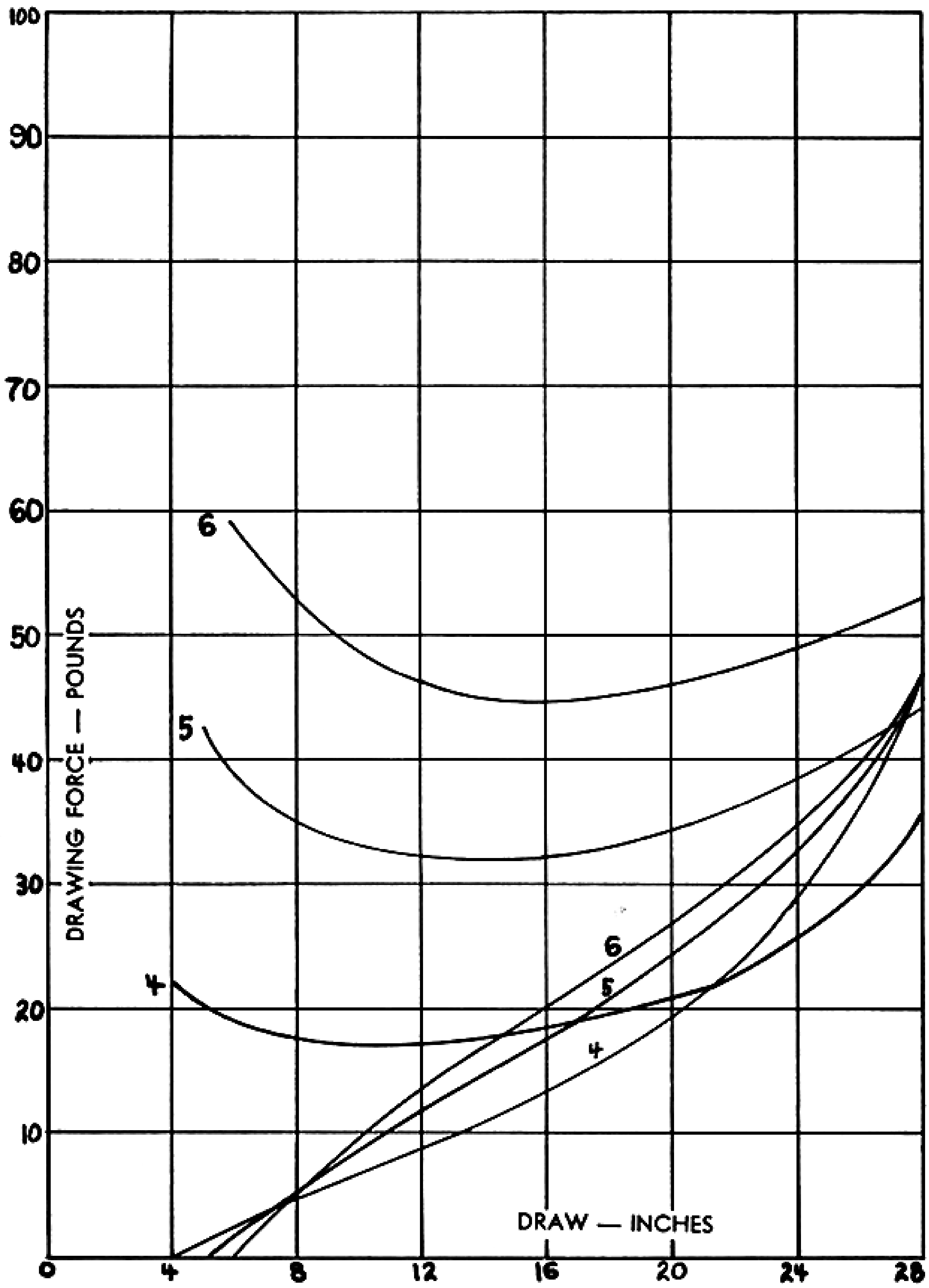
EFFECT OF BOW LENGTH ON STATIC STRAINS AND STRESSES

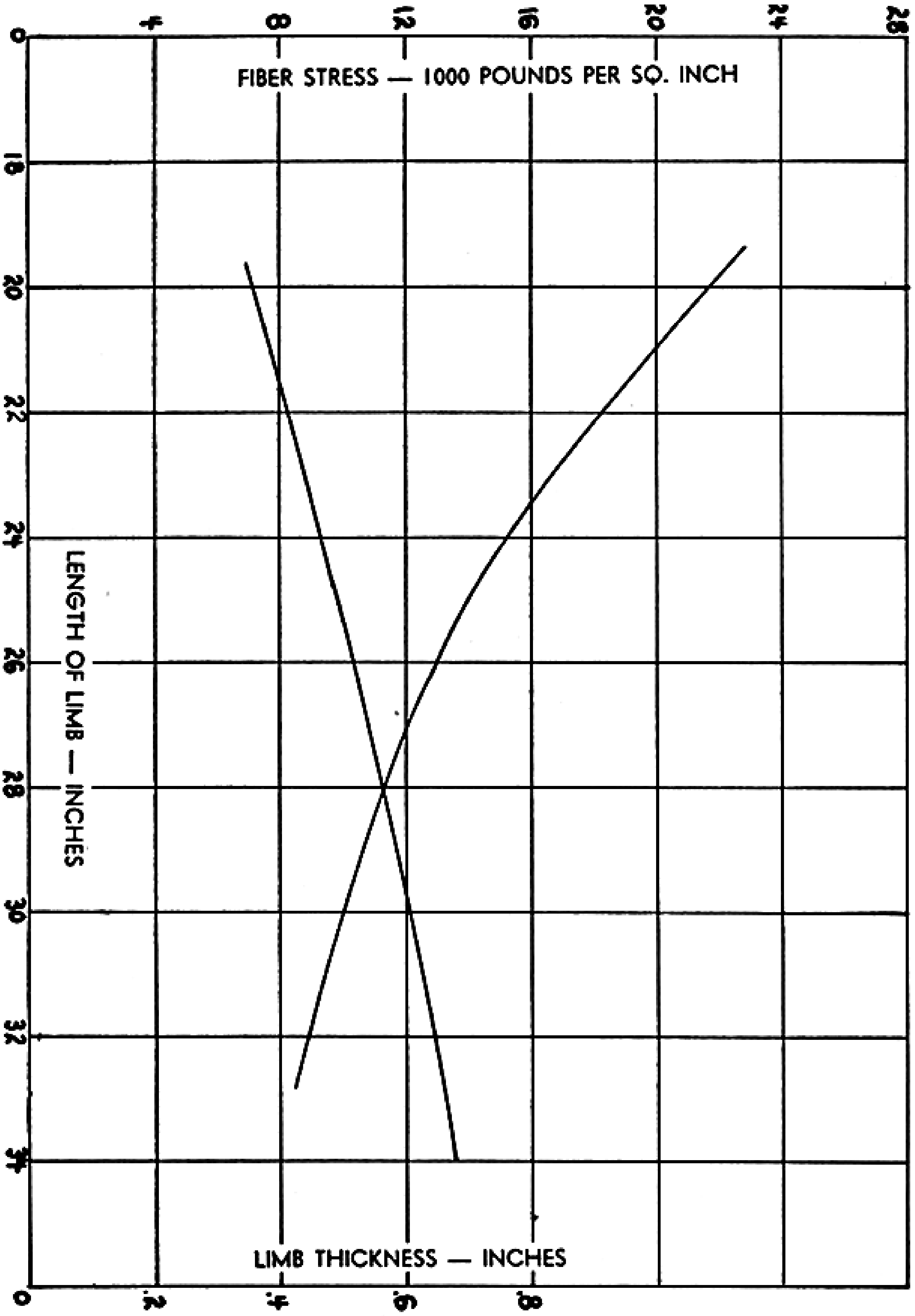
Graph 7A shows the effect of bow length on the drawing force and string tension. Curves are given for bows having lengths of 4, 5 and 6 feet. The weights of the bows are the same for a draw of 27.5 inches. These curves show that the work that may be gotten out of a bow goes up with the length. The string tension also goes up with bow length. The long bow will give a heavy arrow higher velocity, however, due to dynamical considerations that will be treated later, the short bow may give a light arrow a higher velocity than can be obtained from a long bow.

Graph 7B shows the effect on fiber stress of bow length. For a given force at full draw, the short bow has the greatest fiber stress. This same graph shows the limb thickness required to give the same full-draw force for different length bows. The longer the bow, the greater the thickness required.



GRAPH 7A

Effect of Bow Length on String Tension and Drawing Force



GRAPH 7B

Effect of Bow Length on Fiber Stress and Limb Thickness

EFFECT OF THICKNESS AND WIDTH OF A BOW ON ITS FORM OF BENDING

If all bows were made of a homogenious material such as steel, it would be possible to construct them according to theoretical computations. The proper dimensions for any desired bending form could be obtained by relatively simple mathematical computations.

Most bows, however, are made of wood and the wood varies not only from limb to limb, but within the same limb. These variations are due to many factors, such as grain, knots, curing, moisture content, cell size, etc. There is not only a variation in the strength of the wood but a considerable variation in the amount of set that the wood will take.

Long years of experience are usually required in mastering the technique and judgment necessary to construct a bow out of any billet. Any archer who has ever made a bow will admit that his first bows were far from ideal, although they would of course shoot an arrow.

It is impossible to write out instructions for making a bow of wood so that a beginner can make a perfect bow. There are a number of good books on the subject and most of them tell about as much as possible.

The master bowyer can give much valuable advice but he can not give his instructions so well that a beginner can make as good a bow from a billet as the master bowyer could make from the same billet.

The beginner in bow making should thoroughly understand that he can not copy dimensions from another bow and expect his bow to bend in the same form or to be as good as the one he is attempting to copy. In fact, it is quite possible that his bow may be worthless, even though all dimensions are identical with those of a fine bow.

As was stated in the beginning, if bows were made of homogeneous materials, exact dimensions could be given and followed. While it is not possible to give a set of dimensions for a bow made of most woods, nevertheless an understanding of some of the laws of bending should be of great value to anyone making a bow.

It is not the intention to recommend in this paper the shape of a bow nor its cross sectional dimensions. However, a treatment of the effect of thickness and width on the form of bending may be of some assistance to archers who are interested in bow making, and may lead to a radical change in bow construction.

We shall therefore consider some specific cases which are of fundamental importance. It is hoped that those archers, who do not readily follow mathematical developments, will obtain some information from the drawings and text of this article. There are a great number of archers who do follow mathematical developments and who have shown interest in previous articles. It is hoped that they will obtain some value from this treatment.

In order to illustrate the principle used in determining the form of bending, we shall first treat the case of a rectangular bar clamped at one end and loaded with a force at the other end. Fig. 2a shows this bar. Fig. 2b shows a cross-section of the bar in the middle along its length and will be used as reference in the following treatment.

In Fig. 2b let l equal length, w equal width and t equal thickness of a bar clamped at one end and subjected to a force F at the other end.

Let P be a point which is a distance x from the loaded end and a distance y from the center of the cross-section o.

The force of compression at P will be proportional to y.

Let fy equal force per unit area at P.

(1) Then fywDy equals force for a segment having thickness Dy and full width of the bar w.

There is an extension force on the other side of the center-line at a point corresponding to P having the same value as the compression force.

Therefore the moment of force about o will be $2fy^2w$ Dy.

The total reacting force will therefore be:

(2) The integral from y equals t/2 to y equals o of $2fy^2$ w dy

Integrating this expression we get:
(3) f t^3 w/12

But Fx equals moment due to the applied force, and since the applied force equals the reacting force,

(4) f w $t^3/12$ equals Fx or f equals 12 Fx/wt^3

Let Y equal Youngs modulus which is defined as the force per unit area divided by the deflection per unit length.

If we consider an increment of length Dx and remember that the force per unit area at P is fy equals 12 Fxy/wt^3:-

Then Y equals 12 Fxy/wt^3 divided by the deflection at P for an increment of length Dx

(5) Or the deflection at P equals 12 $FxyDx/wt^3Y$

The deflection at the end of the bar is x/y times as much as at P for the increment of length Dx.

Therefore the deflection at the end of the bar due to the bending of the length Dx equals $12Fx^2Dx/wt^3Y$

Then the total deflection at the end of the bar due to the

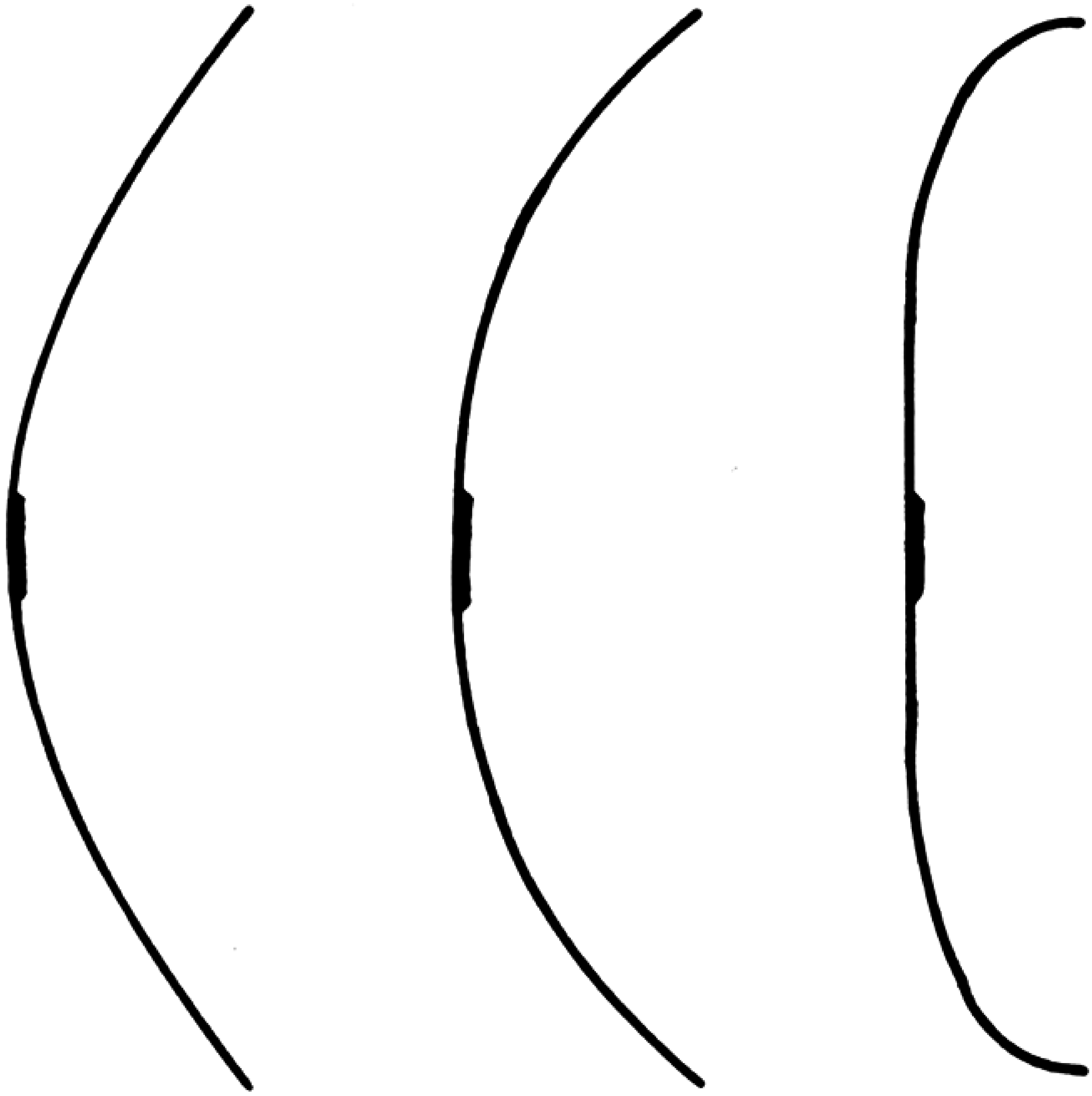


FIG.6a FIG.6b FIG.6c

bending all along the bar instead of for length Dx is given by the equation:

(6) The integral from x equals 1 to x equals o of $12Fx^2 dx/wt^3Y$ which on integretation gives: $4F1^3/wt^3Y$

If we want to know the total deflection of any other point on the bar which is at a distance of D from the clamp, we multiply equation (5) by (x — 1 + D)/y instead of x/y and integrate from x equals 1 to x equals 1 — D

(7) Or the integral of $[12Fx\ (x - 1 + D)\ dx]/wt^3Y$ from x equals 1 to x equals 1 — D

Integrating we get:

$12F\ (x^3/2 - 1x^2/2 + Dx^2/2)/wt^3Y$ for limits of x equals 1 and x equals 1 — D

Substituting these limits we get:

$12F\ (1D^2/2 - D^3/6)/wt^3Y$ which is the deflection of any point on the bar which is a distance D from the clamp.

Fig. 6a shows the form of bending of a bow constructed with limbs corresponding to the bar just discussed. It is shown with an 8 inch rigid section at the middle. A bow of this type would do most of its bending near the handle and would be considered worthless. Except for the rigid section at the middle, any uniform stick or limb would bend in this form.

Using the same method as in the preceding case we may determine the bending form for a bar of length 1, thickness t and width W at the clamp but having no width at the loaded end. Fig. 3a shows such a bar loaded with a force F.

It may be shown as before that the deflection at any point P for a length Dx equals $12FxyDx/wt^3Y$, See equation (5).

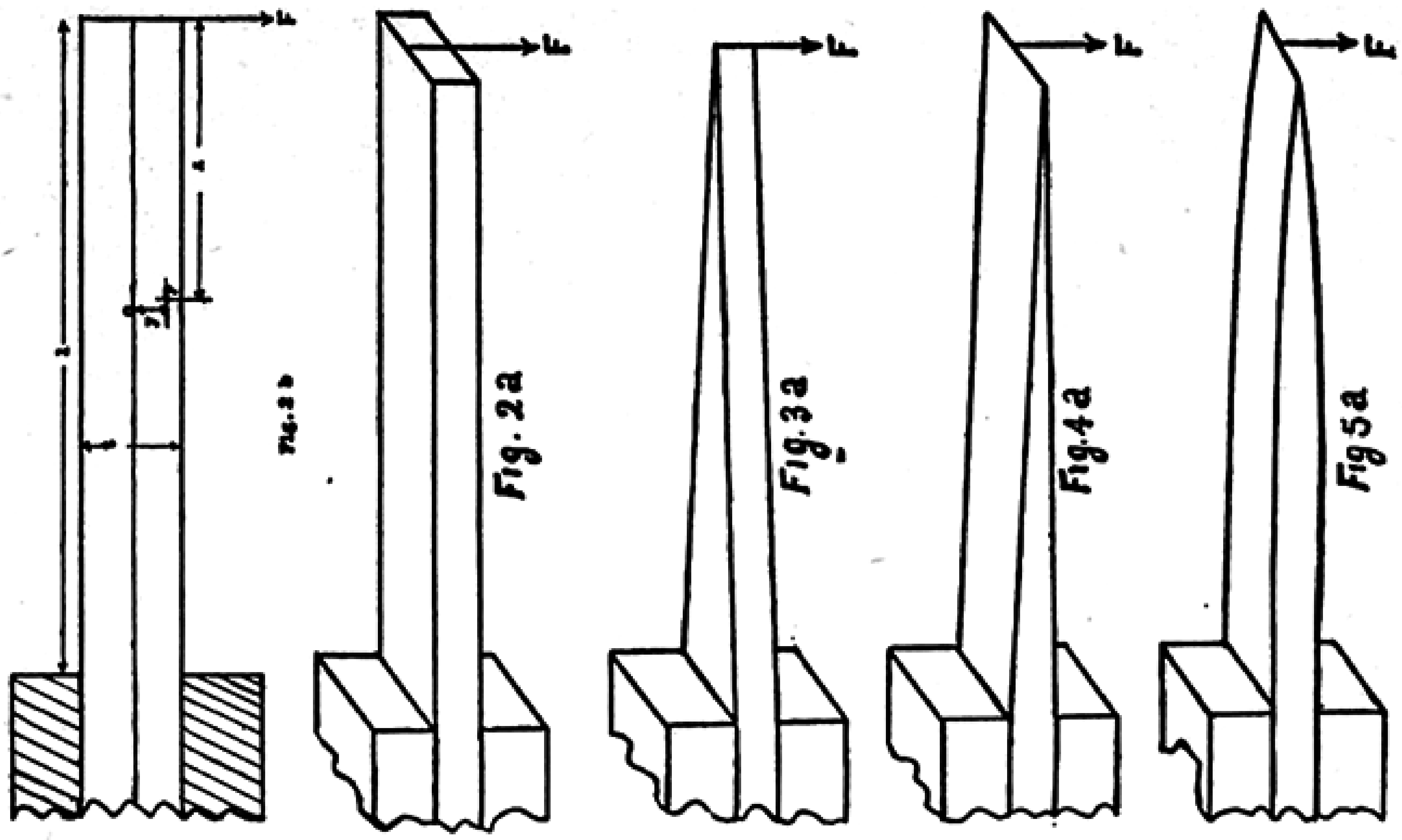
However in this case w is a variable and by inspection it will be seen that w is equal to Wx/1

Substituting this value in the above we get:

(8) $12FlyDx/Wt^3Y$ for the deflection at P

This deflection does not contain x and is therefore a constant at all points. This means that the curvature is constant for all parts of the bar or that the bar is bending in the arc of a circle.

This fact which does not seem to have been previously observed, has some interesting and perhaps valuable applications, not only in archery but in other mechanical apparatus, where it is desired to work all parts of a stressed member to equal values with a simple practical shape.



It should be clearly understood that the width at the clamp has no other effect than that of changing the total deflection for a given load. A member shaped as described above will bend in the arc of a circle at all points and all points will be equally stressed.

Continuing with the mathematical treatment:

The deflection at the end of the bar for an increment of length Dx is x/y times as much as at P and therefore equals: $12FlxDx/Wt^3Y$

The total deflection at the end of the bar is therefore equal to the integral of the above expression from x equals 1 to x equals o

Integrating we get:

(9) $6Fl^3/Wt^3Y$

This is an increase of 50% over the value for the other bar as given in equation (6)

The deflection for any other point along the bar which is at a distance of D from the clamp is as before $(x - 1 + D)/y$ times as much as at P so that the total deflection at any point along the bar is equal to the integral from x equals 1 to x equals $1 - D$ of $12Fl(x - 1 + D)dx/Wt^3Y$

Integrating we get:

(10) $6FlD^2/Wt^3Y$ (where the deflection is measured along the path traced by the point in motion.)

Fig. 6b shows the form of bending of a bow having limbs of this type. In all positions the limbs form arcs of circles. This type of bending is often desired by bow makers.

It is interesting to note again that it does not make any difference how wide the limb is at the handle, if it tapers on a straight line to zero at the end and has a constant thickness, it will bend in the arc of a circle.

Of course you can not apply a string to a limb at its end which has no width. However for all practical purposes the same results will be obtained even though the bow does have a little width where the string is attached. A bow constructed in this manner will have all parts equally stressed and may be worked to a higher efficiency than one having the usual cross section.

If we constructed a bar having a length 1 and constant width W and tapered the thickness from T at the clamp along a straight line, to zero at the end, we have another interesting case. If we let t represent the variable thickness we have by inspection t equals Tx/1.

If we treat this case as those preceding we shall find that the total deflection at the end of the bar becomes infinite. This means that the bow so constructed would be whip ended, doing most of the bending at the ends. This form of bending is shown in Fig. 6c.

The deflection for any point along the bar, which is a distance D from the clamp is given by the equation:

$$\frac{12\,F\,l^3}{W\,T^3\,Y}\left[\mathrm{Log}\frac{l}{l-D}-\frac{D}{l}\right]$$

In the above equation, when D equals l, the deflection becomes infinite.

However if instead of tapering the thickness along a straight line we select a value of t equals T $(x/1)$ ⅓ as shown in Fig. 5a, we shall find on substituting the values in equation 5 that we again have a deflection at P which is independent of x, which means that the bar bends in the arc of a circle.

Substituting the value of t equals T $(x/1)$⅓ in equation (6) we get after integrating $6Fl^3/WT^3Y$ which is the same form as we obtained for the bar which varied in width. This is the total deflection at the end of the bar.

The total deflection of any other point along the bar which is at a distance of D from the clamp will be found to be $6FlD^2/WT^3Y$, which is the same form as equation 10.

A bow constructed with limbs of this type will bend in the arc of a circle as shown in Fig. 6b.

A bow constructed in this manner will not be equally stressed. That portion near the handle will receive more stress than at the end.

Most bows are combination of this type and the second type. The limbs become thicker near the handle. The fiber stress therefore becomes greater as the thickness increases. Either this part of the bow is over stressed or the part near the end is not worked to maximum efficiency. It is believed that there is some merit to the form given in the second case treated in this paper. It will be discussed from a dynamic point of view in a later paper.

In all the cases treated here, the cross section is that of a rectangle. The effect of other cross-sections on the location of the neutral plane of bending and on the static strains and stresses will be treated in subsequent papers.

THE NEUTRAL PLANE OF BENDING OF A BOW

When a symmetrical homogeneous member is stressed by bending, the elongation on one side is exactly equal to the compression on the other side.

If a bow having a symmetrical cross-section is all made from either heart or sap-wood, the elongation along the back of the bow will in general equal the compression along the belly.

In such a bow there is a thin section located midway between the belly and back which is neither stretched nor compressed. We may call this layer the neutral plane of bending.

Many bows are cut from the tree so that the back is composed of sap-wood and the rest of the bow is composed of heart-wood. Other bows are backed with various materials. Any of these bows will have the neutral plane of bending moved back or forward depending on the elasticity of the materials used.

Practically all bows are non symmetrical in cross-section. The belly is usually much narrower than the back. This type of construction moves the neutral plane of bending toward the back of the bow.

It is necessary to know the location of this neutral plane in order to determine the maximum fiber stress in the bow. Since it is the object of the succeeding paper to show the effect of the cross-section on the fiber stresses of a bow, a method for locating the neutral plane of bending will be briefly outlined in this paper.

Let us consider a bow all made from the same kind of wood having a cross-section as shown in Fig. 7a. Let the width of the bow at the back equal w, the thickness from belly to back equal T, the distance from the belly to the neutral plane of bending equal a, and the distance from the back to the neutral plane equal b.

Let us further assume that the portion back of the neutral plane Z Z′ is rectangular in shape and that the portion in front of the neutral plane is represented by the conic section z equals $\sqrt{c(a - y)}$ (a parabola)

When y equals O, z equals w/2 equals $\sqrt{ca}$

This type of construction may be found in many bows. Of course the corners B B′ are usually rounded and the transition from the parabolic curve to the straight portion is gradual at N and N′

Note: We are using the Z axis here in order to reserve the X axis to represent the length of the bow in subsequent treatments.

Let the force of compression at any point P be fy

The moment of force about the Z Z′ axis of a segment Dy is equal to $2zfy^2Dy$

The total moment of force due to compression is therefore:

The integral from y equals a to y equals o of $2fzy^2dy$.

Substituting the value of z equals $\sqrt{c(a - y)}$ we have for the total moment of force due to compression:

The integral from y equals a to y equals o of: $2f\ y^2dy\sqrt{c(a\text{-}y)}$

Integrating we get:

$(32/105)\,fa^3\sqrt{ac}$

In like manner we may find the moment of force due to extension equals:

The integral from y equals b to y equals o of: $2fzy^2dy$.

But here as seen from Fig. 7a, z equals a constant equals w/2

Therefore the moment of force due to extension equals:

The integral from y equals b to y equals o of wfy^2dy.

Integrating we get: $wfb^3/3$

Since w equals $2\sqrt{ac}$, we have for the total moment of force due to extension, $(2/3)fb^3\sqrt{ac}$

The numerical value of the moment of force due to compression is equal to the numerical value of the moment of force due to extension.

Therefore:

$(32/105)\ a^3f\ \sqrt{ac}$ equals $(2/3)\ b^3\sqrt{ac}$

Or

a^3 equals $(35/16)\ b^3$ and a equals 1.30 b approximately.

Since the thickness of the bow T is equal to a + b we have a equals .565 T and b equals .435 T

We therefore find that the distance from the belly of the bow to the plane of neutral bending is 30% greater than the corresponding distance to the back of the bow.

If the same type of bow is backed with a layer of material having a thickness of t and a coefficient of elasticity equal to n times that of the bow wood, the neutral plane of bending will be moved toward the back of the bow.

As before let a equal the distance from the belly of the bow to the neutral plane and b equal the distance from the neutral plane to the back, including the applied layer of backing.

The moment of force due to compression will be the same as before:

$(32/105)\ a^3f\sqrt{ac}$

The moment of force due to extension will be different.

If as before we let fy equal the force per unit of area within the wood at any point, then the total moment of force due to the extension of the wood will be equal to:

The integral from y equals b — t to y equals o of $w\,f\,y^2$

Integrating we get: $wf(b - t)^3/3$

We also have a moment of force due to the backing material.

Since the elasticity of the backing material is n times as much as that of the bow wood we have for the moment of force due to the backing:

The integral from y equals b to y equals b — t of $wnfy^2$

Integrating we get:

$(wnf/3)\ [b^3 - (b - t)^3]$ where w equals $2\sqrt{ac}$

Adding these two moments and equating them to the moment due to compression we have:

a^3 equals $(35/16)\ [nb^3 - n\ (b - t)^3 + (b - t)^3]$

equals $(35/16)\ [nb^3 - (n - 1)\ (b - t)^3]$

Let t equal mb

Then:

a^3 equals $(35/16) b^3 [n - (n - 1)\ (1 - m)^3]$

a equals $b^3\sqrt{(35/16)\ [n - (n - 1)\ (1 - m)^3]}$

If n equals 2 and m equals .1

a equals b (1.30x1.083) equals 1.41 b

a equals .58 T, b equals .415 T

The distance from the neutral plane of the bow to the back has been reduced by almost 5%.

It should be clearly understood that the neutral plane is moved toward the back of the bow only for materials which have higher elasticity than the bow wood and which will stand the elongation without exceeding the elastic limit.

Now consider the cross-section of a bow such as shown in Fig. 7b. in which the belly side of the neutral plane is a semicircle having radius of a., and the distance from the neutral plane to the back of the bow is b and the width of the bow at the back is w.

Following the same procedure as before, the moment of force about the Z Z′ axis due to compression is the integral from y equals a to y equals o of $2zy^2dy$. But z equals $\sqrt{(a^2 - y^2)}$

Substituting the value of z and integrating we get: $3.1416fa^4/8$

The moment of force due to extension is as before $wfb^3/3$.

Substituting the value of w equals 2a

The moment is $2fab^3/3$

Since the moment due to compression is equal to the moment due to extension we have:

$3.1416fa^4/8$ equals $2afb^3/3$

From which a equals 1.194 b

With a bow having this type of cross-section the distance from the neutral plane to the belly of the bow is about 20%

greater than the corresponding distance to the back of the bow. This type does not have the neutral plane as close to the back as the type having the parabolic shaped belly. On the other hand a bow which has a belly with a hyperbolic shape will have its neutral plane closer to the back of the bow than either of these types just discussed.

In case the section of the bow is all of the same kind of wood, a simple method of locating the neutral plane of bending may be followed by the non-mathematician.

Lay out the shape of the cross-section on a heavy cardboard, using any convenient enlarged scale. Cut this cardboard section out with a pair of shears. Draw a line from the belly to the back which divides the section into two equal parts like the lines Y Y′ in figures 7a and 7b. Punch a small pin through the cardboard section on this line at such a position that the section will remain in balance on the pin for any position. After a number of trials you will find a point where the cardboard section may be rotated on the pin to any position, and at which, it will be in balance. This point is known as the center of gravity and is on the line corresponding to the plane of neutral bending. The distance from this point to the back therefore gives the distance of the neutral plane of bending from the back.

If care is used in laying out the cross-section shape on the cardboard and in obtaining the proper balancing point, accurate results may be obtained.

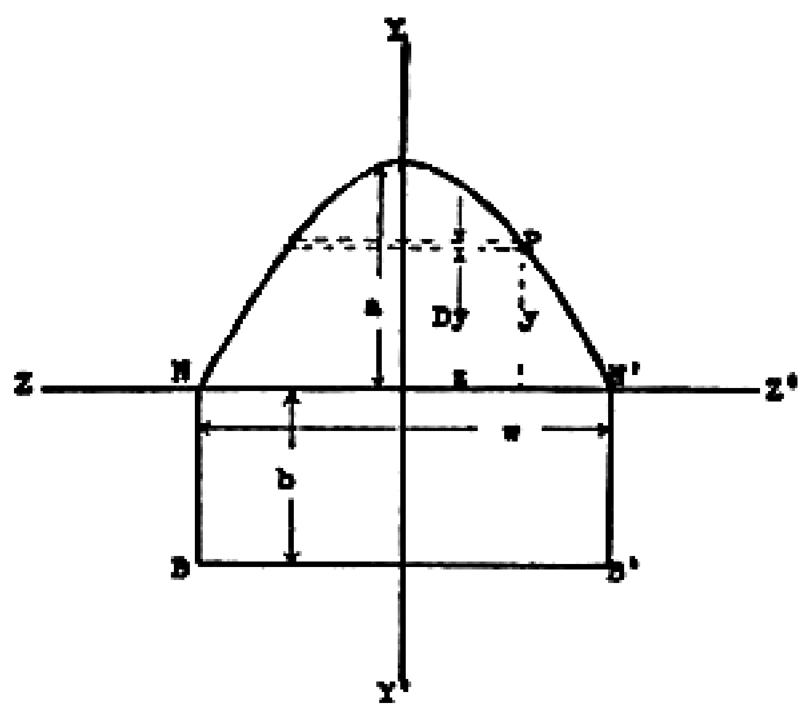


Fig. 7a.

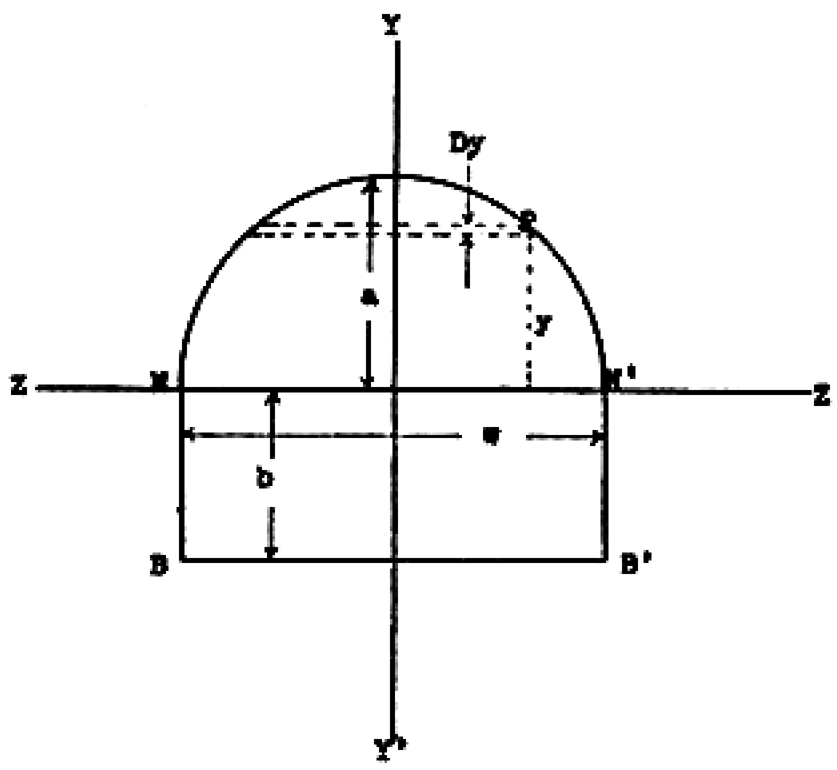


Fig. 7b.

FIBER STRESSES IN BOWS

In a preceding paper we have defined, and given a method for locating the neutral plane of bending of a bow.

The fiber stress in any cross-section of a bow is proportional to the distance from the neutral plane of bending. The fiber stress is therefore greatest at the back or belly of the bow. This stress is usually referred to as the maximum fiber stress.

If the cross-section of the bow is symmetrical with respect to the neutral plane, the fiber stress at the back, which is one of stretch, will equal the fiber stress at the belly, which is one of compression.

If the cross-section of the bow is non-symmetrical with respect to the neutral plane, as discussed in the previous publication, the fiber stress at the back will not equal that at the belly. For example if the cross-section of the bow is such that the belly side of the neutral plane is a parabola and the back side of the neutral plane is a rectangle, the fiber stress at the belly surface will be approximately 30% higher than at the back.

If the cross-section of the bow were kept rectangular in shape on the belly side as well as for the back, the same weight bow could be obtained with a much smaller maximum fiber stress. It is, of course, desirable to work the wood to as high a stress as possible without fracture or serious permanent set.

We shall now determine the effect that the cross-section has upon the maximum fiber stress in a bow.

It has been shown in a preceding paper, (The Effect of Thickness and Width of a Bow on its Form of Bending) equation (3), that the total moment of force about the neutral plane of bending, at any section of a rectangular shaped bar, is equal to $ft^3w/12$, where t equals thickness, w equals width, and f is a constant, which when multiplied by the distance from the neutral plane, gives the force per unit of area at the point.

It was also shown, equation (4), that $fwt^3/12$ equals Fx, where F is the load on the end of the bar and x is the distance from the end of the bar to the section.

Therefore f equals $12Fx/wt^3$ (1)

The maximum stress will be at the greatest distance from the neutral plane. In this case, where the cross-section of the bar has the shape of a rectangle, the neutral plane will be in the middle and the greatest distance from it will be t/2. The force per unit of area at the surface under tension and also at the surface under compression will be ft/2.

Making use of equation (1) we get for the maximum fiber stress: ft/2 equals $6Fx/wt^2$ (2)

It has been shown in some of the early publications that the tension in the string of most bows is approximately equal to the weight of the bow at full draw. Also at full draw, the string pulls in such a direction that the string tension or bow weight may be substituted for the load F in the above formula. This formula will give a rough idea of the maximum fiber stress in a bow.

Let us examine a section of a 40 pound bow having all sections rectangular in shape, constant thickness and a width which tapers along a straight line from the handle to the bow tip. Suppose we take a section which is 30 inches from the end, where the width is one and three-eighth inches and the thickness is three-quarters of an inch. Substituting in equation (2) we find for the maximum fiber stress:

$$ft/2 \text{ equals } \frac{6 \times 40 \times 30}{1.375 \times .75^2} \text{ equals}$$

9,300 pounds per square inch.

The fiber stress at elastic limit, given by The Forests Products Laboratory, for Yew is 10,100 pounds per square inch. The stress at rupture for this wood is given as 16,800 pounds per square inch. We thus see that in this bow the wood is being worked close to, but below the elastic limit.

If this bow had the same thickness and same width throughout its length, the fiber stress would become less and less as you approach the tips. The bow would bend in a form as shown in figure 6a of the paper referred to above. However if the width is tapered on a straight line from the handle to the tips, the decrease in the value of x is exactly offset by the decrease in the width w so that the fiber stress is the same throughout the length of the bow.

For example if we take a section which is 15 inches from the tip the thickness is still three-quarters of an inch, but the width is only one-half as much as before, i. e. 11/16 inches.

Substituting in equation (2) we get for the maximum fiber stress:

$$ft/2 \text{ equals } \frac{6 \times 40 \times 15}{.687 \times .75^2} \text{ equals}$$

9,300 pounds per square inch.

This is the same value obtained for the section 30 inches from the tip. In like manner every other section will have the same maximum fiber stress.

Let us now determine the maximum fiber stress in a yew bow manufactured by a well known manufacturer of archery tackle. This bow weighs forty pounds and is seventy inches long. On examining a section 30 inches from one end of the bow and locating the neutral plane of bending by the method described in the preceding publication, we find that the bow has a thickness of one inch, a width of one and one-eighth inches and a shape such that the neutral plane is .55 inches from the belly and .45 inches from the back.

As shown in the preceding publication, the moment of force due to extension is $wfb^3/3$, where b is the distance from the back to the neutral plane. The total moment about the neutral plane is twice this value. The moment due to the load F is Fx, where x is the distance from the end to the section. Therefore f equals $3Fx/2wb^3$ (3)

Substituting in this equation we get:

$$f \text{ equals } \frac{3 \times 40 \times 30}{2 \times 1.125 \times .45^3} \text{ equals } 17{,}600.$$

The maximum fiber stress will be on the belly side where the distance from the neutral plane to the belly is .55 inches. Since the maximum fiber stress is f times this distance we have: 17,600 X .55 equals 9,660 pounds per square inch for the maximum fiber stress.

Taking another section 15 inches from the tip, we find the thickness is .60 inches, the width .95 inches and the neutral plane is .27 inches from the back and .33 inches from the belly.

Using these values in equation (3) we get:

$$f \text{ equals } \frac{3 \times 40 \times 15}{2 \times .95 \times .27^3} \text{ equals } .48{,}000$$

The maximum fiber stress will be on the belly side which is .33 inches from the neutral plane and will equal: 48,000 X .33 equal 15,900 pounds per square inch.

This is an increase of 68% over the stress at the other section and is beyond the elastic limit given for this wood. It is very close to the value given for the modulus of rupture.

If the thickness had been left the same as at the other section, and the width reduced to ½ its former value (.562), the maximum stress would have been reduced to the same value as at the other section. We would have had on substituting in equation (3):

$$f \text{ equals } \frac{3 \times 40 \times 15}{2 \times .562 \times .45^3} \text{ equals } 17{,}600.$$

And: 17,000 X .55 equals 9,660 pounds per square inch.

The bow would have had a better cast and would not have taken a permanent set.

If instead of the parabolic section for the belly, a rectangular section had been used, the maximum stress would have been reduced about 18% because the distance of the belly from the neutral plane would have been .45 inches instead of .55 inches. The bow would have had exactly the same weight. The full thickness of 1 inch might have been used, with an increase in the weight of the bow of 27%. In which case the maximum fiber stress would have been by equation (2):

$$ft/2 \text{ equals } \frac{6 \times 50.8 \times 30}{1.125 \times 1^2} \text{ equals } 8{,}130$$

pounds per square inch.

Even with this increase in bow weight, the maximum fiber stress is 1,530 pounds less than for the parabolic section.

The reason for selecting these two sections on the bow was to show that the maximum stress exists where the bow took its greatest set. There was no set near the handle but it was very great about 15 inches from the ends of the bow.

On first thought this may be confusing to the reader because we have previously stated that the fiber stress occurs where the bow is thickest. That statement however applies only to a bow the limbs of which bend in arcs of a circle. Obviously this bow does not bend in the arc of a circle. However a casual observation would not reveal this difficulty. An apparently small change in curvature will make a big difference in the stresses.

There is one more point in connection with the cross-section of a bow which should be mentioned. Many bows are worked beyond the elastic limit, but of course not beyond the modulus of rupture.

It has been shown by the Forests Products Laboratory that the modulus of rupture for compression is much lower than the modulus of rupture for extension. In all of the tests which they make in determining the modulus of rupture for static bending, it is the compression side which gives way first. This moves the neutral plane closer to the extension side so that the radius of curvature is increased at this point until finally the extension side gives way.

The archer must not be confused by the fact that a bow always breaks on the back. This happens only because the belly gives way and thus causes greater extension stress along the back by the shift of the neutral plane. The archer does know that a bow will break where there is a bad chrysal on the belly side. Here he observes the belly fault before the break occurs.

In most woods which they have tested, the modulus of rupture for extension is over twice as high as for compression. (By modulus of rupture is meant the maximum fiber stress in pounds per square inch at the breaking point.)

In like manner the elastic limit for extension is over twice as high as the elastic limit for compression.

The orthodox cross-section of a bow is such as to make the fiber stress on the belly or compression side greatest. On the other hand, wood will not stand as much compression as extension. Why then do we not construct bows with the belly side flat and the back side narrow so as to take advantage of the greater elastic limit of extension?

The first answer is: Perhaps we should. Another answer is that the back of a yew bow is usually made of sap wood which may have a lower modulus of elasticity, so that the neutral plane is moved toward the belly side a sufficient amount to more than compensate for the shift due to the shape of the belly. Still another answer is that the elastic limit is not a definite value but depends upon the shape of the specimen. It has been shown by the Forests Products Laboratory that the elastic limit in compression is increased considerably by the presence of other less stressed fibers. The elastic limit in bending is much greater than for compression parallel to the grain, where the entire specimen is subjected to the same stress. This is probably due to the fact that in bending, only the surface layer of the compression side is subjected to the maximum stress. The adjacent layers of less stressed fibers help to support those receiving the highest stress. This raises the limit to which the specimen may be stressed before failure is reached.

There is a strong probability however, that for homogeneous woods, such as osage and lemonwood, that a better cast may be secured by reversing the traditional construction of a bow, by making the belly side the back. In such a bow, however, greater precautions must be taken against slight imperfections on the back surface. A trapezoidal shape with the narrow side for the back, well protected with a thin layer of some good backing material, would probably be the most practical shape.

At the present time we do not have enough data on the tensile strength of woods to reach any definite conclusion as to the best cross-section for a bow.

Past experience has shown that in many arts, the adoption of a specific design was accompanied with a very good reason and science has only been able to make slight improvements. The construction of a bow is an art which has been developed as most arts, by the method of trial and error. It may be found that this method has developed the best bow that can be made. However there is the possibility that this method has not developed the best type of construction and that science may point the way to a considerable improvement. In fact there are already indications that those of us who can not pull a 50 to 60 pound bow, may be able to have our point of aim on the gold at 100 yards with a bow weighing less than 40 pounds.

During the period that Dr. Hickman was writing these articles for Ye Sylvan Archer he included a few which gave the results of experimental investigations. A brief summary of the experimental investigations will now be given.