Look, no backstays: dredging for oysters under sail. Photograph: Nigel Sharp

The Shock of the Old

Part 5: Staying Put

Victorian masts, like Victorian ladies, were held erect by stays.. But how many and what size will your boat need? Over to Moray MacPhail;

Why add wires to a rig? Firstly, as mentioned in W144, changing a mast from a beam in bending – where you need a strong material – to a column in compression – where you need a stiff material – can yield considerable savings in weight, cost or windage, when the material available to you is relatively low strength but high stiffness like tree wood.

Secondly, you can't really set an effective upwind headsail on an unstayed mast of any sensible dimension. Unstayed masts must deflect sideways to do their stuff – see W142 – and any movement at the masthead will cause a good deal of sag in the luff of a foresail. Spars with stays move less, so you get straighter luffs and more useful foresails.

However, if you need a stay forward for the headsail, you also need one sideways and/or aft of the mast to counteract it. And if you would like to sail on both tacks, then you need a symmetrical arrangement of some sort. So evolves the simplest arrangement, and probably the most numerous, shown in Fig 1a. A forestay to the stemhead or bowsprit end combined with a single shroud each side to a point about a quarter of the local beam abaft the mast. Then you will end up with an arrangement of three stays distributed equally. On gaff and lug rigs, the three stays come together at the masthead because the mast is relatively short and you need to allow a saddle, mast traveller or yard to move up and down. On Bermudan rigs where the mainsail is typically in a

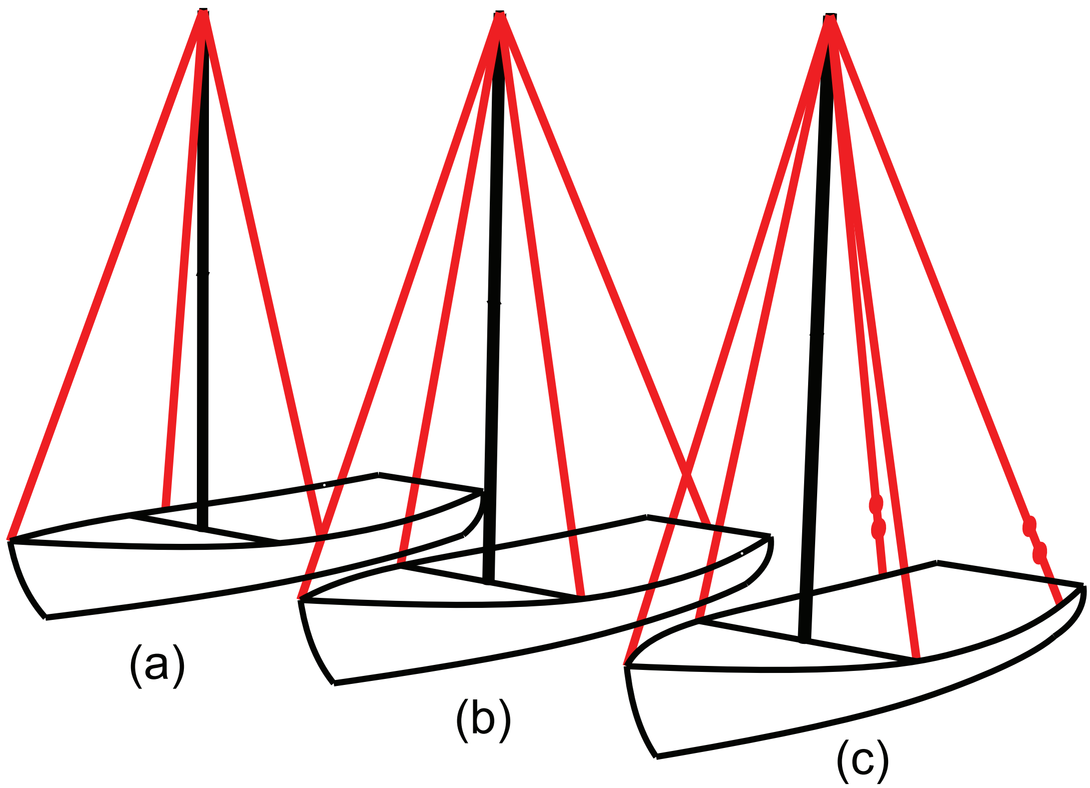


Figure 1: Staying Options for Single Panel Mast

track or groove, there is the option of ending the stays some way short of the masthead, so creating a fractional rig. But, I hear you say, if the shrouds are so far aft, I can't square my boom off downwind. True but surely the disadvantage of slightly reduced area presented to the wind and an increased risk of gybing is easily offset by not having to tend running backstays?

Many fore-and-aft rigged working craft didn't fit runners: Bristol Channel Pilot cutters as originally rigged; Chesapeake Bay skipjacks with heavily raked masts; Severn Trows... to name a few. I have tried on occasion to persuade people to dispense with runners by relocating the shrouds. Like the short-handed crews of working craft, I find their absence makes life much easier on my boat.

If the shrouds go forward to abeam the mast, a backstay will be needed. You then have the arrangements as shown in Fig 1b or 1c depending on whether a fixed backstay is viable.

Two fixed points

So far so simple, why would you want to go more complex? We looked at a number of reasons in W142, including:

- If the shroud base isn't wide enough for a single shroud arrangement – remember the minimum angle is about 9˚ – you need to add spreaders. So you then need to add lower shrouds, unless you are using spreaders to bend the mast.
- You want to reduce the mast sections and weight by splitting the mast into two panels. Again back to W142 for the effect of length on buckling.
- You want to add a second headsail on a distinctly separate stay, as in a cutter rig. This could be for reasons of easier management since smaller sails are each easier to handle and offer more options for reefing; aerodynamics by improving the flow over the mainsail; or of course, aesthetics.
- You have a separate topmast, so the lower panel is the mainmast, the upper the topmast.

In all cases you need to support the two points and Figure 2 shows the basic options. The sloop option with just one headstay, shown in Figure 2a, needs four lower shrouds, whose base is typically about a sixth of the beam fore and aft of the mast. As soon as an inner forestay is fitted permanently, you need either shrouds swept aft – 2b – or running backstays –2d – to provide adequate support.

In both cases you might dispense with one pair of lower shrouds, though as we shall see later when we come to sizing the wires, it can make sense to retain two pairs of lowers with one pair of cap shrouds.

Figure 2b looks like the kind of thing you would expect on a modern racing keelboat but is similar to a host of working boats where a key requirement was the clear deck and ease of handling afforded by the lack of backstays.
In 2c there is a very common rig for small to medium craft – again with the possibility of running backstays – where every wire has its own distinct function.

Finally, Figure 2d shows the multiple running backstay arrangement, with all shrouds athwart the mast and a running backstay to each node. This is actually quite a common arrangement on modern racing yachts, sometimes with three or more sets of spreaders, providing as it does considerable flexibility in shaping the mast.

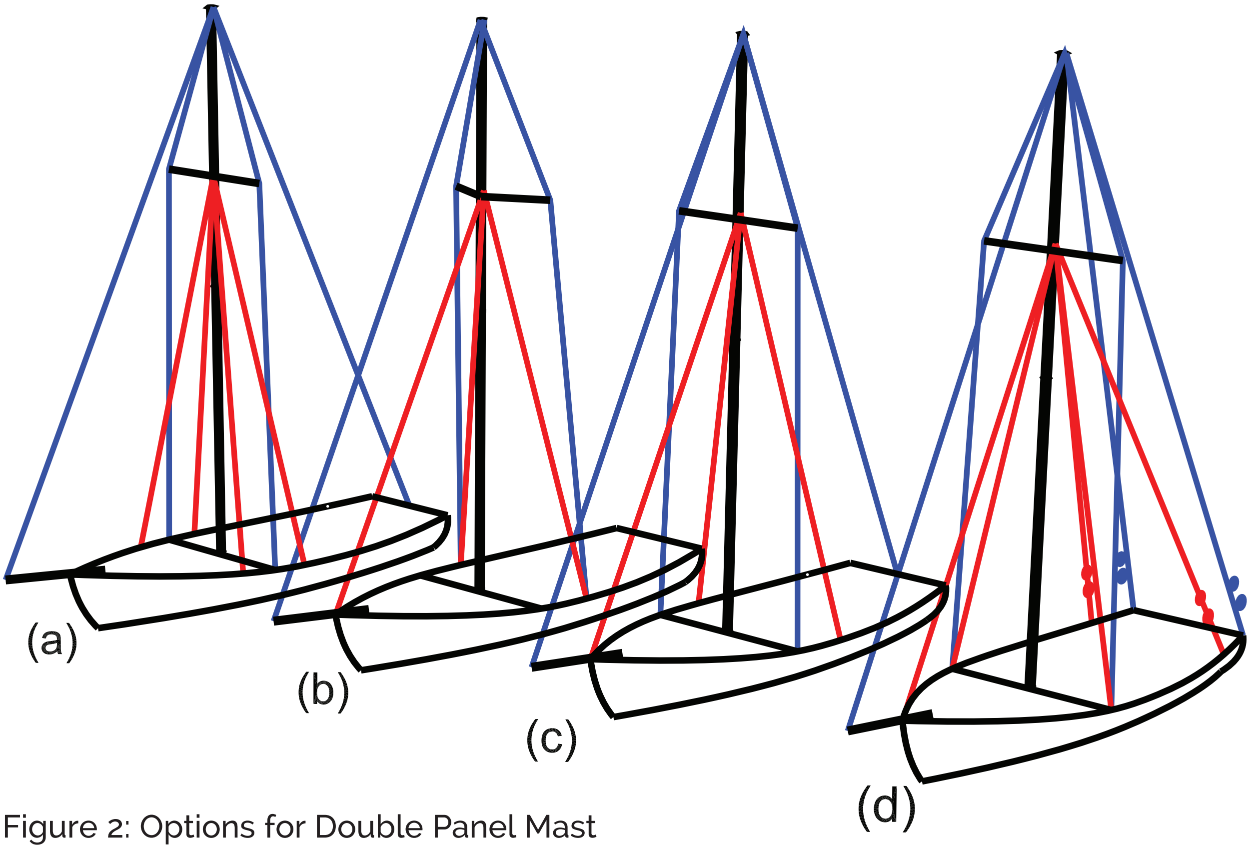


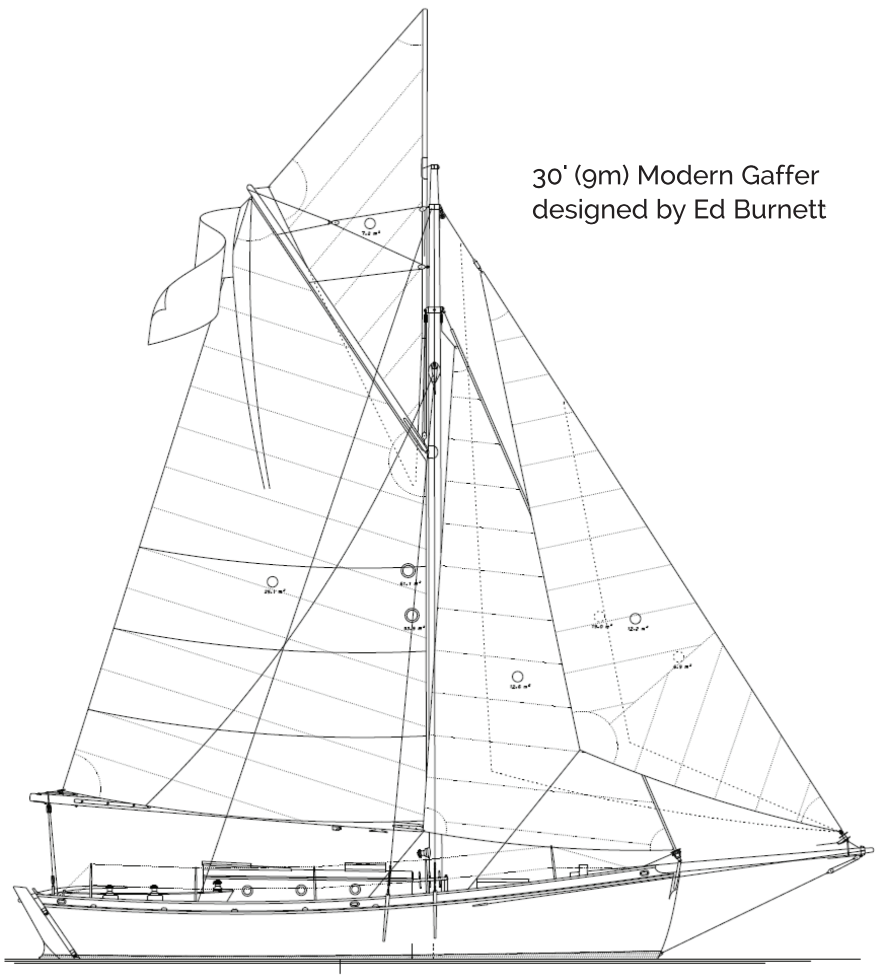
Figure 2: Options for Double Panel Mast

Trying out some rules

As a working example, I'm going to look at a number of possible ways of sizing the mast and shrouds for a 30' (9m) gaff cutter which displaces 8 tonnes, – shown right – with one cap or upper shroud and two lower shrouds.

A crude rule of thumb which I have come across – I don't know its origin – is the idea that the shroud set should break at a load equal to the weight of the boat. So in this case each shroud needs to be able to stand 2.66 tonnes: 8 tonnes displacement divided by 3 shrouds per side. The maximum compression in the mast is in the lower section – see W142 – and is roughly equal to the combined tension in the shrouds, so that means the lower panel of the mast needs to be able to stand 8 tonnes and the upper panel 2.7 tonnes.

Though crude, this rule recognises that the strength of rigging should relate more to the size of boat rather than the size of the rig. A steadying sail on a trawler may be no bigger than the mainsail of a 12' (3.7m) dinghy but because of the relatively large inertia of the trawler's hull, the forces transmitted into the rigging and mast



30' (9m) Modern Gaffer designed by Ed Burnett on the sail by a gust of wind will be very different.

Though he feels that "masts are perhaps a little beyond rational analysis", in his 1955 *An Eye For A Yacht*, naval architect Douglas Phillips-Birt offers this rule for mast scantlings:

B + M + H + 2cos4A.

B is the ballast ratio, here used as a measure of stability in conjunction with M which is the metacentric height as a proportion of the waterline beam. Good luck working that out – I'll not mention it again. H is the foretriangle height as a proportion of the upper half of the mast – ! – and A is the shroud angle. I can see that these factors will bear on the issue but the more I look at it, the less I understand the combination. Why not B x M; what has the cosine of four x the shroud angle got to do with it; and so on. With assumptions so opaque, there is no way of telling whether it applies to my boat. All respect to Mr Phillips-Birt – and much is due – but this is not for me.

Onwards then to Kinney's update of Skene's *Elements of Yacht Design* which offers two approaches to mast and shroud sizing. His 'short method' is based on the righting moment of the hull at 30˚ of heel – why 30˚? He provides a chart to allow a good guess but to what sort of boats does this reasonably apply? The mainmast maximum compressive load is 2.78 x the moment divided by the half beam – why 2.78? One then derives the panel sections by doing a sum about buckling, adding 50% more for a deck-stepped mast which do buckle sooner – W142. By reference to a table apportioning the shroud loads depending on the rig, number of spreaders and lowers, one then works out the loads and adds a further factor of safety of between 1.5 and 3, depending on which wire it is. Well, that is a bit more scientific; at least here there is some recognition of the staying geometry and I can see where the assumptions are made.

Kinney also expounds a 'long method' based on sail loading. Don't get too excited though; it's the same one we discussed – and used – in W145. Now triangulate for shroud tensions and add a factor of safety of 4 – although it was 1.5 to 3 in his other method? Then resolve back for mast loadings, add some extra for weight of sail, boom,

Table 1 – Loads in mast and shrouds

Base Design: 30' (9.4m) LOD, 8 tonnes displacement, keel stepped mast, 2 lower shrouds, 1 cap shroud over spreader 2'6" (0.76m) long.

	Mast Load	Mast diameter[1]	Lower Shroud load (each)	Cap shroud load
Crude Rule-of-Thumb	8 t	135mm	2.67t	2.67t
Phillips-Birt	not calculated	183mm	not calculated	not calculated
Skene (short)	6.75t	171mm	2.02t	3.03t
Skene (long)	6.62t	160 to 165mm	2.4t	2.97t
NBS2	not calculated3 (10 tonne inferred)	141mm (160 mm) [3]	4.09t	3.12t

1: Based on solid round Douglas Fir mast, converted where necessary by matching section inertias.

2: This method takes account of spreader length, so it is possible to vary the shroud loads considerably by varying the spreader length. For example, omitting the spreader changes the loads to 2.9t in the lowers and 6.8t in the caps. It is reassuring, compared with Skene, to note that with a spreader the lowers are more highly stressed than the caps, as one would expect.

3: Interestingly, the NBS method does not specifically relate mast loads to shroud tensions but starts again with the righting moment. The mast diameter goes back up to about 6¼" (160mm) if derived by resolving forces but then we don't know how to interpret the factors of safety used in sizing the shrouds!

tension of halyards and multiply by a factor between 2.7 and 4. It's becoming a bit unwieldy and the assumptions nearly impenetrable.

Updating with a more recent work on the subject, *Principles of Yacht Design* by Lars Larsson and Rolf E Eliasson, first published 1994, the Nordic Boat Standard provides a design guide. "The starting point when dimensioning the rig is to calculate the righting moment. It is commonly agreed that a heel angle of 30˚ is a good design angle. This corresponds to a reasonably high wind strength with the sails still generating high loads and the boat making good speed through the water. Letting the boat heel over more... in reality means a slower boat owing to increased resistance, with a correspondingly smaller dynamic force."

So that's why 30˚ is a good angle – well, not really – but we return to plausible assumptions. Calculation of the righting moment is based on a stationary boat in still water. It has nothing to do with boatspeed, dynamic forces, wind strength or resistance. It is just a calculation of stability in calm conditions, verifiable by experiment. It's fine as a common assumption which can be used to compare craft with each other and/or with empirical data. There is nothing wrong with using a given number as a design point but we need to be wary of thinking that simple assumptions can model complicated real life.

Back to the Nordic Boat Standard. Starting with the righting moment, we add some correction for the crew sitting to windward. Gaffers might safely ignore that bit! The method is then based on the most severe of two load cases: the first under full working headsail only; the second under reefed main, using not sail area but a function of the righting moment. The loads are apportioned to the masthead, hounds and gooseneck and with suitable application of trigonometry, the shroud loads are determined before multiplying by factors of safety of 2.5 to 3. Similarly, the mast compression is based on the righting moment, with factors for keel or deck stepped masts and multiplied by 1.5 "to handle the dynamic factors".

Working craft of the Chesapeake Bay like Nathan of Dorchester, *a skipjack typically used for oyster dredging, used heavily raked masts to avoid the need for running backstays. Photograph: Dorchester Skipjack Committee Inc.*

We may be getting the impression that this is not much advance on earlier efforts. To an extent that is true, but the NBS is one of the most carefully codified approaches to a variety of rig arrangements, all Bermudan of course. It is also reasonably simple, with few fudge factors and the various assumptions are quite clear. That the NBS does not include, say, halyard loads – a drawback of the approach – is true but the criticism misses the point. The method merely tries to provide a model which produces safe answers, though not necessarily emulating every aspect of real life. That's what factors of ignorance – sorry, safety – are for.

So the answer could be...

The crude rule of thumb comes out somewhat shy because there are no safety factors included but apart from that, for a solid mast the diameter works out reasonably close to the real life answer of 6½" (166mm). The main variations are in the lower shroud and mast design loads. Skene has a low mast design load but higher factors of safety in determining the mast size, which brings the mast diameter back in line. Our example is a 'moderate' design, so the rules which make implicit assumptions about stability and arrangement reasonably apply.

Running the same series of sums for a more modern design, I quickly found the limits of all but the NBS rule. However numerate the rules appear, in practice they are all founded on empirical data – how else could the safety factors be determined? - and the similarity of the results confirms that the forces of wind and sea have not changed too much.

Thankfully, masts don't often fall down, except when designers are at the very edge of technology. Over the next articles I shall foolishly rush in to develop General Rules Of Thumb For Traditional Yachts.

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