Laser >> Mast Bending Characteristics
January 2012

1. Background

Following a trial of a possible replacement mast procured by Sailboats (reported in 'NewMastRepMDCNov2011.pdf) bending measurements have been made on the undamaged sections of two (damaged) masts in the author's possession.

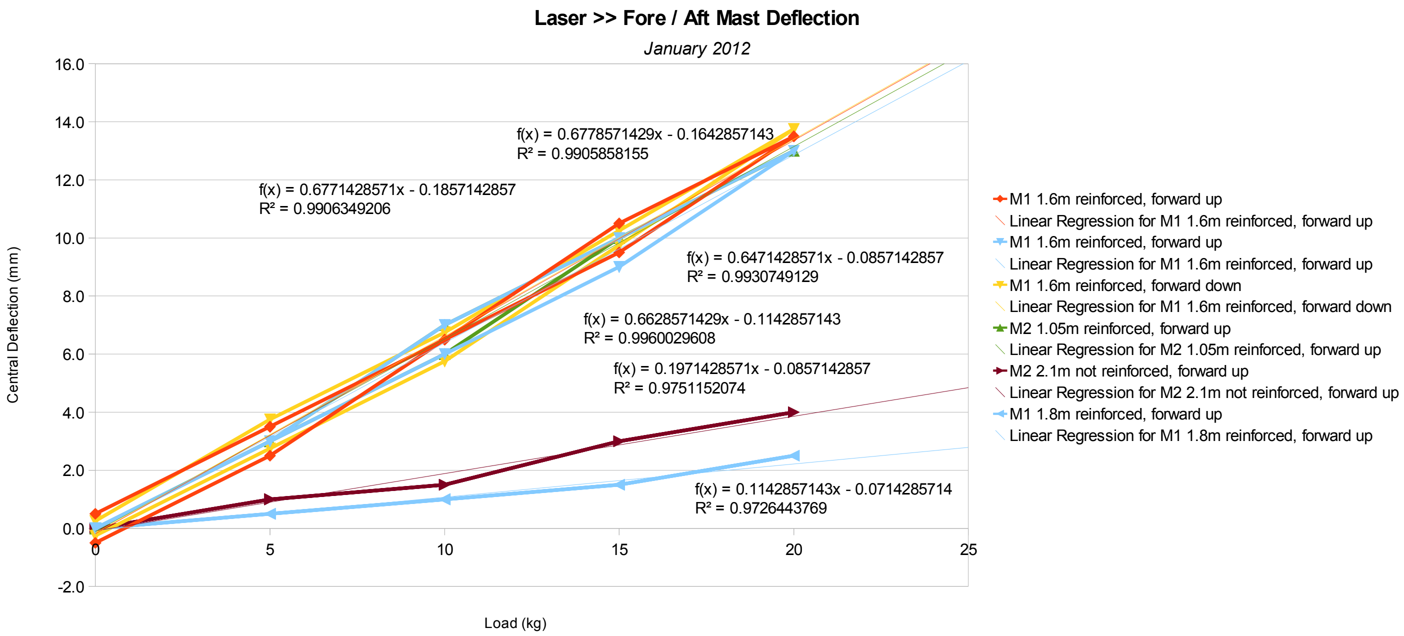
2. Masts

Both masts are of standard 2-piece design, with some fittings removed (and in both cases, no spreader wires fitted). Mast 1 (M1) has suffered a catastrophic failure about 200mm below the D-ring ('low' position): age is unknown, but is more recent than M2, which failed (cracked under the D-ring fitting – old 'high' position) at the 1993 Fowey National Championships and may well be of 1985 vintage. In both cases the remaining sections are 'straight'.

As may be seen in the photo of M1 to the right, the Bethwaite designed section (approximately 64 x 52mm) has an internal reinforcing tube (roughly 40mm ID with 1.5mm wall). This appears to have been used to stiffen the mast in the area below the diamond spreader, although it's location is not consistent between the two masts! For M1, the tube extends some 150mm above the centre of the diamond spreader fitting, whereas on M2 the tube stops just below the lower diamond spreader fitting pop-rivet location and extends to the middle of the lower diamond wire tang fitting.

3. Measurements

Fore / aft stiffness in bending measurements, using the equipment shown in the picture (below) were made on several different lengths of both masts, as indicated in the graph (next page). The spans were between the inner edges of the wooden support blocks and the loading applied centrally using a rope collar. Four 5kg loads were applied additionally, and then removed in turn; central deflections being measured using a steel tape from the stand.



4. Analysis

Least squares fits to the measured data were used to derive the effective stiffness 'k' (N/mm) which was then used to derive the effective second moment of area from the formula:

$$I_{xx} = k \times l^3/48E$$

where:
l = effective span (mm)
E = Young's modulus (70000 N/mm^2 assumed)

5. Results

The derived fore / aft second moments of area are as shown in the following table.

Mast	Span (m)	I_{xx} (cm^4)	Notes
M1	3.2	14.1	Bending aftwards: one half (1.6m) to load point reinforced
M1	3.2	14.1	Repeat of above measurement
M1	3.2	14.8	Bending forwards: difficult to do (unstable shape) but as bent on boat
M2	3.2	14.4	Bending aftwards: approximately 1.05m from one support reinforced
M2	2.1	13.7	Bending aftwards: no reinforcement
M1	1.8	14.9	Bending aftwards: all reinforced

6. Discussion

Firstly, it should be noted that, due to experimental limitations, the maximum deflections measured were relatively small in comparison with what would typically be used when sailing.
Secondly, the stiffness appears slightly higher when bent forwards, than when bent aftwards, possibly due to the way the internal tube reinforcement interacts with the main section, although the difference is small.
Thirdly it should be remembered that not all fittings were present on these masts and the open rivet holes might have had a small effect of the stiffness measured.
With this in mind, the above measurements indicate that the effective fore / aft second moment of area (cm^4) for the reinforced section is of the order of 15 (or more, bending forwards giving slightly higher stiffness than bending aftwards), and that for the unreinforced section around 14 (that is, roughly 9% less stiff).
However, when considering possible replacement sections, it should be remembered that the current 2-piece mast lower section also has an unusual aerodynamic profile, and matching this will probably prove problematic, although the effect would be difficult to quantify. (Ref.1 has some interesting words on the Tasar rig, which was Bethwaite's predecessor to the Laser >>.)

7. Conclusions

As it is highly unlikely that any replacement mast could be realistically procured with similar limited reinforcement, a replacement mast using diamond spreaders with a fore / aft second moment of area in the 15 to 16 cm^4 range, with a taper above the upper diamond attachment point, would offer the closest ***stiffness*** match to the existing 2-piece design.

As discussed above, it is unlikely that any replacement using existing commercial sections known to the author would match the aerodynamic characteristics of the current 2-piece mast lower section.

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Reference

1. http://www.tasar.org/index.php?option=com_docman&task=doc_download&gid=6&Itemid=52