Tillering the Holmegaard (Mølegabet) Bow

by

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(Revised October 2010, June 2012)

Contents

Preface to October 2010 edition

In the first edition of this paper back in 2005, I stressed very strongly that the Holmegaard (Mollegabet) bow should be made with the bending part of its limbs as parallel in both width and thickness. I still stand by this proposition as the easiest way in which to successfully tiller this remarkable bow.

However, since Dave (Yeoman) Clark published his wonderful Ozbow series (http://www.ozbow.net/phpBB3/viewtopic.php?f=3&t=5450) *Using Maths to Build Bows,* working out the proportions of limb thickness to width and length, it became manifestly obvious that using this additional tool in bowmaking, applies just as well to the Holmegaard bow as any other, and, for those who are able to manipulate the various formulae or are able to use them in Excel, a very accurate set of numbers can be obtained by which to make a bow which needs very little additional tillering after it is built to its mathematical blueprint.

Using the maths which Dave explains in his series, it becomes quite clear that a parallel width and thickness bending section limb is NOT necessary to the successful building of a Holmegaard. It just makes it a bit easier than the traditional try-and-see method. A taper width and thickness limb is quite feasible *if you get your numbers right.*

Dave's additional discovery which I call the Yeoman principle *(Princeps yeomanii)* is that the elastic limit of wood is around 66% of its modulus of rupture (MoR) and can be applied individually to any stave intended for a bow by comparing the amount of load required on a small beam of the selected wood to cause it to take a set with the load required to rupture the same piece of wood.

This discovery is still at the hypothesis stage, but seems to be bearing out in Dave's empirical work and I hope supported by my own in time with more testing of standardised beams.

I have made three or four bows using maths using the Hickman formula, a somewhat less accurate method than Dave's to obtain with to thickness proportions for a bow of desired draw weight. Even so, I was astonished at how closely the bow came out to desired tiller shape the first time it went on the tiller, requiring very little additional work, and also at how close it came to desired draw weight. Of considerable surprise was how little set the limbs took with vigorous shooting in the break-in period following.

If you can do the maths, it will cut down enormously on the amount of work required. But if you are not that way inclined, then sticking to the parallel width and thickness stratagem for the bending part of the limb is probably the safest and easiest way. Playing around with tapers can come later. It still remains that the same maths can be applied to a parallel width limb to obtain a very accurate set of thickness figures and vice versa.

I have not altered anything significantly in the text other than to ad this preface, change the order of pages, some sub-headings and minor editing. In view of the developments discussed above, I believe that they needed to be pointed out and quite properly so with due credits.

Introduction

I have noted on a couple of posts on Ozbow and elsewhere that a few people have had a go at making a Holmegaard style bow with limited success. While it discusses a tillering technique, this paper does not teach tillering as such. It presumes a practised skill and knowledge already. It is applied tillering. The 'why' principle should already be understood.

While it is not many, I have made three successful Holmegaards, and two failures which resulted from severe fretting in the middle of the belly of the wide part of both limbs. It was a very useful teaching exercise which, when analysed, allowed me to make successful working Holmegaard bows.

Unhappily, I do not have pictures of my successful bows as they have been given away to deserving people over the last few years. One of these lives in Japan with a good friend of mine. I am not sure where the others are now. I have kept one of my failed attempts as a reminder of overconfidence. It was nearly a thing of beauty and proportion.

Before proceeding, I wish to point out a significant error concerning their layout which occurred in Paul Comstock's article on Volume 2 of the Traditional Bowyer's Bibles[1] and which was rectified in Volume 3.

This error was that this bow was made with the 'under-bark' surface of the bow as the belly, and the inside of the log as the back surface, deriving from a misinterpretation of the original artefact. Paul refers to this design as a 'backwards' bow. This was, in fact, wrong and graciously acknowledged by Paul to Tim Baker by Volume 3.

A further problem occurs in Volume 3 in Tim Baker's article on Bows of the World. Here, Tim opines that the originals were 'man-sized', which meant that relative to the presumed average height of people of the European Neolithic period, the Holmegaards of the time would have been around the mid-60 inches in length (pp. 46).

However, if the reproduced drawing of Errett Callahan (on the same page) taken from the original artefact shows genuine measurement increments of 10cm apart, they add up to a bow which MUST be at least 170-180 cm (67 – 71 inches) in length[2].

This discrepancy between the drawing and Tim Baker's assessment of length and his further discussion of the mechanics of this bow could easily result in confusion and needless difficulty in tillering this remarkable design of bow. However, building it to the dimensions shown in the Callahan drawing would make tillering a little less tricky, but by no means precludes the shorter, much handier length bow from being successfully built.

What follows now is a discussion of what I have worked out and which has resulted in my successes so far. Other than my comments above, what Tim Baker describes is correct about the mechanical properties of this bow design. Most astonishing to me is

[1] Hereinafter abbreviated as TBB.

[2] In fact, the original artefact is 154 cm (60.6 inches) in length.

that the people of northern Neolithic Europe so long ago could obviously understand the mechanical advantages of this highly advanced design which makes remarkable use of available wood in such a way as to get the very best mechanical advantage from a selfwood bow.

My own efforts were restricted to short bows of 62 – 64 inches depending upon the stave length I had at the time. I did not attempt a longer bow for no particular reason other than that I followed Tim Baker's suggestion that these bows were in the low to mid-60 inches in length. A longer Holmegaard would have been less critical to tiller successfully, more durable and probably would have shot just as well.

This paper is divided up into two sections. The first is the anatomy of the Holmegaard bow and the second is the tillering of the Holmegaard bow. The section on anatomy discusses the layout of the stave and potential problems before tillering commences.

1. ANATOMY OF THE HOLMEGAARD BOW

The Holmegaard comprises five distinct sections –
*a handle section **which does NOT bend.***
*two inner limbs **which DO bend,** and*
*two outer straight levers **which do NOTt bend.***

The reason my first attempt failed was because it developed serious frets across the middle of the wide inner limb section because of tillering errors. Unlike full-limb bending designs, this short wide inner limb section in the Holmegaard is that which bears all of the bending load, and is the reason it is made wide and parallel.

The outer half of the limbs are much narrower and step down from full width at mid-limb then taper to a point. This gives this design much of its advantage in quick limb recovery because of its arrow-speed conserving low outer tip mass. Wider blunt tips would defeat the inherent advantage of this design.

The narrow outer half of the Holmegaard limb DOES NOT BEND. Consequently, it remains parallel in thickness or even thickens progressively but slightly toward the tip – just enough to give it the rigidity it needs to be a lever – and then reduces to a point in the last couple of inches to keep tip mass low.

Clearly, this presents the bowyer with the problem of tillering a bow whose limbs bend for only half of their length. Tillering of the limbs of the Holmegaard bow as if the whole limb bends through its whole length will not yield the particular benefits of this design, especially the shallower string angle in a shorter bow.

Shallow string angles allow cleaner looses and an apparent and actual decrease in pressure on the draw-fingers.
Because the outer limbs act as levers, they keep string angle shallow in much the same way (albeit to a lesser degree) that a static recurve does. Non-bending outer limbs on a bow will have a greater tip-to-tip distance when drawn/braced than another bow which has bending outer limbs. The shorter the tip-to-tip distance, the steeper the string angle at the arrow nock.

Parallel thickness inner limbs

The inner limb must be of parallel thickness from the end of the handle dips at the flares to the mid-limb steps[3].

Any amount of taper from either the handle dips or the stiff outer limbs must not extend into the inner limb. If it does, the bending forces will be concentrated further toward the centre of the inner limb with the almost inevitable result that fretting will occur.

[3] On a crowned section limb, thickness is measured from the highest point of the crown to the belly surface. See figure 3.

The thickness of the inner limb must at all times be the *same thickness* from the end of the handle dips (which must be kept as short as possible) out to the mid-limb steps. All tillering effort must be aimed at maintaining this even thickness. The final bend in the inner limb must be circular rather than elliptical to distribute the bending load as evenly as possible along the full length of the inner limb because it is so short.

Figure 1: Side view profile of the Holmegaard limb (Not to scale). The parallel section is shaded. Note that the outer limb increases in thickness until near the tip then tapers down to a point. Compare the shaded area of the thickness profile with the plan view below it. The shaded areas indicate the area of parallel thickness.

Figure 1 above shows the outer limb increasing in thickness toward the tips then sharply tapering. This gradual thickening allows the narrower outer limb to maintain its stiffness by maintaining a high cross-sectional area as its width tapers toward the tip. Even if the outer limb is left too thick it will not affect the tillering outcome so long as the inner limb is parallel for all of its length. Reduction of the outer limb can be done later.

Outer limb reduction should be only sufficient to attain minimum outer limb mass for maximum arrow speed and still maintain the stiff outer limb as a non-bending lever. Because the outer limb *tapers* to a point, it will be resistant to rotational twisting and sideways bending.

To maintain stiffness, it only requires that there be the barest amount of thickening of the outer limb until 2 or 3 inches from the tip, and then it should taper to a point.

The Holmegaard Handle

The handle of the Holmegaard should be a shallow hump barely thick enough to maintain a stiff handle section and no more.

In the picture of Errett Callahan's replica Holmegaard bow on page 45 of TBB Vol. 3, we can see the quite shallow handle area of this bow. It is a hump style handle, that is, a handle design where there are no parallel sections, and the thickest part of the handle is the middle, with anything on either side of this midpoint falling away (dipping) down to where the limbs reach full flare from the handle.

This type of handle has a signal advantage. It allows the limbs to bend very slightly into the handle rise[4], thus relieving some of the strain on the bending part of the inner limb.

On a hump style handle, the dip begins from the mid-handle where it is thickest. On a parallel handle, the dips begin at the ends of the parallel sections. There is a danger

[4] I use the term 'rise' as a descriptive to mean that point where the thickness of the limb begins to increase toward the middle of the handle. Conversely, I use the term 'dip' in its conventional sense to mean that point where the handle thickness begins its decrease toward the limb thickness. Both terms depend upon from where you are viewing the bow. If you are looking from the handle outwards, the handle dips to the limbs. If you are viewing from the limbs inwards toward the handle, the limbs rise to the handle.

inherent in a shallow hump-style handle if one is not careful. If it is made too shallow it can fail and break in your hand during shooting[5].

The way to prevent this is to ensure that the cross-sectional area of the handle always increases from the start of the rise to the thickest point of the handle hump.

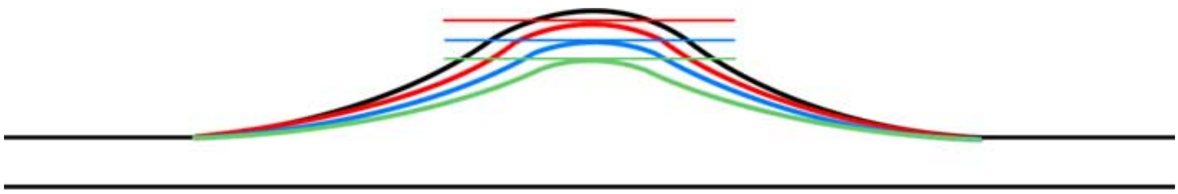

Figure 2: The manner in which height is removed from the handle hump and the dips blended into the inner limb. Progress from the red line through to the green in stages carefull observing how far the inner limbs bend into the dips. The Holmegaard must have the appearance of just commencing to bend through the handle section. This method works for other bows as well.

The way that the bending influence of the dips into the inner limb can be controlled is to firstly make the hump higher than necessary. If the handle shows signs of being too stiff, reduce the height of the hump a little at a time as in Figure 2, then blend the flat section into the dips again leaving no flat section atop the hump. Repeat this process until it *appears* that the handle is beginning to bend.

Crowned and flat sectioned limbs

Whilst a decrowned limb is better for withstanding bending loads, a cambered limb is still perfectly usable because of certain inherent properties of wood.

I have put a lot of emphasis upon keeping the wide middle section of the Holmegaard parallel in thickness and width throughout the tillering process. If your stave is from a quarter-sawn board or a log with the edge grain showing as parallel lines on the back (decrowned) and belly of the stave, then your tillering problems should be minor.

However, if your stave comes from a log, and you have used the underbark surface as the back of your bow, things become a little more complicated, but not especially difficult. The difference between the two is that on the log bow, you have a 'crowned' or rounded back. The amount of curvature on the crown needs to be discussed here.

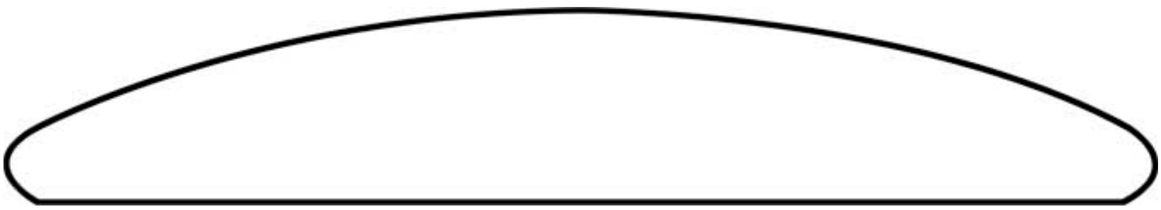

Figure 3: Cambered limb section of Holmegaard log bow.

[5] Although not a Holmegaard, it is my view from the drawings I have studied that this is why the Meare Heath artefact broke through the handle as it did. It had full-length parallel width limbs with minimal taper which acted as huge levers on a too small handle section whose cross-sectional area was less than its limbs. This would have made it very prone to force applied from the side or from the bending forces of two very long levers concentrating too much of their bending load at the weakest point of the bow which was the handle.

For a reasonably strong 50lb+ Holmegaard for a man, you will need a bowstave which is 1¾ - 2 inches (45 – 50 mm) wide and about 2 – 2¼ inches (50 – 55 mm) measured over the curvature of the back. This will give you a stave whose thickness will be around ½ inch (10-12 mm) thick at the middle of the crowned surface of the back. The sides will be well rounded of course, and the belly as flat as can be made as in Figure 3.

Do not worry if the belly has a very slight crown also. This is normal, but try to keep is as flat as you can because this better spreads the compression load over the whole width of the weaker belly surface rather than concentrating it toward the highest point of any crown. The finished draw weight of a bow of this width and thickness will vary with the density of the wood used.

Depending upon the diameter of the log with which you have to work, the above dimensions can be got from halving a small log of around 2½ -3 inches (60 - 75mm). If it is straight and you are very careful, there will be enough wood for two bows, even allowing for a thickened handle area.

For logs which are large enough to be quartered and still obtain a working size with the above dimensions, you will need something in the vicinity of 5 inches (120mm) or larger.

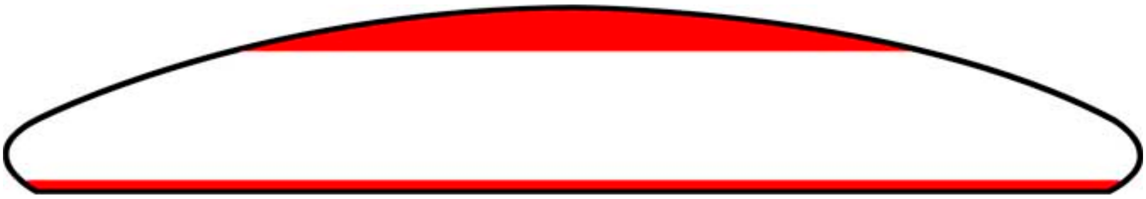

Figure 4: The shaded areas represent the distribution of bending forces in the cambered limb.

Despite the known mechanical benefits of a bow stave which is flat on its back and belly (usually from a board), that of the traditional rounded back does not suffer unnecessarily. This is because of the average 5:4 ratio of tension to compression in favour of tension in most wood. For practical purposes, this means that the moderate camber of the back is well able to withstand most of the usual bending loads (tension) on the back of the average bow without breaking.

The compression load is well catered for by a flat belly which is also wide, thus compensating for the normally lower compression resistance of wood by distributing it over a wide and long surface area.

The high cambered back, on the other hand, concentrates its bending load more toward the centre of the camber, with less out towards the sides as in Figure 4 above[6]. The higher the camber, the greater the concentration of longitudinal tension forces toward the middle of the back. Nevertheless, unless the camber is ridiculously high or there is a huge reflex in the stave, it still seems to cope well because of wood's natural ability to tolerate tension.

[6] Inverted, Figure 4 is a flatter cross section of the English style longbow which leaves its weaker compression side with the least amount of wood to withstand it – which is why they invariably produce greater set than a flatbow of similar draw weight and length.

Humps and hollows, hills and valleys

These are the surface irregularities found on the upper or lower surfacees of the log bow stave which can be allowed for with a little diligence.

Hills and valleys[7] form irregular waves along the limb as in Figure 5. They can occur on either surface and in any degree of irregularity. Humps and hollows are localised protrusions or depressions along a limb as in Figure 6. However, returning to my original premise about keeping the back and belly parallel, this still means that when viewed from the side, the highest point of the crown of the back must parallel its opposite on the belly with the following provisos.

Shallow humps and hollows of about half an inch should not overly concern the bowyer, but anything larger must be taken into account in this maintaining of parallel surfaces.

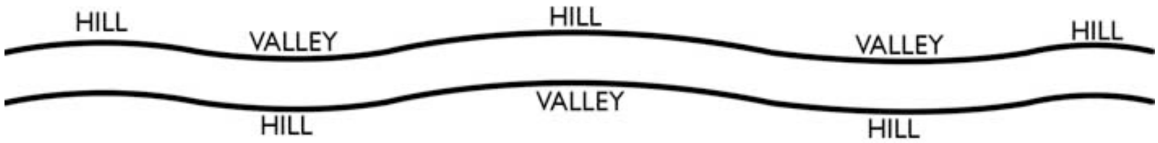

Figure 5: Waves of hills and valleys along a limb.

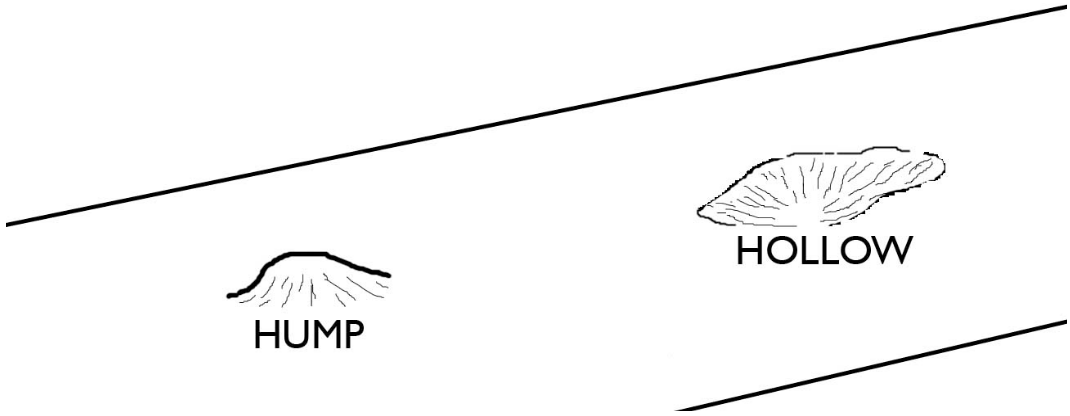

Figure 6: Hump and hollow on limb. These can occur on either surface and are therefore treated differently.

Hollows on the back are of far less concern than hollows on the belly because of the above 5:4 tension/compression ratio in favour of tension. Wood under compression is not as resistant to bending as wood under tension. If you make a significant hollow on the weaker side (the belly) you are asking for trouble in the form of fretting where the higher wood on either side of the belly hollow compresses the wood at the bottom of the hollow.

Fortunately, where there is a shallow hollow on the back, the tension forces required to tear the back apart seem to need to be much higher by comparison in my experience. If there is a significant hump or hill on the belly, it becomes a localised area against which the surrounding wood compresses and frets can form around its base, whereas, valleys and hollows tend to form frets inside the hollow.

[7] These terms are my own. I have not seen them used elsewhere. They are not technical, but intended as descriptives which are verbally suggestive of observed phenomena.

On the back, splinters sometimes rise from the top and sides of humps and from the ‘crater edge’ of hollows[8]. The way to treat significant hollows is to treat them as though they are holes through the limb and widen the limb by the same volume occupied by the hollow as in Figure 7.

Figure 7: Allowing for hollows and holes in limbs. The side bumps are abrupt for illustrative purposes.

Humps on the belly can be flattened and largely ignored and those on the back can be ignored unless they are unsound, such as where a small limb may have been developing and the hump has a soft centre. If it is soft, drill it out to the good wood and allow more wood at the sides to the equivalent volume.

[8] I would welcome the observations of others on the formation of frets and splinters in the area of humps and hollows on both back and belly of bows they have made to verify if my observations form any kind of consistent pattern. My experience is entirely empirical and I do not have mechanical data from stress testing to prove the point. But, I consider that my observations have taught me enough to make fairly reliable predictions about the outcomes of many staves I have worked on over the years.

2. THE SHAPE OF THE HOLMEGAARD TILLER

Tillering effort on the Holmegaard must concentrate only on the two inner bending limb sections.

Observing the bend of the entire Holmegaard limb on a tiller is deceiving. The bowyer must learn to look only at that section of the limb which actually does the bending, and isolating from assessment the outer non-bending limb whilst this is being done. If you have a copy of TBB, Vol. 3, study the picture of the replica Holmegaard at the bottom of page 45, and Tim Baker's comments beneath it. Note also that the limb on the right-hand side of this picture has a greater bend than the left, presumably because the right limb is meant to be the slightly weaker upper limb necessary to a rigid handle bow.

This is the shape you are trying to achieve, and it will pay to burn this picture into your mind so you can recognise it when it emerges and quickly recognise when your efforts are not producing it at an early stage so that corrective action can be undertaken before you lose the bow.

A plan view diagram of this design is shown in the picture at the top of the TBB page 46 article. At the half limb, it clearly narrows via small definitive 'step-downs', then tapers in straight lines almost to the pointed tips. There is a waisted handle section not much longer than a clenched fist, from which, flares bring the stave out to full limb width.

The side view of the Holmegaard bow on the tiller shows that the handle is quite shallow in depth – barely thicker than what you might expect on a D-bow – but which thickness controls the amount of mid-bow rigidity so that it *appears* to bend through the handle, but doesn't. The side view clearly shows however, that the bend of both limbs ceases at the start of the flares and remains unbending for just over the length of the handle and no more.

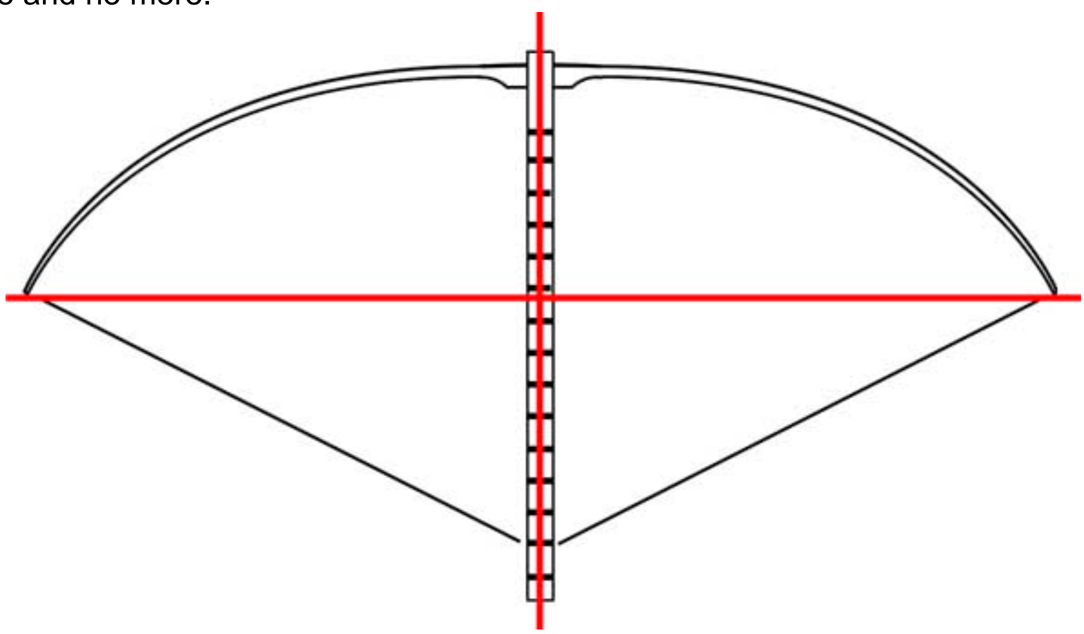

Figure 8: Conventional tiller shape

These two very short bending sections must be tillered very carefully to distribute the bending load most efficiently over their entire short length so that set is minimal. There is a simple method of achieving this correct tiller for a Holmegaard using a long straight-edge.

In conventional tillering, we look at the overall shape of the limbs out to the tips as they come back toward intended draw length. We assess the symmetry of the arcs of the limbs as they bend and the evenness of increasing curvature as in Figure 8. We also tend to presume that if the tips are coming back at the same rate and passing through parallel horizontal lines that tillering is going well. That is a very bad presumption[9].

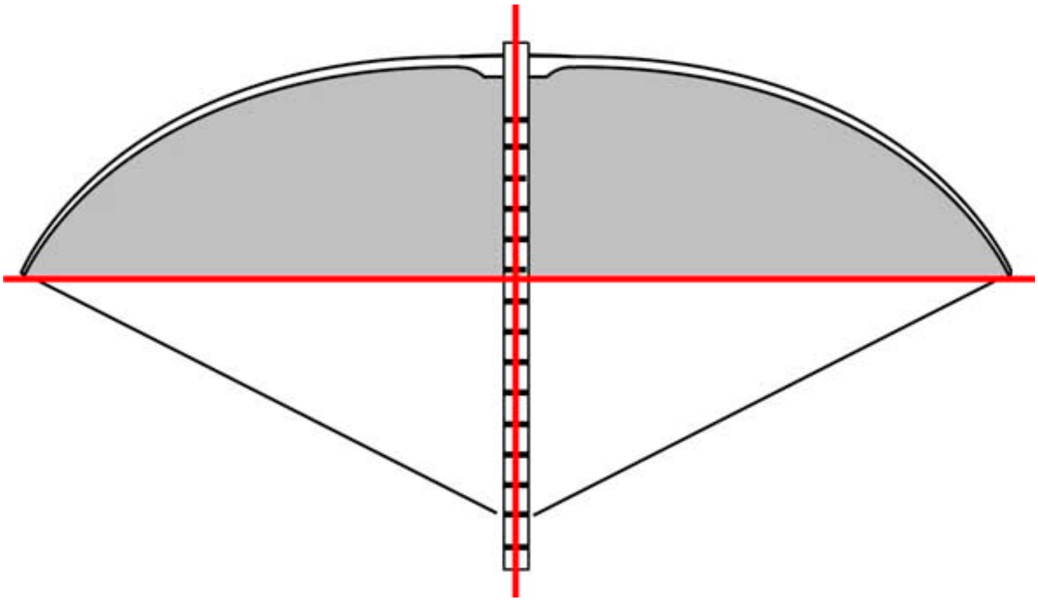

Figure 9: The shaded area beneath these limbs shows the desired symmetry on a conventional bow design.

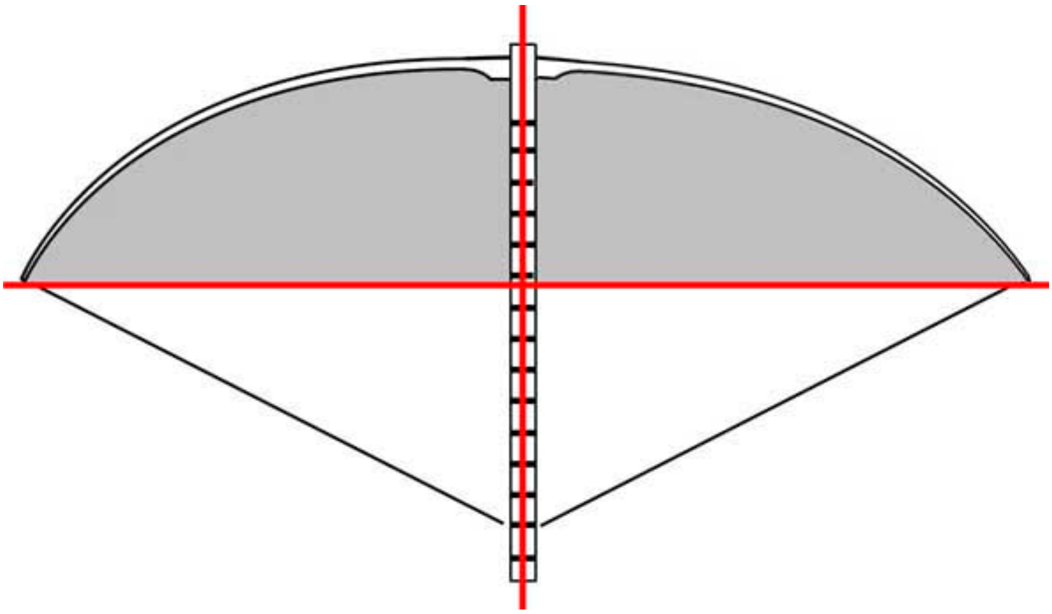

Figure 10: The shaded area beneath these limbs shows distinct asymmetry on a conventional bow design. Can you see where? One limb is distinctly stiffer.

[9] The whole purpose of tillering is to have both limb tips move forward at the same speed when the bowstring is loosed so that the arrow is efficiently propelled by an evenly applied force – and NOT the achievement of symmetrical bends. The shape of the curves is no guarantee of correct tiller at all. Symmetrical bends are evidential of correct tillering but not its proof. One has only to refer to the very asymmetrical Japanese Yumi to appreciate the fallacy that symmetry of arc equals good tillering.

The easiest way to do this is to look not at the bend of the limb, but the *symmetry of the space* in the area occupied by the arc of the limb's belly from limb tip to limb tip on either side of the tiller. Your eye has an astonishing ability to perceive small variations in this symmetry. Step back a little and blur your vision and 'see' the shape of the space. You will see the symmetry or lack of it almost immediately.

Compare the shaded areas below the limb arcs in Figures 9 and 10 to see what I mean. Clearly, the right-hand limb in Figure 9 has a slightly flatter bend in its right limb evidenced by the distinct difference in the amount of shading beneath its arc compared to the bow in Figure 9. This same principle of assessing tiller is applied to the Holmegaard, but with a significant difference. This is where our long straightedge comes in.

In Figures 9 and 10 showing conventional tillering, the horizontal red line represents our long straightedge when used in the tillering of a conventionally tillered bow. Where we align it on the Holmegaard bow is along a line *between the mid-limb steps* rather than the tips. This is the crucial area where all of our tillering effort is to be concentrated because that is the only place where it bends. The shaded area on our Holmegaard will look like Figure 11. Note particularly where we align the straightedge.

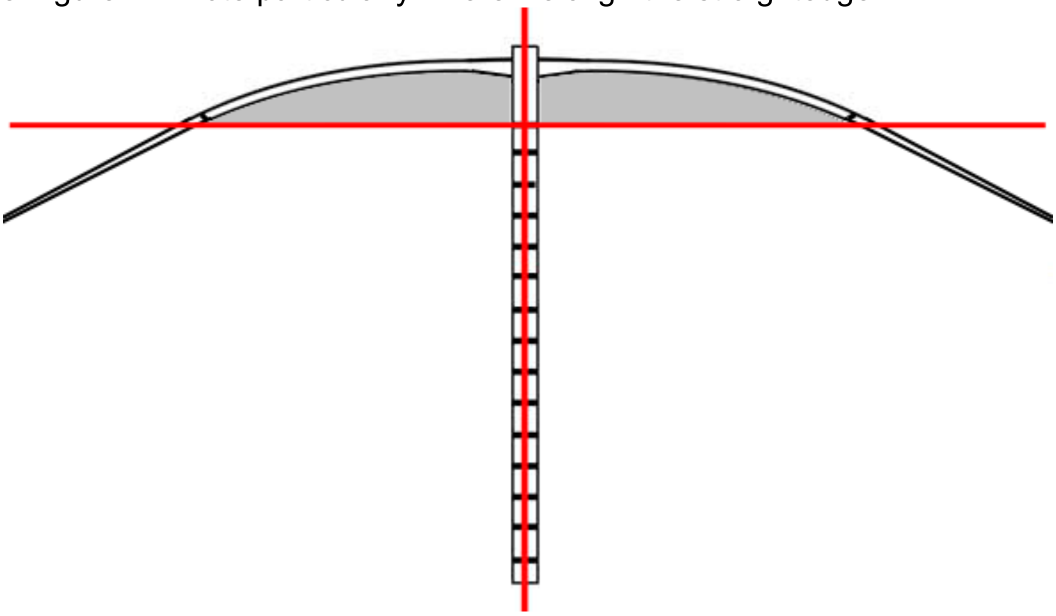

Figure 11: Correct alignment of straight edge for assessing Holmegaard tiller. The small divisions halfway out along the limbs denote the position of the characteristic Holmegaard limb step-downs.

Figure 11 clearly demonstrates the very great difference in side-limb profile of this bow design when compared with the bend in the more conventional side-limb profile above. It is quite clear that the outer half of the limbs is straight and unbending. All the work is being done by the inner half of the limb.

With the outer limbs unbending, our only concern for them is that they indicate when our bend is approaching intended draw length. Their relative thickness at the early tillering stage is not of serious concern except for the following important consideration.

It matters only at this stage that they are thick enough to remain straight, but that thickness must cease abruptly at the mid-limb steps and MUST NOT taper into the inner limb.

The picture of Paul Comstock's Holmegaard on the dust jacket of Volume 3 of TBB is an example of non-typical tillering for this design. The limbs have been tillered in an elliptical arc. The handle is quite thick and the dips very long. You can clearly see the influence of the long dips from the handle going way out along the limbs.

If this bow was to work at all, Paul was obliged to make the outer limbs bend in this way. Almost half the inner length of this bow is stiff and nearly straight – extending outwards on either side of the handle for almost four handle lengths.

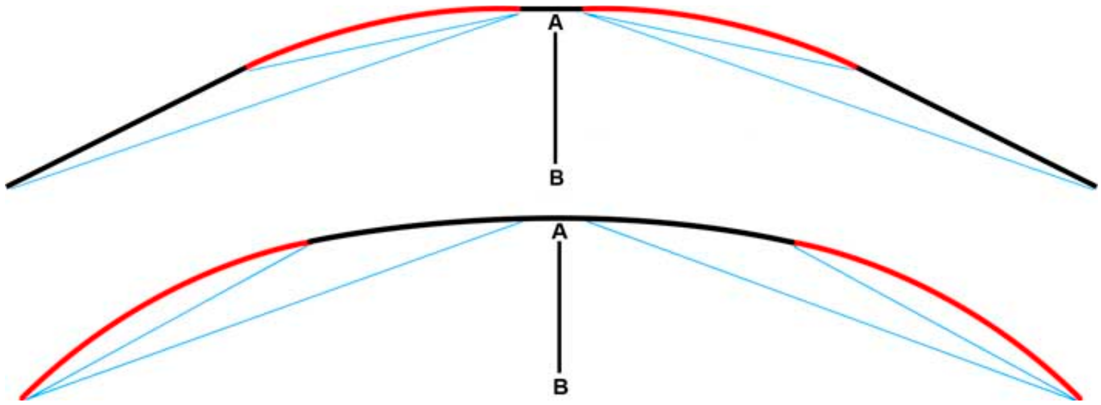

Figure 12: The upper diagram is an example of characteristic Holmegaard tiller (showing the 5 sections of the bow referred to earlier) compared to that of a more conventional elliptical tillered bow below it. The lower diagram is the type of bend which Paul Comstock's dustcover Holmegaard would produce at full draw because of its deep stiff handle. The thin blue lines show the relative amounts of bend necessary to obtain the same draw length in two bows of the same unbraced length. The distances A t o B are equal. This is the paradox of the Holmegaard bow design.

In Figure 12, it can be seen that the length of the stiff outer limbs minimises the amount of bending required by the inner limb. The bending load on the wood is less even though the limbs are at draw length. That is why it is most important to ensure the parallel thickness of the inner limb so that the bend in this section is arc of circle.

Any tapering thickness in this limb section will produce load concentrating ellipses on a Holmegaard.

On the more conventional elliptical tiller in Figure 12, the working outer limb does a lot more bending and assumes a greater proportion of the load. Compared to the Holmegaard tiller, the same length conventionally tillered bow has slightly less tip-to-tip distance and consequently slightly greater string angle for a same length bow.

None of this is to say that, like Paul Comstock's dust cover example, a more conventional tiller cannot be used for a Holmegaard. However, a Holmegaard is a Holmegaard, and if you want to build a Holmegaard, that is what you do. One of the benefits of the Holmegaard design is that allows a shorter bow the shallower string angle of a longer bow.

Acknowledgements

Whilst I have discussed certain minor misgivings I have in the writings of both Paul Comstock and Tim Baker in the Traditional Bowyer's Bibles, nothing can diminish the groundbreaking work these men have brought to the craft.

Paul Comstock's principle of the 'overbuilt' bow and Tim Baker's elaborative common language discussions on engineering principles, Jim Hamm's just as important tillering principle of not bending the stave past its intended draw weight to minimise set, and Ron Hardcastle's accelerated drying techniques, we have much to be thankful for in the preservation of our tradition by these men.