A Method for Specifying Contours of an Arched Plate

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The surface of a typical stringed instrument's arched plate is a complex surface indeed. Experienced plate carvers and first timers possessed of highly refined spatial perception tend to implement these with some ease, while for others even the prospect of rendering such a plate is just too intimidating. This paper proposes a method by which the contours of such plates may be specified. It is a step-by-step design approach which can yield a topographic contour specification such as found in topographic maps[*] for a plate of arbitrary outline. The resulting specification can be directly transferred to a plate blank which is then rough carved with a router to yield a close approximation of the finished plate's contours, such that only minor additional carving is necessary.

The method described is derived from a feature of advanced Computer Aided Design (CAD) facilities called Parametric Solid Modeling (PSM). Using PSM a designer may completely specify the dimensions of a complex solid by specifying the values of a relatively small number of parameters. Folks with a non-technical bent need not be put off by the derivation of the contour specification method to be described, as no CAD or math is required to use it. The method described is a modification and simplification of the CAD-based method I use to develop arching profiles for new instruments, modified and simplified so as to be useable with pencil and paper. As CAD software is increasingly used in lutherie, the method is also described such that it can be performed using basic 2D CAD software as well.

The method begins with the specification of the values of a small number of parameters which describe the plate contours. These parameters are:

1. Outline of the plate;

2. Location of the apex (highest point) of the arch;

3. Thickness of the plate at its edge;

4. Height of the apex of the arch;

5. Contour interval (the size of the step in elevation to be indicated by each contour line);

6. Nominal horizontal arching profile;

For the most part these are self-explanatory, although the last needs to be explained in detail and receives special attention in subsequent paragraphs.

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[*]A short but very good explanation of topographic maps can be found on line at
http://www.geocities.com/geology101lab/topomaps.html for those who are unfamiliar with them.

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Step one is to make a full size drawing of the top view outline of the plate. The example outline I will be using for demonstration purposes is shown in **figure 1**. A vertical center line should be included in the outline drawing. A point indicating the location of the apex of the arch should also be added.

The next step is to specify values for the simple parameters of the arched plate to be created. Values are specified for the thickness of the plate at the edge, the height of the plate at the apex of the arch, and the contour interval. Note that all thickness and height values in this paper are expressed in inches and decimal fractions as measured from the bottom surface of the plate where it will eventually contact the ribs of the instrument. In the example I am using values of 0.25" for the edge thickness and 1.0" for the height of the plate at the apex of the arch. These are typical values for arched top guitars.
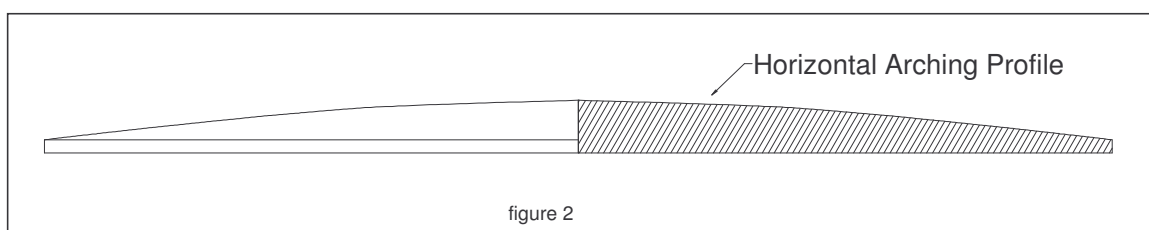
figure 1
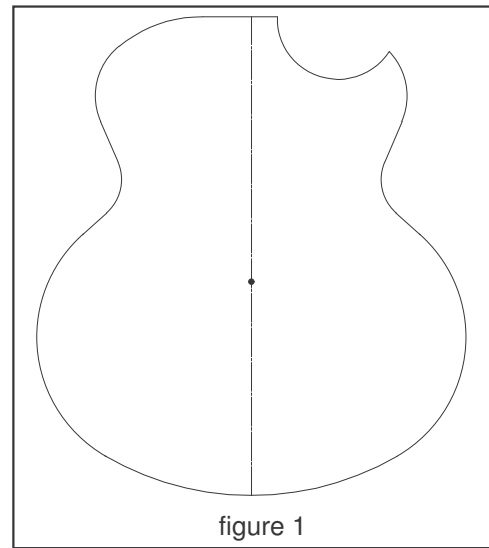
The contour interval used in the example is 0.125", which represents a reasonable compromise. With a larger interval there would be fewer contour lines so the process of deriving the specification would be quicker, however the finished specification would only roughly resemble the ultimate shape of the plate. On the other hand a smaller contour interval would result in more contour lines and more time taken in the production of the specification, which would more closely approximate the shape of the finished plate. Were the derivation of the specification to be performed by fast and tireless computers and the carving of the plate blank to be done by highly accurate Computerized Numerical Control (CNC) machinery, it would make sense to make the contour interval as small as possible (in fact, this is just how tool path specifications for the automated machining of parts are derived). But since the method described uses pencil and paper to derive the specification some compromise must be made here.

The nominal horizontal arching profile must be specified next. Imagine that you had a plate that had been carved, smoothed and sanded on the outside surface only. Imagine again that a pie-shaped section was cut out of the plate and the plate was turned so as to be viewed on edge, looking straight at one of the cut faces. The top line of that cut face is the horizontal arching profile of that plate, as shown in **figure 2**. To specify a horizontal arching profile simply draw a line representing how the curve of the arch should proceed from the height of the edge of the plate to the height of the apex of the arch. The literature contains observations from luthiers concerning the qualities imparted to the sound of an instrument by various arching profiles. Beginners may want to use a simple spline curve drawn against a piece of veneer bent across two pins representing the positions of the height of the edge of the plate and the height of the apex of the arch.

In the next step preliminary contour lines are drawn. The contour lines drawn here will have the same shape as that of the plate outline, only they'll be smaller. This is not the ultimate shape for the contour lines, however. In the step following this one these lines will be modified to their final shapes.

The preliminary contour lines are drawn by reducing the size of the plate outline by some scale factors derived from the contour interval and the nominal horizontal aching profile. The scale factors for the example are:

0.8933 (89%)
0.7816 (78%)
0.6640 (66%)

Horizontal Arching Profile

figure 2

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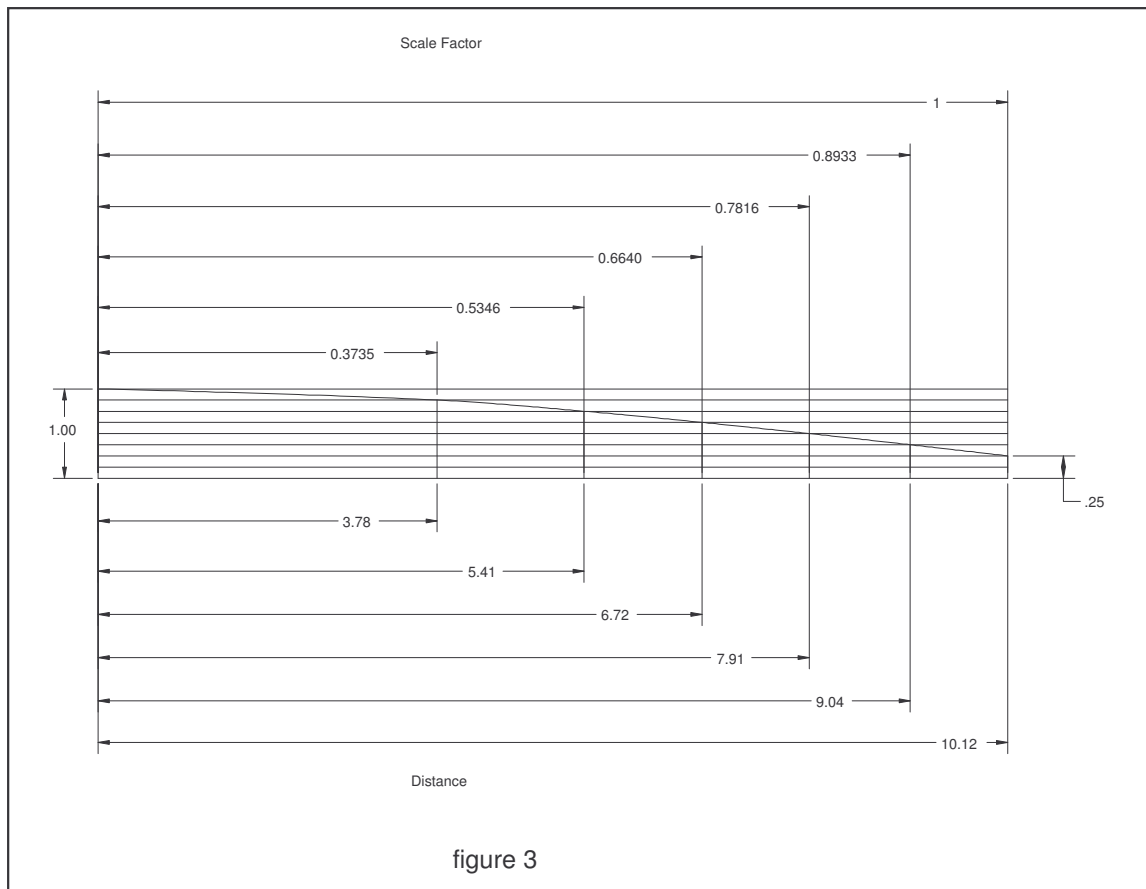
figure 3

0.5346   (54%)
0.3735   (37%)

and their derivation is shown in **figure 3**. This figure shows the nominal horizontal arching profile drawn from the height of the edge of the plate to the height of the apex of the arch. You can see the apex of the arch is 1.0" high from the bottom of the plate, and that the thickness of the edge is 0.25". Horizontal elevation lines are ruled every 0.125", which is the contour interval used in the example. The distances from the center of the arch to the points at which the profile of the arch intersects each elevation line are included on the bottom of the figure. Each of these distances is divided by the distance from the center of the arch to the edge to yield a scale factor value, shown at the top of the figure. These scale factor values are used to scale the outline to derive the preliminary contour lines.

Since the example specification will contain five contour lines in addition to the outline, five copies of the plate outline are made, each reduced in size by one of the scale factors. The easy way to get scaled down outlines is to take the outline drawing to a copy shop that can handle large originals and to have scaled down copies made, one copy for each contour line needed. As indicated, the scale factors for the contour lines of the example are 0.8933, 0.7816, 0.6640, 0.5346, and 0.3735. Reducing copies of the outline by each of these scale factors (i.e., making copies at 89%, 78%, 66%, 54%, and 37%) will yield the required preliminary contour lines. If the copies are pinned together at the apex point and traced, the resulting drawing should look a lot like **figure 4**.

Reduced copies of the outline can also be made using a pantograph drawing device. CAD users can simply use whatever facilities your CAD package provides for scaling objects.

The next step is smoothing the peaks and valleys of the preliminary contour lines to yield the final contour lines. The drawing at this point is not quite representative of how the final arching contours will look. If you skip ahead to **figure 13** (which shows the final contour lines) and compare it to **figure 4** (which shows

the preliminary contour lines) it can be seen that the final contour lines are not merely reduced copies of the outline, but that they get more and more smooth the closer they get to the center. The concave hollows of the waist and the cutaway get less pronounced the closer they get to the center, with the innermost contour line showing no sign of any indentation at the waist at all. Likewise the points of the cutaway get progressively more rounded the closer they get to the center. If the example had a more rounded cutaway, the peak of that cutaway would get progressively rounder as it approached the center of the plate as well.

The valleys (that is, the concave segments at the waist and cutaway) will be smoothed first. Of these the cutaway will be done first since this is the easiest to do. The outermost contour line will be smoothed, and then the rest of the contour lines will be processed in order.

First, a temporary straight line is drawn which spans the concavity of the cutaway on the outermost contour line completely. Next another temporary line is drawn perpendicular to the one just drawn, from the center of that line to the concavity. This line is measured and divided into as many parts as there are contour lines. In the example the line is divided into five parts as shown in **figure 5**. Now, the concavity is redrawn so the redrawn line goes through the point on the perpendicular line that is 4/5ths from the spanning line, as shown in **figure 6**. It is a simple matter to redraw this section of the contour line in the cutaway, as the shape is a circular arc and thus can be drawn using a compass. Actually, there is no need to get too precise when redrawing lines in this smoothing process- just trust your eye. As long as the new line goes through the 4/5ths point as described and the line is roughly the correct shape, everything will be fine. Of course, if the drawing is being made using CAD drawing software then there is no need to eyeball it.

The process described in the paragraph above is repeated for each contour line, but the concavity is redrawn shallower and shallower as the contour lines approach the center. Thus the redrawn arc will go through the point on the perpendicular line that is 3/5ths from the spanning line when working on the next contour line, as shown in **figure 7**. The succeeding one will go through the 2/5th point, and the next one the 1/5th point. Finally, on the innermost contour line the segment is redrawn simply as the line which spans the concavity. Completed smoothing of the cutaway concavity is shown in **figure 8**, with all the temporary lines erased.

The process of smoothing as described for the concavity of the cutaway is now done on the concavities of the waist. Here, the temporary straight line spanning the concavities is drawn so as to be tangent to the convex curves of the upper and lower bouts. This is shown for the outermost contour line of the right side of the waist in **figure 9**. Note that when the temporary perpendicular line is drawn it does not touch the concavity of the waist at its deepest point. This doesn't
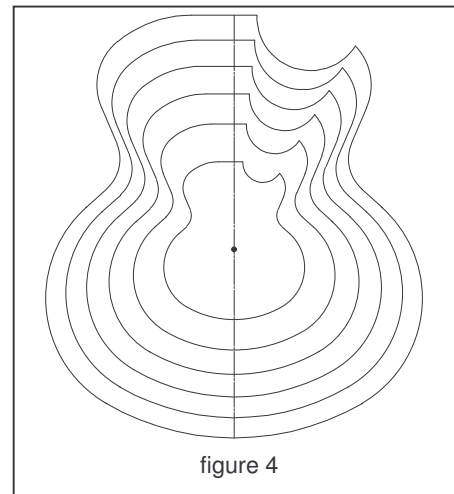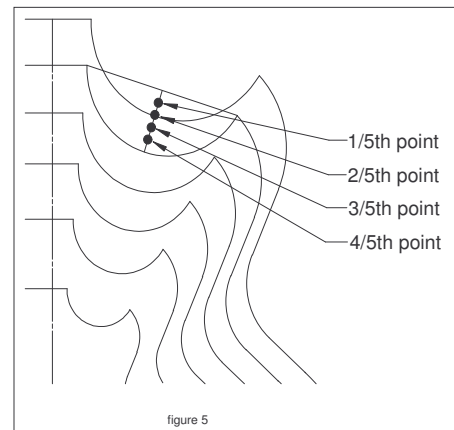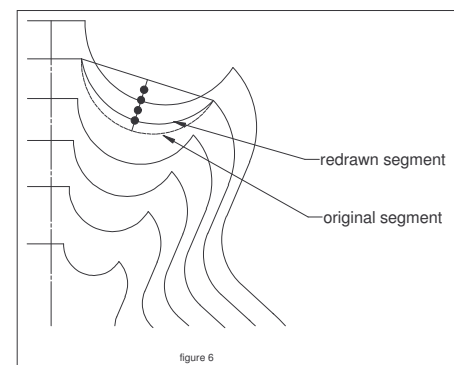

figure 4

1/5th point
2/5th point
3/5th point
4/5th point

figure 5

redrawn segment

original segment

figure 6

redrawn segment
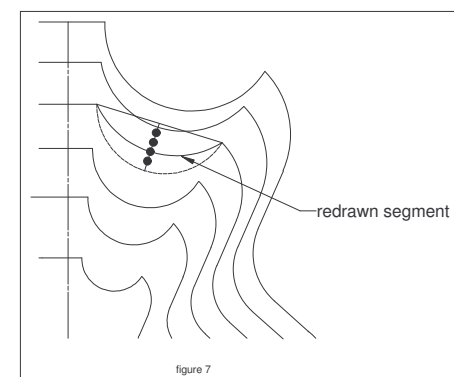
figure 7

matter- these perpendicular lines and their divisions are just references to aid in the redrawing and smoothing of the concavities. Again, use your eye to redraw these concave line segments, keeping the contour lines smooth as possible.

The smoothing/redrawing of the concavities of the waist is completed as described for the cutaway. The completed smoothing of all the concavities is shown in **figure 10**. In a lot of outlines the waist curves will be symmetrical about the center line, so it may be possible to simply trace the smoothed waist segments from one side of the drawing to the other.

The drawing is looking a lot more like that in **figure 13** now that the valleys of the contour lines have been smoothed. Now the peaks, that is, the sharp protuberances, will be smoothed as well. They aren't as sharp as they were since smoothing the valleys, but they still require more smoothing. In the example there are two peaks which must be dealt with, the ones on either side of where the valley of the cutaway used to be. These will appear on your own drawing if it has a cutaway, even if the point of the cutaway is rounded. If your drawing doesn't have a cutaway horn or other peaks then you are done with the smoothing step and can proceed to checking the drawing.

The process of smoothing the peaks is similar to that of smoothing the valleys. We want to make the peaks progressively more rounded over as they approach the center of the drawing, so they are no longer distinguishable as peaks on the innermost contour line.

The process of smoothing the valleys started from the outermost contour lines and worked inward toward the center. In smoothing the peaks just the opposite is done, starting with a peak on the innermost contour line and working outward. The peak that represents the point of the cutaway on the innermost contour line will be the first one processed. As stated above, after smoothing the peak should be so rounded over here that it is no longer distinguishable as a peak. To do that it will be replaced with a circular arc as shown in **figure 11**. The arc is made big enough so that it extends about halfway to the other peak that has to be rounded, which is just to the left. This arc is made with a compass so the radius can be determined after the arc is drawn.

The radius of the arc just drawn is measured and divided by the number of contour lines (5 in the example). This will yield a step value which will be used to decrease the size of the circular arc used to replace the peak on successive contour lines as the outside of the drawing is approached. In the example the radius of the arc just

drawn was 1.75". Divided by 5, that yields a step value of 0.35".

Repeat the smoothing of this peak for each of the remaining contour lines. As this is done the peak on each successive contour line is replaced with a circular arc that has a smaller radius than the previous one did. The step value is subtracted from the radius of the arc used on the previous contour line to determine the radius for the arc for the next contour line. In the example the peak on the innermost contour line was replaced by a circular arc with a radius of 1.75". The peak on the next contour line was replaced by a circular arc with a radius of 1.4", and the radii of the arcs which replaced the peaks on the rest of the contour lines are 1.05", 0.7", and 0.35" respectively. If CAD drawing software is used to create the drawing this rounding operation

figure 8

figure 9

figure 10

about halfway
original segment
new segment
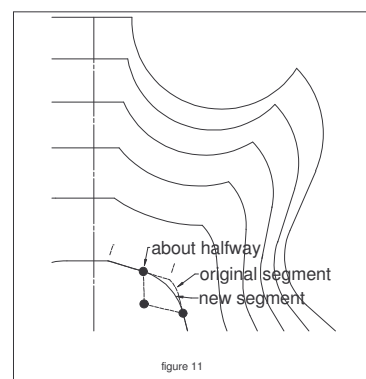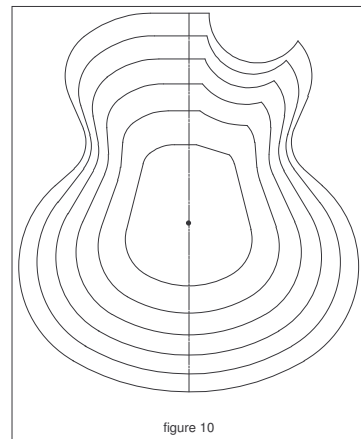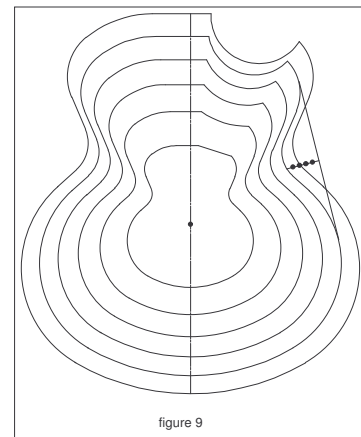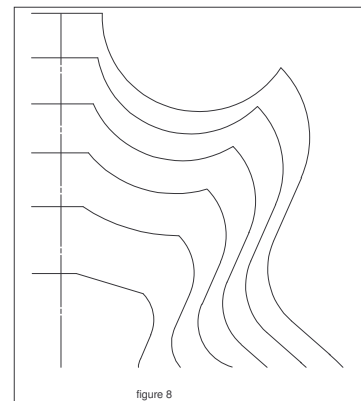
figure 11

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can be performed using a fillet (corner rounding) function if your package provides it. **Figure 12** shows this peak completely smoothed on all contour lines.

The remaining peak on the inside of the cutaway is rounded over in a similar manner. This completes the smoothing process and the contour specification. The results of this operation are shown in the completed contour specification as seen in **figure 13**.

The specification drawing should be checked for anomalous hollows and flat spots once smoothing is complete. The simplest way to do this is to place a straight edge at the apex point such that it intersects the outline, and to visually check the distance between successive contour lines. If it is found that two or more adjacent distances are the same, that indicates there is a flat spot in the arching profile at the plane indicated by the ruler. Likewise if it is found that two or more distances decrease instead of increase as the center is approached, then that indicates a hollow spot in the profile. If the distance between lines continuously increases as the center is approached then all is well. The completed contour specification should be checked in a number of places, paying particular attention to those areas where smoothing operations were done. If anomalies are found the suspect areas should be re-smoothed as described and rechecked.

figure 12

Some variations to the smoothing process should be discussed. One possible variation of the smoothing process is to change the rate at which successive contour lines are smoothed. In the example the contour lines gradually lost the features of the original outline the closer they were to the center. It is a simple matter to attenuate the rate of smoothing so the interior contour lines still retain features of the original outline (although I suspect that this is probably not useful in the creation of plates for arched instruments). Likewise it is possible to accelerate the rate of smoothing so that the amorphous shape appears in more than just the innermost contour line. This may be useful in the design of instruments the plates of which are essentially spherical, cylindrical, or elipsoidal. An example of the latter is the violin, where the shapes of the corners are not continued into the profile of the arch at all.

figure 13

The process of generating the contour specification is complete. Now the generated contour specification can be directly used by transferring it to a plate blank and then using a router to route a series of steps or terraces, one for each contour line. Using the contour interval specified in the example a blank so routed will require very little additional carving in order to bring the surface of the plate to its final contours. Examples of the mechanical processes of routing such steps and faring them down appear in the literature and so are not repeated here.
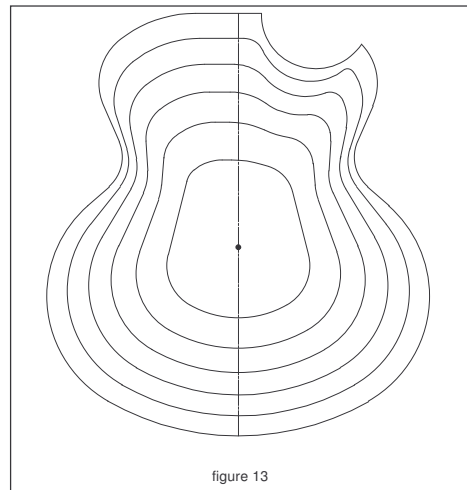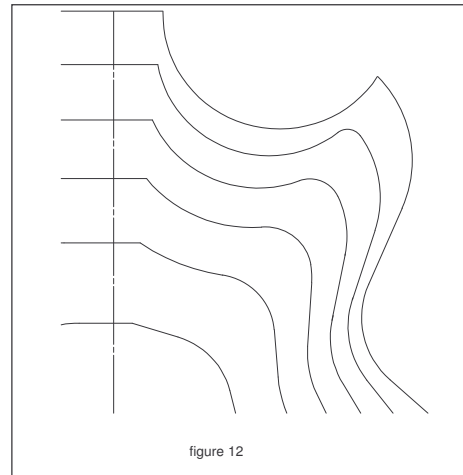
Post Publication Notes

Size constraints on the published article caused the following information to be cut.

Rough Carving the Outer Surface of the Plate

There is a lot of literature describing methods of performing the actual carving of plates [1,2,3,4]. I won't spend too much time on the remaining steps for that reason.

The first carving step involves cutting flat terraces into the plate with each terrace extending from the preceding contour line to the next one. The terraces are cut using a router and straight bit. If a flat plate

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blank is used as described, the router can rest right on the plate blank. It is easier to balance the router if it is equipped with an offset baseplate. As an alternative to balancing the router on the top surface of the blank, the plate can be placed inside a shallow box so that an extended baseplate affixed to the router sits on the top edges of the box. This technique is described by Smart[4].

The terraces are cut starting from the outside of the plate and working inwards. The first terrace is cut beginning at the oversized outline and ends at the actual outline and is .25" high in the example, measured from the bottom of the plate. The rest of the terraces are cut in a similar manner.

Smoothing the Outer Surface of the Plate

Once the terraces are cut the contours of the plate become quite obvious. It is a relatively simple matter to fair down the sharp edges of the terraces to form the smooth contours of the finished plate. Works by Ribbecke and Smart (previously referenced) provide good explanations of the process of smoothing the surface of a terraced plate. To those instructions I'll add a few bits of advice for first time plate carvers: First, use tools that you are familiar with. Since the terraces are only .125" high there are many options available for the smoothing process. Gouges, planes, flat rasps and various rough sanding and power carving tools can all be put to this task. Using tools you are already familiar with will make it possible to perform the smoothing with a maximum of comfort and a minimum of mistakes.

The second bit of advice for first timers is to choose tools and techniques that allow you to go about the smoothing process in a slow and controlled manner. One of my personal favorite tools for the first pass at smoothing a plate is a coarse abrasive flap wheel mounted on a 4.5" angle grinder. The wheels wear out quickly and cost about $8, but offer a lot of control even while aggressively hogging off wood.

Most folks seem to start by smoothing out the longitudinal arch first, and then working from there around the plate. I find it useful to do the smoothing in two operations, grinding down the terraces until only the faintest lines still appear where the inside corners of the terraces used to be, followed by hand sanding with coarse grit paper. When performing the initial sanding it is a good idea to stay out of the area immediately around the apex point. This flat section will be arched during the final sanding of the surface. The outer surface of the plate should be refined to its final form before proceeding to the next step.

Carving the Inside Surface of the Plate

In works referenced earlier Benedetto, Ribbecke and Smart all describe a method of drilling the inside surface of the plate with depth gauge holes and then scooping out the waste. This method seems to be well suited to the needs of first timers so I won't expand further upon it here.

Further Modifications and Refinements to the Method

The method as described will yield an arched plate with dimensions suitable for a typical arched top guitar. As mentioned earlier, the description makes a lot of assumptions and takes a certain number of short cuts for the sake of expediency of presentation. This method is quite versatile however, and can be used to design arched plates for a wide variety of instruments. Understanding the mechanics underlying the method is the key to using it for applications not detailed in the examples.

There are two fundamental operations to the design process- scaling the outline based on scale factors derived from a single horizontal profile to produce preliminary contour lines, and a simple and rather ad hoc smoothing of the preliminary contour lines to a more amorphous shape. Variations to these operations afford much control over the finished contours of the designed plate. What follows is a short discussion of some possible variations.

In the example I derived the scale factors from a single horizontal arching profile, made by drawing a simple spline curve from a point representing the height of the apex of the arch to a point representing the height of the edge of the plate. In the example these height values were 1" and 0.25" respectively, but any values could just as easily be substituted. Likewise any desired arching profile could be substituted for the smooth spline curve demonstrated. The curve was drawn over a surface ruled at 0.125", which was the contour interval used in the example. Any contour interval value could be substituted for this, although in

practice I've found that intervals much greater than 0.125" yield a plate that is so rough as to make it difficult to see the finished contour in it, while intervals less than about 0.0625" are both too difficult to gauge accurately with the router and simply take too much time to cut. Once a suitable curve is drawn over contour interval rulings, scale values are calculated as described in the text. Thus this method can be used to design a plate of arbitrary edge thickness, arbitrary height, arbitrary contour interval, and with any horizontal profile.

References

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4. Smart, L. "The Modern Mandolin."
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