Bending Compound Curves

Laminated staves make bulging cabinets

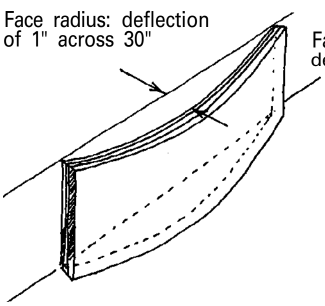
by Jere Osgood

Sides of this chest curve from front to back and bow outward toward the middle.

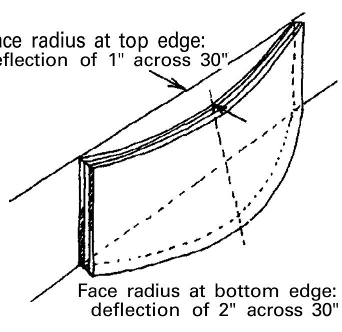
Thin layers of wood are easy to bend into a variety of simple curves—that is, surfaces that bend in only one plane. The basic techniques of layout, stock preparation, making press forms and gluing up are described in my earlier *Fine Woodworking* articles ("Bent Laminations," Spring '77 and "Tapered Laminations," January '78). The same approach can be used to create thin-walled panels that curve in two planes, for use as cabinet fronts, doors or sides, for drawer fronts, or for any other application requiring a compound-curved form. It is done by gluing layers of wood face to face into relatively narrow staves, making each stave take the shape of a different but related curve, and then joining the staves edge to edge. The key to the compound-staved lamination system is realizing that flat layers of wood can be bent to one radius at one edge, and to a different radius at the opposite edge.

Keep in mind that the surface of each stave is a portion of the surface of a cone, straight across its width. A single stave cannot take the shape of a section of a sphere or of any other surface that curves in two directions. Wood is not normally elastic and it will bend in only one plane at a time. However, a number of staves, each bent to a different radius, can be edge-joined together to produce an approximately spherical form (like a barrel or even a pumpkin) or almost any other three-dimensional surface. This assembly will be made up of a number of flats, like the outside of a barrel, but as long as the radius of curvature is not too sharp and the outer laminate is thick enough, you can plane, spokeshave, scrape and sand the surface to a smooth, continuous curve.

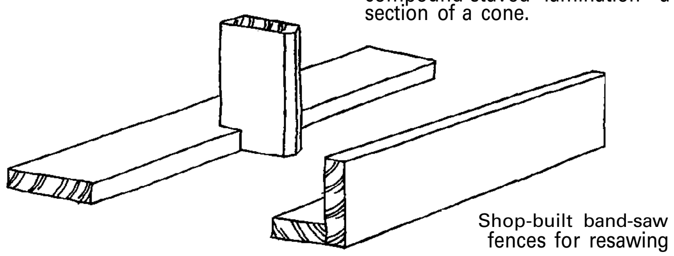
When I want a slightly convex stave, there is a little trick that is helpful, although fallible. I resaw and plane the lamination stock and sticker it overnight. The thin layers usually cup slightly as the moisture gradient within the original board reaches atmospheric equilibrium. I then mark the convex face of each laminate, and when gluing up the stave I stack all the convex cups in one direction. When the press form is opened after the usual glue-curing period, the stave will be perfectly flat across its width. But within 24 hours it usually resumes the cup.



Drawer front, 30" long, is simple curved lamination of three 1/4" layers—a section of a cylinder.



Drawer front, 30" long, is a compound-staved lamination—a section of a cone.



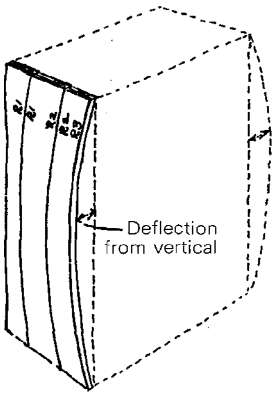
Shop-built band-saw fences for resawing

Compound-curved lamination is a forming process. Panels for cabinetry can be manufactured either as solid-wood laminates or by the veneer-plywood technique. In the former, the thickness of the layers is arbitrary and usually ranges from about 1/16 in. to 3/8 in. or more. A thin layer will bend around a smaller radius than will a thicker layer, but the thinner you resaw the stock, the more good wood you waste in the kerf. When using solid wood the grain of each layer is oriented in the same direction, and the laminated stave behaves and moves just like solid wood. In the veneer-plywood approach layers of thin veneer are cross-banded within each stave, or fancy face veneers are glued to multiple layers of 1/8-in. or 1/4-in. plywood. The alternation of grain direction stabilizes the unit and there is little or no movement across the grain. But springback errors can be disastrous and the need for accuracy is acute.

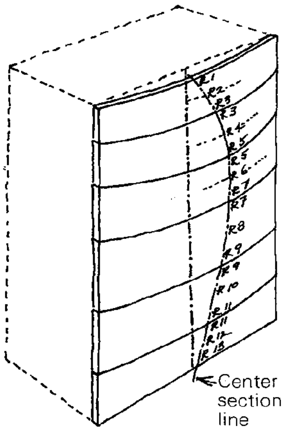
I usually prefer a subtle curve and therefore find using solid wood laminates more congenial. For example, drawer fronts with a gentle curve might be made from two 3/8-in. thick layers glued together. Carcase sides to accommodate a slightly greater bulge might be made of three 1/4-in. layers, the outer layer resawn and bookmatched from some sacred old stock, the two inner layers from a more common unmatched stock.

When resawing planks on the band saw, best results come from a new blade, preferably no finer than four or five teeth to the inch, and 3/4 in. or 1 in. wide. Make sure the blade guides are firm and tight both above and below the table, and that the blade is tensioned to specifications. Most band-saw blades lead to one side or the other, especially when they get dull, so you can't use the rip fence that comes with the saw. Instead, you have to make a wooden equivalent that you can clamp to the table, as in the drawing at left, and angle it one way or the other to compensate for the blade's lead. Or, you can use a vertical *V*-block or rod set in line with the teeth, swinging the end of the stock to compensate for lead. In either case, set the fence for the thickness of the laminate you want, and saw all the stock at this one setting.

If the wood is plain and straight-grained, I usually just resaw it thick enough to run both sides through the thickness

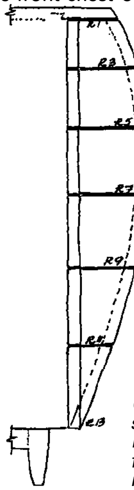


Curved cabinet sides, using compound-staved laminations

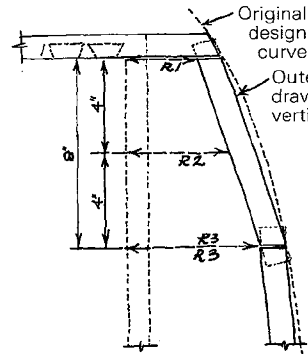


Bulging drawer fronts, using compound-staved laminations

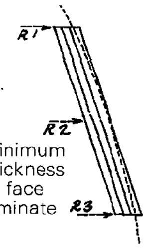
Partial side view of bulge-front chest of drawers.



Enlarged sectional side view. A full-size shop drawing is the key to making forms for bending.



Convert design curve to a series of straight lines. Dimensions R1, R2 and R3 represent the outward deflection from vertical on the centerline, at top, middle and bottom of this drawer front.



To duplicate exactly the design curve, draw the straight line outside it, and shape face laminate back to design curve.

planer. If it is highly figured, it is better to joint the face of the board before each cut. Use a stand or roller to support the wood as it leaves the band-saw table, and always have a push-stick handy for the last few inches of cut. The wood is liable to split suddenly near the end of the cut, and without a push-stick your thumb would plunge into the blade. Most small band saws are underpowered for resawing wide boards. I solve this problem by table-sawing a deep kerf on each edge of the plank. The remaining wood separating the two kerfs will be within the band saw's capacity. No fence is necessary because the band-saw blade tracks in the kerfs.

Most of the time I make bending forms from particle board because it is cheap and strong. I face the forms with layers of Masonite (hardboard) to distribute the pressure evenly, and clamp up with either quick-set clamps or a single five-screw unit from a veneer press. A vacuum press (*Fine Woodworking,* May '79) is ideal for this application, especially when using the veneer-plywood process. When bending solid wood, avoid white glue because it suffers badly from cold-creep under the stress of the wood attempting to straighten out. Yellow glue is better, although it is still subject to some cold-creep, but a urea-formaldehyde such as Weldwood, Cascamite or Urac 185 is best of all. In all lamination processes, good gluing habits are critical. There are four trouble areas: wood moisture content, oily woods, temperature and dull thickness-planer blades. The wood should be uniformly dried to about 8% moisture content—below 6% is risky, and so is above 12%. The curing time of most glues is sensitive to temperature, and many won't cure in a cold shop. But a drop-cloth tent over the work, with a light bulb suspended inside, usually solves the problem. Oily woods should be carefully tested before proceeding to the real thing, and here yellow glue will hold better than urea. Dull planer blades mash the wood fibers, while sharp ones cut them cleanly. A clean, newly machined surface always yields the best glueline. The surface of stock that is resawn and planed and then left sitting around the workshop for months oxidizes slightly, jeopardizing the glue bond.

The first drawing above shows a cabinet whose side is straight at the back edge and bows gently toward the front. The back stave is straight along its rear edge, with the curve (R1) beginning along its front edge. The next stave has the same curve R1 along its back edge, but continues the outward movement toward curve R2 at its front edge. The third stave matches the second along curve R2, and goes a final bit further outward to R3. A variation on this would be returning the front curve R3 to a straight line, although with straights that move to a curve you must take care to avoid too great a change too quickly. In this example, to have a straight vertical at the back and front edges might require one or two more staves. There is no limit to the number of staves, and return curves or *S*-curves can also be used, although the more surfaces you have curving in and out, the harder it becomes to keep all the parts in phase with one another.

The next sketch illustrates a set of drawer fronts designed to bulge outward toward the middle. The top edge of the top drawer is slightly curved, while the bottom drawer line is straight. The carcase sides are shown vertical and straight, but they need not be so. Here each drawer front would be a single stave, with the curve of its top edge matching the bottom edge of the drawer above, and the curve of its bottom edge matching the one below. The intermediate radii shown (R2, R4, etc.) designate the curvature of spacing ribs for the bending forms. In the sketches and photographs to follow, I will describe the procedure for making a cabinet whose drawer fronts bulge outward like the one shown here.

Any project involving compound-staved laminations absolutely requires a good, full-size shop drawing. Front, side, top and sectional views are usually needed. The shop drawing makes it possible to visualize accurately the curves, and measurements for bending forms can be taken directly from it.

In this example, start with the usual front and side elevations and plan view, and construct an accurate side sectional view at the part of the curve furthest forward (on the centerline, in this case). Because the wood will bend in only one plane at a time, you have to convert the vertical curve of each drawer front into a straight line. I draw the straight line just inside the design curve, and leave the drawer fronts flat on the finished piece. But if you want to duplicate the design curve exactly, draw the straight line tangent to, but outside, the design curve. The largest variation between the curve you want and the straight face of the bent stave is the minimum thickness of the face laminate, since you will want to shape the wood back to the true curve without encountering an ugly glue line. If this thickness is too great for the bend you have in mind, you will have to redesign the curve or divide the drawer front into two (or more) staves.

From this sectional drawing, you can measure the deflection at the center of each drawer front, with respect to a vertical line on the plane of its straight outer edges. On this drawing, these measurements are R1, R2 and R3. This is the information you need to lay out and construct the forms for bending each drawer front.

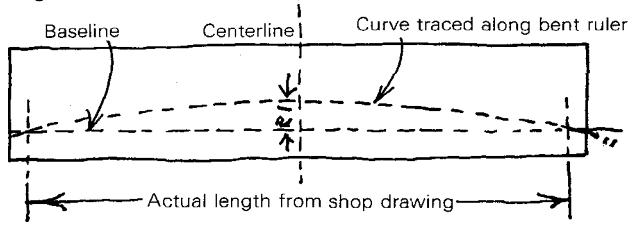
Drawers are often of different heights within a carcase. You can make a different bending form for each drawer front, or you can devise a modular form base to receive at the correct spacing the ribs for all the drawers. Drawer-front heights in multiples of 1½ in. or 2 in. will fit this concept nicely. The form ribs can be on any convenient spacing, as long as the base form is made to accept them all at the correct distance. The maximum distance is about 4 in., as shown at right. Beyond that, the gluing pressure might become spotty.

The sections R1, R2 and R3 need to be converted precisely to particle board or plywood ribs for the bending forms. There are only two measurements needed for this: the length of the drawer front (or of the cabinet side stave) and the amount of deflection in the curve. The bending forms should be made slightly overlong, and the resawn stock should be both overlong and overwide. The extra width in the form is gained by extending the Masonite form liners because the distance between sections R1, R2 and R3 cannot be changed. A typical two-part form would use a Masonite liner on each side: two or three layers of ⅛-in. tempered Masonite, or a single layer of ¼-in. tempered or untempered, depending on the sharpness of the curve.

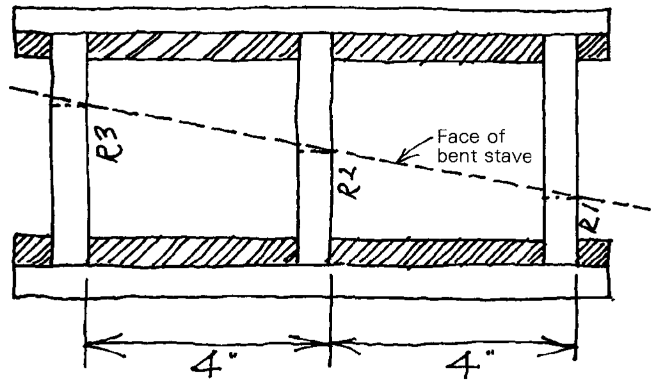
In this example, prepare some pieces of particle board 2 in. longer than the finished length of the drawer front, and about 3 in. wider than the greatest deflection of the curve. That is, if R3 is 2 in., cut the particle board 5 in. wide.

For press-form rib R1, draw a base line and a vertical centerline on the particle board. At the actual length of the drawer front, drive two brads into the base line. Transfer the bulge height (R1) to the vertical centerline. Find a steel, plastic or straight-grained wood straightedge (aluminum does not bend evenly). Rest the straightedge against the nails and bend it up to the limit of R1. Then bend it a little more, say ¼ in. for a deflection of 2 in., for springback. The exact amount to allow depends on the wood species, the severity of the curve, and the number and thickness of the laminates—you need experience with this technique to judge. Trace the curve of the straightedge onto the particle board. I suggest

Bending forms

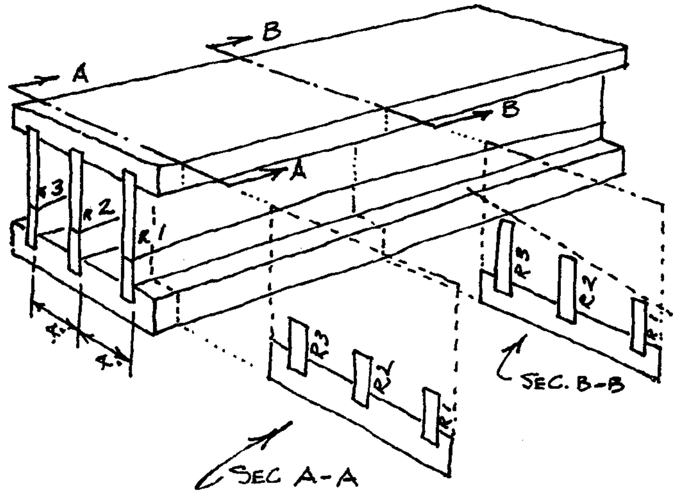


Example: press-form rib R1

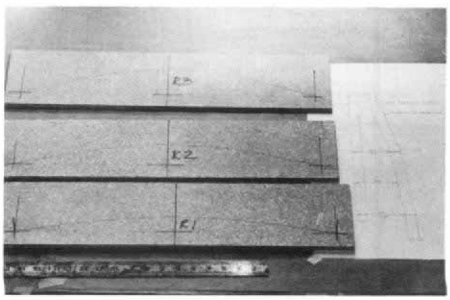


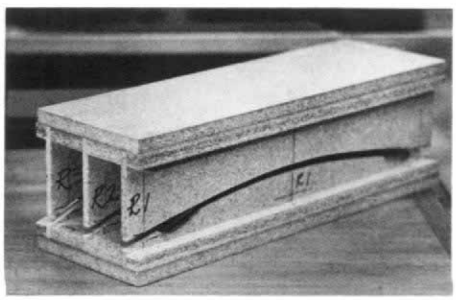
End view of typical form. Note construction for removable ribs.

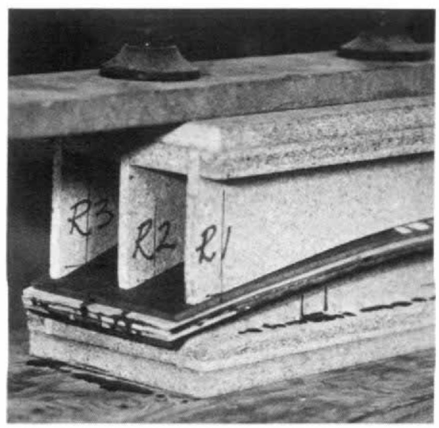
Spacing is measured from the front face of the form ribs. Be sure to keep all the ribs oriented the same way.



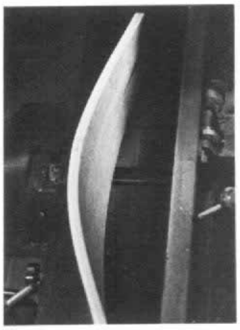
The sections A-A and B-B show deflection from the edges toward the center of the drawer front.

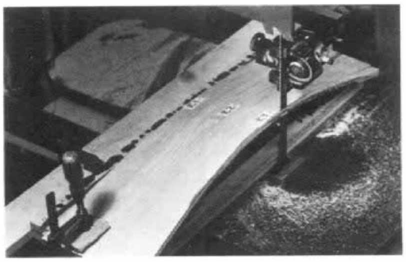






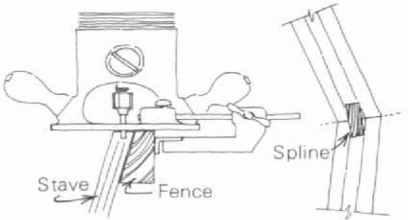
Full-size shop drawing (left) and resulting press-form ribs for drawer-front sections R1, R2 and R3. The pressform (center) with ribs in place. These ribs are removable, so the same base pieces can be used with the ribs for the other drawers in the carcase. One section of a veneer press is used to bend the drawer-front laminates (right). The wood and the form are separated by a layer of Masonite to distribute the pressure.

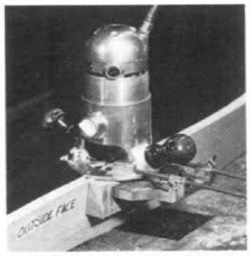




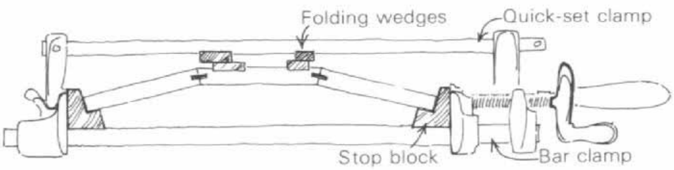
Use the bending form base as a jig to trim drawer fronts to width. The curve can often be freehanded over the jointer.

Joint line bisects angle between staves. Set locating spline just back of center.

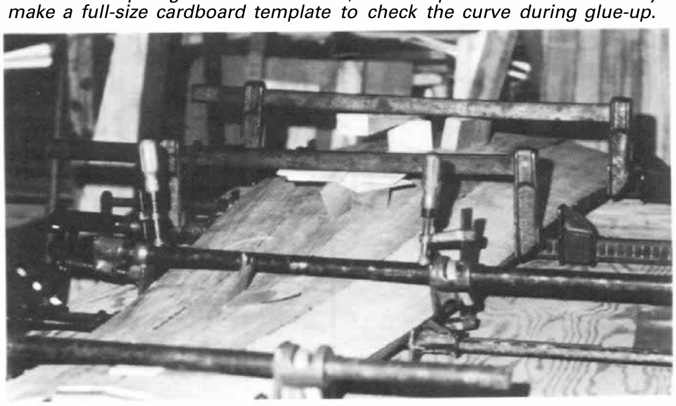




To rout slots for locating splines in staved cabinet sides, use a ¼-in. straight bit and fence blocks beveled to the appropriate angle. A straight fence will follow a convex curve, but a concave curve requires a shaped fence. Always work from the outside face of the staves, to keep them in the same plane.



A combination of clamps, folding wedges and end blocks makes it possible to glue up a staved assembly. The wedges can be driven in and out, and the clamps tightened or released, to manipulate the curve. Always make a full-size cardboard template to check the curve during glue-up.



drawing all of the curves for all of the form ribs in the same session. This ensures that you use the same straightedge, and that the same face is bent outward (or inward). It is particularly important to draw everything at once if the design calls for a return *(S)* curve.

When bandsawing the form ribs, it is not a good idea to tilt the band-saw table. The staves do twist from end to end, and accurate sectional contact might be lost. The square edge in conjunction with the Masonite form liner will distribute the pressure adequately. Note that top and bottom form ribs are cut on the same line. In work like this I would not attempt to make true two-part forms, bandsawing to a different radius for each half. It would be too confusing, and if the curves are so tight that it is necessary, you are probably leading to distortion problems anyway. Such a design is stretching the limits of this procedure.

After the laminates are glued to shape, they need to be trimmed to width at the correct angle, on the section line. An easy way to do this is to use the base of the press form as a jig. Clamp the piece to the form so it overhangs (you'll have to cut a notch in the base so the clamp can clear the table) and feed it into the band saw or table saw. Because these pieces are curved, they can usually be freehanded over the jointer for a clean and true edge.

The angles that compound-curved laminations generate need to be understood. For drawer fronts, all the edges would be cut perpendicular to a real or imagined vertical, because the drawers need to slide straight in and out without interference. For cabinet doors or sides, I prefer a joint that bisects the average angle of the staves to each other. It is easier to glue and also easier to rout slots for splines.

A cross-grain spline is not needed for strength because the mating stave edges are all long grain and glue together well. The spline is only a locator, so it can be ripped from the edge of a board. The twist imparted by the compound curve makes the width of the stave edges vary, and the splines keep flush the face side of the staved assembly. The back side will need to be scraped down level, or the stave edges chamfered to disguise discrepancies.

Gluing up the staves that form curved panels often seems an impossible task, but it yields to experience. The method I have found best is to presand the insides of the panels and chamfer the mating edges slightly. To make clean-up easier I rub a little paraffin on the chamfer so the squeezed-out glue that collects there will pop right off after it dries. Then I use two stop blocks resting on pipe clamps to establish and control the overall width of the staved assembly, and a large quick-set clamp over the top to provide downward pressure, tightened with wedges. The drawing shows what I mean. It's very important to make a cardboard or Masonite template to check the angles between staves when gluing. This arrangement permits you to manipulate closely the pressure and the angle at which the staves meet when gluing up all sorts of curved or coopered panels.

These methods will seem to be fussy and confusing to people accustomed to roughing out curves from solid stock on the band saw. It will appeal to assemblers and to those who like complicated joinery. Here the time is spent on conceptualization, on accurate planning and drawing, instead of on carving off large amounts of waste from heavy unformed stock.

As I've said before in this series of articles, you must use discretion when designing for bent lamination. Consider the overall design appearance first and have the technique evolve from it. Once you master the basic techniques, it is all too easy to conceive of a piece that could be executed in theory, but that in practice would be simply too hard to handle. Such a piece would probably be disorienting as well, so busy that one couldn't bear to be in the same room with it. I have found it best to stay with one design experiment in one piece of furniture, and to keep the rest of the piece restrained. Being able to build a piece of furniture that bulges wildly in all directions at once is not a good enough reason for doing so. □

Jere Osgood is professor of woodworking and furniture design at Boston University.