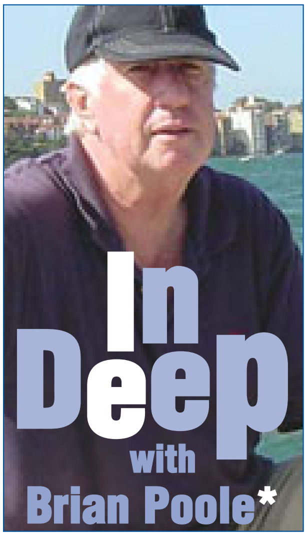


What is 'FREE SURFACE'?

Every so often I go in deep with technical explanations of boat engineering fundamentals. So often these subjects cannot be half done. It's a case of a little information being dangerous.

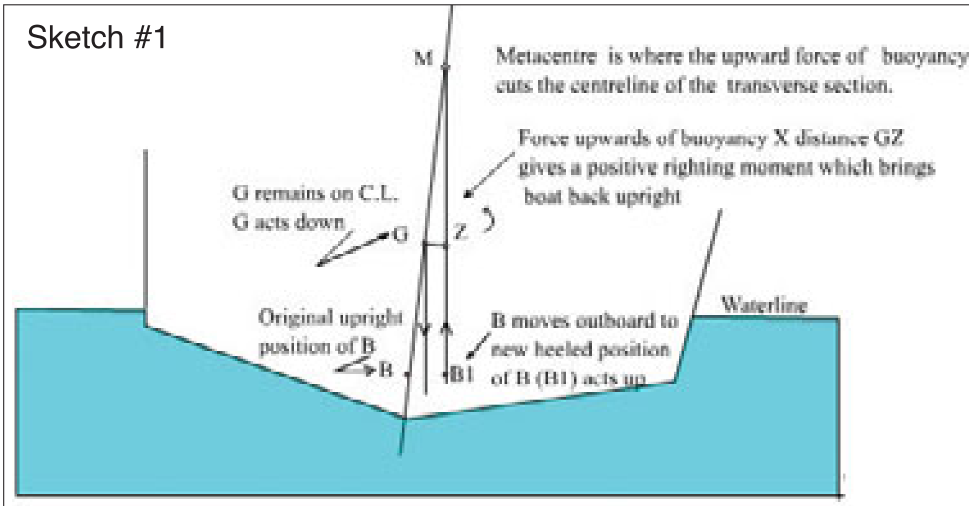
Understanding correctly what is free surface of unrestrained liquid in a small craft, and when it can be a problem, is one such subject.

As always, the lower deck lawyers are the experts on everything and there is always some truth in what they say. They will tell you that free surface in a boat reduces stability, and this is true. But there is more to it than that. We need to know:

- ***What is meant by free surface?***
- ***What is the correct definition of stability?***
- ***Why does free surface reduce stability?***

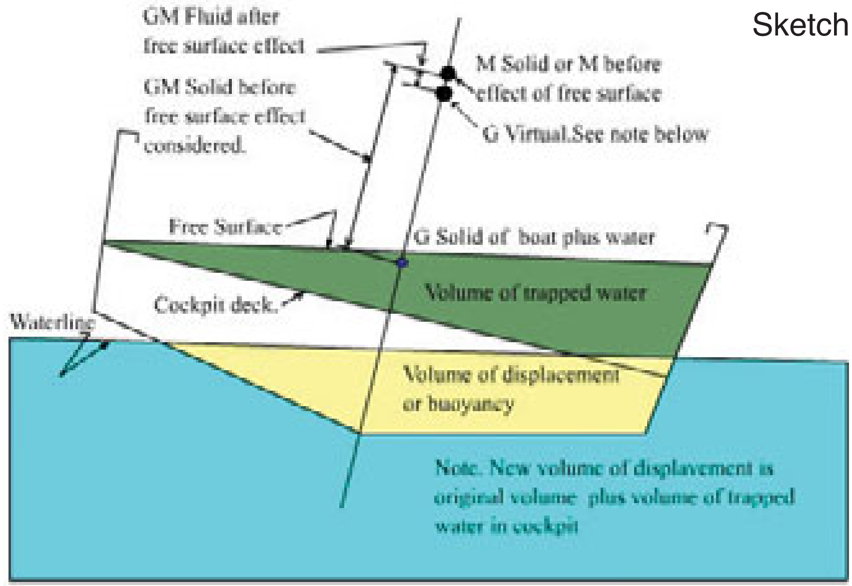
I shall try to explain it all in the simplest possible way. Note this is an explanation not an engineering analysis. I will not attempt to explain the engineering details. I attempted to do that, but when I got to 10 pages and 12 illustrations I realized

Sketch #1



SKETCH 1. Fundamental concept of upright stability showing a transverse section through a boat.

Sketch #2



Sketch 2.Free surface effect on full width cockpit..Note. free surface has the same effect as a rise in G, the centre of gravity of the craft. This new position ofG is called G Virtual.

that I was in far too deep.

So what is free surface?

It is any unrestrained surface of liquid in the bilge or in tanks, that can move from side to side, as the vessel heels.

The more restrained the fluid is, the less is the effect of free surface, that is why longitudinal baffles are fitted in wide fuel tanks, apart from supporting the tank top. (See sketch 4).

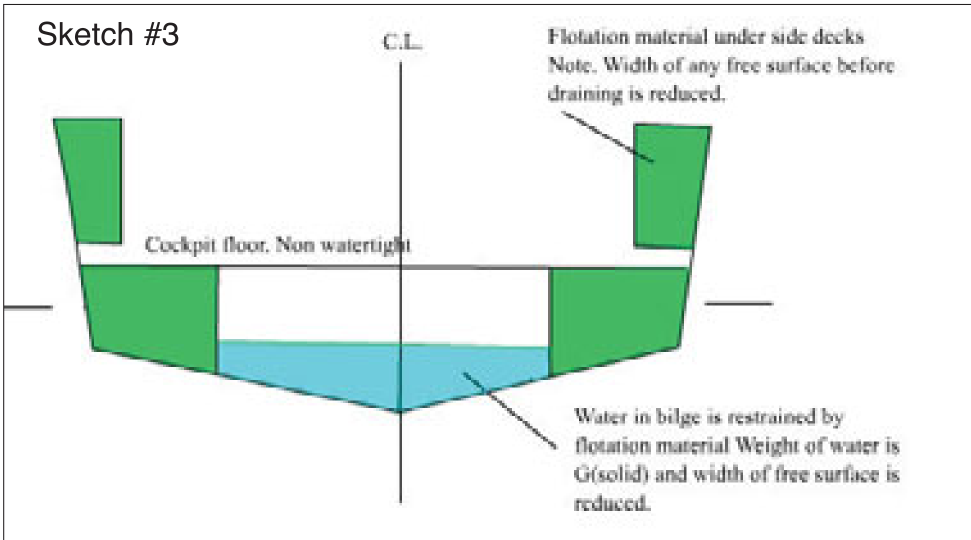
Stability is the ability of an upright vessel to return to the upright when heeled over by an external force such as wind or wave. Note that we call this heel. List is something different. List is when a vessel is listed over by moving existing weights aboard to one side. We can list a craft over by moving all passengers to one side. We assume for the purpose of stability that a seagoing vessel has no list, but of course this is an ideal situation. There is always some list, however small.

To understand how free surface works we must first understand how stability works

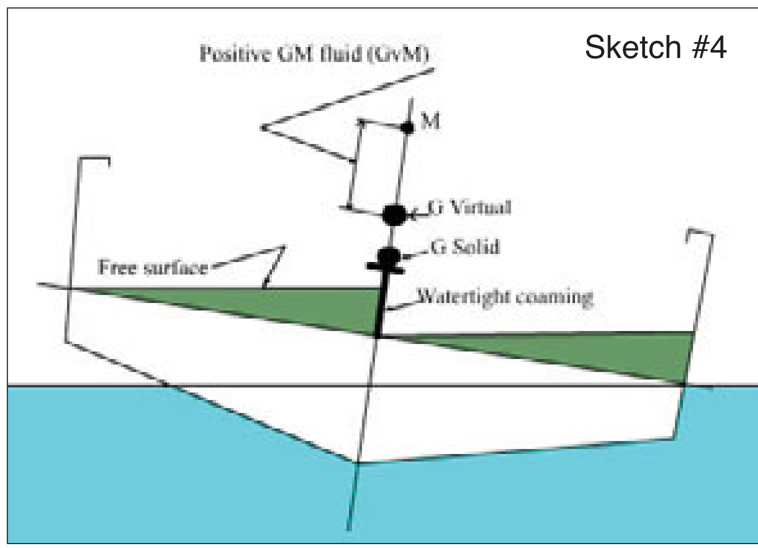
An stable upright craft when heeled over generates a righting moment. See sketch 1. This positive righting moment brings the craft upright. Where the upward force of buoyancy crosses the centreline is called the metacentre. If the combined centre of gravity of the craft (including all loads) is below M, the craft is stable.

If the centre of gravity is above M, the craft is unstable and will capsize.

For smaller craft, the centre of gravity is generally determined by calculation and accurate weights are required. The position of the vertical centre of gravity



SKETCH 3. IDEAL DISTRIBUTION OF FLOTATION MATERIAL



(KG) can then be validated after the craft is in the water by an inclining experiment. This is usually only required on vessels over 6 metres. It also happens that we can prove from calculus that the distance BM is the Moment of Inertia of the water plane divided by the volume of displacement.. Since we can also calculate KB, we can determine the length GM. **(see Sketch 1)**

Now the problem with free surface with an intact vessel is that the distance from B to M, which we call BM, is reduced by any free surface of liquid in tanks or compartments. For tanks in smaller craft, which are seldom more than a metre wide, the effect is not great. Further, a conventional small craft of (say) 6.0 metre to 10.0 metres has considerable BM.

This is because, in relation to say a much larger ship, the beam to length ratio is much larger. For example a typical beam to length ratio for a boat is 1 is to 3. Whereas for a large ship it would be about 1 is to 10. This means that relatively small intact craft are very stable, and there are no stability problems with a correctly designed conventional small craft in say the 5 to 8 metre range.

A typical conventional outboard powered 6 metre monohull would have a BM of about 2.2 metres. Its centre of buoyancy would be about 0.2 metres above the keel depending on the hull shape. It's centre of gravity with all persons standing up would be about 0.6 metres above the keel. The GM therefore would be about 1.8 metres, which is a large margin of safety. In other words the centre of gravity would have to raise 1.8 metres for this 6 metre craft to be unstable.

(Sketch 2)

So how could this boat be made unstable in the upright condition? Only if the effect of a very large quantity of water with a large free surface came aboard.

Let's say the vessel has a watertight cockpit and landed a relative large 'greenie' which, for a period of time before the water is freed, filled the cockpit to 100mm above the deck.

This would have two effects.

First, the weight of the water, at about 0.9 tonne, would not effect the position of G very much because the CG of the craft is about or higher than the CG of the trapped water, but the craft's volume of displacement would increase by about 75%, that is, from 1.4 tonne to 2.3 tonne.

Then there is the free surface effect. Let's say the cockpit is 4.0 m long by 2.3 m wide, and there is a 150mm coaming into the forward cabin to stop the water getting down into the bilge. The free surface effect would reduce the GM by about 1.75 metres and the vessel would be barely stable, with just 0.05 metres of positive GM. For simplicity, it is usual to say that Gv (G Virtual) rises, and if it rises above M, the craft capsizes. We call the GM in any condition of free surface G (fluid).

The effect of any list caused by an off centre load, such as passengers thrown to one side, could cause the craft to capsize due to the dynamics of the seaway.

As the water frees, the free surface will remain until the cockpit is cleared. In fact for a period of time the effect becomes worse.

This is because the effect of the free surface on GM depends on the free surface area divided by the volume of displacement. 50mm of water would have the same surface inertia initially, however the volume of displacement would be reduced by 0.45 tonne. This would result in GM being reduced by about 2.1 metres and the craft would be unstable because G (fluid) would be above M. In a smooth water situation we can put a lot of water into the boat and providing the CG of the extra water is not higher than the original CG of the craft and passengers, it is less likely to capsize than if it had less water but the same amount of free surface.

Now in smooth water, with persons aboard correcting any heel that occurs, the craft can be easily made to remain upright. This is what I call the automatic stability machine effect where the person aboard automatically corrects any heel by a slight body movement. If a passing boat creates a wave, the craft may well capsize.

In fact with a damaged and listing warship, the correct practice is to jettison from the high side first. The reason for this is that if you jettisoned from the low side the combination of free surface, weight change, and sea conditions, may cause the craft to list to the other side and capsize.

What happens with a flooded small craft is that when the boat rolls to one side the persons aboard can overcorrect causing the craft to roll back to the original high side. The combination of free surface and the off centre load on the original high side, then capsizes the craft.

Let's say the craft does not have a self-draining cockpit and water went into the bilge. With the water captured under the cockpit the combined centre of gravity of the craft in the new condition would drop, and the free surface effect would be less. **(Sketch 3)**

The self-draining cockpits in offshore monohulls under 6 metres present an identifiable hazard. That is why the Australian Builders Plate requires internal flotation, including under floor material, in all craft smaller than 6 metres.

On another aspect of stability. The intact BM of a vessel depends on the inertia of the boat's water plane. Let's take Peter Webster's modification to the 8.2m x 2.5m beam *Far-Away*.

Peter made the waterline beam greater by about 200mm by fitting chine pods. The engineering effect of this on the distance GM (solid) would be an increase in GM (or stability) of roughly 0.45 of a metre.

In other words, placing a 100mm of surface width to each side of the waterline at the maximum distance from the centre line had a significant positive effect on stability.

Swamping is just one cause of free surface. Leaking of the hull or cockpit deck is another. At least the height G is lowered by the weight of the water but this may not cancel out the free surface effect. The subdivision of the under cockpit spaces in larger craft by watertight bulkheads is the only way excessive free surface can be avoided.

In smaller craft less than 6.0 m LOA, polyurethane flotation material under cockpit floors port and starboard and above floor material under the side coamings is required for conformance to the new Australian Builders Plate requirements. (Sketch 3)

The person validating the information on a plate as conforming to requirements could not be said to be competent if he or she did not understand the engineering aspects of free surface effect as described in this article. Yet under the legislation a competent person is defined as a builder, importer, or quote 'other competent person'.

What constitutes being competent is not defined.

Free surface effect is just one aspect that a designer must take into account in order to reduce the risk of capsize in an adverse situation. Other considerations are excessive top weight resulting in a high centre of gravity, and the effect of high windage on the side particularly with extensive cockpit clears in position. Another consideration is the angle that a craft can heel to in the intact condition without losing positive stability. A conventional ship has its maximum righting moment at about 40 degrees of heel.

However a small chine craft may well be approaching loosing all stability at this angle of heel because the chine may well come right out of the water causing the moment of inertia of the water plane to drop due to the reduced width of water plane.

Volume of displacement will remain the same because the weight of the vessel has not changed.

Off centre loads (such as passengers thrown to the low side) will not assist the situation. An overloaded small craft with excessive bilge water would have little chance if heeled over by the waves of a passing high speed motor cruiser.

In summary, a well-designed conventional craft has a good margin of intact stability. Craft under 6.0 metres are more vulnerable to misadventure, but larger craft are still at risk in an out of line situation such as a major swamping by a rogue wave.

An appreciation of the effect of free surface is necessary in order to take appropriate corrective action in an emergency before it is too late.

F&B

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