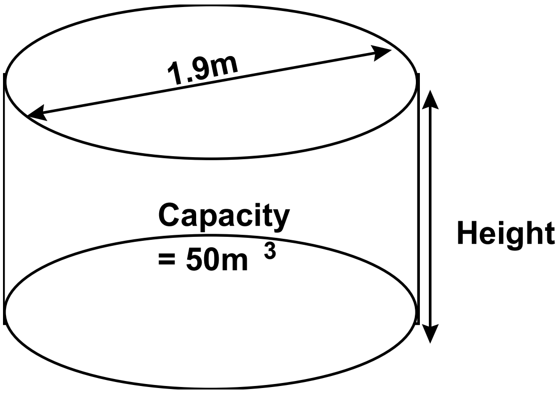
$D = \frac{45.36}{4 \times 2.7}$

$D = \frac{45.36}{10.8}$

D = 4.2 m

Written Activity 3.5 - Tank Height

a) Calculate the height of a cylindrical fuel tank given that it's diameter is 1.9m and the tank capacity is 50m^3. Give your answer correct to 2 decimal places.



Written Activity 3.5 -Your Task

b) Locate a regular shaped tank on your vessel. Write down what you understand is the tank's capacity (volume). Now measure the tank and calculate the actual volume.

Note: Be aware of the material thickness of the tank.

Should material thickness be considered in your answer?

Are the two volume measurements the same? If not, discuss this with your facilitator and recalculate your volume measurement.

Record the information here:

Known tank Volume =

Height of fuel tank =

Width = or Diameter =

Length =

Now, estimate the material thickness and take this into account in your calculations. Does this significantly effect your earlier estimation of the tank's volume?

Discuss this with your facilitator.

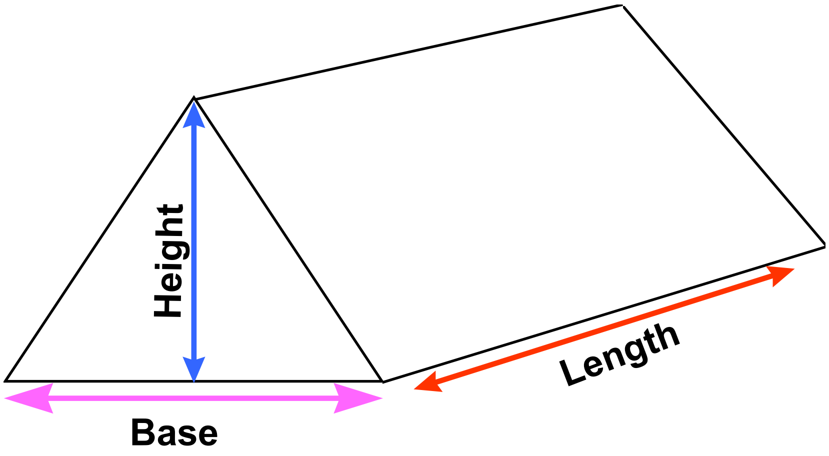
3.6 Irregular Shaped Tank Volumes

TRIANGULAR TANKS:

The volume of a triangular prism is calculated by multiplying the area of the triangle by the length of the prism.

Volume = $\frac{1}{2}$ base (b) × height (h) × length (L)

Volume = area x length = (1/2 base x height) x length



Example:

A triangular tank has a base of 1.4m, a height of 2.5m and a length of 4.1m. Calculate the volume of this tank in square metres and litres.

Calculation:

Volume = $\frac{1}{2}$ b × h × L

Volume = $\frac{1}{2}$ x1.4 × 2.5 × 4.1
= 7.175m^3

1m^3 = 1000 Litres

Volume = 7.715m^3 x 1000L/m^3

Volume = 7175 Litres

If this triangular tank is filled to two fifths of its capacity, calculate the volume of liquid in Litres and metres cubed.

Calculation:

Volume of liquid = $\frac{2}{5}$ x Volume of tank

V = $\frac{2}{5}$ x 7175 Litres

= 2870 Litres (the tank at two fifths capacity)

Volume at two fifths capacity (in m^3)

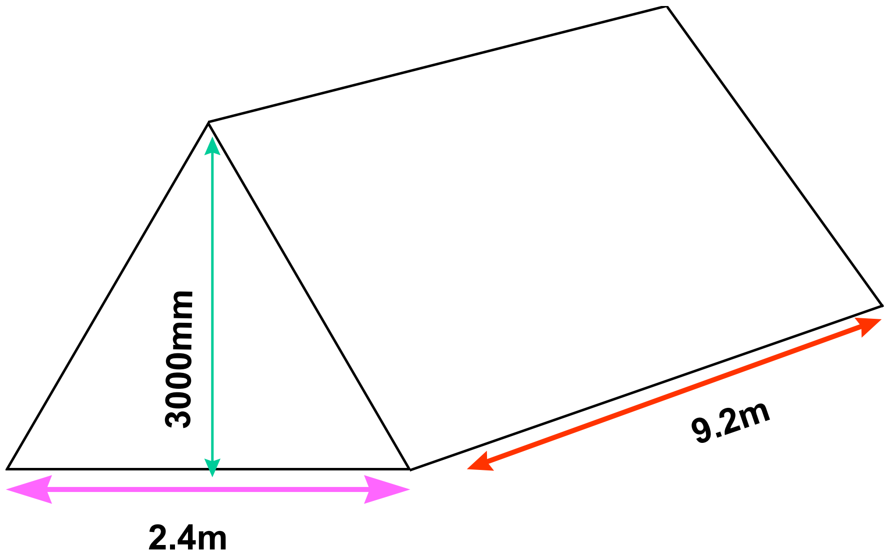
1000 Litres = $1m^3$

= 2870 Litres ÷ 1000Litres/m^3

= $2.87m^3$

Written Activity 3.6 - Volume of Part Filled Triangular Shaped Tanks

a) Calculate the volume of the irregular shaped tank illustrated below.

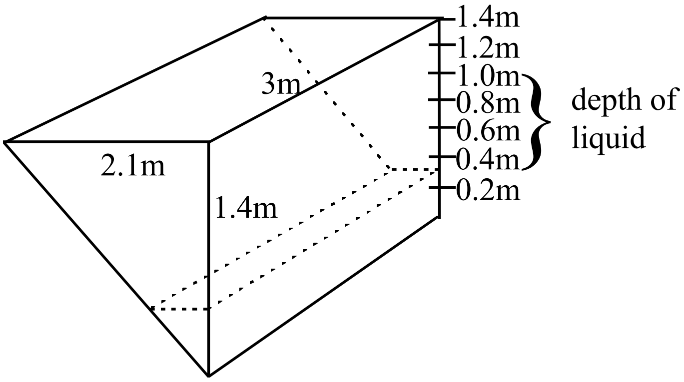


b) What is the capacity of this irregular shaped tank in Litres?

c) If this tank is part filled to one sixth capacity, how many litres of liquid is in the tank?

d) What is the volume of the tank, in cubic metres, when it is holding one sixth of its capacity?

e) Triangular tanks can be deceptive when calculating liquid quantities. A triangular tank with liquid half way up the side will not be half full. To illustrate this point, complete the following table for the tank shown:



Depth of liquid (m)	Volume of liquid (L)
0.2	
0.4	
0.6	
0.8	
1.0	
1.2	
1.4	

Tip

You must use proportions to calculate the width of the liquid as the container has more liquid in it.

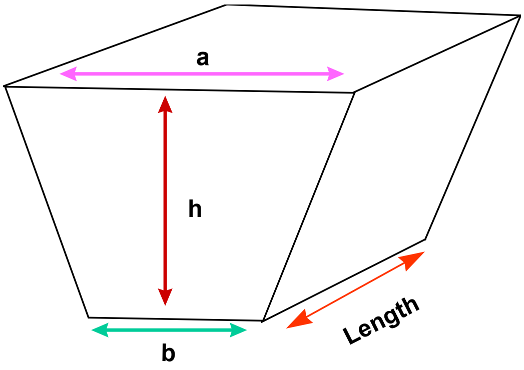
0.2 is $\frac{1}{7}$ of the vertical side, so the width will be $\frac{1}{7}$ of 2.1m. ie. 0.3m. Volume can then be calculated.

TRAPEZOIDAL TANKS:

The volume of a trapezoidal shaped tank is calculated using the following formula:

VOLUME = AREA OF TRAPEZIUM × LENGTH OF PRISM

$$\frac{1}{2} \times \textbf{\textit{height}} \times \textbf{\textit{(a + b)}} \times \textbf{\textit{length}}$$



Example:

A tank measures 3.2m long and has ends in the shape of a trapezium, with parallel sides of lengths 4.2m and 3.7m which are 1000mm apart. Find the volume of the tank in cubed metres and its fluid capacity in litres.

Calculation:

Volume $= \frac{1}{2} \times \text{height} \times (a+b) \times \text{length}$

Volume $= \frac{1}{2} \times 1 \times (4.2 + 3.7) \times 3.2$

$= 12.64\text{m}^3$

Capacity $= 12.64\text{m}^3 \times 1000 \text{ Litres / m}^3$

$= 12640$ Litres

If this tank is currently holding 3160 litres of fuel, what fraction of the tank is filled.

Calculation:

= 3160 litres ÷ 12640 litres

$= \frac{1}{4}$

Written Activity 3.6 – Volume of Part Filled Trapezoidal Shaped Tanks

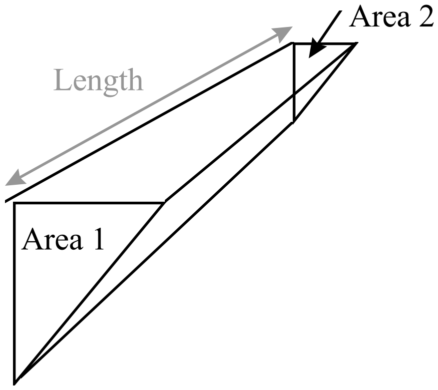
f) What is the volume, in cubic metres and the fluid capacity (litres) of a fuel tank measuring 2.1m long with trapezoidal ends of parallel sides 4.2m and 6.8m being 2400mm apart?

g) Using the fuel tank from part (a) calculate the litre capacity of the tank if it is filled to half of its volume.

TAPERED TANKS:

Some tanks are tapered and require an additional process when calculating the volume:

Where two ends are the same shape (but have different areas due to the tank becoming narrower over its length) calculate the volume in the following manner.



VOLUME = $\frac{Area1 + Area2}{2}$ **X Length**

This calculation will work with any tank that has flat sides.

Assessment Checklist

Can you now:

☐ use calculations to determine the perimeter (circumference) of rectangles and circles

☐ calculate the areas of circles, rectangles, trapeziums and triangles

☐ calculate the volume of regular shaped tanks including rectangular prisms and cylindrical tanks

☐ calculate volumes of fuel in tanks given ullages or sounding of fuel

☐ calculate height of fuel in tanks given the volume

☐ calculate the volume of part filled fuel tanks of irregular shapes (eg triangular and trapezoidal shaped tanks)

Section 4: Calculating Tank and Pumping Capacities

1.1 Fuel in Litres for Regular Tanks

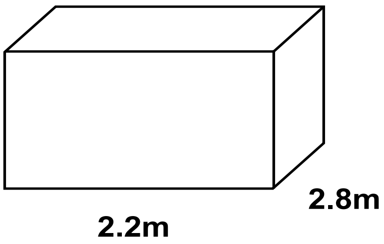
To determine the quantity of fuel in Litres for regular shaped tanks follow these basic steps.

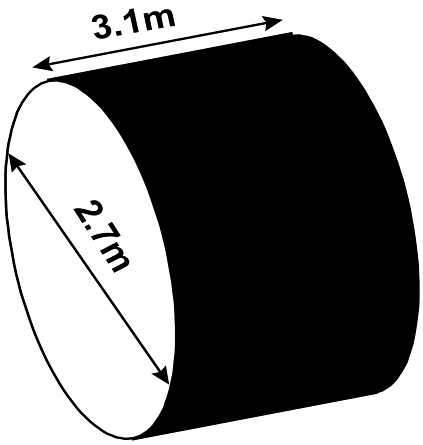
Step 1.Calculate the volume of the tank in m^3 (using the appropriate volume formulas for regular shaped fuel tanks).

Step 2.Convert this to litres given **1 m^3 = 1000 Litres.**

Example:

Calculate the quantity of fuel in litres for the following regular shaped fuel tanks.





Volume = L × W × D

= 2.2 × 2.8 × 1.1

= 6.776 m^3

6.776 m^3 = 6776 Litres

Volume = πr^2 × *height*

= $\pi \times 1.35^2 \times 3.1$

= 17.749 m^3

Given ⇒ **1 m^3 = 1000 Litres**

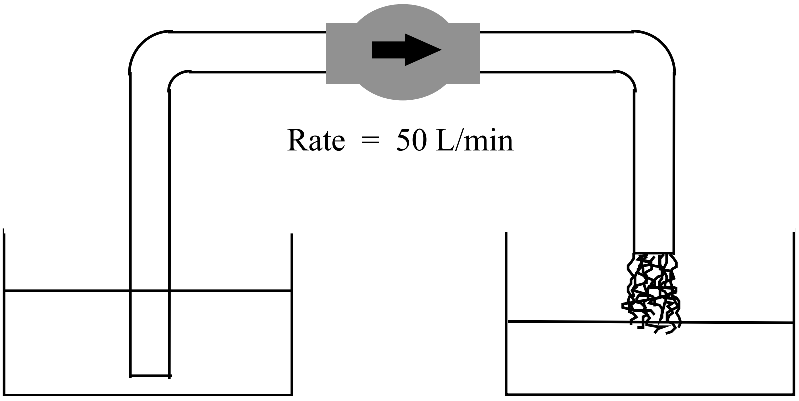
17.749 m^3 = 17749 Litres

Written Activity 4.1 - Volume in Litres

A regular shaped fuel tank is 4 metres long, 2 metres wide and 3.2 metres deep. Calculate the quantity of fuel in litres for this tank.

4.2 Pumps: Time and Flow rate

A flow rate is the measure of how quickly a pump can transfer a quantity of liquid. Flow rates of pumps are generally measured by the time required to empty a tank of specified size. The time required to empty a tank can be calculated given the flow rate of the pump. The flow rate of the pump can be determined provided the time taken to empty the tank has been stipulated.



Flow rates are measured as litres per minute, litres per second, or similar. If you know the flow rate and the quantity of liquid it is a simple matter to calculate the time taken to transfer the liquid. But first you need to know the flow rate of a pump. Manufacturer's specifications may no longer be accurate with an old pump. If this is the case, use the pump to transfer a known quantity of liquid and see how long it takes.

Flow rate (litres/minute) = $\frac{\text{Quantity of Liquid (litres)}}{\text{Time (minutes)}}$

Example: Flow Rate

A ballast pump can pump out a 5000 litre tank in 2.5 hours. What is its flow rate per minute?

5000 $\div$ 2.5 = 2000 litres per hour

2000 litres $\div$ 60 minutes

$=33\frac{1}{3}$ litres per minute

Example: Time required

Change the above formula to:

Time = $\frac{\text{Quantity}}{\text{Flow rate}}$

A ballast pump can empty out a 20000 litre tank in 2 hours. A feed pump can empty out the same tank in 4 hours. If a crew member used both pumps at the same time, how long would it take to empty the 20000 litre tank.

Total capacities per hour = $\frac{1}{2} + \frac{1}{4} = \frac{3}{4}$

Total time required = 1 hour ($\frac{60}{60}$) $\div$ $\frac{3}{4}$

= 1 $\frac{1}{3}$ hours

= 1 hour 20 minutes

Written Activity 4.2 - Time Required and Flow Rates

Calculate the time required to empty a 10,000 litre water tank, given the pump can pump at a rate of 3500 litres per hour for the first two hours and then slows to 1200 litres per hour thereafter.

4.3 Speed, Size and Flow Rate

Pumping calculations are useful when transferring or bunkering fuel from one tank to another. Time required, speed at which the task can be completed and the flow rate of the pump/s being used is essential information. If a vessel is stranded and needs to transfer reserve fuel from a holding tank into the main tank the time, speed and rate at which this can be done could be critical.

Provided you know two of the three variables, size of the tank and/or speed at which fuel can be pumped, and/or the time taken or required, the third can easily be calculated.

To calculate these variables work through the example below.

Example: Transferring or Bunkering Fuel

The reserve holding tank is of the same dimensions as the main fuel tank, but it is not connected to the main fuel line. Therefore, the fuel needs to be transferred or bunkered from the reserve holding tank to the main fuel tank.

The tanks measure 2.2 metres long, 1 metre wide and 0.8 metres deep (size). Using a split, common, pump line to transfer fuel from a full reserve tank to the main tank, calculate the time taken to fill the main tank, the flow rate is 4 litres per second.

Volume = L x W x D

Volume $= 2.2 \times 1 \times 0.8$

$= 1.76m^3$

If 1 m^3 = 1000 Litres

$1.76m^3$ **=**1760 Litres fuel capacity of each tank).

If the pump can expel and pass 4 litres per second, the time required to empty the reserve and fill the main is as follows:

$$\text{Time} = \frac{\text{Quantity}}{\text{Flow rate}}$$

$1760 \div 4(a) \div 60(b)$ = 7 minutes and 20 seconds to complete the task.

(a) Divided by 4 because it pumps four litres per second

$$= \frac{1760}{4}$$

= 440 seconds

(b) Divided by 60 because there are 60 seconds per minute

$= \frac{440}{60}$

= 7 mins 20 seconds

Written Activity 4.3: Pumping speed and flow rate

A vessel has two fuel tanks, both measuring:

L = 4.2m, W = 2.15 m and D = 1.05m.

a) Calculate the capacity of each tank.

b) If a pump can transfer fuel between the two tanks at a rate of 205 litres every 30 seconds, how long would it take to transfer the full fuel load from one tank to the other (if the second tank is empty)?

c) A tank measuring 3m x 3.5m x 1.8m is full of fresh water that is contaminated. A pump with a flow rate of 5.6 l/sec runs for 53 minutes. What quantity of water remains in the tank?

4.4 Transferring with different flow rates.

The same principles from the example in 4.3 apply when calculating transferring or bunkering capacities for pumps of different flow rates operating in parallel.

Example: Transferring Capacities for Pumps of Different Flow Rates.

A new pump has the capacity to transfer fuel from one tank to another at a rate of 8 litres per minute. An older model pump has the capacity to transfer fuel from one tank to another at a rate of 3.2 litres per minute. Calculate the transferring capacities to the nearest minute for these two pumps, with different flow rates, if they are operating in parallel to fill a 960 litre tank.

Calculation:

The new pump can fill the tank in: $960 \div 8$ = 120 minutes = 2 hours

The old pump can fill the tank in: $960 \div 3.2$= 300 minutes = 5 hours

Total capacities per hour $= \frac{1}{2} + \frac{1}{5} = \frac{7}{10}$ = 0.70 = 70%

To calculate the time required to fill the tank:

a) From above we know that the two pumps can fill 70% of the tank in one hour (60 minutes).

b) If it takes 60 minutes to fill 70% of the tank then 10% of the tank can be filled in 8.57 minutes (60÷7)

c) Multiply the time in (b) by 10, to calculate the time it takes to fill the whole tank (100%)

= 8.57 minutes × 10

= 85.71 minutes

= rounded to the nearest minute

= 1 hour 26 minutes

Written Activity 4.4: Different flow rates

If a tank has a volume of 3 cubic metres, how long would it take to empty the full tank using two pumps each having a pumping capacity of 5 litres per minute and 10 litres per minute respectively. The pumps will be used simultaneously.

Assessment Checklist

Can you now:

☐ calculate the quantity of fuel in litres for tanks of regular shapes

☐ calculate time required to pump a fuel tank given the flow rate of pumps

☐ use speed, size and flow rate to determine pumping calculations for transferring/bunkering of fuel tanks

☐ calculate transferring/bunkering capacities for pumps of different flow rates operating in parallel

Section 5: Calculating Fuel for a Voyage
5.1 Amounts of Fuel

The conversion of volumes to quantity enables fuel quantities to be determined and is achieved using the formula already discussed;

$1\ m^3 = 1000$ litres

Now we can calculate the amounts of fuel used for a voyage.

When given different variables, such as the speed of the vessel; the reduced level of fuel in the tank; the fuel consumption at various speeds, the amount of fuel used by the vessel on a voyage can be calculated.

Example: Fuel Used on a Voyage

A trawler has a cylindrical fuel tank 3 metres long with a diameter of 2.6 metres. How much fuel is left in the tank if the trawler takes 9 hours to complete the voyage at a constant low speed consuming 75 litres / hour.

Calculation:

Volume $= \pi r^2 \times$ ***height***

$= \pi \times 1.3^2 \times 3$

$= 15.928 m^3$

Where ($1\ m^3$ = 1000 Litres)

= 15.928 x 1000 = 15928 litres

Fuel Consumption = no. of litres per hour x time

= 75 litres x 9 hours

= 675 litres

Remaining Fuel = 15928 - 675

= 1525 litres

Written Activity 5.1 Fuel quantities

A vessel has two irregular shaped fuel tanks. The first tank is a trapezoidal tank which is 0.75m high, 3.20m length and has two sides of 3.6 and 3.75m respectively.

The second tank is a cylinder with a length of 2.45m and a radius of 1.1m.

a) Calculate the quantity of fuel that each tank can hold.

If the vessel consumes fuel at a rate of 60 litres/hour when travelling at half throttle, how long can it travel before:

b) Changing from the trapezoidal tank to the cylindrical tank?

c) It finally runs out of fuel?

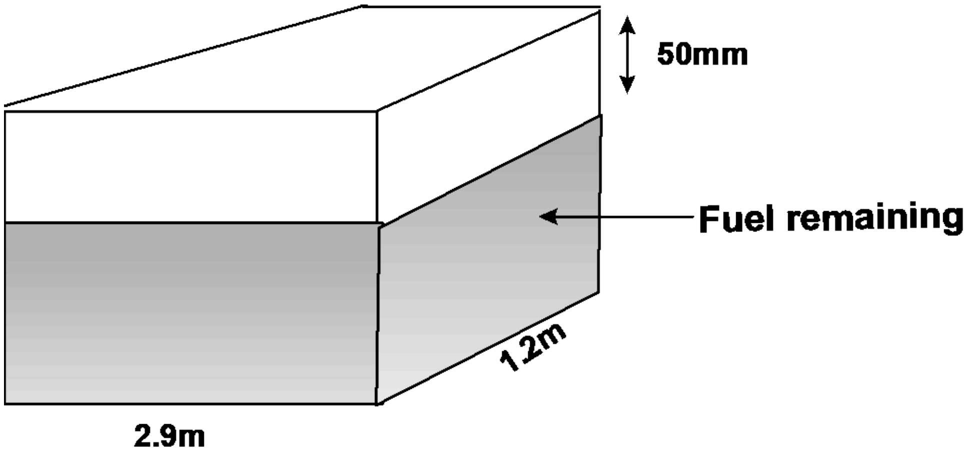
5.2 Quantity of Fuel and Ullages

To calculate the quantity of fuel used for a voyage, the soundings or ullages of fuel method can be used. The soundings for particular fuel tanks or ullages has been demonstrated in Section 3 of this workbook. Follow the example below for this method.

Remember: ullage or sounding of fuel is the amount by which the fuel falls short of filling the tank.

Example:

A cruiser has a fuel tank of the following dimensions;



How much fuel in litres, is used on a voyage if the level of fuel in the tank decreases by 50mm, (50mm is the ullage or sounding of fuel).

Calculation:

Volume of fuel consumed on the voyage:

$= 2.9 \times 1.2 \times .05$

$= 0.174 m^3$

1 m^3 = 1000 litres

$0.174 m^3$ = 174 litres

The vessel consumed 174 litres of fuel on the voyage.

Written Activity 5.2: Ullages

A vessel has two regular shaped fuel tanks, each measuring 3.35m length, with a height of 0.9m and being 2.69m wide.

a) Calculate the tank's volume.

b) If the tank is 75% full, what is the ullage? Give your answer in litres and as a measurement of tank depth.

c) If the fuel level fell by 0.15m during a voyage, how much fuel (in litres) was used?

5.3 Mass of Fuel and Relative Density

In Section 2 you were asked to calculate Mass, in kilograms and tonnes, given Relative Density and Volume. Now using the same formulas we can calculate the quantity or volume of fuel used for a voyage.

Formulas from Section 2:

Mass (tonnes) **= Volume** (cubic metres) × **Relative Density**

Mass (kilograms) **= Volume** (litres) × **Relative Density**

The quantity of fuel in litres used on a voyage, given the Mass and Relative Density, is calculated by applying the following formula;

$$\textbf{Volume (litres)} = \frac{\text{Mass (kilograms)}}{\text{Relative Density}}$$

Example:

The total mass of fuel in a full tank is 35 kilograms and it has a relative density of 70%, calculate the quantity of fuel in the tank (in litres) if the vessel has consumed 20% of the mass in one voyage.

Volume (litres) $= \frac{\text{starting mass} - \text{mass used}}{\text{relative density}}$

$$= \frac{35 - (35 \times 0.2)}{0.7} \quad \text{or} \quad \frac{35 x 0.8}{0.7}$$

$$= \frac{28}{0.7}$$

= 40 litres of fuel left in the tank after the voyage

Quantity of fuel used on the voyage;

$$= \frac{35 \times 0.2}{0.7}$$

$$= \frac{7}{0.7}$$

= 10 litres of fuel was used for the voyage

Written Activity 5.3: Fuel mass and relative density

If a vessel has a fuel tank with dimensions:

L = 2.75m,

W = 1.3m and

D = 1.25m,

a) calculate the volume of the tank in litres.

b) If the fuel has a mass of 396 kgs, when 9% full, calculate the relative density of the fuel.

Theoretical Hourly Fuel Consumption

When given the **speed** at which the vessel travels and the **distance** travelled, you can calculate the theoretical hourly fuel consumption of a vessel for a voyage.

The calculation is theoretical as other factors, such as pounding, wind force and sea behaviour, may influence the rate at which fuel is consumed on a voyage. Allowances need to be made for such factors when deciding how much fuel should be taken on a voyage.

To calculate the theoretical hourly consumption of fuel for a voyage follow these basic steps.

Remember: 1852 metres = 1 nautical mile

AND

1 nautical mile/hour = 1 knot

Step 1. Convert the distance to be travelled to nautical miles.

Step 2. Divide the distance by the speed in knots (nautical miles/hour) to determine the time taken for the voyage:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

$$\text{Time} = \frac{\text{Distance}}{\text{Speed}}$$

$$\text{Time (hours)} = \frac{\text{Distance (nm)}}{\text{Speed (nm/hr or knots)}}$$

Caution: Ensure that you use the correct measurements or convert to the correct measurements.

Step 3. Divide the total fuel consumption for the voyage by the time taken for the voyage to determine the average hourly fuel consumption

Example: Theoretical fuel consumption

What is the theoretical hourly fuel consumption for a vessel if it travels at a speed of 20 knots on a 280 nautical mile voyage that consumed 320 litres of fuel.

Step 1. 280 nautical miles (from the question)

Step 2. $\frac{280\ \text{nm}}{20\ \text{knots}}$ = 14 hours

Step 3. $\frac{320\ \text{litres}}{14}$ = 22.86 Litres (to 2 decimal places)

The theoretical hourly fuel consumption for the 280 nautical mile voyage is 22.86 litres per hour.

Using propeller pitch and RPM to calculate fuel consumption

Understanding the theory of engine revolutions, gearbox ratios and propeller pitch will assist you in calculating the speed and distance covered by your vessel.

Each engine will have a quoted engine speed, which will be the number of revolutions made by the engine per minute. This will depend upon the engine size and configuration.

eg. engine speed of 360 revolutions per minute (rpm).

A gearbox reduces the engine speed by a fixed ratio and rotates the propeller shaft.

Example:

If a gearbox has a ratio of 4 to 1, this means that for every four revolutions of the engine, the propeller will revolve once.

So if the engine speed is 360 rpm and the gearbox ratio is 4:1, the propeller will rotate at 90 rpm.

$$\textbf{Gearbox ratio} = \frac{\textbf{Engine speed}}{\textbf{Propeller speed}}$$

The propeller pitch is the theoretical distance a vessel will travel for one revolution of the propeller. The actual distance is less as there is slippage resulting from factors such as water action and wind

This is represented by the following formula:

Distance travelled (metres/minute) =

propeller pitch (metres) x propeller speed (rpm)

Example:

If a propeller speed is 500 rpm and the pitch is 1.1 metres, the vessel will travel a distance of 550 metres per minute.

D = Pitch x propeller speed

D = 1.1 x 500

D = 550 metres/minute.

Now convert this distance to nautical miles per hour (knots) as follows:

Speed = 33000 metres/hour (by multiplying metres and minutes by 60)

Remembering that 1852 metres = 1 nautical mile and that
1 nautical mile/hour = 1 knot

Speed = 17.82 nm/h or knots

Having used the propeller pitch and engine RPM to calculate the distance travelled by the vessel, it is possible to now determine the fuel consumption.

Example:

Using the previous example, if that same vessel undertook a voyage of 400 nautical miles and consumed 300 litres of fuel, what was the rate of fuel consumption?

Calculation:

From the previous example we calculated the vessels speed at 17.82 knots and we are advised that the vessel travelled 400nm and used 300 litres of fuel.

Speed = $\frac{\text{Distance}}{\text{Time}}$, now changing the formula

Time (hours) = $\frac{\text{Distance (nm)}}{\text{Speed (nm / hr or knots)}}$

Inserting the known factors:

Time (hours) = $\frac{400}{17.82}$

Time = 22.45 hours or 22 hours 27 minutes

Now divide the total fuel consumption by the time taken for the voyage:

Rate of fuel consumption = $\frac{300}{22.45}$

Rate of fuel consumption = 13.36 litres of fuel per hour

Fuel calculations using displacement, fuel coefficients and speed

Fuel consumption can also be calculated using the vessel's displacement, fuel coefficients and speed. The fuel coefficient is an indication of the vessel's engine efficiency. The higher the fuel coefficient, the higher the engine efficiency.

Fuel consumption, FC, can be calculated using the following formula:

FC per day = Vessel displacement (tonnes)$^2/_3$ x Speed (knots)3

Example:

A vessel has a displacement of 500 tonnes and a fuel coefficient of 75000. Determine the daily fuel consumption if the vessel travels at 17 knots.

Calculation:

FC per day = $\frac{\Delta^{2/3} \times S^3}{\text{fuel coefficient}}$

= $\frac{500^{\ 2/3} \times 17^3}{75000}$

= 4.13 tonnes

Specific fuel consumption

Specific fuel consumption is the mass of fuel consumed for each kilowatt of power generated by an engine.

Specific fuel consumption:

- is usually expressed in grams per kW. Hour (g/kW.hr)
- for diesel engines of around 1000kW, the specific fuel consumption is approximately 200 g/kW.hr

- is not always included in the technical manual, but if supplied it is usually included in the technical data section.

Written Activity 5.4

a) A vessel with a 200 tonne displacement and a fuel coefficient of 53500, travels at a speed of 14.25 knots. Calculate the fuel consumed in a day.

b) Calculate a vessel's hourly rate of fuel consumption if it travelled 472.5km at an average speed of 14 knots and consumed 750 litres of fuel.

c) A vessel has a cylindrical fuel tank with a length of 4.3m and a diameter of 1.4m. On a voyage taking 66 hours at an average speed of 13 knots, the vessel consumed 70% of the fuel from the tank. What was the fuel consumption rate? Round your answer to two decimal places.

d) If a vessel had an engine speed of 375 rpm and a propeller pitch of 1.25m, how much fuel would be consumed on a voyage lasting 267nm if the rate of consumption was 23 l/h.

5.5 Steaming Time Remaining

By determining the remaining fuel on board, it is possible to calculate the remaining steaming time available, provided you know the speed at which the vessel is travelling and its rate of consumption at that speed.

Example: Steaming Time Remaining

A vessel travelling at 18 knots, consumes 15 litres of fuel per hour. Given that the tank capacity is 900 litres when full, calculate the steaming time remaining if the fuel tank is two thirds full.

First: Determine the remaining fuel on board:

$\frac{2}{3}$ x 900 = 600 Litres.

Second: Calculate the steaming time remaining:

600 Litres ÷ 15 litres/hour = 40 hours of steaming time left.

Written Activity 5.5: Steaming time

A vessel has two irregular shaped fuel tanks. One tank has a capacity of 1200 litres and the other tank has dimensions of:

L = 2m, H = 0.5m and parallel sides of 1.3m and 1.1m respectively.

If the vessel consumes 12 litres of fuel per hour at 12 knots, how far can the vessel travel on two full tanks of fuel?

Assessment Checklist

Can you now:

☐ convert volume to quantity and determine amount of fuel used for a voyage?

☐ using tank soundings for particular fuel tanks, calculate quantity of fuel used for a voyage?

☐ given mass of fuel used and using specific gravity/relative density, calculate quantity of fuel used for a voyage?

☐ given speed and distance OR propeller pitch and RPM, calculate the theoretical hourly fuel consumption for a voyage?

☐ calculate the remaining steaming time available after determining the remaining fuel on board?

☐ assuming displacement and fuel coefficient remain constant, calculate increases in consumption relative to increases in speed of ships?

☐ calculate the quantity of oil required to replenish oil lost in lubricating oil storage tank

Section 6: Calculating Change in Draught

Draught, Buoyancy and Displacement

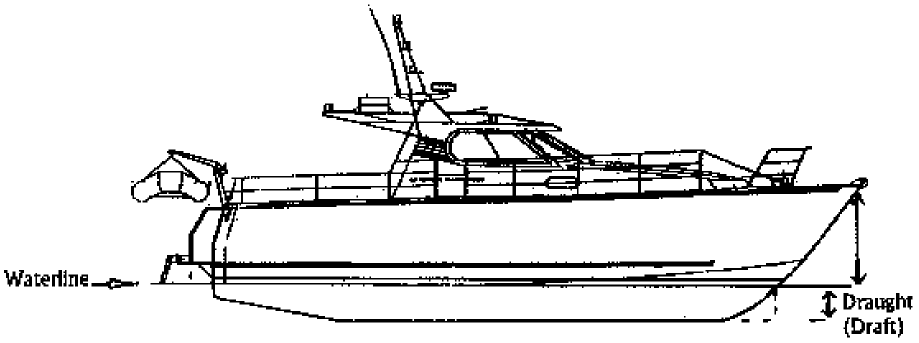
There are three regular hull shapes on vessels. These are:

- round bilge
- soft chine
- hard chine

Draught

Draught is best described as the submerged part of the hull, and measured as the vertical distance from the keel to the waterline.

The vessel in the diagram is used as a guide only, the important feature is the waterline in relation to the hull.



Buoyancy

In comparison, salt water is more buoyant than fresh water.

The relative density of salt water is 1.025.

The relative density of fresh water is 1.000.

When a vessel passes from salt water to fresh water the level of buoyancy decreases causing the vessel to “sit” lower in the water, resulting in an increase in the draught.

To calculate the increase in draught when the vessel passes from sea to fresh water you can follow the these steps:

Step 1. Measure on the hull the sea water line and mark it with a SWL label, Sea Water Level. The distance from the keel to the water line is the draught for sea voyaging.

Step 2. Measure and mark on the hull the fresh water line, the distance from the keel to the fresh water mark and label this FWL, Fresh Water Line.

Step 3. Calculate the increase in draught by subtracting the distance between the FWL and the keel from the distance between the SWL and the keel. Alternatively, you could measure the distance between the two lines.

Displacement

When in the water a vessel's hull displaces an amount of water.
This displacement is measured in tonnes per centimetre and known as TPC.
The process of accurately calculating a vessel's displacement is complicated given the various types and changing shapes of a vessel's hull.

For ease of understanding, we will work with a regular shaped pontoon as an example and assume that the pontoon has a length of 15m and width of 7m.

Step 1 Calculate the pontoon's Water Plane Area (WPA), which is the two dimensional area that the pontoon will cover on the water (ie, the top view).

WPA = Length x Width (m^2)

WPA = 15 x 7

= 105 m^2

Step 2 To calculate the pontoon's displacement or TPC use the following formula.

Displacement (t/cm) = $\frac{WPA\ x\ \mathrm{Re}\,lative\ Density\ of\ water}{100}$

Note that the relative density of fresh water and salt water are different.

So if the pontoon was in freshwater the displacement would be:

Displacement = $\frac{105\,x\,1.000}{100}$

TPC = 1.05

6.2 Draught and Full or Empty Tanks

When tanks are full the vessel will sit lower in the water due to the additional weight of the liquid.

When the tanks are empty the vessel will weigh less and will ride higher in the water. For a vessel with full tanks, the draught is greater than for a vessel with empty tanks.

To calculate this change in draught, physically measure the draught when the tanks are full and subtract the draught when the tanks are emptied. This gives the change in draught.

You may also use the following formula, but you should be cautious to ensure that the initial calculation of the vessel's TPC is accurate. Otherwise your calculations can only be taken as an estimate.

Increase in draught = $\frac{additional\ mass\,(t)\ x\,9.81\ (gravity)}{TPC}$

From the previous pontoon example:

If the pontoon was loaded with an additional mass of 1.3 t, the increase in draught would be:

Increase in draught = $\frac{1.3\ x\,9.81}{1.05}$

= 12.15 cm

Written Activity 6.2 - Draught

a) Outline below two situations that cause an increase in draught.

i) ____

____

____

ii) ____

____

____

Practical Activity 1 - Draught

Inspect the hull of a vessel, preferably one with which you have an association. With your facilitator, work through and familiarise yourself with calculating the draught of the vessel. Demonstrate your understanding, by pointing out markings to your facilitator

Assessment Checklist

Can you now:

☐ calculate the increase in draught when the vessel passes from sea to fresh water

☐ calculate the change in draught when tanks are filled or emptied

Section 7: Simple Levers and Machines

7.1 Terms Relating to Simple Machines

A LIFTING MACHINE/LEVER is a mechanism designed to assist with the lifting of heavy loads using relatively small forces.
EFFORT is the force that is applied to lift the load.

LOAD is the weight being lifted by the machine or lever.

MECHANICAL ADVANTAGE is the advantage or benefit of using a lifting machine to lift a big load with a small effort.

$$\textbf{Mechanical Advantage (MA)} = \frac{\textbf{Load Lifted (W)}}{\textbf{Effort Applied (P)}}$$

VELOCITY RATIO is the ratio of the distance moved by the effort to the distance moved by the load.

$$\textit{Where; VR} = \frac{\textbf{Distance Moved by the Effort}}{\textbf{Distance Moved by the Load}}$$

VR can be found with this formula and for pulley systems, can also be measured by adding the number of ropes supporting the load block ie. the total number of pulleys.

EFFICIENCY measures the work that has been done as compared to the amount of effort to supply the work. Expressed by the ratio of useful work done to work supplied, the formula is;

$$= \frac{\text{Useful Work Done}}{\text{Work Supplied}}$$

$$= \frac{\text{W (load) x distance W moves}}{\text{P (effort) x distance P moves}}$$

$$= \frac{\text{MA}}{\text{VR}}$$

MOMENTS is described as the movement or rotation of a physical quantity about an axis.

Written Activity 7.1- Simple Machines

A set of rope and pulley blocks has 4 sheaves in the top and 3 sheaves on the bottom. An effort of 500 Newtons is required to lift a load of 2.45 kilonewtons.

Calculate:
1.the mechanical advantage of using this lifting machine
2. the velocity ratio
3. the efficiency
Source several text books (possibly from your facilitator or a library) and research all of the terms described in this section. You may possibly note that each text book may give a slightly different definition and may use different examples. Discuss these with your facilitator and write down your own definitions below. Have your facilitator confirm your definitions.

____
____
____
____
____
____
____
____
____
____

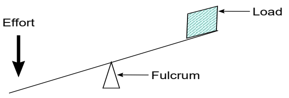
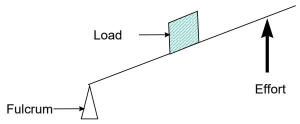
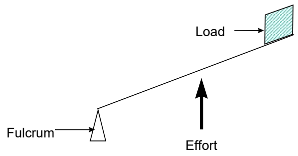
7.2 Simple Levers

Order of simple levers

Simple levers are identified from the Load, Effort and Fulcrum, the fulcrum being the pivotal point. Examples of simple lever systems include crow bars, see-saws or the balance of a dual tank system about the centreline of the vessel.

There are three basic orders (types) of simple levers. The order of the simple lever is determined by the position of the load with respect to the fulcrum. This will in turn determine the effort required to move, lift or balance the load.

TABLE OF SIMPLE LEVERS

1st order	2nd order	3rd order
		
A see-saw is a common example of a 1st order simple lever.	A crow bar is a common example of a 2nd order simple lever.	A mobile crane is a common example of a 3rd order simple lever.

Practical Activity 2: Simple levers

Search around your workplace and locate examples of simple levers. List these below and discuss their use with your facilitator.

1st order simple levers____

____

2nd order simple lever ____

____

3rd order simple lever ____

____

7.3 Using Moments

Moments are described as the movement or rotation of a physical quantity about an axis. Moments can also be referred to as stability or equilibrium.

An example of moments in maritime, is the ability of a vessel to return to its original upright position when laterally displaced.

When stable, a vessel's centre of gravity and centre of buoyancy are aligned. As the vessel becomes unstable and lists to one side, the centre of gravity and centre of buoyancy separate, creating a moment or force. The equilibrium effect is for the vessel to return to its original position.

To calculate moments, the following formula is applied:

Moments = Mass + (the distance from the axis or fulcrum)^2

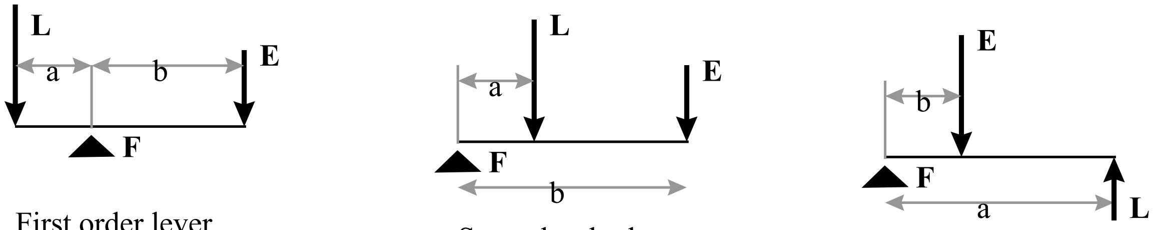
When there is equilibrium the Moments equal zero (M=0) and the following equation can be used.

Effort x Effort arm = Load x Load arm

Where: Effort arm is the distance from the effort to the fulcrum.
Load arm is the distance from the load arm to the fulcrum.

The following diagrams show how this formula relates to the three orders of levers.

Equilibrium of levers



First order lever

Second order lever

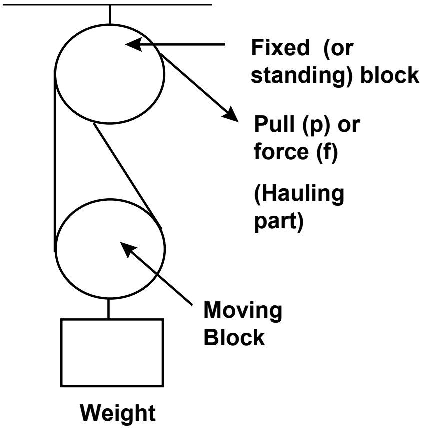
Third order lever

L = Load E = Effort F = Fulcrum a = Load arn b = Effort arm

7.4 Parts of a Simple Machine

Mechanical Advantage differs depending on the type of pulley system you use. The mechanical advantage can be determined by means of calculation.

By comparing the mechanical advantages of various pulley systems, you will be able to select the system that offers you the most appropriate mechanical advantage.



Example:
Determine the *MA* of the above lever system given that the rope pulley blocks used are 3 sheave blocks at the top and a 2 sheave block at the bottom. The effort of 400N (Newtons) is required to lift a load of 2.26 kN (kilonewtons).

Calculation:

$$MA = \frac{\textbf{Load}}{\textbf{Efford}} = \frac{\textbf{W}}{\textbf{P}}$$

$$= \frac{2.26\text{kN}}{400\text{N}} = \frac{2260\text{N}}{400\text{N}}$$

= 5.65

By using a different lever system, the effort required to lift the same load of 2.26kN is 150N. Calculate the mechanical advantage of this system and determine which is more efficient.
Calculation:

$$\text{MA} = \frac{\textbf{Load}}{\textbf{Effort}} = \frac{\textbf{W}}{\textbf{P}}$$

$$= \frac{2.26kN}{150N} = \frac{2260N}{150N}$$

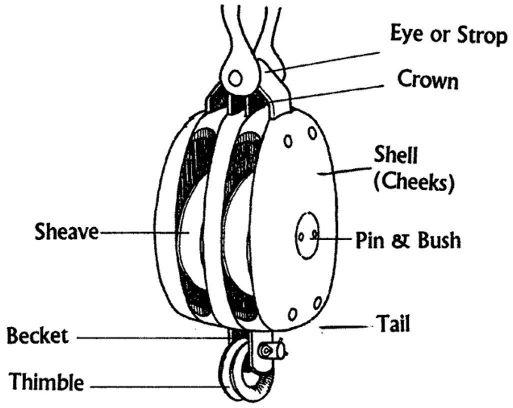
$$= \textbf{15.07}$$

The mechanical advantage of the second system is higher indicating that this system would be more advantageous than the first.

7.5 Effort Required and Load Lifted

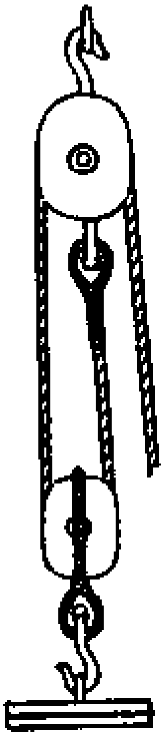
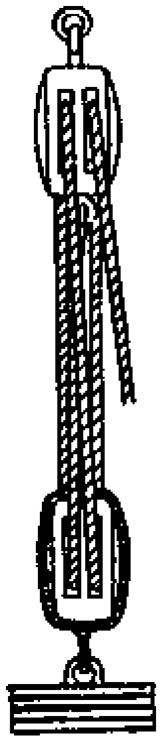
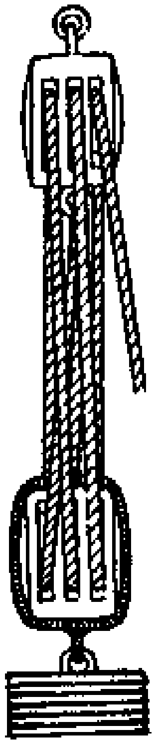
Simple machines

A simple machine is made up of two blocks and a rope. More complex machines employ a number of blocks. The type of machine used is determined by the type of block used, namely the number of sheaves in any one block. **THE PARTS OF A BLOCK**



The purpose of using simple lever systems is to increase the capacity of the rope above its Safe Working Load.

TABLE OF SIMPLE MACHINES

 Made up of two 1 sheave blocks.	 Made up of two 2 sheave blocks.	 Made up of two 3 sheave blocks.

Written Activity 7.5: Mechanical Advantage

a) In a rope and pulley system, a 2 sheave block is used at the top and bottom. Given the effort required to lift a load of 2.982kN is 420N, find the Mechanical Advantage when lifting this load.

b) Now find the MA of a system that requires an effort of 425N for the same weight.

c) Which system is the better?

Simple block and tackle

A simple block and tackle will be used to demonstrate how to calculate the effort required and load lifted. To calculate the effort required and the load lifted the formula for MA can be manipulated.

Effort Required (P) $= \dfrac{\text{Load Lifted}}{\text{Mechanical Advantage}}$

$= \dfrac{W}{MA}$

Load Lifted (W) = **Mechanical Advantage × Effort Required**

= **MA × P**

Example: Effort Required Find the effort required to lift a load of 1.26kN given the mechanical advantage of a lifting system is 4.2.

Effort Required $= \dfrac{W}{MA}$

$= \dfrac{1 \cdot 26}{4 \cdot 2}$

=0.3N

$\Rightarrow$ 300kN

Example: Load Lifted

Find the weight of the load lifted if the effort required to lift the load is 300N and the mechanical advantage of lifting the load is 4.2.

Load Lifted = **MA × P**

= 4.2 × 300

= 1260N

$\Rightarrow$ 1.26kN

7.6 Effects of Friction

When using lever or pulley systems be aware that friction also affects the load. If friction did not exist, then the effort required to lift the load would be the ***Ideal Effort**.* Theoretically, in a friction-less machine, ***MA*** would be equal to ***VR*.**

$$\textbf{\textit{Ideal Effort}} = \frac{W}{VR}$$

Example: If a load is 245N and the velocity ratio is 2.5, what is the ideal effort?

Calculation:

Ideal effort $= \frac{W}{VR}$

$= \frac{245}{2.5}$

= 98N

The **Effort** that would be required to overcome friction is equal to the actual effort applied, less the ideal effect and can be calculated by applying the following formula:

Effort to overcome Friction = Actual Effort -Ideal Effort

$$= P - \frac{W}{VR}$$

Example:

Using the ideal effort calculated in the above example and on actual effort of 5.3W, determine the effort required to overcome friction.

Effort to overcome friction $= P - \frac{W}{VR}$

= 5.3 - 3.27

= 2.03N

Friction also impacts on the efficiency of the machine or lever system by reducing the load. This load can be calculated using the following formula:

Load Loss = P x VR - W

Example:

Using the variables from the above two examples, calculate the load loss.

Calculation:

Load loss = P x VR - W

= 5.3 x 75 - 245

= 152.5N

Efficiency

The aim of every machine is to have 100% efficiency, but in reality there is always some loss of efficiency, possibly in some cases the result of friction
Friction reduces the practical efficiency of a machine, often by a considerable margin.

By comparing a machine's mechanical advantage **MA** and its velocity ratio **VR**, the efficiency can be calculated. Efficiency is generally expressed as a percentage and is calculated using the following formula:

$$\boxed{\textbf{Efficient (\%)} = \frac{MA}{VR} \ \mathbf{x} \ \frac{100}{1}}$$

Assessment Checklist

Can you now:

☐ define terminology relating to simple levers/machines including mechanical advantage; velocity ratio; efficiency; load; effort; moments?

☐ identify the order of simple levers ie. first order, second order, third order?

☐ using moments, calculate effort required and/or load lifted using the different orders of levers?

☐ determine the mechanical advantage gained by using different levers?

☐ calculate the effort required and/or load lifted using blocks and tackles?

☐ calculate mechanical advantage, velocity ratio and efficiency of pulley systems including the effect of friction on the system?

Section 8: Stress and Strain
8.1 Stress and Strain: Definitions
Stress

Stress is the internal resistance of a material when an external force is applied to that material. Always expressed as stress intensity, stress is the force carried per unit area of the material and is measured by applying this formula:

$$\text{STRESS} = \frac{\text{Total Force (Newtons)}}{\text{Area (square metres)}}$$

Some examples of stresses on vessels include:

- the impact of waves on the bow of the vessel
- waves breaking on the deck of the vessel
- pounding in rough seas

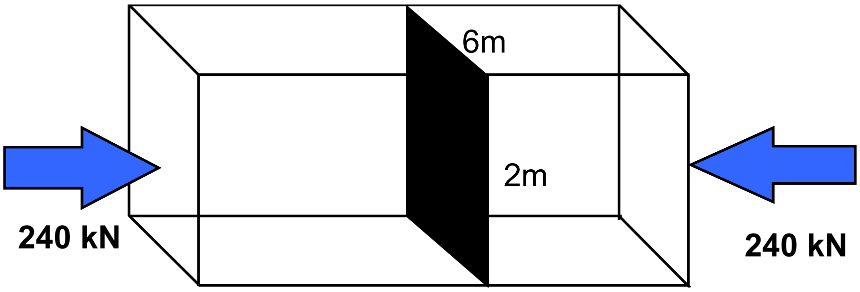
When the force applied to an object has a tendency to **shorten** the object, the stress is referred to as **compressive stress**.

Conversely, if the force has a tendency to **lengthen** the object, the stress is referred to as a **tensile stress**.

If the force causes the object to **break apart** and the pieces **slide over each other**, the stress is referred to as **shear stress**.

NOTE: For tensile or compressive forces, the cross sectional plane of the material, which is at right angles with the force, is the area carrying the force.

Example:



The diagram shows a direct compressive force of 240kN (kilo newtons) applied to a solid block of timber of rectangular cross section 6 metres by 2 metres.

Calculate the cross sectional area supporting the load.

Calculation:

Area = 6m x 2m
= $12m^2$

Caution: Be aware that you have converted all measurements to the standards required in the formula.

As **STRESS** measures Newtons/square metre ⇒ N/m^2

For the above diagram

$$\textbf{Stress} = \frac{\textbf{Total Force (Newtons)}}{\textbf{Area (square metres)}}$$

$$= \frac{240 \times 10^3}{6 \times 2}$$

$$= 20000 N/m^2$$

Strain

As an object is being stressed, the shape of that object may change, this change in shape is known as strain. When the force applied shortens, (compresses) or lengthens (tenses) the material, the change of length per unit of length is referred to as Linear Strain and is measured by dividing the change in length by the original length.

Shear Strain

Shear strain is the measure of the distortion resulting from the effect of shear stress. Shear strain is calculated by dividing the length of movement caused by the shear strain, shown as x in the diagram below, by the object's height, shown as y in the diagram.

$$\textbf{Shear strain} = \frac{x}{y}$$

Example:

If an object of height 16cm suffers a movement of 4cm caused by shear stress, calculate the shear strain.

Calculation:

Shear strain = $\frac{x}{y}$

where x = 4cm and y = 16cm

Shear strain = $\frac{4}{16}$

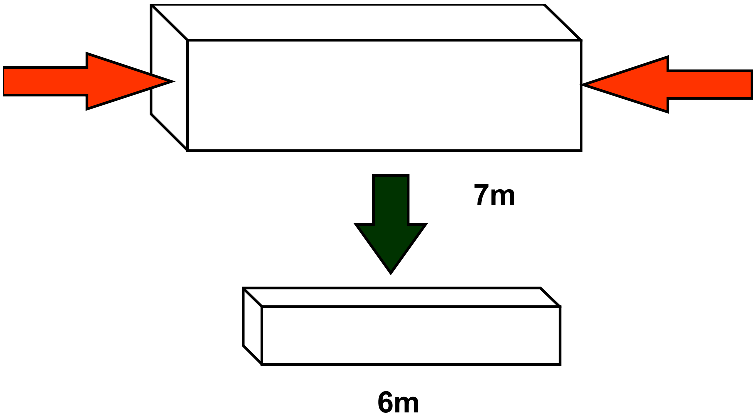
= $\frac{1}{4}$

= 0.25

Linear Strain

Linear strain measures the change in an objects length per unit of length. This change can be the result of both tensile and compressive stress.

Linear strain from compressive stress.

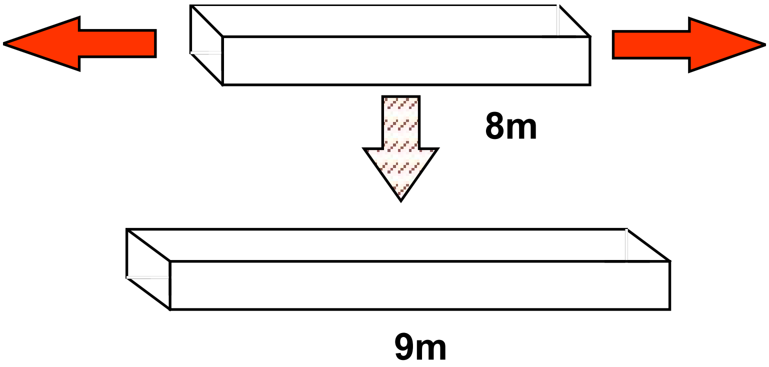


Calculation:

$$= \frac{7-6}{7}$$

$$= \frac{1}{7}$$

Linear strain from **tensile** stress.



Calculation:

$$= \frac{9 - 8}{8}$$

$$= \frac{1}{8}$$

Ultimate Tensile Strength - UTS

The strength of a material is determined by the degree or level of stress that is required to fracture the material. Ultimate Tensile Strength, UTS, expresses the strength in tension and is calculated by dividing the maximum force required to break the material by the original cross sectional area at the point of fracture.

$$\boxed{\textbf{UTS} = \frac{\textbf{maximum breaking force}}{\textbf{original area of the cross section}}}$$

Example: A sample of steel with a width of 40mm and height of 20mm is tested for strength in a testing machine. The sample fractured when the maximum pull on the steel was 90kN.
Calculate the Ultimate Tensile Strength, UTS, of this sample.
Calculation:

$$\boxed{\textbf{UTS} = \frac{\textbf{maximum breaking force}}{\textbf{original area of the cross section}}}$$

$$\text{UTS} = \frac{90000}{40 \times 20}$$

$$\text{UTS} = 112.5 \text{ N/mm}^2$$

Factor of Safety

Factor of Safety is the ratio of the stress which would cause the material to fracture, and the working stress allowed in the material.

$$\textbf{Factor of Safety} = \frac{\textbf{Breaking Stress}}{\textbf{Working Stress}}$$

Example:

Find the FOS of a mast assuming a UTS of 500 MN/m^2 and a Working Stress of 25 MN/m^2.

Calculation:

$$\textbf{Factor of Safety} = \frac{\textbf{Breaking Stress}}{\textbf{Working Stress}}$$

$$\textbf{Factor of Safety} = \frac{500}{20}$$

$$= \textbf{20}$$

Working Stress - (Safe Working Load)

For safety reasons the stress permitted in any piece of material or machinery under normal working conditions, must be much less than that which would make the material or machinery fail. In determining Safe Working Stress, the conditions under which the material or machinery is to work, needs to be considered.

Working Stress is calculated using the following formula;

$$\textbf{Working Stress} = \frac{\textbf{Breaking Stress}}{\textbf{Factor of Safety}}$$

Example:

If a piston rod has a Factor of Safety, FOS, of 14 and assuming Ultimate Tensile Strength, UTS, of 490 MN/m^2, calculate the working stress.

$$\textbf{Working Stress} = \frac{\textbf{Breaking Stress}}{\textbf{Factor of Safety}}$$

Working Stress = 14

= 35 MN/m^2

8.2 Stress and Strain Units

Stress and strain can be measured in multiple units. Here is a table outlining the abbreviations for these multiple units.

UNITS USED FOR MEASURING STRESS AND STRAIN

UNITS	DESCRIPTION	MEASUREMENT OF:
N/m^2	Newtons per Square Metre	Pressure
GN/m^2	Giga Newtons per Square Metre (Giga = 10^9 = 1 000 000 000)	Pressure
MPa	Mega Pascals (Mega = 10^6 = 1 000 000)	Pressure
GPa	Giga Pascals (Giga = 10^9 = 1 000 000 000)	Pressure

One pascal is the pressure caused by the force of one newton acting on an area of one square metre (1 Pa = 1 N/m^2). As the newton is a small force it follows that the Pascal is also a small pressure. As a result, we commonly find that force or pressure are referred to as kilonewton (kN) or megapascal (MPa).

Assessment Checklist

Can you now:

☐ define the terms stress, strain, ultimate tensile strength, working stress (safe working load), factor of safety?

☐ identify units used in relationship with stress and strain such as: N/m2, GN/m2,MPa and Gpa.?

☐ differentiate between tensile, compressive and sheer stress?

☐ calculate the stress of materials under compressive, tensile and sheer forces including sheering stress on bolts?

☐ given the maximum breaking force, calculate ultimate tensile strength (UTS) for common materials?

☐ identify UTS levels for common engineering materials?

☐ calculate Working Stress (SWL) and the factor of safety for common materials?

☐ solve simple algebraic equations relevant to marine Engine Driver Grade 1 mathematics?

Answers to Exercises

Section 1

Written Activity 1:

Question a.	$1\frac{23}{28}$
Question b.	$5\frac{16}{21}$
Question c.	$5\frac{33}{40}$
Question d.	$\frac{9}{28}$
Question e.	$\frac{5}{-8}$
Question f.	$\frac{6}{35}$
Question g.	$\frac{15}{28}$
Question h.	$\frac{14}{15}$
Question i.	$2\frac{13}{21}$
Question j.	8.97
Question k.	18.05
Question l.	20.83
Question m.	2.80
Question n.	20 litres
Question o.	70 litres end $\frac{7}{10}$
Question p.(i)	99 litres
	(ii) $\frac{1}{4}$
	(iii) 16 minutes

Section 2

Written Activity 2.4

a) Distance: in metres

Where 1 nautical mile (nm) = 1852 metres (m)

27nm = 50004m

b) 5m/sec

Calculation:

1 hour = 3600sec.

Distance travelled in 1 hour (m)= 3600 x 5

= 18000m

There are 1000m in one km.

Therefore: 18000m = 18km

The vessel travels 18km per hour

Convert km/hr to knots

1.852km/hr = 1k

18km/hr = 9.72 knots

c)Density = $\frac{\text{Mass (tonnes)}}{Volume(cubicmetres)}$

$= \frac{2}{4}$

$= \frac{1}{2}$

= 0.5

d) A relative density of 0.76 means that for one cubic metre this liquid weighs 76% of an equivalent volume of fresh water.

e) Volume = L x W x D

= 8 x 5 x 0.75

= 30m^3

f) Mass (tonnes) = Volume (cubic metres) x Relative Density

= 5.75 x 0.85

= 4.8875 tonnes

Section 3

Written Activity 3.1 - Perimeters and circumferences

a) 9cm + 9cm + 5cm + 5cm = 28cm

b) $2\pi r = 2 \times \pi \times (\frac{1}{2} \times 18) = 56.55$ cm

Written Activity 3.2 – Areas

a) $\pi r^{2} = \pi \times (\frac{1}{2} \times 4.12)^2$

b) $\pi r^{2} = \pi \times .55^2 = 0.95\ m^2$

c) L x W = 6.2 x 4.7 = 29.14m^2

d) L x W = 0.87 x 3.7 = 3.22m^2

e) A = $\frac{1}{2}$ base x height

= $\frac{1}{2}$ x 2.6m x 0.85

= 1.105m^2

f) A =$\frac{1}{2}$ x 60 x 40

= 1200cm^2

g) A = $\frac{1}{2}$ x h x (a + b)

= $\frac{1}{2}$ x 1m x (4.02 + 7.1)

= 5.56m^2

h) A =$\frac{1}{2}$ x h x (a + b)

= $\frac{1}{2}$ 0.6 x (1.23 + 2.32)

= 1.065m^2

Written Activity 3.3- Volumes

a) V = L x W x D

= 7.1 x 3 x 4.5

= 95.85 m^3

b) V = L x W x D

= 3.08 x 1.42 x 0.64

= 2.799m^3

2.799m^3 = 2799 litres

c) V = πr^2 x h

= π x 3.1^2 x 4.242

= 128.07m^3

= 128070 litres

Written Activity 3.4

V = πr^2 x h

= π x 2.4^2 x 3.2

=57.91m^3

=57910 litres

Ullage = πr^2 x h where h = 6 - 3.2 = 2.8

= π x 2.4^2 x 2.8

= 50.67 m^2

= 50670 litres

Written Activity 3.5

a) $V = \pi r^2 \times h$

$50m^3 = \pi r^2 \times h$

$50m^3 = \pi \times 0.95^2 \times h$

$$\frac{50}{\pi \times 0.95^2} = h$$

$h = 50/(\pi \times 0.9025)$

$h = 17.64m$ (approximating $\pi = 3.14$)

Written Activity 3.6

a) $V = \frac{1}{2} \times b \times h \times l$

$= \frac{1}{2} \times 2.4 \times 3 \times 9.2$

$=33.12\ m^3$

b) $V = 33.12m^3 \times 1000$ litres

= 33120 litres

c) $\frac{1}{6} \times 33120$

= 5520 litres

d) 5520 litres $\div 1000\ l/m^3$

$= 5.52m^3$

e)

Depth (m)	Volume (l)
0.2	0.63
0.4	1.26
0.6	1.89
0.8	2.52
1.0	3.15
1.2	3.78
1.4	4.41

f) Volume = $\frac{1}{2}h \times (a+b) \times c$

$= \frac{1}{2} \times 2.4 \times (4.2 + 6.8) \times 2.1$

= 27.72 m^3

f) $\frac{1}{2}$x 277720 = 13860 litres

Section 4

Written Activity 4.1

Volume = 4 x 2 x 3.2

= 25.6m^3

1m^3 = 1000 litres

25.6m^3 = 25600 litres

Written Activity 4.2

Pumps

Pump rate = 3500 litres per hour

Total litres = 10,000 litres

After one hour = 10,000 - 3500

= 6500 litres

After two hours = 6500 - 3500

= 3000 litres

Pump rate slows = 1200 litres/hour

After three hours = 3000 - 1200

= 1800 litres

After four hours = 1800 - 1200

= 600 litres

If it takes 1 hour to pump 1200 litres, it takes half an hour to pump 600 litres.

Total Time Required **=** $4\frac{1}{2}$ hours

Written Activity 4.3

a) Tank volume:

V = L x W x D
= 4.2 x 2.15 x 1.05
= 9.4815m^3
= 9481.5 litres in each tank

b) Pump rate:

205 litres every 30 seconds
= 410 litres every minute

$$\text{Time} = \frac{\text{Tank Volume}}{\text{Pump Rate}}$$

$$= \frac{9481.5}{410}$$

= 23.13 minutes

= 23 minutes 8 seconds

c) Rump rate / quantities:

Tank volume = 3 x 3.5 x 1.8
= 18.9m^3
= 18900 litres

5.6 litres every second
= 336 litres every minute

After 53 minutes the pump would have removed 17808 litres of water from the tank.

So the amount of contaminated water remaining in the tank after 53 minutes would have been:

18900 - 17808 = 1092 litres

Written Activity 4.4

Time for Pump A:

= 3000 ÷ 5

= 600 (minutes)

= 10 hours

Time for Pump B:

= 3000 ÷ 10

= 300 (minutes)

= 5 hours

Total proportionate capacity per hour = $\frac{1}{10} + \frac{1}{5} = \frac{3}{10}$

As a percentage this means that, used simultaneously, the two pumps can empty 30% of the tank in one hour. Therefore it takes two minutes to empty 1% of the tank, (ie, 60 minutes ÷ 30).

Multiply 2 minutes by 100 to find the time taken to empty 100% of the tank.

= 200 minutes

= 3 hours 20 minutes.

It will take 3 hours 20 minutes to empty the tank using both pumps simultaneously.

Section 5

Written Activity 5.1:

a)

Tank 1

V = $\frac{1}{2}$ h x (a + b) x l

= 0.375 x 7.35 x 3.20

= 8.82m

= 8.82 x 1000

= 8820 litres

Tank 2

V = $\pi r^2 \times h$

= $\pi \times 1.1^2$

= 9.31 m^3

= 9.31 x 1000

= 9309 litres

b) Consuming 60 litres/hour the vessel will empty the trapezoidal tank in 147 hours.

c) maintaining the same consumption rate, the vessel will empty the cylindrical tank in 155 hours 9 minutes.

In total the vessel can travel for 307 hours 9 minutes at the quoted consumption rate.

Written Activity 5.2:

a) V = L x W x D

= 3.35 x 2.69 x 0.9

= $8.110m^3$

= 8110 litres

b) Ullage = Tank capacity - fuel level

= 8110 - (75% x 8110)

(or = 25% x 8110)

= 2027.5 litres

= $2.0275m^3$

From the formula:

V = L x W x D

2.0275 = 3.35 x 2.69 x D

$$D = \frac{2.0275}{9.0115}$$

D = 0.225m

c) V = L x W x D

= 3.35 x 2.69 x 0.15

= $1.352m^3$

= 1350 litres

Written Activity 5.3

a) V = L x W x D

= 2.75 x 1.3 x 1.25

= $4.469m^3$

= 4469 litres

b) then 9% x 4469 = 402.21 litres

$$RD = \frac{M}{V}$$

$$= \frac{395}{402.21}$$

Relative Density = 0.98

Written Activity 5.4:

a) Fuel Consumption, FC, per day.

FC per day $= \frac{\Delta^{2/3} \times S^3}{\text{fuel coefficient}}$

$= \frac{200^{2/3} \times 14.25^3}{53500}$

= 1.85 tonnes

b) 472.5km x 1.852 = 875.07 nm

S $= \frac{D}{T}$

14 $= \frac{875.07}{T}$

T = 62.5 hours

$\frac{750l}{62.5 hours}$ = **12 litres per hour**

c) V $= \pi r^2 \times h$

$= \pi \times (0.7)^2 \times 4.3$ (approximating $\pi = 3.14$)

$= 6.616 m^3$

Tank capacity = 6616 litres

70% of tank capacity = 70% x 6616

= 4631.2

Fuel Consumption $= \frac{4631.2}{66}$

= **70.17 litres per hour**

d) Speed = 1.25 x 375

= 468.75 metres/minute

= 28125 m/hour

= 15.19 nm/h or knots

Then if: S = $\frac{D}{T}$ T = $\frac{D}{S}$

T = $\frac{267}{15.19}$

Time = 17.58 hours

Total fuel = Consumption rate x time

= 23 x 17.58

= **404.38 litres**

Written Activity 5.5:

V = $\frac{1}{2}$ (0.5) x (1.3 + 1.1 x 2

= 0.25 x 2.4 x 2

= 1.2m^3

= 1200 litres

Capacity of both tanks is 2400 litres.

Using fuel consumption at 12 l/h:

Steaming time = $\frac{2400}{12}$

= 200 hours

At a speed of 12 knots:

S = $\frac{D}{T}$

D = S x T

= 12 x 200

D = 2400 nm

Section 6

Written Activity 6.2:

Draught

The two situations are:

- when vessel passes from salt to fresh water
- when vessel is carrying a load, as opposed to being empty.

Section 7

Written Activity 7.1

a) MA = 500 = 4.9

b) VR = number of ropes supporting load block

= total number of pulleys

=7

c)Efficiency $= \frac{MA}{VR} = \frac{4.9}{7}$

= 0.7

=70%

Written Activity 7.5

a) MA = $\frac{2982}{420}$ = 7.1

b) MA = $\frac{2982}{425}$ = 7.0

c) (a) is the better alternative as it has higher mechanical advantage