A lesson from Mr Spruce H Mast

Who said that a spruce tree cannot speak - they shout at me!
Here is what one of them told me:

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Hi Arne,
my name is Spruce H Mast (...H for Hollow...). I am a round, hollow tube of spruce with a diameter of 20cm and with the wall thickness being 20% of that diameter.
My breaking moment at this $D = 20\text{cm}$ is $3100$ kilopond meter (kpm), at least. When deciding on which diameter of me you should use as a junkrig mast for your boat, you need to know or guess...

- .. the righting moment of the boat.
- .. the intended kind of sailing. If ocean voyaging is on your mind, make me 3 times stronger than the boats righting moment (JR sloop). If the sailing is less ambitious, reduce that strength factor to 2.5 times or even 2.

The righting moment of any boat is
$Mr = \text{Displacement} \times \text{max righting lever}.$
If the max righting lever is not given, you have to guess it:

- A boat with narrow beam and high ballast ratio has a righting lever, $L_r$, of about $\frac{1}{4}$ of the beam, that is $L_r = 0.25B$.
- A very wide boat with little ballast has a righting lever, $L_r$, of only $1/5.5$ beam, that is $LR = 0.18B$.

You have to guess where your boat is on this scale. In most cases you are on the safe side if you guess that $Lr=0.20B$

Example: Let’s say your boat has a displacement, $D_{\text{isp.}} = 2500\text{kg}$ with a beam, $B = 2.40\text{m}$ and 40% outside ballast.

- If you guess that the $Lr = 0.20B$, the righting moment of the boat is $Mr = 2500\text{kg} \times 2.40\text{m} \times 0.20 = 1200\text{kpm}$
- However, if you guess that the $Lr = 0.25B$ ($1/4$ of 2.40m), then the righting moment comes out at $Mr = 2500\text{kg} \times 2.40\text{m} \times 0.25 = 1500\text{kpm}$

If you play safe and opt for the highest righting moment of 1500kpm and with a 3 times strength factor for offshore use, the mast needs to have a breaking moment of $Mb = 3 \times Mr = 4500\text{kpm}$.

All you need then, Mister, is to beef me up from my initial $Mb$ of $3100\text{kpm}$ at $20\text{cm}$ diameter, to something that gives $4500\text{kpm}$. Here is the procedure:

- Find the beef-up factor .. $Kb = \text{wanted strength}/\text{strength at 20cm} = 4500\text{kpm}/3100\text{kpm} = 1.45$.
- BUT! The strength of me, the mast, varies with the cube of my diameter. In other words, my diameter varies with the cube root of my breaking moment. In cold numbers this means that the diameter factor = the cube root of $Kb$, that is
Kd = Cube root of 1.45 = 1.13

- Finally find the needed diameter D = 20cm x Kd = 20 x 1.13 = 22.6cm.

Now that is the worst-case diameter. If you estimate the boat righting lever, Lr to be only 0.20D and only want to sail in sheltered waters, you will find that I’ll do fine with a D=18.4cm. Check it yourself!

A final word before you leave - don’t make me too tall! If my length above partners, LAP, exceeds 40 times my diameter, then I may start complaining when pitching in a bad head sea!

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Sooo, as you see from the above, the big, foggy, variable factors lie not in the calculation of the strength of the mast, but rather in deciding the loads that it will have to take. That is the same problem as with all sorts of masts

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Cheers,
Arne

PS 20141104: This is actually a shortened and slightly altered version of “Arne on Mast scantlings…”, found under Other technical Articles on my page: http://www.junkrigassociation.org/arne