Voicing the Steel String Guitar by Dana Bourgeois

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Transcribed from Dana's lecture, 1990 Guild of American Luthiers convention.

"This is perhaps the strongest article ever published in American Lutherie about voicing the top and bracing of the steel string guitar. The fall-out from this piece has been very wide spread." Editor, American Lutherie

There are many valid approaches to voicing, and each maker must find a method that suits his or her style. I'd like to outline my own voicing procedure and try to explain why it has worked for me.

My method has been cobbled together over the years as a result of my own experimentation and my communication with several makers whose work I respect. Outside of a few exceptions, my own building has been limited to dreadnought , OM and 12-fret 000 guitars in the traditional Martin style. I don't want to get too much into design today, but I did want to give you that background so that you will know that my approach was not developed by building, say classical or archtop guitars. For all I know, what I do may not be valid for other categories of guitars.

In this discussion I will try to isolate the stages in construction where I am able to make the most reliable judgments about selecting my materials and dimensioning my top, back and bracing. The key to voicing, as I see it, is not only knowing what to do, but also knowing when to do it.

I start by selecting a design. In making that decision one chooses a reasonably narrow parameter in terms of what it is possible for the guitar to sound like. I say reasonably narrow, relative to the entire spectrum of what we call the guitar. A dreadnought is going to sound pretty much like a dreadnought regardless of how well or badly it's voice, or whether it's made of rosewood or mahogany. There will be differences, but all will somehow share in "dreadnoughtness". The same is true for other generic types of guitars.

Secondly I will choose the species of woods that I will use. As with design, wood species selection will have a major impact on the character of the individual guitar. I have not built with every wood that can be used in guitar making, but for backs and sides I have used Brazilian and Indian rosewood, maple, mahogany and koa. The top woods that I've used are European spruce, Engelmann spruce, Sitka spruce, Eastern red spruce and koa. I've come to appreciate the uniqueness of each of these woods, to define them in my own mind, and to have certain preferences when I want to push a guitar in one direction or another.

Necks also have their effect on the tone of the guitar; mahogany seems to sound different from maple. Furthermore, I can sort of mix and match the top, back and neck woods to get a variety of colorations. I don't claim to have precise knowledge of the exact effects of all the possible combinations and permutations of these woods, but general experience leads me to have certain predispositions which I call upon when selecting materials for building a specific guitar.

The next thing is to select the individual pieces of wood. Within a species, one individual piece of wood can vary significantly from another and this degree of variation is as significant a variables species selection. Sometimes these differences are degrees of quality; one could

select either good wood or bad. Sometimes they are simply varietal; some wood has one kind of tonal response and another responds differently, but they might be equally good pieces of wood.

There is a series of things that I look for when I am buying top wood. First I flex the wood just to get an idea of whether it is floppy or stiff. I generally look for wood that is reasonably stiff across the grain and along the grain. Wood that is available for purchase will come in a variety of thicknesses, and this will affect the stiffness, so you have to get an idea of how stiff your top wood should be relative to its thickness. If you flex a lot of wood you'll get a sense of it. You might as well start flexing now, if you're not already experienced.

The next thing I look for is what the wood sounds like when I tap it. Does it sound musical? If so, what is the quality of the music I am hearing? Is it complex or is it thin and sharp? Does it ring for a long time? Does it sound differently when I tap it in different ways? I'm not listening for any specific note, but for the quickness of the response. What that means is that the tone jumps out of it easily, without much work or coaxing. I am also looking for something that has a complex tonal response. I want to hear a distinct high end and a distinct low end. It's often difficult to hear the middle, at least the way that I conceptualize what I am hearing. But, if I can get a good separation between highs and lows, and if the wood sounds different but equally good when I tap it in different ways, and if there's a richness to the tone and there's a long ring, then this is what I mean by complex.

Let me show you how I usually tap an unglued top panel. I hold it near the middle of the top panel on the long side, somewhere between the edge and as far as 3/4" from the edge. You sometimes have to move around a little bit to find the right spot to hold it. I start tapping in the middle of the panel and move around until it sounds best, all the while holding it real close to my ear. Sometimes it sounds good almost wherever you hold it and wherever you tap it, and sometime you have to get just the right place.

If there's too much moisture in the wood it's going to be hard to get a clear response. It always sounds better when it's dry, but when you're buying wood you don't always have the luxury of specifying moisture level. Therefore you have to somehow be able to factor moisture level into what you are hearing.

So first I flex it, then I tap it, and then I look at the cut of the wood. I prefer top wood which is well quartered and which does not have a lot of surface runout. If a billet is split along the grain, and the top that is sawn from that billet is skewed to the grain, the top may be quartersawn but will have surface runout.

If there is too much runout it will be difficult to do what I will talk about later- namely, to hand plane the top. A top with runout will have the runout going in opposite directions on either side of the joint line, making hand planing difficult. But I have made good sounding guitars out of tops that had pretty bad surface runout, as long as the wood was stiff and sounded good. So I don't think that runout itself is a compelling reason for rejecting top wood.

If you have a matched set of belly wood and you really like the tone and it's nice and stiff, but it has a bit of runout, do you ever consider a reverse match so that the direction of the runout is the same on each panel?

Yes, I've done that and it can work. But it only works if you turn one panel end-for-end keeping the same face up. To get away with that visually, your grain has to be real even all the way across the panel, so it usually doesn't look convincing

One way to tell if the wood has runout is to look at the edge grain. If the wood was rough sawn when it was wet the fibers will standout when it is dry. Or you can look at the surface. If it is hairy and fuzzy then you're looking at end grain coming up at the surface, especially if it's in a different direction on either side of the panel. When in doubt, make a little split in the corner of the panel along the edge and watch the direction of the split line. In his lecture, Jean LarrivÈe said that if you split the piece of wood and it doesn't runout for a couple of inches, then you're all right. I'd go along with that.

So, I flex the top, listen to it and check the grain for directionality. The last thing I consider when buying top wood is the appearance of the wood. Obviously, I try get a pretty piece of wood on a special guitar, but only if it is going to make it sound good! I try not to be seduced by appearance, so I make that my last criterion. Having said that, there's probably a 75% correlation between the appearance of a top and the way that it sounds. I mean , if the color is even , the grain spacing is even, the grain is straight, and there's lots of medullary ray, chances are the top's going to be a killer. But not necessarily. The trick is not to take that for granted. Conversely, a funky looking top can sound spectacular.

What about Bearclaw or other figure?

I love Bearclaw. There seems to be a high correlation between the occurrence of Bearclaw and the occurrence of the other qualities I look for. I don't know why that is. I don't know if it's even a truly valid observation, or if I've just had good luck with Bearclaw

Doesn't Bearclaw have runout in localized areas?

Yes. Because of the way the grain folds. But I've said that my only problem with runout is the way the wood planes. Because I plane my own tops I know I should use Bearclaw only at my own peril, but I tend to use it pretty often. I guess I'm a gambling man.

Do you use the same criteria for stiffness and everything when you use Koa?

I've only built one guitar with a Koa top. The customer wanted the most outrageous, flamed, fancy, dazzling Koa all over, and he really couldn't be interested in spruce. Well, it's against my principles to turn down business, so I started looking for Koa, but I couldn't find anything that sounded like what I thought a top ought to sound like. At every stage of the voicing process I struggled with the guitar to make it sound good. Finally I said, "This is not happening." By that time I was already too far into it so I finished the guitar anyhow, hoping not to have to build another one. For some reason the guitar turned out to be a real nice one, and I still don't know why. The finished guitar did not sound like a spruce guitar; it had its own sound, but it was very good. So the answer to your question is that I still don't really know very much about Koa tops!

So I've chosen my design, decided on my species, and bought a pile of wood. Now I want to select individual pieces of wood out of my inventory. I've found that when the top and back panels are in rough unglued form, I can flex and tap them and get useful information. This information tell me whether or not to buy the wood. However, when I glue the two panels up into

a larger panel which is roughly square, I find that for most tops, even good ones, there's almost no way to hold and tap without getting a muffled sound. That's probably because the nodal points for this particular shape are too far in from the edge for the hand to grab them. So I try to refrain from making any decisions whatsoever when the wood is in this form.

Next, I cut the glued-up panel to the outline of the guitar before thicknessing it, and I find it will ring again when I tap it. In fact, it sounds better than it did before it was glued. My primary method of tapping when the wood is in this form is to hold the outside of the lower bout with one hand and to hold the other lower bout against my chest. I do this with the upper bouts of the top pointed upward. It usually sounds best when I tap from where the bridge will be, to the bottom edge of the top.

When possible, I hold off top selection until the wood is in this form. This is the last stage at which I can get hard information about what the wood sounds like before I have to commit myself to a specific top on a specific guitar. Tapping the wood in this form often reveals information that is not apparent in tapping the unglued panel, and I like to get the benefit of both stages of tapping before making my selection.

At Schoenberg Guitars, I built guitars in runs of 10, 15 or 20 at a time. I selected my top wood after it was cut to shape, then matched back to tops. After that I inlaid the rosette, cut out the soundhole, and began thicknessing.

As tops came off the sander I would flex them. When a top felt like it was at the right stiffness I would set it aside. Everything that didn't feel right yet would go through the sander again and have another 0.005" removed, and again I would set aside whatever seemed to be right. I kept that up until all of the tops were where I wanted them to be. When I was done, the tops would have varying thicknesses, but would be reasonably similar in stiffness.

One thing that I should note is that if I thickness a top and then put in the rosette, I always end up inadvertently thinning the top some more in the process of leveling the rosette. This defeats the purpose of thicknessing to a given point of flexibility. Unfortunately, when you try to tap a top with its soundhole cut you usually don't get any really nice clean notes. This is why I don't bother to tap the tops as I am thicknessing them.

The next thing is to brace the top. I do a little stiffness test when I'm making a batch of X braces. I cut the rough braces all to the same length and run them through the planer so that they are all the same height and width. I have a jig which supports the brace at each end and holds a dial indicator that bears down at the center of the brace. Then I hang a weight at the center of the brace and read the deflection on the dial. The particular weight that I use is a drill press vice which hangs from a hook made out of a coat hanger! Most braces deflect by 0.020" to 0.050", so I just write the number that represents the deflection of the brace. Low numbers are stiff braces, and high numbers are relatively flexible braces.

Ideally, I would test a lot of wood and throw away all but the stiffest tops and all but the stiffest braces. This way I would have the lightest possible top at a given point of flexibility, which would give me the most responsive possible guitar. When you're only building one or two guitars a year it's not terribly difficult to maintain ridiculously high material standards; but try being idealistic about wood selection when you're selling 100 guitars a year. Generally, though, I've been able to get excellent brace wood from people like Bruce Harvey and Steve McMinn. So,

being a builder in the real world I try to buy the stiffest and lightest wood available, knowing that I won't achieve absolute uniformity, and only eliminate wood which is flexible beyond a certain point. Then I deal realistically with what is left. If I have tops that I may have thicknessed beyond the optimum point of flexibility, I give these the stiffest braces. Also, if a top weighs too much, I try to match it with stiff brace material because I know that at least the brace material will end up being light by the time it is worked down to its proper stiffness.

So I have thicknessed my top and selected my brace wood. My braces are then preshaped on a pin router before being glued. They are intentionally oversized, perhaps by as much as 20%. Next I glue them to the top. I find, though, that tapping a braced top does not produce a clear enough tone to allow me to hear the results of making small changes in the shape of the braces. So this is another stage at which I consider the attempt to make more important judgments unreliable.

Next I glue the top to the rim. Then I can remove the top and sides from the mold and hold them up by the neck block. Now when I tap the top in the bridge area I get all kinds of response. To me, this is the point where it makes the most sense to finish shaping the braces, because now I can hear the results of even subtle changes that I might want to make.

When I am building a batch of guitars I make a work sheet to keep all of my information straight. I want to be able to know at a quick glance what species of top I'm using for guitar #1, what the individual piece of wood is (that is, what supplier, what log), the stiffness of the bracing, the thickness of the top, my impression of the stiffness of the top before it was thicknessed, and the weight of the top. I will also have comments as to whether I consider the top to have good bass overtones, good treble, whether it's very responsive, reasonably responsive, and so on. I look at my written information to try to figure out if anything is lacking in this guitar. I also listen to the top and the back to see if I can confirm this with my ears. The question is, is there anything that I can do to bring out something that may not be inherent in the wood or in the design of the guitar?

If the top is a very bright and stiff piece of wood, then what I will need to do is to bring out some bottom end, especially if it is something other than a dreadnought. So I'm going to try to loosen the top up a bit by working on the X braces and the tone bars to make them more flexible. At this point, I will be tapping as I am removing wood, and I will want to hear the results of what I am doing. When I am done, I will want to hear some top end, and also some bottom end, and, as a matter of fact, I will want to hear as many distinct different notes as I can get without letting the top get too flexible.

I can't really be too specific about how I decide what to do in any given situation. I don't have a method that is as precise as Bob Lundberg's method of voicing lutes. But I do know that if I want to bring out the bottom end of the guitar I'm going to remove wood in order to loosen up the top. If, on the other hand, the guitar is kind of thumpy and has a nice low rumble, but doesn't have a lot of high end, that means I may have made the top too flexible to begin with. When this happens, there's not an awful lot that I can do with it, except hope that the customer wants it that way. It's easy to bring the bottom end out because you do that by removing material and therefore loosening up the top. But the only way to bring out the top end is to start out stiff. That's why I like a stiffer than average material. When I make the top light enough to be responsive I want there to be some stiffness left.

At every step along the way, when you're thicknessing the top, matching the top to brace wood, and shaping the braces, it's better to keep it a little stiff than too flexible, although it's actually best to do it just right. At least if it's a little overbuilt, you can loosen it up later. Once you've gone too far, you're out of luck.

Does binding the top change the top significantly?

It probably changes it a little bit, but I haven't noticed enough of a change for it to foul up my voicing. The top often looses its tone and its springiness when the binding channel is cut, but it seems to get it all back when the binding goes on.

When you were working with Schoenberg Guitars, what were the range of finished thicknesses?

For OMs, tops ranged between 0.130" and 0.100", which is a significant variation. A stiffer than average but not outrageously stiff top would probably end up at 0.120". If that top got a set of braces that was also stiffer than average but not outrageously stiff, I would probably remove a moderate amount of wood from the bracing, and I would do a little perimeter thicknessing as well, which I will go into next.

A comment I want to make here is that in building an OM guitar, my approach to voicing is almost diametrically opposite to the one I use in building a dreadnought. The OM has an inherent bright, sparkling, singing treble end. There's something about the relationship of the scale length, the surface area of the top, and the air cavity that makes all OMs seem to work this way, regardless of who builds them. This is an example of the significance of design selection. It is difficult to build an OM that has a nice, rich bass with as much presence as the treble, so when voicing an OM, you're usually trying to make sure the top is not too tight.

The dreadnought is a different story. It has a naturally powerful bottom end which is pretty much going to be there unless you really blow it. The trick with a dreadnought is to make the treble register have the same kind of presence that the bottom end has. What I try to do in that case is to make sure that I don't make the top and the top bracing too flexible . I also make sure that I have an extra stiff brace on the treble side of the X. I want the top to be light enough in weight to be responsive, but I don't want it to lose too much stiffness, otherwise the height frequencies are going to suffer. Ultimately, a lot of your success in this case is going to be determined back down the line in the wood selection department.

I don't do a lot of voicing on the back. My backs are either 0.090" or 0.100" if they are rosewood, and 0.100" or 0.110" if they are anything else. This is determined by weight more than flexibility. When I match a back to a top I try to compliment the tonality of the top. If the top is extra bright I probably won't match it with an extra bright sounding back, unless I have a very specific reason for building it that way. I would usually look to compliment that kind of top with a back that has a nice dark, low ring. When I tap the back, I like to hold it the same way that I hold the top, with the lower bout against my chest. In order to be able to hear it, this must be done before bracing.

You can get a good ring out of a braced back by holding it as far in as you can in the general area of the waist. You have to move your hand around to find the right spot to hold it, but there are a lot of places that you can tap it successfully. This seems to work on the back because it doesn't have a soundhole.

I've noticed that in almost all the best old Martins I've examined you can get a lively response by tapping the back, and you can usually get more than one distinct note: so that's what I'm trying for. I suspect, though, that there's a lot more that could be done with voicing backs than this.

With the back glued on and all the braces shaped, there's one more thing I can do to bring out the responsiveness of the guitar if it's not already where I want it to be. That is to thin out the perimeter of the top. If I've done my job right up to this point, the top is going to sound great and I won't need to do anything more. But if I feel that the top is still a little heavier than it needs to be, I get out the hand plane and start working around the edge of the top.

There's a little trick I use to tell me how stiff the top should end up . I firmly tap the top in the bridge area with the end of my middle finger. Then instead of pulling my finger off I let it drag lightly on the top. When the top is too stiff it won't act like a spring and return the energy that's been delivered to it. When it's too limber it might be springy, but only if you tap it lightly. What I'm looking for is an immediate kickback when I tap it with a reasonable amount of force. When I get it just right, not only will there be an immediate kickback, but the vibration will have a reasonable length of sustain. The trick to being able to feel this is knowing how hard to tap the top and also knowing how hard to drag your finger on the top after the tap. It's pretty easy to damp the top if the pressure of dragging your finger is too great. Once you get the hang of this technique, though, it's real easy to monitor subtle changes in top response as you remove wood from the perimeter.

Once the top stops improving, I stop thinning right away and hope that I don't have to do a lot of cleanup. This is why I don't like runout wood. If I've got a tear that was caused by planing, I might end up removing so much wood in leveling the top that I go beyond the optimum point of springback.

When you're planing a top you want to work as cleanly as possible in order to minimize cleanup. It's okay to leave things a little ragged on the inside of the guitar, but it's hard to get away with it on the outside! You inevitably lose a little bit of mass when you clean up your top, but you also add some mass and stiffness when you apply a finish. With any luck, the cleanup and the application of finish will somehow balance out.

What, if anything, do you do with the bridge of the various models, or do you use a standard bridge?

Up until now, I have been building copies of Martin guitars, and within the limits of building copies one can only make very small changes in the bridge. However, design changes in the bridge can have an effect on the sound of the guitar. For example, the most recent guitar that I built had a real nice bottom end but lacked fatness and sustain in the top end - what I call a singing quality. Since it was not a copy of a traditional design I went to a slightly longer bridge with thicker wings and this brought out what I was looking for. I'm not sure why, because this is something that I haven't done a lot of experimenting with, but the change was quite noticeable.

You can also have a great effect on the sound by varying the height of your bridge and saddle, and this is really a matter of varying the set of your neck. A higher bridge and saddle will create more torque on the top and lower bridge and saddle will create less torque. Ideally, the stiffness of the top wants to bear a direct relationship to the torque under which it is loaded. A flexible top loses sustain if the bridge, and therefore the torque, is too high, and a stiff top will be too quiet if

the bridge is too low. I take this into account when I am building or repairing a guitar. At Schoenberg Guitars I had to live with the fact that the people at Martin set the neck; though we specified an average bridge height there were certainly some variations.

Do you prefer continuous linings, or do you use mahogany kerfed lining?

I use kerfed linings. Most of my building has been in the Martin tradition, and that is what has always been used. I believe that you can change the response characteristics of the top by the width of the lining you use, and also by the style of purfling; if you cut away the edge of the top for a very wide purfling you can get a different sounding guitar.

Do you have an opinion on the contrast between plastic and wood binding?

At this point, I don't. I don't have much experience that would lead me to draw a conclusion, and I'm trying to limit the advice that I'm giving out here to what I know from experience.

What can be done in the way of after-market voicing?

It depends on the instrument. If the guitar is severely overbuilt you can often go in and make a dramatic improvement, but you never have the benefit of having selected the wood. Nor do you have much information about it, other than it sounds terrible on whatever the guitar in question is.

How do you do it? It depends on what's lacking in the instrument and what you feel that you can bring out. The rule of thumb is that by removing brace wood you make the guitar bassier and at the same time more responsive - to a point. That works great if the guitar is too trebly and unresponsive. But if the problem with the guitar is that it is already over bassy then I don't know how the hell you would fix it.

Can you remove wood from the treble side?

Yes, but you're not necessarily going to get a brighter treble. You might get a more responsive treble, or a fatter, more sustaining treble. But you also might get a bassier sound all over, where the treble notes won't stand out in a chord. I don't know of a way to raise the resonant frequency of a guitar through the process of material removal. This is a good illustration of why I like to start with a stiff top and bracing material.

One could get a higher frequency by adding material. I've found that changing the bridge patch works best.

I can see that there are situations in which that would work. I usually find, though, that guitars that are overly bassy are that way because the top wood and the brace wood are too flexible to begin with. Adding a heavier bridge plate or adding a bigger bridge or adding a brace is only going to make it heavier, and that's going to cut into the response. But that might be an acceptable tradeoff.

There is one other thing, although it's radical; that is to augment the treble frequency of the guitar by enlarging the soundhole.

Again, there may be certain circumstances where the work may be quite viable. For example, your customer could be a Tony Rice wannabee!

When you're thinning the perimeter, do you pay much attention to the upper bout or are you concentrating on the lower bout?

I can usually get the results I want by concentrating on the lower bout. Sometimes in desperation I've tried thinning the upper bout. When things really aren't happening, I'll try anything not to have to build another guitar! Sometimes working on the upper bout seems to help, but usually not. When I do a fair amount of thinning, I usually feather back in at the waist.

I feel that perimeter thinning should only be a subtle correctional tool. If I've done my other jobs perfectly, I won't need to do it at all. You're probably not going to be happy with the end result if you've got too much to fix by the time you get to this stage.

How does a cutaway effect the tone?

I think that you get a little fuller sound without a cutaway, and that's why I've tried to design such a minimal one.

Does it have to do with the decreased air volume, or the decrease in the free-ness of the top's vibration?

Probably both. I would think that the more symmetrical a top is, the more efficient it is as an oscillator. I think that air volume has an effect as well. I find that the larger the guitar, the easier it is to make it sound pretty good; the smaller the guitar, the harder it is to make it sound pretty good. Of course, it's not easy to make any guitar sound truly great!

It would seem that the cutaway would affect the resonant frequency of the treble side?

I would assume so. It's lucky we don't have to put them only on the bass side! I don't know very much about the physics of what is going on. My method is mostly empirical, and I sort of try to keep it that way, at least as long as I'm getting good results.

Can you talk more about bridge patch selection?

A Brazilian rosewood bridge plate give you a little more high end response, all things being equal. Rosewood also tends to add a sort of reverby character to the guitar. A maple plate seems to just do the job of protecting the top without adding much coloration to the tone. Bridge plate selection is a relatively small part of your overall voicing scheme, but one thing I do to help the high register of a dreadnought is to use a Brazilian rosewood bridge plate. On OMs I use maple.

Cocobolo is easier to come by than Brazilian, so I've used Cocobolo for about five years.

There are a number of substitutes for Brazilian rosewood that seem to give a very similar sort of result. Cocobolo is one of them.

Are you striving for a constant interval between your bass and treble tap tones?

I don't listen to the pitch. I'm just trying to make the guitar responsive, and make the response as complex as possible. I want highs, lows, and mids, but the pitches aren't that important. I suppose they might be, but I wouldn't know how to control them and still maintain the point of flexibility that I am looking for.

Have you noticed differences using braces off the same billets and not off the same billets?

I mentioned that I measure the stiffness of my braces. If I number the braces that come off the same billet so that I can later reconstruct the billet - say a wide billet that's just high enough for one brace - and if I measure the stiffness of the braces, they can have radically different stiffness as you move from one side of the billet to another. I suppose that's because different growth eras of the life of the tree tend to produce structural differences. This isn't the case in every billet; some produce braces of a very uniform stiffness. To answer your question, I think the stiffness is more important than the billet that the brace comes from. I frequently use braces from different billets on the same top, and sometimes I even use braces of different species of spruce on the same top.

Do you have any observations about the placement and size of the soundhole?

I've mostly copies traditional instruments, so I haven't been able to experiment much with that. My soundholes range from 3-7/8"-4", and that's not much of a variation. I have always put the soundhole at the end of a 20-fret fretboard.

When you voice a top do you tend to stick to a basic Martin style of brace shape and bracing layout?

Because I vary my shaping so much, I can't really say that they all look like they could have been done by Martin. I suppose if you're being really critical you'd have to say that very few are identical. But, yes, they're in the same sort of style.

I've experimented a fair amount with bracing layout. This, by the way, is more of a design issue than a voicing issue. But I think that you can make considerable changes in the basic character of an instrument by changing your bracing layout. As I stated earlier, design is one of your two most important variables in shaping the sound of the guitar. If you're going after something that's truly different and you want to maintain consistency, then you have to be committed to going beyond voicing alone.

I do know that there is no one silver bullet that makes a guitar come out good or bad. I feel that a reasonably competent maker is going to build a guitar that reflects a given design, and also reflects the qualities of the individual pieces of wood that go into it. The process of voicing is simply a matter of optimizing the interaction of these factors.

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