

# *veritas*®

## Steam-Bending Instruction Booklet



05F15.01

## Bending Solid Wood with Steam and Compressive Force

There are three basic requirements for the successful bending of solid wood using steam.

1. The wood must be plasticized. Although wood can be plasticized chemically or even by microwaves when in a green state, the most convenient way to plasticize wood is with steam.

Wood cells are held together by a naturally occurring substance in the wood called lignin. Imagine the wood fibers to be a bundle of rods with the space between them filled with lignin. The strength of this lignin bond between the rods can be decreased by subjecting the wood to steam. With unpressurized steam at 212° Fahrenheit, steaming for one hour per inch of thickness (regardless of the width) will soften the bond enough for bending. Substantial oversteaming may cause the wood to wrinkle on the concave face as the bend progresses.

2. Only air-dried wood of an appropriate species should be used.

Kiln-dried wood must not be used; the lignin in the wood has been permanently set during the hot, dry kilning process. No amount of steaming or soaking will weaken the lignin bond sufficiently for successful bending. The same applies to air-dried wood that has been allowed to dry and stabilize below 10% moisture content; the lignin will only partially plasticize with steam, not enough for successful bending of anything beyond a shallow curve.

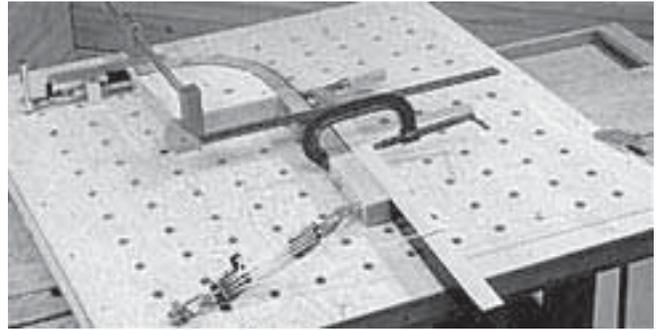
3. Wood must be kept under compression during the bending process.

Because of this third requirement, the Veritas line of clamping equipment for steam bending was developed. Wood fibers will stretch only a small amount before they fail, usually less than 1/2 of 1%. If you think of bending a stick over your knee, as the wood bends, it is the fibers on the outside of the bend that start to separate and break first. The drier the wood, the easier it will break. However, when well plasticized, wood will compress to an amazing degree. It is these two properties of wood that we avoid and exploit respectively in the steam-bending process.



To stop the wood from stretching on the outside face during the bending process, it must be restrained at either end by stops securely attached to a metal backing strap. The wood face in contact with the strap is not

allowed to stretch as the bend progresses; however, the wood face against the form is subject to compression exerted by the end stops.



For example, a straight piece of wood 1" thick and 18" long bent to 90° around a 4" radius will remain 18" along the outside (immediately next to the strap), but will have the inside dimension reduced to almost 16". Nearly two inches have virtually disappeared through compression along the inside face!

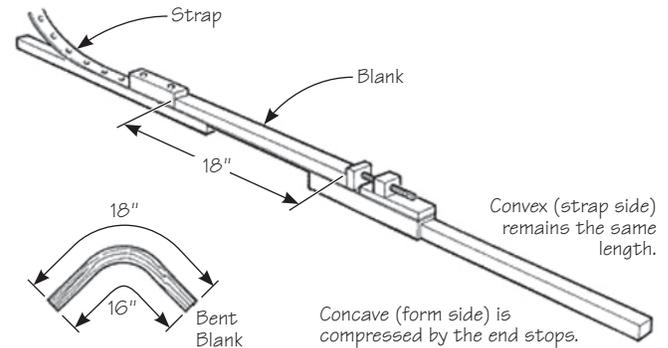


Figure 1

### Species for Steam Bending

To avoid a lengthy description of wood cell structure here, we are providing general guidelines regarding appropriate woods for compressive steam bending using the Veritas Steam-Bending System.

Two rules of thumb are:

1. Exotic woods do not bend well.
2. Softwoods do not bend well and should be avoided.

Some common domestic hardwoods will bend with great success. Based on air-dried 1" thick stock at 25% moisture content going into the steam box, the smallest bend radius you can achieve without risk of failure is shown in the table below. You can get tighter radii but at higher risks.

Species	Smallest Radii
Oak (red and white)	2"
Hickory	2"
Elm	2"
Walnut	3"
Ash	4.5"
Cherry*	6"
Maple**	8"

\* Requires some experience to bend flawlessly. It is prone to compression wrinkles on the inside face. These can often be removed during shaping and sanding once the bend is complete and cured.

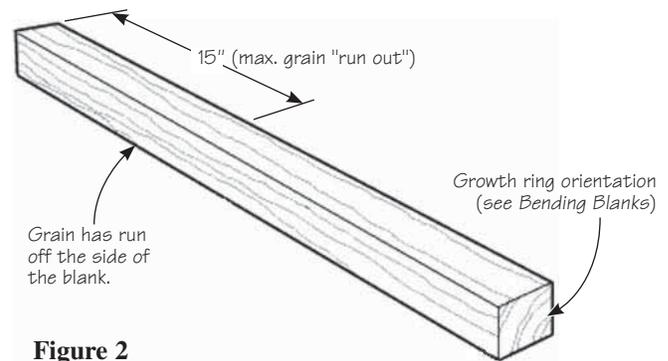
\*\* Can be difficult to bend. It requires more leverage to put the blank into compression.

## Bending Blanks

The stock itself should be the straightest grained, knot-free material you can find. The ends should be square-cut and all sides planed smooth. Generally, we recommend bending pieces only slightly larger in cross section than the finished piece needed, just enough to square up, sand, or scrape the surface down to clean wood. The exception is if you are bending a wood that is notoriously difficult or if you are bending to a very tight radius. For example, cherry is prone to compression failure so bend a piece  $\frac{1}{8}$ " or  $\frac{1}{4}$ " thicker than needed and then bandsaw away the inside face marks. If the exact curve is critical, you have to remember to accommodate this difference on the bending form.

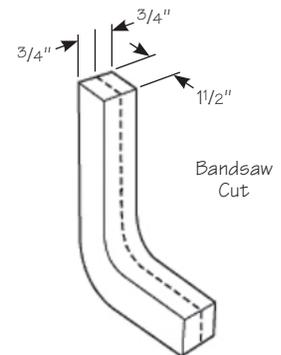
The discoloration caused by the metal strap in contact with the wood may also require additional thickness. Woods high in tannic acid such as red oak, white oak and walnut will develop a  $\frac{1}{16}$ " deep purple stain if the strap is left on as the piece dries on the form. Most woods (ash, cherry, hickory, maple) do not develop this stain to the same degree. Light stains can be removed by sanding or scraping. Deep stains may be more easily removed by bandsawing a thin slice off the stain area, followed by sanding.

When bending tight radii, some reduction in stock thickness will occur as a result of the wood being compressed between the strap and the form, particularly right at the corner of an "L" or "U" bend. Bending a piece of 1" thick ash around a 2" radius form may reduce the thickness as much as  $\frac{3}{16}$ ". Backing off the end stop one turn, halfway around the bend, will decrease this amount.



**Figure 2**

The grain of the blanks should be relatively straight. The grain should not "run out" in less than 15" along the blank, and preferably not where the bend is to take place (see **Figure 2**). Knots should be avoided. However, if there are small grain irregularities, then they should be put next to the strap side of the blank; the wood remains relatively neutral there, neither in tension nor compression. Our tests have not revealed any advantage in bending wood with the growth rings of the blank's plane, rift or quartersawn face against the form face. Never attempt to bend a piece that is thicker than its width, as it is prone to collapsing. To obtain such narrow pieces (e.g., a boomerang), bend a square cross section, and then bandsaw it to the required width once it is dry (see **Figure 3**).



**Figure 3: To achieve narrow pieces.**

## When to Steam Bend

The ability to bend solid wood can give your projects both a structural advantage and an aesthetic appeal. For example, a sweeping curve on the back leg of a chair can be very weak if it is cut from a wide solid board. A portion of the leg will inevitably be short grain and prone to failure if it is subject to any stress. That same leg, if steam bent, will retain virtually all of the strength of the original straight piece of wood. The grain will also follow the curve and visually reinforce the shape you have created.

Questions that you might want to ask yourself before deciding to steam bend a curved part of your project are:

- Is the curved part structurally important?
- Is it visually important that the grain follow the curved shape?

If both answers are "No", maybe a bandsawn shape will do. From a design point of view, try to avoid steam-bent parts that have unanchored ends that are not fastened down. Humidity changes can cause the extended piece to "wave" a bit.

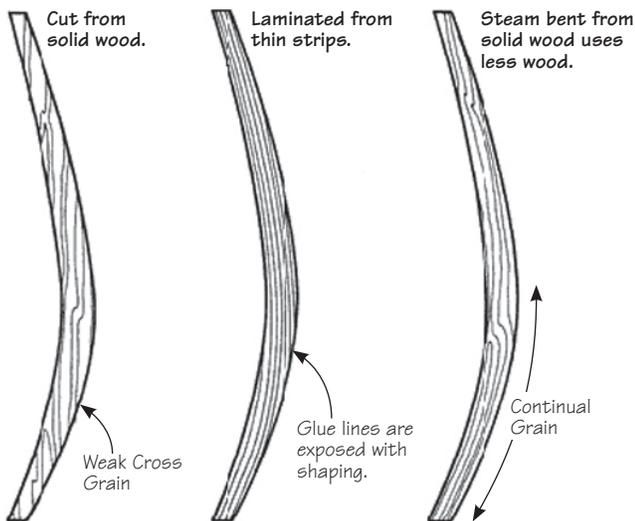


Figure 4

- Will I be shaping the piece afterwards?

Laminating a curve from thin strips of wood may cause problems when applying the finish. Any glue that is exposed during shaping will not accept the final finish in the same way as the wood. Also, the laminates are always under stress and, if some are cut away during shaping, the curvature may change. Steam-bent parts, on the other hand, have no memory of ever being any other shape, unless immersed in water.

### Making Forms for Wood Bending

The best bending forms are made of plywood stacked slightly higher than the width of the blank to be formed. Particleboard can also be used, but is lower in tensile strength, so larger cross sections are necessary. When bending to a tight radius (e.g., less than 4"), it is best to use plywood for most of the form and insert a hardwood nose.

If bending on a bench, screw the form down to a larger piece of particleboard and in turn secure that to your work surface. If you are using a bending table, you will have to drill holes in the form to match table holes. Whenever possible, the back of the bending form should be cut parallel to the face; it makes it much easier to apply clamps as the bend progresses.

There are some exceptions to this practice. To minimize clamp congestion, large holes (e.g., 1 1/4") can be drilled in the form to accommodate clamp heads (see Figure 5).

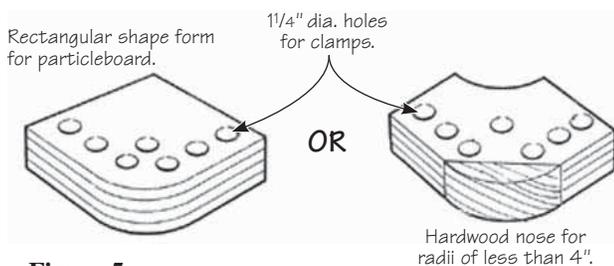


Figure 5

If you are using particleboard forms, it may be necessary to use more holes because of the greater width of the form. It might even be simpler to leave the form in its basic rectangular shape and rely completely on clamp holes and bar clamps.

The work surface should be attached to the floor (or anchored to the wall or a post) if the blank is thicker than 3/4". Whenever possible, cut the back of the bending form parallel to the face (see Figure 6 and Figure 18) so that it is easy to clamp the part as the bend progresses.

When bending a piece narrower than the strap, it is best to still have the part run down the center line of the strap. This helps to keep the forces on the strap and end stops balanced, which in turn reduce the possibility of the workpiece skewing perpendicular to the bending plane. Block the table up with spacer blocks 2" apart along the face of the form so that the part can be tapped down snugly to the blocks to keep it parallel to the table during the bending process.

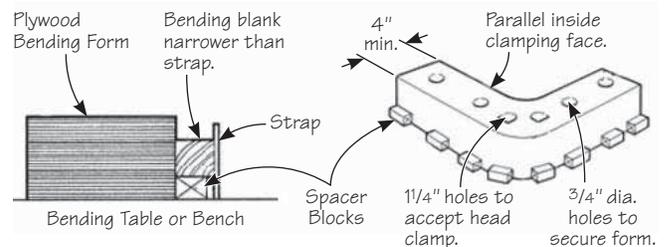


Figure 6

### Springback, Close-In and Failures

It is difficult to give hard and fast rules in wood bending because of the variability of the material. Not only do you have to deal with differences between species but even within species. There is even variation within a single board due to the uneven grain. As with many things, your own experience becomes your best guide. But there are general precautions you can take that will avoid many problems.

If all the main variables are under control: air-dried domestic hardwood at the appropriate moisture content, temperature in the box, steam time, bending radius not too tight, correct end pressure (not so compressive as to create wrinkles on the concave face nor so loose that fiber separation occurs on the outside of the bend) and the form is cut to the exact shape you want, there are still a few things to keep in mind.

### Springback

Springback can occur when the curve is so shallow that the lignin does not shift enough to hold the new shape, the part is too dry (either from original moisture content too low before steaming **or** insufficient steaming time), the end pressure was not adequate, the part was not left on the bending form until fully cooled, the part was

allowed to straighten while being transferred to the drying jig, or the part was not allowed to dry thoroughly (less than 10% M.C.).

### Close-In

Close-in can occur for several reasons. If the moisture content of the wood is too high when bending (in excess of 30%), the displaced and compressed wood fibers continue to contract as the bent wood dries out.

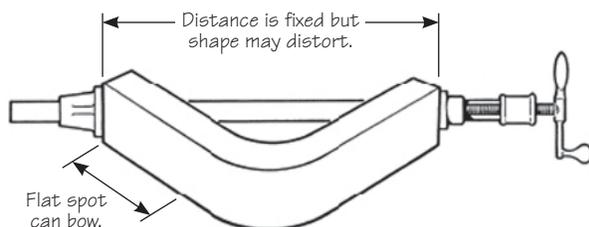
If the accumulated end pressure is too great during the bending process, the overcompressed inner face of the blank will contract as the wood dries out. On a "U" shape, it is advisable to back off the thrust screw a couple of turns halfway around the "U". (See **Figure 24**.) If a part is bent to a radius smaller than the limiting radius for that species, again the overcompressed face will contract on drying.

### Failures

Most bending failures happen when you step outside the guidelines (e.g., you might be trying to bend kiln-dried wood, or you forget to pre-tension the strap). But if you follow the guidelines, you will have very few failures. When you do, you will often find that there was a pin knot at a critical spot in the wood that you did not notice or another abnormality at a point of high compression. If you follow recommended practices, your only bending failures will occur at some point of inconsistency in the wood.

### The Drying Process and Setting the Shape

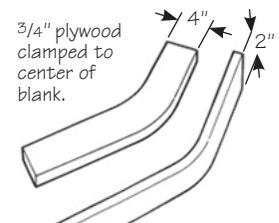
The drying rack should be exactly the same shape as the original bending form because, as the part dries, it takes the shape of the drying rack. It is best to support the part being dried over most of its length. For example, placing a clamp diagonally across the legs of a 90° "L" bend may stop the shape from opening, but it won't stop the legs of the "L" from bowing (see **Figure 7**). It is better to cut "L"s out of plywood and clamp the steam-bent "L" shape to the drying rack at several points.



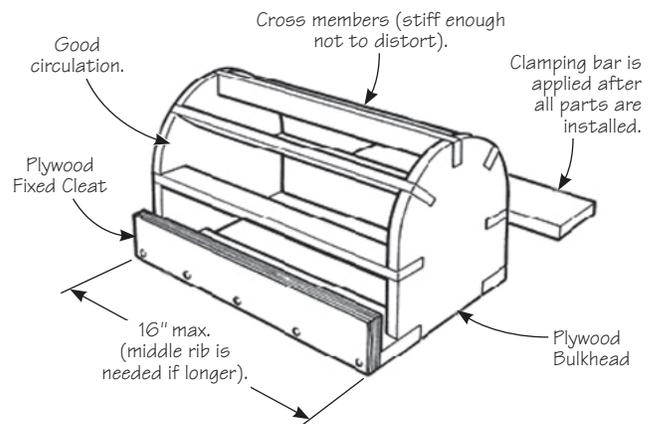
**Figure 7: Method not recommended.**

For one-offs, simply leave it on the bending form but remember to take the strap off within an hour; otherwise, the wood will discolor. For very small quantities of relatively narrow stock, cut 3/4" plywood drying racks. Be sure to clamp the drying rack on the center line of the bent part, as shown in **Figure 8**; otherwise, lateral twisting may occur.

For wide bent parts or large quantities of narrow parts, constructed drying racks are better. A bulkhead every 12" will stop the cross members from deflecting. The cross members should be closer together at the curved portion of the part.



**Figure 8: Part clamped along drying jig will not distort.**



**Figure 9: Parts are laid over drying jig and the free end is clamped.**

There is an accumulation of stress as the parts are loaded onto the drying rack; it must be strong enough to withstand this. Whatever the drying rack used, it is absolutely essential that the parts be moved quickly to the drying rack from the bending form. Unless the parts are left on the bending form for 8 hours before moving to the drying rack, the parts will immediately start to open up as you move them. Typically, the parts are removed from the bending form after 20 to 40 minutes and transferred quickly to the drying rack. This time can be reduced to as little as 5 or 10 minutes if compressed air is blown across the part to cool it quickly and thus start the resetting of the lignin bond. Speed is of the essence; otherwise, breakage will occur as the part is rebent on the drying rack.

The ideal drying condition involves passage of lots of dry, warm air over the parts. Pieces at 25%, 1" thick will dry to 8% in as little as 96 hours. A danger in drying too fast is surface checking and/or developing a case-hardened outer shell on the blank. Once the parts are mounted on the drying rack, put it aside for 12 hours covered with a fabric blanket. This allows the surface moisture from the steaming to evaporate slowly, thus avoiding checks. Checking is particularly prevalent with woods like oak with strong medullary rays. They tend to open on the plane-sawn surface alongside the ray.

Once the blanket has been removed, blow air across the parts with a household electric fan on a timer, one hour on, one hour off. This draws the moisture out of the wood by osmosis without undue damage to the parts. The time lapse from 25% to 8% is approximately 5 to 7 days for 1" stock.

### Moisture Content

Domestic hardwood species that are suitable for bending typically have a moisture content of about 70% when fresh sawn. Wood bends best between 20% and 30%. It is best to catch this "on the way down" rather than to try to remoisturize the wood once it has passed this point. The proper moisture content is important if you are bending to tight radii and less important when bending shallow curves. Once the wood has air dried to 6% or 8% it may not be possible to bend it to small radii. The lignin bond is only partially reversible at this moisture content, particularly if the wood has been sitting for a year or more in this dry state. It is not possible to gain all the original elasticity back by remoisturizing the wood, even by excessive steaming or soaking in water for extended periods (days or weeks).

Moderate bends may still be possible with wood at 10% to 20% moisture content, 10" to 12" radius on 1" stock in ash, oak, etc., but not very tight radii of 1" or 2". Remember, too much moisture (i.e., over 30%) extends your drying time and may contribute to erratic curves piece to piece once the parts are dry. At one end of the scale, wood bent "green" using the compression method may fail due to hydraulic rupturing of the wood cells. Too little moisture makes the wood difficult to bend and you run the risk of breaking your bending equipment.

### Plasticizing the Wood with Steam

The general rule is one hour per inch of thickness (regardless of width). Wood at 30% will require a little less time, wood at 15% a little more. Oversteaming is not recommended, as it may cause compression wrinkles to develop as the bend progresses around the form. Experience is the best teacher.

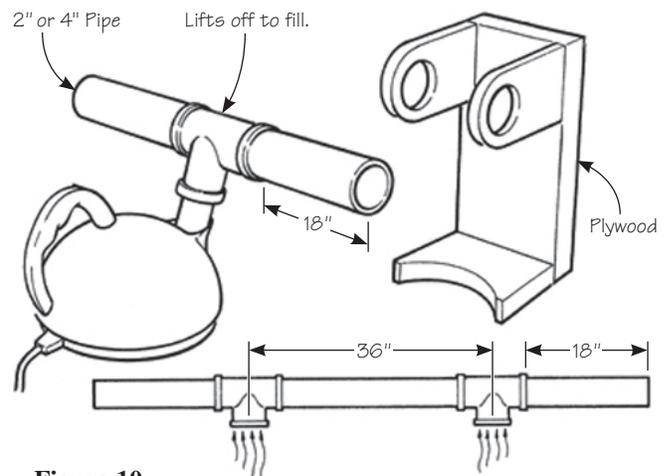
Try to get as close to 212°F (boiling water at standard atmospheric pressure) as possible inside the steam chamber. We recommend drilling a few drain holes in the bottom of the chamber, particularly at the extremities. Drilling a hole at the top will allow you to insert a thermometer to check for the correct temperature, if you are concerned about the temperature. This hole can be plugged with a cork, but leave the drain holes open. If the temperature at the extremities in the chamber falls below 200°F (93°C), insulate the outside of the box with fiberglass (similar to what is used to wrap water heaters).

**! BE VERY CAREFUL WHEN WORKING AROUND STEAM** — it will scald skin on contact. When you open the steam box a cloud of steam will escape. Keep your face and any other bare skin away. Use tongs to pull out the blank. Wear work gloves when handling the steamed bending blanks.

**! Under no circumstances should the steam chamber be pressurized or allowed to become pressurized should, for example, the drain holes become clogged. It is actually detrimental to successful wood bending and it is extremely dangerous.**

### The Steam Chamber

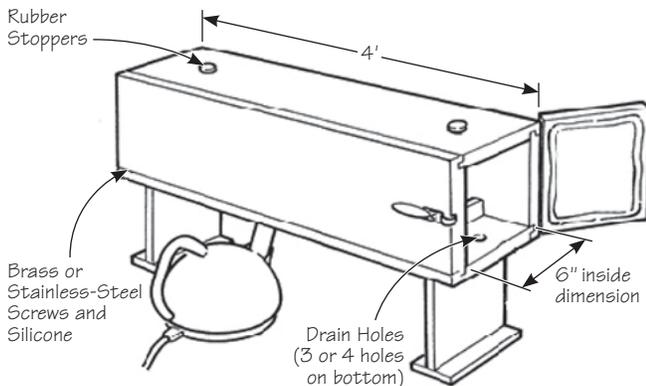
"Keep it simple" is the rule here. Consider the size of the blanks you will be bending. For walking sticks, shelf brackets, small chair parts, etc., a chamber made from commonly available ABS pipe will be sufficient (**Figure 10**). However, a chamber made from plywood in a straightforward manner will accommodate most needs. There are a few points to consider when constructing the box.



**Figure 10**

1. Use 3/4" exterior-grade fir plywood; the glue is steam resistant. (The glue line should be very dark brown.) Do not attempt to use interior-grade poplar ply.
2. Tongue and groove the corners, silicone the joints and use brass or stainless-steel screws every 6" along the corners.
3. **Do not** paint or seal the box in any way. The steam will eventually penetrate the finish and rot the box. It is best to let the plywood absorb the steam and then thoroughly dry out between uses.

4. An interior end dimension of 6" square seems to work well. With the use of an electric kettle, making the length modular is also a good idea. Start with a 4' section, then add 2' sections as necessary. A dried bead of silicone makes an adequate gasket between the sections. If only localized steaming is necessary, then the open ends of the box can be fitted with specially made baffles or simply stuffed with rags. If the box is 6' or more, then two steam sources should be used.
5. Install hinged doors on both ends of the 4' box and one door on the shorter sections. The door should be operable in as simple a way as possible. A rubber band stretched over protruding screw heads is fine. The screws on frequently used latches tend to work loose in the hot, damp plywood.
6. The blanks should be supported off the bottom of the box. Brass or copper rods or even 1/2" dowels through the sides are all effective. **Do not** pack the blanks in the box tightly. Steam should be free to circulate around all surfaces of each blank.
7. When set up, the box should slope to a drain hole in one end to prevent condensation from collecting. **Do not** reuse this water because it will have contaminants that may damage your steam source.



**Figure 11: Exterior plywood sheathing (no finish).**

### Generating Steam

For blanks of smaller cross sections, up to 1" by 2", an electric kettle is an excellent source of wet steam.

For volumes of steam beyond the capacity of a kettle, commercial steam generators are available. Wallpaper steamers can be purchased or rented. A simple source of steam can be fashioned using an inexpensive electric hot plate and a 1 or 2 gallon (4 to 8 litre) pot with a 1 1/2" diameter hose from the lid to the chamber. If your source of heat is an open flame, then it must be used outdoors.



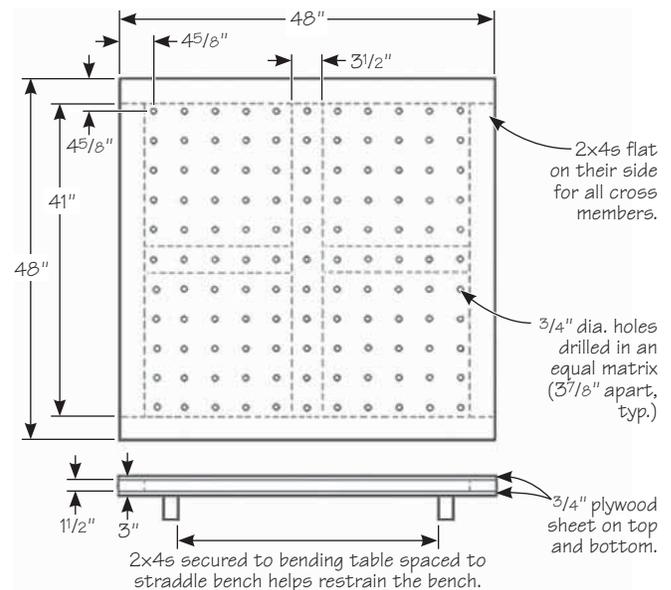
**CAUTION:** *Be very careful when working around boiling water and steam. It will scald skin on contact. Under no circumstances should the steam source be allowed to become pressurized.*

### The Steam-Bending Table

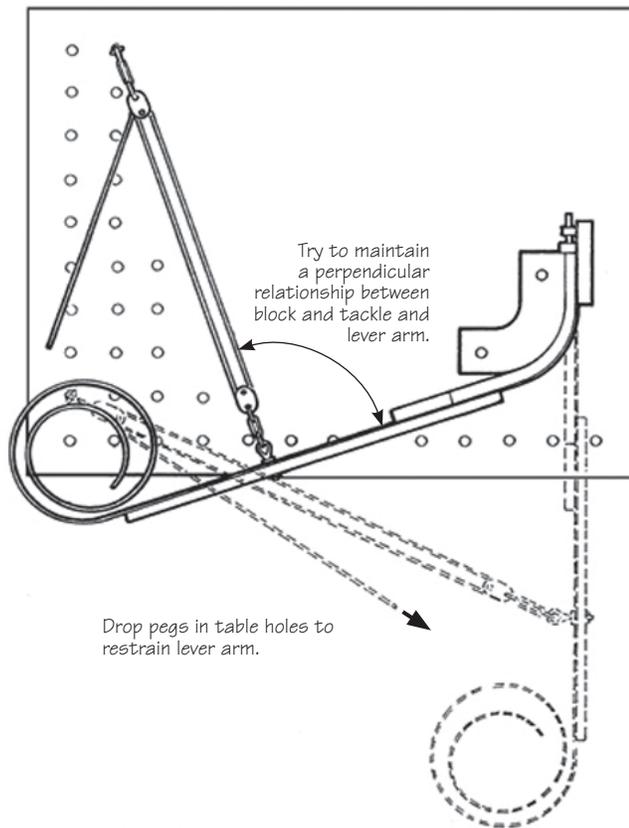
If you are going to be doing a large amount of steam bending or bending pieces with large cross sections (greater than 2 1/2 square inches), you should construct a steam-bending table. A bending table can be built according to the sketch provided, using plywood and 2x4s. Clamped to the top of your existing bench, this table is solid enough to counteract the bending forces exerted. A substantial amount of weight should be put on the base to counteract the force of bending your blanks, or secure your bench to the floor if necessary.

Because all Veritas bench accessories (brass Bench Dogs, Pups, Wonder Dog clamps, and Hold-Down) are based on 0.740" diameter stock (slightly less than 3/4"), we strongly suggest drilling 3/4" holes in your steam-bending table to accommodate all these tools. Spacing these holes in a matrix will also add to the versatility of the table. If you know exactly where all the holes in the table are before you make your forms, you can mark and drill your restraining holes in your forms accordingly. Any 3/4" steel stock (e.g., 3/4" bolts) can also be used to hold your forms in place. If you are bending small stock, under 1 square inch in cross section, 3/4" hardwood dowels could also be used to hold your forms in place. You may want to hold your forms down with several wood screws or bolts during heavy bending so the forms do not lift off the surface of your bending table.

**Materials required:** two 4' x 4' x 3/4" thick plywood sheets, 24' of 2 x 4s, glue and #10 flat-head screws 2 1/2" long



**Figure 12: Steam-bending table.**



**Figure 13: Using the block and tackle.**

**The Block and Tackle**

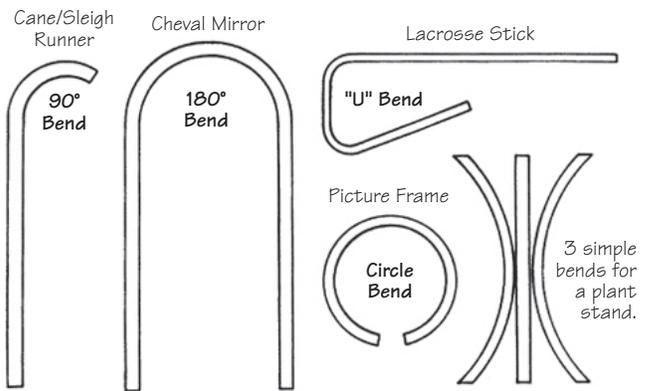
When bending wood with large cross sections (greater than 2½ square inches), you may need the block and tackle to help bend the blank around the form. As the cross-sectional area increases, so does the force required to bend the part. When using the block and tackle, it is best to have it attached directly to your bending table, and not to a structure nearby; otherwise, the pull of the block and tackle will cause you to pull your work around the shop. As shown in **Figure 13**, try to maintain a 90° angle between the block and tackle and the lever arm as the bend progresses. This exerts the maximum pull on the lever arm at all times.

**Introduction to Bend Types**

The Veritas Steam-Bending System is very versatile in the fact that an endless variety of shapes can be made using the various components alone or in combination with each other. From simple bends to "S" bends to change-of-plane bends the same three components are essential: an adjustable end stop, a fixed end stop, and a steel strap.

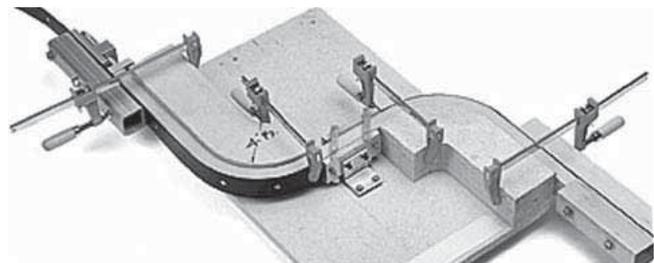
**Simple Bends**

The adjustable end stop, in conjunction with the strap, and a fixed end stop allow you to do simple bends as shown below. All these bends are in one direction and in one plane.

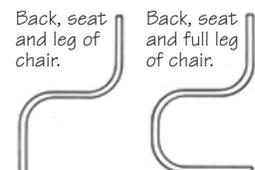


**Figure 14**

**"S" Bends**

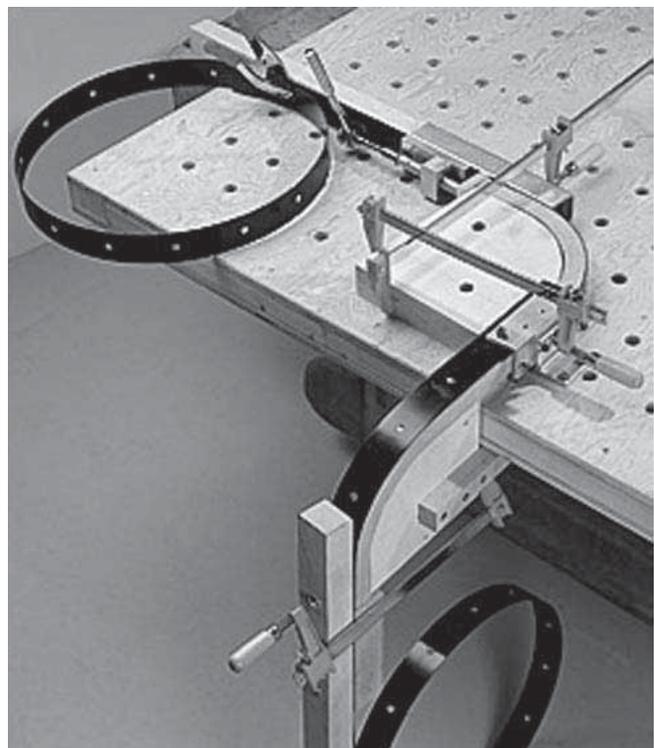


The adjustable end stop, fixed end stop, and two steel straps in conjunction with the S-bend unit allow you to reverse the direction of the bend to make "S" bends as shown. All these bends are in two directions but in one plane.



**Figure 15**

**Change-of-Plane Bends**



The adjustable end stop, fixed end stop, and two straps, in conjunction with the change-of-plane unit, allow you to change the plane of the bend to make the shapes shown. All these bends are in two directions and two different planes.

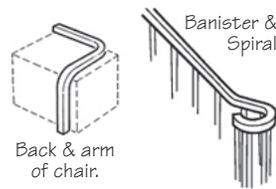


Figure 16

### Combination of Bend Types

Each system can be used in conjunction with each other to give you an endless variety of combinations of bends. Shown are a couple of examples of combinations that can be put together to form more complex designs. Your imagination is the limit.

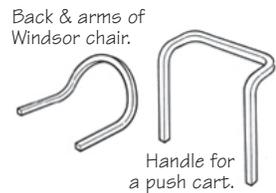


Figure 17: Two combination bends.

### Single Bends

It is very important that the requirements for steam bending air-dried hardwood be followed, as outlined in the introduction. If you have not read the introduction, do so before attempting to bend. Damage to your equipment may result if the guidelines are not followed. To simplify your introduction to steam bending wood, we will first walk you through the process of bending a 3/4" x 1 3/4" x 24" piece of air-dried hardwood (approx. 20% moisture content) around a 6" radius 90° bend. The last section will provide some general information for bending a wide variety of single-plane shapes.

### Building the Bending Form and Drying Jigs

Laminate three pieces of 3/4" x 12" x 12" plywood. Mark off the radius, bandsaw the curve and prepare the face so it is free of bandsaw marks. Mark out the inside curve and bandsaw. This face does not have to be finished in any way; it is just providing a clamping face that is parallel to the form face. If you have built a bending table, then the form can be secured to the table with 3/4" pins. Otherwise, the form can be screwed to your work surface.

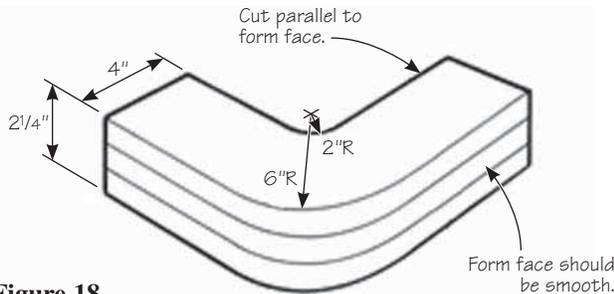


Figure 18

If you want to try more than one bend, the blanks can be dried on individual jigs or frames as detailed in the introduction.

### Assembling the Strap and End Stops

In addition to the components in the Veritas System, you will need a wooden end stop and a lever.



**CAUTION:** As it is coiled, this strap is under tension and care must be taken when cutting the restraints. First, cut the tape holding the outside end down, and then clamp this end to a fixed surface. While holding the coil, cut the remaining tape, and slowly unwind the rest of the coil.

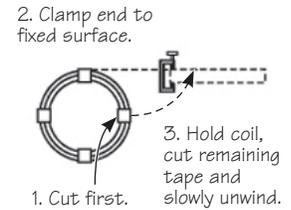


Figure 19

Attach the strap to the adjustable end stop as illustrated in Figure 20. Adjust the end stop so that there is at least 1/2" between the end stop and the thrust plate. (This space will allow you to back off the end stop in certain applications.) Measure off the length of the bending blank and mark the strap.

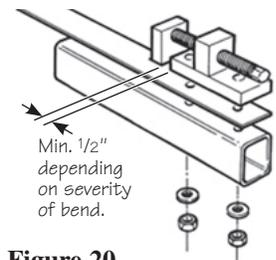


Figure 20

Because most bending situations involve blanks of different lengths and cross sections, making a hardwood fixed end stop with a series of equally spaced holes is recommended. Making the fixed end stop (as shown in Figure 21) will accommodate most conditions. However, in some instances a custom-made fixed end stop will have to be made.

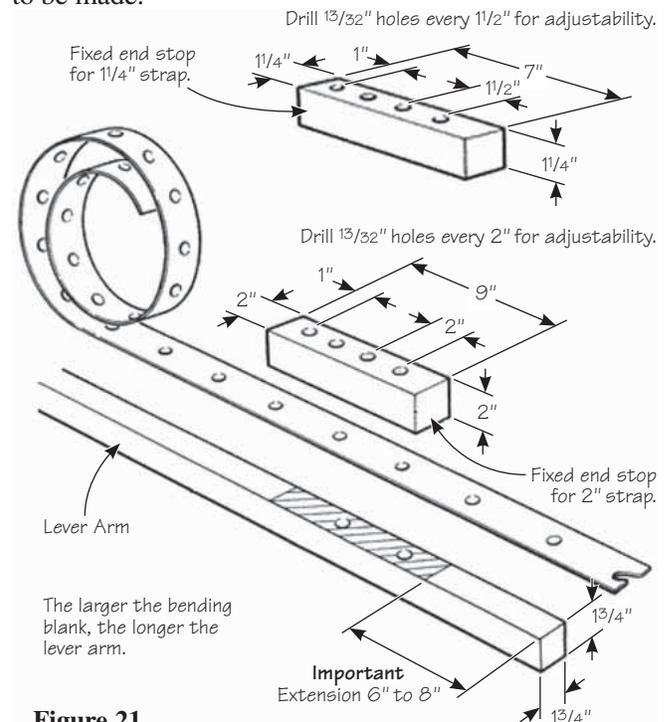


Figure 21

The width of the fixed stop should be equal to the strap width and not less than the thickness of the blank to be bent. For this specific bend, the fixed end stop dimensions are  $7/8" \times 2" \times 9"$ . The position of the two  $13/32"$  holes is measured from the mark on the strap to the center of the first hole that is at least  $3/4"$  away, then on center to the next hole.

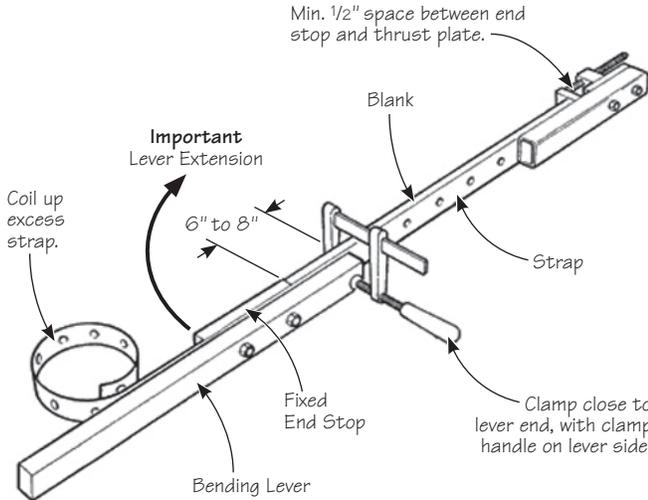


Figure 22

The bending lever is the next part required. This lever will be  $13/4" \times 13/4" \times 36"$ . **It is extremely important that the lever extend past the fixed end stop by at least 4" on thin (<1"), narrow stock to as much as 8" on thicker stock** as shown in Figure 22. Drill the two holes in the lever (remember to drill the first hole back far enough to accommodate the lever extension). Take care to drill the holes perpendicular through both the end stop and the lever for good hole alignment.

Assemble the fixed end stop, strap and lever as illustrated in Figure 22. By clamping this extension to the bending blank, local compression at the fixed end stop is eliminated. Before steaming, lay a blank on the strap assembly and bring the adjustable end stop to within  $1/8"$  of the blank. Once the hot blank is removed from the steamer, you will have to work quickly, so it is best to be prepared beforehand. Remove the unsteamed blank and swing the lever in the approximate path that it will travel as the wood is bent. Clear any obstruction that will interfere.

### The Bending Procedure

Before inserting the blank in the steam chamber, go over the safety instructions in the introduction. After the appropriate steaming time (in this case 45 to 60 minutes), remove the steamed blank. The blank will be uncomfortably hot, so wear gloves. The strap clamp is designed to lay on its side for easier handling. Install the blank in the strap clamp and lightly clamp the blank to the extended portion of the lever. The clamp should be close to the extension end with the handle of the clamp on the lever side of the strap as shown in Figure 22.

With the blank held tight to the strap, tighten the adjustable end stop so that the blank is in contact with both the fixed and adjustable end stops. Continue to tighten the adjustable end stop until the strap **just** begins to arch away from the blank. Tighten the clamp on the extension lever. The assembly should now be stiff and can be put in place up against the bending form as shown in Figure 23. Securely clamp the steamed blank to the face of the form with the adjustable end stop up against the end of the form.

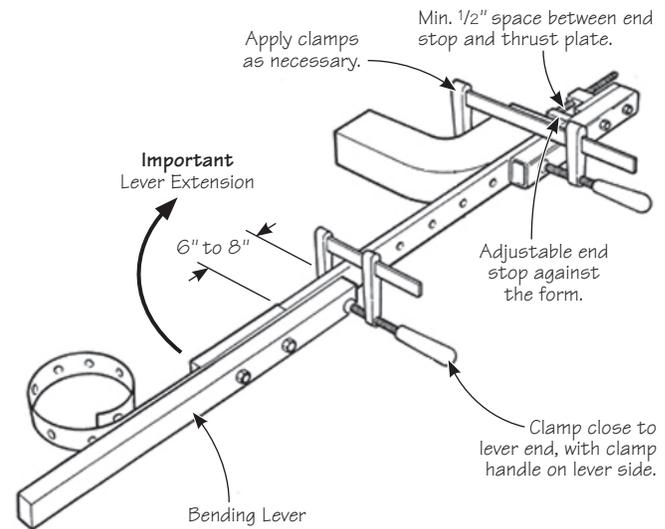


Figure 23

Slowly bring the lever around, applying clamps as necessary to keep the blank tight to the form. The very first clamp applied while the assembly was flat on the bench will soon come in contact with the form face. This clamp can now be removed and the blank can be brought tight to the form, secured and allowed to cool.

In other applications, if there is excessive compression wrinkling on the inside face of the steamed blank, the adjustable end stop can be backed off a turn or two before continuing with the bending process. Back off too much and the wood will tear on the outside face.

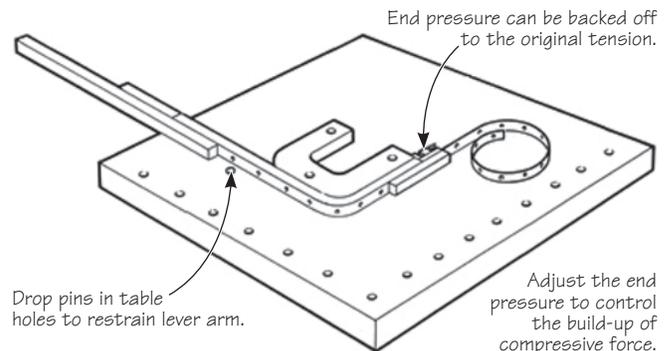


Figure 24

## Removing the Bent Blank

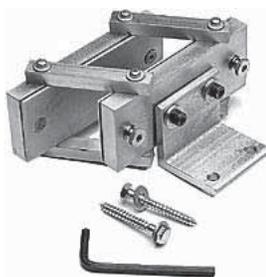
If this is a one-off bend, then it can be left on the form; however, it is best to remove the metal strap after an hour or so. If a number of bends are to be completed one after the other, then the bent parts have to be removed from the strap. However, it is extremely important that the individual bends be allowed to partially set until cool on the bending form before being transferred. This allows the lignin to begin to bond in its new position. The time varies for this according to the mass of material and the severity of the bend. The piece that has been bent for this demonstration should be allowed to set for 20 minutes. The setting process (in this example) can be reduced to 5 to 7 minutes if a jet of compressed air is directed at the bent part. As with a lot of the elements of wood bending, experience is the best teacher.

Once the blank is cool, the adjustable end stop can be loosened and the clamps removed. One thing is certain at this point, and that is the necessity for speed while transferring the parts from the bending form to the drying jigs. Failure may occur if the part is allowed to straighten out too much while being transferred. The wood fibers may unsuccessfully attempt to stretch as the part is reformed to the drying jig.

Once a bent part has dried thoroughly, a measurement of the inside face will reveal the amount of compression that has taken place. In this instance, the compression will be approximately  $1\frac{1}{4}$ ", most of which has occurred at the curved portion of the inside face.

## Recurve or "S" Bends

The addition of the S-bend unit and a second strap to the single bending strap assembly opens up a number of design possibilities. You can either cut the 10' strap included with the 2" Strap Clamp (will leave approx. 8' bending blank capacity), or purchase a second strap. The purpose of this parallelogram assembly is to enable you to transfer the strap (the restraining force) from one side of a blank to the other, ensuring that a bend reversal still keeps the entire blank under compression. The **maximum** size of wood that the S-bend unit is designed for is  $1\frac{1}{4}$ " thick  $\times$  2" wide. **Although a thicker piece can be placed within the unit, doing so will position the linkage in such a way that the loads it experiences rise dramatically and may break the unit.**



It is strongly recommended that the novice user gain some experience in bending wood by completing a variety of curved pieces with the single bend strap assembly before attempting "S" bends. The bending forms and compressive forces at work are more complicated when using the recurve hardware.

As with the single bend hardware, it is easier to get the basic information across if specific instruction is given on completing a typical recurve using the parallelogram hardware package.

## Building the Bending Form and Drying Jigs

In this case, we will be bending a symmetrical "S" of two 8" radii. The bending blank will be  $\frac{3}{4}$ " thick  $\times$   $1\frac{1}{2}$ " wide  $\times$  76" long. The bending table previously described would come in handy; however, a piece of  $\frac{3}{4}$ " plywood 28"  $\times$  36" can be used. Laminate two three-piece stacks of  $\frac{3}{4}$ " plywood 12"  $\times$  16". Mark out the 8" form face radius and 4" inside clamping face radius on both pieces, bandsaw to shape, and smooth the outside face as shown in **Figure 25**.

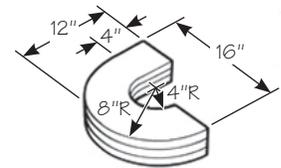


Figure 25

On your bending table or plywood, draw two centered perpendicular pencil lines, as illustrated in **Figure 26**. This forms an axis that will assist in keeping your two forms in alignment when they are attached to the table. Lag screw the parallelogram securing bracket to the bending table (as shown in **Figure 26**) or, if you are using a piece of plywood, the bracket should be bolted in place using two  $\frac{1}{4}$ "  $\times$   $1\frac{1}{2}$ " flat-head bolts. The head of the bolt should be countersunk into the underside of the plywood so that it can rest flat on the work surface.

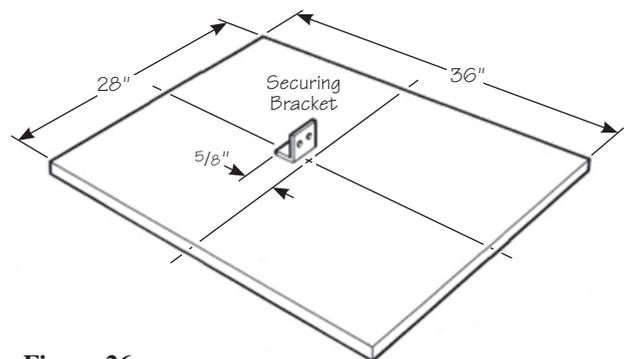
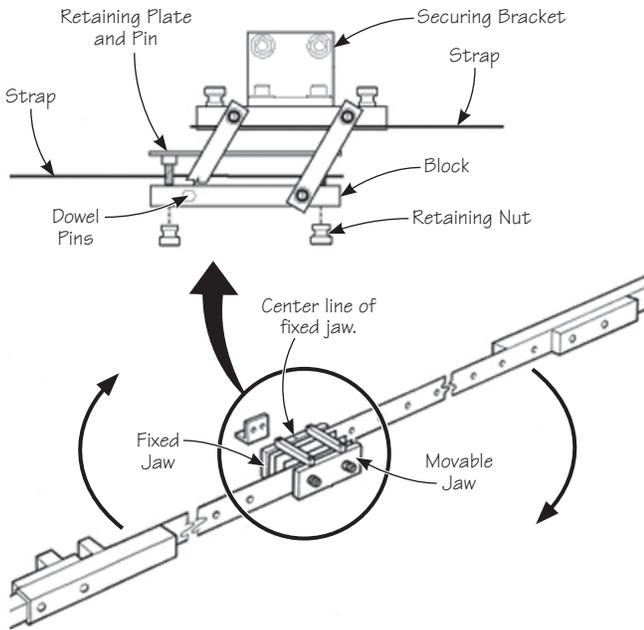


Figure 26

### Assembling the Strap

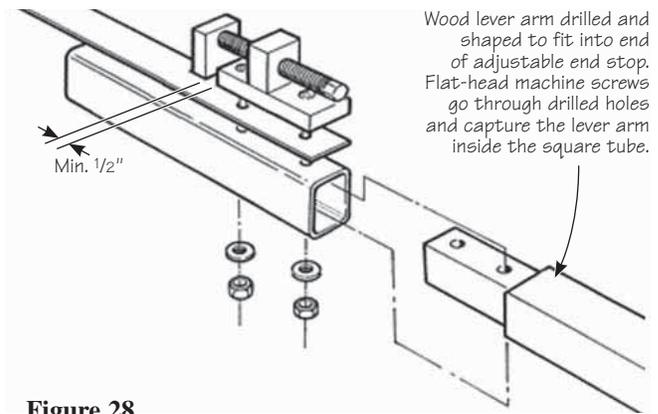
Attach the S-bend unit to the securing bracket with the hex socket head cap screws and hex key provided. Attach the two straps as shown in **Figure 27** to the inside face of the jaws of the parallelogram.



**Figure 27: Close-up of "Nuts & Bolts".**

Mark off half the length (38" for this demonstration) on an unsteamed blank and slide it into the S-bend unit parallelogram until the halfway mark meets up with the center of the fixed jaw of the parallelogram. Lightly clamp across the jaws to hold everything in place. Depending on the size of your work surface, a stand or support at either end will assist in keeping the long strap assembly manageable while attaching the end stops.

On the strap that will bend to the left, attach the adjustable end stop. The thrust screw will have to be adjusted until the flat-head machine screws line up with the holes in the strap and square tube. In this and other applications, always maintain the 1/2" minimum space between the adjustable end stop and the thrust plate. At the same time, it is not recommended that the thrust screw be extended out to the maximum. In some instances, the length of the bending blank will have to be adjusted to meet these requirements.



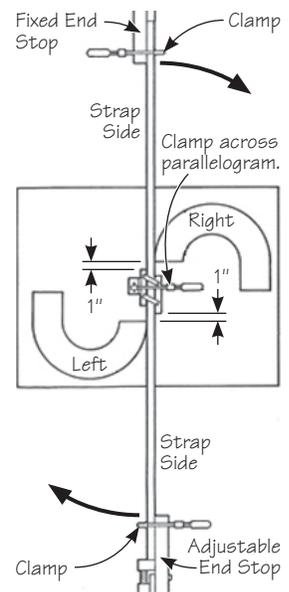
**Figure 28**

Before the square tube can be assembled, a predrilled lever arm (as shown in **Figure 28**) must be inserted into the square tube. The washers and nuts can then be tightened in place. Temporarily clamp this assembly to the blank.

The fixed end stop is attached to the other strap next. This end stop is brought up against the end of the unsteamed bending blank and the corresponding strap holes are marked on the fixed end stop. The lever arm is added next. **Do not** forget to accommodate the extension part. Securely bolt this assembly together and lightly clamp it to the bending blank. The S-bend strap assembly should now be rigid and in line with the axis previously laid out on the table.

The center line of the left form (or the beginning of the curve) is positioned 1" from the end of the movable parallelogram jaw as shown in **Figure 29**. This is a **minimum** dimension; otherwise, the strap will pull away from the inside of the jaw and damage the retaining pins in the parallelogram.

The position of the right bending form is also 1" (minimum dimension from the end of the fixed parallelogram jaw). Both forms must be securely fastened to the work surface, either using 3/4" pins (at least two per form) or several wood screws per form. The adjustable end stop should be backed off 1/8" to allow for easy installation of the soon-to-be-hot blank. The unsteamed blank can now be unclamped, removed from the set-up and put in the steam box.



**Figure 29**

## The Bending Procedure

After the appropriate steaming time (in this case 45 to 60 minutes), carefully remove the steamed blank. The blank will be uncomfortably hot, so wear gloves. You have about 3 or 4 minutes to complete the bend before the wood cools too much.

With the end stops resting on the supports and held slightly to one side, slip the steamed blank through the parallelogram assembly. Bring the strap into place and lightly replace the three clamps from the earlier set-up. Tighten the adjustable end stop thrust screw until the steamed blank is in contact with both end stops, then give it one more turn so that the whole assembly is under slight tension. A bit of experience is useful at this point. Too little tension and the wood fibers next to the strap will tear, too much and compression wrinkles will occur along the inside face of the bends. The three clamps can now be firmly tightened.

Start bending the side with the fixed end stop first. The speed at which you should be bending is difficult to describe; it is medium (steady, taking about 10 seconds to go through 90°). Once 90° has been reached, a judgment call is made whether or not to back off the end stop thrust screw a turn. This radius and wood thickness generally do not require it at this point. However, a clamp or two may be necessary to hold the blank tight to the form face as the bend progresses. Extra pins can be dropped in the appropriate table holes to restrain the lever while the clamps are applied. Once the first bend has been completed, it is left clamped in place.

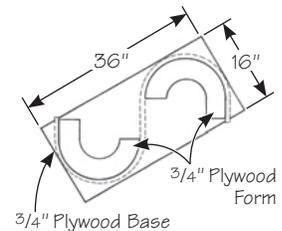
Whether or not you released any pressure in mid-bend, for sure you will have increased end stop pressure substantially by now and you should back off your end stop thrust screw to a point that re-establishes the same pressure as when you first started to bend. Complete the second half of the bend in the same manner as the first half, using the same speed and clamping methods.

## The Drying Jig

The procedure for transferring the recurve bent part to the drying jig is the same as for single bends, except the part should be left on the bending form for 40 minutes (without extra cooling) or 15 minutes if bathed in a jet of compressed air. The recurve parts are more difficult to handle during the transfer and thus require more intermediate setting time.

To extract the bent part, the two upper bars across the parallelogram jaws must be removed. **Do not forget to re-install them before the next bend.** This fixture is subject to an incredible amount of stress during the bending process and will fail if all four bars are not in place.

The drying jig is exactly the same shape as the bending form; however, it can be a single layer of plywood cut to shape and screwed to a larger backing sheet (see **Figure 30**). Because it is against plywood, it does not have to be centered. This applies to most recurve bending applications.



**Figure 30: "S" bend drying jig.**

## Change-of-Plane Bends

The addition of the change-of-plane (C.O.P.) fixture to the Veritas Steam-Bending System allows the user to bend wood in two planes. The purpose of the fixture is to transfer the strap (the restraining force) from the outside surface of one bend to the outside of another bend in a different plane. This keeps the wood under compression at all times. For example, the back rail of a chair might continue into the armrest and on to form the front leg. By using two 90° transition fixtures on one strap assembly, both front legs, both arms, and the back rail could be bent at one time.



The freedom gained by being able to bend in two planes is only compromised by the necessity to build somewhat more complicated bending forms that will both accommodate the shapes you wish to create and withstand the considerable forces that come into play as the bending blank is compressed around the form.

As with S-bends, C.O.P. bends require two straps. You can either cut the 10' strap included with the 2" strap clamp or purchase a second strap.

It is strongly recommended that the user first gain some experience in bending wood by completing a variety of pieces with the single strap assembly before attempting C.O.P. bends.

As with the single bend hardware, it is easier to get the basic information across if specific instruction is given on how to complete a typical two-plane bend using the C.O.P. fixture.

## Building the Bending Form and Drying Jigs

A typical two-plane bend would have one bend in the horizontal plane and one in the vertical plane. In this example, we will make each bend 90° at a 6" radius. This is half of the chair back-to-arm bend sequence mentioned earlier.

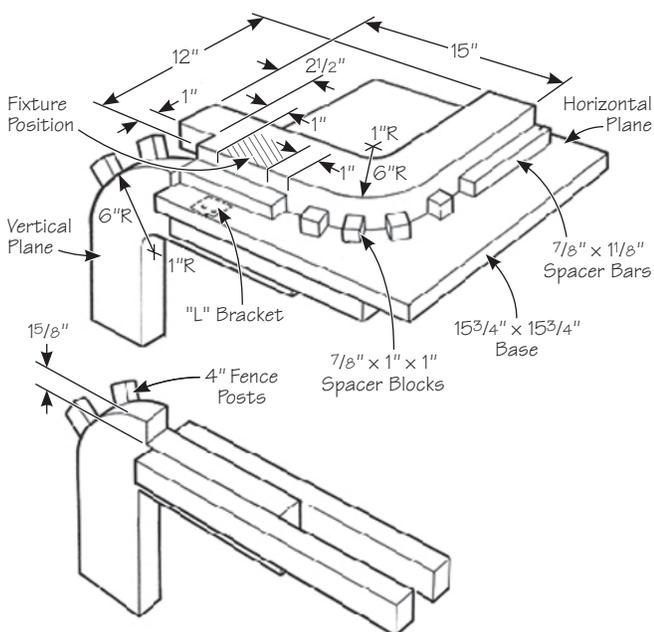
The bending blank will be  $1\frac{1}{8}'' \times 1\frac{1}{8}'' \times 42''$ . Air-dried ash or oak (at 25% moisture content) is a good choice for a novice steam bender. The bending blank, at  $1\frac{1}{8}''$  sq., is narrower than the 2" wide strap. This is often the case, so the following form construction instructions will tell you how to accommodate such a difference.

Because of the three-dimensional nature of this bend and the orientation of the curves, it is easier to assemble the bending jig on the right-hand front corner of the work surface.

A piece of plywood  $\frac{3}{4}''$  thick and  $15\frac{3}{4}''$  square will form the base on which to fasten the various components of the bending form. In this case, as in most cases involving two-plane bends, the bending form is also the drying jig. (If multiple bent parts are required, then enough bending/drying jigs have to be constructed to allow the individual bent parts to set before removal.)

Two bending forms ( $12'' \times 15'' \times 2''$  thick) will be required. Due to the nature of the transition fixture, your forms must always be 2" thick. Two pieces of  $\frac{3}{4}''$  ply and one piece of  $\frac{1}{2}''$  will provide the correct thickness. The inside and outside radii and the two different corner cut-outs should be carefully marked out.

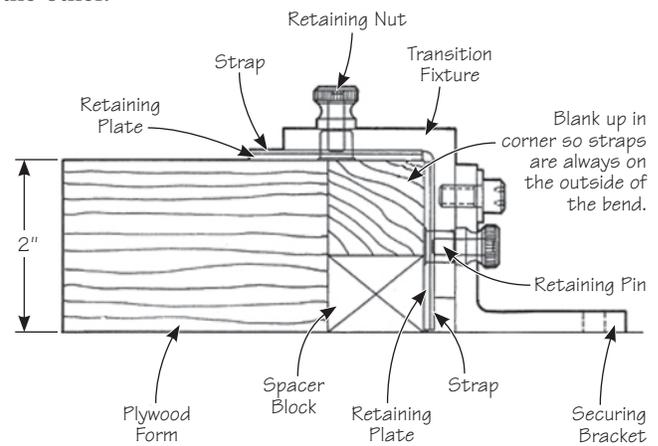
The two forms must be screwed and glued in position to the plywood base, as shown in **Figure 31**. The transition portion joining the two curved forms must be a **minimum of 7" long**. There must be at least 1" on either side of the transition fixture before the curves begin; otherwise, there is a risk that the strap will pull away from the fixture and ruin the locating pins on the fixture.



**Figure 31**

Glue and screw the two  $\frac{7}{8}'' \times 1\frac{1}{8}''$  spacer bars to the inside corner of the straight portions of the upper bending form, followed by the four smaller spacer blocks that fit around the curved portion of the form.

For simple bends and "S" bends, keeping the blank centered on the strap was emphasized. That can only be done with change-of-plane bends when the blank is the same width as the strap. When a blank is narrower than the strap, it has to be blocked up so that it fits snugly in the corner of the change-of-plane fixture. Otherwise, part of the blank would inadvertently be put under tension during the transition from one plane to the other.



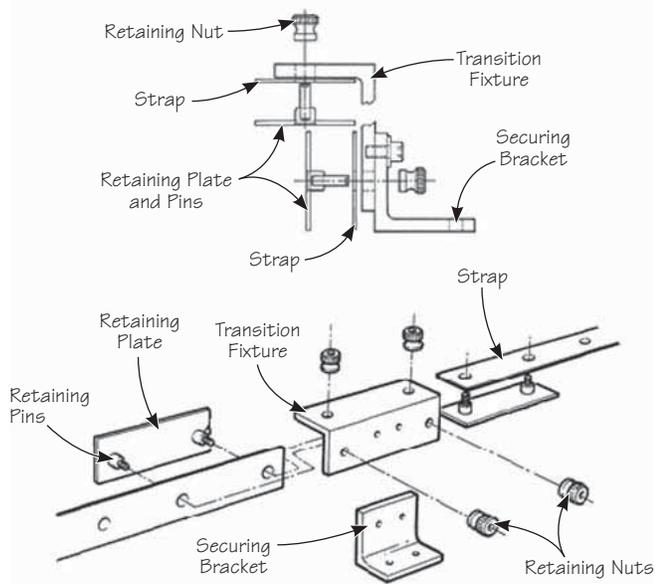
**Figure 32: Two-plane bend.**

Attach "fence posts" (as shown in **Figure 31**) to the side of the lower bending form. These should protrude above the surface of the form by a little over the thickness of the blank being bent;  $1\frac{1}{4}''$  projection here is about right. If the blank being bent is less than half the width of the strap, the stop may show a tendency to slip off of the blank. Small blocks the same thickness as the bending blank should be attached to the face of the bending form. This will support the edge of the strap that is not over the blank.

Once the bending form is complete, it can be attached to the right-hand corner of the work surface. If clamps are used, they have to be located where they won't interfere with the bending blank or lever as it is pulled into position. Sandpaper glued to the underside of the base (grit out) will stop it from slipping as leverage is applied to the steamed blank.

### Assembling the Straps to the Transition Fixture

Assemble the two straps to the transition fixture as shown in **Figure 33**. Place the center mark (23") of the 46" long unsteamed blank on the center of the transition fixture. Snug the blank into the inside corner of the fixture (as shown in **Figure 32**) and temporarily clamp it in place.



**Figure 33: Change-of-plane strap assembly.**

On the strap that bends around the vertical form, attach the fixed end stop up against the end of the bending blank. Do not forget about the extension on the lever when locating the position of the fixed end stop. The length of the lever extension in these applications should be about 6" to 8".

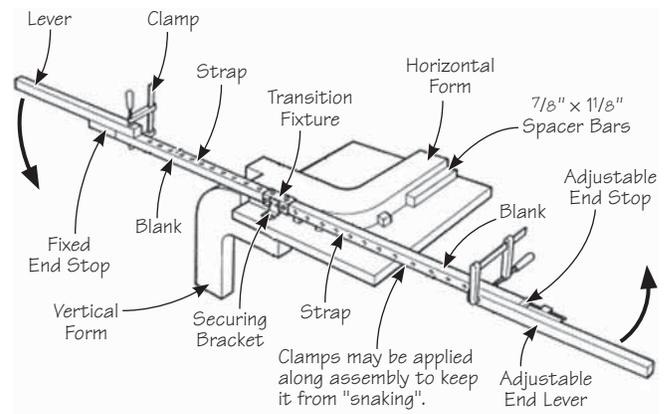
Temporarily clamp this to the blank (the handle of the clamp should be on the strap side).

Follow the same procedure for the adjustable end stop. The thrust screw will have to be adjusted until the bolts line up with the holes in the strap. However, before assembling, the adjustable end lever with predrilled holes should be inserted into the square tube. Once assembled, lightly tighten the thrust screw so that the whole assembly is in tension. Temporarily clamp this end to the blank.

To become familiar with the placement of the clamps, a dry run is in order.

Remove the first clamp holding the transition fixture and place the entire assembly into position on the bending form as illustrated in **Figure 34**. A stand can be used to support the portion of the assembly that is extending off the work surface.

The transition fixture should be clamped to one or both forms. (In some applications the securing bracket will suffice here and can be attached to the table with lag screws or bolts, with the machine screws being used to mount or unmount the strap assembly.) The blank should be shifted in the strap so that it runs along the outside edge of the straps. Several small clamps can be applied along the strap to stop it from "snaking" during the bending process. The handles should be on the strap side.



**Figure 34: Ensure the length of the lever is such that vertical bend can be completed without lever contacting floor.**

Remove the clamps and the unsteamed blank and lay the strap assembly out flat on a surface that will accommodate the length.

### The Bending Procedure

After the appropriate steaming time (in this case, 80 to 90 minutes), carefully remove the steamed blank. The blank will be uncomfortably hot, so wear gloves. You have about 3 or 4 minutes to complete the bend before the wood cools down.

The strap should easily receive the steamed blank (positioned as in the dry run) and the thrust screw tightened until the blank is pressed up against both end stops. Give the thrust screw an additional 1/2 turn or until the assembly just begins to arch under compression. The clamps at hand should be placed on the strap as in the dry run. Place the assembly on the form and securely clamp the transition fixture in place as shown in **Figure 34**.

The table top bend (horizontal) should be completed first. As the bend progresses, replace the small clamps spaced along the strap with the larger clamps to secure the blank to the form. The adjustable end stop should not have to be backed off until the first bend is done. The thrust screw should then be backed off to the original tension level and the second bend completed.

The blank can be tapped or clamped to the spacer blocks to keep it true during and immediately after the bend. The strap can be removed after 20 minutes of intermediate setting or 7 minutes if the form is bathed in compressed air. Watch for wood fibers that lift off the surface, apply a clamp as necessary and leave the blank to set a little longer before removing the strap. Once the strap is removed, immediately reclamp the bent blank to the forms/drying jig for full setting.

## Veritas® Steam-Bending Equipment

### Strap Clamps

For simple bends. Strap clamps are available for material up to 1 1/4" square and up to 2" square. Each strap clamp includes 10' of steel strap, an adjustable end stop, a ratchet wrench, and a socket. Bolts are also provided for the fixed end stop. Extra lengths of steel strap are available.

- 05F10.01** 1 1/4" Strap Clamp
- 05F11.01** 2" Strap Clamp
- 05F10.04** 1 1/4" × 10' Strap
- 05F10.06** 1 1/4" × 20' Strap
- 05F11.04** 2" × 10' Strap
- 05F11.06** 2" × 20' Strap



### S-Bend Unit & Change-of-Plane (C.O.P.) Unit

The S-bend unit lets you strap opposite sides of the wood up to a maximum of 1 1/4" thick by 2" wide. The change-of-plane unit lets you strap adjacent surfaces to bend wood in two planes. Both units can be used only with 2" strap clamp. Since a length of strap must be clamped on both sides, you will need to either cut the 10' strap included in the 2" strap clamp or purchase a second length of strap.



- 05F12.01** "S" Bend Unit
- 05F12.02** C.O.P. Bend Unit

### Block & Tackle System

Fits only the 2" strap clamp. For large cross sections, the block and tackle system with custom fittings helps bend the wood.



- 05F13.01** Block & Tackle System

### Veritas® Bench Pin

A necessity in steam bending where you have to hold forms in place, these are equally useful for general shop activities. For some purposes, it is easier to drop a bench pin through something into a bench dog hole (it is the same diameter, 0.010" under 3/4") than to use a bench dog. Pins are 6" long and have an "O" ring stop 1/2" from one end. Zinc plated.



- 05F16.01** Bench Pin, each

### Sources of Air-Dried Wood

If you do not have a known source for air-dried wood, you could try any of the small bandsaw mill operators that dot the landscape from coast to coast. Since most of these operators have no drying kiln, any wood they have would be air dried. Remember, you do not want wood that has been dried below 10% moisture content and, preferably, you should get wood that has about 20% moisture content.

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