The Shock of the Old

Part 6: Single Panel Masts

Back to school, where Moray MacPhail is doing the 'hard sums' for us.

In theory, the arithmetic of a single panel mast – one where all shrouds and stays meet at one point on the mast – should be easy to work out. This type of rig covers a wide range of craft ranging from unballasted dinghies to yachts derived from working vessels. In *Principles of Yacht Design*, Lars Larsson and Rolf Eliasson start with the righting moment at 30˚, add various factors and resolve the forces to get shroud and mast loads. But you need to know the righting moment of your particular hull – which most of us don't – and in smaller boats, the crew is a major factor in the righting moment – sometimes all of it.

Some guidance can be found in Kinney's update of Skene's *Elements of Yacht Design* – see Figure 1 – but that relates to craft over about 22' (7m) waterline, larger than many of the boats we want to look at here. So I will continue the thread started when we looked at unstayed masts in W145 and work from the sail loading to find shroud and mast loads.

Some Sums for Single Panel Masthead Rigs

For traditional rigs – lug, gunter, gaff – which are stayed at the masthead because the mast has to be kept clear for travellers, jaws or saddles, we need to compare the loads resolved from the sail forces with the critical buckling load of the mast.

The total sideways sail force is:

$$P = p \cdot sf \left(SA_m \cdot f_m + SA_j \cdot f_j \right)$$

where:

- SAm and SAj are the sail areas in square metres for the main and jib
- fm and fj are the amount of load for each sail to apportion to the masthead. For the main, I'd suggest 0.3 for a bermudan sail, 0.5 for a lugsail and 0.65 for a gaff or gunter. For the jib I suggest 0.3. These numbers based on the considerations on how and where the sail acts in W145.
- p is the sail loading between 50 and 75 depending on size of boat (N/m2)
- sf is the safety factor, but because we are dealing with instability I reckon this should increase to 2.5 to 4, not the 1.5 to 3.5 used in W145. You can be more certain with bending than buckling.

Now a bit of trigonometry to get to the design load in the shrouds and the compression in the mast. Back to W142, and the critical load at which a solid round mast buckles is:

$$P_{crit} = K \frac{\Pi^2 EI}{L^2} \text{ or } K \frac{\Pi^3 E r^4}{4 L^2}$$

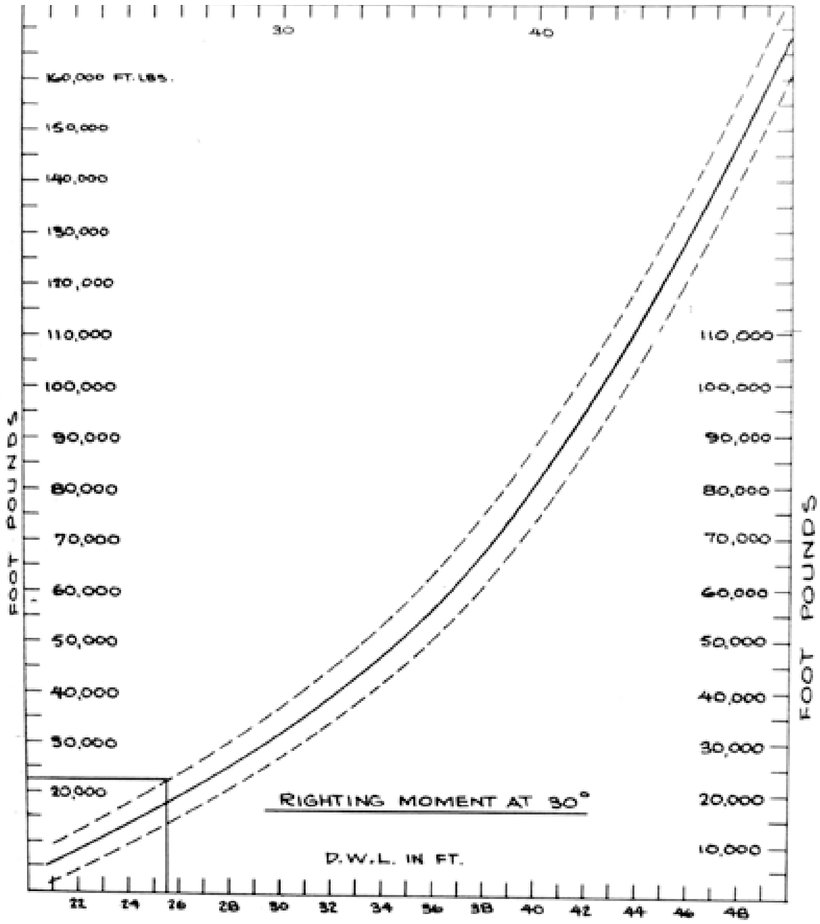


Figure 1: Righting Moment at 30° (From Kinney).

where:

- The safe bet for K is to use a value of 1, which relates to a column pinned at both ends. Even if the mast is wedged firmly into a tabernacle or into a collar at deck level there is always a possibility that it isn't really fixed, but acts more like a hinge. With buckling it's best to go safe, so we'll stay with a value of K = 1.
- E is the Young's Modulus, the stiffness of the material
- I is the section moment of inertia
- L is the length
- r is the radius of the section

You have probably had enough of sums, so I have put up a spreadsheet for you on my website – see contacts at end. In the case of my own boat, I do know the righting moment, and so have been able to compare the NBS method with the one proposed here.

The shroud design loads come out within 3% and argue for a 4mm (5/32") stainless wire. That is correct; I tried 3mm (1/8") but heard the occasional ping, so went up to 4. However the mast size seems shy from the NBS method at 2¾" (68mm). This I know because a sister vessel quickly broke a 3" (76mm) stick, but the 3½" (90mm) replacement has stood for a decade. However, I accept that a sample of one is statistically challenged and would like more data to validate these sums.

Single Panel Fractional Rigs

Though common for bermudan dinghies and yachts, the combination of jib and main in a fractional rig is relatively rare for traditional rigs. Because the main acts at a different point from the jib, you need to adjust the sideways force at the hounds for the extra leverage, and also allow for the bending moment there. The combination of bending and compression makes the maths horrid, so I am going to skip lightly past it for now – though this nettle will need to be grasped when we deal with booms.

A General Rule Of Thumb for Traditional Yachts

For two-panel rigs I propose an approach which steers a course between the intellectual squalor of making everything doubly heavy just to be safe and a fiendishly complex – aka expensive – analysis which only applies to one boat. It won't be a complete solution, but it has to be possible to develop consistent and safe rigging components using either traditional or modern materials.

So let's estimate as simply as possible the design load for the lower panel of the mast; and from that the rigging arrangement, establishing shroud and upper mast design loads.

To keep it simple, I'll 'show my working' in metric measurements but will include the roughly equivalent imperial figures in brackets – mainly for the editor's benefit.

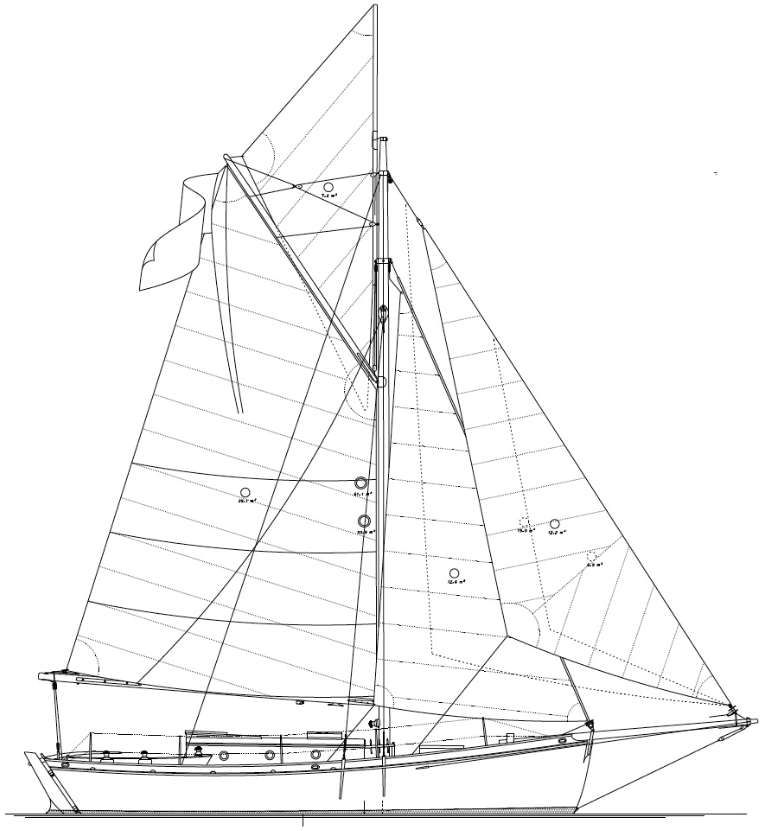
Mast Lower Panel

What I have done for our 'typical' 10m (33') gaff cutter is to see what happens when you vary the various parameters of the rig and plug the numbers into the NBS process. It is a bit more than glorified trigonometry, in that the loading assumptions are empirical but not by a huge amount.

Craft with this kind of staying arrangement tend to be larger than those with a single panel rig, so they fit more happily into the scope of the righting moment diagram presented by Kinney in Figure 1. He comments that "This chart is sufficiently accurate for most present-day cruising auxiliaries", which I think suits our purpose here.

If DWL is in metres, then the upper curve we'll use here equates to:

$$RM_{30}=141.6\cdot DWL^{3}-2284\cdot DWL^{2}+22890\cdot DWL-76633$$



30' (9m) Modern Gaff Cutter designed by Ed Burnett

The other parameters are:

- Mb is the ratio of the mast height to the half beam. I have taken mast height as the distance between the point at which the cap shrouds are attached, and the deck.
- Hm is the height of the hounds – where the spreaders and lower shrouds are attached – as a proportion of the mast height from the deck.
- Sb is the length of each spreader as a proportion of the half beam.

First then what happens as the height of the rig increases? Figure 2 shows how the loads on the lower mast, lower shrouds and cap shrouds change as the height of the rig increases. The need to keep shroud angles below 9˚ imposes a natural limit to the mast-to-half-beam ratio of a single spreader rig of about 9. For our sample boat that gives a 13.5m (44') mast on a 3m (10') beam. At the other end, a rig with a ratio of less than 4 – a 6m (20') mast on this same boat – would be more like a steadying sail, though there isn't a defined lower limit. Not surprisingly, as you can see from the figure, as the rig gets taller, the loads on shrouds and mast increase but maybe not as much as you might expect. The reasons why they don't deserve a digression all of their own.

Why A Taller Rig May Not Be A Good Plan

Despite its limitations, using the righting moment at 30˚ (RM30) as the basic input to rig loading provides an indicator of sail carrying capacity for a given hull, as well as a comparator across different hulls of the same type

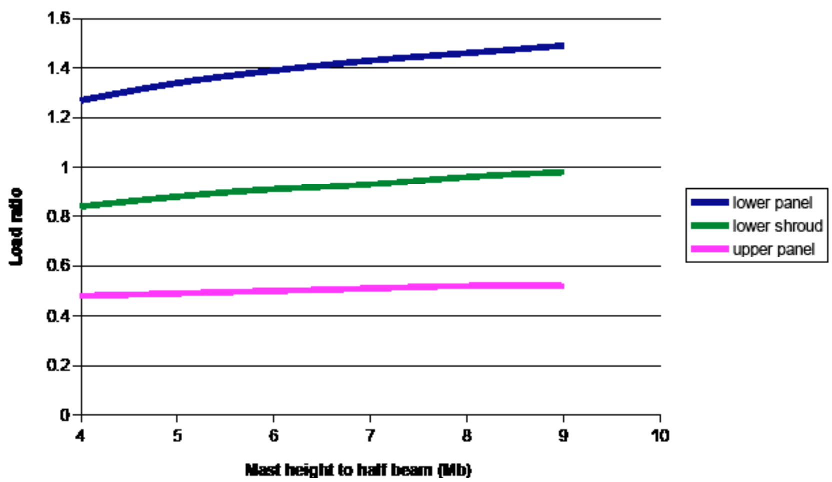
What Figure 2 indicates is that you are able to raise the height of the rig without much penalty as far as the loading on the mast goes. This is slightly misleading for at least a couple of reasons.

Firstly, we saw in W142 that the longer the spar for a given load, the larger the cross section needs to be to avoid buckling. If it is bigger, then it is heavier, other things being equal.

Secondly, with a fixed righting moment – which is a length multiplied by a force – if you double the length, then you must halve the force for the same moment. If you reckon that the amount of force has at least something to do with the amount of sail area, then halving the force means halving the sail area. Going down this track leads to the pencil-thin mainsails beloved of Scandinavians – and me – as shown acroos the page.

I'm ignoring the benefits of higher aspect ratio at this level of argument, but in round numbers a lower rig

Figure 2: Effect on Lower Mast Load of Rig Height Sb 0.5, Hm 0.7



can have a greater sail area. Since at least some of the forces from the sails are pushing you forward rather than sideways, the greater sail area means you should be able to go faster.

I know at least one case where this has proved to be true. In the 1920s and 30s a number of classes were 'modernised' from gaff to bermudan rig. Such a class was the Orwell One Design, one of which was converted back to the 1906 gaff rig in the late 1990s. Compare the rigs below..

The local handicapper reckoned it was at least 10% faster with the ludicrously low aspect gaff rig than with the taller bermudan rig. And if we could see a way of making gaff and lug sails more efficient… I'm sure you can guess which way this argument is heading but please wait a while. In the meantime also remember that you can't just stick a few metres/feet on top of the rig and expect an improvement in performance. You may just tip over more. Or have to reef very early. Next time,we'll take this forward to get mast and shroud design loads.

moraymacphail.com/reference/

Above: Scandinavian Skerry yachts. Photograph: Nicholas Carey
Below left: Orwell One Design 'modernised' with a bermudan rig.
Right: Orwell OD reverted to gaff rig – which proved 10% faster