FLUIDS 1

BUOYANCY

This section looks at buoyancy (a topic in fluid statics) – and its engineering applications.

FLUIDS 1

BUOYANCY

OVERVIEW

In this section you will learn:

- About the forces caused by static fluids of different densities
- Why things float, sink or display neutral buoyancy
- Why balloons rise and ships float
- About stability in ships

OBJECTIVE

Buoyancy explains why things experience upwards and downwards forces in static fluids and explains why balloons and ships float.

Front picture: “Hot air balloon in flight” by Kropsoq. Licence: CC BY-SA 3.0.

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TOPIC 1 – THE NATURE OF BUOYANCY

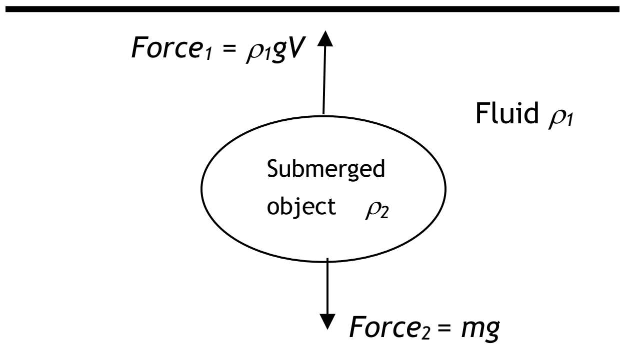
Buoyancy is the reason that ships float and hot-air balloons rise. If you drop a material into a fluid which has lower density than that fluid, it will float. If it has higher density than the fluid, it will sink. The Greek philosopher Archimedes was said to have discovered this. Buoyancy (assuming that surface tension can be neglected) also controls how one fluid behaves when enveloped in another (like smoke rising from a chimney or oil floating on water).

TOPIC 2 – THE MATHEMATICAL BASIS OF BOUYANCY AND BALLOONS

If we displace a volume of water V from a tub (say by submerging an air filled balloon in the water), the balloon will experience an upthrust equal to the weight of water it displaced:

$$\text{Upthrust} = \rho g V$$

Actually, when we look more closely, it's not quite as simple as this. We've assumed that the weight of the balloon and the air it contains is itself zero. This is quite a good approximation for air, which weights 770 times less than water, but in general the upthrust is countered by the weight of the object itself which opposes it.



Upthrust force is $\rho_1 gV$.

Weight of object = $mg = \rho_2 gV$

So total force on object is $\rho_1 gV - \rho_2 gV$

So it will rise (positive force) if $\rho_2 < \rho_1$ and sink (minus force) if $\rho_2 > \rho_1$, if $\rho_2 = \rho_1$ then the object is neutrally buoyant. In some cases (for example in submarines or underwater vehicles) *Ballast* (extra weight or low density, high volume material) is added to objects in order to make them neutrally buoyant.

Although the example above refers to a balloon, it applies equally to any region of one fluid immersed in another – although in this case, if there is no boundary between them, the fluids will be continuously diffusing and mixing with each other (so the effect is more difficult to calculate).

TASK 1

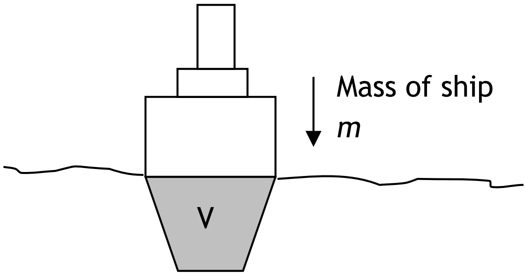
A high-altitude research balloon at sea-level weighs 50kg (the weight of its envelope and payload). It is inflated by hydrogen to a (circular) radius of 20m.

- *a) What upwards force will the balloon experience?*
- *b) What will its initial acceleration be?*
- *c) Why will this acceleration decrease with altitude?*
- *d) When will the balloon stop rising (assuming it doesn't burst first)?*

The upthrust force acts through the *centroid* of the volume of fluid displaced. Let's look at a couple of applications.

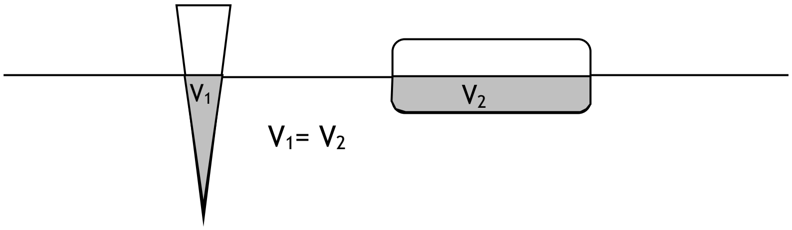
TOPIC 3 – BOUYANCY AND SHIPS

The section above tells us how deep a ship will sink (that is, what its *draft* is). Consider the ship below.



The ship displaces a volume V (shown by the shaded area) of water. So upthrust is $\rho_w g V$. The weight of the ship is mg. So the ship will float when $\rho_w g V = mg$ or when the volume displaced is $V = \frac{m}{\rho_w}$.

The exact depth to which it will sink will, of course, depend on its shape. Long thin ones will have a larger draft than broader hulls.



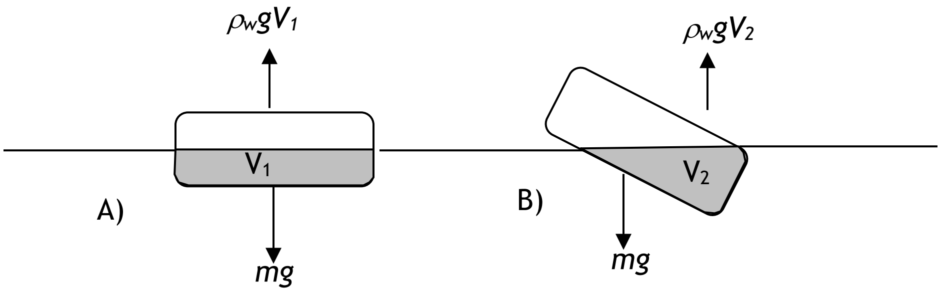
TASK 2

The "Isle-of-Lewis" (ferry boat) weights around 5000 metric tonnes.

a) *What is its displacement in freshwater?*
b) *What about salt water?*

TOPIC 4 – STABILITY AND SHIPS

Buoyancy also explains why ships right themselves when they roll.

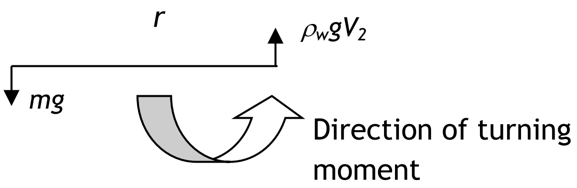


Case A) is what we've already investigated. The weight of the ship (mg) is balanced by the upthrust ($\rho_w g V_1$), where V_1 is the shaded volume. If the ship rolls – as in case B), the weight is still the same and acts through nearly the same point (the centre of gravity of the ship). However, the displaced volume has shifted (and the volume itself may have changed to V_2). But, importantly, the upthrust acts through the *centre of volume* – and this had shifted the upthrust force to the right.

So there is now a moment or couple acting (that is, a turning force). This acts to right the ship – we say that the ship is *Passively Stable*.

Couple =

$(mg+\rho_w gV_2)r$



TASK 3

1. *The ship described in task 2 heels, so that it displaces 3000m^3 (in salt water) which is centered 5m from its center of gravity.*
    a. *What is the righting (turning) moment on the ship?*
    b. *What else would be need to know to calculate the initial angular acceleration of the ship back to an even keel?*
    c. *Will this initial acceleration change as the ship rights itself?*
2. *What do you think the advantages and disadvantages (in the wider engineering sense) of a long thin ship with a deep keel?*

SUMMARY

- Buoyancy controls whether objects (or regions of gas or liquids) float or sink in a fluid.
- Buoyancy in fluids with no boundary between them is more difficult to calculate due to the diffusion of one fluid into another.
- The force on a contained region of fluid inside another is the difference between the weight of the displaced fluid and the weight of the fluid in the region.
- Objects which neither sink nor float but remain stationary are said to be “neutrally buoyant.”
- Ballast is sometimes added to an object if it is required to neutrally buoyant.
- Buoyancy plays a central role in naval architecture in particular in calculating:
    - This displacement of vessels.
    - Their stability.

REFERENCES AND BIBLIOGRAPHY

You may also wish to refer to some basic references on ship design to understand how different shapes of hull effect design. You can find some of these on-line or in youtube videos.