The SHOCK of the OLD

Part 15: RE-SPARRING MY CANOE YAWL

Moray MacPhail continues his series on refining traditional rigs.

My article on re-masting in W157 was written primarily in hindsight – *if I knew then what I know now*, sort of thing – but if 20 years ago when I did the job on my 18' (5.5m) Orwell One Design, I'd had these articles for guidance, it would have been better. Trouble was, I had not written them back then!

Here, I'm looking at re-sparring my 15' (4.6m) canoe yawl above – a Selway-Fisher *Lillie* design, inspired by George Holmes' *Ethel* of the 1880s – and I'm more confident I can do so with theory on my side. This is the start: seven sticks as per Table 1 here.

Table 1 – Existing canoe yawl spars

Item	length	Typical dimension	Weight (kg)
Main Mast	4.1 m	77mm dia	10.75
Main Yard	3.42m	45 mm square	3.8
Main Boom	2.9 m	40-42mm sq	3.2
Mizzen Mast	2.34 m	61 mm dia	3.75
Mizzen Yard	1.3 m	35mm sq	0.75
Mizzen Boom	1.4 m	38 mm sq	0.9
Boomkin	1.85 m	40 x 25mm	1.9

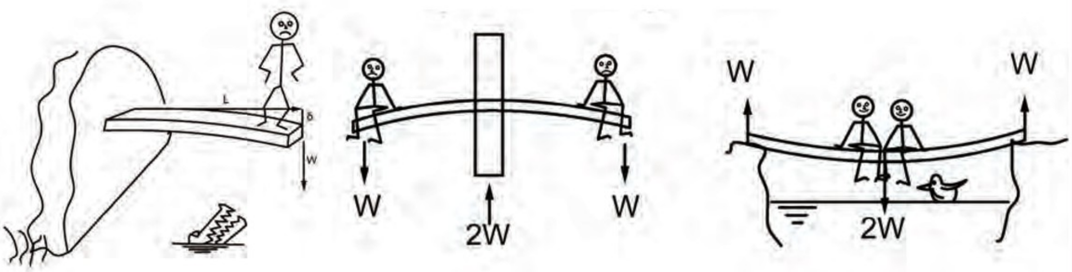


Figure !: *Bending of a cantilever beam – applicable here to both masts. The middle cartoon shows two cantilever beams are equivalent to the beam supported at both ends shown on the right, which is applicable to the yards.*

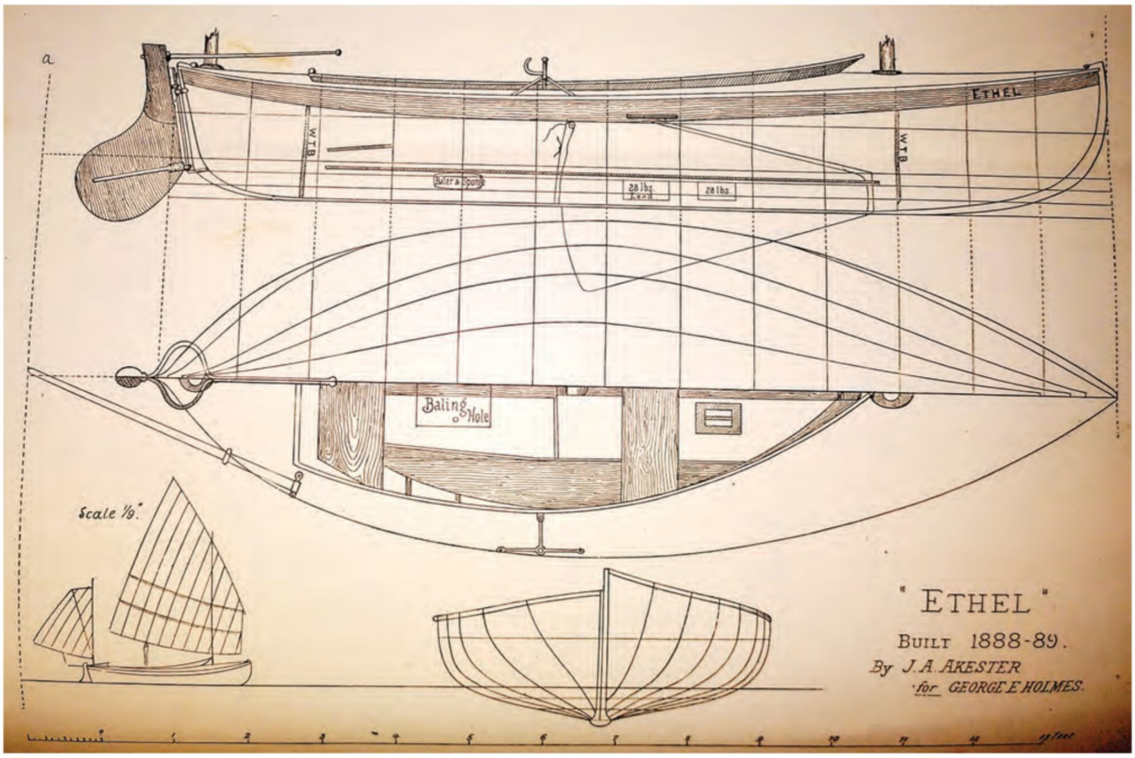
All the spars are Douglas Fir for which I estimate a maximum compressive stress of 48 MPa and a modulus of 12.3 GPa. The sail area is 8m² (86 sq.ft) on the mainsail and 1.8m² (19 sq.ft) on the mizzen.

The total weight of these spars is 25kg (55 lbs), a significant part of the all up dry weight of the boat of around 160kg (353 lbs). Being spars, their combined centre of gravity is inevitably high up, some 1.9m (6') above the waterline. In this article I'm going to see what alternatives might be possible, how much it might cost and whether it makes sense.

For the purposes of looking at better options, I'm going to use the carbon tubes offered by Carbon Fibre Profiles, which come in a variety of sizes and wall thicknesses in lengths of up to 6m (20'); this isn't an endorsement by the way – other suppliers are available! Though the CFP people think I could use higher values, I'll stick with my assessments of max 500 MPa compressive stress and 110 GPa modulus.

The two masts and the boomkin are cantilever beams so I'm going to use all the stuff we went through in W145 for the masts. The yards are beams pinned both ends with a load

Figure 2: *The inspiration for the Lillie design, from Dixon Kemp's* Manual of Yacht and Boat Sailing *8th Edition 1895.*



part way along – see Figure 1 – so simple beam theory works here. The booms are a bit more complicated since depending on where the sheet is attached they are a combination of bending and compression which is fiddly. Let's take each in turn...

The Masts

For those with a less-than-perfect memory, here is a re-run of my W145 calculations for unstayed masts. Converting to metric sizes – because that's how carbon tubes are sold in the UK – and then extending the idea to hollow masts made from any material you like, for solid spars we get this equation:

$$d = 17.2 \cdot \sqrt[3]{\frac{SA \cdot p \cdot L \cdot sf}{\sigma_{max}}}$$

For tubular spars with thin walls – thin meaning less than 5% of the diameter – the equation becomes:

$$d = t + 25.22 \cdot \sqrt{\frac{SA \cdot p \cdot L \cdot sf}{\sigma_{max} \cdot t}}$$

In these equations:
d = diameter in millimetres
SA = sail area in square metres, in this case 8m² main and 1.8m² mizzen
p = sail loading which varies between 50 and 75 Newtons per square metre; I'll use 55 here.
L = the length of the mast in metres. I'll assume as per original 3.44,1.93 and 1.65m for the main, mizzen and boomkin respectively. These are the unsupported lengths.
sf = factor of safety between 1.5 and 3.5 for small to large boats respectively. In this case I'll use 2.5. It may be a small boat, but I'd like a reasonably robust answer for a boat intended primarily for pottering.
σ = Maximum tensile or compressive stress in MPa.
t = the wall thickness of a thin walled tube in millimetres

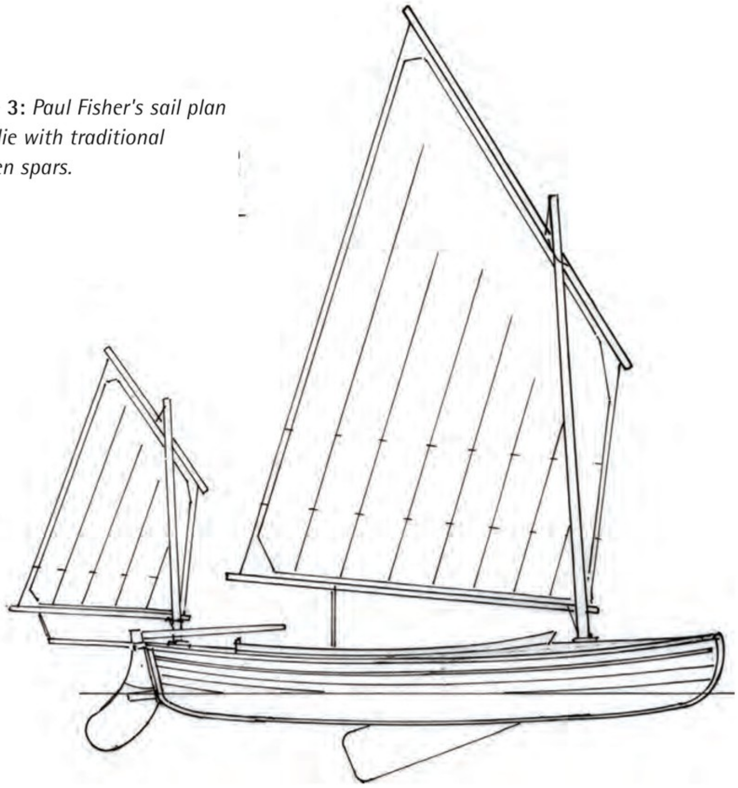


Figure 3: *Paul Fisher's sail plan for Lillie with traditional wooden spars.*

The Main Mast

From the above, the design sail load is estimated to be 550N at the masthead. For the existing Douglas fir spar I calculate a mast diameter of 74mm, so we are in the right area with the actual 77mm diameter. The deflection under the design load would be about 350mm.

Switching to carbon, a possible stock solution is a tube of 50mm diameter with 2mm wall thickness. It deflects more at 560mm but the bare tube weighs only 2kg. The next size up – 60mm diameter, 2.5mm wall thickness – would also work. It weighs a bit more at 3kg but is stiffer than the wood, deflecting 260mm.

The Mizzen Mast

The existing spar seems over specified at 61mm. At that size the maximum stress is 10 MPa and the deflection 33mm. The mast could be reduced to 40mm – 35 MPa/180mm – which would get the weight down to 1.5kg. With carbon, a tube of 30 x 1.5 mm would seem to work – 250 MPa/135 mm – and would weigh 0.5kg.

The Boomkin

The boomkin is that mini-bowsprit sticking out of the stern and at 1.65m (5'5") free length I can't help feeling this could be shorter. Certainly it is in the original 1885 design at about 1.2m (4'), so I'm going to see if any offcuts come from the rest of the spars and maybe use one of those.

The Yards

To check the material properties I'm using for the wood, I slung a railway sleeper 'chair' – the cast iron things which hold the rails apart – as a 205N weight from it. That created a deflection of 35mm by comparison with a calculated value of 38mm. The maximum stress is 10.5 MPa, well within the 48 MPa limit.

A 30 x 1.5mm tube could serve – 180 MPa/ 75 mm – if the increased flexibility was allowed for in the cut of the sail. Weight would be 0.7kg. The mizzen yard bends imperceptibly under a 10kg load at 2.5mm. A carbon tube of 20 x 1.5mm would bend about 11mm. Again I'm sure the sail could be re-cut to cope if needed.

Figure 4: *Measuring deflection of the existing wooden boom the old-fashioned way.*

The Booms

As we'll discover in a future article analysing booms can be complex. The loading from the sail tack and clew is compression, so like a stayed mast it's buckling you need to worry about. If the mainsheet comes off under the clew then everything remains in compression, so that's fine. But when you add a centre mainsheet or a kicking strap, there is a sideways force on the boom and you need some bending resistance to cope with that. But that sideways force reduces the resistance to buckling. If you push on the end of a ruler, and then nudge it sideways you will see the effect.

I know the existing wooden spars on my Lillie have worked perfectly well since she was built 30 years ago, so matching their properties should also work. Whether that is optimal is another question. Also for traditional rigs, a boom of something like 60 to 70% of the mast diameter has always seemed about right.

To match the properties of the wooden main boom both in bending and buckling requires a carbon tube of 35 x 1.5mm. And the ratio of a 35mm diameter boom to a 60mm mast is 58%. I'm not sure the mizzen boom bears that much analysis. Like the mizzen yard it seems over size. So maybe I'll just get a 3m length of 20 x 1.5mm tube which would then do both yard and boom. The ratio of 20mm on 30mm mast is 66%.

The weight saving is around 19kg, with a combined centre of gravity about 1.9m above the waterline. Not all of that will be achievable in reality; the tubes will have to be plugged and there will need to be some reinforcement added. But the starting cost isn't ridiculous.

Aside from the need to allow for a bit more flexibility in the spars, I think a key question is whether these thin wall tubes will be robust enough in service. And I can think of only one way to find out. It will be an interesting season and I'll remember to take oars.

Next time I'll wrap up standing rigging with some guidelines and tips for mast furniture.

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Table 2: Weight and cost implications of converting to carbon spars

Item	length	Typical dimension	Weight (kg)	carbon	Weight (kg)		£
Main Mast	4.1 m	77mm dia	10.75	60 x 2.5	3.05	6m length	479
Main Yard	3.42m	45 mm square	3.8	30 x 1.5	0.7	6m length with mizzen mast	95
Main Boom	2.9 m	40-42 sq	3.2	35 x 1.5	0.72	3m length	112
Mizzen Mast	2.34 m	61 mm dia	3.75	30 x 1.5	0.5	See main yard	95
Mizzen Yard	1.3 m	35 sq	0.75	20 x 1.5	0.2	3m length with mizzen boom	40
Mizzen Boom	1.4 m	38 sq	0.9	20 x 1.5	0.20	See mizzen yard	40
Boomkin	1.85 m	40 x 25	1.9	23.5 x 1.75	0.4	2m length (guessed dimensions)	51
Total			25.05		5.77		912