A watery balancing act:
The science behind loading container ships

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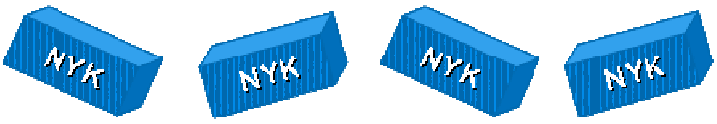


The world of container shipping:

On 23rd April, 1966 the first container ship set sail on its maiden voyage from Port Elizabeth in the USA to Rotterdam in the Netherlands.

It was an event which revolutionised the trade of commodities between countries. For the first time potentially fragile items, such as electrical goods, could be transported safely in watertight containers all around the world. So important did container shipping become that between the 1970s and 1980s the trade of commodities by this method grew by 300% and almost every country was doing it.

The container shipping industry has become an extremely valuable industry in our everyday lives. Here in the UK over 95% of the products we use on a day-to-day basis are brought to use by container ship. Anything from the clothes we wear to the electrical gadgets we own and the foods we all enjoy such as chocolate are likely to have been shipped by container at some stage.

A watery balancing act – the science behind container shipping:

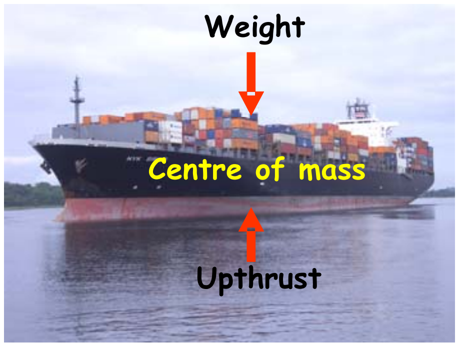
For container ships to work, they need to be perfectly balanced in the water and be able to float. The **upthrust** of the water acts through the boats **centre of mass**, keeping it **stable** and **buoyant** in the water (*see sideline science*).

However, as soon as containers are loaded onto the boat using a crane the ships **centre of mass** is affected. Ports have to load the container ship in a very specific way so that the centre of mass is not shifted too far, causing the boat to **capsize** (pictured). .

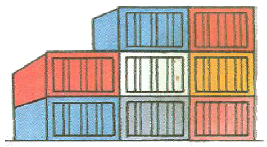
An example of how not to load a ship!

Sideline Science…

The science of buoyancy:
A ship will float, or be **buoyant**, only if the **weight** of water displaced by the ship **equals** the upward force from the water, termed **upthrust**. This has a lot to do with **density**.



The science of stability:
The **centre of mass** of an object is **the point through which all of the mass of an object acts**. Don't forget that **the weight of an object e.g. a container, is its force due to gravity** Container ships have to be perfectly balanced when loaded with cargo, and **forces must act through a centre of mass** for the ship to remain **stable** in the water.



Ship stability is affected by moments. **Moments are forces applied to levers or pivots**. In the case of a ship, if a moment is applied beyond its pivot (**centre of mass**) the ship will capsize! A wave is an example of a moment acting on ships

The moment of truth: loading container ships investigation

When a **force** acts on something which has a **pivot**, it creates a **turning effect**. A turning effect is called a **moment**

A pivot is the point around which a rotation happens, for example the centre of mass on a ship. A moment might be a wave, or overloading one side of the ship with cargo so that the centre of mass is shifted. **If a moment is applied beyond a ships pivot, it will capsize!**

Other sources of moments acting on ships include:
- The movement of cargo during voyage
- The movement of water inside the ships ballast tanks

The size of the moment depends on:

a) **the size of the turning effect** e.g. how much force (weight of cargo for example) is placed on one side of the ship
b) **the distance between the force and the pivot** e.g. how far away from the pivot (the centre of mass on a ship for example) a force is applied (cargo loading for example).

The ability of a ship to come back to an upright position (right itself) after a moment has been applied tells us how stable the ship is. This can be tested.

Moments are all or nothing events!

When an object is **balanced**, the **clockwise** and **anticlockwise moments** are the **same**.
We say the object is in **equilibrium** (Figure 1).

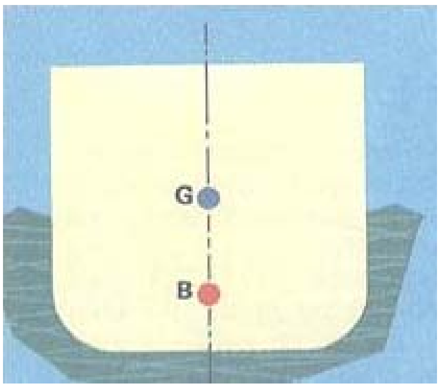
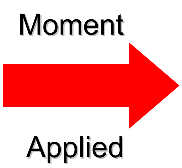


Figure 1. Ship is balanced



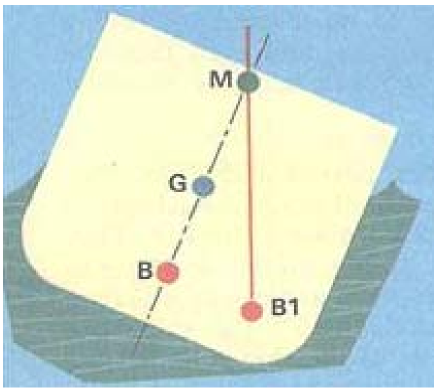


Figure 2. The ships centre of mass has shifted to the right

When a moment is applied though, depending on the size of the moment, a ship will either **capsize** or **right** itself (Figure 2.).

We can measure the moment of the force (**in Newton meters – N m**) by using the equation:

Moment of the force (N m) = force (N) x perpendicular distance from pivot (m)

(Perpendicular just means the direct distance between the pivot and the moment force being applied)

If the moment forces are equal either side of the pivot, then the ship will be stable. This is because the **anticlockwise moment** is the **same** as the **clockwise moment**. The forces are in **equilibrium**. If the **moment force** is **greater** on **one side** than the other though, the **turning force** will act in that direction. If this is great enough, the ship might **capsize**!

An important rule to remember when loading cargo ships is that:

The further away from the pivot a force is applied, the greater the moment will be

Time to experiment!

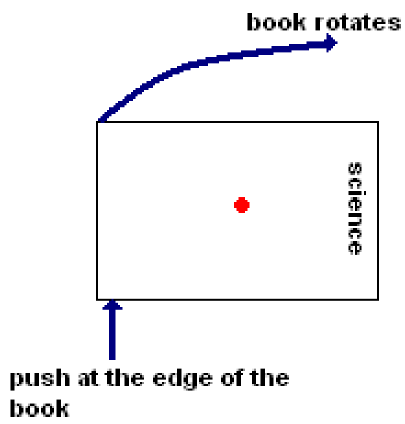
Experiment one: finding the centre of mass

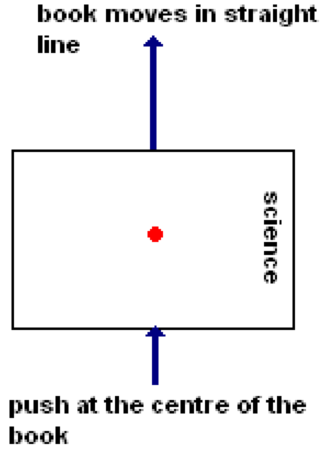
Reminder: the centre of mass of an object is the point through which all of the mass of the object acts.

You will need: a text book

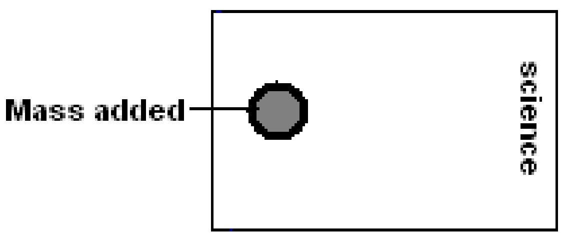
What you need to do: You can find the centre of mass by pushing the book with your finger.
- If the object moves in a straight line, then you are pushing through the centre of mass /
- If the object rotates, you are NOT pushing through the centre of mass.

See if you can find the centre of mass of your book, using the diagrams below as an example:





Now add some mass to your book and try the experiment again.



Answer these questions:

1 – Where do you need to push to get the book to move in a straight line?

____

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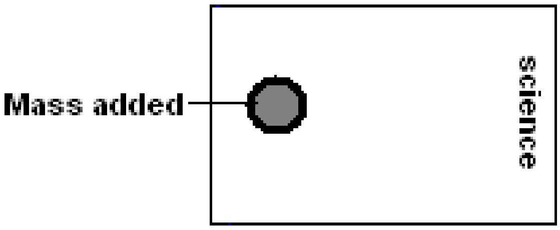
2 – What has happened to the book's centre of mass?

____

____

3 – Mark the new centre of mass of the diagram right:



Experiment two: finding the balance

Reminder: When a force acts on something which has a pivot, it creates a turning effect. A turning effect is called a moment

You will need: a 30cm ruler, a rubber

What you need to do: Try to balance a ruler on your finger.

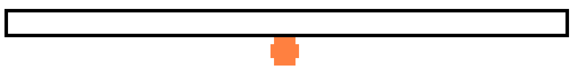
- All the weight of the ruler is acting down through its centre of mass.
- Your finger is providing the upward force (just like upthrust on a ship) to hold the ruler up
- If the force from your finger is acting through the centre of mass, the ruler is balanced.

Now add a rubber to one end of the ruler. What happens?

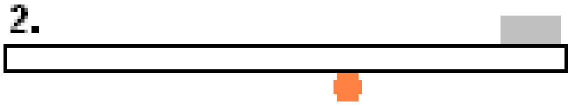
- You have shifted the centre of mass by applying a force (a moment) so that the force from your finger is not acting through the centre of mass anymore, but the rubbers instead.
- The ruler is now unbalanced, just like a ship would be.
- You can re-address the balance by shifting your finger to the new centre of mass. On a ship you would add cargo to balance out the imbalance.

Try this now using the diagrams below as an example:

1.

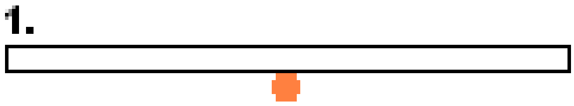


2.

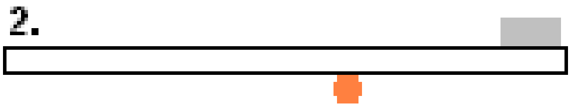


Answer these questions:

1 – Label the pivot on this diagram



2 – Label the moment and indicate the direction of the moment by adding an arrow to this diagram



Experiment three: loading container ships

Reminder: When a force acts on something which has a pivot, it creates a turning effect. A turning effect is called a moment

You will need: a 1m ruler, a stand, two spring balance force meters, various weights in g

What you need to do: investigate how much weight you can add to different points along your 'boat' (ruler) before the boat capsizes.

- As soon as items are loaded onto cargo ships, its centre of mass is affected. Unlike the ruler situation, we cannot just shift our finger to re-address this balance, so ports have to load ships in a very specific way so that the centre of mass is not shifted too far, causing the boat to capsize.

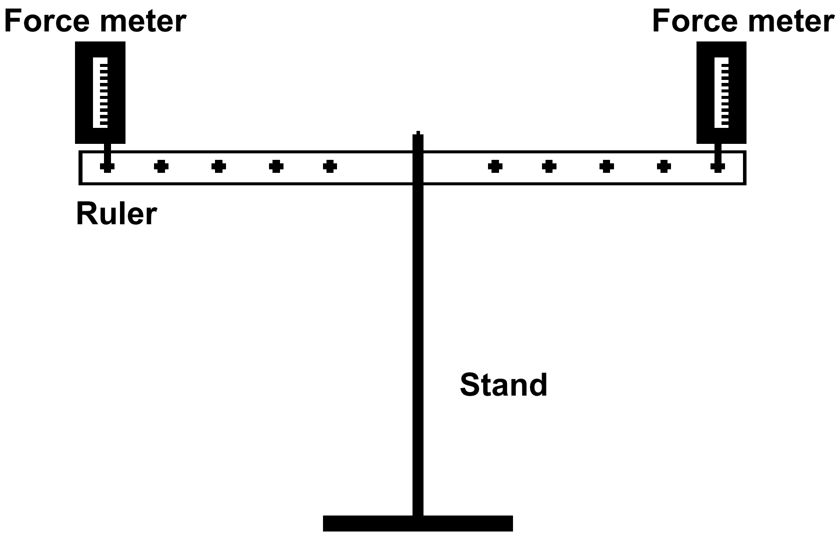
- The difference between unbalancing a boat and unbalancing a ruler is that the boat is in water and is subject to upthrust. By sinking one end of the boat (i.e. by adding containers), the up-thrust increases on the other side until a new equilibrium is reached.

- In this experiment, tension in the springs of the force meters will act as upthrust, so you can read how much extra upthrust force is needed at one end to keep the boat afloat while loading.

Be careful though; too much imbalance and the boat will capsize.

Important: if one of the springs reaches zero Newtons (N), then there is no longer an upthrust from the water. This means that this side of the boat has been raised out of the water and it will soon capsize.

Using the diagram and results table overleaf, investigate how much weight you can add to different points along your ship before it capsizes i.e. one of your force meters reads zero Newtons.



Distance from centre	Amount of weight added before toppling (g)	Amount of upthrust on this side before (N)
10cm		
20cm		
30cm		
40cm		
50cm		

Answer these questions:

1 – Where can you add the most weight before the boat capsizes?

____

____

2 – When the boat is on the verge of capsizing, what should you do before adding more weight to this side?

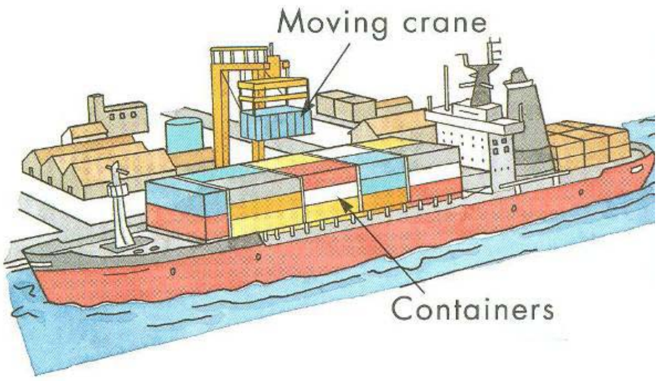
____

____

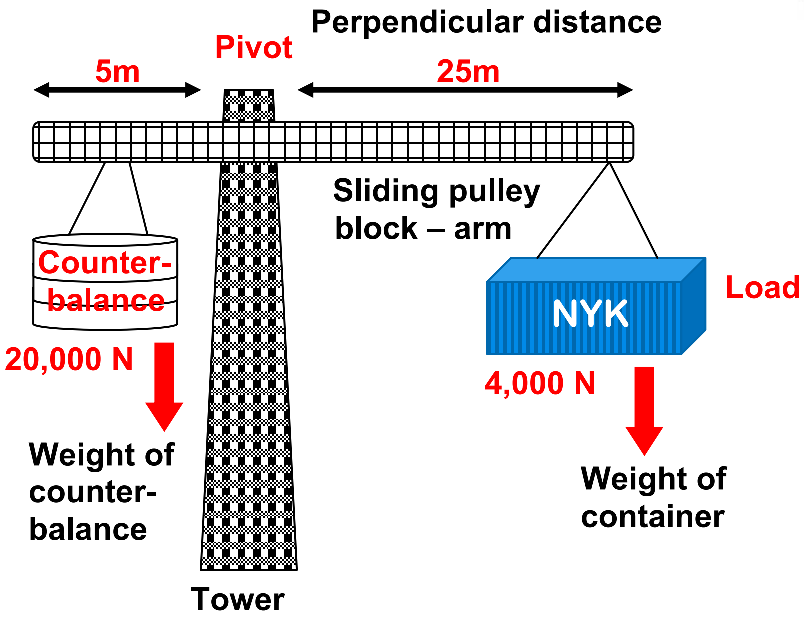
Did you know?

In an average year, a container ship travels nearly 300,000km. That is more than seven times around the globe and three quarters of the distance from Earth to the moon!

Extra: the loading of cargo ships – how cranes work:



Containers are very heavy objects, often weighing at least 1000kg. Because of this, special cranes are used to lift containers onto container ships.



These cranes, just like ships, need to be balanced in order to work. There needs to be a counter-balance during lifting of a container for example so that the crane doesn't topple over!

Answer these questions:

1 – Using the values in the diagram above and the equation below:

Moment of the force (N m) = force (N) x perpendicular distance from pivot (m)

calculate the moment (turning force) of both container and the counter-balance. Don't forget to include units in your answer.

Container_________________________

Counter-balance__________________

2 – Is the crane balanced when lifting containers onto the container ship?

____

3 – Why?

____

4 – If the perpendicular distance between the pivot and the container is reduced to 20m, would the crane still be balanced?

____

____

5 – If not, why not and which way do you think it would topple

____

____

6 – What is the maximum load that can be lifted if the perpendicular distance between the pivot and the container is reduced to 20m? Hint: you may need to rearrange the equation for calculating moments. Show your calculations and include all workings and units.