Chapter 1
Forces and moments

The solution of many of the problems concerned with ship stability involves an understanding of the resolution of forces and moments. For this reason a brief examination of the basic principles will be advisable.

Forces

A *force* can be defined as any push or pull exerted on a body. The S.I. unit of force is the Newton, one Newton being the force required to produce in a mass of one kilogram an acceleration of one metre per second per second. When considering a force the following points regarding the force must be known:

(a) The magnitude of the force,
(b) The direction in which the force is applied, and
(c) The point at which the force is applied.

The resultant force. When two or more forces are acting at a point, their combined effect can be represented by one force which will have the same effect as the component forces. Such a force is referred to as the 'resultant force', and the process of finding it is called the 'resolution of the component forces'.

The resolution of forces. When resolving forces it will be appreciated that a force acting towards a point will have the same effect as an equal force acting away from the point, so long as both forces act in the same direction and in the same straight line. Thus a force of 10 Newtons (N) pushing to the right on a certain point can be substituted for a force of 10 Newtons (N) pulling to the right from the same point.

(a) *Resolving two forces which act in the same straight line*
If both forces act in the same straight line and in the same direction the resultant is their sum, but if the forces act in opposite directions the resultant is the difference of the two forces and acts in the direction of the larger of the two forces.

Example 1

Whilst moving an object one man pulls on it with a force of 200 Newtons, and another pushes in the same direction with a force of 300 Newtons. Find the resultant force propelling the object.

Component forces 300 N → A · 200 N →

The resultant force is obviously 500 Newtons, the sum of the two forces, and acts in the direction of each of the component forces.

Resultant force 500 N ↠ · A *or* A · 500 N ↠

Example 2

A force of 5 Newtons is applied towards a point whilst a force of 2 Newtons is applied at the same point but in the opposite direction. Find the resultant force.

Component forces 5 N → A · ← 2 N

Since the forces are applied in opposite directions, the magnitude of the resultant is the difference of the two forces and acts in the direction of the 5 N force.

Resultant force 3 N ↠ · A *or* A · 3 N ↠

(b) *Resolving two forces which do not act in the same straight line*

When the two forces do not act in the same straight line, their resultant can be found by completing a parallelogram of forces.

Example 1

A force of 3 Newtons and a force of 5 N act towards a point at an angle of 120 degrees to each other. Find the direction and magnitude of the resultant.

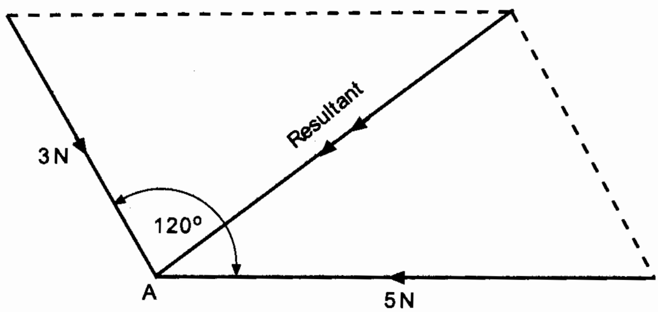

Fig. 1.1

Ans. Resultant 4.36 N at 36° $34\frac{1}{2}'$ to the 5 N force.

Note. Notice that each of the component forces and the resultant all act towards the point A.

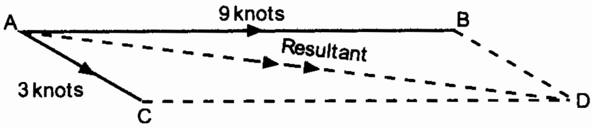

Fig. 1.2

Example 2

A ship steams due east for an hour at 9 knots through a current which sets 120 degrees (T) at 3 knots. Find the course and distance made good.

The ship's force would propel her from A to B in one hour and the current would propel her from A to C in one hour. The resultant is AD, $0.97\frac{1}{2}^{\circ} \times 11.6$ miles and this will represent the course and distance made good in one hour. *Note.* In the above example both of the component forces and the resultant force all act away from the point A.

Example 3

A force of 3 N acts downwards towards a point whilst another force of 5 N acts away from the point to the right as shown in Figure 1.3. Find the resultant.

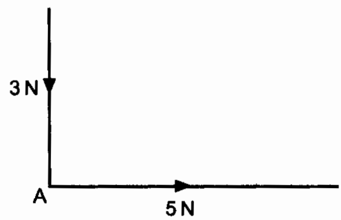

Fig. 1.3

In this example one force is acting towards the point and the second force is acting away from the point. Before completing the parallelogram, substitute either a force of 3 N acting away from the point for the force of 3 N towards the point as shown in Figure 1.4, or a force of 5 N towards the point for the

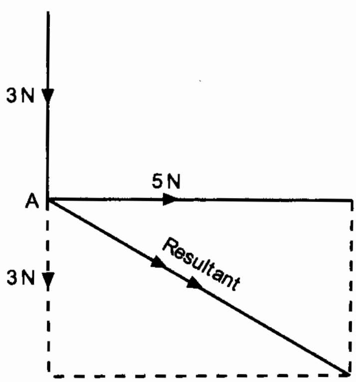

Fig. 1.4

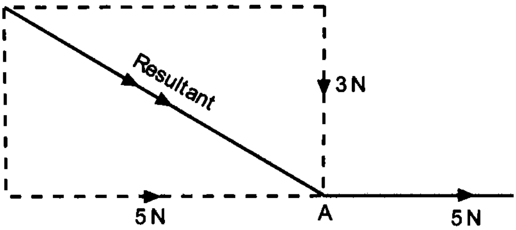

Fig. 1.5

force of 5 N away from the point as shown in Figure 1.5. In this way both of the forces act either towards or away from the point. The magnitude and direction of the resultant is the same whichever substitution is made; i.e. 5.83 N at an angle of 59° to the vertical.

(c) *Resolving two forces which act in parallel directions*
When two forces act in parallel directions, their combined effect can be represented by one force whose magnitude is equal to the algebraic sum of the two component forces, and which will act through a point about which their moments are equal.

The following two examples may help to make this clear.

Example 1

In Figure 1.6 the parallel forces W and P are acting upwards through A and B respectively. Let W be greater than P. Their resultant, (W + P), acts upwards through the point C such that $P \times y = W \times x$. Since W is greater than P, the point C will be nearer to B than to A.

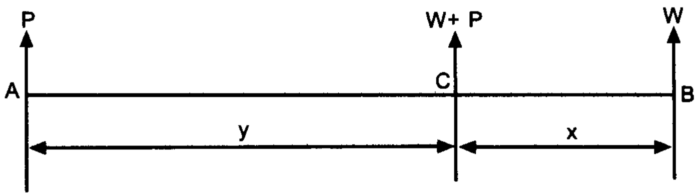

Fig. 1.6

Example 2

In Figure 1.7 the parallel forces W and P act in opposite directions through A and B respectively. If W is again greater than P, their resultant, (W − P), acts through point C on AB produced such that $P \times y = W \times x$.

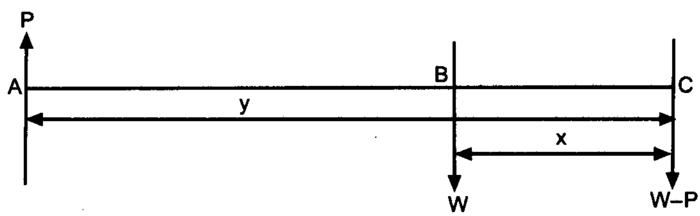

Fig. 1.7

Moments of Forces

The moment of a force is a measure of the turning effect of the force about a point. The turning effect will depend upon the following:

(a) The magnitude of the force, and
(b) The length of the lever upon which the force acts, the lever being the perpendicular distance between the line of action of the force and the point about which the moment is being taken.

The magnitude of the moment is the product of the force and the length of the lever. Thus, if the force is measured in Newtons and the length of the lever in metres, the moment found will be expressed in Newton-metres (Nm).

Resultant moment. When two or more forces are acting about a point their combined effect can be represented by one imaginary moment called the 'Resultant Moment'. The process of finding the resultant moment is referred to as the 'Resolution of the Component Moments'.

Resolution of moments. To calculate the resultant moment about a point, find the sum of the moments to produce rotation in a clockwise direction about the point, and the sum of the moments to produce rotation in an anti-clockwise direction. Take the lesser of these two moments from the greater and the difference will be the magnitude of the resultant. The direction in which it acts will be that of the greater of the two component moments.

Example 1

A capstan consists of a drum 2 metres in diameter around which a rope is wound, and four levers at right angles to each other, each being 2 metres long. If a man on the end of each lever pushes with a force of 500 Newtons, what strain is put on the rope? (See Figure 1.8(a).)

Moments are taken about O, the centre of the drum.

$$\text{Total moment in an anti-clockwise direction} = 4 \times (2 \times 500)\ \text{Nm}$$

$$\text{The resultant moment} = 4000\,\text{Nm (Anti-clockwise)}$$

$$\text{Let the strain on the rope} = \text{P Newtons}$$

$$\text{The moment about O} = (\text{P} \times 1)\ \text{Nm}$$

$$\therefore \text{P} \times 1 = 4000$$

$$\text{or P} = 4000\,\text{N}$$

Ans. The strain is 4000 N.

Note. For a body to remain at rest, the resultant force acting on the body must be zero and the resultant moment about its centre of gravity must also be zero, if the centre of gravity be considered a fixed point.

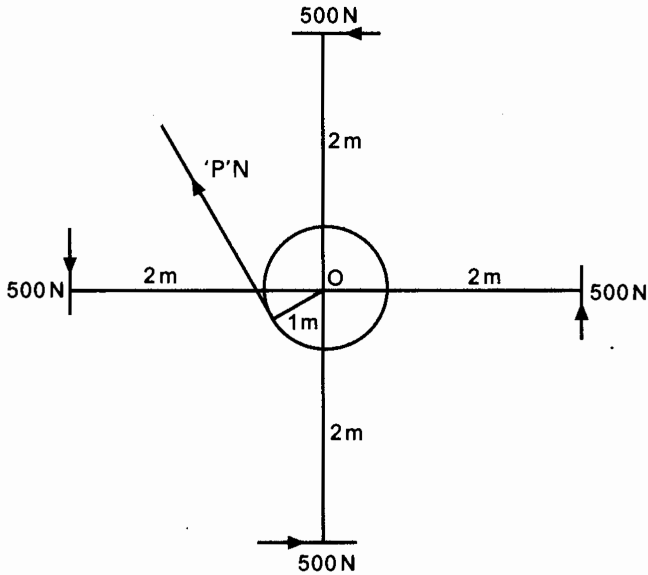

Fig. 1.8(a)

Mass

In the S.I. system of units it is most important to distinguish between the mass of a body and its weight. Mass is the fundamental measure of the quantity of matter in a body and is expressed in terms of the kilogram and the tonne, whilst the weight of a body is the force exerted on it by the Earth's gravitational force and is measured in terms of the Newton (N) and kilo-Newton (kN).

Weight and mass are connected by the formula:

$$\text{Weight} = \text{Mass} \times \text{Acceleration}$$

Example 2

Find the weight of a body of mass 50 kilograms at a place where the acceleration due to gravity is 9.81 metres per second per second.

$$\begin{aligned}\text{Weight} &= \text{Mass} \times \text{Acceleration}\\ &= 50 \times 9.81\end{aligned}$$

Ans. Weight = 490.5 N

Moments of Mass

If the force of gravity is considered constant then the weight of bodies is proportional to their mass and the resultant moment of two or more weights about a point can be expressed in terms of their mass moments.

Example 3

A uniform plank is 3 metres long and is supported at a point under its mid-length. A load having a mass of 10 kilograms is placed at a distance of 0.5

metres from one end and a second load of mass 30 kilograms is placed at a distance of one metre from the other end. Find the resultant moment about the middle of the plank.

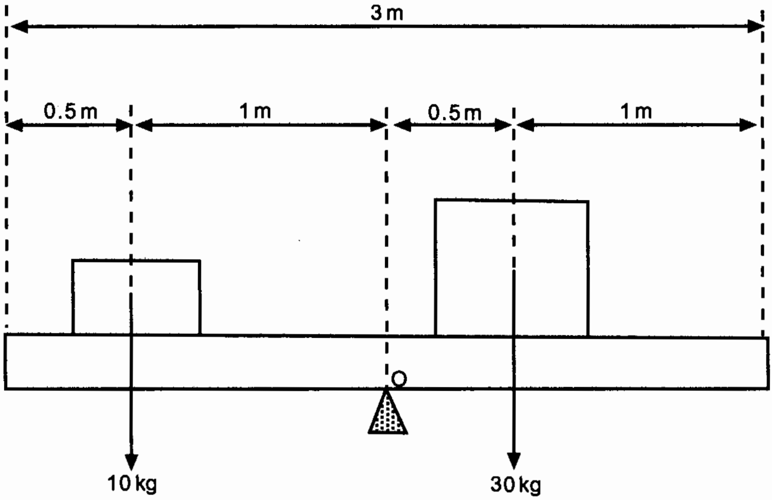

Fig. 1.8(b)

Moments are taken about O, the middle of the plank.

$$\begin{aligned} \text{Clockwise moment} &= 30 \times 0.5 \\ &= 15\ \text{kg m} \\ \text{Anti-clockwise moment} &= 10 \times 1 \\ &= 10\ \text{kg m} \\ \text{Resultant moment} &= 15 - 10 \end{aligned}$$

Ans. Resultant moment = 5 kg m clockwise

Exercise 1

1 A capstan bar is 3 metres long. Two men are pushing on the bar, each with a force of 400 Newtons. If one man is placed half-way along the bar and the other at the extreme end of the bar, find the resultant moment about the centre of the capstan.

2 A uniform plank is 6 metres long and is supported at a point under its mid-length. A 10 kg mass is placed on the plank at a distance of 0.5 metres from one end and a 20 kg mass is placed on the plank 2 metres from the other end. Find the resultant moment about the centre of the plank.

3 A uniform plank is 5 metres long and is supported at a point under its mid-length. A 15 kg mass is placed 1 metre from one end and a 10 kg mass is placed 1.2 metres from the other end. Find where a 13 kg mass must be placed on the plank so that the plank will not tilt.

4 A weightless bar 2 metres long is suspended from the ceiling at a point which is 0.5 metres in from one end. Suspended from the same end is a mass of 110 kg. Find the mass which must be suspended from a point 0.3 metres in from the other end of the bar so that the bar will remain horizontal.

5 Three weights are placed on a plank. One of 15 kg mass is placed 0.6 metres in from one end, the next of 12 kg mass is placed 1.5 metres in from the same end, and the last of 18 kg mass is placed 3 metres from this end. If the mass of the plank be ignored, find the resultant moment about the end of the plank.

Chapter 2
Centroids and the centre of gravity

The centroid of an area is situated at its geometrical centre. In each of the following figures 'G' represents the centroid, and if each area was suspended from this point it would balance.

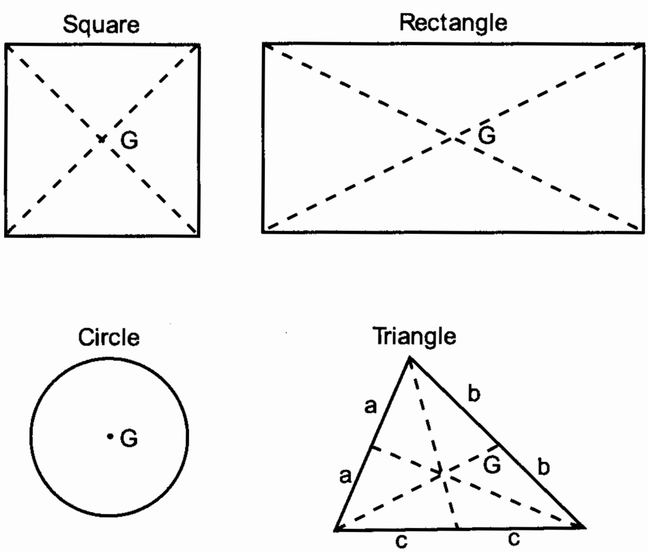

Fig. 2.1

The centre of gravity of a body is the point at which all the mass of the body may be assumed to be concentrated and is the point through which the force of gravity is considered to act vertically downwards, with a force equal to the weight of the body. It is also the point about which the body would balance.

The centre of gravity of a homogeneous body is at its geometrical centre. Thus the centre of gravity of a homogeneous rectangular block is half-way along its length, half-way across its breadth and at half its depth.

Let us now consider the effect on the centre of gravity of a body when the distribution of mass within the body is changed.

Effect of removing or discharging mass

Consider a rectangular plank of homogeneous wood. Its centre of gravity will be at its geometrical centre – that is, half-way along its length, half-way across its breadth, and at half depth. Let the mass of the plank be W kg and let it be supported by means of a wedge placed under the centre of gravity as shown in Figure 2.2. The plank will balance.

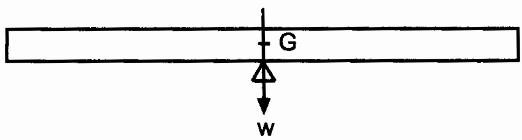

Fig. 2.2

Now let a short length of the plank, of mass w kg, be cut from one end such that its centre of gravity is d metres from the centre of gravity of the plank. The other end, now being of greater mass, will tilt downwards. Figure 2.3(a) shows that by removing the short length of plank a resultant moment of $w \times d$ kg m has been created in an anti-clockwise direction about G.

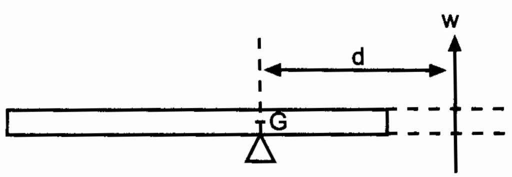

Fig. 2.3(a)

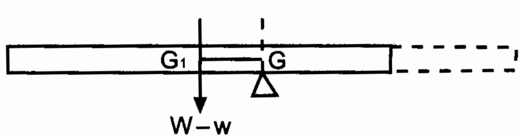

Fig. 2.3(b)

Now consider the new length of plank as shown in Figure 2.3(b). The centre of gravity will have moved to the new half-length indicated by the distance G to G_1. The new mass, $(W - w)$ kg, now produces a tilting moment of $(W - w) \times GG_1$ kg m about G.

Since these are simply two different ways of showing the same effect, the moments must be the same. i.e.

$$(W - w) \times GG_1 = w \times d$$

or

$$GG_1 = \frac{w \times d}{W - w} \text{ metres}$$

From this it may be concluded that when mass is removed from a body, the centre of gravity of the body will move directly away from the centre of gravity of the mass removed, and the distance it moves will be given by the formula:

$$GG_1 = \frac{w \times d}{\text{Final mass}} \text{ metres}$$

where GG_1 is the shift of the centre of gravity of the body, w is the mass removed, and d is the distance between the centre of gravity of the mass removed and the centre of gravity of the body.

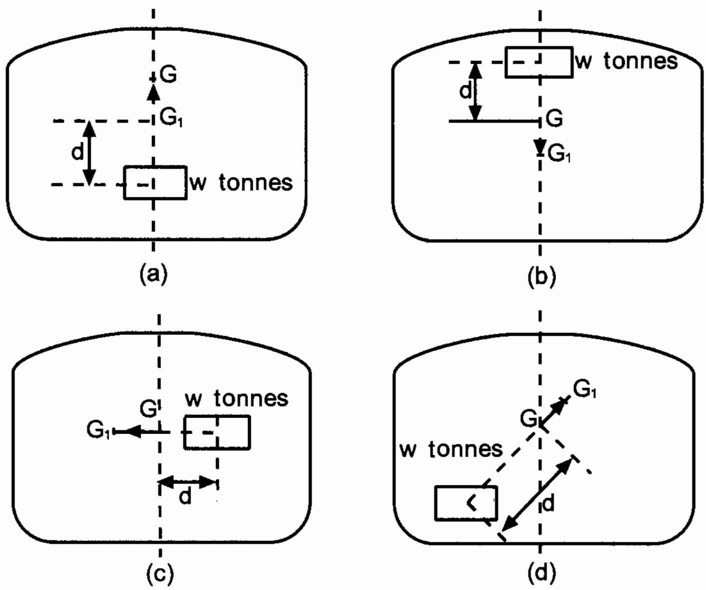

Fig. 2.4. Discharging a mass w.

Application to ships

In each of the above figures, G represents the centre of gravity of the ship with a mass of w tonnes on board at a distance of d metres from G. G to G_1 represents the shift of the ship's centre of gravity due to discharging the mass.

In Figure 2.4(a), it will be noticed that the mass is vertically below G, and that when discharged G will move vertically upwards to G_1.

In Figure 2.4(b), the mass is vertically above G and the ship's centre of gravity will move directly downwards to G_1.

In Figure 2.4(c), the mass is directly to starboard of G and the ship's centre of gravity will move directly to port from G to G_1.

In Figure 2.4(d), the mass is below and to port of G, and the ship's centre of gravity will move upwards and to starboard.

In each case:

$$GG_1 = \frac{w \times d}{\text{Final displacement}} \text{ metres}$$

Effect of adding or loading mass

Once again consider the plank of homogeneous wood shown in Figure 2.2. Now add a piece of plank of mass w kg at a distance of d metres from G as shown in Figure 2.5(a).

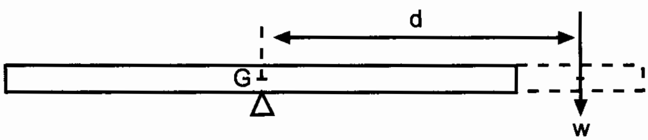

Fig. 2.5(a)

The heavier end of the plank will again tilt downwards. By adding a mass of w kg at a distance of d metres from G a tilting moment of w × d kg m. about G has been created.

Now consider the new plank as shown in Figure 2.5(b). Its centre of gravity will be at its new half-length (G_1), and the new mass, (W + w) kg, will produce a tilting moment of $(W + w) \times GG_1$ kg m about G.

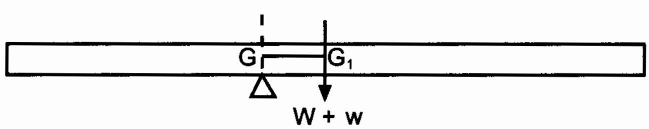

Fig. 2.5(b)

These tilting moments must again be equal, i.e.

$$(W + w) \times GG_1 = w \times d$$

or

$$GG_1 = \frac{w \times d}{W + w} \text{ metres}$$

From the above it may be concluded that when mass is added to a body, the centre of gravity of the body will move directly towards the centre of gravity of the mass added, and the distance which it moves will be given by the formula:

$$GG_1 = \frac{w \times d}{\text{Final mass}} \text{ metres}$$

where GG_1 is the shift of the centre of gravity of the body, w is the mass added, and d is the distance between the centres of gravity.

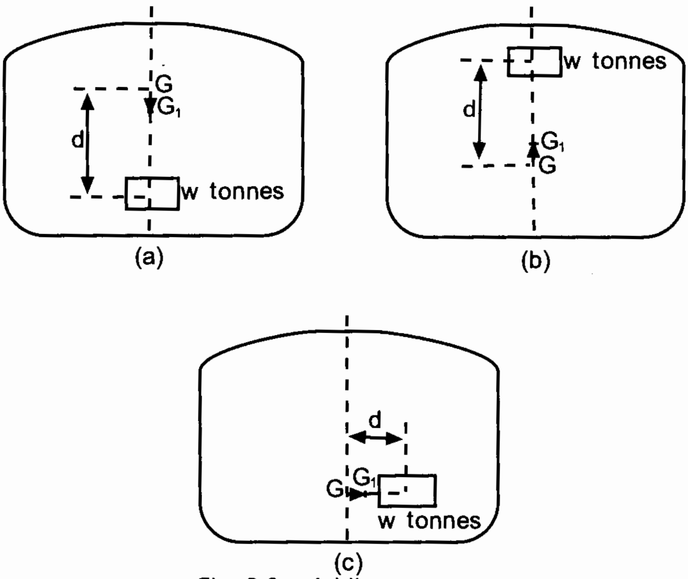

Fig. 2.6. Adding a mass w.

Application to ships

In each of the above figures, G represents the position of the centre of gravity of the ship before the mass of w tonnes has been loaded. After the mass has been loaded, G will move directly towards the centre of gravity of the added mass (i.e. from G to G_1).

Also, in each case:

$$GG_1 = \frac{w \times d}{\text{Final displacement}} \text{ metres}$$

Effect of shifting weights

In Figure 2.7, G represents the original position of the centre of gravity of a ship with a weight of 'w' tonnes in the starboard side of the lower hold having its centre of gravity in position g_1. If this weight is now discharged the ship's centre of gravity will move from G to G_1 directly away from g_1. When the same weight is reloaded on deck with its centre of gravity at g_2 the ship's centre of gravity will move from G_1 to G_2.

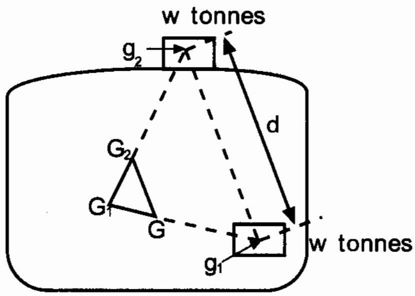

Fig. 2.7. Discharging, adding and moving a mass w.

From this it can be seen that if the weight had been shifted from g_1 to g_2 the ship's centre of gravity would have moved from G to G_2.

It can also be shown that GG_2 is parallel to g_1 g_2 and that

$$GG_2 = \frac{w \times d}{W} \text{ metres}$$

where w is the mass of the weight shifted, d is the distance through which it is shifted, and W is the ship's displacement.

The centre of gravity of the body will always move parallel to the shift of the centre of gravity of any weight moved within the body.

Effect of suspended weights

The centre of gravity of a body is the point through which the force of gravity may be considered to act vertically downwards. Consider the centre of gravity of a weight suspended from the head of a derrick as shown in Figure 2.8.

It can be seen from Figure 2.8 that whether the ship is upright or inclined in either direction, the point in the ship through which the force of gravity may be considered to act vertically downwards is g_1, the point of suspension. Thus the centre of gravity of a suspended weight is considered to be at the point of suspension.

Conclusions

1. The centre of gravity of a body will move directly *towards* the centre of gravity of any *weight added.*
2. The centre of gravity of a body will move directly *away* from the centre of gravity of any *weight removed.*
3. The centre of gravity of a body will *move parallel* to the shift of the centre of gravity of any *weight moved* within the body.

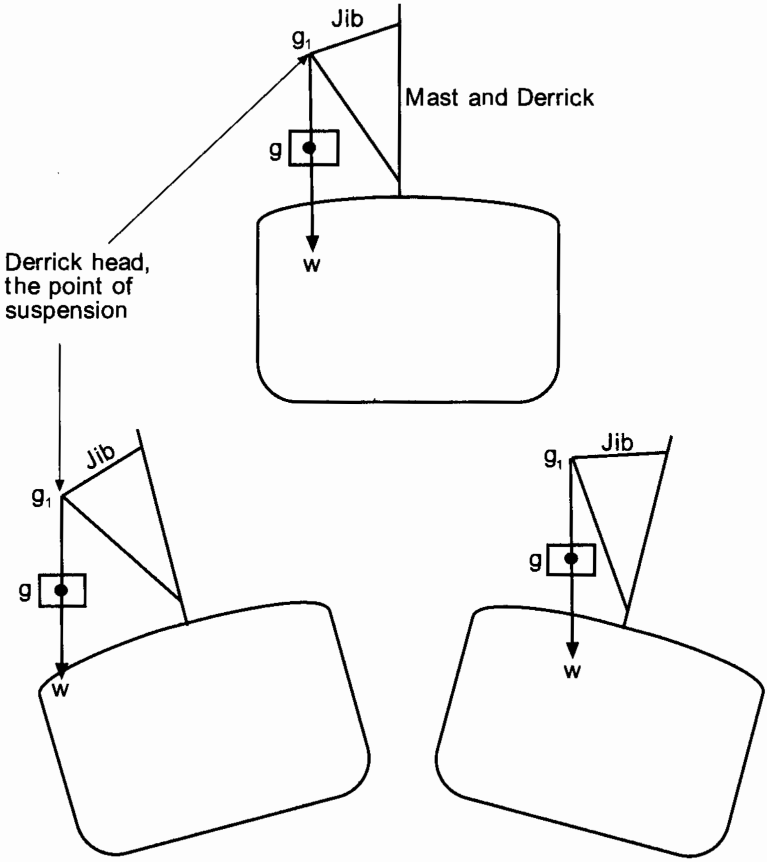

Fig. 2.8

4. The *shift of the centre of gravity* of the body in each case is given by the formula:

$$GG_1 = \frac{w \times d}{W} \text{ metres}$$

where w is the mass of the weight added, removed, or shifted, W is the *final* mass of the body, and d is, in 1 and 2, the distance between the centres of gravity, and in 3, the distance through which the weight is shifted.

5. When a weight is *suspended* its centre of gravity is considered to be at the *point of suspension.*

Example 1

A hold is partly filled with a cargo of bulk grain. During the loading, the ship takes a list and a quantity of grain shifts so that the surface of the grain remains parallel to the waterline. Show the effect of this on the ship's centre of gravity.

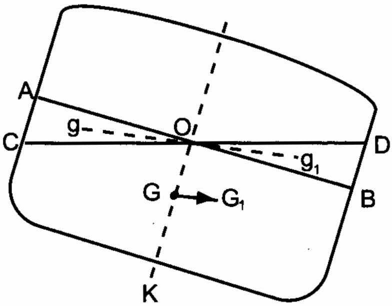

Fig. 2.9

In Figure 2.9, G represents the original position of the ship's centre of gravity when upright. AB represents the level of the surface of the grain when the ship was upright and CD the level when inclined. A wedge of grain AOC with its centre of gravity at g has shifted to ODB with its centre of gravity at g_1. The ship's centre of gravity will shift from G to G_1, such that GG_1 is parallel to gg_1, and the distance

$$GG_1 = \frac{w \times d}{W} \text{ metres}$$

Example 2

A ship is lying starboard side to a quay. A weight is to be discharged from the port side of the lower hold by means of the ship's own derrick. Describe the effect on the position of the ship's centre of gravity during the operation.

Note. When a weight is suspended from a point, the centre of gravity of the weight appears to be at the point of suspension regardless of the distance between the point of suspension and the weight. Thus, as soon as the weight is clear of the deck and is being borne at the derrick head, the centre of gravity of the weight appears to move from its original position to the derrick head. For example, it does not matter whether the weight is 0.6 metres or 6.0 metres above the deck, or whether it is being raised or lowered; its centre of gravity will appear to be at the derrick head.

In Figure 2.10, G represents the original position of the ship's centre of gravity, and g represents the centre of gravity of the weight when lying in the lower hold. As soon as the weight is raised clear of the deck, its centre of gravity will appear to move vertically upwards to g_1. This will cause the ship's centre of gravity to move upwards from G to G_1, parallel to gg_1. The centres of gravity will remain at G_1 and g_1 respectively during the whole of the time the weight is being raised. When the derrick is swung over the side, the derrick head will move from g_1 to g_2, and since the weight is suspended from the derrick head, its centre of gravity will also appear to move from g_1 to g_2. This will cause the ship's centre of gravity to move from G_1 to G_2. If the weight is now landed on the quay it is in effect being discharged from the derrick head

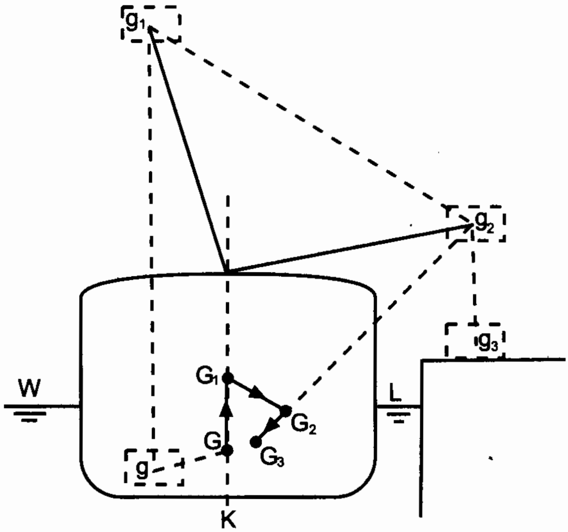

Fig. 2.10

and the ship's centre of gravity will move from G_2 to G_3 in a direction directly away from g_2. G_3 is therefore the final position of the ship's centre of gravity after discharging the weight.

From this it can be seen that the net effect of discharging the weight is a shift of the ship's centre of gravity from G to G_3, directly away from the centre of gravity of the weight discharged. This would agree with the earlier conclusions which have been reached in Figure 2.4.

Note. The only way in which the position of the centre of gravity of a ship can be altered is by changing the distribution of the weights within the ship, i.e. by *adding*, *removing*, or *shifting* weights.

Students find it hard sometimes to accept that the weight, when suspended from the derrick, acts at its point of suspension.

However, it can be proved, by experimenting with ship models or observing full-size ship tests. The final angle of heel when measured verifies that this assumption is indeed correct.

Exercise 2

1 A ship has displacement of 2400 tonnes and KG = 10.8 metres. Find the new KG if a weight of 50 tonnes mass already on board is raised 12 metres vertically.

2 A ship has displacement of 2000 tonnes and KG = 10.5 metres. FInd the new KG if a weight of 40 tonnes mass already on board is shifted from the 'tween deck to the lower hold. through a distance of 4.5 metres vertically.

3 A ship of 2000 tonnes displacement has KG = 4.5 metres. A heavy lift of 20 tonnes mass is in the lower hold and has KG = 2 metres. This weight is then raised 0.5 metres clear of the tank top by a derrick whose head is 14 metres above the keel. Find the new KG of the ship.

4 A ship has a displacement of 7000 tonnes and KG = 6 metres. A heavy lift in the lower hold has KG = 3 metres and mass 40 tonnes. Find the new KG when this weight is raised through 1.5 metres vertically and is suspended by a derrick whose head is 17 metres above the keel.

5 Find the shift in the centre of gravity of a ship of 1500 tonnes displacement when a weight of 25 tonnes mass is shifted from the starboard side of the lower hold to the port side on deck through a distance of 15 metres.

Chapter 3
Density and specific gravity

Density is defined as 'mass per unit volume'. e.g.

The mass density of FW = 1000 kg per cubic metre or 1.000 tonne/m^3
The mass density of SW = 1025 kg per cubic metre or 1.025 tonne/m^3

The specific gravity (SG) or relative density of a substance is defined as the ratio of the weight of the substance to the weight of an equal volume of fresh water.

If a volume of one cubic metre is considered, then the SG or relative density of a substance is the ratio of the density of the substance to the density of fresh water. i.e.

$$\text{SG or relative density of a substance} = \frac{\text{Density of the substance}}{\text{Density of fresh water}}$$

$$\text{The density of FW} = 1000\,\text{kg per cu. m}$$

$$\therefore \text{ SG of a substance} = \frac{\text{Density of the substance in kg per cu. m}}{1000}$$

or

$$\text{Density in kg per cu. m} = 1000 \times \text{SG}$$

Example 1

Find the relative density of salt water whose density is 1025 kg per cu. m

$$\text{Relative density} = \frac{\text{Density of SW in kg per cu. m}}{1000}$$

$$= \frac{1025}{1000}$$

$$\therefore \text{ relative density of salt water} = 1.025$$

Example 2

Find the density of a fuel oil whose relative density is 0.92

$$\text{Density in kg per cu. m} = 1000 \times \text{SG}$$
$$= 1000 \times 0.92$$
$$\therefore \text{Density} = 920\,\text{kg per cu. m}$$

Example 3

When a double-bottom tank is full of fresh water it holds 120 tonnes. Find how many tonnes of oil of relative density 0.84 it will hold.

$$\text{Relative density} = \frac{\text{Mass of oil}}{\text{Mass of FW}}$$

or

$$\text{Mass of oil} = \text{Mass of FW} \times \text{relative density}$$
$$= 120 \times 0.84 \text{ tonnes}$$
$$\text{Mass of oil} = 100.8 \text{ tonnes}$$

Example 4

A tank measures 20 m × 24 m × 10.5 m and contains oil of relative density 0.84. Find the mass of oil it contains when the ullage is 2.5 m. An ullage is the distance from the surface of the liquid in the tank to the top of the tank. A sounding is the distance from the surface of the liquid to the base of the tank or sounding pad.

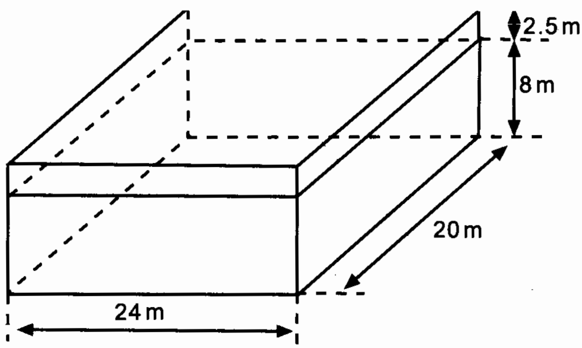

Fig. 3.1

$$\text{Volume of oil} = \text{L} \times \text{B} \times \text{D}$$
$$= 20 \times 24 \times 8\,\text{cu. m}$$
$$\text{Density of oil} = \text{SG} \times 1000$$
$$= 840\,\text{kg per cu. m or } 0.84\,\text{t/m}^3$$
$$\text{Mass of oil} = \text{Volume} \times \text{density}$$
$$= 20 \times 24 \times 8 \times 0.84$$
$$\text{Mass of oil} = 3225.6 \text{ tonnes}$$

Example 5

A tank will hold 153 tonnes when full of fresh water. Find how many tonnes of oil of relative density 0.8 it will hold allowing 2% of the oil loaded for expansion.

$$\begin{aligned} \text{Mass of freshwater} &= 153 \text{ tonnes} \\ \therefore \text{ Volume of the tank} &= 153\,\text{m}^3 \\ \text{Volume of oil} + 2\% \text{ of volume of oil} &= \text{Volume of the tank} \\ \text{or } 102\% \text{ of volume of the oil} &= 153\,\text{m}^3 \\ \therefore \text{ volume of the oil} &= 153 \times \frac{100}{102}\,\text{m}^3 \\ &= 150\,\text{m}^3 \\ \text{Mass of the oil} &= \text{Volume} \times \text{Density} \\ &= 150 \times 0.8 \text{ tonnes} \end{aligned}$$

Ans. = <u>120 tonnes</u>

Exercise 3

1 A tank holds 120 tonnes when full of fresh water. Find how many tonnes of oil of relative density 0.84 it will hold, allowing 2% of the volume of the tank for expansion in the oil.

2 A tank when full will hold 130 tonnes of salt water. Find how many tonnes of oil relative density 0.909 it will hold, allowing 1% of the volume of the tank for expansion.

3 A tank measuring 8 m × 6 m × 7 m is being filled with oil of relative density 0.9. Find how many tonnes of oil in the tank when the ullage is 3 metres.

4 Oil of relative density 0.75 is run into a tank measuring 6 m × 4 m × 8 m until the ullage is 2 metres. Calculate the number of tonnes of oil the tank then contains.

5 A tank will hold 100 tonnes when full of fresh water. Find how many tonnes of oil of relative density 0.85 may be loaded if 2% of the volume of the oil loaded is to be allowed for expansion.

6 A deep tank 10 metres long, 16 metres wide and 6 metres deep has a coaming 4 metres long, 4 metres wide and 25 cm deep. (Depth of tank does not include depth of coaming). How may tonnes of oil, of relative density 0.92, can it hold if a space equal to 3% of the oil loaded is allowed for expansion?

Appendix I

Standard abbreviations and symbols

K	The keel.
B	The centre of buoyancy when the ship is upright.
B_1	The centre of buoyancy when the ship is inclined.
BM	The height of the transverse metacentre above the centre of buoyancy.
BM_L	The height of the longitudinal metacentre above the centre of buoyancy.
CB	Centre of buoyancy.
G	The original position of the centre of gravity.
G_1	The new position of the centre of gravity.
M	The original position of the transverse metacentre.
M_1	The new position of the transverse metacentre.
M_L	The longitudinal metacentre.
KB	The height of the centre of buoyancy above the keel.
KG	The height of the centre of gravity above the keel.
Kg	The height of the centre of gravity of an item above keel.
KM	The height of the transverse metacentre above the keel.
GM	Initial transverse metacentric height.
CF	Centre of Flotation.
GZ	The length of the righting lever about centre of gravity.
KN	The length of the righting lever about keel.
V or ∇	The ship's volume of displacement.
W or Δ	The ship's weight of displacement.
w	A weight to be loaded, discharged, or shifted.
⊕	Amidships. (The symbol ⊕ is shown on trim diagrams).
L	The ship's length.
D	The ship's depth.

B	The ship's maximum beam.
d	The ship's draft.
F	Forward, or centre of flotation.
A	Aft.
M or m	Metres.
C_w	The water-plane coefficient.
C_b	Block coefficient.
C_m	Coefficient of midships area.
C_p	Prismatic coefficient.
I or i	Second moment of an area.
l	The distance of the centre of flotation from aft.
P	The upthrust on the keel blocks when drydocking.
μ	The permeability of a compartment.
WL	The original waterline.
W_1L_1	The new waterline.
G_v	The virtual centre of gravity.
t	The trim.
MCTC or MCT 1 cm	The moment to change the trim by 1 cm.
TPC	The tonnes per centimetre immersion.
GM_L	The longitudinal metacentric height.
SG	Specific gravity.
θ	An angle of list or heel.
WPA	Area of a water-plane.
FWA	Fresh water allowance.
FW	Fresh water.
SW	Salt water.
CDB	Cellular double-bottom tank.
CI or h	The common interval used in Simpson's Rules.
E	Young's Modulus.
y	Depth from the neutral layer.
f	Stress.
q	Shearing stress.
ρ	Density in tonnes/m^3.
ρ_{FW}	Fresh water density @ 1.000 t/m^3.
ρ_{SW}	Salt water density @ 1.025 t/m^3.
ρ_{DW}	Dock water density as given in t/m^3.
δ_{max}	Maximum squat.
S	Blockage factor.
y	Static underkeel clearance.
y_2	Dynamical underkeel clearance.
H	Water depth relating to squat.
T	Ship's mean draft relating to squat.
V_k	Speed of ship relative to the water.