Chapter 6b

(...of the Cambered Panel Junk Rig)

The Hybrid Mast.

This chapter is about a mast type where the lower section is an aluminium tube and the top section is of wood. It is, as *Chapter 6* about the wooden mast, a practical guideline, based on my limited experience with two boats, and also a result of checking a number of boat designs. I don't claim to know it all, but still dare to write this, since the masts of my own boats seem to cope well. The challenge is to be able to scale up and down from known boats and trying to make useful general rules to find the needed strength of a mast. To calculate the strength of a mast itself, either from wood or aluminium, is fairly easy - plain maths. The tricky bit is the process of deciding how strong a mast needs to be on a specific boat.

Note: I mainly focus on smaller yachts here, planned with a sloop JR. With two or more masts, I guess one will have to rethink about the strength factor for each mast. In addition, as will be seen, there are natural size limits for the hybrid masts.

So what is right and wrong with the all-wooden masts?

I have found that wooden masts work well, but they have some limitations:

- A short mast, up to 6-7m long and max 100mm diameter, can be made easily and quickly from well-chosen planks, right from the sawmill. I had one such mast made, 5.3m long, and just varnished it with 2-pot polyurethane varnish. This worked very well. In this size range, an all-spruce mast would be my choice.

- However, if you want to make bigger masts, over 7m tall, you must probably either build the mast from staves, which first must be carefully scarfed together to get them long enough. This costs a lot, both in work, time, tools and in required skills. In addition, you will need access to a workshop for quite a number of days. The alternative that I have described in Chapter 6; hollow or solid pole masts also means some work, and if you start from a raw tree, it involves half a year of drying.

Enter the hybrid aluminium-wood mast...

After having read **Annie Hill**'s story about making a hybrid mast for her Raven 26, *Fantail*, I successfully adapted her method, first on my 6.5m *Frøken Sørensen* (2013), and later on the 7.9m Marieholm IF, *Ingeborg* (2016).

Lundsvågen, 20130530. Dryfitting the 1.6 (+0.4)m top section into a 6m long 100 x 4mm aluminium tube.

Advantages...
The advantages with this mast type are:

- The aluminium tube for the lower section comes in 5 or 6m lengths. They need no extra workshop handling. This lets one buy tubes from tempered, and thus stronger, alloys. The timber for the top section will also be easy to find at the saw mill, as that section is generally shorter than 6m.
- The hybrid masts comes out quite a bit lighter than an all-wooden mast.
- As the diameter seems to lie around 70-90% of that of a wooden mast, the windage of this mast will be lower as well.
- The material for both the lower and upper section can be transported on the roof rack of most cars. This is a good argument for assembling the mast in the harbour where the boat sits. Easy logistics could well be the deciding factor which gets a project started.

Drawbacks...
The hybrid mast also has some limitations:

- Aluminium tubes of the right size and quality may not be found everywhere. There can be quite big gaps between one dimensions and the next in the suppliers' stock, so compromises must sometimes be found.
- The mast cannot be too tall, or the wood-to-aluminium joint will become a weak spot (more about that later).

Early conclusion...
The aluminium-wood hybrid method is best suited for constructing masts between 7 and 11m long. Within its limitations, this is just about the quickest and easiest way to construct a light and dependable mast.

Deciding the strength of the lower section of a hybrid mast.
You will soon see that the easy part of making a hybrid mast is the actual hands-on construction of it, while the hard part is to decide which strength is needed and then (to some degree) to calculate the strength of the available tubes.

Step one is to find or estimate the righting moment of the boat.
That will be the basis for finding the needed strength of the mast.

The formula for righting moment, M_r of any yacht is:

$$M_r = Displacement \times L_r$$

..where L_r is the length of the righting arm of a heeled vessel. Quite often the builder of the boat can show a heel-to-righting-arm curve, and in that case it is easy to find the maximum value of M_r. However if L_r is not available, it has to be found somehow. After having checked the data of a number of yachts, it seems that the L_r varies between ¼ and 1/6 of the beam (B) of the hull.

A boat with narrow beam and high ballast ratio (a 'lead mine') has a righting arm of almost ¼ beam, that is...

$$Righting\ arm = L_r = between\ 0.22B\ and\ 0.25B$$

On the other hand, if the boat has a wide beam and a low ballast ratio (almost a dinghy shape), the righting arm may be between 1/5.5 and 1/6 of the beam, that is...

$$Righting\ arm = L_r = beteen\ 0.18B\ and\ 0.167B$$

To spell it slowly, here is the boiled-down hint for guessing the righting arm of a hull:

1. *Boats with no or little ballast: Choose any L_r between 17 and 19% of the beam.*
2. *Boats with 'normal' ballast keel of 30 to 40% of the displacement: Choose any L_r between 19 and 21% of the beam.*
3. *Boats with over 45% ballast ratio: Choose any L_r between 21 and 24% of the beam (extreme designs may perhaps reach 25%)*

If you follow these loose rules, the error margin of your guess on the righting arm, L_r, and thus the righting moment, M_r, will hardly exceed +/- 20%.

Example:
I use *Ingeborg* as an example by showing how I calculated and later constructed a hybrid mast for her:

Basic data:
LOA= 7.9m,
Beam= 2.2m,
Disp.= 2150kg,
Ballast= 1250kg (58%).

According to my own guidelines, I put *Ingeborg* in the category 3 and I thus guess the max righting arm to be 22% of the beam of 2.2m, that is...

$$\boldsymbol{L_{r\,max}} = 2.2m \times 0.22 = \mathbf{0.48m}$$

The max righting moment will thus be:

$$\boldsymbol{M_{r\,max}} = Disp \times L_r = 2150kg\ \times 0.48m = \mathbf{1032kpm}$$

Step two is to decide a strength factor for the mast.
Obviously, we cannot let the breaking strength of the mast be the same as the max righting moment ($M_{r\,max}$) of the boat. Again, based on experience with former masts in wood, I have come up with another loose set of rules:

- For coastal cruising and no wild racing, I aim for a breaking strength at

$$M_b \geq 2.0\ \times M_{r\,max}$$

- For serious offshore cruising, or for racing, I recommend the strength to be beefed up to

$$M_b \geq 2.5\ or\ up\ to\ 3.0 \times M_{r\,max}$$

With *Ingeborg*'s righting moment in mind; $M_{r\,max}$*=1032kpm*, the strength of the mast at the partners should thus be between **($M_{b\,safe}$=) 2064kpm** (coastal) **and 2580-3096kpm** (offshore or racing)

Step three is to find an aluminium tube of suitable strength
In many cases the supplier can give you the breaking, or rather the yield moment, M_b, of the aluminium tube. If not, you at least must be given the accurate dimensions and what alloy it is made of.
I am afraid we will then have to do a bit maths, but before we do so, there is another question to ask:

Big diameter and thin walls or small diameter and thick walls?

Both can produce strong enough masts, but at some point, as we reduce the diameter, the mast will become too flexible for practical use, and too heavy as well. The junkrig itself seems to be fairly tolerant to mast flexing, but I guess I am less tolerant, after having spent most of my time with stiff spruce masts.
Now, attacking this question of mast-top deflection scientifically involves a lot of measured numbers and calculations. This is over my head and also over my needs. Instead, I have seen what is in use and compare them with the spruce masts I am used to, and have from there made yet another rule of thumb:

The wall thickness of the lower alloy mast section should be somewhere between 2.5% and 5% of the outer diameter. (I would anyway not make a mast with less than 2.5mm walls, to avoid denting and buckling.)

This rule seems to produce sensible mast scantlings with neither too thick (heavy), nor with too thin walls.

Here is the formula for max bending moment of a round tube:

$$M_B = \delta * \left(\frac{\pi}{32} * \frac{D^4 - d^4}{D} \right)$$

..where ...

- δ *[N/mm²]* is breaking stress of the material. For aluminium, use yield strength.
- *D [mm]* is outer diameter of the tube.
- *d [mm]* is inner diameter of the tube, i.e. D minus twice the wall thickness.
- *1N*=1 Newton = 1/9.807kp (kilopond)

Example, the lower mast tube for my IF, *Ingeborg*:
After checking 2-3 available tubes in the supplier's catalogue, I landed on this one and calculated its strength:
Dimensions, 6m x 150mm x 5mm, 6082-T6 alloy (where Sigma, (δ) = 250N/mm^2).

From the formula above (and remembering to use matching units) the yield strength is found to be...

$$\boldsymbol{M_{b\,yield}} = 250\,{}^{N}/_{mm^2} * \left[\frac{\pi}{32} * \frac{150[mm]^4 - 140[mm]^4}{150[mm]}\right] = 19976929\text{Nmm} = \mathbf{19977Nm}$$

Divide by 9.807(g) to get the answer in kilopond-meter, *kpm*, and the max moment will be:

$$\mathbf{M_{b\ yield} = 2037kpm}$$

This is only a little less than the 2 x $M_{r\ max}$, which I found for Ingeborg (2064kpm). I decided to use it since the next available tube, one step up, was on the heavy side.

> **(..both the 100 x 4mm mast on the 740kg *Frøken Sørensen*, and the 150 x 5mm mast on the 2150kg *Ingeborg* has proven to work fine. They appear neither to bend much, nor to be too stout and heavy. *Ingeborg*'s mast, at about 53kg, adds only 2.5% to the displacement, which I think is very good. Any such ratio landing on 3% or lower is fine...)**

As said before; no welding or work is needed on these lower mast tubes. This saves workshop costs, and one avoids weakening the tempered alloy.

The wooden top section.
Wood has a much lower useful material strength than aluminium. One must therefore check to make sure that the joint between the two sections will not be a weak spot.

I looked it up and found the strength of spruce to be $\boldsymbol{Sigma_{spruce}\ (\delta) = 44.8N/mm^2}$.
By using this on the same formula as used on the aluminium tube above, the strength of a 200mm hollow spruce section, with wall thickness of 1/5 of the diameter, will be:

$$\boldsymbol{M_{b\ 20cm} = 3122kpm}$$

This is a 'master formula', which makes finding the strength of other spruce masts simple, as long as we stick to a wall thickness of 1/5 of diameter, D. Since the strength of a pole varies with the cube of the diameter, we can find the strength of any mast as:

$$\boldsymbol{M_b = 3122kpm \times (D \div 200mm)^3}$$

The strength of the 140mm wooden top section of *Ingeborg*'s mast (at the joint) will therefore be (if hollow - a bit stronger if solid):

$$\boldsymbol{M_{b(140mm)}} = 3122kpm * \left(\frac{140mm}{200mm}\right)^3 = \boldsymbol{1071kpm}$$

The question is then, what is the bending moment on the mast at the joint?
I choose to use a worst-case scenario where the whole force from the sail on the mast is concentrated at the mast top. In that case, the bending moment will start on zero at the mast top, and will increase linearly down the mast until it reaches the safe maximum, 2037kpm, at the partners. Since the top section is 3.7m and the LAP= 8.7m (total mast length is 9.7m), the bending moment at the joint between the sections will be:

$$\boldsymbol{M_{b(joint)}} = M_{b(at\ partners)} * \frac{Length\ of\ topmast}{Lenght\ above\ partners, LAP} = 2037kpm * \frac{3.7m}{8.7m} = \boldsymbol{877kpm}$$

In other words, the max load of 877kpm is lower than the found strength (1071kpm) of the 14cm wooden top section.
Good!

Bury - how deep must the wooden top section be inserted into the lower section?
I treat the top section as if it were another mast, so the bury should for that reason be at least 10% of the top section above the joint. In addition, to avoid too high forces in the joint, I would want the bury to be at least 4-5 times the inner diameter of the lower section:

The top section's bury into the lower section should be at least 4 (better 5) times the inner diameter of the lower section <u>and</u> at least 10% of the top section above the joint...

Going taller...
As one can understand (..or not...) from the calculations above; if one tries to make a taller and taller hybrid mast, and the lower mast is not available in more than 6m length, the top section will become a bigger and bigger part of the whole thing, so the load on the joint will increase according to the formula above. One does not want the resulting load on that joint to exceed the strength of the wood. In addition, when stretching the mast far enough, it gets difficult to find wooden planks long enough to make the top section without scarf joints. In other words, these hybrid masts cannot be made much more than 11m tall.

> **Now I found the max LAP to be 10.54m before the M_b at the joint exceeds 1071kpm. The top section thus becomes 5.54m - just check it yourself with the formula above (Remember that one metre of *Ingeborg*'s lower mast is below the partners).**

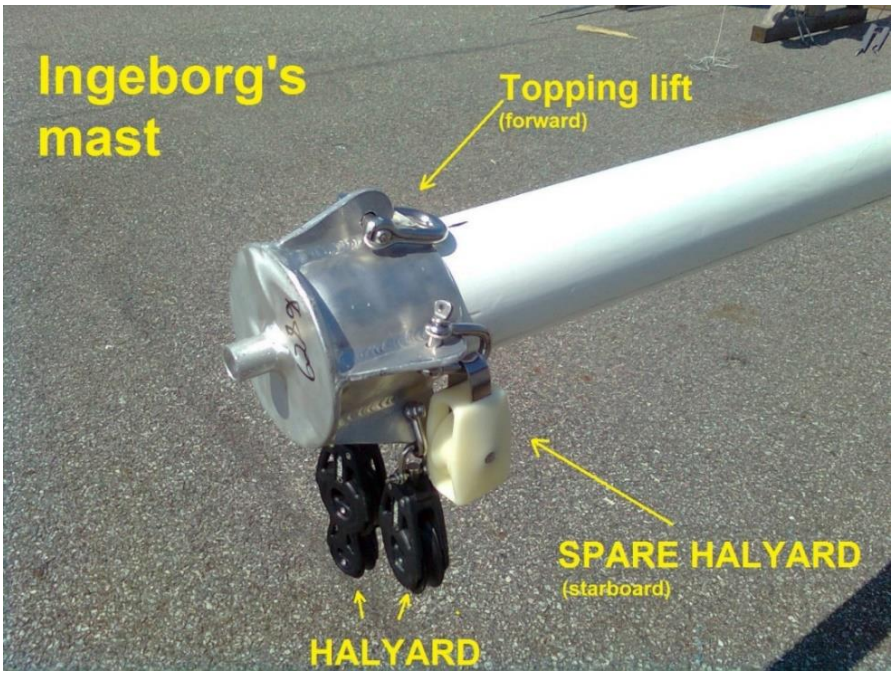
Fitting the wooden top section to the lower aluminium section.
After first dry-fitting the mast, I sanded the inside of the tube with fine-grit sandpaper. Then I applied the slightly thickened epoxy and inserted the top section. Only when that had cured did I add the fairing above the joint. I simply used thickened epoxy for this too, and then added one round of glass tape on top of this. Finally, the joint was painted with 2-pot polyurethane, the same as used on the topmast. Neither the topmast on *Frøken Sørensen* nor the one of *Ingeborg* was fully glassed, only that fairing. I am curious to see how well the paint alone will last, but it looks good, so far (third season on *Ingeborg*, 2018).
The mast top on *Ingeborg* (diameter 90mm) was fitted with a welded aluminium cap, which was only pressed and glued down onto it. I avoid screwing in wood, if I can, as it easily ends up as a rot spot.


20160526, the glassed and...


..the painted mast joint for *Ingeborg*'s mast...

To paint or not to paint...
I haven't painted any of my un-treated aluminium lower masts (or any of my yards or battens either). From a life-expectancy point of view, it is not necessary, but a white sail will collect some black stain from the aluminium, right at the mast position (as mine have). It could well

be an idea to paint the mast for that reason alone. In addition, the 2-pot paint could make the mast marginally slippier, which is always a good thing. I guess I would start with a coat of etch-primer, and then add 2-3 coats of 2-pot polyurethane on top of that.
Your choice.



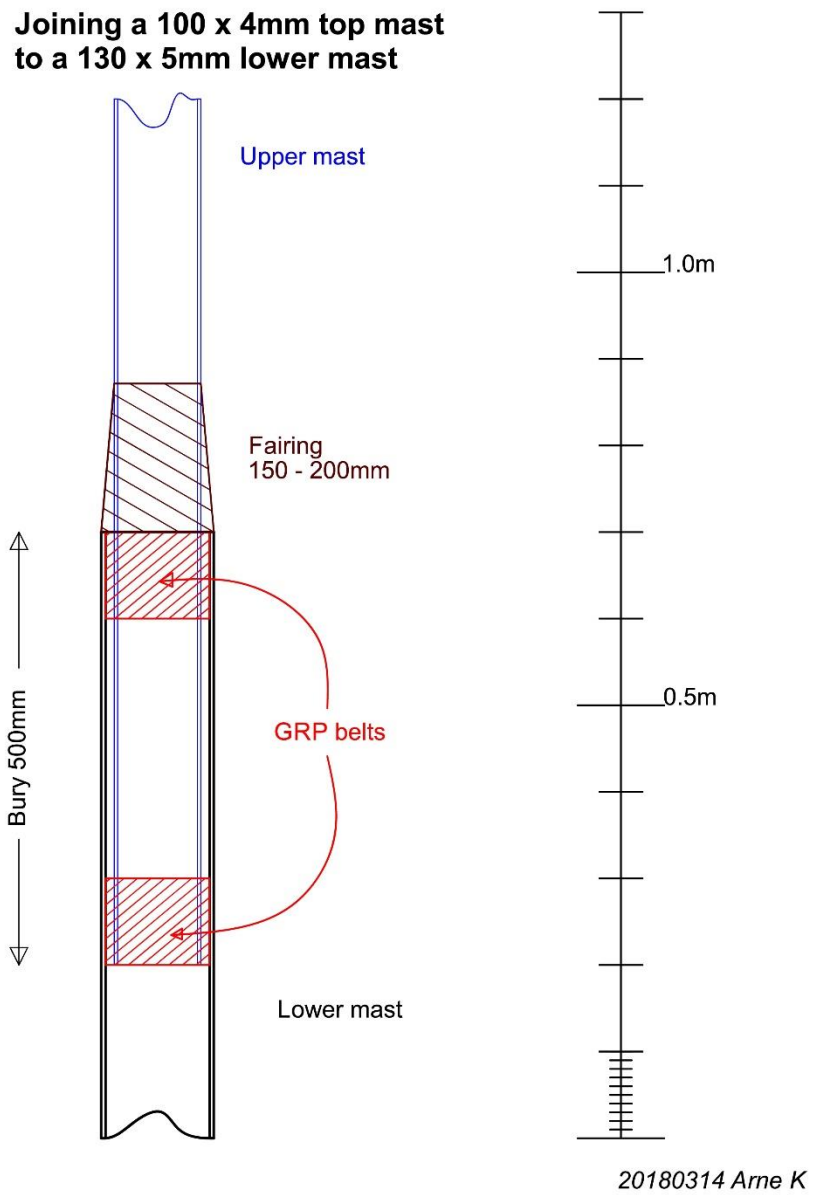
20160531 The welded mast cap of 5mm aluminium, fitted to *Ingeborg*'s 90mm wooden mast top

20130713 The lighter mast of *Frøken Sørensen* was fitted with a webbing type mast cap. Well and fine, except that it should have been given a fez-type, cylindrical sunhat...

Two-section, glued aluminium mast.

The bright reader will no doubt ask, why not fit a top mast of aluminium instead of wood? That would be a good question. My first reason for using aluminium-wood was that it appeared to be so straightforward. It was a known quantity and the tapered topmast would be

fairly easy to make. Besides, tapering it towards the top makes it look quite smart. However, now I think it would be easier, and just as good to fit a topmast of aluminium. That topmast would obviously be a roomy fit, so some form of 'waistbelts' would be needed, as shown on the diagram below:



This is how I can imagine it done. Since I haven't actually made jointed aluminium masts, I'd better not go in more detail on it. However, others have used the method, and it appears to work well. Some gluing tests with epoxy on aluminium, done by JRA member **Graeme Kenyon**, indicate that holding power increases a lot if one sands the aluminium surfaces well with fine sandpaper, just before priming them with epoxy resin.

Better stop there...

Stavanger, Sunday, 16th Sep, 2018,
Arne Kverneland