Measurements made during the Construction of a Violin

(THE PROFILE OF VIOLIN No2)

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This account is a summary of the laboratory measurements made during the construction of a violin. It began with the measurement of the properties of the spruce and maple used, followed by measurement of the weight and tuning of the plates at all stages during the making process. Simple equipment was assembled except for some final analysis of recorded sounds using Bruel and Kjaer sprectrum analyser Type 2032. It must be pointed out that considerable time was needed for these measurements and that a maker earning his living would not give up the time or think some of the tests were necessary. This is offered in the hope of a better understanding of the instrument and that eventually a parameter may emerge that will correlate with the player's assessment. The burning question is, after all this, was the violin any good? I can say that some professional players have commented favourably on it. A real test of acceptance would be the ranking gained in a competition and whether a professional player would part with hard cash to own it.

Wood Properties

Wood samples were taken from the quarter sawn billets for determination of density and shear modulus. Measurements of sound velocity (at 60 kHz) were made on the joined billets. Density was determined by weighing a carefully machined and measured block from the offcuts. Throughout, room temperature and humidity were constantly monitored and extremes were avoided.

Young's Modulus was calculated from the measured sound velocities using c^2p. The sound velocities were obtained with a Lucchi Tester (1).

Two shear moduli were obtained G_{LR} and G_{LT} using a simple torsion pendulum and appropriately cut samples which allowed the extraction of the moduli from the experimental data (2).

The values of the wood properties are summarised in table 1.

Table 1

		Top (No4) European Spruce		Back (No2) European Maple	
Density(p)	Kg/m^3	400		584	
E_L	N/m^2	11.39	x 10^9	11.25	x 10^9
E_R	"	1.07	"	1.95	"
G_{LR}	"	0.53	"	1.52	"
G_{LT}	"	0.90	"	1.01	"
$Q(E_L)$		124		84	
$Q(E_R)$		15		30	
$Q(G_{LR})$		56.6		59.7	
$Q(G_{LT})$		44.0		51.9	
E_L/E_R		10.6		5.77	
c/p		13.4		7.5	

For a population of billets made up of 11 tops and 11 backs, the moduli showed the expected increase with rise in density except with the shear moduli for spruce where no correlation was evident. The Q values for the elastic moduli are representative having been obtained from vibrating beam samples using f/df where df is the bandwidth at half power and f is the resonant frequency of the lowest beam mode. The Q values for the shear moduli were calculated using $Q = \pi N$ where N is the number of cycles from an amplitude of A to A/e during torsional vibration.

Summary of making process

The method of making centered round a design that resembled the Guarneri "Kreisler" 1733 with Stradivari like ff-holes.

An inside mould 13 mm thick was cut from plywood and the edges waxed except where the blocks would be temporarily glued. The ribs were scraped to 1.3 mm and glued to the blocks using aliphatic glue. One set of linings was fitted and glued in the same way. Blocks and linings were of willow. The C-bout linings were let into the corner blocks. The assembled ribs on the mould at this point were stabilised by exposure to ammonia gas. When the top and back were finished, the ribs were taken off the mould and the linings on the other edge were fitted after the ribs were trimmed to 30 mm.

The top and back were cut out and finished to the design outline. The archings chosen were those of Sacconi (3) taken from Stradivari's "Il Cremonese" of 1715. Four templates were made for arching contour lines and marked on the joined billets. The contour levels were set by drilling and the outside arching rough carved. Finishing was done with thumbplane and scraper. The arching contours were checked with a height gauge constructed for the purpose. Moire patterns were taken of the outside arching of both the top and back. These are shown in figures 1 and 2.

Thicknessing the top plate

This proceeded in steps; at each one the weight and mode frequency were determined. The amplitude of vibration for a steady speaker input of 115 dB at the plate was also determined. These results were plotted and showed a good linear relationship with weight; mode frequencies decreasing and amplitudes increasing with decrease in weight. A large reduction in mode frequency with little change in amplitude accompanied the cutting of the ff-holes for modes 2 and 5. Mode 1 was least affected. The bassbar restored the mode frequencies but lowered the amplitude which was not returned fully to pre-bassbar values.

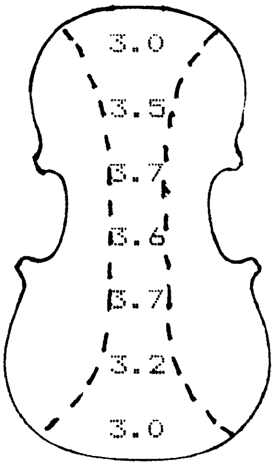
Representative stages are as follows:

The top was thinned to 10 mm (no purfling, edges unfinished). Mode 1 gave 234 Hz (mode 5 was 524 Hz). The arching was left at 16 mm. The weight at this stage was 165.13 g.

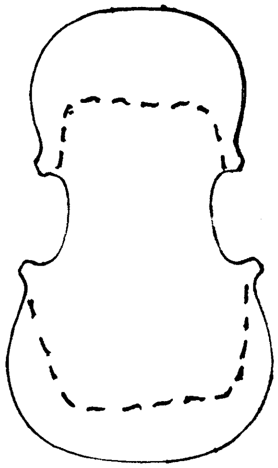
Thicknessing to 84.89 g

Mode	1	2	5
Hz	98	190	377
Q	49	83	126

Modal pattern acceptable.



Mode 2



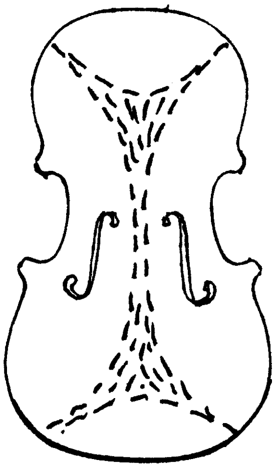
Mode 5

ff's cut 81.52 g

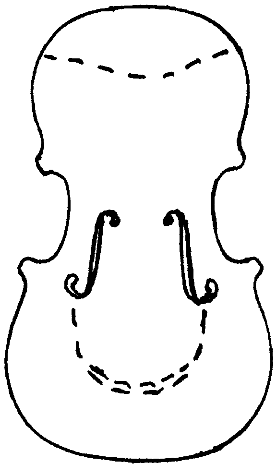
Mode	1	2	5
Hz	87.2	171	310.8
Q	58	57	66

Mode 2 and 5 modal pattern distorted.

I prefer to cut the ff-holes when the thickness is finished.



Mode 2

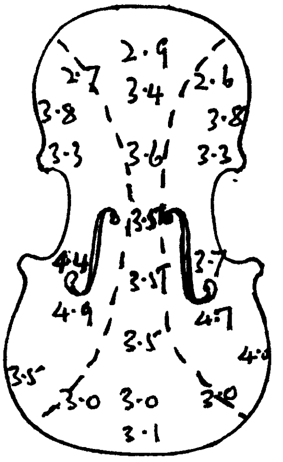


Mode 5

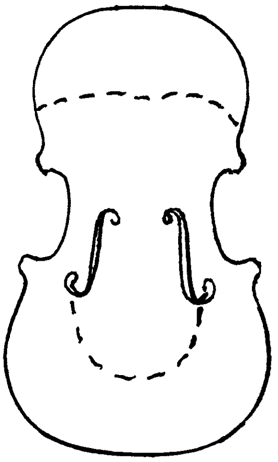
Thicknesses adjusted to equalise tap tone in both upper and lower bout.

Weight to 79.4 g

Mode	1	2	5
Hz	81.3	164	288
Q	45	55	58



Mode 2



Mode 5

Purfled and edges finished,
bassbar blank fitted.

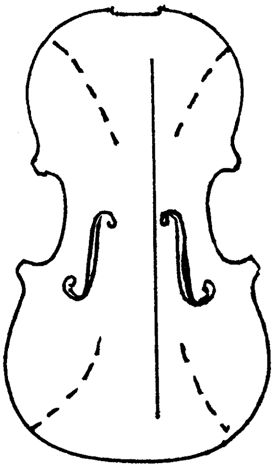
Weight to 85.01 g

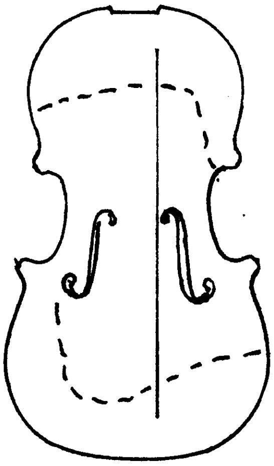
Mode	1	2	5
Hz	93.7	197	?

After tuning bassbar.

Weight to 82.02 g

Mode	1	2	5
Hz	91.3	191	376


Mode 2


Mode 5

Final tuned condition with
saddle added. Mode shape unchanged.

Weight to 80.91 g

Mode	1	2	5
Hz	91.1	186	351
Q	57	60	70

[It would be interesting to fit a new bassbar and retune mode 5 to 370 Hz]

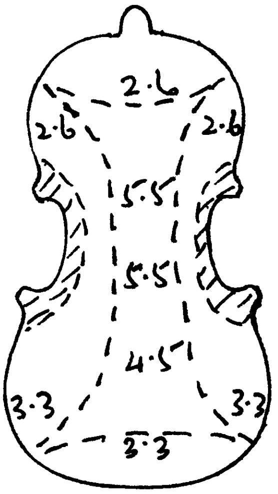
Plate vibration modes were found using the method of C.M. Hutchins with polystyrene "grit" to delineate the nodal lines. A magnet (0.15 g) was placed with double sided tape at an antinode and the velocity sensed with a coil; the resonance frequency occuring at maximum velocity. Both input and output were good sinewaves and the behaviour was very stable. Q values were found from the bandwidth at half power (velocity max. x 0.7071 assuming zero background). The final nodal paterns obtained are shown in figure 1.

Thicknessing the back plate

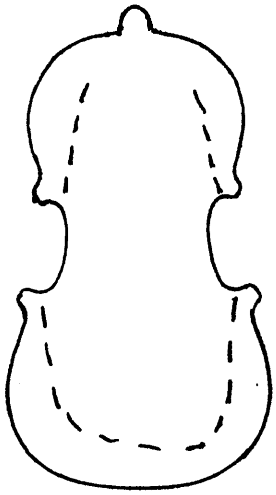
Thicknessing the back began by leaving a 10 mm wide margin in the C-bouts as recommended by Chimneys(4), to keep instrument power up. The mode frequencies and amplitudes showed similar linearity with weight as the plate was thinned as found for the top plate. Mode 5 amplitude decreased slightly, the other modes increased slightly.

Weight to 122.4 g

Mode	1	2	5
Hz	129	190	394
Q	71	95	49



Mode 2



Mode 5

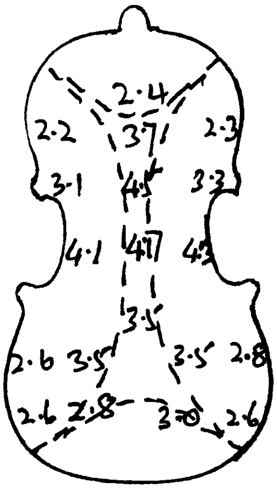
Weight to 112.12 g

Mode	1	2	5
Hz	113.5	171.5	365.4
Q	67	61	54

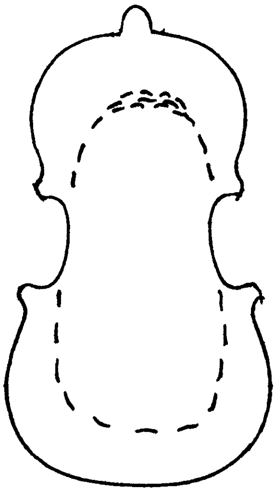
The final values for the back (as shown in the figure) after thinning the C-bout margins.

Weight to 110.38 g

Mode	1	2	5
Hz	115.8	176.1	373
Q	72	68	62



Mode 2



Mode 5

The final nodal paterns obtained for the back plate are shown in figure 2.

<u>Behaviour on partial assembly</u>

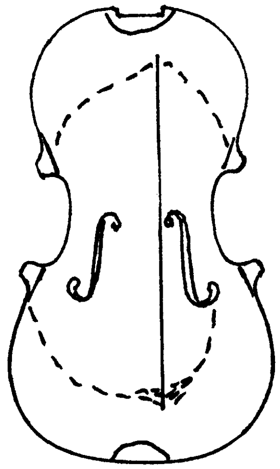
The neck was morticed into the top block before the top plate was glued in place. On this occasion the top was temporarily glued to the ribs without the neck and mode 5 found.

Weight of top and ribs 144.15 g

Mode 5 274 Hz

Q 54.8

The nodal lines, as shown, had moved to the ends of the bassbar and altered shape compared with the free plate condition.



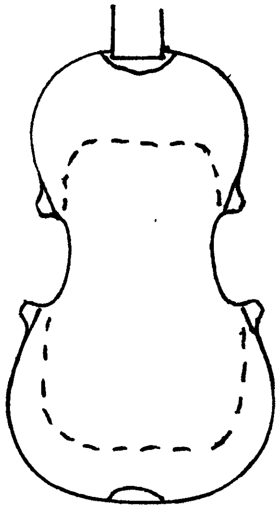
Mode 5

The top was then taken off. The neck was glued into the mortice and trimmed where it projected below the bottom edge of the ribs. This edge was made true on 240 grit garnet paper glued to plate glass. The back was temporarily glued in place without the top.

Weight to 230 g

Mode 5 320 Hz

Q ?



Mode 5

The final assembly was made by removing the back and then gluing the top on, assisted by a pin in the bottom block, to position it and establish the correct margin. The top block was adjusted to align the neck so that the fingerboard which was fitted and clamped in place, was positioned correctly with respect to the ff-holes and lying on the axis of the violin.

Before the top was glued onto the ribs, a fine saw cut was made through the neck and top block so that a taper of 2 mm from the top corners could be made. Some classical violins have tapered ribs but not always in the above position. From published photographs the back edge of the ribs have appeared tapered in the top bout, lower bout or both and also on the top edge of the ribs in the top bout; but not all together. There would seem to be a logic in tapering the ribs to prestress the body to compensate for the combined force of the strings. However, it is not known what the intention of the makers was; maybe to allow for a warped plate and obtain a better fit.

The tapered surface was made true on 240 grit garnet paper glued to plate glass as above. Before the back was glued on, the volume was measured using dry sand and the expected length of the soundpost and slope at the ends from the inside arching were found. The volume was 1940 ml. The estimated length of the soundpost was 50.8 mm and the slope of the arching from the plane of the plate 10 and 7 degrees for the top and back respectively.

The violin was sealed inside and out with "Cera Colla" and burnished with a polythene rod suitably shaped followed by light scraping. Two applications were made on the outside. The violin was then fitted up but with the fingerboard glued temporarily with a piece of paper inserted and weak glue. It was taken off for varnishing.

Determination of resonances

Air resonances were determined with the strings damped and the violin suspended vertically in a frame on rubber bands. The element from an earpiece and a small microphone were placed in the lower bout near the block. A sinewave signal was sent to the earpiece element and a range of frequencies scanned. The results are shown in table 2. In the same table results are included where the two transducers were placed outside close to the two ff-holes. These measurements were taken after the "Cera Colla" and before varnishing.

Table 2

Peak Frequency (Hz) using earpiece/microphone.

Internal	External
-	285
495	495
564	
668	
937	
1404	
1983	

Fingerboard tuning

The fingerboard was tuned to be near C# in two steps; (1) cutting to the required length, and (2) thinning the underside of the free end. The results are in table 3. This was done with the body assembled but not fitted up. The fingerboard was glued temporarily with a paper insert and weak glue. A magnet sensor was placed on the end of the fingerboard and the back of the violin was excited with a speaker.

Table 3

Condition	Weight of F/board (g)	F/board Resonance (Hz)
Uncut	72.43	198
End cut	71.5	204
End thinned	69.48	277

To estimate the amount of thinning, weights were attached to the end of the fingerboard and the fall in frequency noted. In this case 2 g appeared to be the amount needing to be removed.

Whole body resonances.

An extended listing of resonance peaks detected with air to air and speaker to body sensing are given in table 4. Similar frequencies have been placed in line but this has no implication since there was no positive identification of the modes in each case. The violin was fitted up for these determinations. The strings were damped. The violin was suspended horizontally and the back was facing the speaker. A small magnet (0.15 g) was attached to the G-string side of the bridge with double sided tape and a coil (2500 turns) placed over it to indicate the velocity. The signal from the coil was displayed on a C.R.O. to show the waveform and measured with an A.C. voltmeter. A clean sinewave was generally obtained and the system was very stable. These results were repeated and a more extensive survey was done after varnishing.

Table 4.

Peaks found in general survey.

Air to air Internal		External	Speaker excited (magnet/coil detector)				
Hz	Hz	Hz	Hz	Q	Hz	Hz	Q
		285	290	44.6	274	275	21.2
			305	min.	299	297	24.8
					333	356	
			362		374	373	
						379	
399	392					397	
						442	
			441	min.			
	456						
			475	32.5	470	483	
			488	min.			
497	497	495				503	
	533						
563	550		548	75.1	559	558	
						570	71.3
	640					632	
703					799		

		827
		839
938		
	988	976
		997

Further peaks above 1000 have not been listed. A further comparison of the methods appears in table 9. The columns of frequencies represent separate runs. Only maximum and minimum readings were taken except where Q values appear.

Further preliminary studies of body resonances were made by again suspending the violin horizontally on rubber bands over a speaker. The magnet/coil pickup was placed as before. Resonance peaks and minima were recorded over a limited range of frequency and Q values calculated from the bandwidth at half power assuming zero background. The peaks should be those associated with sound production. The results are shown in table 5. The setup is shown in figures 3 and 4, the speaker was mounted in an enclosure not attached to the aperture plate. Trial resonance curves were plotted under these conditions. Maxima, minima and some extra points were recorded to assist plotting . The sound intensity at the aperture was about 115 dB. The results are shown in figures 5 There are differences between the two curves both in the number and placement of resonances found. This may be related to the ease of exciting a resonance from the top or the back. The strength of peaks e.g. A1 and T1, in the two plots is different. The recorded peak heights with back excitation are about half of those with top excitation.

Table 5

Peak Frequency (Hz)		Q	Probable Mode
289.9		44.6	Ao
305	min.		
362			
441	min.		
474.9		32.5	~~A1~~ b1−
488.8	min.		
548.4		75.1	T1 (B1) B1+

For the 548 Hz peak, the change in frequency with weights placed behind the G-foot of the bridge was determined. The results are shown in table 6.

Table 6

Weight (g)	Frequency (Hz)
0	548
1	547.6
2	539.2
5	531.5
10	512

Using the Schelleng (6) formulae, the effective mass and the effective stiffness for this resonance was calculated. The weight of the violin fitted up without chinrest (all tests) was 425 g. The formulae are:

$$m = -(1/2\ f)/(df/dm)$$

$$s = -(2\ \pi^2\ f^3)/(df/dm)$$

$$R = (s\ m)^{1/2}/Q$$

$$Z = (s\ m)^{1/2}$$

where df/dm = the slope (Table 6)
f = frequency at $dm = 0$
m = effective mass
s = effective stiffness
Q = sharpness of resonance
R = radiation constant
Z = impedance

The results of these calculations are shown in table 7.

Table 7

f	548 Hz
m	80.7 g
s	0.96×10^6 N/m
Z	278.3 Kg/s
Q	77.2
R	3.6

Similar determinations were made for the plate modes with the following results shown in table 8. All these results were taken before any surface treatment was applied.

Table 8

Plate	Mode	f(Hz)	m(g)	s(x 10^6 N/m)	Z	Q	R
Top (No4)	1	92.0	17.5	0.0058	10.1	56.9	0.18
(wt.82.8g)	2	188.4	49.6	0.0695	58.7	59.9	0.98
	5	354.0	59.0	0.292	131.3	70.2	1.87
Top + ribs (wt.144.2g)	5	273.7	62.2	0.184	107.0	54.8	1.95
Back (No2)	1	115.6	19.2	0.0102	14.0	72.4	0.19
(wt.112g)	2	174.8	31.2	0.0377	34.3	67.7	0.51
	5	372.3	38.0	0.2077	88.8	62.2	1.43

Varnishing procedure

The steps used in varnishing were as follows:

1. Two coats of "Cera Colla" (beeswax : glue, 1 : 1) both smoothed with a polythene rod and scraped.
2. Tartrazine glaze (water solution)
3. Four coats of Sandarac in spirit.
4. Rubbed back lightly (Repo).
5. Colour glaze (WN 553,654,142) applied with the finger, dried for one day.

6. One coat of Amber oil varnish, exposed to sunlight for one week.
7. Second coat of Amber oil varnish, exposed to sunlight for one week.

The top layers of varnish, including the colour layer, were very "chippy" after this treatment. This only became apparent after some time had elapsed. It could be that the length of exposure to ultra violet light was responsible.

The weight of the instrument

Final weight of violin fitted up (without chinrest) 440 g

Weight of individual parts:

Top	82.8 g
Back	112.0 g
Neck & Head	64.0 g
(neck root not trimmed)	
Sides	64.0 g
(not tapered or morticed)	
Varmish	10.5 g
F/board	69.5 g

Acoustic study of complete, varnished violin.

Four methods have been used to study resonances in the violin:

(1) Air to air. Following C.M.Hutchins (5) an element from an earphone and a small microphone was placed in the lower bout, the violin being suspended vertically on rubber bands attached to a frame, and the response determined as the frequency is scanned. The earpiece element and microphone were also placed outside the violin near the f-hole opening to detect the lower air resonance. See figure 6.

(2) Speaker below violin. Air and body resonances were found using the CMH plate tuning setup, by again suspending the violin horiontally on rubber bands attached to a frame so that the back was irradiated by the speaker. It was expected that body resonances detected by this method would be those connected with sound production. See figure 4.

(3) Speaker/cone transducer excitation. Body resonances were also detected by attaching a slender paper cone to the centre of a small (3") speaker and connecting the end of the cone to the E-string side of the bridge. This was done by flattening the tip of the cone to make a small tab and using double sided tape to fasten it to the bridge. The cone of the speaker was perforated to reduce the sound level and still preserve the speaker coil supports. This speaker was connected to the signal generator in the place of the one in 2 above. See figure 7.

(4) A fourth method of studying the resonances was to excite the violin by placing a coil over a small magnet attached to the E-string side of the bridge and driven by the signal generator

and amplifier, and detecting the response with a microphone placed near the left foot of the bridge. The setup was similar to that for method 1. See figure 8.

In cases 2 and 3 the response of the violin was obtained by attaching a small magnet (wt. 0.15 g) to the G-string side of the bridge and measuring the voltage generated in a coil (2500 turns) placed over it. Displayed on a C.R.O., the signal showed a clean sinewave (as did the input to the speaker). In 3 another method was also used i.e. a small microphone placed beneath the back at about 10 cm.

A summary comparing results from each of these methods is shown in table 9.

Table 9

Method	Resonance Frequency (Hz)				(Q values)	
	A0	(Q)	~~A1~~?	(Q)	T1	(Q)
(1) Air to air	286		N.D.		N.D	
	N.D.		497		550	
	285		495		N.D.	
			497		563	
(2) Speaker below (magnet/coil pickup)	274		470		559	
	275	(21.2)	483		570	(71.3)
	276		482		573	(49.8)
	277		482		575	
(3) Speaker/cone E-string side (magnet/coil pickup)	N.D.		475	(15.8)	563	(24.0)
	N.D.		482		568	
	283		482	(21.9)	567	(25.8)
	280		483	(18.9)	565	(24.6)
	280		480		565	
(microphone pickup)	294		480		564	
(4) Magnet/coil E-string side (microphone G-string side)	282	(25.6)	490		572	(35.8)

The strings were damped for all measurements listed in the table. Commenting on the results, A0 was not detected from inside the violin, but was found on placing the earphone/microphone outside and close to the ff-holes. Methods 1, 3 and 4 appear to give the most reliable results. In method 2 the presence of the experimenter's person near the test rig caused wild fluctuations in behaviour so that adjustments had to be made remotely. In method 3 a machinist's marking-off gauge was used to mount the speaker/cone exciter which allowed the easy positioning of the cone tip. The exciter could be aligned with the bridge and the double sided tape allowed minimal disturbance when connecting the cone to the edge of the bridge. The tape connection appeared not to affect the results. The magnet sensor was also attached using double sided tape and the coil mounted on a marking-off gauge for ease of adjustment.

The change in T1 frequency with added mass (placed behind the G-string foot of the bridge) was determined using method 3. The results are shown in table 10.

Table 10

Added mass (g)	Frequency (Hz)
0	567
1	563
2	559
5	544.5

Schelleng's expressions, above, were used to calculate the effective mass and stiffness, the impedance and the radiation constant. The results are shown in table 11.

Table 11

	(strings damped)	(strings undamped)
f (T1) Hz	567	566
df/dm	-4500	-3800
m (g)	63.0	74.5
s (N/m)	0.80×10^6	0.94×10^6
Z (Kg/s)	224.4	264.9
Q	25.8	36.5
R	8.7	7.3

Since the top plate is the most active part of the violin at this mode it might be fair to say that the effective mass is that of the top plate and this is about 75% of the weight of the top, therefore about 75% of the plate area is active. A small active area would be associated with a poor instrument. The effective stiffness of the assembled violin as expected is greater than that of mode 5 of the free top (0.29×10^6 N/m) and the top with ribs only (0.18×10^6 N/m). It is also greater than the free back (0.21×10^6 N/m). The impedance of the soundpost was measured at 60 Kg/s. The connection between these values and measures of instrument performance cannot be made without more work. The radiation constant, R, is higher than the result for the free top by a factor of 4. This is due to the lower Q measured for an instrument resonance compared with that of a free plate. Good radiation it seems is therefore obtained with lower rather than very high Q values.

Two comparisons can be made with previously published results. An approximate one with values deduced from the paper by John Schelleng (6) and with values reported by Ian Firth (7). The comparison with Schelleng appears in table 12.

Table 12

	J.Schelleng	This report
f (Hz)	500	567
s (N/m)	0.176×10^6	0.80×10^6
m (g)	17.8	63.0
Z (Kg/s)	56	224.4
Q	9.8	25.8
R (total) (Resistance to bridge motion)	5.7	8.7
R (Radiation resistance)	0.698	5.2

This may not be a fair comparison as the resonance used by Schelleng which was taken from the work of Saunders, could have been the ~~upper air resonance~~. B1-

The comparison with results quoted by Firth is more reliable. These are for top plates supplied by C.M.H. as part of an ongoing project. The relevant values have been reproduced in table 13 for comparison with those in table 8 above.

Table 13

Top	Plate mass M(g)	f (Hz) (mode 5)	m(g)	m/M	s (N/m) ($\times 10^6$)	Q	Z (Kg/s)	R (Z/Q)
A	79.2	368	49.0	0.619	0.264	40	113.7	2.84
B	77.9	363	45.7	0.587	0.29	60	115.1	1.92
D	83.6	396	39.7	0.475	0.246	50	98.8	1.98
H	80.0	362	55.5	0.694	0.29	60	126.9	2.12
This work	82.8	354	59.0	0.713	0.29	70	131.3	1.87

The comparison of results from this work and those of Firth shows no disagreements. A comparison of the data for the violin after sealing and again after varnishing (tables 7 and 11) shows that only the Q values are different giving in turn different R values.

Saunders' Loudness Curve

Another form of "response" curve is the Saunder's Loudness Curve which is obtained by bowing an octave of semitones on each string as loudly as possible without vibrato and recording the Sound Pressure Level (SPL). The levels are plotted against the notes as shown in figure 9. The A0 peak was present but others were not prominent. The average level of the curve after the "Cera Colla" was about 88 dB, with low values on the D-string. After varnishing it was about 86 dB with a similar shape. The decrease occurred on the A and E strings. This curve can be obtained in a normal living room and serves to highlight any abnormal resonances. The playing position in the room can be kept constant and the distance to the Sound Level Meter which in this case was 1 metre level with the instrument on the treble side.

After the new bassbar was installed, a Loudness Curve was determined for the re-assembled violin which now was without varnish but with "Cera Colla" sealer. The result is shown in figure 10 where it can be seen that the average loudness is about 85 dB on the three lower strings but about 88 dB with a wide variation on the E-string.

Harmonic analysis of open string sound

Open string sounds were analysed for their harmonic content. They were recorded on a small battery powered tape recorder in a normal living room. The sounds were sampled and analysed on an Apple MacIntosh using their Recorder program. No harmonics appeared above 7 kHz, The results are shown in figure 11. The number of harmonics found were as follows.

Open string	Number of harmonics
G	29
D	20
A	12
E	10

After this analysis was done it became possible to repeat the work using a more sophisticated analyser. Consequently new samples were taken and figure 12 shows the result. The analyser kindly made available by Professor Byrne of the University of N.S.W., was a Bruel & Kjaer Spectrum Analyser Type 2032. The essential difference is the higher resolution and precision with peak heights. The improved results allow comparison of the profiles shown in these figures with the instrument response which should be similar.

Further studies on the finished violin

After construction was complete, players thought the G-string needed more resistance to the bow. This was translated to mean an increase in stiffness of the top plate. A new bassbar was fitted with this in mind. The results of this change to the top plate are summarised in table 14. The nodal lines on testing after removal were more diffuse than before; mode 2 in the top bout, and mode 5 in the lower bout. this defect remained after the new bassbar was installed. However their shape and position were unaltered.

Table 14

Top plate condition	wt(g)	Mode frequencies			Mode Q values		
		#1	#2	#5	#1	#2	#5
as removed	86.67	93.3	197.5	358.4	51	55	65
varnish off	84.17	87.5	183.7	345.5	44	63	50
bassbar off	78.82	81.2	163.3	294.3	45	47	55
new bassbar (tuned)	84.66	91.6	190.3	378.3	37	45	64

The varnish was removed from the rest of the violin and the top plate replaced. Removing the varnish did not remove the "Cera Colla". It is expected that revarnishing will raise these values slightly.

Further testing was carried out on re-assembly and before varnishing. This consisted in exploring other instrument resonances and the analysis of the bowed open string sound and response curves from the analysis of impulse excitation. The resonances of the fingerboard and tailpiece were explored in the range 100 to 300 Hz by attaching the magnet sensor to the part being studied and exciting the violin with a speaker under the back. Table 15 summarises the findings.

Table 15

Instrument condition	wt(g)	Location of magnet	Resonance peaks (Hz)			
Ebony tailpiece	17.7	fingerboard	124	165	174	257
		tailpiece	124	-	174	-
Boxwood tailpiece	10.3	fingerboard	135	170	-	256
		tailpiece	135	-	192	-

As for all tests on the fitted up violin, the strings were damped at the junction of the body and neck and the instrument was suspended on rubber bands. The chinrest was absent and the only addition was the magnet.

The resonances in table 15,at 124 Hz was that of the tailpiece and that at 257 Hz was the fingerboard. Both were quite strong. The other two were weaker. The peak at 165 Hz may possibly be the B -1 peak of C.M Hutchins (8). Following this result a further 2 g was taken from the fingerboard to bring the resonance up from 257 Hz to 268 Hz which is close to a semitone below Ao. This is where it sits at present. The wood was removed with the fingerboard in place and it became too difficult to take any more out.

The peak survey of the violin in this unvarnished condition was extended to 1 kHz using method 4 and combined with the above results, the sequence of identifiable resonances appears to be: Tailpiece 135 Hz, B -1 188 Hz, Bo 268 Hz, Ao 280 Hz, A1 480 Hz, ~~T1~~ (B1+) 551 Hz with the new bassbar. With the first bassbar and the violin varnished, the two latter peaks were at 490 Hz and 572 Hz. The interval between A1 and T1 is constant at about 80 Hz. Another determination, not listed here, gave similar values to those mentioned last.

The use of a B & K Spectrum Analyser to redetermine the harmonic content of the open string sound has already been mentioned. The opportunity was taken to record the sound produced by impulse loading at the bridge and subsequently analysing this for peaks. Such impulse loading is known to excite all the modes with antinodes at the bridge feet since the impulse contains an infinite number of frequencies. There is a fall off above about 5 kHz but no compensation was attempted in this instant. The result for this violin before the change to a new bassbar is shown in figure 13. The three main peaks Ao, A1, and T1 are clearly shown and possibly B -1. More work is needed before one can comment on the rest of the curve.

This study of a violin was conducted with a minimum of complex equipment. Simple additions to a basic plate tuning setup only, were used. The value to a violin maker is hard to assess. Perhaps the study of a small number of violins might establish a better understanding and the establishment of a making routine that would minimise further extensive testing. These few results need to be supplemented with many more to provide a data base for further progress. As most of these tests are nondestructive they could be applied to master instruments to the great benefit of violin making. This consideration could be most important. The achievement of Stradivari and Guarneri have become the pinnacle to which to-day's makers aspire, yet we know so little about the instruments. We do not have details similar to that above for the great violins. An opportunity should be taken when such a violin comes in for repair to determine the free plate modes if for any reason the plates are taken off and a response curve by exciting the bridge. Modal analysis could be done on some of these violins if they can be made available. These tests are non invasive so there would be no risk to the instruments and there would be a chance to compare the two sets of data. The unknown factor is the effect of any structural changes made in the intervening years.

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J.E. McLennan

Definition of terms used.

The volume density, or simply density, is a measure of the concentration of matter and is expressed in kg/m^3. For wood this will include any moisture that is present in the wood so that the density will change with relative humidity.

The elastic modulus is the constant of proportionality between the stress in a body due to an applied load and the strain accompanying it when the deformation is completely recoverable on removal of the load. In the case of elastic deformation produced in the direction of the applied load we have the modulus described here, known as Young's modulus. If the deformation is a twist caused by an applied torque the constant is a shear modulus. The moduli determined on visco-elastic materials such as wood during vibration studies, are 10 - 30 % higher than those values found under static test conditions. They are also affected by relative humidity, being higher at low relative humidity. Wood being orthotropic, has values for the elastic moduli that vary with direction in the wood. There are three characteristic values in the longitudinal (L), radial (R), and tangential (T) directions from which values in all other directions can be calculated. The shear moduli are associated with deformation on the planes containing the principal directions LR, LT and RT.

The Lucchi Tester measures the time an elastic wave takes to travel a given distance from which the velocity, c, is directly determined. The dynamic elastic modulus in the direction of the velocity measurement is obtained by the velocity squared multiplied by the density.

For the values of elastic moduli of quarter cut spruce in the L and R directions and the length and width of the violin top plate, an elastic wave starting at the centre will arrive at the C-bout edge and the end blocks at about the same time.

The shear moduli become important in deformation at the high harmonics.

An important parameter that indicates the ability of tonewood to transform vibration energy into sound is the radiation resistance and calculated by dividing the density into the sound velocity in the material, usually in the L direction. A high value indicates a high sound conversion. A high velocity and low density would be desireable. For the same material a low value of the wave resistance which is the product of the velocity and the density, is desireable. Spruce has a high value of about 13 m^{2}Kgs^{-1} units for the radiation resistance and a low value of about 2.0 x 10^6 Kgs^{-1}. These values are the highest and one of the lowest respectively, of most materials. Maple has values about half that for spruce.

In vibrating systems such as the violin, the frequency of resonance,fo, for a partular mode of vibration, is determined by the effective mass and effective stiffness for that mode through the equation:

$$fo^2 = (1/2\pi)^2 \ s/m$$

If the vibration is largely confined to the top plate as is the case for the main top plate mode at about 550 Hz, the effective mass can be compared with the top plate mass to roughly indicate how much of the top is active. The maker wants this to be a maximum.

The resistance felt at the bow is given by $(sm)^{1/2}/Q$. A high value is desireable. A high Q, corresponding to a strong narrow resonance peak, would give a low resistance which points to the appearance of a "Wolfe" note. The radiation resistance can be estimated from $\pi df^2A^2/c$ where d is the density, f the frequency and c is the sound velocity. A can be approximated from the ratio of effective mass/total plate mass multiplied by total plate area. A high effective plate area will lead to a high radiation resistance.