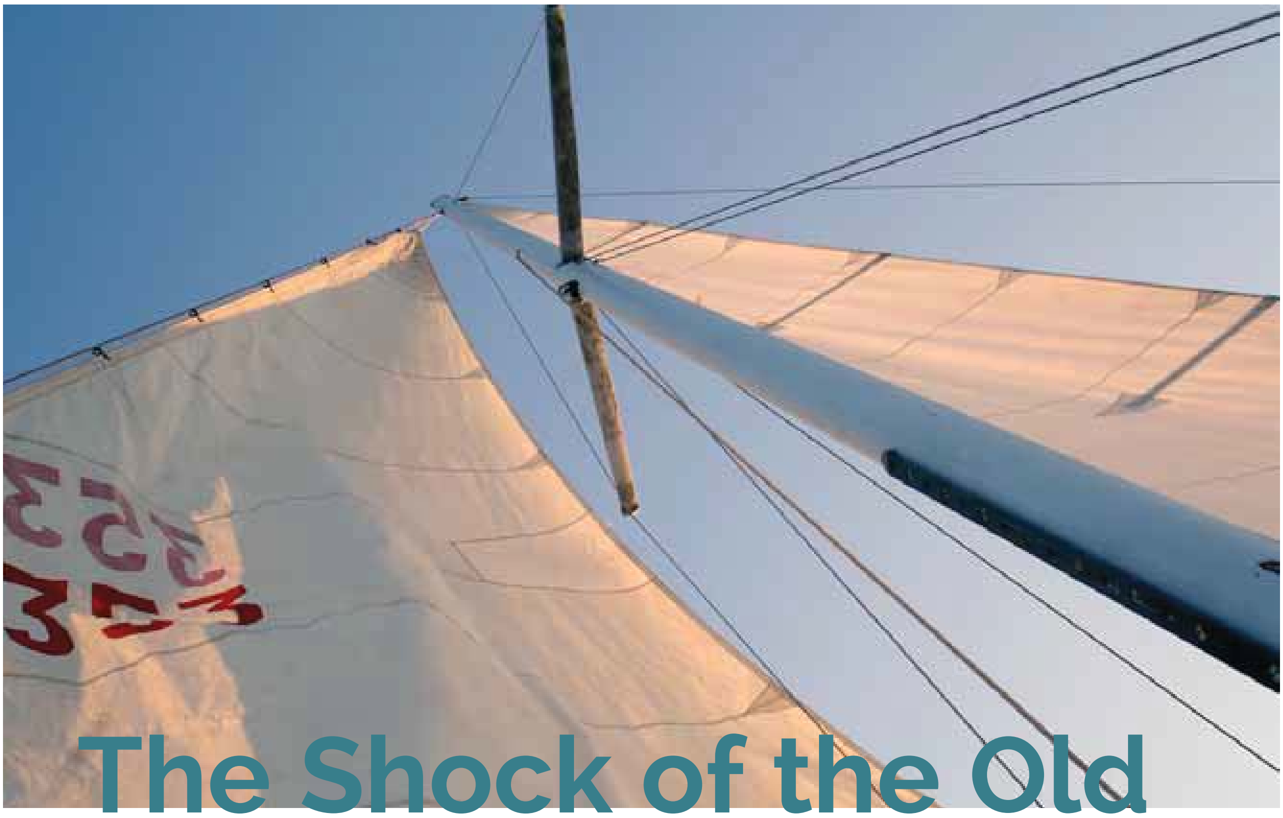

The Shock of the Old

Part 8: It's The Thick End Of The Wedge...

That's more important for keel-stepped masts, writes Moray MacPhail

For our sample Ed Burnett gaffer, all we've done so far has derived loads of 11.4 tonnes for the lower mast and the rig geometry leads us in the direction of two lower shrouds. Since I am often asked about the feasibility of converting a Bermudan rig to gaff, I'll digress for a moment before we look at shroud sizing.

As we saw in W148, a Bermudan rig has a good deal more flexibility in the position and number of pairs of spreaders. This means that the effective span sideways, spreader to deck, spreader or masthead, may be a good deal shorter than the effective span fore and aft. This can be as much as deck to masthead if single lowers are used. They provide lateral support but not longitudinal support. Hence the widespread use of oval or tear-drop mast sections with different section inertias on different axes. So you would

Our example gaffer designed by Ed Burnett

Table 1 Differences Gaff to Bermudan			
	Gaff rig	Bermudan	Gaff relative to Bermudan
Mast to Half Beam ratio	6.93	6.93	
Hounds height ratio	0.75	0.5	Higher – so saddle can be raised
Spreader to beam	0.5	0.8	Shorter, because higher
Lower mast load (t)	11.4	9.36	Higher because hounds higher (W148)
Lower shroud load (t)	8.2	5.33	Hounds higher so angle smaller
Cap shroud load (t)	3.2	4.03	Lower
Upper panel load (t)	3.2	4.03	
Lower mast length	7.4	4.9	
Upper mast length	2.4	4.9	
Lower mast dia (keel stepped)	160 mm	174 x 123	Oval section for Bermudan with single lower shroud
Upper mast diameter	79 mm	119	
Lower shrouds	2 x 8mm	1 x 8 mm	Rounded up to fit available sizes
Cap shrouds	1 x 6mm	1 x 8mm	

need to check the adequacy of the smaller moment of inertia over the shorter span – say, spreader to spreader – and the larger inertia over the longer span – say, deck to forestay. Suppose I put a Bermudan rig on our sample gaffer, turning it into a masthead sloop – admittedly a bit under-canvassed – with one set of spreaders.

As you'll see from Table 1 above, there's quite a lot of difference. It wouldn't be just a case of swapping fittings on the existing mast. As well as the mast being a challenging shape for a saddle, the hounds would probably need to take two lowers rather than one and that's before you get to the gaff and its fittings – quite an undertaking, best done when spars and sails are either non-existent or at the end of their life and need replacing anyway. Digression over.

Let's now convert the numbers we arrived at into some sort of reality by designing a mast to withstand those loads and then add stays to suit.

For the purposes of this exercise, I have decided on circular solid spruce spars. If you remember all the stuff in W142 about buckling, the key variables in designing a 'column' in compression are length, cross-section, stiffness of material and the fixity of the lower end. It goes as as follows

$$P_{crit} = K\frac{\Pi^2 EI}{L^2} = K\frac{\Pi^3 Er^4}{4L^2}$$

where:

- Pcrit is the critical load at which the column buckles
- K is the load factor which depends on how the ends are fixed – see below
- E is the Young's Modulus – the stiffness of the material
- I is the moment of inertia derived from the shape of the section
- L is the length between supports
- r is the radius of the section

We know the length, the stiffness of the material chosen – in this case spruce – and the section, so to get to the diameter the remaining thing to consider is the fixity of the ends. I skipped lightly over this in W142 but it needs to come into play here.

Figure 1 below left illustrates the principal options. A deck stepped 2-panel mast is represented on the left. The mast foot is fixed in space, but free to rotate in all directions. This is referred to as 'pinned'. The same applies at the hounds and at the masthead. Even though the tabernacle for a deck-stepped mast will provide some support, it is safer to assume that it is pinned. Similarly the section of the lower mast joined to the upper mast at the hounds will in reality constrain the end more than a pin end could. The masthead is genuinely free to rotate.

On the right of the diagram the foot is reckoned to be fixed, both in space and in terms of rotation. For some reason structural engineers use the French term *encastré*. The only time I think it actually safe to assume a fixed end at the deck is with a keel stepped mast and with wedges securely in place. The hounds and masthead both remain pinned. The point of all this is that for a pinned column the load factor K is 1, for a fixed one K=2

This matters as you can see from the following two diagrams. Figure 2, over the page relates the load, length and diameter of keel stepped masts – remember the length I'm talking about is the length of the lower section from deck to hounds.

Figure 1. Buckling Shapes for Single Spreader Masts

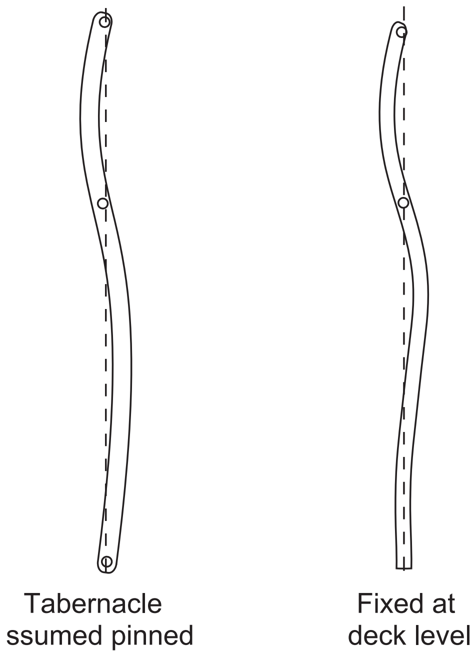

Figure 2 Keel Stepped Spruce Masts

Lower Panel - Critical load in tonnes

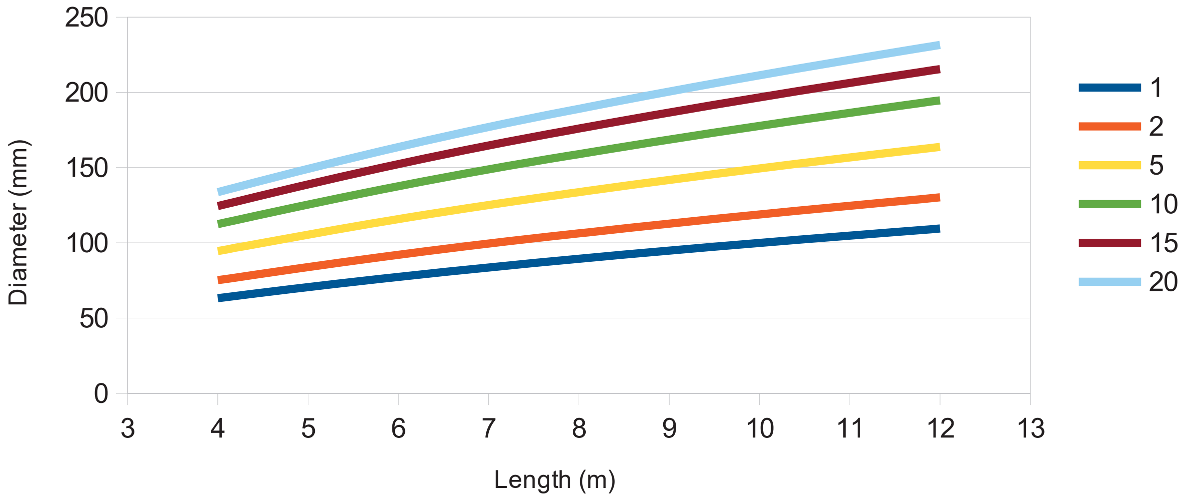

Figure 3, below, relates the load, length and diameter of the upper section of the mast and/or the lower section of a deck-stepped mast. Both of these cases use loads which already include a factor of safety of 2.5 to 3 inherited from the NBS method so they can be thought of as design loads.

You can see that getting those wedges in around the masr tight really does make a difference. Let's say the design load is 10 tonnes for a 7m (23') long mast. If it is keel stepped, fixed at the deck, then from Figure 2 you need a spruce mast 150mm (6") in diameter. If the mast is deck stepped, then according to Figure 3 you need something like 180mm (7").

Which means amongst other things that if you are thinking of converting that mast from keel stepped to deck-stepped – for example by using a tabernacle with a pillar below decks, like Marten-Jan's Chebacco on page XX – it is well worth checking that your existing mast is going to be adequate.

In our case we have a lower mast section 7.4m (24') long which is required to take 114 kN (11.4 tonne) load. If you assume both ends are pinned – in other words, it is deck stepped – then you will need a diameter of 190mm ($7\frac{1}{2}$"). If you assume keel-stepped, so one end fixed, then a mast of about 159mm ($6^{3}/_{8}$") would suffice.

Now if we do the same for the upper section of the mast – this time pinned at both ends whatever is going on at

Figure 3 Deck Stepped Spruce Masts

Lower Panel - Critical Load in tonnes

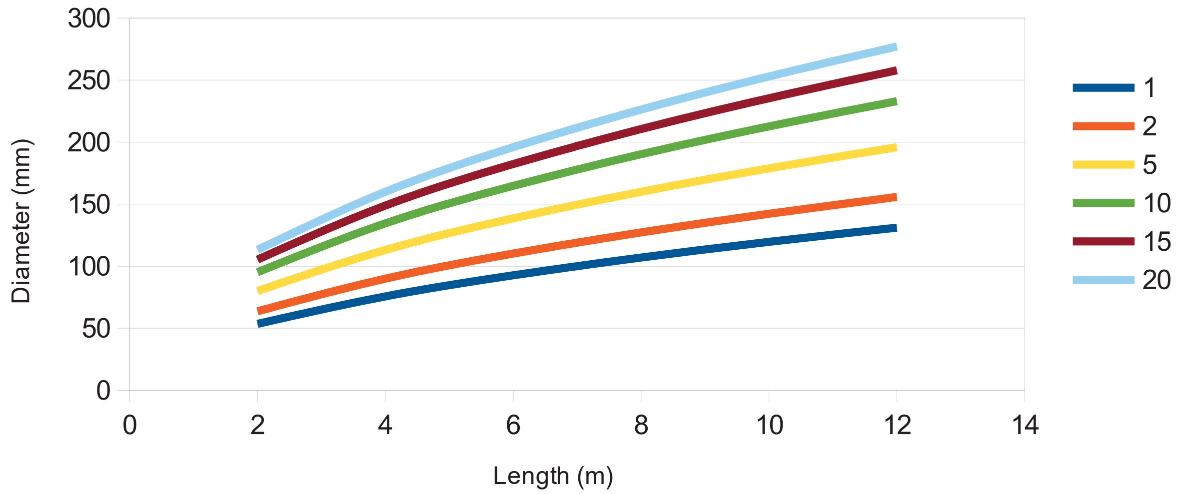

Table 2 Wire Sizes for Stays Relative to Lower Shrouds	
Item	Relative wire size to lower shroud
Principal Forestay	+1 or same on smaller boats
Secondary Forestay	Same or -1
Backstays	
• single fixed • twin fixed or running • running lower	same -1 -1
Jumpers/diamonds	-2

the deck - then the 2.4m (8') long section, loaded by 32 kN (just over 3 tonnes) needs to be 79mm (just over 3") in diameter.

Practical considerations will affect just how you interpret those numbers. On a gaffer you need the mast to be substantially parallel below the hounds to give a consistent fit to the saddle. So you would use the lower mast diameter up to the hounds and then taper above that –though not an abrupt step down from 190 to 79mm diameter!

Anyway, I think that sorts out the mast for our gaffer, so let's move on to consider the shrouds.

Staying with the plot

For illustration here, I'll just use standard 1×19 stainless wire for sizing. In a later article we'll have a look at other options for the stays together with connections and other practical aspects. Meanwhile for our purposes in this article we can get a quick guide to the strength of stainless 1×19 in N by multiplying the square of the diameter in mm by 770, or the square of decimal inches by 500,000. So for example 6mm (1/4") wire can take 6 x 6 x 770 = 27720 N = 2.8 tonnes (or 0.24 x 0.24 x 500000 = 28800 = 2.9 tonnes). It's a guide and good enough to use here, so please no angry letters to the editor – or me – about the difference.

For our sample boat the lowers need to take 81850N, and the caps 31830N. That gives 6.5mm (1/4"-ish) for the caps, and a single lower of 10.3mm (3/8") or two lowers of 7.4mm (5/16").

Since you can't buy the exact sizes, in those countries now metricated let's say 6mm for the caps and 2 lots of 8mm for the lowers. If you want to use all the same rigging screws, then 8mm caps would work as well.

There is no point in going lighter than recommended. There will be enough times when a boat needs to be nursed home without you deliberately creating more. But is it a good plan to go up a size 'just to be on the safe side'? I would argue not. Doing so means you have extra weight and windage where you don't need it. There is the extra expense not just of the wire but also the rigging screws. But most important in my view is that while any event which breaks a wire is unfortunate – a crash gybe onto a backstay; a collision which overloads a forestay or shroud – it is better that the wire breaks rather than the mast or hull fittings. At least then – if the spar is still standing – there is something to which you can attach a temporary stay. If the stay is overstrong, the damage can be unnecessarily extensive.

For the other stays, I'm afraid it is now time to leave any semblance of science behind and rely on good old rule of thumb, based on the size of the lower shroud. Should you feel short changed by the sudden lurch from engineering to empiricism, my excuse goes as follows: For the shrouds we can make a good estimate of the major loads expected, coming as they do from the action of sails on the mast, a bit of trigonometry and the reaction of the boat. Things are much less simple for the stays. Look for example at the forestay. The loads on it are going to come from one or more of:

- The foresail side loads,
- The foresail halyard loads,
- The peak halyard – or part of it
- The mainsheet when close-hauled
- The runners or backstays
- Filling the foresail with water
- Anything else I haven't thought of.

I defy anyone to convincingly determine a design load from first principles at the level of analysis we are working at, so rule of thumb it is. Table 2 shows my best guesses.

That gives us a size of wire for the fore and backstays. In our case with 8mm lowers we use:

- Jjibstay: 6 or 8mm
- Staysail stay: 10mm
- Each running backstay: 6 mm

As I say we are in the realms of rule of thumb, but if your rigging schedule is significantly different from these guidelines, you might wonder why.

I think that will do this time; next time bowsprits heave into view.