FORM STABILITY – THE SHAPE FACTOR

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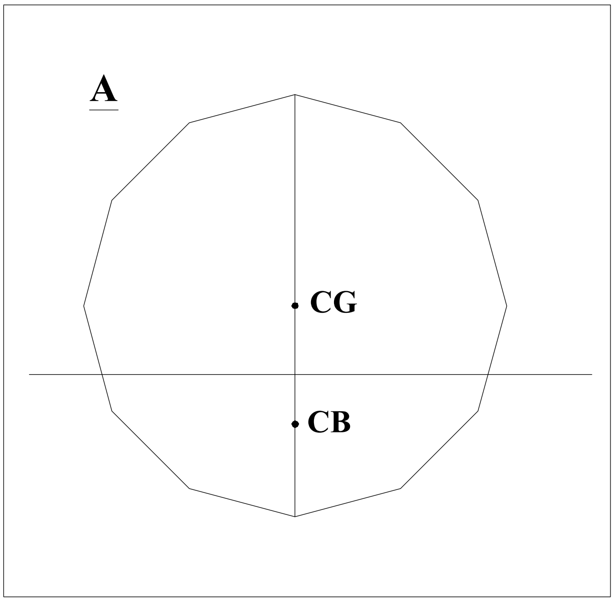
Perhaps you have asked yourself the question 'what keeps this boat upright?' or 'why is this boat more stable than another?' The complete answers can be found in an obscure, esoteric black art called 'Hydrostatics' practiced by reclusive yacht designers in dark offices on moonlit nights, but it is really not all that complicated. There are basically only two ways in which a vessel can obtain stability, either by the use of ballast, or by a naturally stable hull form. An unstable boat will inevitably end in heartbreak for an unwary amateur builder who does not understand the principles involved, so how does one avoid choosing a design which will result in what must inevitably be an inferior and perhaps unsafe vessel. The answer is to have just a basic understanding of the principles of stability.

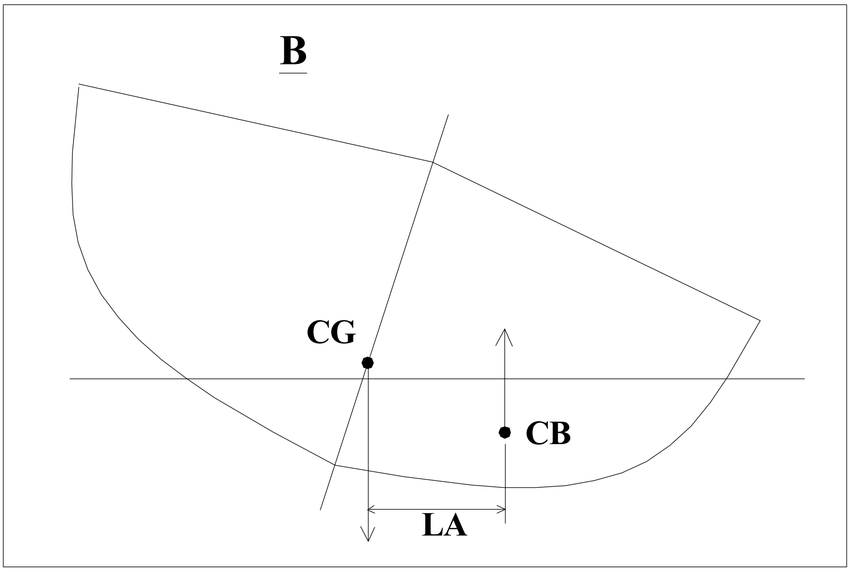
Stability can, as mentioned above, be obtained in two ways, by the use of ballast or by the 'form' of the hull. In one sense, ballast stability is the human way, whilst form stability is nature's way. To understand how each works, one must be aware of two major elements in the design of a boat, the Centre of Gravity (CG) and the Centre of Buoyancy (CB).

The CG of a vessel is the point through which it's overall weight acts downward under the pull of gravity, and should generally be fairly constant in any boat (we won't get into boats with water ballast, pendulum keels, or where constantly moving crew make up a high proportion of the weight). The CB is the point through which the buoyancy of the hull applies force in an upward direction, and will normally change its position as a boat heels. When a boat is at rest and in an upright position, the CG must always be directly above (or below) the CB. If it is not, then the hull will heel, or trim fore and aft (or both) until it is. (One would not expect this on a well designed and correctly built boat.)



To understand how a boat obtains stability, one must consider the interplay between these two centres as the boat heels. Let us consider four examples of hull shape.

The first example (A) is a true cylinder, or barrel shape. The CG of the cylinder will be at the geometric centre, and at rest the CB will be directly below the CG. The cylinder is at a point of stable equilibrium. If the cylinder rolls over to any degree, the constant cylindrical shape will result in the CB always remaining exactly under the CG, Therefore the cylinder will find a new state of equilibrium at any point to which it may role, and there will never be any tendency for it to return to its initial state. A little thought will tell you that such a situation is totally unacceptable for any boat. (The only way to make a boat with a cylindrical or near cylindrical hull shape stable is to use ballast to move the CG below the geometric centre of the hull shape, thus giving it some degree of stability in much the same way as discussed below for hull (C), the Plank on Edge Hull Form.)

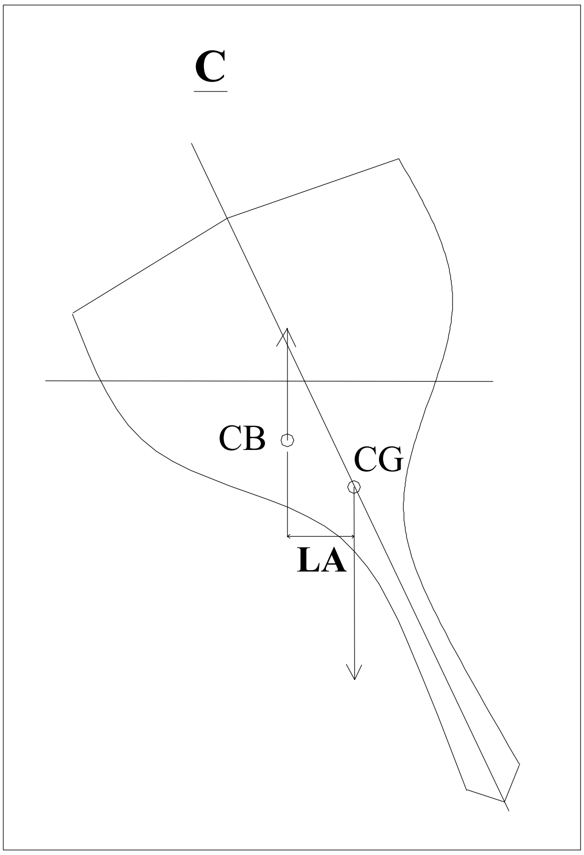


In example (B) we see the basics of stability. The hull has been widened and shaped in such a way that as the hull heels the CB will move towards the immersed side of the boat, thus setting up a lever arm (LA) between the downward acting CG and the upward force of the CB. The actual stability of this boat is measured by the 'righting moment' which can be simply defined as the length of this lever arm, multiplied by the displacement of the boat, multiplied by the force of gravity. As the force of gravity is constant, it is fairly obvious that the longer the lever arm, the more stable a boat of a given displacement will be.

The next thing that can be appreciated from this drawing is that in order to increase the stability of the boat one must lengthen the lever arm, either by moving the heeled CB further outboard, or by moving the static CG lower in the boat, as in a heeled yacht, lowering the CG will effectively translate to an increase in the lever arm as the CG moves down and away from the immersed side.

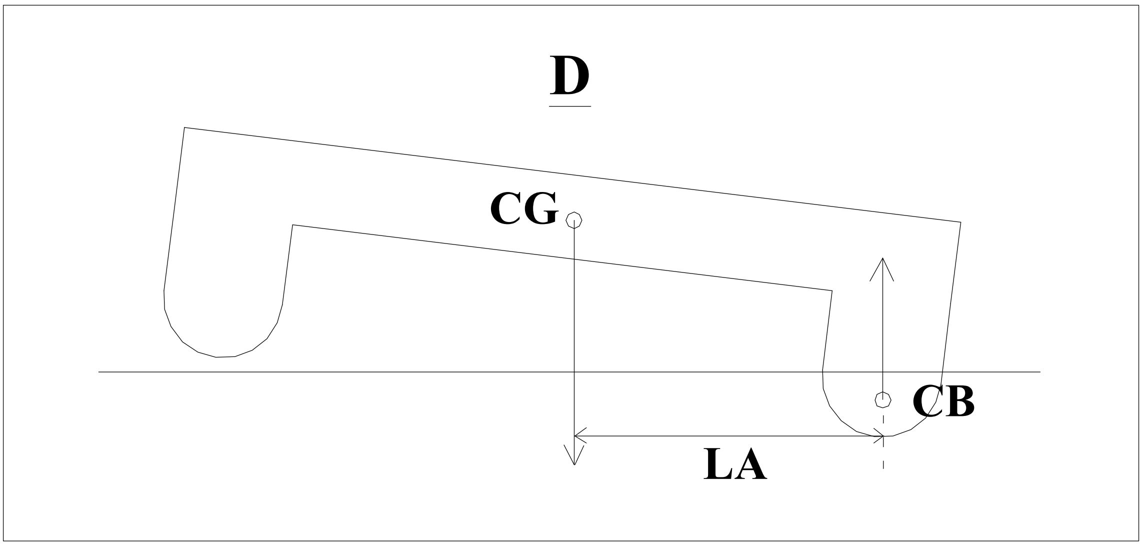
The second method was probably employed in its most extreme form by the 'plank on edge' style of keel boat (example (C)) once commonly seen in Europe, and to a lesser degree elsewhere. This style of yacht virtually ignored the natural principals of form stability and relied for stability on a lot of ballast, placed low down. As the hull heeled, the CG was carried away from the CB, thus increasing the lever arm.

A far better alternative is to design form stability into the hull so that as the boat heels the CB moves outboard, applying a lever arm to force the boat back upright. This is the method most commonly used today, although usually combined with ballast placed low down to gain maximum affect. The



'plank on edge' hull style is not seen on today designs as it produced yachts which tended to be wet and sail at a heavy angle of heel. Modern 'high tech' racing yachts will combine high form stability with large quantities of ballast carried low down in bulb keels to obtain the best of both techniques.

The most extreme use of form stability is displayed in the modern multihull, which having no ballast, relies entirely on hull shape for stability. The first example of form stability was probably the simple raft, and the multihull is simply an extension of the raft principle, that of creating a very large lever arm by pushing the CB out as far as possible. This principle is illustrated in example (D). When a multihull heels even a small amount, its buoyancy is shifted quickly and dramatically to the leeward hull, instantly creating a lever arm equivalent to almost half the beam of the boat. By comparison, the lever arm in a 40 foot keelboat may only be a foot or two at most. The large lever arm of the multihull creates enormous initial stability. To a lesser degree, the principle of creating stability entirely through form is also employed by most powerboats, and by some smaller unballasted sailing yachts (although in small dinghies you must consider the crew to be ballast).



So, what have we learned? There is no magic formula for the amateur builder to tell how much form stability a design has. That is the domain of the designer, and can involve quite complex calculation.

It is made more difficult by the fact that larger yachts will have ballast, which will also affect the stability, and that simple figures quoting ballast ratios etc will not always give a fair appreciation of the real stability of the boat.

A good general principal is that as a hull shape approaches the cylindrical shape, so its form stability will reduce to zero. For a boat which is very deep and narrow, such as the 'plank on edge' types, form can actually act against you, with a tendency to capsize the boat. This must be counteracted by employing huge quantities of expensive ballast.

A hull which is wider in proportion to its depth (approaching dish shape) will have better form stability. A boat with a rounded bottom but wide flared hull sides will be initially tended, but will pick up stability as the topsides heel down into the water. A hull with a flatter bottom and a hard turn at the bilge will display high initial stability, but will become more unbalanced as it heels. As is so often the case, the best compromise falls somewhere between the two.

For powerboats, the same principles hold true. Boats with chine hulls usually have excellent form stability from the chines pushing down into the water. Round bilge hulls must follow the same careful design principles as the yacht to ensure that the shape is as far removed from the cylinder as reasonably possible. Remember that power boats may also carry ballast, often in the form of heavy internal engines and full fuel tanks.

How can you tell what is right? The best way is experience. Read about design principles, and look at a lot of boats. Hang around the yacht club and see what works for the best boats. Try looking at their hulls from end on while the boats are out of the water. If your boat plan does not have a lines drawing (which building plans for simpler boats often do not) the hull shape can be seen simply by looking at the boat, or a photo or accurate drawing from the end on perspective, or you can look at the frame sections, which reflect the actual hull shape. It won't take that long to familiarise yourself with 'good form'. Think about that cylinder! Remember, in a boat, if you haven't got good stability, you haven't got anything!