Rudders – problems and misunderstandings

By Dr Kim Klaka

Rudder balance – why is the steering heavy?

Why is it that some boats are finger-light on the helm whilst others are so heavy they pull your shoulder sockets apart? The answer lies in the design of the rudder – a well-designed rudder should be very light to steer, but not so light that you don't know what is going on. This effect is called rudder balance. There are three types of balance, which I shall call under-balance, overbalance and neutral balance. Other terms are used (e.g. balanced, semi-balanced), but they are ambiguous and sometimes misleading. The balance condition is determined by where the rudder stock is located in relation to where the steering force (the force generated by the flow over the rudder) acts. Whilst these principles apply to all rudders, I shall apply them to the typical spade rudder found on most production sailing boats.

Under-balance

In figure 1a below, the force acts at a point behind the rudder stock. The force will generate a turning effect on the helm (a torque or turning moment) that tends to turn the rudder back in line with the flow. This is under-balance. Such a condition is stable, in so much as when the helm is let go the force generated by the rudder will tend to turn it back to the centreline. This is a desirable condition, but if the rudder stock is too far forward of the rudder force, the torsion will be great, thus requiring a lot of effort to keep the rudder at an angle i.e. a heavy helm.

Over-balance

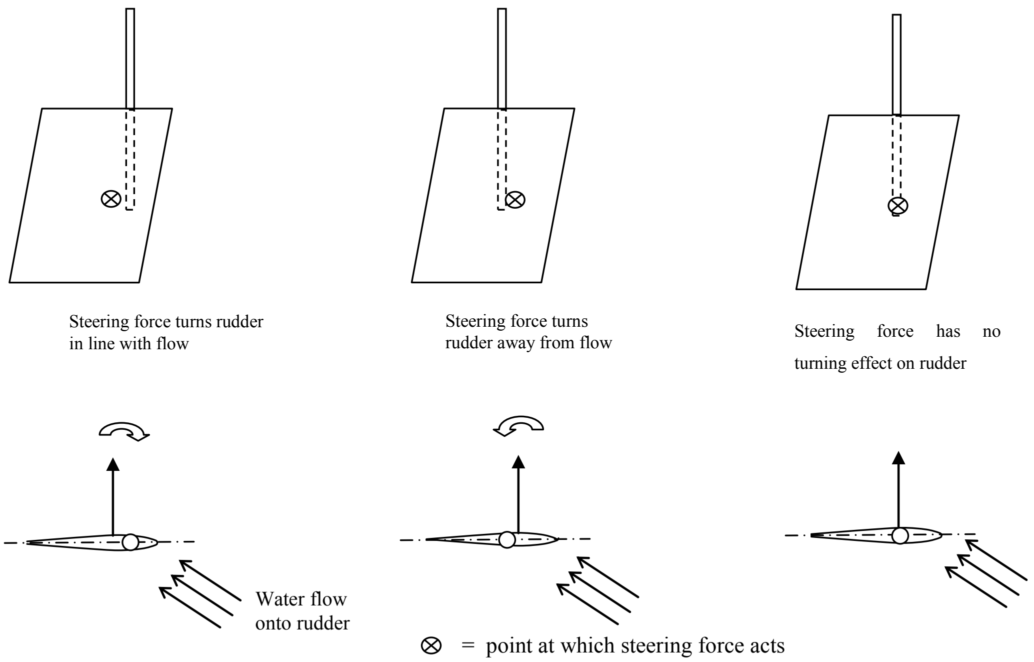
Figure 1b shows the opposite condition, where the force acts forward of the rudder post. This is overbalance, and is very bad news indeed. Why? Because if you apply just a small angle of rudder, the rudder force generates a turning effect which tries to make the rudder angle larger, leading to a greater rudder force, leading to a greater turning effect, greater angle etc. i.e. an unstable condition. You may have experienced this when trying to steer a boat backwards using a tiller – unless the tiller is kept dead centre it tries to rip itself out of your hands. Imagine what that would be like if it happened all the time when moving forwards! The effect is not so pronounced when wheel steering is fitted, but it can still be there.

Neutral balance

The third condition, in figure 1c, is where the rudder stock is at exactly the same position as the steering force, so there is no tendency for the rudder force to turn the helm, it just goes to where it is put. This means you have no "feel" to the helm, and can only tell what the rudder angle is by looking at the position of the tiler or wheel. This is called neutral balance. A well-balanced rudder is one that is just slightly under-balanced under all conditions. Unfortunately this is almost impossible to achieve because the position where the force acts moves around with boat speed, rudder angle and other factors. This is one reason why the weight on the helm changes with conditions, and why selecting the position of the rudder stock is a bit of a black art, understood only by a few good yacht designers.

Note that this is all about balance of the rudder, not the balance of the boat.

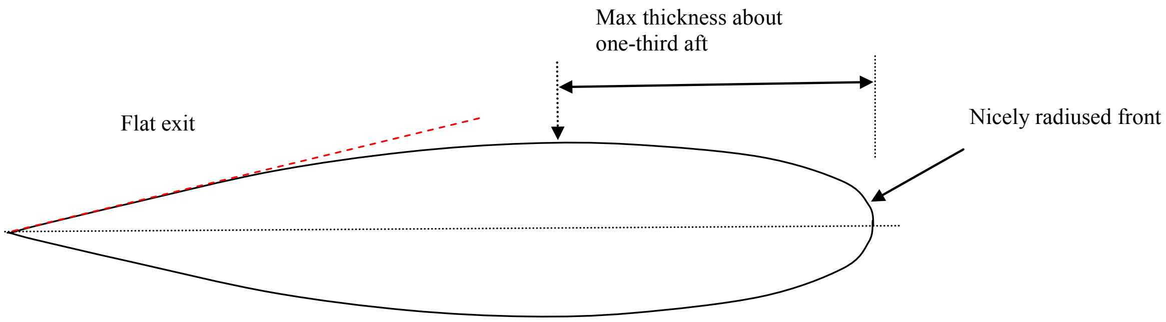
Figure 1a: underbalance Figure 1b: overbalance figure 1c: neutral balance



Rudder sections – what shape should it be?

There's a lot of nerdy talk written about rudder sections - NACA profiles, laminar buckets (!) etc. Here's a very simple guide to avoiding the worst shapes. See figure 2.

Figure 2: Section shape



Front

The most important thing is not to have a sharp leading edge –a fairly small radius is usually best, merging into the traditional aeroplane wing shape. The worst thing you can have is what you often see on rudders made up of plate metal – the two sides are bent round some frames then welded together down the leading edge in a rough vee shape. Not good. It should be nicely rounded, no flat parts. So for the front part of the rudder, think musically – no sharps or flats.

Thick part

Next thing is to make sure the position of maximum thickness (however much it might be) is about one third back from the front edge.

Back

And the final thing is to have the exit of the section straight i.e. if you offer a straight edge up, it should touch the rudder surface all the way from the back edge to about one quarter of the way forward. Some racing yachts have a slight hollow in the section aft. Whilst this might work for high performance racing keels, it is not good for rudders. Why might it be OK for keels but not rudders? Keels only have to work at waterflow angles up to about 5 or 10 degrees (i.e. the leeway angle), whereas rudders have to perform well at up to 20 degrees angle when turning the boat.

Stall, cavitation and ventilation – what's going on down there?

Stall

Stall occurs when the angle of water flow onto the rudder is so large that the flow separates from most of the downstream surface of the rudder, leading to loss of most of the available turning force. This usually happens at flow angles of about 20 degrees.

Ventilation

Ventilation occurs when the pressure on the surface of the rudder is low enough for air to be drawn down from the water surface on to the rudder, again with loss of available turning force. Ventilation rarely occurs below 10 knots boat speed.

Cavitation

Cavitation occurs when the pressure on the surface of the rudder is so low that the water literally boils i.e. vaporises, albeit at normal temperature. Cavitation does not require the drawing of air down from the water surface. Cavitation rarely occurs on a rudder at speeds below 30 knots, which means that sailing yacht rudders do not cavitate unless you are talking about Volvo speedsters or racing catamarans. Even then it is unlikely, because the rudder will probably ventilate before it cavitates.

So cavitation, ventilation and stall all result in loss of available turning force, but they are quite different mechanisms demanding different solutions to stop them happening. The best way of avoiding them is to handle the boat skilfully so you don't need such large rudder angles and rudder forces. The next best thing is to make sure the rudder is well below the water surface so it can't draw air down.

What happens if a rudder breaks?

Loss of the rudder leads to two potentially catastrophic events: loss of control and sometimes loss of watertight integrity. In other words you have great difficulty keeping away from rocks, and you can end up with a big hole in the boat and may sink in just a few minutes. The text book response to rudder failure is to deploy your emergency steering system . Most people's emergency steering is a spare tiller and if the rudder is missing, that's about as much use as an umbrella on a motor bike. Steering a boat without a rudder is extremely difficult indeed (I have done it for 60 miles and it was utterly exhausting). It is also something that cannot be practiced properly because a boat handles completely differently if the rudder is missing. There is also the more fundamental problem – losing the rudder often creates a very big hole in the boat, so you sink very quickly. Emergency steering then becomes purely ornamental.

Why do rudders break?

It is alarming that so many yachts suffer broken rudders in this age of technological advance – high performance FRP laminates, finite element structural analysis and so on. It is usually the rudder stock that breaks, and this usually (though by no means always) occurs near where the rudder stock enters the hull i.e. at the lower bearing. There are many reasons, but one of the most common is human weakness, or to point the finger at my own kind, a failing by yacht designers and builders. They often fail to believe the results of their rudder force calculations. It is an old adage that the difference between a good engineer and a poor engineer is that a good one knows the answer before he or she starts doing the calculations. To put it a different way, you need to have a sense of what is correct, based on past experience. Unfortunately this only works if past experience is learned from. The forces acting on a rudder are huge, so designers are understandably sceptical about the results they get from their calculations; consequently they reduce safety factors, tweak the assumptions etc until they get an answers that looks sensible. Unfortunately it isn't always sensible. To illustrate the point, consider this guideline: the side load on a spade (balanced) rudder of a typical production cruiser is very roughly equivalent to three quarters of the weight of the entire boat. In other words you should be able to almost lift your boat up by its rudder. There is no way in the world that a skimpy 40mm diameter stainless steel rudder stock on a 10m yacht is going to survive that, so it should come as no surprise when it doesn't. There are of course many other reasons why rudder stocks break – corrosion, fatigue, wave impact loads, grounding loads, poor quality fabrication – but these are really just another way of saying the rudder isn't designed to be strong enough, because they are all factors likely to be experienced by a rudder.

So what can the beleaguered boat-owner do about all this? The rudder stock comes with the boat and is not something that is easily replaced. Well, here's a few suggestions:

Owner of an existing boat:

Do a web search for rudder failures of your boat, its builder and its designer. Talk to owners of the same class/designer/builder; class associations are also a great place to find out inherent weaknesses in any class of boat. A nil return doesn't mean there isn't a problem but it gives a bit of confidence. A record of rudder failures should set the alarm bells ringing. Document your findings, contact a reputable naval architect (look for the qualification MRINA as a guide), explain what you have found, ask for a rudder survey and a solution. It might be expensive – the existing blade might be reusable but the stock will probably have to be increased in diameter, meaning a new set of rudder bearings and rudder tube. But it is a very great deal less expensive than losing the boat on the rocks or the deep ocean.

If looking to buy a new or second-hand boat:

Do that same web search for the boats you are seriously interested in. Also, take a look at the rudder stock sizes of similar sized boats; if the stock on yours is smaller than average, be very probing of the seller/agent. Quiz them thoroughly and ask for warranties, designers drawings and builder's drawings, and compare as-built with as-designed. If this is too technical for you, employ a naval architect for half a day to do this on your behalf, and get them to provide a design appraisal of the boat whilst they are about it. You should anyway be getting a pre-purchase survey of any boat, be it new or second-hand (by a qualified surveyor, not just a shipwright or marine engineer).

Does all this sound like too much trouble when there are so many other things to worry about, such as the rigging, sails and engine? A broken mast, a torn sail, or an engine that won't start are all potentially hazardous, but there are steps you can take to stop them developing from a problem into a disaster. That is very much harder to do with a broken rudder. It is comparable in consequence to a keel falling off, and much, much more likely to occur. You owe it to yourself and your crew to be thoughtful and thorough.

Biography

Kim Klaka is a naval architect with 40 years' experience in yacht design. He holds a Masters degree and a Doctorate in sailing yacht performance and has lectured on the topic for over 30 years. He has sailed over 30,000 miles offshore, in a dozen different countries. He owns a Van de Stadt 34 based at Fremantle