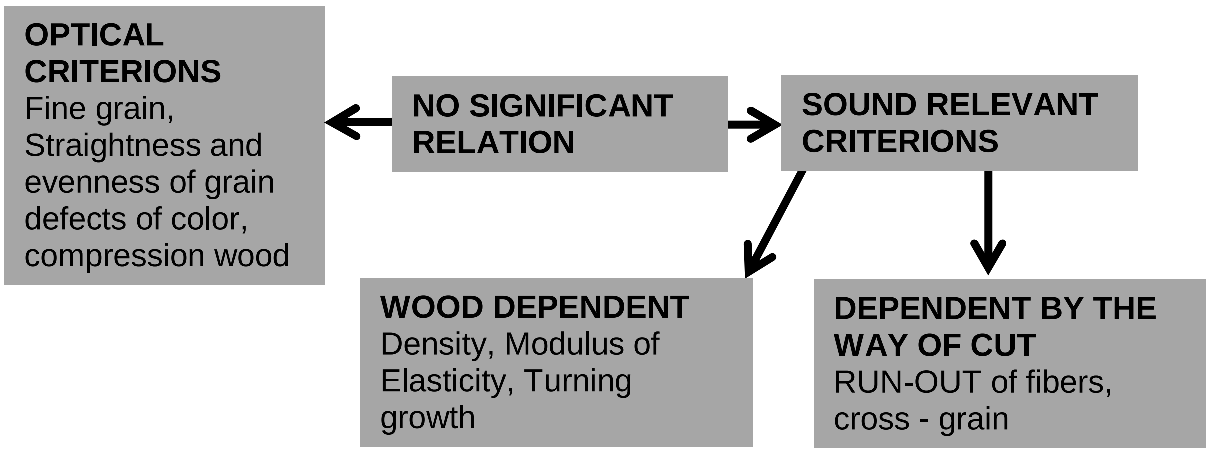
CRITERIONS OF QUALITY FOR TONEWOOD

By Matthias Dammann

Unfortunately most of the sound relevant properties of tonewood are invisible. Nevertheless suppliers are still focused to offer fine grain wood without any defects, as the eye buys first the ear last. Of course, it is desirable to get both, beautiful appearance and excellent physical features. But very often, if you look for outstanding low density or extremely NO-RUN-OUT grain, the samples will have some defects of appearance. Consequently in that case those defects should be accepted.



To get more insight in the physical properties of tonewood, the suppliers should provide their products with the same measured values which, in order to be comparable, should be independent of the sample`s dimension.

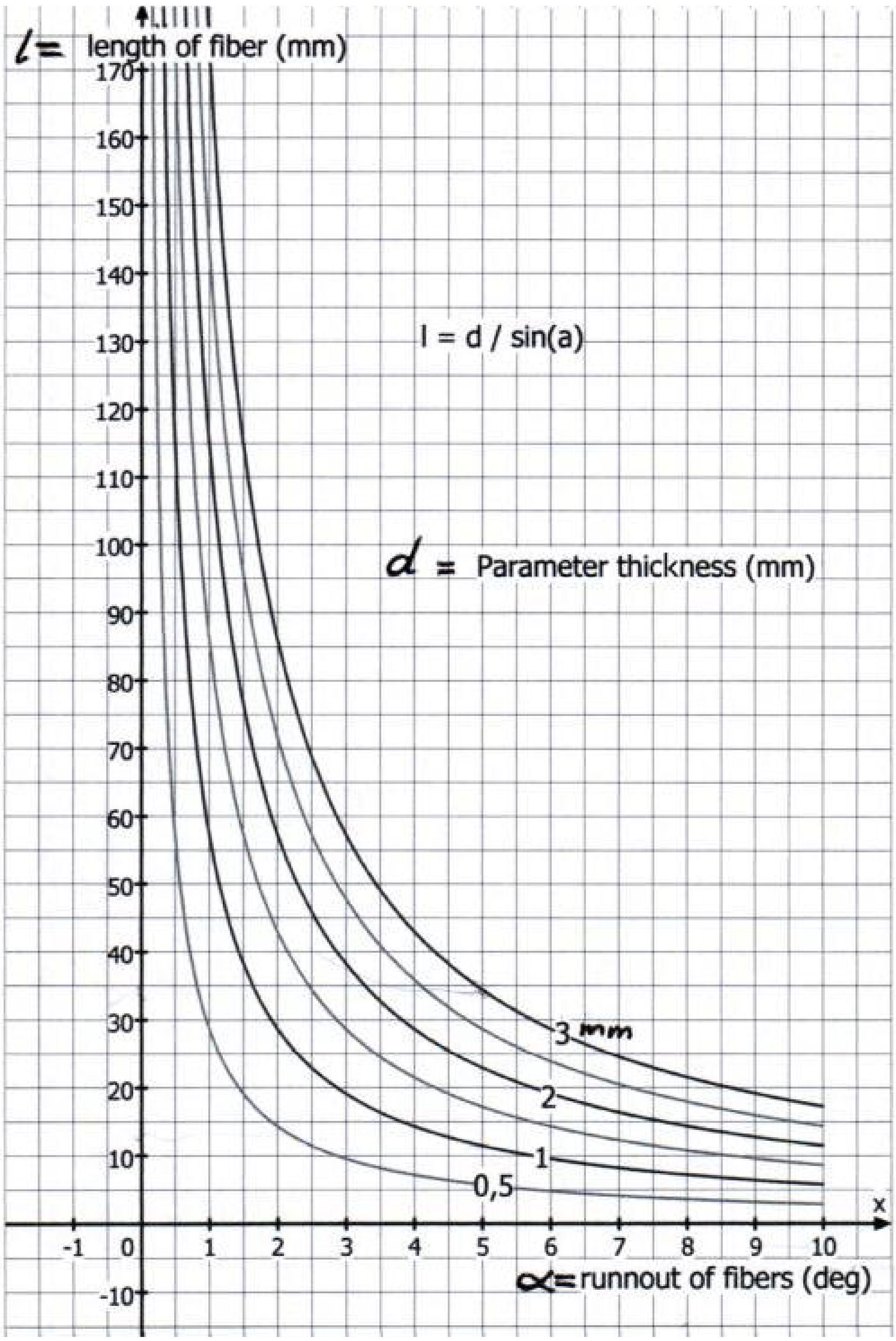
These are:

Density (D), E-Modulus (Em) and the thereof resulting Speed of soundwaves (c)

Here should be mentioned that density is the only really dimension – independent value. Em is normally measured when the thickness is 4mm and more. If there is a certain RUN-OUT of fibers, Em will increasingly correspond, the thinner the plate is worked out.

The following diagram shows the relation:

While the decrease of fiber length for 3mm thickness is moderate, it becomes much steeper for lower thickness. So, a good value of Em does not guarantee NO-RUN-OUT.



To make measurements better comprehensible, to check them and to do them by oneself, the fundamental mathematical relations shall be described.

Basic parameters	Symbol	Unit
Length	l	m (Meter)
Width	b	m (Meter)
Thickness	d	m (Meter)
Mass	m	kg (Kilogram)
Time	t	s (Second)
Distance	a	m (Meter)

Derived parameters	Symbol	Calculation	Unit
Volume	V	$l * b * d$	m^3
Density	D	$m * l^{-1} * b^{-1} * d^{-1}$	$kg * m^{-3}$
Force (weight)	F	$m * g$; $m * a * t^{-2}$	$kg * m * s^{-2}; N$
Frequency	f	t^{-1}; $d * l^{-2}[Em * D^{-1}]^{0,5}$	$n * s^{-1}; Hz$
Speed of Sound	c	$a * t^{-1}$; $[Em * D^{-1}]^{0,5}$	$m * s^{-1}$
Gravity Acceleration	g	$a * t^{-2}$	$m * s^{-2}$
Stiffness (Rigidity)	R	$F * a^{-1}$; $m * g * a^{-1}$; $m * t^{-2}$	$kg * s^{-2}; Nm^{-1}$
Elasticity (Compliance)	C_E	reciprocal to R	reciprocal to R mN^{-1}
Modulus of Elasticity	Em	$l^3 * d^{-3} * b^{-1} * F * (4a)^{-1}$	$kg * m^{-1} * s^{-2}; N * m^{-2}; Pa$
Constant of Elasticity	e	reciprocal to Em	reciprocal to Em

Our interest is focused on these dimension-independent terms:

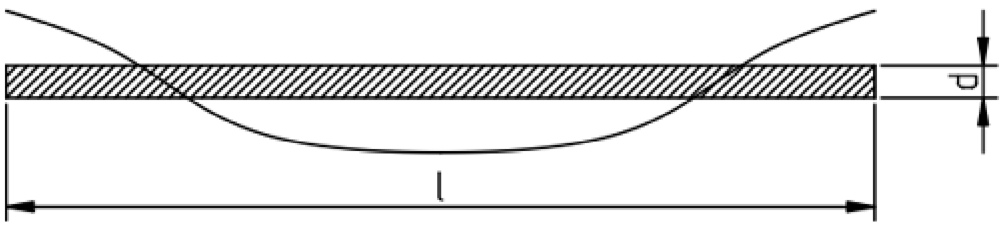
Density	Modulus of Elasticitiy	Speed of Sound
$m * l^{-1} * b^{-1} * d^{-1}$	$Em = l^3 * d^{-3} * b^{-1} * F * (4a)^{-1}$	$c = Em^{0,5} * D^{-0,5}$
For checking purposes the calcuslation of untis		
$kg * m^{-3}$	$kg\, ms^{-2}\, m^3\, m^{-1}\, m^{-3}\, m^{-1} = kg\, m^{-1}\, s^{-2}$	$(kg\, m^{-1}\, s^{-2}\, kg^{-1}\, m^3)^{\frac{1}{2}} = ms^{-1}$

The calculation of Speed of Sound by Em and D requires 5 values to be measured: l, b, d, m, a.

l and d appear in the power of three and require high accuracy.

To get sufficient accuracy, when measuring the excitation s, it should be not much less than 1mm. Depending on the size of the sample, this can force it into the non-linear range.

By measuring the frequency of the plate resonance, the procedure becomes much easier.



The fundamental resonance has the equation:

$$f = \frac{d}{l^2} \sqrt{\frac{Em}{D}} \qquad (1)$$

or

$$f = \frac{d}{l^2} \sqrt{\frac{F*l^3*b^{-1}*d^{-3}*(4a)^{-1}}{m*\,l^{-1}*b^{-1}*d^{-1}}} \qquad (2)$$

or

$$f = \frac{1}{2} \sqrt{\frac{F}{m*a}} \qquad (3)$$

with

$$\frac{F}{a} = \frac{1}{C_E} \qquad f = \frac{1}{2} \sqrt{\frac{1}{C_E*m}} \qquad (4)$$

Please note the width b is eliminated in Equation *(2)*.
This is also proved by splitting a sample in several strips, without observing a change of resonance.

To check equation *(1)*, it can be calculated just with its units:

$$f = \frac{m}{m^2}\sqrt{\frac{kg\ m\ s^{-2}\ m^3\ m^{-1}\ m^{-3}\ m^{-1}}{kg\ m^{-1}\ m^{-1}\ m^{-1}}}$$

$$f = \frac{1}{m}\sqrt{\frac{m^2}{s^2}}$$ **à** $$f = \frac{1}{s}$$

with $$c = \sqrt{\frac{Em}{D}} \qquad (5)$$

Equation *(1)* can be converted into:

$$c = f\ \frac{l^2}{d} \qquad (6)$$

Now, there are only three values required. l is powered only by 2 and is the most simple measurement. The excitation a of the plate resonance is within a range of µm. Thus, non-linear effects can be excluded.

Equation *(3)* $f = \frac{1}{2}\sqrt{\frac{F}{m*a}}$ was proved by measurements on different samples. It became evident that the equations before are only true, when a constant c_o is introduced:

$$f = c_o\ \frac{1}{2}\sqrt{\frac{F}{m*a}} \qquad c_o = 2f\sqrt{\frac{m*a}{F}}$$

With $C_E = 7{,}546 * 10^{-5}\ mN^{-1}; m = 0{,}2005kg; f = 134\ Hz;\ c_O\ was\ 1{,}0424.$
This is a good accordance with $1{,}03638$ which is claimed in the basic formula for the fundamental resonance of a plate with rectangular cross-section.

Thus Equation *(3)* hat to be completed:

$$\boldsymbol{c = f * \frac{l^2}{d} * \frac{1}{c_o}} \tag{7}$$

The measurement of the resonance frequency can also replace F and a in the determination of Em:

$$Em = \frac{l^3}{d^3\, b} * \frac{F}{4a} \quad \text{à} \quad \boldsymbol{Em = \frac{l^3}{d^3\, b} * m \frac{f^2}{c_o^2}} \tag{8}$$

$$\boldsymbol{\frac{F}{4a} = m \frac{f2}{c_o^2}} \tag{9}$$

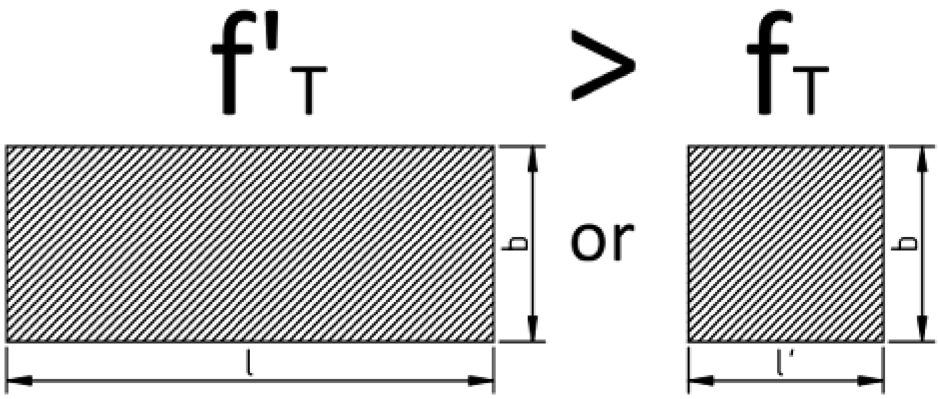
<u>Hints for calculation</u>:

$$\begin{aligned}
1mm &= 1 * 10^{-3}\, m \\
1cm &= 1 * 10^{-2}\, m \\
1mm^2 &= 1 * 10^{-6}\, m^2 \\
1cm^2 &= 1 * 10^{-4}\, m^2 \\
1mm^3 &= 1 * 10^{-9}\, m^3 \\
1cm^3 &= 1 * 10^{-6}\, m^3 \\
1g &= 1 * 10^{-3}\, kg
\end{aligned}$$

It is basically advisable to put only Meter and Kilogram with corresponding exponential notation, to the formulas!
Note the difference between mass (kg) and weight (N)

Interpreting b as length and l as width, gives the corresponding values for the transversal resonance (fT). Although this resonance is more difficult to hear, with some practice, it can be identified as well.

The transversal resonance is not unlimited independent by the length. When the ratio l/b becomes more than 2 (this is always the case) this resonance becomes higher.

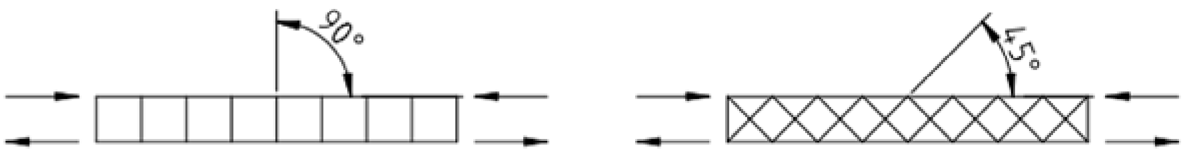


$^{l}/_{b} > 2$ $^{l}/_{b} < 2$

The error for standard guitar top dimensions $l = 0{,}55m/b = 0{,}2m$ is:

$$f_T = f'_t * 0{,}944$$

f_T is also much dependent by the way the plates have been cut, thus it does not represent not a really specific constant of wood.



(Cross-section of wood)

The cut of the plates gives the possibility to vary the ratio of stiffness of long direction to transversal direction, a unique feature of wood.

There are three ways to determine the resonance frequency:

1. The sample is gripped at the nodal line and stimulated close to the loop. The tone represents an interval to a driven tuning fork. Then, the interval is converted into a ratio of frequencies and multiplied with 440Hz. Finally one has to jump into the right octave.

   $$f = 440\ Hz * 2^{\frac{n}{12}}$$

   N = number of semitones in the interval, i.e. V **à** $n = 7$

2. The tone in identified by a reference tone source, like a tuned guitar or a tuner, and with a list of frequencies there is no need to hear intervals.

3. The pitch of frequency is measured by electronic devices and computer software, those does all the calculations.

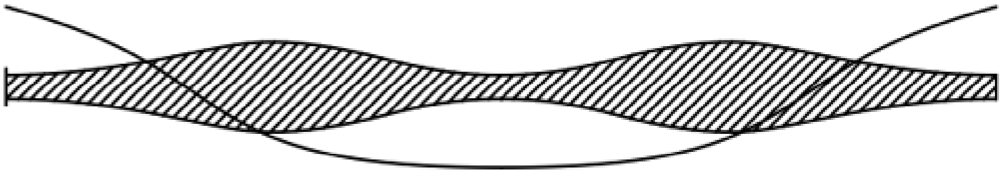
If it is true, that the more machines are involved, the less skill people develope, one should practice the first two methods.

Especially for the Luthier, a skilled ear is irreplaceable anyway. Special guitars often can be inspected only for few moments, and an approach with technical equipment is excluded. With some practice all the fundamental guitar resonances can be identified within some seconds.

Common to the three methods is the need of a very accurate value for thickness. Uniform thickness is given in only few cases. Even electronic engineers still owe a solution for measuring the effective thickness. This would be really without alternative.

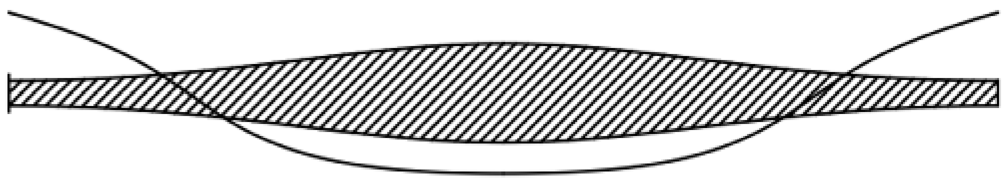
Usually the average value is taken. But also this can give large errors:

Examined are two plates with contrary distribution of thickness



(A)

The average thickness is the same,



(B)

…but the resonance at (B) is much higher!

CONCLUSION

The speed of sound $c = \sqrt{\frac{Em}{D}}$ seems to be an excellent representation of the wood`s ratio between stiffness and mass, but it doesn't tell us how much contribution D has. So, the density D should be added anyway.

Guitar Soundboards with very high value of c, do they really make better guitars? All theoretical consideration should be proved by the results.

In my experience the relations seem to be even paradoxical. Guitars with excellent "high speed"-tops mostly haven't had an attractive sound. Whereto the theory escaped?

Obviously Luthiers tend to "invest" high c rather in stiffness than in lightness. Wood suppliers and Luthiers as well seem to have a blind believe that the stronger the wood, the better.

If one examines the sound and construction of guitars around 1900 especially those of Antonio de Torres, one can get the impression that in that period the contrary view was common:

The more flexible, the easier vibrations can be stimulated. Considering the relatively deep spectrum of guitar sound, this could be plausible as well.

I think that in the beginning period of guitar making, rules have been more developed by the final sound of the guitars. Later there raised more and more static criterions. The falling in and deformation of the guitar top, caused by the string-tension, was increasingly considered as a problem. Terms like tired soundboards raised.

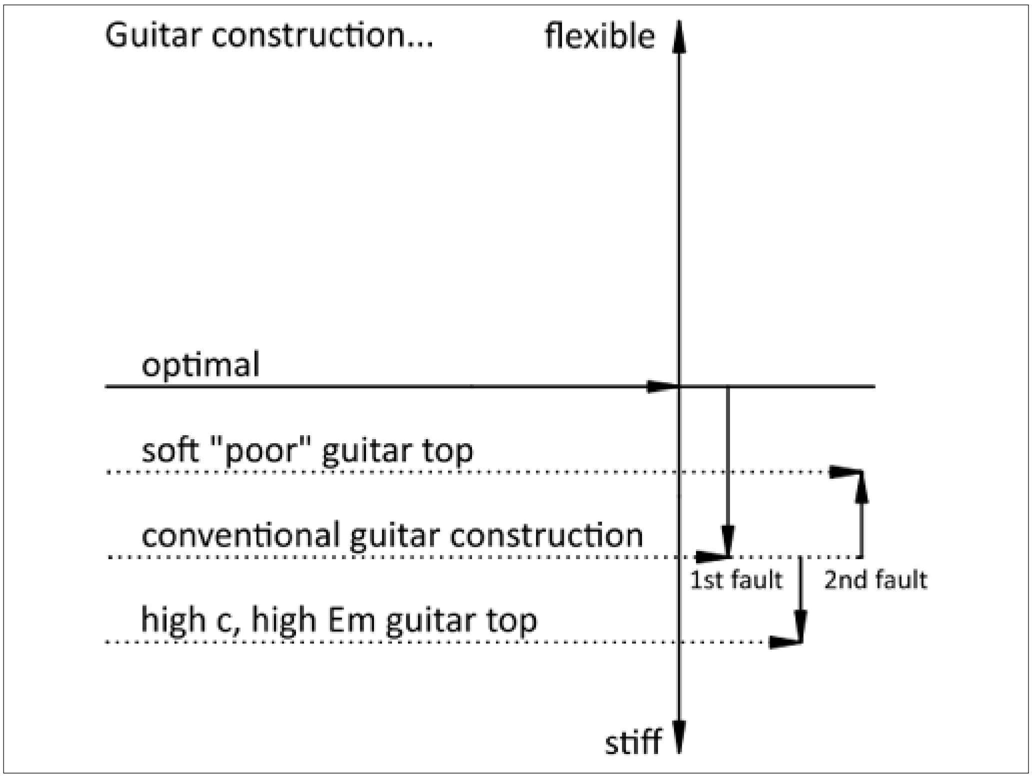
A solution to that paradox can be again a mathematical one:

As is well known, two faults, one after another can create a right.

Assuming the first fault is the adaption of a construction system that automatically, without intention of the maker leads to a much too stiff system. The use of a soft, in technical sense “poor” wood might be considered as the second fault. So the second will compensate the first one and will contribute to a good guitar.

The musician will not ask if this is the right way!

However, when the construction of the guitar top is not modified and adapted to the relatively deep voice of the guitar (there is no deeper instrument in that size), the use of wood with high Em and c will not be necessarily a benefit for Lutherie.



Here has to be emphasized that modification does not relate to the COMPOSITE-construction that I developed, not at all.

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