SPECIFIC TOP THICKNESS IN THE GUITAR

(NOTE: this article is still in progress)

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Top thickness is, along with bracing, the most debated and tinkered-with area of guitar making. It is so for two absolutely important reasons. The first is that the physical characteristics of the top set the stage for tone -- along with the corollary that the lighter the construction of the top is, the better the sound. The second is that there's a minimal top thickness/stiffness that must be respected if the plate is not to cave in under string load. If *sound* is one's objective, then the luthier's balancing act is in finding the correct balance point between the imperatives of 'light construction' and 'not too light'.

In my work, I take my tops to a target deflection under a standard weight rather than to a predetermined, formulaic thickness. I've worked like this for a long time now and have written about my thinking and techniques at length. Still, my method may not work for everyone. There are a lot of guitar makers out there who swear by specific target measurements, and I'm not sure I have the right to say they're wrong to do so; my own preferred method is simply different. The question comes up, then, of what is the proper justification for focusing on one or another specific number for top thickness? And, what would that number be? Well, it seems to me that a good place to begin would be to have some idea of where the measurements that we *do* know about, read about, have heard about, and use come from.

PAST GUIDANCE AND WISDOM

Many of my generation of American luthiers got our start by reading Irving Sloane's seminal book <u>Classic Guitar Construction</u>, which appeared in 1966. This was, after A.P. Sharpe's 32-modest-pages long <u>Making the Spanish Guitar</u> (published in 1957) the first available 'real' book on guitar making. Sloane advised the reader to make his tops 3/32" thick -- which measurement is equivalent to.094", or 2.34 mm. Mind you, this instruction appeared before any of the two-dozen-plus books on lutherie that are now available, and before the plenitude of secondary sources of information that now exist. How did Mr. Sloane -- who was not only writing very early in the game but had, as far as I can ascertain, only built a few guitars on his own then -- come up with this number? Well, perhaps by reading Sharpe's book (he recommended the same measurements) and very likely by measuring some guitar tops and by talking with some makers.

He probably didn't speak with Vicente Tatay, one of the early Spanish luthier-transplants to the U.S., though. Tatay came from a prominent Valencian family of guitar makers and presumably knew what he was doing, guitar-making-wise, even before he took his plunge into the New World[1]. Once here, he wound up

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__FOOTNOTE 1)__ Officially, Tatay wasn't making 'classic' guitars. According to authority Richard Brune, this was in the days before Spanish guitar makers recognized any difference between 'classic' and 'flamenco' guitars; that distinction didn't take hold until as late as the mid 1950s. Until then, the guitar makers simply made 'guitars' to order -- either with cheap domestic cypress or expensive imported rosewood, depending on the client's budget. But while Tatay, who lived from 1889 to 1942, would not 'officially' have been making 'classic' guitars he was certainly doing so technically: he was following the techniques that informed the creation of soundboxes that merely weren't yet being called that.

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working out of a store in Greenwich Village and became, by so doing, one of Mr. Sloane's fellow New Yorkers. There's a wonderful article by Steve Newberry, published in American Lutherie ("Vicente Tatay and His Guitars", issue #66, Summer 2001, pp. 47-49) about the state of lutherie and its lore in the U.S. many years ago. It is told from the point of view of the author who, as a teenager, became fascinated by Mr. Tatay's work and talked him into being allowed to hang out in Tatay's shop after school hours and be of some help by sweeping, cleaning, etc. In exchange he got to observe Mr. Tatay at work, of course. This turned out to be a mixed pleasure: Mr. Tatay is described as having been a gruff, cantankerous, cranky and closed-mouthed chain smoker who had an explosive temper and spoke only Spanish. Still, one afternoon toward the end of the Summer, in an uncharacteristic moment of expansiveness and letting down his guard, Mr. Tatay motioned the young Newberry over to his workbench and, using hand gestures and some coins, indicated to him that the secret to his lutherie was to make the guitar top about *the thickness of a nickel* in the middle, and *the thickness of a dime* at the edges. (I should add that a lot of Spanish guitar making in those days was done just like that: by skilled feel and eye, and with amazing accuracy.) Tatay might or might not have known the numerical values of his thicknesses but he certainly knew how to work to such tolerances at the workbench. Incidentally, the breadth of a nickel and a dime are .075" and .050" (i.e., 1.9 mm and 1.34 mm), respectively. Give yourself a treat and look that article up; it's as well written as anything Mark Twain ever wrote.

Four other books on guitar making followed Irving Sloane's pioneering work on guitar building. Classic Guitar Making by Arthur Overholtzer, published in 1974, immediately doubled the available information on this subject[2]. The other three

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FOOTNOTE 2) *The earliest photograph of me as someone involved in woodworking appears in this book, on page 21. It was taken in 1972 in back of MacBeath Hardwoods, in Berkeley. The store had received a shipment of Brazilian rosewood and had given me a call to drive over and pick out some. About a hour after I arrived a van full of the Overholtzer contingent pulled up, disgorged itself like the proverbial Thousand Clowns, and they started going through the same pile. The man standing with Mr. Overholtzer is Mr. MacBeath senior, the owner. I'm the bearded guy in the background. The planks of wood on the scale (it was being sold at a princely $1.25 per pound!) next to these gentlemen were the ones I'd already picked out.*

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were Donald Brosnac's The Steel String Guitar; Its Construction, Origin, and Design (1973), David Russell Young's The Steel String Guitar; Construction and Repair (1975), and Irving Sloane's follow-up book Steel String Guitar Construction (1975). These were the first sources of published information on the steel string guitar and their recommended guitar top measurements were 3/32" (.094"), 3/32" (.094"), and 7/64" (.109"), respectively. Overholtzer's top measurements took into account wood density: for classic guitars his recommendations are 3/32" (0.094") for soft spruce and 1/16" (.062") for hard, dense spruce. For steel string guitar tops he recommends 3/32' to 1/8" (.094" to .125").

With the exception of Mr. Overholtzer, who had been a violin maker for some years previously, the others were pretty much acting as novice discoverers, craftsmen, and pioneers -- as I myself was, except that I hadn't written a book yet. I think it's safe to assume that these young makers/authors were following each others' and the Martin Company's leads; and I was certainly following theirs. The Martin Guitar Company comes into this discussion because it was the premier steel string guitar producer of that time and would have been everyone's main point of reference for making that kind of guitar. Mr. Sloane, whose second book Guitar Repair (1973) focused on steel string guitar repair procedures, was surely on this track: the book was photographed on the Martin Guitar factory premises, and the repair procedures that are described were carried out on the Martin company's workbenches. Ditto Mr. Brosnac; I asked him, in a recent conversation, where he got his book's recommended measurements from; he told me that he got them from Jon Lundberg, the legendary Berkeley-based Martin guitar retro-voicing pioneer, who was in those days possibly the world's leading expert in that guitar[3]. Both Overholtzer and Sloane seemed to take a lot of cues toward their classic guitar making from the work of Robert Bouchet (1898-1986), a noted and innovative French builder.

FOOTNOTE 3) *I was living in Berkeley myself in those days and knew Jon Lundberg; he owned and was running Lundberg's Music store, a great magnet for friends of the steel string guitar. Richard Johnston, who has recently written two comprehensive books on the Martin guitar's history, was working for Jon Lundberg at the time; I remember exditedly walking into that store and showing Richard the very first guitar I ever made. Don Brosnac was living in San Francisco then. All of us in this small community knew one another.*

In 1987, twelve years after the last of the above books was published, the bibliography of guitar making took a major step forward when William Cumpiano and Jon Natelson published Guitarmaking: Tradition and Technology. This was the first book to address making both classic and steel string guitars and its recommended top thicknesses were the most comprehensive yet in recognition that not only does size of guitar and species of wood used make a difference, but that different makers have significantly different building designs and ways of using their materials. Accordingly, top thicknesses are suggested rather than instructed. Top thickness targets for classic guitars are given as around .100" (2.5 mm) for spruce and .110" (2.8 mm) for softer wood such as cedar. For steel string guitar the recommendation is 1/8" (.125", or 3.17 mm) for a first-time project, but otherwise ranging from .095" up to .130" (2.4 mm to 3.30 mm) depending on size and shape of instrument as well as species of wood used. One can see that thinking about top thickness was getting more sophisticated.

CURRENT RULES-OF-THUMB FOR TOP THICKNESSES

So, according to published instructions to those dates, top-measurement for classic guitars are[4]:

1/10" (.100") to 7/64" (.110"), **or** 2.5 mm to 2.8 mm;

3/32" (.094"), **or** 2.34 mm;

And for steel string guitars, they are:

3/32" (0.094"/.095") to 7/64" (0.109"), **or** 2.38 mm to 2.77 mm;

and from 1/8" (.125") to a fat 1/8" (.130"), **or** 3.17 mm to 3.30 mm

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FOOTNOTE 4) *For the record, and chronologically, here's what later authors have recommend for top thickness:*

1971, The Classical Guitar, by Donald Mcleod and Robert Welford: "between 2 and 3 mm" (This is a British book, unknown to Americans until much later than its date of first publication)

1981, Make Your Own Classical Guitar, by Stanley Doubtfire: "2 mm at the minimum".

1986, A Guitar Maker's Manual, by Jim Williams: .125" (3.2 mm) for steel string guitars, and .100" (2.5 mm) for nylon string guitars

1993, Making Master Guitars, by Roy Courtnall (classic guitars), including:

(1) Daniel Friedrich: 2.1 mm in the middle; 2.2 mm at the

periphery; 2.5 mm in upper bout (note that this is the only maker on this list who makes his tops thinner in the middle! I know that luthier Dake Traphagen has worked the same way, but this technique has to be the subject of a separate article)

(2) Jose Romanillos: appx. 2.75 mm in the middle to 2.0 or 1.9 mm at the edge

(3) Robert Bouchet: 2.0 to 2.1 mm thickness overall

(4) Roy Courtnall: no less than 2.5 mm in the middle, or 2.0 to 2.3 mm at the edge

1996, The Guitar Maker's Workshop, by Rik Middleton (classic guitars):
2.5 mm at the center to slightly less than 2.2 mm at the edge, but not less than 1.5 mm

2004, Build Your Own Acoustic Guitar, by Jonathan Kinkead (steel string guitar):*
"1/8" (3 mm)"
** also spelled Kinkade throughout the book*

2006, Step-By-Step-Guitar Making, by Alex Willis (steel string):
3/32" (2.5 mm) at center, and 5/64" (2 mm) at perimeter

2007, Classical Guitar Making, by John Bogdanovich (classic)
.100" under the bridge, and .090" to .095" otherwise
*1/16" (.0625"), **or** 1.59 mm;*

*Mr. Tatai: 0.075" to 0.050", **or** 1.9 mm to 1.34 mm (the thicknesses of a nickel and a dime)*

Does this get us anywhere? Well, sort of. It tells us that, at least in the classic guitar, one can go as thin as 1/16" (about 1-1/2 mm) and still have the instrument hold together. That's useful to know -- as is the fact that Overholtzer is in a minority in promoting such thinness; he and contemporary luthier Greg Smallman go remarkably thin, but very few others follow suit. As for steel string guitars, we have no published accounts of whether there is a top-thickiness limit that's below 3/32"; if anyone one has tried to push that envelope they haven't written about it.

I'll address some additional specifics further below, but for starters you should know that Tatay's top-shaping approach is the traditional one used by Spanish classic and flamenco guitar makers: the top is made to its target dimension in the middle but it is thinned in the outermost inch and a half or two of the lower bout, from the waist down. We know this because work of this type is found in the instruments of established classical guitar makers whose work has been carefully measured and studied. Experts can even date certain classic guitars through specific variations in their measurements, which will have been documented from the various periods of their makers' careers[5].

> ***FOOTNOTE 5)*** *I should add, as a caveat, that the canonic 'Spanish lutherie tradition' is Andalusian and Madridean -- where the most famous Spanish luthiers worked -- but not Valencian. Valencia, the home of the Tatay family, is on Spain's East coast; and it seems to have been more a center of production-oriented lutherie. According to Google, the Tatay Company has grown into a concern that currently produces 40,000 instruments annually. As far as I know, no Andalusian or Madridean maker operates at that level. Also, in illustration of the importance of the Valencian school in Spanish guitar making, the Casa Zavaleta's (Zavaleta-guitarras.com) inclusion on Google cites more than two dozen historical guitar makers of that school and region.*

Flamenco guitars, unfortunately, lack the social and academic respectability of their rosewood-built brothers and have not received such formal attention; they get played a lot but not studied. Ditto steel string guitars. And speaking of these, Sloane's and Overholtzer's recommendations of uniformly thick classic-guitar-top measurements, previously cited, actually come out of the steel string guitar making tradition in which the top is the same thickness throughout, without any selective tapering or thinning.

VARIATION AND INCONSISTENCY

While both steel string and nylon string guitar makers tend to follow their own top thickness recipes, the former work to top measurements that are far less agreed upon or consistent than are the target measurements for the latter. Therefore those measurements -- ranging, as we've seen, from .094" to as much as .130" -- are not so useful to rely on as guides. This great variation is attributable to six main influences, the most important two of which I consider to be the following:

First, there *needs* to be a lack of dimensional consistency from maker to maker in steel string guitars because steel string guitars come in so many shapes and sizes. This itself is a function of industrial priorities of (1) needing to make one brand of guitar distinguished from another in the marketplace (hence different physical parameters), (2) different orchestral uses for the guitar as the provider of mass musical entertainments, and (3) the need to make mass-market products durable. There is a legitimate logic for producing workhorse/beater guitars in a mass-entertainment culture: consider the fact that there is nothing like Willy Nelson's guitar among classic musicians.

And second, in the absence of a craft tradition in which independent luthiers ongoingly seek ways of refining their work, the newer generations of steel string guitar makers have -- knowingly or not -- been copying copies of copies of copies of copies of copies of copies . . . of mostly Martin guitars, but also Gibsons, Guilds, Harmonys, Epiphones, etc. [6]

FOOTNOTE 6) *A strong third reason -- besides the absence of a strong crafts tradition, but closely associated with it -- is the absence of a strong teaching tradition. I won't beat the existing guitar schools up for doing the best they can: they are all, after all, fairly new arrivals on the scene. But their efforts don't (and cannot) extend past a beginner's level education in making-and-assembling-guitar-parts. This education lasts as little as ten days to as much as several months. It's a great starter kit but, necessarily, cannot be more than that.*

In comparison, there are respected schools of furniture making that turn out competent journeymen craftsmen and which put their students through several years of training -- which includes design, proportion, a variety of woodworking techniques, history, joinery, and *finishing. The better violin-making schools have a four-year curriculum! A large part of the problem is that many people simply don't know that there's any more to making a guitar than its just being a more complicated woodworking project than, say, making movie sets. You know: looking good but nothing substantial behind the façade. I think you can appreciate that just learning to put a guitar together -- with very little actual joinery (sand-flat-apply-glue-line-it-up-and-then-clamp-it is not a difficult skill to master) or tone-making savvy going on -- is not going to provide a realistic foundation for any kind of success. A hobby, maybe; but not an income. The other important influences are:*

* *Even if we were to consider that a viable craft tradition in this area has by now been established, there has been an absence of individual makers whose work is important enough to have set a standard worth studying. Lutherie by skilled individuals is too new. The importance of a viable craft tradition is that craftsmen -- if they are paying mindful attention to the work and their materials and not simply working to recipe formulas -- are in effect continually seeking and prototyping new designs.*

* *Any interest in the qualities of steel string guitar construction and its relation to sound has been a scientific backwater. These instruments have been mostly considered folk instruments, designed to be bought and played, period, and uninteresting enough to be seriously looked at. They have lacked the cachet of having been subject any systematic, serious examination by scientists. Almost all of the studies that have been published are about classic guitars.*

* *The whole kit-and-caboodle-issue of the relationship between structure and sound has been bypassed by a focus, among manufacturers as well as players, on the use of amplification. Who needs to worry about the fine points of dimensional optimizing when one knows that consumers will expect to get their sound by plugging their guitars in and setting the dials of their amps and effects modules?*

* *Finally, there's the bedrock influence of the Industrial Revolution. Three paragraphs before this footnote citation I'd mentioned that Sloane and Overholtzer's recommendations of uniformly thick classic-guitar-top measurements actually come out of the steel string guitar making tradition in which the top is the same thickness throughout, without any selective tapering or thinning. This itself is rooted in the Modern Tradition of Industrial Production in which the wood is put through a sander, followed by the braces being glued onto the thinned-to-a-target-measurement plate that the machine spits out at the other end. There's much less craftsmanship, hand-work, or time-consuming concern with the fine points and subtleties expended in what are, basically, mass-produced products for a mass-market. The academic and intellectual implication of*

this is that if and when such instrumenets are formally studied, the results are based in the study of instruments that have all been made under these conditions, with no control group of a different architecture to compare against.

While copying -- or imitation, as Oscar Wilde put it -- is the sincerest form of flattery, it does cut down on investigation, discovery, originality, increased understanding, and improvement. Nonetheless, copying copies of copies of copies of copies of copies has worked well enough for a long time, and the top thickness measurements put forward in various books and plans are generally taken more or less as givens without being questioned. For that matter, how could it be any different unless one has had any other experience to compare against?

More important than this blind acceptance, though, is that, more or less by default, these guitars' sound is attributed to this or that variation of "X" bracing (or fan bracing) rather than to any more reasoned and optimal thicknesses of soundboards. As far as steel string guitar making goes, ways of refining and fiddling with "X" bracing and its offshoots have consequently received *lots* of attention. Look in any modern guitar magazine for pictorial examples of this: every brand has its own version of the "X" with different angles, different scalloping and profiling of the main legs of the "X", different height of their intersection, variously profiled finger braces, differently spread tone bars, etc. No one ever mentions differential top thickness, basic plate tapering, etc.[7]

FOOTNOTE 7) *This is a generalization, of course: there have been Spanish guitar factories cranking out guitars just as efficiently and formulaically as anything that these steel string guitar factories have done -- with similar results as far as tone goes. But I believe this generalization holds up as containing some useful truth.*

Also, the phenomenon of no one ever mentioning top thickness is merely a public one and, in private, it is not true that these dimensions go unquestioned. Many luthiers are fascinated by the idea of "correct" top thickness and live with a nagging suspicion that there may be 'better' top thicknesses out there than the ones they're using.

When luthiers get together the question 'how thick do you make your tops?' is frequently asked. And makers often feel protective of that specific piece of information, if theirs differs from the norm.

And other makers don't. An example of this comes from a conversation that I once had with flatpicker extrairdinaire Dan Crary. He told me that when Bob Taylor -- whose guitars Crary has long played and endorsed -- took him on a tour of his production facilities, Taylor explained to him the tonal reasons for his guitar tops' being made to exactly .109" thickness.

Incidentally, none of the methods, techniques, procedures, or measurements so far mentioned are "wrong". Far from it. All of them are merely an account of How Things Have Been Done At This Or That Time. And all of them offer a peek at Truth. One can appreciate this by noticing, for example, that none of them urge that guitar tops be made 1/4" thick.

MY OWN EXPERIENCE

I've made my steel string guitar tops thinner and lighter over time; I've found others' typical construction to be too heavy. I've used many variations of "X" bracing in them, and even tried fan-bracing on a few. I've also made my Spanish guitars with thinner and thinner tops; I've mostly used traditional fan bracing on them but have done a little lattice bracing also, and even some "X" bracing.

The upshot of this trajectory is that I like the sound of my steel string guitars with comparatively thin tops and coupled "X" bracing, more than I like the sound of my (and others') classic guitars that have thin tops plus either fan bracing or lattice bracing. I find that I can get a rich, deep, and pleasing sound from my thinnish-topped steel string guitars. But classic guitars with thin tops -- both my own and others' -- have a quality of sounding a bit sharp, or harsh, or spare, and in general musically uninteresting to my ear, even though they may be loud. I like a richer, mellower, more complex sound. If any of you have heard the sound of a Friederich [also spelled Friedrich much of the time] guitar you'll know what I'm talking about.

These are, admittedly, my personal preferences. But they are also shared by many others. Matters of tone have both subjective and objective components, of course. The objective part has to do with the things that tonewoods are known to realistically do when worked to this or that thickness. The subjective part has to do with musical tastes and with whether or not these woods produce sound and tone coloration that give pleasure.

In this regard, in the matter of nylon string guitars, we can return our attention to the matter of the differences between Sloane's and Tatay's recommended Spanish guitar top thickness. You'd expect that guitars with tops .094" thick would produce sounds different from those produced by guitars with tops tapered from .075" to .050", wouldn't you? But, oddly, along with the various instruction to "do it like this" or "do it like that" that appear in various books there's no accompanying explanation of just exactly what it is that you get if you follow those recommendations. Sometimes, in the more scientific presentations, there are graphs or photographs of testing for monopole, dipole, and tripole Chladni patterns; these show that these guitars do have clear monopoles and dipoles, etc. **[See Chladni photos from p. 121 of <u>Engineering The Guitar</u>]** It is useful to know where various vibrational areas are most dominant, and at approximately what frequencies these tend to be most active. Most readers will not be sufficiently sophisticated to get more than this fundamental sense of how the average guitar works, though; I'm certainly not. And one is still left to infer many things from the sizes and shapes of the various blotches and wiggle-patterns in the photos. I have found them to not be of as much use as I would have liked in trying to understand some of the more specific aspects of frequency response.

An important clue is contained in Steve Newberry's article, previously cited, when he states that Tatay's guitars were *loud* (emphasis his; he really wanted to make a point). Interestingly, other words that are used to describe an impressive sound are: 'powerful', 'brilliant', 'projective', 'full', 'rich', 'resonant', 'piano-like', and so on. "Loud" merely suggests *volume* -- a quality that is basic and not likely to imply character or complexity. I mean, when is the last time you heard any kind of explosion or crash described as being, say, rich or resonant? Also, the sound of an exploding volcano or an avalanche would probably be described as a *roar* instead of merely *loud*, which suggests the preponderance of a certain segment of the frequency spectrum, so I'm of the opinion that colloquial speech carries more information that one might at first think. In fact, many "sound" words such as bang, roar, thunk, and crash are onomatopoeic; that is, the word captures something of the actual sound it's identifying. But before exploring this further -- which we will do further below in the section titled 'Correct Top Thickness' -- let us take a brief look at how woods do their tonal work.

WOODS' AND GUITARS' VARIOUS ACOUSTICAL TASKS

Tonewoods, by definition, make a sound -- all by themselves. You have only to tap the good ones to get a surprisingly bell-like ring, when they are suspended in the air while held from just the right nodal spot. Compared with ordinary woods that merely go *thud*, *thunk,* or *boink* regardless of how or where they are held, such a response indicates a liveness and, especially, a high-frequency capacity. Indeed, tonewoods are sometimes described as being *vitreous*, which means glass-like -- and of course having the ringing and sustaining vibrational quality associated with that material. If you tap these same woods while holding them at different nodal points they will also give you a lively and sustaining low-pitched hum. Such woods can do it all. Many rosewoods, spruces, cedars, redwood, cocobolo, wenge, padauk, etc. are *bona fide* tonewoods[8]. *[note; footnote is on following page]* Bubinga, teak, maple, cherry, oak, ash, African blackwood, zebrawood, Goncalo Alvez, ebony, olive, myrtle, koa, walnut, bocote, ziricote, and mahogany are generally not -- or very little, at best.

There are significant differences between steel and nylon string guitars. The woods might all be the same; but the stringing, structure, and mechanical tensions these guitars operate under are hugely different. Steel string guitars want to produce a bright sound, not a bassey one, as a function of their basic construction and stringing. The natural voice of the fan-fretted nylon strung classic guitar, on the other hand, is the opposite: the bass is normally stronger than the treble. This is likewise a function of its basic design, construction and stringing.

> ***FOOTNOTE 8)*** *Brazilian rosewood (dalbergia nigra) was originally used to make marimbas: the sections were simply cut to size and length that would produce a specific musical note!*
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> *There is, in addition, a separate category of guitar making woods that are also called 'tonewoods' but really aren't so in this sense of the word. That is, they are used for making guitars and will of course therefore make sounds, but they don't have anything like the vitreousness of true tonewoods -- or perhaps only a little bit. There are also selections of normally 'live' woods such as rosewood, spruce, cedar, etc. that don't give you much sound: that's where proper wood selection comes in. A large separate category of not-very-live woods, furthermore, is made up of the visually spectacular*

species such as the figured/ornamental maples, walnuts, and mahoganies. Figuring is a direct function of plentiful movement and irregularity in the grain; the greater the figure the crazier the grain. This feature always makes such woods less stiff than a straight-grained sample of the same material is, and therefore less able to vibrate in a vitreous, sustained manner; they're ropey and floppy rather than brittle. The sheer beauty of such woods sometimes makes up for their less-than-full sound, but the fact is that such materials serve, mechanically, to absorb string energies rather than to move with them. The sound will consequently be shorter in duration (less sustain), and will be mellower, less rich, and with less bite and sparkle. Nonetheless, under string load, all of these will make sound.

Finally, I admit that I'm giving voice to my prejudices with a bit of factual information to justify them. The fact is that all kinds of really successful guitars have been made with exactly such "unsuitable" woods. I'm merely describing gradations of qualities, not absolutes. The real key is not what selection of wood you may have made, but what you'll do with it. Keep in mind that beauty contests of all kinds, in which there's a "best" followed by a bunch of "runners up" is one of the great artificialities of human culture. If this weren't so, then only the lucky man married to the one single "best" woman would ever be happy and all the rest of us would get assorted runner-ups and rejects. Along those lines, I believe that Donald Trump believes that he has the best of the best in everything.

Yet, these are not at all the desired target sounds for these instruments. In any discussion about classic guitars it is essential to recognize that the 'best' instruments have treble notes that sound *brilliant*. They not only stand up to the bass notes, but they have their own very clear identity: that's the standard by which these guitars are judged. 'Best' is here defined by the 'romantic' standard that Andres Segovia created, and which standard is still applied even to the newer classic guitars with thinner tops (about which I'll say more further below). When an experienced classic guitar player puts his hands on any guitar that he's never played before, his left hand immediately goes to the twelfth fret position and the first notes he plays will be the high ones; it's the acid test, pretty much the first thing one does. It's sort of like stepping into a new racing car and immediately revving the engine to get a sense of its power.

And what is this *brilliance*? Well, listen to some of Segovia's early recordings in which he plays expressively and romantically. He emphasizes some of the high notes in such a way that their smoothly accented *ping* becomes part of the romantic sensibility of the song. Those notes are rich, very musical, and they *sparkle*.

On the other hand, in any discussion about the steel string guitar, the 'best' ones are those that have a full, good, solid, vigorous, punchy, present, and open low end response. Historically, the quest for a strong bass response has been the main factor behind the creation of the larger steel string guitar bodies such as the dreadnoughts and the jumbos. Low-end response is important in the steel string guitar; but smaller soundboxes can't give it easily. (It is interesting to note that the Spanish guitar, in spite of having every opportunity to grow physically bigger along with its metal-strung cousin has -- with only one technical exception -- not done so. That exception is the Mexican *mariachi* bands' bass guitar, the *guitarron* -- which has a specific target sound and muscal use that is its own. The traditional classic guitar has long since found its optimal size.[9])

FOOTNOTE 9) *The physics of sound-producing energies dictates this. It takes much more energy to generate bass response than it takes to generate high-frequency signal, and the nylon string guitar has a much smaller energy budget than the steel string guitar does. If you designed a nylon string guitar to use that limited energy for bass response (as in the guitarron), you wouldn't have much treble response at all.*

I think it is to the guitar's credit that while its various standard designs and stringings produces sounds that are not, as I said above, the ideal target responses, the guitar's design has sufficient internal and dynamic flexibility that any soundbox can be tweaked so as to bring out and emphasize the target frequencies. This is where the luthier's skill comes in -- and within the larger context of making Spanish and steel string guitars, the luthier's challenges in making either one of these models of the guitar are directly opposite. I repeat: to achieve a good target sound in the steel string guitar the maker has to 'build in' a good bass response, which the instrument will normally lack. In the nylon string guitar -- to achieve a good target sound -- the maker has to 'build in' a good treble response, which the instrument will otherwise lack. (NOTE: these things are precisely the topic of chapter 32 of my book <u>The Responsive Guitar</u>.)

TONE PRODUCTION AND THE LOGIC OF MATERIALS USE

Bass response is associated with a top membrane that is loose enough, while also sufficiently 'held together' with bracing, to move as a single unit. This can be visualized as a sail that is billowing in and out under the wind. A thin, relatively flimsy top that is held together by any interconnected latticework of bracing will be able to billow back and forth, in unison with itself, and at relatively low frequency. In the guitar, this is called *monopole* movement[10]. Furthermore, any

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> ***FOOTNOTE 10)*** *To further underline the importance of looseness to the billowing action, imagine a ship with sails made of plywood; the billowing action will pretty much cease. While loss of monopole is not disastrous in a sailboat (it merely needs adequate surface area of sail, without it being so heavy that the boat will capsize), a guitar needs topwood that will move.*

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specific high-frequency potential or behaviors of the topwood -- i.e., of the material itself, independent of the interconnected bracing lattice -- are not so relevant to this mode. This is because metal strings themselves, by virtue of their own mass and stiffness, will bring plenty of high frequency signal into the system. One doesn't need the wood to bring its own additional high-frequency contribution into the soundbox.

On the other hand, treble response is associated with a top membrane that is stiff enough to allow high-frequency/low amplitude motion, and which is not simultaneously 'drowned out' or overshadowed by dominance of monopole movement. The more the monopole is suppressed, and the top is prevented from moving like a sail or undulating like gentle waves -- and the more it is enabled to move in rippling fashion in small-to-tiny sections -- the better the high end. This is usually identified in the literature as *dipole* and *tripole* movement. Put in different words, the more that the top discharges its energy by billowing in and out like a bellows or a sail (*monopole*), the less energy is left over for the high end (*dipole* and *tripole*). And vice-versa. As with electronic speakers, it takes much more energy to produce low-frequency sound than it does to produce high-frequency sound.

The trick, obviously, is to not make the plate so loose that you lose the high-frequency end, nor so tight that you lose the low-frequency end. You want both, and the luthier's task essentially becomes one of management-of-energy-budget. And thus, at this point, the question of 'correct stiffness' can finally meet up with some numbers that are associated with 'correct thickness'.

SOME PROBLEM-SOLVING TOOLS

I've discussed the Cube Rule enough that I don't have to repeat it here, except to remind us that it applies to length as well as height or thickness. In the matter of length, however, the Rule is *inverted*. The longer something with a weight on it is, the more it sags ; the shorter something with the same weight on it is, the less it sags -- *all in accordance with the Cube Rule.* And, we should be speaking of *deflection* instead of *stiffness* in these matters: stiffness is, strictly speaking, a quality that is independent of dimension.

Furthermore, if we're comparing stiffnesses and deflections, the fact is that you don't get the same difference going "up" from smaller to bigger as you do when going "down" from the bigger to the smaller. Cubed quantities don 't yield multiplicative proportional differences like that. For instance, reducing 100 by 10% brings you to 90, but increasing 90 by the same 10% doesn't get you back to 100; it only gets you up to 99. You can get different results with the math if you're not careful[11].

FOOTNOTE 11) *You can get a fuller sense of this by looking at a table of cubed quantities. You can immediately see that the Cubed intervals are bigger in one direction and smaller in the other.*

CUBED NUMBER	*INTERVAL DIFFERENCE*	*CUBED NUMBER*	*INTERVAL DIFFERENCE*
1 cubed = 1	*1*	*14 cubed = 2,744*	*547*
2 cubed = 8	*7*	*15 cubed = 3,375*	*631*
3 cubed = 27	*19*	*16 cubed = 4,096*	*721*
4 cubed = 64	*37*	*17 cubed = 4,913*	*817*
5 cubed = 125	*61*	*18 cubed = 5,832*	*919*

6 cubed =	*216*	*91*	*19 cubed =*	*6,859*	*1,027*
7 cubed =	*343*	*127*	*20 cubed =*	*8,000*	*1,141*
8 cubed =	*512*	*169*	*21 cubed =*	*9,261*	*1,261*
9 cubed =	*729*	*217*	*22 cubed =*	*10,648*	*1,387*
10 cubed =	*1,000*	*271*	*23 cubed =*	*12,167*	*1,519*
11 cubed =	*1,331*	*331*	*24 cubed =*	*13,824*	*1,657*
12 cubed =	*1,728*	*397*	*25 cubed =*	*15,625*	*1,801*
13 cubed =	*2,197*	*469*			

Let's assume that you've been making pretty successful dreadnought guitars with tops at .090". Dreadnought soundboxes are 21" long and have scale lengths of 25.4". Let's also assume that you've been commissioned to make an 18" long parlor guitar with the same scale length, and it of course needs to also sound good. It would make sense to figure out the logical top thickness of that 18" length guitar, based in your current 21" guitar criteria; you'd want a number that represents *equivalent deflection*; these guitars would both, after all, be functioning under the same string load. Interestingly, there are two distinct methods whereby one could arrive at an answer: an intuitive one and a mathematical one. In the interest of comprehensibility, I'm going to describe only the former; the latter is full of complicated mathematical formulas.

THE INTUITIVE METHOD

Let's start with the fact that Guitar A is 21" long and Guitar B is 18" long, and that the difference in lengths is 3".

3/21 = proportional difference in length, from the point of view of Guitar A, is about 14%
3/18 = proportional difference in length, from the point of view of Guitar B, is about 16%

It won't work to assume that differences of 14% and 16% can be considered to average out at 15% for the sake of convenience. *Guitar B is 14% shorter than Guitar A*, and *guitar A is 16% longer than guitar B.* We need to work with real numbers and we can't get around this.

We could do some math around the above quantities, again keeping in mind that (1) deflection changes geometrically with thickness, and (2) geometrically *as the inverse* of length, and (3) that the math will give you different numbers depending on whether you're going from smaller-to-larger or larger-to-smaller. A

14% loss or a 16% gain in length means that these guitars can be designated as having lengths of 1.00 and .86, or 1.00 and 1.16. (It would be a bad idea to label these guitar tops as 1.16 and .86 respectively; we'd be counting the difference twice.) On the other hand, the math for this involves both direct and inverse Cube relationships and it gets just a little a bit tedious.

So, instead, one could cut to the chase by recognizing that, precisely because we are dealing with Cube and Inverse Cube quantities, the *change in measured deflection from a 14% decrease in length* will be "cancelled out" by a *14% decrease in thickness*. The Cubed loss/gain of one will match the inverse of the Cubed loss/gain of the other. As a basic example, if you make something twice as long you weaken it to 8 times the original deflection; if you make it twice as thick you *increase the measured stiffness to 1/8 as much deflection* (even though thinking of "increasing stiffness to less deflection" sounds confusing). In any event, 1/8 x 8 = 1, and net gain or loss are cancelled out.

I repeat: the longer something is, the more it sags under a weight (larger deflection number); the shorter something is, the less it sags under the same weight (smaller deflection number). Now, remember that we're at 14% and 16% levels of size difference, depending on which direction you're looking at this from. If we're making 21" guitars at .090", then we'd make 14% shorter guitars 14% *thinner* for them to have equivalent measured deflection. The .090" top would become a .0774" top. That seems easy. But that's not the whole story: the guitar top's *width* also has some bearing on the top's stiffness.

FACTORING IN THE PLATE WIDTH

An 18" long guitar is 86% the length of a 21" guitar; and it will probably also be narrower by some proportion. Let's assume that the 21" guitar has a 16" lower bout and the 18" guitar has a 15" lower bout. I repeat yet again: thickness/height varies as the Cube; length varies as the inverse of the Cube; and width affects stiffness in a linear way.

The math for making these adjustments *with respect to equalizing stiffness* is interesting because translating width measurements into thickness measurements (as when a *narrower* guitar top needs to be *thicker* in order to maintain constant deflection, or when a *wider* top needs to be *thinner* in order to maintain constancy of deflection) involves translating a *linear* quantity into a *cubed* or *cube-root one*. Finally, the 16" to 15" shift is an approximation because these are not rectangular plates.

We can deal with these numbers as follows:

Guitar A is 16/15 (106%) the width of Guitar B,
and Guitar B is 15/16 (94%) the width of Guitar A;

Therefore, as far as plate width influencing plate thickness goes:

Guitar A, being *wider* than B, needs to be *thinned* by the *cube root* of that 106%. Reciprocally, guitar B, being narrower than Guitar A, needs to be left thicker by the cube root of the percent of difference. These calculations will yield small numbers -- something on the order of .002" .

One can more easily affect these numbers by how one braces the top: it's otherwise very difficult to remove exactly .002" of wood. Metal, yes: machine shops do that kind of work all the time; but wood shops, not so much. Otherwise one can get calculation-happy very quickly by trying to figure out these balancing acts mathematically. I can tell you, however, that after a while one simply develops a feel for what is right. And the math is still a useful, if cumbersome, guide for whenever one has a project that is way outside of one's experience. If you really want to go ahead and remove small amounts of thickness forget about using sanders and learn to use a hand plane.

Finally, one would think that a smaller guitar *will be more stressed per inch of top* than a larger guitar -- because the considerable pull of the strings is spread out into a smaller top plate; each inch of top has to hold up to more pull. That certainly sounds logical, yet it is incorrect *-- because of the inverted Cube-Rule relationship between area and resistance to deflection.* As we've just been learning, a larger top plate is looser than a smaller one of the same thickness, in direct proportion to the Cube Rule. Therefore one can legitimately say that a larger guitar top will be more stressed per inch than the one on a smaller instrument, because its top will be *more yielding* to the strings' pull. Each square inch of a larger top has less ability to hold up to string pull than each sauare inch of a smaller top of the same thickness. What we're seeing is that smaller surfaces have enormously more resistance to deflection *in an inverted Cube-Rule way.* It gets wonderfully complicated.

[AS I WROTE ABOVE, THIS ARTICLE IS STILL UNDER CONSTRUCTION]