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THE SOUNDPOST IN THE VIOLIN

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PART I. THE EFFECT OF SOUNDPOST STIFFNESS ON PEAK RESONANCE AND SOUND OUTPUT.

SUMMARY

When no soundpost was present the output on the three lower strings was considerably lower than that of the upper string by about 6 dB on the violin studied. Wolf notes were present on the A string in the region of the strong body resonances near 500 Hz when no soundpost was present. The fundamental was extremely small on the G and D strings. The number and strength of other harmonics were unchanged.

Placing a soundpost in a "standard" position i.e. behind the right foot of the bridge, raised the average S.P.L. of the lower strings closer to that of the top string compared with a no soundpost condition. The tendency to Wolf was removed and player reaction and sound quality were improved.

Soundposts with calculated impedances varying from 111 kg/s to 12 kg/s have shown that soundposts with values above about 60 kg/s in the violin used, correlated with a more uniform sound level across the instrument using a Saunders Loudness Test. A balsa soundpost cut radially (Z = 3 kg/s) gave a similar result to no soundpost at all.

The frequency of resonance peaks, notably A0, B1- and B1+ were lowered slightly by fitting soundposts with lower stiffness. A Glass fibre Reinforced Plastic soundpost, although of greater stiffness was unsuccessful probably because of its higher mass.

INTRODUCTION

It is known that when the soundpost is installed in the violin the body is stiffened; Hutchins (1974) demonstrated the rise in the main air resonance of about 30 Hz. The soundpost in addition to stiffening the body, introduces an asymmetry to the vibrational behaviour of the instrument that is essential for it to radiate sound effectively at the lower end of its range. The violin has to act as a "simple source" because it is smaller than the wave-length of the sound being emitted in this part of its compass. The size of the violin becomes comparable to the wavelength at about 1 kHz so that the breathing action is important for most of the fundamentals of notes played.

The soundpost has a profound effect on the vibration mode shapes of the body and their frequency and strength. Schelleng (1971) described the compromise mode created with a nodal point at the soundpost. He outlined the conditions that had to be satisfied by resonances when the sound-post was present. Trott (1982) attempted to measure the input and transfer admittances relevant to the Schelleng prediction but found the behaviour of the violin studied too complicated to allow a satisfactory analysis.

Since the pioneering work of Schelleng, body modes have been extensively studied and the part played by the soundpost in determining their shape demonstrated. It was thought some further work would be useful exploring the effect of soundpost stiffness, care being taken to standardise the position and attention paid to ensure a satisfactory fit free from avoidable tension. By cutting soundposts in a radial direction a greater range of stiffnesses would be possible along with those cut in the normal longitudinal direction. It turned out a range of 10 to 1 was easily achieved.

Three main lower resonances were chosen to follow the effect of changes in soundpost stiffness; namely A0, B1- and B1+ as they could be readily verified using Chladni patterns. Impulse excitation and recording the output on tape with subsequent analysis was used to obtain response curves. The Saunders Loudness Test with hand bowing was used to follow the changes in sound output resulting from the different soundposts. These experimental techniques were thought to be adequate in view of the known variation between instruments. The same violin was used throughout.

The stiffness of the soundpost is proportional to the elastic modulus along its length, its cross sectional area and inversely proportional to its length i.e. $S = Ea/l$. Soundposts are by tradition made of spruce and cut along the grain, and since for any given violin the length is fixed, the stiffness can only be altered by a change in the cross section. For a given soundpost, any alteration in the shape that effectively reduces the cross section lowers the stiffness. For spruce which is an anelastic solid, the unrelaxed modulus would apply during playing.

EXPERIMENTAL DETAILS

An experiment was conducted to determine the effect of varying the stiffness of the soundpost on the position of resonance peaks in the tap response. The sound output resulting from these changes was determined using a modified Saunders Loudness Test as an easily realizable method. The S.L.T. was introduced in the 1930´s by Professor F.A.Saunders (1937) to express the loudness of bowed notes on the violin as they would be heard by a listener and would give an indication of the influence of the resonances on the output. A bowed note would include the effect of all the overtones present. In the test, an octave of semitones was played on each string and the loudness i.e. Sound Pressure Level (S.P.L.), recorded. The notes on the E string were extended beyond the octave. The aim of the S.L.T. was to show the position of prominent air and body resonances. A bow force just short of losing sound quality was required which meant the bow force (and bow speed) varied with each note. In the present experiments a consistent technique i.e. a constant bow force and bow speed, was maintained as near the maximum as possible, with the bow about 3 cm from the bridge. The strict S.L.T. conditions were not used. High on the E string the bow was nearer the bridge.

To validate the modified S.L.T. for the purpose of determining the output of a violin over its range under playing conditions, a bowing machine, McLennan (2000), was made that could be mounted on the instrument and still allow it to be held at the shoulder to stop notes as when playing normally. A satisfactory agreement was obtained between mechanical bowing and the hand bowing technique used in these experiments.

The modified Saunders Loudness Tests were conducted in a semi-reverberant living space. The player was seated in a position and oriented to avoid standing waves. The Sound Level Meter was mounted on a tripod and placed 1 m from the violin in the general direction of bowing. A second person who was seated at right angles to this line, recorded the highest consistent reading from several down bows. The SLM was set to A weighting and fast response.

The tap response was determined by suspending the violin vertically on a dexion frame with rubber bands at the scroll and the four corners. A bar of alumimiun 100 mm long and 6.2 mm dia. made hemispherical at the striking end and wrapped with a piece of foam rubber at the other to stop ringing, was suspended on two threads 100 mm long so that it could act as a pendulum. It was allowed to strike the E string side of the bridge in a horizontal direction. This was preferred to other directions following the comment of Weinreich (1983), and it was easier to set up. The bar was suspended so that at rest its striking end was 5 mm from the bridge and was withdrawn about 30 mm to deliver the impact, and caught after each hit to prevent a double strike. Five taps were recorded on tape with a microphone 150 mm in front of the bridge. The 5 taps were taken by a B & K 2032 Spectrum Analyser to give response curves which were then averaged by the Analyser.

The mode shapes of the strong peaks near 500 Hz were found using the method reported by Miller (1992). The same frame holding the violin was supported horizontally above an enclosed speaker which irradiated it with a single frequency sine wave. Tea leaves were used to delineate the mode pattern. B1- and B1+ were identified in this way and agreed with those published by Marshall (1985). It was important to identify which peaks in the no soundpost condition corresponded to these two modes if in fact they were present. Figure 1 shows the mode patterns obtained. Mode patterns for adjacent peaks were affected by these two strong peaks.

EXPERIMENTAL RESULTS.

To obtain a range of stiffnesses, soundposts were cut across the grain in the radial direction as well as along the grain. The response of a violin made to a Stradivari "P" mould with a top arch of 13 mm (back 15 mm) and sides 1 mm thick was determined for different soundpost conditions. Five soundpost conditions were studied using Norway spruce with longitudunal grain as normally used and Sitka spruce cut radially so that the annual rings ran across the post and parallel to the ends. The response curves are shown in figure 2 and the soundpost parameters are set out in Table 1.

Table 1. Parameters of soundpost materials used.

Soundpost No	1	2	3	4	5
Material	Norway sp.	Norway sp.	Sitka sp.	Sitka sp.	Balsa
Grain orientn.	longl.	longl.	across	across	across
Length/dia.(mm)	55.5/6.0	55.5/6.4	55.5/6.0	55.5/4x4	55.5/6.5
E (10^9 N/m^2)	24.4	9.9	1.8	1.2	0.057
D (kg/m^3)	628	367	463	467	155
Stiffness (10^6 N/m)	12.4	5.8	0.94	0.36	0.034
Impedance (kg/s)	110.6	60.4	26.0	12.1	3.1

In this table the stiffest soundpost had wide latewood bands thus giving a high elastic modulus and a high density as shown. There were 6 annual rings with the latewood on average 0.5 mm wide. The frequencies and strengths of the peaks and troughs of interest up to 600 Hz are given in Table 2 together with those of a no-soundpost condition. The peaks that have been identified in current literature have been labelled. Corresponding peaks have been matched across the table. The similarity between the curves in figure 2 has been used to make this judgement. It can be seen that as the admittance of the soundpost increases there is a downward shift in peak frequencies.

Table 2. Peak frequencies and strengths from Impact Response curves shown in Figure 2.

S/post	1		2		3		4		5		None	
Peak (f=2 Hz)	Hz	dB	Hz	dB	Hz	dB	Hz	dB	Hz	dB	Hz	dB
A0	276	67.2	280	67.2	276	66.1	272	65.8	252	66.2	256	67.7
	388	61.3	384	64.9	376	66.3	376	59.3	392	82.4	388	77.9
*	396	51.5	390	56.2	388	55.7	382	55.3	404	65.1	396	54.5
	428	72.5	424	71.9	420	71.0	420	70.8	410	71.3	408	78.1
*	440	57.5	436	61.5	436	58.4	432	46.9	440	60.0	452	54.8
B1-	476	76.7	472	79.3	468	78.8	464	78.9	484	69.3	480	61.2
*	504	56.3	504	52.1	500	56.7	496	60.9	494	67.5	488	53.8
B1+	536	79.6	536	80.5	532	78.8	532	79.9	528	75.0	520	76.7
*	584	59.4	572	60.9	572	62.9	584	57.0	536	59.6	544	58.7
	596	71.4	584	74.2	576	75.9	600	70.2	560	71.2	552	70.5

* minimum

From the numbers given in Table 2 values for Δ = B1+ - A1 can be obtained. An independent determination of A1 was made inside the instrument giving a value of 485 Hz. There appears to be a decrease in Δ = B1+ - A1 with decrease in soundpost stiffness. The frequency of A1, the first higher air resonance, was determined in the lower bout together with A0. While A0 did not vary in frequency with change of soundpost, without the soundpost it dropped by 30 Hz. A1 on the other hand remained essentially constant at 480 - 485 Hz. On the air to air plots a dip in the curve was found at 525 - 530 Hz. This is close enough to the B1+ peak to identify with it. Chladni patterns determined over a speaker with unused tea leaves confirmed this assumption. In the air to air measurement there was no dip for B1- on the lower side of the A1 peak. A1 remained at 485 Hz when the soundpost was removed. The peaks at 410 Hz and 408 Hz in Table 2 for the Balsa soundpost and the no soundpost condition respectively, had nodal lines across each end of the back and nodal lines on the top that in general ran along the length. These are similar to the nodal pattern at 420 Hz with a soundpost. It would seem desirable to identify peaks using Chladni patterns rather than rely on position only in a frequency plot. It would appear that A1 does not appear as a peak on these tap responses. The body modes would be expected to absorb energy and appear as dips in the air resonance plot if they are excited. Similarly, higher air modes should absorb energy and appear as dips in the tap response.

Jansson et.al. (1993) showed that the introduction of a soundpost (assumed in a "standard" position) raised the frequency of some resonances (e.g. A0 and some body resonances). The 500 Hz antiresonance is clearly visible and B1- and B1+ are equally prominent although the level is down by 10 dB compared with the single peak that appears in this position when the soundpost is absent. Further comment can not be made without a positive identification of these peaks.

It is suggested that the Balsa soundpost is effectively equivalent to no soundpost. There is little similarity with the other response curves. The sound quality was extremely poor and after an hour the post had developed a buckle.

Saunders Loudness Curves were determined for four soundpost conditions. These are shown in Figure 3. For this violin there were no prominent peaks due to air or body resonances in these plots. Similar tests at an earlier date did reveal the presence of these peaks although they were not dominant. From the general appearance of these plots one is tempted to look at average sound levels. The average SPL below and above 600 Hz have been obtained and listed in Table 3. The ambient conditions for the S.L.T´s were 25 ± 3 C and 70 ± 10% R.H.

Table 3. Average sound levels from the S.L.T´s in Figure 3.

Soundpost	Impedance (kg/s)	SPL Av (dB) <600Hz	SPL Av (dB) >600Hz	Difference in level	Player reaction
Norway sp.	110.6	83.28	86.54	3.26	Not assessed
Norway sp.	60.4	88.02	90.27	2.25	Somewhat demanding Strings even
Sitka sp.	26.0	87.45	89.79	2.34	Easier to play Singing tone
Sitka sp.	12.1	86.76	89.95	3.19	Easy to play Singing E Good sound G and D
Balsa	3.1	82.78	88.54	5.76	Sweet sounding E Weak on G,D and A
No Soundpost		80.28	86.04	5.76	Wolfs on A string

As the soundpost becomes stiffer the sound level of the three lower strings is raised closer to that of the higher string. For this violin with the exception of the result for the stiffest soundpost (not included in figure 3), there appears to be a trend towards uniform output with increase in soundpost stiffness.

Harmonic analysis of the sound from the bowed open strings showed some differences that may be attributed to the changes in the condition of the soundpost. For this instrument there were many harmonics on each string. The strength of the fundamental varied. As expected the G-string fundamental was weak and the D-string fundamental was generally low. The A-string fundamental was the highest harmonic in all cases. The E-string fundamental was not the strongest harmonic which was either the third or the fifth. In all cases there were eight to ten low number harmonics to support the fundamental. For the G and D strings they were stronger than the fundamental and for the A and E strings the upper partials were not as strong as the fundamental except in two instances. Table 4 gives some comparative values for this violin taken from the harmonic analysis. The soundposts are numbered from 1 (the stiffest) to 5 (the Balsa post), see Table 1; the values are in mV (linear scale), the fundamental (F) and an average of the next 8 overtones (O) are given in the table.

Table 4. Summary of strength (mV) of Fundamental (F) and lower Overtones (O) on each string for the soundposts in Table 1.

Soundpost	1		2		3		4		5	
	F	O	F	O	F	O	F	O	F	O
G string	1	16.3	0.4	1.5	0.2	3.2	1	11.3	1	14.9
D string	5	20.8	9	10.6	5.5	15	5	4.9	1	5.1
A string	47	8.6	27	6.1	36	8.9	50	15.8	73	10.1
E string	1	6.7	3	7.3	2.7	2.3	38	13.6	13.5	15.9

TROTT´S EXPERIMENT

If Trott´s (1982) negative trend line (his figure 2) for his transfer admittance can be interpreted as mass control this would agree with Beldie´s (1975) assumption and there should be an antiresonance at the intersection with the stiffness line for the soundpost if they are working together. The data from soundposts used in this work has been plotted on Trott´s figure 2 and reproduced here as figure 4. If the general slope of the transfer admittance curve is taken to be that drawn in, the admittance line for the different soundposts intersect it at about 2.5 kHz, 1.7 kHz, 700, 400, and 120 Hz. Sides with a lower admittance i.e. heavier, would move these intersections to lower frequencies. Sides with a higher admittance would move the intersections to higher frequencies.

An explanation is required for the plotting of the results of this work on Trott´s figure 2. The 20 log Y value for his soundpost at 1 kHz was calculated back to obtain his value for the (stiffness) compliance from $C = Y/2\pi f$. It appeared he had neglected the mass of the soundpost and his expression 20 log Y assumed a denominator in Y/Yo of 1. Taking his value for the elastic modulus and a soundpost length of 55 mm the diameter was 6.0mm. With a density of 400 kg/m^3 the mass would be 0.618 g and the calculated impedance, Z, 61.9 kg/s. These values are quite reasonable and confirm the validity of the procedure. The results calculated for the compliance of the soundposts in this work, for plotting purposes, are given in Table 5.

Table 5. Calculated compliance values for the soundposts in Table 1 and plotted in Figure 4.

Soundpost No	1	2	3	4	5
Admittance (s/kg) (20log Y at 1 kHz)	-66	-59	-43.5	-35	-15

One can take the discussion of Trott´s figure a little further. The trendline for the ribs, drawn in at -6 dB/octave for a made rib assembly of 60 g compared well with the effective mass calculated from $1/m = 2\pi fY$ of 57 g. A 10 g change in the rib assembly mass displaces the trendline by about 1 dB.

The intersections between the rib trendline and the soundposts, given above, suggest, following Trott, that there would be antiresonant troughs at these points. There are so many peaks and troughs in the tap responses that identifying any effects due to a "rib-soundpost assemmbly" would be very difficult.

DISCUSSION

In this study a modified S.L.T. was used as a convenient practical way for determining the output of the violin over its range. A consistent bowing technique was applied to all notes in terms of bow force, bow speed and bow position (except for high notes on the E string). That the S.L.T. plots did not show evidence of peaks to match those in the tap response at the lower end of the range can only be interpreted as due to the contribution of overtones in the bowed notes contributing to the overall sound pressure level. From Table 4 it can be seen that the lower 8 overtones give good support to the fundamental of each open string.

The identification of peaks is important before they are labelled because they cannot always be assumed from the appearance of the response curve. In Table 2 the labelling of B1+ for the case with no soundpost required the determination of a Chladni pattern. Both B1- (480 Hz) and B1+ (520 Hz) were verified in this manner. Without a soundpost B1+ has a pattern different in appearance to that with one, while B1- remains essentially unaltered as shown in Figure 1. For B1+, in the top, the lower nodal line does not take in the soundpost position; in the back, the two longitudinal nodal lines had come together in the centre. It is thought the soundpost has separated them.

These findings are different from those of Bissinger (1994) where he reports a different configuration for the B1+ peak. The peak labelled B1 (in his figure 1) has a similar frequency with the soundpost in or out which is in agreement with the behaviour of B1+ in this work. The mode shapes for this peak (his figure 6) were markedly different with and without a soundpost whereas the present work found a similar mode shape for the two conditions.

These preliminary trials exploring the effect of the soundpost suggest that it has most influence below about 600 Hz. An additional trial was carried out with a Glassfibre Reinforced Plastic (G.R.P.) soundpost which had an impedance, Z, of 174 kg/s fitted at position 5/15 in the same violin. The S.L.T. was quite irregular and the player reaction was very adverse. The tap response was similar in appearance to those in this paper; the peak at 430 Hz and B1- were lower while B1+ was higher. Peaks were well defined. It is thought that the unfavourable behaviour of the instrument may have been due to the high density of the G.R.P. of 1960 kg/m^3 giving a mass for the soundpost of 2.3 g compared with spruce, density 450 kg/m^3 with a mass about 0.63 g, and therefore had a greater inertia.

The length and fit of the soundpost has to be perfect for each position to get a true result. The soundpost should have a stiffness > 5x10^6 N/m (which is given by an annual ring width of about 0.5 mm) although it is not clear if it can be too stiff. It can however be too compliant when wolf notes are more likely and eventually a no soundpost condition will be approached.

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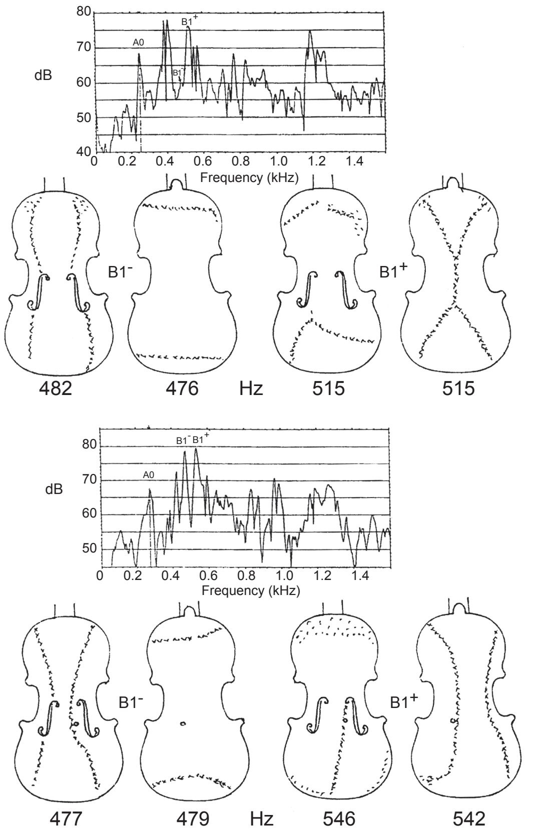


Figure 1. Tap response and mode shapes for:
(top) with NO SOUNDPOST
(bottom) with SOUNDPOST

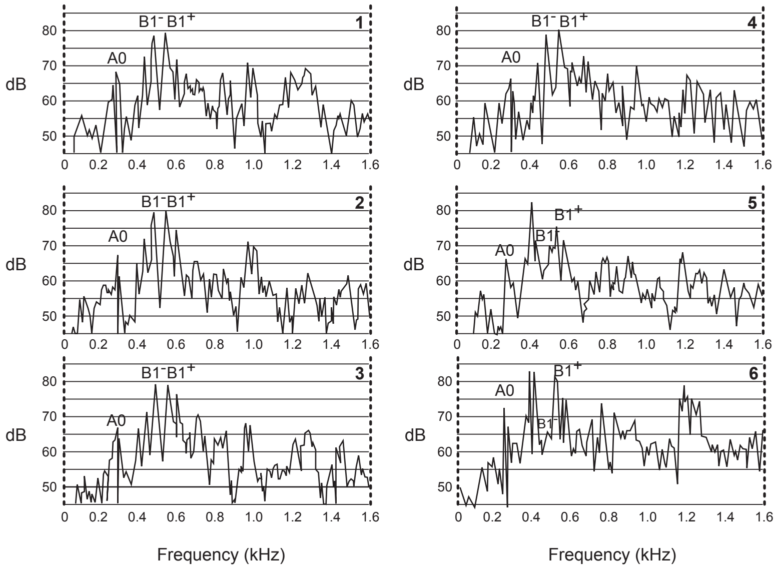
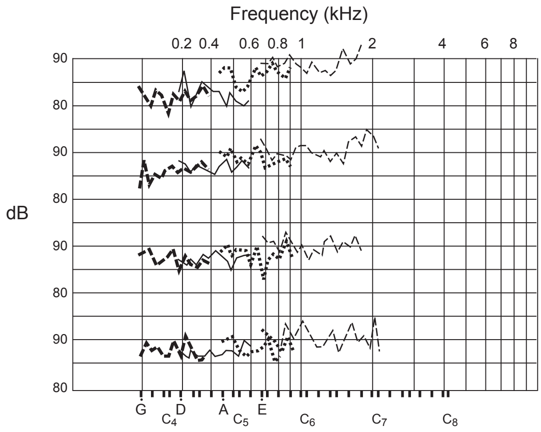


Figure 2. Impact response (dB) from 0 to 1.6 kHz of violin No 1. Fingerboard tuned to A_0, strings undamped, chinrest fitted, soundpost changed, in order:

1. Norway sp.	(Longl.) S = 12.4 x 10^6 N/m
2. Norway sp.	(Longl.) S = 5.8 x 10^6 N/m
3. Sitka sp.	(Radial) S = 0.94 x 10^6 N/m
4. Sitka sp.	(Radial) S = 0.36 x 10^6 N/m
5. Balsa	(Radial) S = 0.034 x 10^6 N/m
6. No soundpost	



Soundpost	Dia (mm)	S (10^5Nm)	Z (Kg/s)
Balsa	6.5	0.034	3.1
Sitka Sp.	4x4	0.36	12.1
Sitka Sp.	6.0	0.94	26.0
Norway Sp.	6.5	5.8	60.4

Figure 3. Saunders Loudness Curves for violin No. 1 fitted in turn with 4 different soundposts.

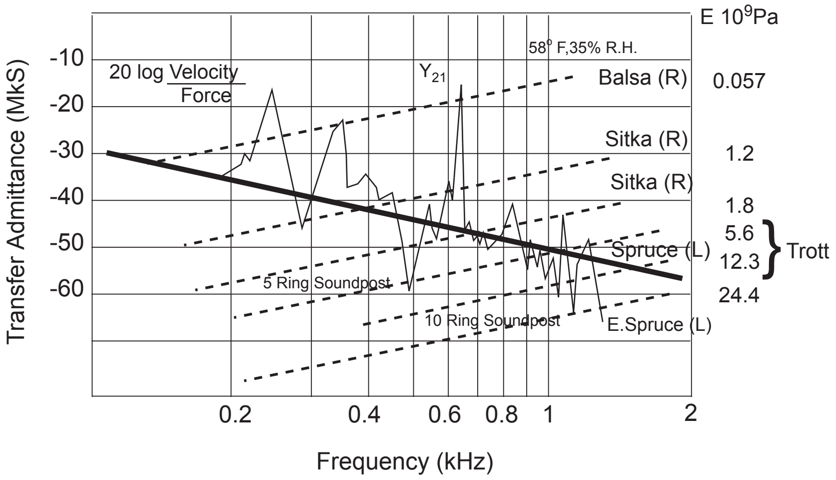


Figure 4. Trott's figure 2 for transfer admittance on SUS 181 without soundpost. (b) Additional curves for soundposts of Sitka spruce (radial cut) and Balsa (radial cut) added.