Tonewood Testing

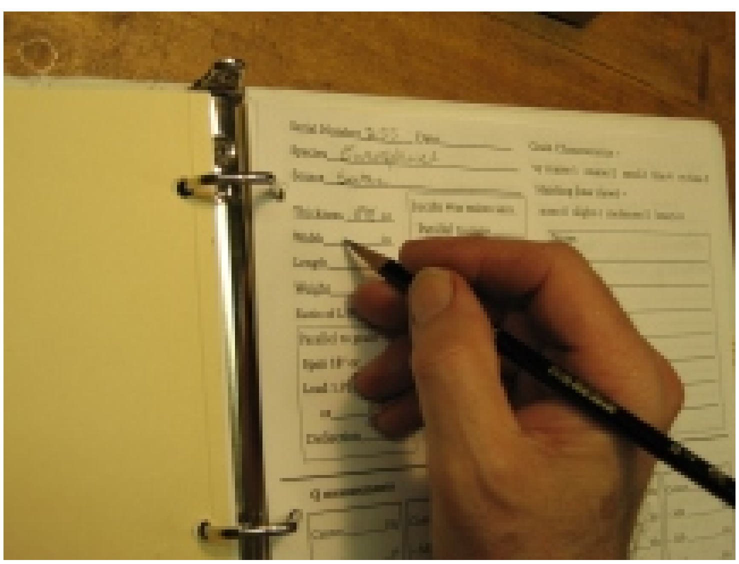
When I started making guitars again in 1993, I put together two flamencos from parts that were left over from my first attempt at being a guitar maker back in the early 1960’s. One of them turned out spectacularly well. I took eight orders off that guitar before I began to doubt whether I could reproduce that wonderful sound. The fact was, that I didn’t really know what I had done right. I knew the dimensions to very close tolerances, but I suspected that there was more to it than that.

About that time the late classical guitar builder John Gilbert spoke to our luthier’s group NCAL. John was famous for his consistency--you ordered a Gilbert, you got a Gilbert. He said that the key to his success was his wood selection process, which involved careful testing of each piece of wood that went into his guitars.

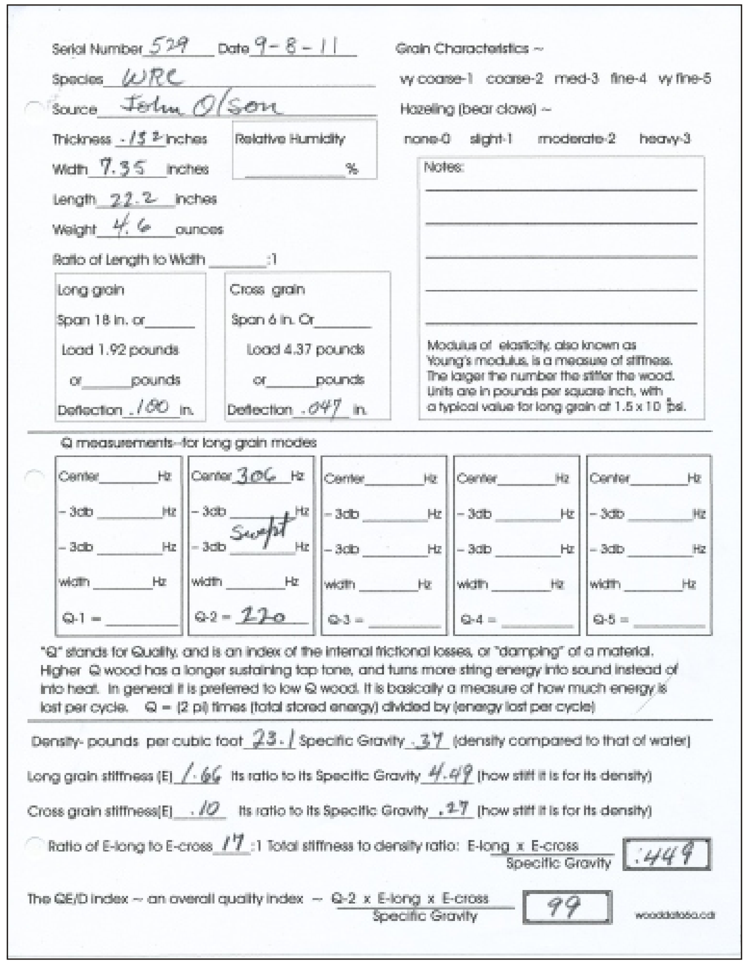
John’s approach made sense to me, so I began testing my back and soundboard woods for all the properties that previous researchers thought useful to know. These turned out to be long-grain and cross-grain stiffness, density, and internal damping (Q).

I was flat-out amazed at the variability! Factors of three, four, and five were not uncommon between different sets of the same species and grade from the same supplier! No wonder that “identical” guitars varied from so-so to excellent.

So these notes are a guide to what I do, and how I do it. I use the numbers to decide which tops and backs are good enough to take through the “initial voicing” stage. The whole process takes about a half hour for a top or a back, and is well worth the effort.



I use Coreldraw for making up my own forms for keeping track of data. I also use it for all my design and publishing work. A blank copy of my form is later in these notes.



Serial Number 529 Date 9-8-11

Species WRC

Source John Olson

Thickness .152 inches

Width 7.35 inches

Length 22.2 inches

Weight 4.6 ounces

Ratio of Length to Width ______:1

Relative Humidity ______ %

Grain Characteristics ~
vy coarse-1 coarse-2 med-3 fine-4 vy fine-5

Hazeling (bear claws) ~
none-0 slight-1 moderate-2 heavy-3

Long grain
Span 18 in. or ______
Load 1.92 pounds
or ______ pounds
Deflection .100 in.

Cross grain
Span 6 in. Or ______
Load 4.37 pounds
or ______ pounds
Deflection .047 in.

Notes:

Modulus of elasticity, also known as Young's modulus, is a measure of stiffness. The larger the number the stiffer the wood. Units are in pounds per square inch, with a typical value for long grain at 1.5 x 10⁶ psi.

Q measurements--for long grain modes

Center ______ Hz	Center 306 Hz	Center ______ Hz	Center ______ Hz	Center ______ Hz
– 3db ______ Hz	– 3db ______ Hz	– 3db ______ Hz	– 3db ______ Hz	– 3db ______ Hz
– 3db ______ Hz	– 3db Swept Hz	– 3db ______ Hz	– 3db ______ Hz	– 3db ______ Hz
width ______ Hz	width ______ Hz	width ______ Hz	width ______ Hz	width ______ Hz
Q-1 = ______	Q-2 = 220	Q-3 = ______	Q-4 = ______	Q-5 = ______

"Q" stands for Quality, and is an index of the internal frictional losses, or "damping" of a material. Higher Q wood has a longer sustaining tap tone, and turns more string energy into sound instead of into heat. In general it is preferred to low Q wood. It is basically a measure of how much energy is lost per cycle. Q = (2 pi) times (total stored energy) divided by (energy lost per cycle)

Density- pounds per cubic foot 23.1 Specific Gravity .37 (density compared to that of water)

Long grain stiffness (E) 1.66 Its ratio to its Specific Gravity 4.49 (how stiff it is for its density)

Cross grain stiffness(E) .10 Its ratio to its Specific Gravity .27 (how stiff it is for its density)

Ratio of E-long to E-cross 17 :1 Total stiffness to density ratio: E-long x E-cross / Specific Gravity .449

The QE/D index ~ an overall quality index ~ Q-2 x E-long x E-cross / Specific Gravity 99

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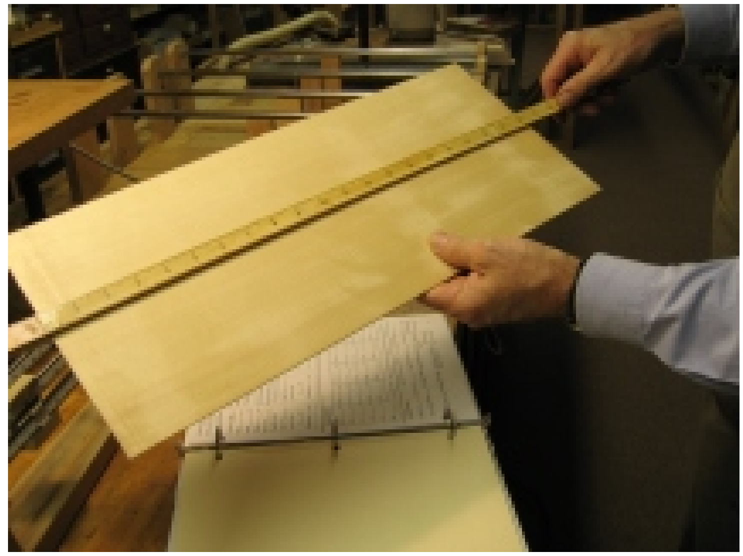
First, I measure the thickness in thousandths of an inch at 10 points around the circumference, and average the readings. Stiffness varies by the cube of the thickness, so this step is important! If the readings vary by more than ± .010”, I surface the piece, unless I want to be able to return the set to the supplier. I test only one half of a set.

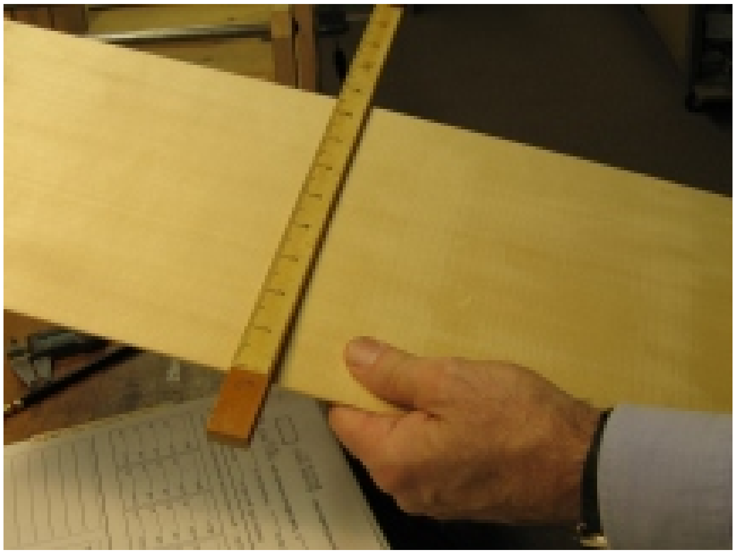
When testing sets by hand flexing, small differences in thickness can sure fool you!

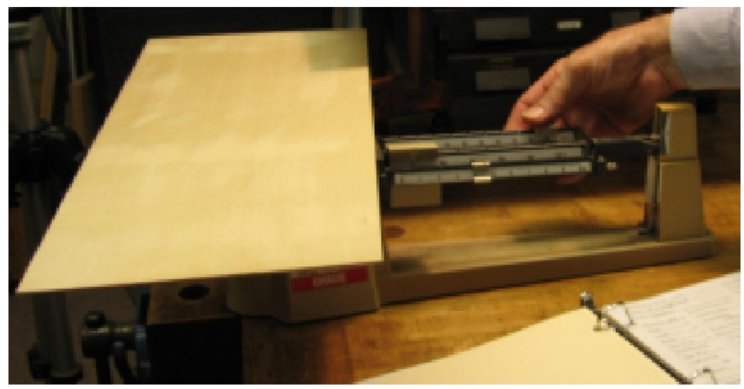
I use three ring binders to keep track of information. As fond as I am of my computer, I find it much more convenient to store information that is printed on paper.

Next come width and length measurements. I made a hook rule that reads in tenths of an inch, as decimal inches are more convenient than fractions. The Stanley Powerlock tape #33-272 is in decimals as well as fractions.



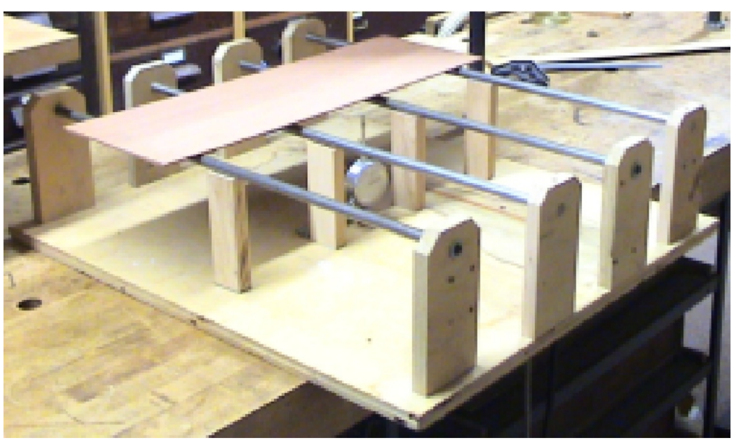
I weigh the sample on a triple beam balance that reads in grams, and then convert to ounces--28.4 gms = 1 0z. An electronic postal scale would work as well.





These measurements are used to calculate density. I use English units as they are what I'm familiar with. My wood books specify density in pounds per cubic foot. My spreadsheet also calculates specific gravity, which compares a material's density to the density of water.

Now come the deflection measurements, which will give us the long grain and cross grain stiffness numbers.



"biasing" and deflection weights

Weights for deflection can be whatever you have handy. The long grain weights at left are about 2 pounds, and the cross grain weights are between 4 and 5 pounds. There is no need to size your sample. The spreadsheet takes weight and size variations into account.

This deflection testing fixture is made with hardware store ½" rod, with the two rods in the center being about 1/4" lower than the outer ones. This allows for testing cross grain deflection without having to move the dial indicator. Dial indicators are really cheap, at $10 or so. I drilled and tapped the rod ends, but a snug fit in the end supports would work as well. Working drawings are at the end of these notes.

Adjusting bezel to zero

Long Grain Deflection

First, a "biasing weight" is placed directly over the dial indicator, and the bezel of the dial indicator is set to zero. This gets the sample down tight on the rods.

Then the actual deflection weight, a 1" steel rod of approximately 2 pounds, is added. You do need to know this weight accurately.

Deflection weight being put in place, and reading taken

" Biasing weight" in place, and bezel being set to zero

When the deflection weight is removed, the dial indicator will often not return all the way to zero. If it still reads two or three thousandths, I subtract that from the overall reading. It helps to polish the tops of the rods, and I spray some Top Cote Teflon spray on them to reduce friction.

Very thin samples can deflect enough to touch the two center rods, and you will need to use a lighter deflection weight.

Cross Grain Deflection

Since the rod spacing for cross grain deflection is only 6", we need to use more weight, both for getting the sample to press snugly down against the rods, and to get enough of a deflection reading to be reliable.

I had the piece of pipe, and a metal cutting bandsaw, so the half pipe was the result. A smaller diameter pipe, that will accept the deflection weight, won't require cutting.

" Biasing weight" in place, and bezel being set to zero

Deflection weight being put in place, and reading taken

This completes all of the mechanical data gathering for calculating stiffness and density. My wife set up an Excel spreadsheet for crunching the numbers, and I would be happy to send you a copy. Just email me at:

brian@lessonsinlutherie.com

Data entry into the spreadsheet is as easy as pie--no knowledge of spreadsheets is needed--I have none (;->).

Formulas for Tonewood Testing--all contained in an Excel spreadsheet available on request

~ **Density** of wood is often expressed in pounds per cubic foot. Since I take measurements of length, width, and thickness in **inches**, and weight in **ounces** there are factors in this formula to convert to feet and pounds.

$$\text{Density} = \frac{\text{Weight x 1728}}{\text{Length X Width X Thickness x 16}}$$

To convert grams to ounces, divide by 28.4.

~ **Specific Gravity** divides the weight of a cubic foot of wood by the weight of a cubic foot of water~62.6 lbs. This is a more useful number for massaging the other data, and works in the metric system.

$$\text{Sp. Gr.} = \frac{\text{Density in lbs./cu. ft.}}{\text{62.6 lbs./cu. ft.}}$$

Typical values ~ Spruce at about .4, Rosewood at .8

~ **So why bother to calculate the Modulus of Elasticity ("E") ?** Because it allows us to compare pieces of wood that are of different sizes and shapes directly to one another (even scraps of previous instruments). There is no need to get all your wood milled to the same dimensions before you can start testing. Just get each piece to an even thickness with straight edges. The formula takes all size variations into account. Even pieces that are tapered in width can be tested, provided that the taper is straight. Just use the average width dimension.

Modulus of Elasticity for a beam in bending, ends free, as taken from Bruce Hoadley's book *Understanding Wood* (highly recommended) page 122. Sorry for the mostly non-intuitive letters he uses; I didn't want to make more confusion by changing them. Units are pounds & inches

E ~ is the modulus of elasticity **.25 ~** is a constant for center loaded beams

P ~ is the load on the beam **L ~** is the span of the beam **b** ~ is the beam's width

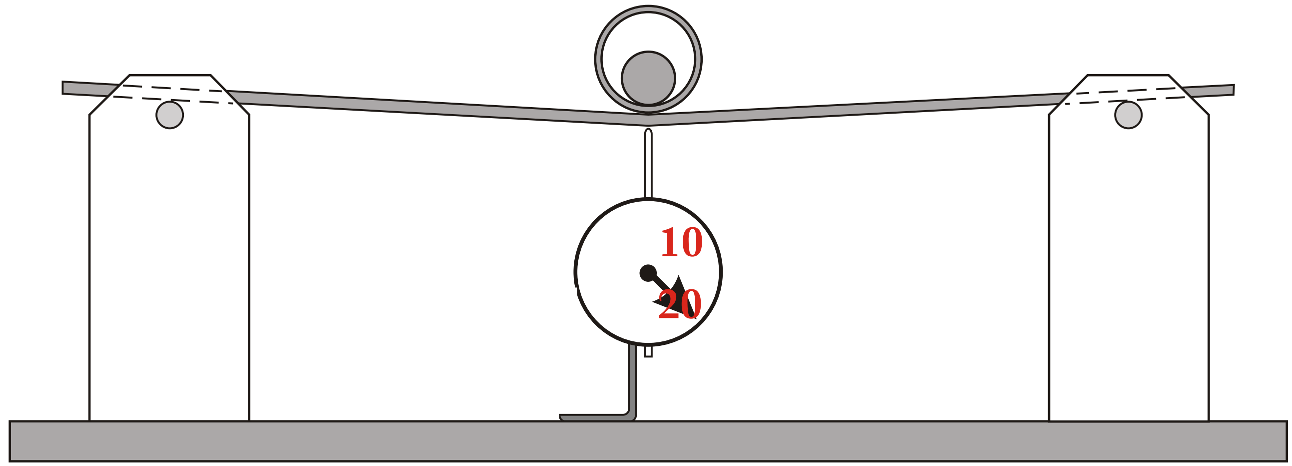
y ~ is the deflection of the beam at its center **d ~** is the thickness or depth of the beam

$$E = \frac{.25PL^3}{ybd^3} \quad \textbf{Or} \quad E = \frac{\text{.25 x load x span}}{\text{deflection x width x depth}}$$

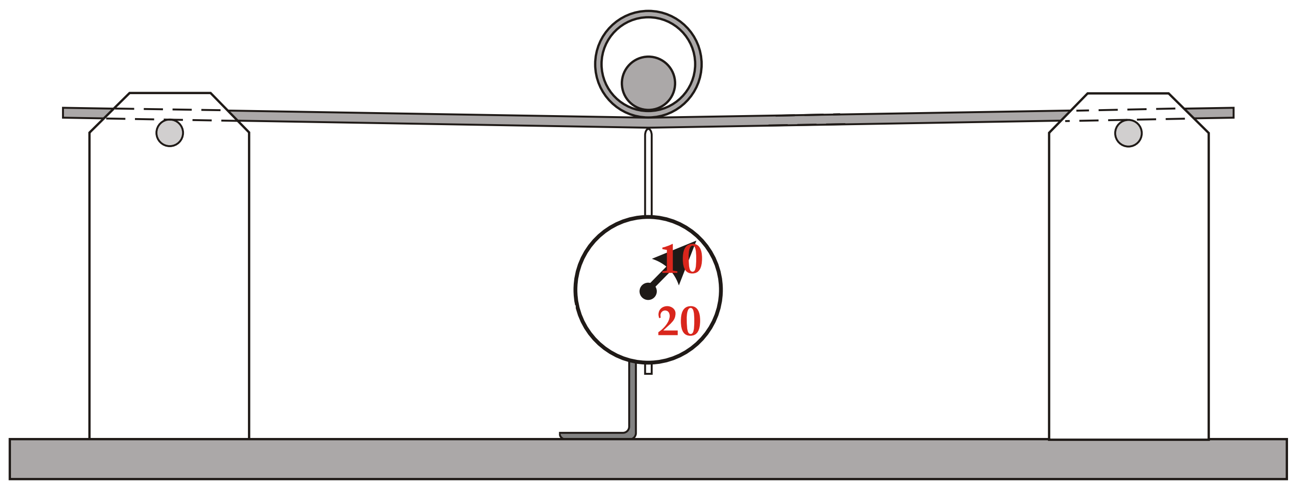
E comes out in millions of pounds per square inch (I don't really understand why either), and is usually abbreviated as say 1.43 x 10^6 lbs/in , or simply as E=1.43. The larger the number, the stiffer the board. In soundboard woods, parallel E is always on the order of 15 times greater than perpendicular E. Hardwoods, oddly enough, put most of their additional density into cross-grain stiffness, and are usually only somewhat stiffer long-grain than softwoods.

~ **E/Sp.Gr.** is the modulus of elasticity divided by the specific gravity. This is the **"stiffness to density ratio"**, a “muscularity index”. A good measure of how efficiently a piece of wood uses its material to make a structure that resists bending. Long-grain E/Sp.Gr. for Spruce is about twice that of Rosewood.

Modulus of Elasticity "E "
is a unit of stiffness



E =1.0 Deflection = 20



E =2.0 Deflection = 10

Q Testing

The single most difficult thing for me as a teacher of guitar making is convincing my students that it is worthwhile to spend several hundred dollars on the audio analysis program Spectra Plus. I would eat beans, and mow lawns to get the money for it, if I had to.

I use it for:

~ Making Q measurements for judging the qualities of tops, backs, and bridges for use in a particular guitar.

~ Deciding when a top or back has been thinned to the right thickness in the "initial voicing" process.

~ Making final adjustments to top and back bracing during the final voicing process to get the guitar's resonances moved to where I want them.

~ Tracing the cause of dead notes, and fixing them.

~ Measuring the acoustic effects of different finishes.

I consider all of these steps to be critical to producing really first rate instruments.

"Q" is a measure of acoustic power loss in a piece of wood, and is roughly equivalent to how long the "tap tone" rings.

Q is entirely independent of the mechanical properties! The redwood top below has Q's as high as old Brazilian rosewood, at half the density of the rosewood. Higher Q wood makes for a louder guitar with longer sustain.

A small rare earth magnet is glued to the end of the sample with cyanoacrylate (Hot Stuff etc.). A coil stolen from a relay is located directly over the magnet, and is connected to an amplifier. This effectively turns the sample into a loudspeaker.

Spectra Plus has a signal generator feature that generates a sine wave (pure tone) signal that can be set to sweep over any audio range, at whatever speed you choose. I usually set it to cover 65 Hz to 1320 Hz in 2 minutes.

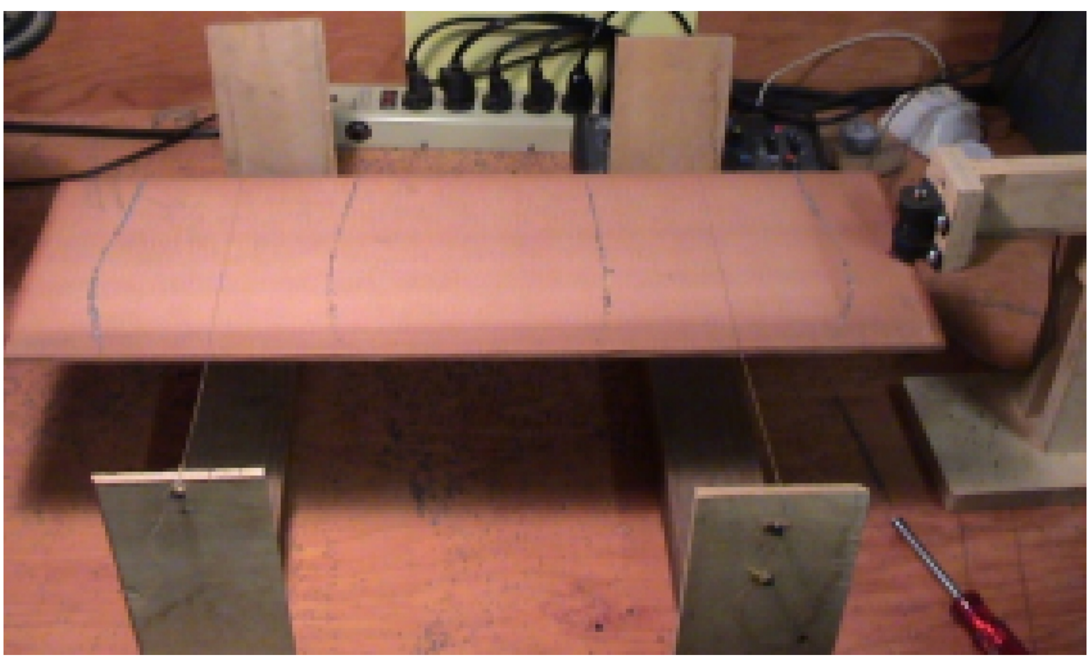
The computer audio output goes to the amplifier, which boosts the signal enough to drive the wood to quite audible levels.

A microphone picks up the sound from the wood, and sends it back to the computer's audio input. The computer displays a graph of the volume on the vertical axis, and frequency on the horizontal axis. This graph is an "acoustical fingerprint" of that piece of wood.

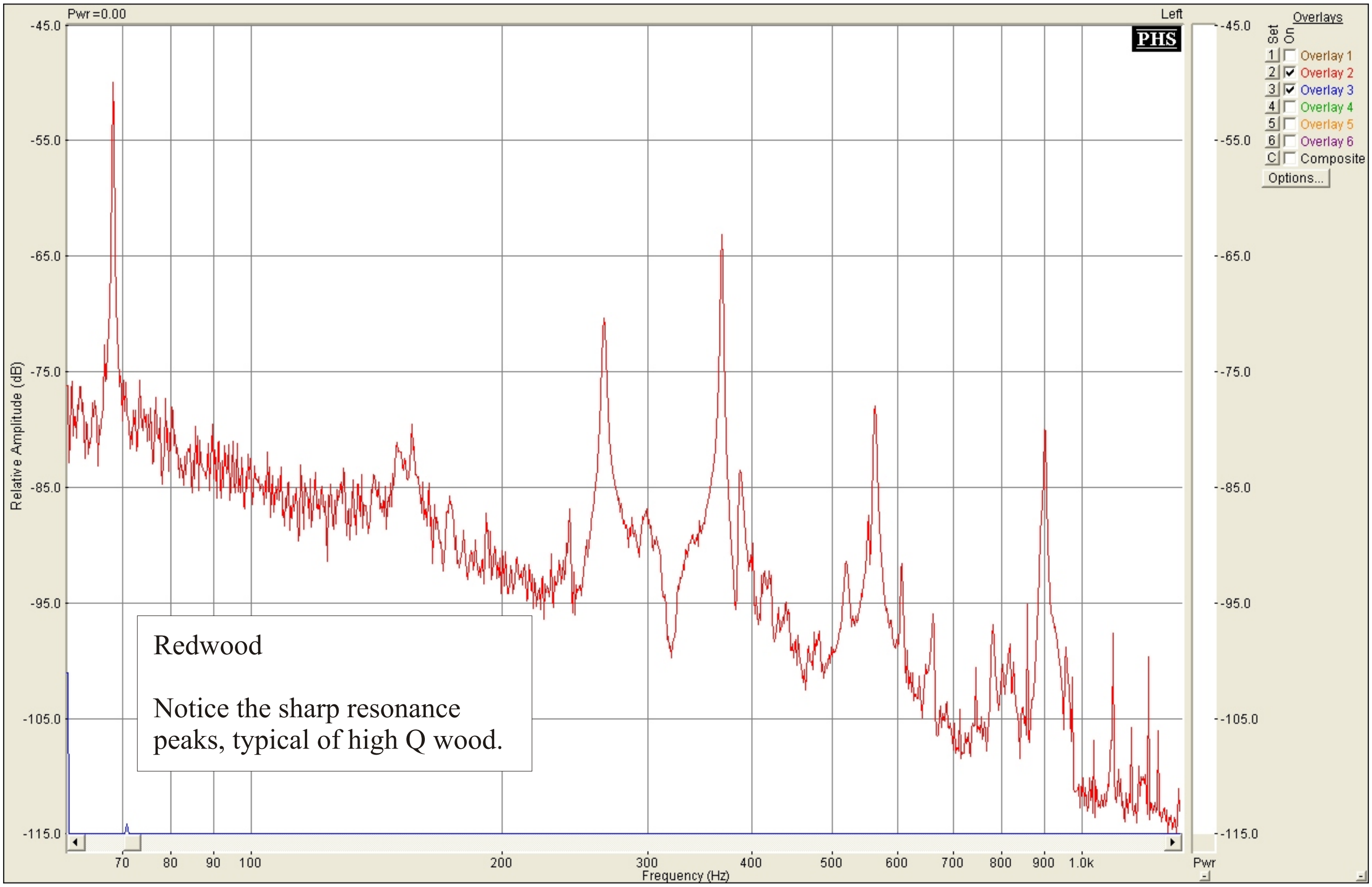
To get the Q measurement you select a resonance peak on the graph, and right click on it. Spectra Plus then calculates the Q for that peak.

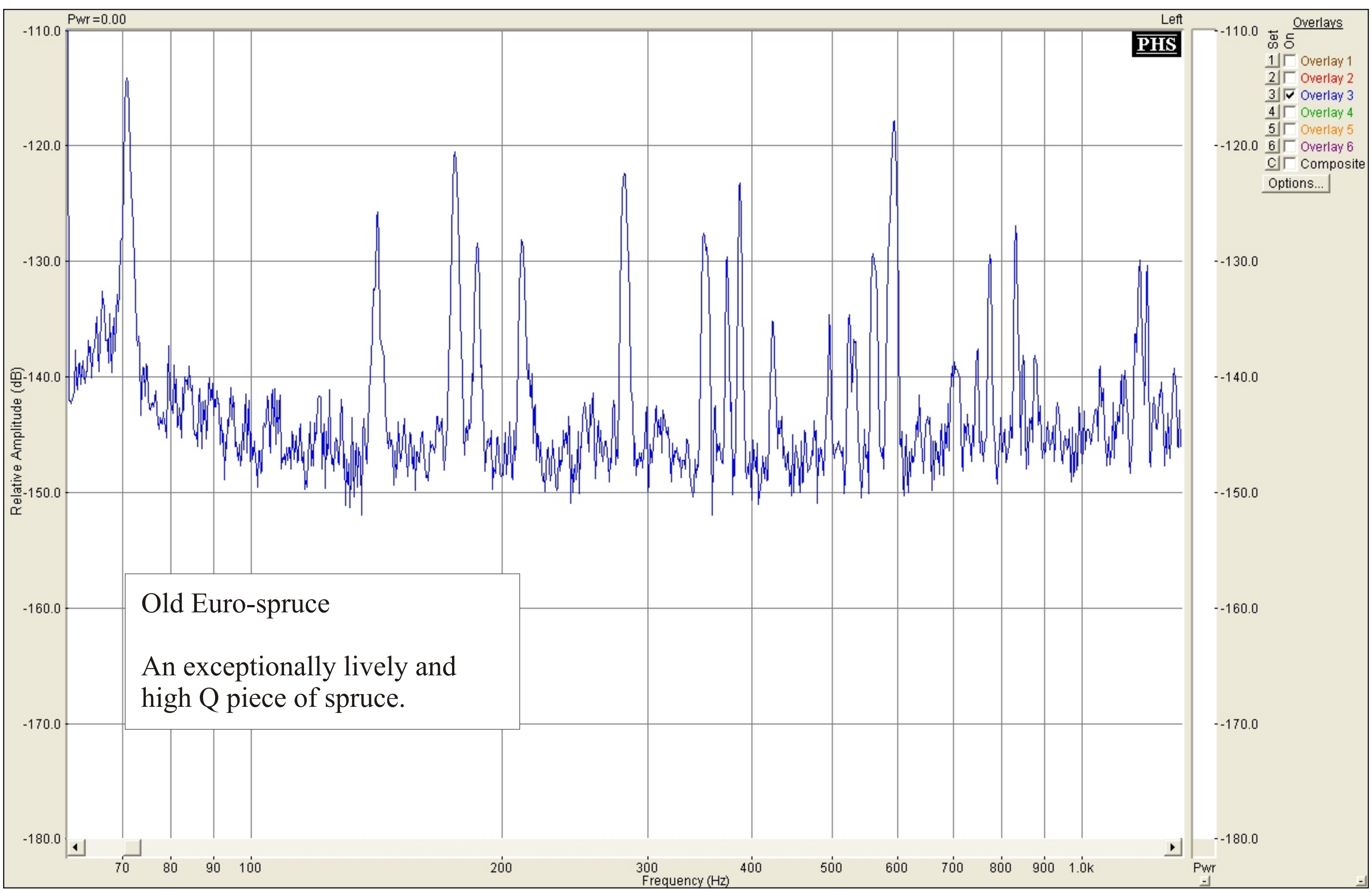
I chose this long grain vibrational mode as the one to represent a sample of wood (Q-2), as it is usually a strong peak, and is in the upper treble range of the guitar where nylon string instruments need some help. It has five peaks and four nodes, the nodes are indicated by the poppy seeds lining up in areas of minimum vibration.

Any old PC, any old amplifier, and any old microphone, will run Spectra Plus, and store the resulting .wav file for future reference. People give PC's away when they upgrade.



The sample is supported on threads about 20% from each end.


Pwr=0.00
Left
PHS
Overlays
Set
On
Overlay 1
Overlay 2
Overlay 3
Overlay 4
Overlay 5
Overlay 6
Composite
Options...
Relative Amplitude (dB)
-45.0
-55.0
-65.0
-75.0
-85.0
-95.0
-105.0
-115.0
70
80
90
100
200
300
400
500
600
700
800
900
1.0k
Frequency (Hz)
Pwr
Redwood
Notice the sharp resonance peaks, typical of high Q wood.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-130.0
-140.0
-150.0
-160.0
-170.0
-180.0
70
80
90
100
200
300
400
500
600
700
800
900
1.0k
Frequency (Hz)
Pwr
Old Euro-spruce
An exceptionally lively and high Q piece of spruce.

Serial Number__________ Date_______________

Species_______________________________________

Source____

Thickness _______inches

Width___________inches

Length___________inches

Weight___________ounces

Ratio of Length to Width ________:1

Relative Humidity

______________%

Grain Characteristics ~

vy coarse-1 coarse-2 med-3 fine-4 vy fine-5

Hazeling (bear claws) ~

none-0 slight-1 moderate-2 heavy-3

Long grain	Cross grain
Span 18 in. or_______	Span 6 in. Or________
Load 1.92 pounds	Load 4.37 pounds
or_______pounds	or_______pounds
Deflection________in.	Deflection________ in.

Notes:

____

____

____

____

____

Modulus of elasticity, also known as Young's modulus, is a measure of stiffness. The larger the number the stiffer the wood. Units are in pounds per square inch, with a typical value for long grain at 1.5×10^6 psi.

Q measurements--for long grain modes

Center________Hz	Center________Hz	Center________Hz	Center________Hz	Center________Hz
– 3db __________Hz	– 3db __________Hz	– 3db __________Hz	– 3db __________Hz	– 3db __________Hz
– 3db __________Hz	– 3db __________Hz	– 3db __________Hz	– 3db __________Hz	– 3db __________Hz
width _________Hz	width _________Hz	width _________Hz	width _________Hz	width _________Hz
Q-1 = ___________	Q-2 = ___________	Q-3 = ___________	Q-4 = ___________	Q-5 = ___________

"Q" stands for Quality, and is an index of the internal frictional losses, or "damping" of a material. Higher Q wood has a longer sustaining tap tone, and turns more string energy into sound instead of into heat. In general it is preferred to low Q wood. It is basically a measure of how much energy is lost per cycle. Q = (2 pi) times (total stored energy) divided by (energy lost per cycle)

Density- pounds per cubic foot_______ Specific Gravity______ (density compared to that of water)

Long grain stiffness (E)______ Its ratio to its Specific Gravity_______ (how stiff it is for its density)

Cross grain stiffness(E)_______ Its ratio to its Specific Gravity______ (how stiff it is for its density)

Ratio of E-long to E-cross_____:1 Total stiffness to density ratio: $\frac{\text{E-long} \times \text{E-cross}}{\text{Specific Gravity}}$ [ ]

The QE/D index ~ an overall quality index ~ $\frac{\text{Q-2} \times \text{E-long} \times \text{E-cross}}{\text{Specific Gravity}}$ [ ]

wooddata6a.cdr

Interpreting the numbers

Below is a table of the average values that I have measured in 201 sets of European spruce over a period of 18 years. The second table below shows the range of values covered by the 201 samples. These tops were all cut and sold by tonewood suppliers for use in building guitars. There were no "lumberyard specials" included. Factors of 3, 4, and 5 are common! I rest my case in favor of wood testing (;->)...

When I'm doing a rough sorting of top sets, I look first at the QE/D rating. That's an overall quality index that is roughly equivalent to Daniel Haines' "loudness index".[1] I have somewhat arbitrarily decided that the cutoff on this scale is 50. Any top that can't make at least 50 has probably got enough things wrong with it that it's not worth using.

For tops that rate over a QE/D of 50, I next look at all the numbers that went into that rating, particularly at the stiffness and density values. I like to see at least average values for long and cross grain stiffness, and not too much variation from an 18:1 ratio between them.

Lower density tops tend to come out of the initial voicing process lighter weight than higher density ones. A resonance consists of a stiffness and a mass. Stiffness varies by the cube of the thickness, but mass only varies linearly. So, a low density top can be left a little thicker at only a small increase in overall mass. I tend to use the lower density, lighter weight tops on flamencos, for faster attack, and shorter sustain. The denser tops go on classics.

Q numbers tend to be quite variable in raw wood sets. If a set's Q is low, but the stiffness numbers look ok, I might well take it through the glue up and voicing process. Q numbers measured after initial voicing are quite reliable for comparing sound boards one to another.

Long grain stiffness correlates somewhat to density. As density goes up, long grain stiffness goes up. If I recall correctly, about 30% of the time. All the other factors vary independently, and can be quite widely different.

Seasoning of wood improves test numbers, particularly cross grain stiffness. I've tested new top wood sets, and then at 5,7, and 10 years, and cross grain stiffness went up about 10% even between 7 and 10 years.

That two sets come from the same tree, or even the same billet, is no guarantee that they will have similar acoustic characteristics. And there is the skill of the sawyer to take into account. I'm fond of saying "When it comes to wood, all generalizations are false".

[1] "On Musical Instrument Wood" by Daniel Haines
Catgut Acoustical Society Newsletter #31, May 1979

Average values for 201 sets of European spruce

Density- pounds per cubic foot **25.7** Specific Gravity **.41** (density compared to that of water)

Long grain stiffness (E) **1.59** Its ratio to its Specific Gravity **3.88** (how stiff it is for its density)

Cross grain stiffness(E) **.10** Its ratio to its Specific Gravity **.24** (how stiff it is for its density)

Ratio of E-long to E-cross **18:1** Total stiffness to density ratio: $\frac{\text{E-long x E-cross}}{\text{Specific Gravity}}$ **.382**

Average Q-2=137

The QE/D index ~ an overall quality index ~ $\frac{\text{Q-2 x E-long x E-cross}}{\text{Specific Gravity}}$ **56**

The range of values for 201 sets of European spruce--highest are in red--lowest are in blue.

Density- pounds per cubic foot **32.2 – 20.9** Specific Gravity **.52 – .33** (density compared to that of water)

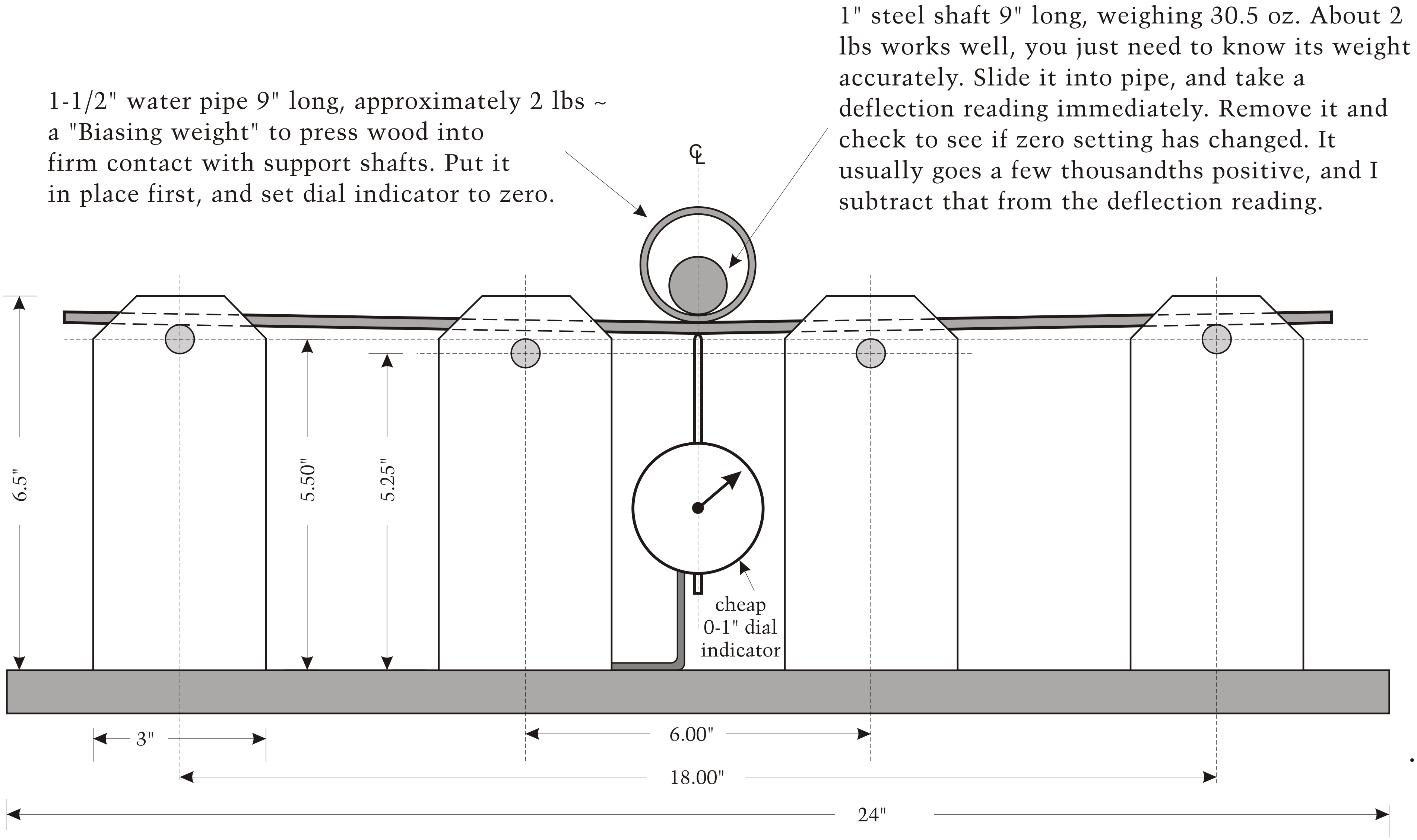
Long grain stiffness (E) **2.45 – .97** Its ratio to its Specific Gravity **5.24 – 3.05** (how stiff it is for its density)

Cross grain stiffness(E) **.17 – .04** Its ratio to its Specific Gravity **.44 – .08** (how stiff it is for its density)

Ratio of E-long to E-cross **52:1 – 9:1** Total stiffness to density ratio: $\frac{\text{E-long x E-cross}}{\text{Specific Gravity}}$ **.738 – .126**

Q-2 = 203 – 67

The QE/D index ~ an overall quality index ~ $\frac{\text{Q-2 x E-long x E-cross}}{\text{Specific Gravity}}$ **119 – 15**

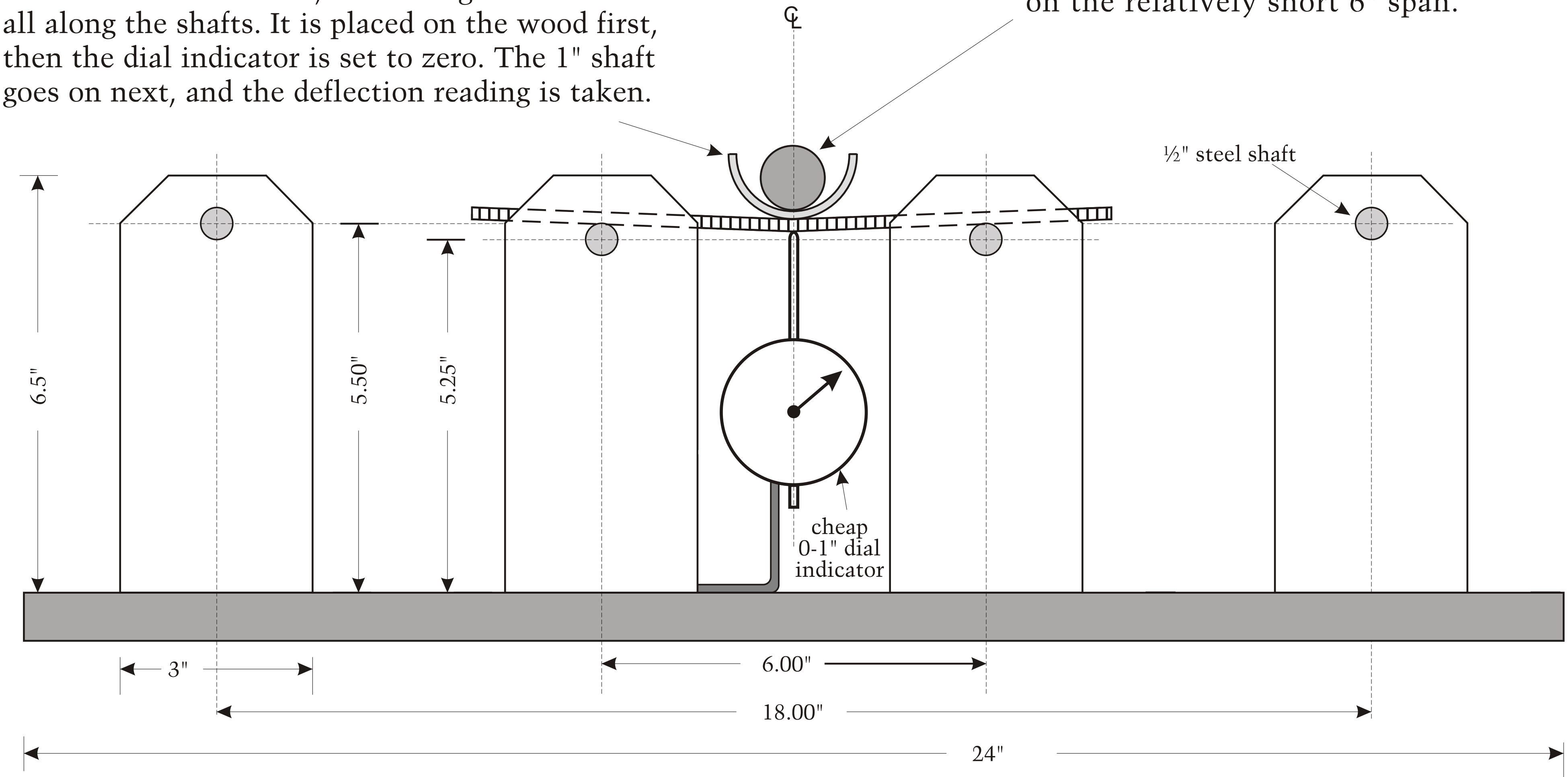


NOTE ~ The two center shafts are set .25" lower than the outside ones, and don't touch the wood when testing long grain stiffness.

Stiffness testing fixture
being used to test
long grain stiffness

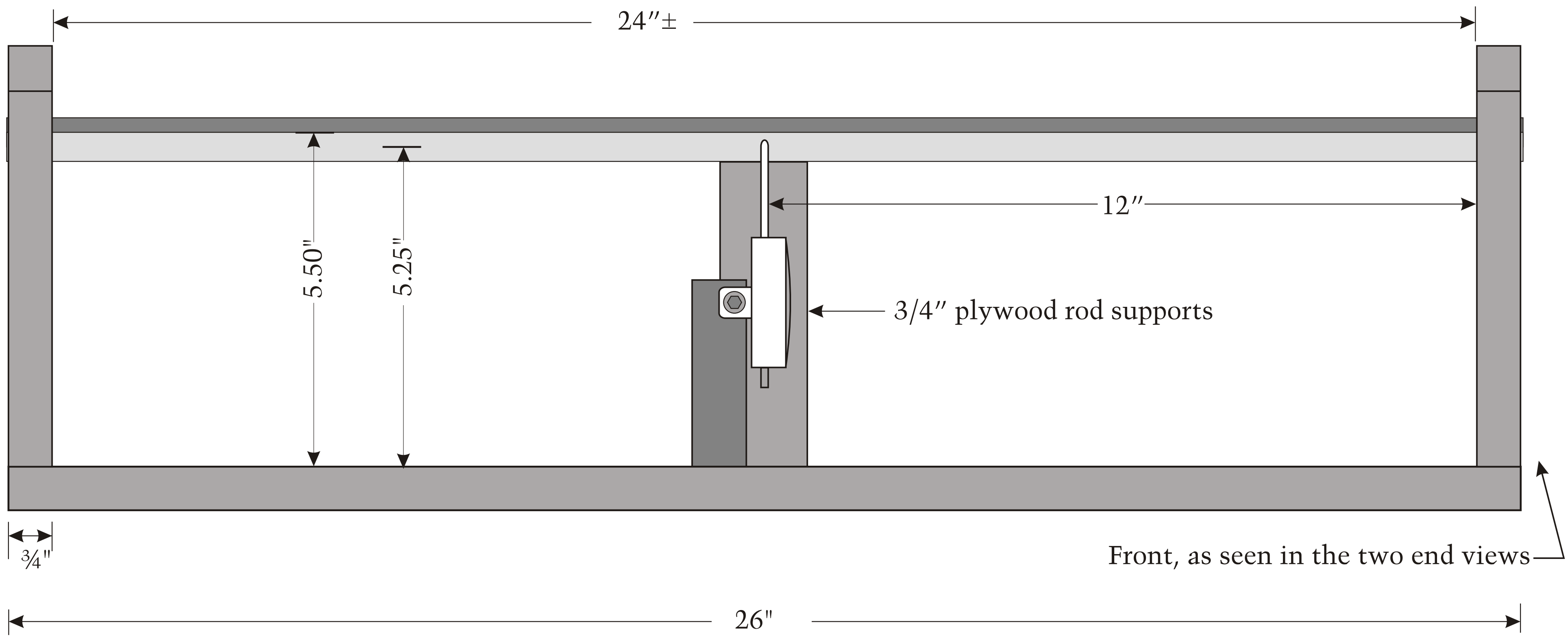
This weight presses the wood to be tested, tightly against the shafts. It is 2" water pipe 24" long, sawn in half lengthwise ~ approximately 3.5 lbs. On particularly stiff wood I use both halves, one cradled inside the other, to insure good contact all along the shafts. It is placed on the wood first, then the dial indicator is set to zero. The 1" shaft goes on next, and the deflection reading is taken.

1" steel shaft 20" long, weighing 4.37 lbs. This larger load is needed to get a reliable deflection reading on the relatively short 6" span.



Piece to be tested can be a half or full width soundboard or back. Even scraps of previously made instruments can be tested. Just make sure the thickness is uniform to ± .003" (.1 mm). Edges need only be straight. If they aren't parallel, just take an average width measurement across the center of the piece.

Stiffness testing fixture being used to test cross grain stiffness



Side view of stiffness testing fixture
as viewed from center

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