"In search of the best-sounding tone wood"

(version 1.1)
by Tom Frinta Ph.D.

According to the classic view narrow year rings make for better tone wood, because the wood is grown at a slower pace. Actually microscopic analysis shows that winter grown wood will develop thinner cellular membranes leaving more space for secretion to flow. A cold growth environment can also be found throughout all seasons at high elevation. This is where most of the tone wood is harvested. However, only one out of a hundred trees is good for tone wood. Listen to what forestry scientist (univ.) and luthier Andreas Pahler has to say. 1)

For definitions see end of paper.

1. Thickness of cellular membranes in wood
To better understand the importance of this let us look at the sound transmission on a violin top. Initially the sound wave hits the top via the bridge. In order to make the whole top oscillate without noticeable distortion towards the edges the wave must be transported at the highest possible speed in the direction of the wood grain to the far ends of the bouts. From this central line the wave then travels laterally to the sides of the top. One might expect the sound to transmit itself in a concentric manner from the bridge, but this is not the case, because the lateral speed of sound (perpendicular to the grain) is only 1 - 2 per cent of the speed down the centre line (with the grain). Therefore when the sound wave will have arrived at the neck of the violin the same wave will only have covered less than one centimetre left and right of the bridge.

This lateral propagation of a change in frequency is not to be confused with the resultant vertical motion of the violin top when it oscillates under the resulting standing wave. These standing waves can be visualized by Chladni figures.

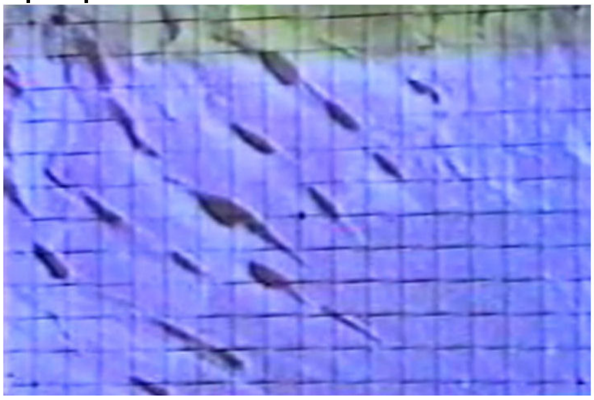
Why is this? The answer is quite simple. Cellular membranes present a big obstacle to the transmission of sound since they have a low elasticity when reacting to incoming sound waves. They react like a marshmallow. This slows down the speed considerably.
Nature Magazine Nov. 2006 reports that Stradivarian wood had undergone chemical treatment of oxidization and hydrolyzation. According to Nagyvary 8) this diminishes the violin's excess low noises adding that this was only part of the equation that gave these violins their characteristic tone.

When examined in the electron microscope at a magnification of 1:2000 the wood structure of a Stradivarius seems to be filled with open holes. The so-called pit-holed membranes are missing. The same open pit holes can be seen in Nagyvary's own seasoned wood. Untreated tone wood however shows solid closed off pit-holes.

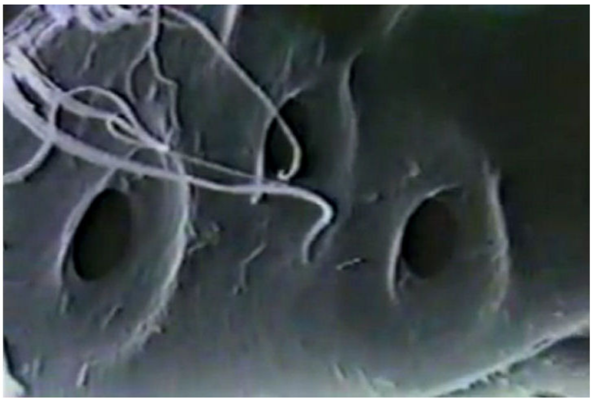
Nagyvary believes that the old violin makers couldn't help using wet seasoned wood because it came from Venice, the centre of the wood trade, where merchants kept their logs in the sea. Nagyvary contends that freshly cut green wood is very slowly decomposing by natural microorganisms.

As we shall see (below) the thickness of intra-cellular membranes has an important effect on the speed of sound. Perforated membranes pose the ideal setup for high speed of sound.

Open pit-holed membranes

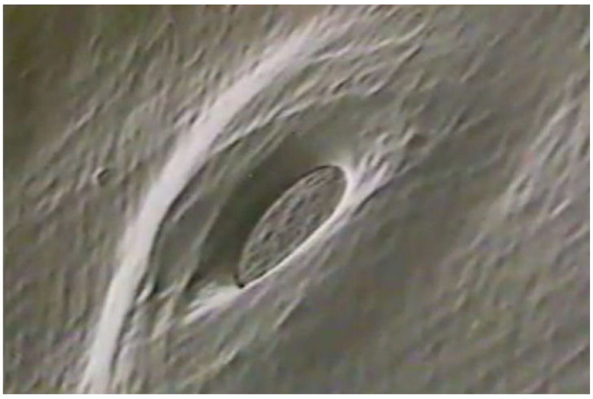


Stradivarius wood



Nagyvary's seasoned wood

Closed pit-holed membranes



Tone wood without hydrolysis

Here is an anecdote 8) about a violin made by Nagyvary . One day Ben Koodlach who was over many years the luthier of Jascha Heifetz was confronted by Zina Schiff with the newest violin of Joseph Nagyvary. Koodlach was quite impressed by the sound and so he went to a Zina Schiff concert. His conviction was strengthened and he said it was indeed the best new violin he had ever heard.

2. Criterias for tone wood

Key requirement for any tone wood is that there are no disturbances e.g. branch inlets, since this would cause the wood to deflect sound and the wave could not propagate symmetrically.

Moreover the speed of sound must be as high as possible in order for the sound waves to hit the full length of the violin as quickly as possible. Otherwise the waves would become distorted while expanding laterally to the sides. While this might not be a problem with the basic tones, harmonics have a much shorter wave length. Anything below 10 kilo-Herz can be easily heard. But at this frequency the wave length is already that of the violin body length.

3. Year rings and their importance
Except for the fact that slow growing wood will naturally have tight year rings, the year rings themselves bear no relevance to the speed of sound whatsoever. What matters is the thickness of the membranes. So it could well be that some wood has wide year rings but has yet thin membranes. Also very tight year rings can have thick cellular membranes (refer to sample "th1" further down). Since the proportions of the cellular length and width are somewhat constant, a reduction in diameter of the cells will also shorten their length. Thus tight year rings might eventually reduce their capability to support a high sound speed because of an increase in the number of longitudinal cellular membranes.

The only difference we noted with tops having narrow year rings as opposed to wide year rings is that the first will produce a more treble sound whereas wider year rings will give the instrument a slightly more voluptuous sound. This we found by building two violins with exactly the same material and dimensions, one with 9 rings and the other with 7 rings to the centimetre.

4. The ultimate measures of quality
Tone wood scientists have come up with two criteria In measuring wood properties.

4.1. The "Q" Factor:
This is a measure of damping i.e. a measure how fast the sound of a tap tone dies away. Damping is a direct consequence of sound energy being converted to mechanic energy through molecular displacement within the wood. To better understand this let us consider a pendulum that has been set in motion. It will gradually come to a halt, its oscillations loosing amplitude over time. Now let us place this pendulum in a vacuum cabinet. This time the pendulum will take much longer to come to a halt. Why? In the first experiment the kinetic energy of the pendulum was drained by the resistance of the surrounding air. Thus in a dampened environment energy of the wave will dissipate much faster resulting in a reduced output of sound.

How can damping be explained physically? If the material does not have a tendency to return to its initial molecular structure after it had been exposed to force, e.g. the marshmallow, we speak of high damping with conversely little stiffness or small elasticity.

Hardened steel would in the event of molecular displacement quickly return to its original structure. Try bending a spring feather. We call this phenomenon "stiffness" or "elasticity". Therefore high elasticity means strongly reduced damping. One might therefore wish for no damping at all. But beware, it has been shown that no damping can also have an adverse effect on the qualities demanded from tone wood.

The widely held opinion is that the Q-Factor should be high (meaning low damping) and that vibration damping is a negative quality in the materials used in lutherie. It turns out there are many counter examples, where damping improves tones and playability, particularly in bowed instruments. And it is likely that even if it were true that decreasing material damping in plucked instruments were beneficial, there would be some limit to this benefit and going beyond it would be detrimental to tone. As is the case with other properties, damping is neither good nor bad - it is simply one of the factors that shape the tone of an instrument. 2)

4.2. The "Radiation Ratio" (RR):
RR can be defined as the speed of sound divided by the specific weight. Since a sound wave must shift molecules while in transit it will use up less energy within a thinner medium such as a low specific weight. Thus the lesser the specific weight the lesser the loss in sound. Therefore describing a medium by virtue of its speed of wave propagation and its capability to do so with as little energy as possible, the RR is the right measure.

5. Selecting tone wood without measurement instrumentation

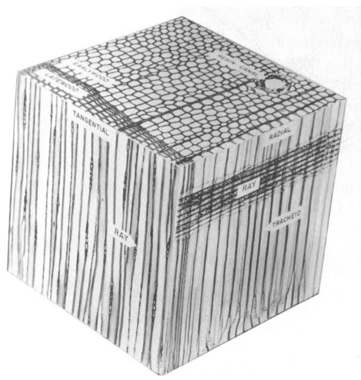
Many luthiers judge the speed of sound in wood by tapping it and comparing its pitch by ear. With larger objects e.g. a cello top they tap with the knuckle at different places expecting exactly the same pitch. A change of pitch would point at an irregularity within the wood. The pitch will not only give an indication of the speed of sound but also a feel for damping. If the ring comes to an abrupt halt this is an indication of high damping. Freshly cut wood will show high damping because of an excess of water content.

The assumption is the higher the pitch the higher the speed of sound. But this only applies to samples of similar size. Obviously comparing without instrumentation becomes a rather crude way of selecting tone wood, because with several samples this method is not precise.

6. Speed of sound

The speed of sound is generally higher with rising specific weight and high elasticity. Therefore speed will increase in the direction from air, water, wood, metal to diamond. In wood there are always two distinctly different speeds of sound, longitudinally (in the direction of the grain) and laterally (perpendicular to the grain).

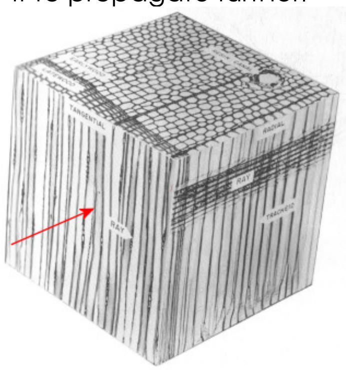
In the following diagram one can see the construction of the lignin cells in wood with vertical grain.



6.1 Lateral speed of sound

Here comes seemingly an anomaly. The lateral speed of sound decreases with decreasing thickness of the wood. We found this speed in a raw slab of tone wood averaging a thickness of 3 centimetres to be only 10% of the longitudinal speed. After the wood's thickness is reduced to 6 millimetres the lateral speed shrinks further by 75% to only 2-1/2% of the longitudinal speed. However since violin tops can get as thin as 2 millimetres this speed will eventually be reduced to a mere 1% to 2% of the longitudinal speed.

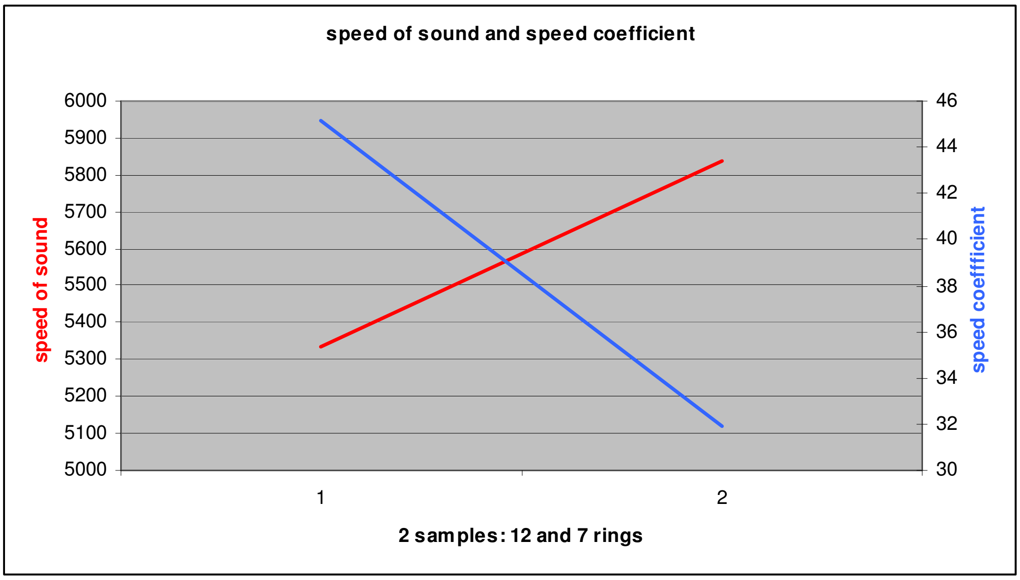
Why is the lateral speed depending on the thickness of the wood? There can only be one reason. When the wood is fairly thick the sound will be able to flood a large cross section (the direction of sound is indicated by the red arrow in the image below). This makes it possible for the sound to find openings between the grain cells where it can slip through before the inelastic cellular membranes allow it to propagate further.



It is the thickness of these membranes and their quantity that control the lateral speed. Unfortunately we cannot judge membrane thickness but we know that its thickness governs the speed of sound.

6.2 Very narrow year rings and their repercussion on speed of sound

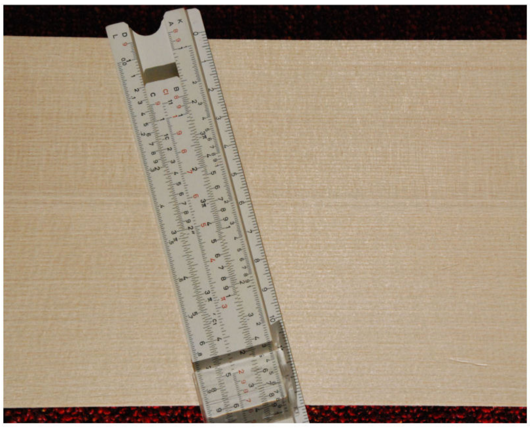
Next we shall witness the interesting phenomenon that narrow year rings can at some point become a detriment to the speed of sound. We are examining 2 samples th1 and th2, the first with 12 rings/cm, the other with 7 rings.



How can the often times hailed wish for tight year rings lead to poor acoustic qualities?

We see the first sample has a low longitudinal speed and also high speed coefficient, meaning a relatively low transversal speed – poor results all around. The second sample with only 7 rings however excels.

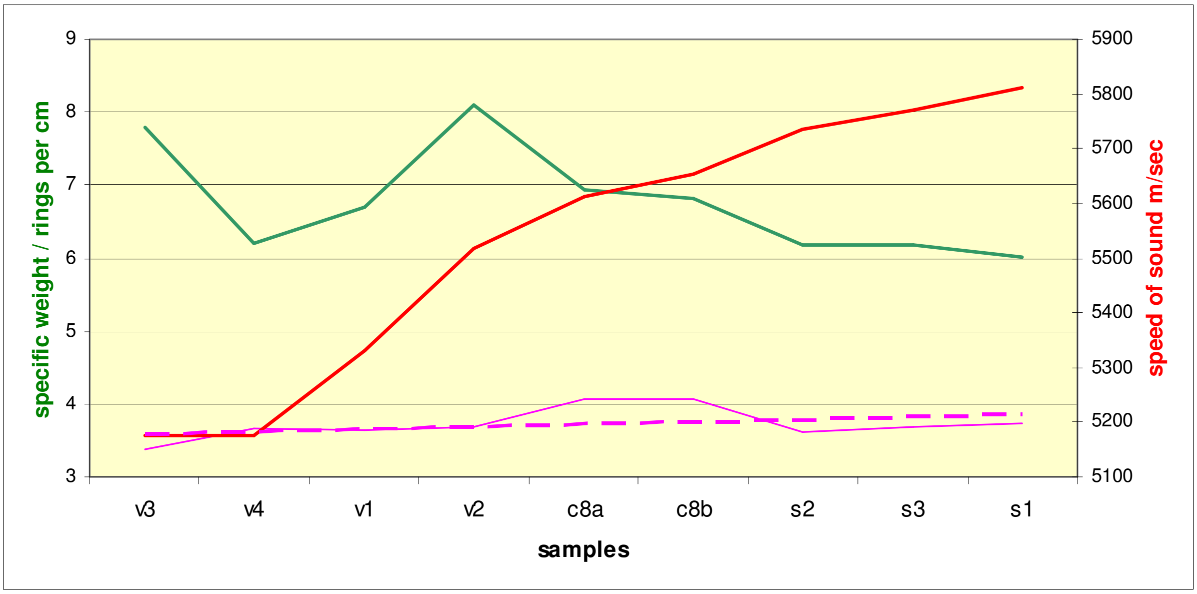
Sample "th1" - 12 year rings / cm



Sample "th2" - 7 year rings / cm

There is a simple reason: When rings get very close their longitudinal cellular length also is shortened. This means that the increased number of membranes that have to be surmounted reduce the speed of sound. Possibly also the longitudinal channel may become too narrow for the flawless transmission of sound. Therefore beware of too narrow year rings.

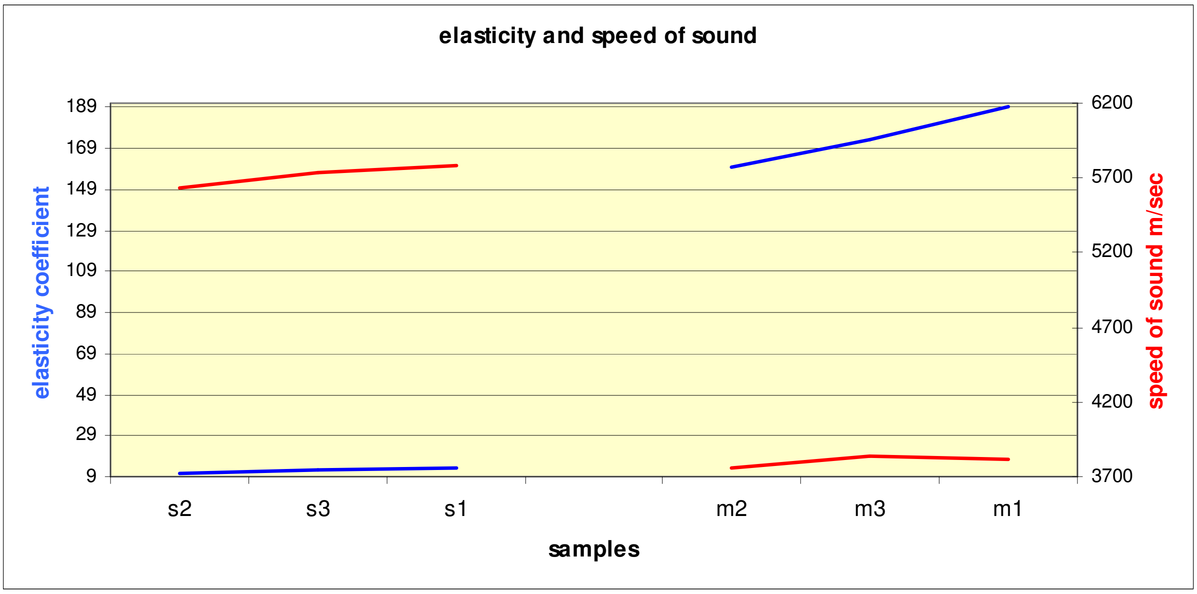
6.3 Comparing specific weight, year rings and speed of sound
In the diagram below we can compare 1. speed of sound (red), 2. year rings (green) and 3. specific weight (purple).



While the speed of sound increases in the samples from left to right the year rings show no correlation whatsoever. We do however have a slight positive correlation between the specific weight and the speed of sound.

In the following diagram we see a clear relationship between elasticity and the speed of sound in the wood. In the left part of the diagram are three samples of spruce with relatively little elasticity (blue) and a high speed of sound (red). In the right part we have three maple

wood samples with about 15 times the elasticity as compared to spruce. Growing elasticity equates most of the time to a growing speed of sound.



6.4 Limitations of selecting tone wood without measuring the sound speed
While inspecting some 50 samples that had all optically been approved as good candidates, we found more than 10 per cent of these which could not be measured, because the sound propagation within the wood was gravely disturbed. This means that all these samples were pretty useless as tone wood, although from the outside there was no adverse visible sign.

While finding the measurement procedure as described by J.P. Schmidt very helpful indeed, we performed several independent frequency tests to safeguard against drawing wrong conclusions. The drawback in this method is that the wood will show several frequencies which respond, so care must be taken to identify the right peak. Good documentation is thus imperative.

Once frequency data has been collected for a certain type of sample it becomes easy to check on other samples of similar dimension.

Experimental setup for measuring the speed of sound
There exist two widely used methods.
Giovanni Lucchi offers an instrument called "Lucchi Meter". 5)
Furthermore J.P. Schmidt describes a method incorporating public domain software analyzing the frequency spectrum of a sound generated by hitting the sample. This measurement can be used to calculate the speed of sound. 6)

Experimental setup for measuring the damping in wood
It is also possible to establish the damping of wood on hand of the same software as above by finding the basic ring tone from a small sheet of test wood. The results give a fair approximation and can be described as "stiffness coefficient". 7)

We have done this and found the results to be credible.

Although the speed of sound can be measured with the above instrumentation in any sample, damping can only be measured in a fairly thin and flat specimen and will give a general reading for the type of wood used.

Definitions:

cellular membrane - the wall of a lignin cell, their assembly making up for the physical structure of the wood

chladni figures - a membrane (violin top) vibrating at resonance is divided into regions vibrating in opposite directions, bounded by lines of zero vibration called nodal lines

correlation - the ability of two parameters to move in the same direction

damping - an effect that reduces the amplitude of oscillations, the tone terminating quickly

elasticity - the amount of stiffness of a material. The measure of a material's ability to reshape itself after it has been deformed. E.g. diamond has very high elasticity, polyethylene extremely low.

elasticity coefficient - a measure comparing the elasticity in varying wood samples. Mathematically the coefficient is proportional to (f^2*s), where f=base frequency and s=specific weight of the sample (see also footnote 7)

q factor - a measure of damping (refer to chapter 4.1)

radiation ratio – a measure of tone wood quality, speed of sound divided by specific weight

ring - the extent by which a tone can extend when there is low damping

speed coefficient - the longitudinal speed of sound divided by the lateral speed of sound. The thinner the wood the higher will be this coefficient (see also chapter 6)

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FOOTNOTES:

1) Andreas Pahler: http://www.youtube.com/watch?v=6kcRRB4sGqk

2) R.M. Mottola: http://LiutaioMottola.com
A former engineer and a luthier since 1994, R.M. Mottola is also the technology editor for American Lutherie, the quarterly journal of the Guild of American Luthiers, and has been an active researcher since 2001. He maintains the Liutaio Mottola Lutherie Information website and is a member of New England Luthiers.

3) Haines, D. W. "On musical instrument wood"
Catgut Acoust. Soc. Newsletter 31, 1979, pp. 23-32.

4) McIntyre, M.E., Woodhouse, J. "ON MEASURING THE ELASTIC AND DAMPING CONSTANTS OF ORTHOTROPIC SHEET MATERIALS"
Acra meroll. Vol. 36, No. 6, 1988, pp. 1397-1416,

5) Lucchi Meter: http://soundpostonline.com/archives/340/

6) John P. Schmidt: http://jpschmidtviolins.com/radratio.html

7) John P. Schmidt, Laurinburg, NC
"Simple, Inexpensive Testing of Stiffness in Violin Wood"
http://www.freewebs.com/violins88/testing%20wood%20strips.pdf

8) Joseph Nagyvary is professor emeritus of biochemistry at Texas A&M University College Station, Texas 77843
Chem. & Eng. News, 23 May, 1988 and The Chemical Intelligencer, 1996, 2(1), 24

9) Interview with Ben Koodlach, luthier of Jascha Heifetz
http://www.youtube.com/watch?v=4DPyPh5-NCY