Chapter 6

(...of The Cambered Panel Junk Rig...)

The (Wooden) Mast.

Deciding the mast strength, hints on how to make mast, partners and step and even a few words about battens, boom and yard.

(Edit: Some text added in September 2018, is in this colour...)

The title above is quite ambitious. Maybe one day the text below will do justice to it, but for now I will rather present a few examples – plus the method used by PJR (..and my modified version of it...). My own experience is solely with unstayed spruce masts, solid as well as hollow. After having read through this, you should not feel quite as lost if you want to rig a boat between 1 and 10 tons with a wooden mast.


Malena 1994, 6 panels


Johanna 2003


Edmond Dantes 2006, tacking


Peregrine 2005


Zuleika 2004

6.1 Wooden mast scantlings

To find the right scantlings – not too strong and heavy – not too light and flimsy, is a never-ending challenge to any engineer, whether they design bridges, aeroplanes or junk rigs. The forces that a sailboat's mast may suffer are not easy to predict. It helps though to look around and see what is out there sailing. Some formulas have also been made to aid calculation. They should be used with a bit of sound scepticism.

Some examples of wooden junk rig masts

Here are a few examples on wooden masts I know about:

Malena, 7.1m/1400kg, SA=32sqm, LAP=8.4m: Diam= 21cm, hollow, dug out, 25% wall thickness.

- Malena's mast is grossly overdone. At about 70kg on that little boat, its weight can be felt. In hindsight I think it would have been enough with 19cm.

Johanna, 8.85m/3000kg, SA=48sqm, LAP=9.4m: Diam=25cm, hollow dug out, 20% wall-thickness.

- Johanna's mast is also on the stout side, but is not nearly as overdone as that of Malena. It is a go anywhere mast (.. including on a rock at 5.5knots...) which I thrust. Around 90kg, I guess. It seems to me that its windage of 1.6sqm could be a bigger problem than weight when a gale really starts howling.

Edmund Dantes, 9.4m/4000kg.

- ED has an exact copy of Johanna's rig. With higher displacement and heavier keel it puts a higher load on the mast. However, the safety factor seems so high that the mast holds up well without undue bending.

Peregrine, 11.3m, 12000kg, SA=80sqm, LAP=12.3m: Diam=32cm solid Douglas fir.

- Peregrine has already seen some offshore gales, and stood up well to them. Her 300kg mast seems to work well on her. I'd love to have it dug-out though, saving about 30% of its weight. Peregrine is a bit on the tender side.

Zuleika, 8.5m, 5000kg, SA=33sqm, LAP=9.14m: Diam=24cm hollow, glued staves.

- Zuleika has travelled a lot and never lost her mast. Strong enough.

Jester, about 7,6m, about 2.1t, SA=22sqm, LAP=9.4m: Diam=18.14cm hollow, glued staves.

- Both Jester 1 and 2 have a lot of miles behind them but have also lost one mast each. All calculations below suggest some increase in diameter.

Practical Junk Rig's formula for calculating wooden masts

The formula that is used by Hasler and McLeod in PJR for a hollow wooden mast is:

$$D[cm] = \frac{LAP[m] + 2\sqrt{SA[m^2]}}{0.85}$$

(add 13% for fore mast and reduce with 10% for solid mast)

It has proven to be very conservative unless you rig with a SA/disp. of around 14. More often than not, it will result in over-strong and heavy masts.

Twisting the PJR formula

When designing my first junk mast, I tried to use the PJR formula as it was, but the result suggested so heavy mast that I couldn't use it. The reason for this mismatch is that the formula seems to be made for boats with moderate sail area. Now, with more experience, I think I can say that the PJR formula is good if the SA/disp. is somewhere near 14. However, I have a totally different view on what the right sail area should be: On a little boat, any SA/disp. below 20 is for chicken – I aim for 23-25 as long as I can handle the halyard and sheet. Remember the gospel about the easy reefing of the junk rig? That gospel holds water in practical life – and therefore you can safely pile on a lot of sail. (Edit: Not so smart for bigger boats, when deck space and manhandling puts practical limits on the SA...)

Here is a trick if you want to rig to the PJR formula, but want to give your boat a SA/disp. of, say, 20:

- Draw up your rig with your preferred sail area and measure the LAP of the mast.
- Knowing your boat's displacement, calculate a fake sail area that gives a SA/disp.=14.
- Now put this fake sail area plus the real LAP into the PJR formula to find the mast diameter at partners.

Edit: I use my Marieholm IF, *Ingeborg* as an example:

- Displacement, Disp. = 2150kg = 2.15 metric tons

- Sail Area, SA = 35sqm
- The mast's length above partners, LAP = 8.7m

The formula for SA/Disp. is $SA/_{Disp.} = \frac{SA[m^2]}{(Disp.[metric\ ton]:1.025)^{2:3}}$

For Ingeborg that means, $SA/_{Disp.} = \frac{35}{(2.15:1.025)^{2:3}} = 21.4$

> **(The reason for dividing the metric displacement by 1.025, is that the formula is about displacement in volume of *salt* water. Since salt water is 1.025 times that of fresh water, we need to correct it to get the same result as in the Imperial version of the formula. See Appendix)**

To find the fake area, which gives a SA/Disp. = 14, the formula above can be turned around a little:
The sail area will then be $\boldsymbol{SA_{14}} = 14 * (Disp.: 1.025)^{2:3} = 14(2.15 : 1.025)^{2:3} = \boldsymbol{22.9m^2}$

If we use this fake SA in PJR's original formula for hollow wooden masts, we get:

$$D[cm] = \frac{LAP[m] + 2\sqrt{SA[m^2]}}{0.85} = \frac{8.7+2\sqrt{22.9}}{0.85} = \boldsymbol{21.5cm}$$ (*versus* ***D=24.2****cm with SA=35m²*)

If we compare this with later findings in **Chapter 6b** about hybrid masts, we find that this twisted PJR formula still produces quite strong masts, in this case about three times the max righting moment of *Ingeborg*. Nevertheless, I keep it as it is, since the actual strength of wood may vary quite a bit. I reckon this mast to be fully offshore-capable.

See table below over boats and their wooden mast diameter at deck level.

	MAST IN USE. DIAMETER AT PARTNER	CALCULATED D. FROM PJR FORMULA	CALCULATED D. FROM PJR, BUT WITH SA/DISP.=14
Malena, 1.4t, SA=32sqm	21cm, hollow spruce	23.2cm (LAP=8.4m)	19.7cm (fake SA=17.5sqm)
Johanna, 3t, SA=48sqm	25cm, hollow spruce	27.3cm (LAP=9.4m)	23.7cm (fake SA=29.1sqm)
Edmond , 4t, SA=48sqm	25cm, hollow spruce	27.3cm (LAP=9.4m)	25.0cm (fake SA=35.3sqm)
Peregrine, 12t, SA=80sqm	32cm, solid Douglas fir	31.9cm (LAP=12.3m)	31.5cm (fake SA=73.4sqm)
Zuleika, 5.0t, SA=33sqm	24cm, hollow, glued staves	24.2cm (LAP=9.14m)	25.8cm (fake SA=40.0sqm)
Jester, 2.1t? SA=22sqm	18.1cm, hol., glued staves	22.1cm (LAP=9.4m)	22.3cm (fake SA=23.0sqm)

These examples give you an idea on how to guestimate the diameter of the wooden mast for your boat.

6.2 Making the wooden mast

There are 2 basic ways to make a wooden mast; from sawn planks or from a trunk of tree. Frankly, unless you get the planks in full length, I would advice amateurs against building a

mast from staves. Even then you should be a really good hobby carpenter, unless you go simple and make it four-sided (see PJR on Sumner rig).

> *The Sumner Mast, being 4-sided glued stave job looks like a good idea to an amateur. With only right angles to plane and 2 and 2 identical planks to make, I think that even I could do it. The gluing job can be done in sequence, without any frantic coordination of 10 pairs of hands. You don't need to be king of logistics or conductor of an orchestra.*

Whatever method you use, making the top diameter 40-43% and the step 50% of the deck diameter seems to give an even loading of the mast. Note: The way you "sharpen" the mast upwards from deck to the top is linear. The mast above deck is in fact to be a tall, cut-off cone. Also: Leave a 40cm section at the partners cylindrical (See fig 6.... showing the building plan for *Johanna*'s mast).

Making a hollow or solid pole mast from a tree

Shaping the mast:
In my country there are more spruce trees than people so they are cheap. This is how it is done:

- Uses spruce or fir, hopefully from your neighbourhood. The best is if it is slow-grown. If the end-rings indicate it has grown rather fast, it may still be used, but it is not quite as strong. Then remember that strength of a mast varies with the cube of the diameter. Increasing the diameter with 5% will boost the strength with 16% and if you increase it with 10%, you get 30% more strength. Simple!
- Start with a raw tree trunk if you can. If it is dry and split, I would not use it, at least not for making a hollow mast.
- Shape the mast according to building plan, first to a 4-sided shape, then 8-sided.
- Note: You may want the step to be 4-sided, so wait with the below-deck section after you have reached the 4-side stage.
- If you want to make your mast solid (about 40% heavier than a hollow mast with 20% walls), you are almost there: If you started with a raw trunk; now make a cut with a circular saw from end to end. The cut should be adjusted to go about half-way in to the middle of the mast. When the mast is drying, this cut will open and relieve the tension that would otherwise create shakes in the surface.
- Before leaving the solid mast to dry, you may continue finishing it to 16 sided etc. until it is round. Leave the sanding until after the drying out.
- If you are a keen wood-butcher and wants to make a hollow mast, now cut the mast in two *(.. lengthwise, please..).*
- The two halves are roughly dug out with an adze or (safer) a BIG round chisel (.. I left this job to a boat builder...)
- "Close" the mast again with battens in between, holding the halves a little apart. Tie them together to ensure they will not warp during the drying process.
- Before leaving the mast to dry out (hollow or solid), paint the ends to slow down the drying there. The rest of the mast can be left un-treated. I suggest a ventilated shed, protected from rain and direct sun.

Drying out:
The drying process is fairly quick, whether the mast is solid or hollow.

> *I have seen a 32cm solid mast being left to dry in the sun (OK, ok at 59deg N. Latitude, and under plastic cover..) with this saw cut in it. The saw-cut opened close to 20mm, I guess, and the mast was declared dry when the cut stopped opening after 6 months. No shakes were found anywhere on that mast.*

When drying is finished, after about 6 months, it is time to finish the mast.

Finishing:
Finishing the solid mast:

- The saw-cut you made has now opened quite unevenly along the mast.
- Make the cut even with a router. Ensure that the cut gets deep enough to take the piping for the necessary wiring.
- Install the piping.
- Glue in splines to cover the cut, using epoxy.

Finishing the hollow mast:

- Before gluing back together the two mast halves, it might be an idea to plane or sand the inner section to get rid of a bit more weight. The boat builder, who did this for me, rebuilt a plane with a new round shoe and reshaped the blade too, to get this job done.
- The inside was then coated with epoxy, and piping for the wiring installed.
- Finally, before starting stirring more epoxy, we crunched aluminium foil into the full length of the mast's cavity. Radar reflector, you know...
- With the "lid on" it was secured with a number of clamps – but not half as many as if we had been making a glued stave job. The fact that we had left the mast 8-sided before drying out, made the clamping job much easier.
- With glue dried, the mast can be finished on the outside.

Suddenly I started writing in PAST form. Of course; it is a description on how it was done on Malena and Johanna...

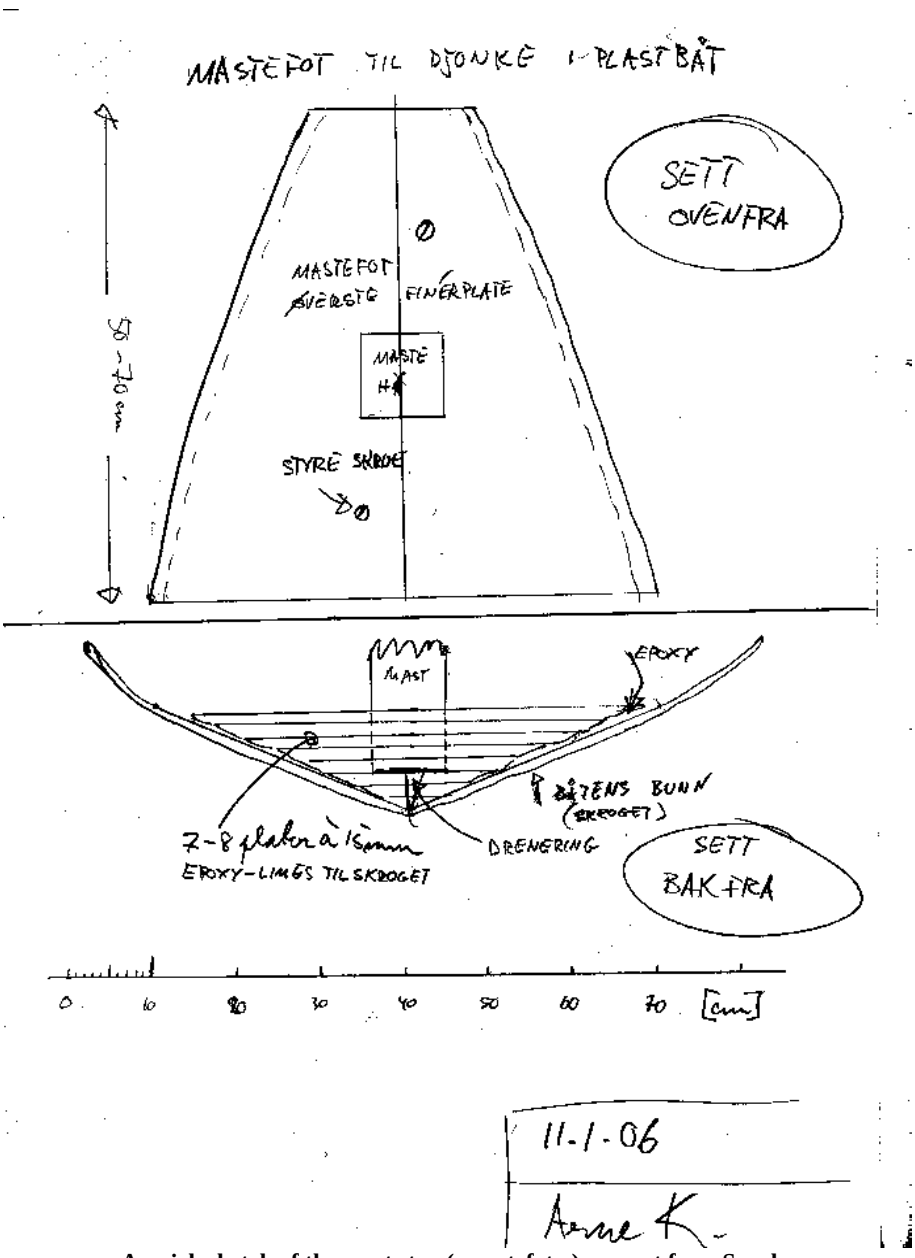
Final coating of the mast:
Any wooden mast needs some treatments. The main issue is to ensure that it will not trap any water. You will also want to have a surface that doesn't need regular maintenance. *Malena*'s hollow mast from 1995 was covered with one layer of thin glass roving in epoxy and then 7 coats of a 2 pot Polyurethane varnish. Edit: The glassing died around 2010. On *Johanna* I use the same recipe, but with white colour in the varnish for extra sun protection. I have also seen a couple of masts that just have been varnished with Coelane 1-pot varnish, and this seems good too. I suggest you do a good job; repainting masts every year is a pain...
By the way: On my masts, I beef up the area at the partners with 2 extra layers of glass roving in epoxy. This is to ensure that the fibres in the mast shall not be crunched by the wedges holding it in place.

Well, that's all I know about making wooden masts.

If you are not lucky enough to live where trees are cheap and plentiful, I suggest you start hunting for aluminium, or GRP lamp posts or something. However, I know too little about them to suggest scantlings or how they should be made.

Edit:
But now you can look up Chapter 6b about the hybrid aluminium-wood mast.

6.3 Mast step, partners and masthead *(Edit: Check links in the appendix...)*



A quick sketch of the mast step (..mastefot...) , meant for a Swede, so I forgot to write in English. It should explain itself though.

Mast step

For some reason I like to make things from plywood and epoxy; shelves, boxes, outboard brackets etc, and now; mast steps. I have only fitted mast steps for 2 boats, both having solid GRP hulls. I don't know if this is the best method, but it worked for me. The fine thing with it is that the progress was step by step. In addition, I could see the end result and assess it before it was carved in stone (read: before mixing epoxy commenced). Look at fig. 6..... The main idea was to lay up a number of layers of plywood with a hole for the mast foot to rest in. The design ensures a huge contact area against the hull, preventing it from EVER breaking loose.

Dry-fitting the plywood:

- True up the boat to be level. If your boat is afloat, keep a spirit level ready to make sure that the boat is not listing when critical measurements are to be taken.
- Drill a little pilot hole in the deck where you want the centre of the mast to go. The mast step should spread out evenly for and aft of the mast position.
- Mark up on the hull where the mast step will be and rub this hull area up with an angle grinder. No Topcoat or paint must be left, just a glean GRP with a slightly dented, uneven surface.
- Have a vacuum cleaner ready and clean up at once afterwards or the dust will soon make a mess of the whole boat.
- Dry-fit the first plywood plank to the hull with tape. The mast will stand on this plank. By making it narrower than the mast, it is easy to make drain channels for eventual water to escape through. Tape it securely to the hull.
- Fit the next layers one by one until the total height is 8-10cm or until the contact area against the hull is sufficient (60 by 60cm?). Each layer is just fastened to the one below with 2 screws, less than twice the plywood thickness long. I actually recommend drilling holes for the screws and using machine screws. They are not meant to hold well, but to act as guides when dismounting and remounting the step (several times). Flush screw heads of course.
- For each layer of plywood you dry-fit, mark them with a thin felt-tip pen against the hull.
- Note: When planing the edges of each layer of plywood to fit the hull, the fit can be fairly loose. Still, there should not be more than 2-4mm gap between the hull and plywood. Reason: When the gluing job begins, we don't want a high volume of epoxy in any cavities, or it may "go off" (.. *Yes, I know what I'm talking about*...). so, if you by accident make one with too much clearance to the hull, chuck it away and start over again.

Making the mast hole in the step:

- Hang a plumb (.. a big nut will do...) from the pilot hole in the deck and mark the mast centre on the mast step. Double-check that you hit the centreline of the boat.
- Mark up the close-fitting mast hole, loosen the plywood and saw out the mast hole.
- Screw it back on to the remaining mast step and use it as a template for marking the mast hole on the layer underneath.
- Repeat this unscrewing, sawing the hole, refitting, marking etc, until you are back to the lowest plank, the one that carries the mast. *Double-check that the position of the lowest plank is well marked on the hull.*
- If you have the mast nearby, you could even reconnect all the layers (including the bottom one) correctly outside the boat, thanks to guiding screws, and trial fit it on the mast. The mast should fit like a hand in a glove.

  On my first mast step, in Malena, the mast was a rather loose fit. As the boat pitched, we could hear the dunk-noise at it moved in the step (it took a while to trace that noise). We got away by fitting a couple of wide but thin wedges that was tapped in place. That worked fine.

Installing the mast step:

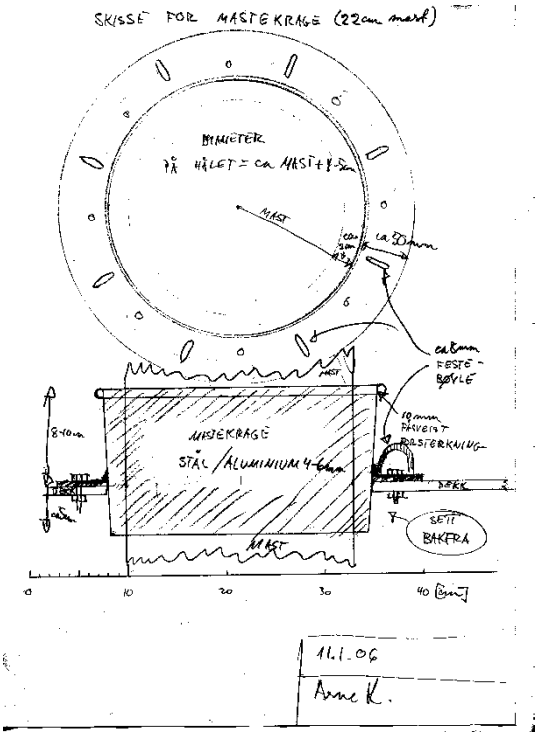
- I use to install the mast step layer by layer. I feel I have better control then.
- Coat all separate layers of the mast step with epoxy, particularly the edges, but don't fill those guiding screw holes. If the cured surfaces get waxy, clean them before installation. I use to give such coated surfaces a light sanding too before re-gluing. The

reason for coating in the first place is to ensure that the epoxy is not sucked up by the wood. Again, *the mast step is an item that must never be allowed to fail*.

- I recommend fitting the lowest plank first, and let the epoxy cure before fitting the others.
- The rest of the job, you can imagine – stir epoxy and glue layer after layer to the one underneath, and to the hull.
- When finished, wipe off drips of epoxy in the mast hole, and maybe give the whole lot an extra clear coating of epoxy the day after. You will want your mast step to be well sealed, you know.

Partners

In case you have designed your rig to let the mast go through the fore deck (and not through the trunk cabin), there will be little need for any reinforcements of deck at the partners. The method on *Malena* and *Johanna* has been to just glue a 15mm plywood plate to the deck's underside where the mast is to come (about 60 x 60cm). Its main purpose is to spread the load of the 8 bolts that holds the steel or aluminium deck collar in place. Both *Malena* and Johanna have balsa sandwich in the deck, and without the plywood backing plate, the nuts might crush the GRP. A rule of thumb says that the distance from mast step to deck partners, *the bury*, should at least be 10% of the LAP.



Just as fast a sketch for the partners. You can do it better yourself.

The deck collar (above) is a straight forward job of steel or aluminium. It should maybe be shaped as a cone, like in the sketch. Frankly, mine has always ended up straight-sided, and that seems to work too. They have been welded up of 4mm steel (with an 8mm rod on top) and then hot-dipped in zinc. It is fixed to the deck with about 8 bolts after having been adjusted to be at right angle to the mast with some paste of hi-density epoxy under the flange.

Frankly, on Johanna a little leak soon developed somewhere at the mast. After several un-successful tries, I ended up painting the steel collar and the surrounding deck with 2-pot polyurethane paint. This crept into any small

cracks (probably a little gap between the steel flange and the epoxy filling) and the leak stopped.

Masthead

A welded mast cap is fitted with a number of ears on. I hang everything from this cap, PJR style; halyard, spare halyard, mast lift and lazy jacks. The wiring comes up in a hole in the middle. A 20mm stub of tube is welded around the hole. To this a plastic hose is clamped and strapped down to keep rain out.
I didn't fix the mastcap with screws, just hammered it down with some glue in between. In fact, there is not a single screw in the whole mast (Photo:)

Edit: *Malena*'s mast cap was welded up from mild steel and hot-dipped in zinc.
The mast caps for *Johanna* and *Ingeborg* were both welded up from 5mm aluminium.

Johanna's masthead (aluminium).
From left to right: Mastlift, halyard - and halyard; I use 2 blocks.
Note plastic hose on top which covers the lantern wire.
For size referenc; the lines are 10mm

6.4 Battens, boom and yard

I haven't done any studies on this from a serious engineering point of view (..not this either...). I happen to be an engineer, but in electronics, I'm afraid. All I can do is to pass on my limited experience on the subject, connected to Malena and Johanna.

Battens

Except for a short experiment with bamboo battens, I have only used battens of round aluminium tubes.

Malena:
When I rigged *Malena* for the first time in 1990 i needed 4.6m+ battens. I had no idea how stiff or strong they should be, but decided they at least should have rather thick walls to avoid buckling and collapsing. In the shop I had the chance to lift and feel on several sizes. I soon realised that weight would grow quickly with size so I ended up with battens with 25mm OD with 3mm walls ("25-3mm"). These turned out to be almost right; the two upper ones were later replaced with some of 32-3mm. These are still in use. They are a little too flimsy, and not as light as I should wish on that little boat. If my calculations are right, the 25-3mm tubes weigh 0.55kg/m and the 32-3mm weighs 0.73kg/m.
Edit: Today I aim for bigger outer diameter and thinner walls, The 25 x 3mm tubes would have been replaced with 35 x 2mm and with a 50 x 1.5mm for batten no. 2 from top.

The batten ends on Malena were just hammered flat. Then a hole was drilled and a shackle fixed to it. To this shackle the sail was tied as well as the sheetlets.

Johanna:
For *Johanna*'s 5.8m battens I was lucky to find 6m lengths of 50-1.5mm tubes. They were wonderfully stiff and light. I had concerns about buckling, but there seem to be no reason for my fear: In a wild make-it-or-break-it sail (dead run), the long (6.3m) no.2 batten was bent. I knew it was under much harder stress than the others and had seen it panting in the blows. Luckily, as said, it just bent without collapsing. That batten is now replaced with a 50-3.2mm tube. I am very happy with these battens. The 50-1.5mm tubes should weigh 0.61kg/m and the 50-3.2mm tube 1.26kg/m. Note that the 50-1.5mm tubes are only 10% heavier than the 25-3mm tubes and yet they are so much stiffer and stronger.

The batten ends on Johanna are not hammered flat. Instead a 6mm runs through, about 30mm(?) from the end. The nut holding the bolt is an eye-nut. In addition a 3-link stub of chain is hung on that bolt. The eye-nut and chain stubs are good fixing points for sails, parrels etc. No problem with chafe.

Batten end on Johanna

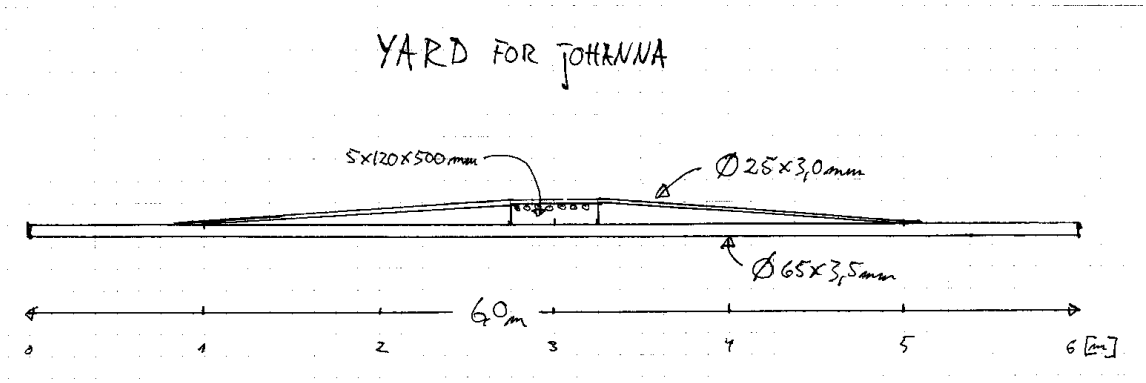
Boom

I guess most of us instinctively would seek for a heavier section for the boom than for the battens. Still, on both Malena and Johanna they are of the same sections as the (lower) battens, and I have never had any trouble with them. Period
Edit: When rigging Ingeborg (2016), I made the boom from the same size (50 x 1.5mm) as for batten no. 2. I wanted to beef the boom up a bit so I could rig the tack line to give some kicking strap effect. This partly helps to keep the leech of the lowest panel taut, and it will also be useful in combination with my Fan-up Preventer, FUP.

Yard

Malena:
The 4.6m yard for Malena was made from spruce, exactly according to the PJR method (See ch. 10, Fig 10.1). For that little boat, it was no problem to hoist with a 4:1 halyard. It is still in use.

Johanna:
For Johanna's 5.9m yard I tried the same recipe, but the cube scale factor had done its work; that yard became a monster. I never weighed it, but it felt to be well over 20kg. I then designed one in aluminium. This is much lighter; I haven't checked but it should be below 10kg, I think. Together with a well placed winch it suddenly made hoisting the sail quite easy, even for lazy old me. I generally hoist the five first panels by hand in one go. Then I rest a bit while stuffing the (5-part) halyard in a canvas bag. Then I winch up the two last panels.



Johanna's second yard, made of aluminium

This yard has proven to hold up well. I can see that it bends a bit sideway against the mast, particularly under full sail (..Johanna's mast is a bit short, so it is a squeeze...). For a bigger boat, I guess I would beef the yard up sideways by welding on "cheek plates" on each side, covering the middle half of the length.

Edit: I have later dropped welding on that bracing tube the way I did on Johanna. Almost by accident, I found a good way, which doesn't require any welding. I select the main tube for the yard, so I reckon it almost strong enough alone. Then another tube (batten size) is bolted (one bolt at each end) and glued on top of it to add stiffness in the vertical plane. So far I have made three such yards, and they hold very well.
Still, the welded, braced yard above is good. Many seem to use it, now.

20160528 Ingeborg's yard bolted and epoxied together, with the epoxy string covered with 2-pot paint. Dimensions, main tube: 65 x 3.5mm, upper tube: 35 x 2mm.

I hope this updated version of *Chapter 6* is an improvement over the original.

Stavanger 20180919, *Arne Kverneland*

Appendix:
Here are a couple of links to some write-ups, found on 'my' page on the JRA site:

- http://www.junkrigassociation.org/arne

More about how to use the formula for Sail Area/Displacement ratio:

- http://www.junkrigassociation.org/Resources/Documents/Arne%20Kverneland%27s%20files/How%20to%20calculate%20Sail%20Area%20to%20disp.%20ratio,%20ver.%2020100923.pdf

More about mast step, partners and mast cap:
(Check JRA Magazine 76, p.7, or the link below):

- http://bit.ly/2sf2tsW

..end of Chapter 6, at 20100706...
..and edited add-ons, in blue, September 2018...