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Making Violins with Tasmanian Tonewood: expect the unexpected

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ABSTRACT

Tonewood is the term employed to describe the wood species used to make musical instruments. These species have a proven record of consistent mechanical and acoustic qualities. Existing data show that a number of Tasmanian tonewood species have been used by luthiers over the past 25 years with varying success. Violin makers in particular, having to carve instrument plates from a solid block of wood, have found these species to be quite unpredictable when compared to the traditional, and reliable, European resonance spruce and curly maple. The aim of this paper is to discuss the acoustic qualities of 6 Tasmanian tonewood species which are not currently used in violin making, and the remarkable differences found between some Tasmanian species and some European species. In order to gather further information on Tasmanian tonewood, 30 specimens of wood from 6 species currently used by luthiers for guitars and other instruments were sourced; 175 test samples were then cut off the mother boards. These samples were used to conduct a series of acoustic tests for acoustical characterization of specimens. A new criterion to study the anisotropy of resonance woods was proposed (the ratio between the acoustic radiation and acoustic impedance). The most effective combination of species seems to be for the top Huon or King Billy Pine and Beech Myrtle for the back

INTRODUCTION

The violin can be described as four strings mounted on a box made of wood which contains an almost closed air space. (Hutchins, 1978).

The string tensions tend to compress the length of the top plate, increasing the longitudinal and sideways arching curvatures in the bridge area. (Segerman, 2001) The violin strings are put into motion by the bow. Their vibration is transmitted to the bridge, which in turns vibrates and communicates this motion to the top plate. (Hacklinger, 1979)

The top plate transmits its vibration to both the air outside and inside the instrument, while the back plate is set in motion by the inner air and by the soundpost and the ribs (Giltay, 1923). Air and main body resonances are not isolated means, but in good instruments are matched for best total effect to insure a strong lower register. (Schelleng, 1963)

The bridge is very efficient at transmitting power to the sounding box at frequencies from about one to four kHz, which is where the ear is most receptive (McLennan, 2005). The resonant box of the violin consists of a top plate and a back plate glued to the ribs enclosing an air volume. (Jansson, 1973) Both plates are arched slightly outward, and are shaped from a solid block of wood using carving tools like chisel, gouges, thumb planes and scrapers (Hutchins, 1978). The average thicknesses for violin top and back plates used by Antonio Stradivarius, and still followed by makers today, range from a maximum of 4.5 mm around the bridge area, to a minimum of 2.4 mm in the top half of the plates (Sacconi, 1972).

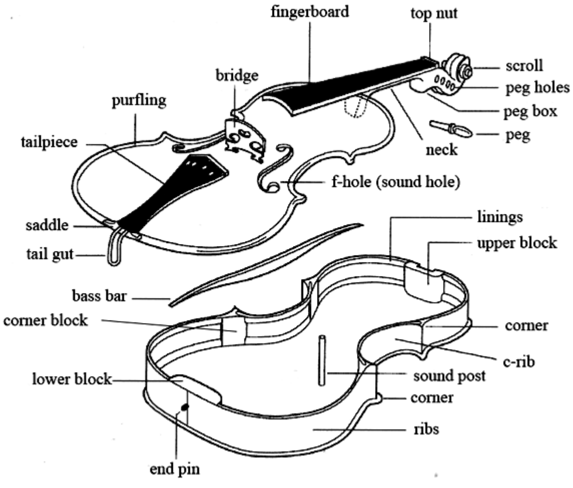

Figure 1. Violin anatomy (Hutchin 1975)

The density of the wood used for the fittings (pegs, tailpiece), and the thicknesses of the neck and fingerboard, will also have an effect on the delicate balance of frequencies within the instrument. (Hutchins, 1990)

When using traditional methods and models in the making of violins with Tasmanian timbers though, some of the thicknesses must be reviewed to ensure that top plates, in particular, are able to sustain the stresses of permanent pressure from the strings and bridge (Doe and Forster, 1987).
Violin makers are faced regularly with issues arising from the deformation of violin bodies under string tension. (Jansson, 1992) However, the method of carving arching requires aesthetic judgement rather than adherence to standard templates. (Caldersmith, 1999b) (Caldersmith, 1999a)

The term *tonewood* applies to wood species that have shown consistent mechanical and acoustic qualities when used in musical instrument making.

The quality of wood for violins have been largely commented in reference books (Bucur, 2005) (Barlow, 1997) and a series of articles published by the Catgut Acoustical Society USA. (Haines, 1979) (Hutchins, 1977) (Caldersmith, 1984b) (Caldersmith, 1991)

The main qualities of the tonewood used to make tops of violins are:

- High stiffness (parallel to the grain)
- Density (light weight without being soft)
- Aesthetics (colour, figure and grain orientation)

Traditionally, the wood most sought after for top plates was Swiss or Tyrolese spruce *(Picea)*, and for the back and sides the maple *(Acer)* which grew on the southern slopes of the Carpathians and in some parts of the Eastern Alps (Heron-Allen, 1885). These species have continued to be in use and are still the violin makers' first choice when selecting high quality tonewood. (Barker, 2001) (Newman, 2008) Their main properties are:

- Spruce has low density, a high elastic modulus per unit of density, low internal friction and high flexibility across the grain (Wegst, 2006)
- Maple has the strength to resist bending across the grain, a high degree of damping and great beauty of the flame (Hutchins 1975)

The aim of this article is to study the acoustical properties of several Australian wood species using ultrasonic velocity methods, and to propose selection criteria (combination of stiffnesses or velocities for the calculation of acoustic radiation or acoustic impedance) for the species to be used in violin making.

TASMANIAN TONEWOOD SPECIES

All through history, 'new' or exotic wood species were introduced, at different times, for the making of different musical instruments. (Brémaud I, 2008) In what concerns the species used in violin making, little has changed since the 17th century. (CIARM, 2008)

Several Tasmanian wood species are currently used in the making of acoustic and classical guitars. Results from research conducted on their acoustic qualities, confirms that they can be used as tonewood. (Morrow 2007) (Jones, 2008) (Caldersmith, 1984a) (Caldersmith, 1990) (Tonewoods) Based on those findings, samples from three softwood and three hardwood species were chosen for this experiment.

Softwood species for violin top plate

King William Pine *(Athrotaxis selaginoides)*, colloquially known as 'King Billy Pine', is a medium to large softwood of the high rainfall areas of western Tasmania. The heartwood is pink to pale reddish brown which fades on exposure. It has fine but uneven texture, straight grain and prominent growth rings due to the considerably darker latewood. (Bootle, 1996) Some problems may arise when compression wood and/or resin exudation are present (TasmanianTimber, 2007).

It has been used with success for violin top plates because of its crisp and resonant qualities, but it bruises easily. (Akerman, 1996). Tests conducted using small sample strips have shown that, in general, the radial stiffness in both the axial and radial directions are lower than spruce (Doe and Forster, 1987).

Huon Pine *(Dacrydium franklinii)* is medium sized softwood of the high rainfall areas of south-western Tasmania. The heartwood has a pale straw color, becoming yellow after long exposure. It has fine and even texture, straight grain, growth rings closely spaced and a characteristic scent due to the essential oil methyl eugenol. (Bootle, 1996) Because samples can vary greatly in density and crispness careful selection for its use in violin making is necessary. (Searle, 2003) It has been found to be easy to work with but to present some challenges during the application of varnish (Akerman, 1996).

Celery-top Pine *(Phyllocladus asplenifolius)* is a medium-sized softwood of the high rainfall areas in Tasmania. The heartwood is pale yellow to pale brown. It has fine and even texure, and the grain is usually straight. Growth rings are conspicuous and very close together. The presence of compression wood is frequent. (Bootle, 1996) Samples showing compression wood are generally rejected by violin makers due to the potential negative effects on the wood properties such as strength, stability and most importantly the acoustic characteristics. (Morrow, 2007)

When well dried, it has crisp characteristics, and it has shown more resistance to bruising than King Billy pine. Sometimes there can be defects found within the structure of an anular ring which can lead to unwanted splitting. (Akerman, 1996)

Hardwood species for violin back, neck and sides

Southern Sassafras *(Atherosperma moschatum)* is a medium sized hardwood of the high rainfall areas of Tasmania. The heartwood color can show various shades of brown. It has fine and even texture, straight grain and, usually, very little figure. (Bootle, 1996) It is easy to work with and is good for steam bending. (Emmett, 2009)

It takes stain and polishes well. The 'black heart' colourful parts of the wood should be avoided as they are areas which have been subject to a fungal attack. Whilst attractive, consist of denatured timber with little strength. (Akerman, 1996)

Blackwood *(Acacia melanoxylon)* is a medium sized hardwood tree of occasional occurrence in tableland areas in South Australia and all the eastern States but the only areas of considerable commercial yield are the wetter districts of Tasmania. The heartwood is golden brown, often with narrow bands of darker colour indicative of the growth rings. Some reddish streaks are also present. Its texture is medium and even, grain usually straight but sometimes wavy, producing a fiddleback figure. It is easy to work, although figured material will need special care, and it is good for steam bending. (Bootle, 1996) The sanding dust can be an irritant to the skin and bronchial tubes of some people. (Akerman, 1996) It has been used in the back and sides of violins successfully both in appearance and tonal qualities. (Searle, 2003) Blackwood has consolidated its reputation as the hardwood of choice both nationally and overseas, and it is considered to be a world class tonewood. It has emerged as a flagship for not only Tasmanian, but Australian timbers in this area (Morrow, 2007).

Tasmanian, Beech, Myrtle *(Nothofagus cunninghamii)* is a medium sized hardwood the heavier rainfall areas of Tasmania and eastern Victoria though most supplies come from Tasmania. The heartwood is pink to reddish brown. It has fine and even texture, grain sometimes wavy, and visible but not prominent growth rings. (Bootle, 1996) Its behaviour during drying is variable for it often has an uneven distribution of moisture. It is good for steam bending. (Somerville, 1964) When used in violin making it has been found to be quite dense. Some samples with pleasingly figured grain are available. (ForestryTasmania, 2009)

METHODOLOGY

Sample selection

The samples have been selected from 30 specimens belonging to the six Tasmanian wood species described above. Preliminary data collection on full length boards was conducted in order to ascertain grain straightness relative to the board edges, and the uniformity of structure and color. Visual appraisal is a non-destructive method that has been used for centuries. (Bucur, 2003)

Based on identification, 175 samples across the full boards were generated. Sample dimensions in mm, in L, R and T directions: 150 x 50 x 50 mm.

Wood absorbs moisture very slowly over a period of weeks, while it can lose moisture under conditions of low relative humidity in a period of 24 hours or less. (Hutchins, 1982) For this reason, the samples were conditioned until all of them showed approximately the same moisture content (12%) as required by the international and Australian standards for wood testing. This step is important due to the fact that the physical and mechanical properties of wood are affected by moisture content variation. (Woodworking, 2006)

Ultrasonic Velocity Method

Direct transmission ultrasonic technique was used for the measurement of ultrasonic velocities using transducers of 1 MHz for longitudinal and shear waves (figure 2).

This methodology was largely described in the literature (Bucur 2005) Because of time limitation for the experimental work, in this article we will comment only the results refereed to the longitudinal waves.

The ultrasonic device was composed from an ultrasonic generator, two ultrasonic transducers of 1 MHz frequency and an oscilloscope for signal display and processing. The 1MHz frequency has been selected to induce in spruce an ultrasonic wave having about 5 mm

For the other species the wave length coud be about twice of fiber length.

Figure 2. Transducers holding test sample

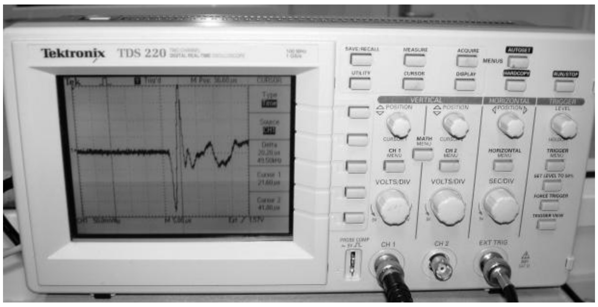

Figure 3. Ultrasonic signal on the oscilloscope screen used for time propagation readings

The velocities were measured in three anisotropic directions of wood, L R T, and have been noted as

- V_{LL}, V_{RR} and V_{TT} for longitudinal waves

The first index corresponds to the direction of propagation, the second one to the direction of polarization of the ultrasonic wave. For longitudinal waves, these directions are parallel – the indices are the same.

- Other parameters have been calculated such as: acoustic impedance, acoustic radiation and stiffnesses noted C_{LL}, C_{RR} and C_{TT} in all anisotropic directions .

Further tests

In order to complete this project, two violins will be made using the same structural model: one using European tonewoods, the other using the Tasmanian tonewoods showing best results from the acoustic velocity tests. The two finished instruments will undergo further testing.

In contrast with our current situation, when the violin reached its current form during the seventeenth century, the studies of vibration were studies of *musical sound*. (Dostrovsky, 2000) Historically, violin research falls into two areas: studies done before 1920 without electronic testing devices, and the following work using increasingly sophisticated electronic equipment to learn more about the vibrational characteristics of the instrument. (Hutchins, 2000) A mixed methods research approach has been designed for this project. (Creswell, 2009)

The violin, as a musical instrument, must be studied in musical context in order to be fully understood. This involves not only the instrument itself, but the player, the style of music being played, the acoustics of the environment, as well as musical taste and background of the listeners. Unless we can begin to understand more of the elements in this relationship, we are only looking at part of the system. (Hutchins, 1992) Violin makers and musicians, usually work on a more intuitive basis, and tend to be sceptical of scientific measurements when not all relevant areas are taken into account. (Creel, 1970) For that reason, the conclusions arrived at in this paper will be tested against the results from the two following tests:

Impulse response test: to be conducted by tapping the bridge, and placing a microphone at the bass f-hole to measure the resulting pressure response. (Jansson, 1997) (McLennan, 2008) (Inta, 2005)

Listening and playing test: the violins will be played and listened to by a group of advanced violinists from the Hobart conservatorium. Using a system that awards quality points, a rating of the violins will be established. (Inta, 2005) (Jansson, 1992) This type of method draws meaningful measures of musical quality over a range of properties related to the violins tonal qualities. (Caldersmith, 1988) (Caldersmith, 1989)

RESULTS

Results on samples

Table 1 gives the values of the ultrasonic velocities in L, R and T anisotropic directions of wood. It can be seen that for softwoods, in L direction Huon Pine and Celery – top pine have an anisotropy ratio V_{LL}/V_{RR} closed to the resonance European spruce.

In terms of the anatomic structure it is useful to note that European spruce has very long fibers (tracheids) which explain the very high velocities in L direction. Note the Huon Pine with V_{LL}/V_{RR} = 2.69. The velocities related to the axis R express the presence of the rays, very abundant in the European spruce. In transversal plane the Huon Pine has the lower anisotropy in Tasmanian woods (V_{RR}/V_{TT} = 1.16) but when compared with European spruce (V_{RR}/V_{TT} = 1.57) the anisotropy of Huon Pine is not as high as in spruce.

From the literature and from empirical experience of the violin makers it was generally accepted that the softwood for the top of the violins must have an important anisotropy (stiff in L direction and very flexible in RT plane).

For the hardwood species which absorb acoustic energy, when used for the back of the violin, it was generally accepted that the anisotropy must be lower than in wood species for the top.

The variability of the experimental data reported in this article is between 5% and 19%, which is normal for a natural biological material as wood.

Table 2 gives the values of the acoustic impedance and acoustic radiation for all studied species.

Table 3 gives the values of stiffness in all three anisotropic directions as well as some ratios and the acoustic invariant calculated as the summ of the stiffness with longitudinal waves.

Data from **Table 4** allow the establishment of criteria of species selection by comparing different ratios of stiffnesses. From this analysis it seemed that an interesting combination of species could be Huon or King Billy Pine for the top and Myrtle beech for the back of the violin.

From the previous practical experience of Australian violin makers it was noted that in some cases even when the samples showed good results, the material was rejected for other reasons (gluing, varnishing properties).

Huon pine was the less popular amongst the softwoods. The problems during gluing and varnishing have been the main reasons given. Some Blackwood and Sassafras samples for violin plates were found to be too plain, and /or to have wide grain. In the future these aspects need to also be studied.

Finally in this study a new criterion for the selection of species was proposed and was based on the comparison between the ratio of acoustic radiation over acoustic impedance for different combinations of species in all anisotropic directions as shown in **Table 5**. This parameter shows that for the resonance spruce - curly maple combination the ratio is about the same, (2.2) in all anisotropic directions.

Having this criterion in mind, the combination of Huon Pine and Myrtle beech seems to be the best selection. The ratios were respectively in L, R and T directions 1.6, 1.6 and 1.3.

Table 1 Ultrasonic velocities with longitudinal waves at 1 MHz, in some Tasmanian species for violins and for European resonance spruce and maple

Species	Density (kg/m3)	Ultrasonic velocities measured in 3 principal directions of wood elastic symmetry – average values (m /s)					
		V_{LL}	V_{RR}	V_{TT}	V_{LL}/V_{RR}	V_{LL}/V_{TT}	V_{RR}/V_{TT}
Softwoods							
King Billy Pine	400	3840	2009	1462	1.91	2.63	1.37
Huon Pine	550	4217	1567	1350	2.69	3.12	1.16
Celery-top Pine	650	4305	1909	1510	2.26	2.88	1.28
ResonanceSpruce - European (Bucur 2005)	435	6294	2130	1354	2.95	4.65	1.57
Hardwoods							
Blackwood	640	4776	1966	1479	2.52	3.35	1.39
Beech Myrtle	700	4751	1635	1554	2.93	3.09	1.07
Sassafras	473	4756	1956	1518	2.44	3.14	1.29
Curly maple (Bucur 2005)	650	4350	2590	1914	1.67	2.27	1.35

Table 2 Acoustic impedance and acoustic radiation with longitudinal waves in L,R and T anisotropic directions

Species	Density ρ (kg/m3)	Acoustic impedance expressed by the product velocity x density, in 3 principal directions of wood elastic symmetry – average values $10^3 (\frac{m}{s} \cdot \frac{kg}{m^3})$			Acoustic radiation expressed by the ratio velocity / density, in 3 principal directions of wood elastic symmetry – average values $(\frac{m}{s} * \frac{m^3}{kg})$		
Softwoods		In L	In R	In T	In L	In R	In T
King Billy Pine	400	1536	803	584	9.60	5.02	3.65
Huon Pine	550	2319	861	742	7.67	2.84	2.45
Celery-top Pine	650	2798	1240	981	6.69	2.94	2.32
ResonanceSpruce - European (Bucur 2005)	435	2737	926	588	14.46	4.89	3.11
Hardwoods							
Blackwood	640	3056	1277	946	7.46	3.07	2.31
Beech Myrtle	700	3325	1144	1087	6.78	2.33	2.22
Sassafras	473	2249	925	718	10.04	4.13	3.20
Curly maple (Bucur 2005)	650	2827	1683	1244	6.69	3.98	2.94

Table 3 Stiffneses with longitudinal waves at 1 MHz, in some Tasmanian species for violins and for European resonance spruce and maple

Species	**Density (kg/m3)**	**Ultrasonic Stiffnesses measured in 3 principal directions of wood elastic symmetry – average values (10^8 N/m ^{2})**					
		C_{LL}	C_{RR}	C_{TT}	C_{LL}/C_{TT}	C_{RR}/C_{TT}	Σ (C)
Softwoods							
King Billy Pine	400	58.98	16.14	8.50	6.90	1.89	83.68
Huon Pine	550	97.80	13.59	10.02	9.76	1.35	121.41
Celery-top Pine	650	120.46	23.68	14.82	8.13	1.59	158.96
ResonanceSpruce - European (Bucur 2005)	435	172.3	19.73	7.90	21.80	2.49	199.93
Hardwoods							
Blackwood	640	145.98	24.73	13.99	10.42	1.76	184.70
Beech Myrtle	700	158.00	18.71	16.90	9.35	1.07	193.61
Sassafras	473	106.99	18.09	10.89	9.82	1.66	135.97
Curly maple (Bucur 2005)	650	122.9	43.60	23.80	5.16	1.35	190.30

Nb : The Stiffness is calculated as C = $[\, v^2 \bullet \rho \,]$ or = $[\, \frac{m^2}{s^2} \bullet \frac{kg}{m^3} = \frac{m}{s^2} \bullet \frac{kg}{m^2} \,] = [\, \frac{N}{m^2} \,]$

Σ (C) = the summ of the stiffnesses with longitudinal waves = CLL + CRR + CTT

Table 4 The ratios of different parameters for softwood and hardwood compared with the ideal combination of species Spruce and maple

Combination of species	Ratios of Σ (C)	C_{LL}/C_{TT}	C_{RR}/C_{TT}	Notes
Resonance Spruce/ Currly Maple	1.05	4.22	1.84	Ideal combination
King Billy Pine / Blackwood	0.45	0.66	1.07	
Huon Pine/ Blackwood	0.65	0.93	0.76	
Celery-top Pine/ Blackwood	0.86	0.78	0.90	
King Billy Pine / Beech Myrtle	0.43	0.73	1.76	
Huon Pine/ Beech Myrtle	0.62	1.04	1.26	
Celery-top Pine/ Beech Myrtle	0.82	0.86	1.48	
King Billy Pine / Sassafras	0.61	0.70	1.14	
Huon Pine/ Sassafras	0.89	0.99	0.81	
Celery-top Pine/ Sassafras	1.17	0.82	1.13	
Selection criteria	Celery-top Pine/ Sassa-fras	Huon Pine/ Beech Myrtle	King Billy Pine / Beech Myrtle	Houn or King Billi Pine / Beech Myrtle

Table 5 Acoustic radiation and acoustic impedance for spruce and curly maple and for huon pine and beech myrtle

Species	Parameters - average values	Units	L	R	T	Notes
Resonance spruce and curly maple	Acoustic impedance	$10^3 (\frac{m}{s} \cdot \frac{kg}{m^3})$	0.968	0.55	0.47	
Resonance spruce and curly maple	Acoustic radiation	$(\frac{m}{s} * \frac{m^3}{kg})$	2.177	1.22	1.05	
Resonance spruce and curly maple	Acoustic radiation / Acoustic impedance Ratios	$10^3 \left[\frac{kg}{m^3}\right]^{-2}$	2.25	2.23	2.23	Ideal combination
Huon pine and Beech Myrtle	Acoustic impedance	$10^3 (\frac{m}{s} \cdot \frac{kg}{m^3})$	0.697	0.75	0.78	
Huon pine and Beech Myrtle	Acoustic radiation	$(\frac{m}{s} * \frac{m^3}{kg})$	1.13	1.22	1.02	
Huon pine and Beech Myrtle	Acoustic radiation / Acoustic impedance Ratios	$10^3 \left[\frac{kg}{m^3}\right]^{-2}$	1.62	1.63	1.30	**Recommended**

Expect the unexpected

The variations that occur naturally between different wood species, can also be encountered in samples belonging to the same species, and even the same trees. (Brémaud, 2006)

Despite the fact that a species may produce material valuable for a specific purpose, the unpredictable quality of wood as a natural biological raw material, and the rigorous quality demands of violin makers and players, need to be taken into consideration when comparing European and Tasmanian-tonewoods (Morrow, 2007).

Unlike European tonewood, sourced from hand picked trees and then processed following traditional methods, (Florinett, 2009) the Tasmanian species have the tendency to present the violin maker with a few unexepected surprises.

Unable to use veneers, the much thicker blanks are able to hide blemishes that might not surface until the plate is near to completion. Depending on the nature of the problem (knots, bark pockets, internal checks), the blank would have to be discarded. Other issues include structural changes in the top plate (bridge unable to sustain pressure long term caves in), problems applying varnish when using Huon Pine due to natural oils, and the developing of allergic reactions when using Blackwood. (Akerman, 1996)

One of the main issues violin makers are facing at present is the inability to access good quality seasoned material that has been quarter sawn.

Recently collected data shows that the current supply of special timbers is Tasmania cannot meet demand. (Farley, 2009)

The reality is that, because in most cases the tonewood is available as a log or a slab, the violin maker must learn how to recognize potential problems. Visual appraisal is a skill that needs to be developed when working with Tasmanian tonewood.

CONCLUSIONS

From the acoustical point of view, the wood species with high anisotropy are the best for making violin tops, providing the finished instrument with better acoustic qualities. For the back of the violin, the anisotropy must be as low as possible.

From this research in which the anisotropy of wood was analysed with longitudinal waves, the most effective combination of species seems to be Huon or King Billy Pine and Myrtle beech. Further investigations are needed to study the influence of anisotropy with shear waves and to also predict selection criteria.

On the other hand it must be stated that the violin is an art object and only the acoustical and mechanical considerations are not sufficient to guarantee a good instrument. Several other factors such as maker's skill can influence positively the final result. In our opinion the knowledge of the acoustical qualities of wood species can help the violin maker in reproducing fine instruments with specific properties.

REFERENCES

AKERMAN, J. (1996) Tasmanian timbers in stringed instrument building. *JAAMIM*, 18-23.

BARKER, J. (2001) *Violin-making: a practical guide,* Marlborough, The Crowood Press Ltd.

BARLOW, C. Y. (1997) Materials selection for musical instruments . Proceedings of the Institute of Acoustics 19: 69-78.

BOOTLE, K. R. (1996) *Wood in Australia*

Types, properties and uses, Sydney, McGraw-Hill Book company.

BRÉMAUD, I. (2006) Diversity of woods used or usable in musical instruments making. (in French). *Mechanic of materials.* Montpellier, University of Montpellier II.

BRÉMAUD I, MINATO K, GÉRARD J & THIBAUT B (2008) Vibrational properties of tropical woods with historical uses in musical instruments. *International conference on wood science for preservation of cultural heritage: mechanical and biological factors* Braga, Portugal.

BUCUR, V. (2003) Nondestructive characterization and imaging of wood. New York, Springer.

BUCUR, V. (2005) *Acoustics of Wood,* 2nd edition, Heidelberg, Springer.

CALDERSMITH, G. (1984a) Testing Tonewood Samples. Takoma, USA, Guild of American Luthiers.

CALDERSMITH, G. (1984b) Vibrations of orthropic rectangular plates. *Acoustica,* 56**,** 144-151.

CALDERSMITH, G. (1988) A violin quality assessment method: pilot study. *Acoustics Australia,* 16**,** 84-86.

CALDERSMITH, G. (1989) A violin quality assessment method: study II. *Acoustics Australia,* 17**,** 41-43.

CALDERSMITH, G. (1991) Vibrations of orthotropic rectangular plates: II, anticlastic effects in free plates. *Acoustica,* 73**,** 240-247.

CALDERSMITH, G. (1999a) Arching and voicing in violin plates. *American Lutherie.* Tacoma, America, Guild of American Luthiers.

CALDERSMITH, G. (1999b) Reconciling structural and acoustic design in violin making. *American Lutherie.* Tacoma, America, Guild of American Luthiers.

CALDERSMITH, G. F., E. (1990) Wood properties from sample plate measurements I. *CASJ,* 1.

CIARM (2008) Interuniversity Center of Acoustics and Musical Research Bologna, date accessed 11/02/2010 www.acustica.iacma.it.

CREEL, W., ROGERS, P. & HUTCHINS, C. (1970) Focus on stringed instrument research and development. *CAS Newsletter***,** 16-18.

CRESWELL, J. (2009) *Research Design - Qualitative, Quantitative, and Mixed Methods Approaches,* London, SAGE Publications Inc.

DOE, P. & FORSTER, C. (1987) Engineering considerations in establishing a manufacturing industry for bowed stringed musical instruments. *Acoustics in the Eighties.* Hobart, Australian Acoustical Society.

DOSTROVSKY, S. (2000) Musical overtones and the origines of vibration theory. *CASJ,* 4**,** 11-12.

EMMETT, C. (2009) Island Specialty Timbers. Geeveston, date accessed 25/01/2010 www.islandspecialtytimbers.com.au

FARLEY, M., FARLEY, H & BISHOP, M (2009) A review of the Tasmanian Woodcraft Sector for the Woodcraft Guild of Tasmania Inc & Forestry Tasmania. Hobart, Forestry Tasmania.

FLORINETT, A. G. (2009) Tonewood Switzerland. Bergün, date accessed 15/08/2009 www.tonewood.ch.

FORESTRYTASMANIA (2009). Hobart, date accessed 22/03/2010 www.forestrytas.com.au.

GILTAY, J. W. (1923) *Bow Instruments*

Their form and construction, London, William Reeves.

HACKLINGER, M. (1979) Violin adjustment - Strings and bridges. *The Catgut Acoustical Society Newsletter***,** 17-21.

HAINES, D. (1979) On Musical instrument wood. *The Catgut Acoustical Society Newsletter***,** 23-32.

HERON-ALLEN, E. (1885) *Violin-making: as it was and is,* London & Melbourne, Ward Lock & Co. limited.

HUTCHINS, C. (1977) Acoustics for the Violin maker. *CAS Newsletter***,** 38-42.

HUTCHINS, C. (1982) Problems of moisture changes when tuning violin plates. *CAS Newsletter***,** 61-62.

HUTCHINS, C. (1990) Acoustical effects of 'dressing down' a fingerboard and/or thinning the violin neck. *CASJ,* 1**,** 59.

HUTCHINS, C. (1992) The Future of Violin Research. *CASJ,* 2**,** 19-26.

HUTCHINS, C. (2000) A History in Violin Research. *CASJ,* 4**,** 4-10.

HUTCHINS, C. M. (Ed.) (1978) *The Physics of Music,* San Francisco, W. H. Freeman and Company.

INTA, R., SMITH, J & WOLFE, J, (2005) Measurements of the effect on violins of ageing and playing. *Acoustics Australia,* 33**,** 29.

JANSSON, E. (1973) On higher air modes in the violin

*CAS Newsletter***,** 30-33.

JANSSON, E. (1992) Acoustical measurements of quality rated violins and a new measurement method. *Acoustics Australia,* 20 11-15.

JANSSON, E. (1997) Admittance measurements of 25 high quality violins. *Acoustica- acta acoustica,* 83 (2)**,** 337-341.

JONES, H. (2008) Wood sound spectrums: levels of acoustic performance.

MCLENNAN, J. (2005) Violin acoustics: an introduction. Sydney.

MCLENNAN, J. (2008) The violin, music acoustics from Baroque to Romantic. *School of Physics.* Sydney, UNSW.

MORROW, A. (2007) Evaluation of Australian Timbers for use in musical instruments. IN FELLOWSHIP, G. (Ed. *Gottstein Fellowship reports.* Clayton South, VIC, Gottstein Memorial Trust Fund.

NEWMAN, T. (2008) Tonewood in the making. Goose Bay, date accessed 07/08/2009 www.tonewood.ca, Musical Forests Inc.

SACCONI, S. (1972) *I 'segreti' di Stradivari,* Cremona, LIbreria del Convegno.

SCHELLENG, J. (1963) The violin as a circuit. *The Journal of the Acoustical Society of America,* 35**,** 326-338.

SEARLE, C., SEARLE, F (2003) Tasmanian wood productivity. Smithton.

SOMERVILLE, J. (1964) *Tasmanian Timber Trees,* Hobart, Teaching Aids Centre Publications

TASMANIANTIMBER (2007) IN CSAW (Ed. Launceston, date accessed 07/05/2010 www.tastimber.tas.gov.au.

TONEWOODS, A. Australian Tonewoods. WA, date accessed 30/04/2010 www.australiantonewoods.com.

WEGST, U. (2006) Wood for sound. *American Journal of Botany, 93:1439-1448.*

WOODWORKING, F. (Ed.) (2006) *Selecting and drying wood /The New Best of Fine Woodworking,* Newtown, Taunton Press.