"THE VIOLIN AS A STRUCTURE - A CONSIDERATION OF THE STATIC FORCE IN THE INSTRUMENT" *

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ABSTRACT

Some of the deflections in a violin have been measured (a) on loading an unstrung instrument at the position of the bridge feet - (b) on tensioning a strung instrument up to pitch.

It seems that the stiffness of the two sides of the instrument is about the same, but the nature of the displacements induced by loading at the two positions is different.

Tensioning the strings of a violin distorts the instrument. These initial trials suggest the top suffers a wave-like distortion modified by the bassbar. The back was not thoroughly studied, but is thought to have a less complicated distortion.

INTRODUCTION

Much attention has been given to the vibration characteristics of violin plates and in turn to assembled instruments by people interested in violin acoustics. Less attention has been given to the static forces present in the instrument in playing condition and their effect on it. The basic nature of these forces are intuitively well known, although the exact evaluation of them is extremely difficult and a complete analysis has not yet been done.

It is known that the combined tension in the four strings is 48-50 lbs. wt. and that through the instrument geometry a vertical force of about 10-12 lbs. wt. is transferred through the bridge to the top plate. The tensions are similar in each of the four strings, increasing from the G string to the E string. Thus the force through the right foot of the bridge is about 20% greater than through the left foot.

It is understood that the tension in the strings places the top plate in longitudinal compression,as well as the compressive force excited by the bridge. This latter force is resisted by the arching and by the soundpost near the right foot and the bassbar under the left foot. The back is possibly in longitudinal tension. The tension and compressive forces set up in the instrument by the strings are in internal equilibrium and are balanced by bending moments and shear stresses set up in the plates and blocks. These are by nature indeterminate.

The forces are usually considered in a longitudinal section only. Leipp[1] gives a simplified force diagram as shown in fig.1. He shows this for the soundpost side of the violin and draws attention to the symmetrical nature of the diagram about a line through the string nut and the top plate. He does not consider a section through the bassbar.

The body of the violin is basically very strong because of the use of two dimensional arching in the plates which are joined together by ribs and end and corner blocks. The ribs would resist attempts to twist the body because of their in-plane strength, and the blocks would resist differential lateral displacements between the plates. However, bending at the plate margins may allow this to occur. The ribs do not restrict movement that results in their lateral displacement, i.e. normal to their surface.

The dynamic forces generated during playing are very much smaller than the static forces present in the instrument.

The purpose of these experiments was to explore the displacements at a number of positions on the instrument as a result of forces applied to it. Two kinds of experiment were carried out; one was to measure the response to direct loading at the position of the bridge feet, and the other was to measure the deflections that occur when the instrument is strung and brought up to pitch.

EXPERIMENTAL DETAILS

The violin used was a factory-built one by Ch J.B.Collin-Mezin 1925. The soundpost was placed 2 mm behind the right foot of the bridge.

The instrument was mounted on a surface plate on four ground steel pillars, positioned at the top and bottom blocks and the two top corners. Polythene buttons between the instrument and the pillars protected the varnish. Three simple clamps with magnetic bases and cork protection for the varnish were placed at the top corners and the bottom block. This proved to be quite rigid after careful adjustment to give even support, as indicated by the reproductibility of the measured displacements.

Dial gauges reading to 0.0001 inches, were placed at points of interest on the violin,using magnetic bases.

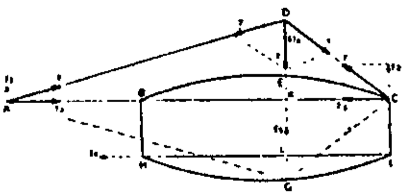


Fig 1 Longitudinal static force system in a violin after Leipp (1)

LOADING EXPERIMENTS ON UNSTRUNG INSTRUMENTS

The set up for the loading experiments is shown in fig. 2. Loading was achieved using a simple counter-balanced lever with a 5:1 ratio and transmitted to the point of application by a polythene cone truncated to give an area similar to the cross section of the bridge leg. The displacement at this point was measured with a dial gauge on the lever. A correction for compression of the polythene cone was obtained from a preliminary loading experiment against a steel pillar and applied to the readings of this dial gauge. Load increments of 0.5 lb. were used. After each change of load, the surface plate was lightly tapped with a small soft mallet to bring the system to equilibrium.

The placement of gauges is shown in fig.3. Gauges at points 1 and 2 indicated changes in position of the violin due to compression in the polythene supports. Readings from dial gauges other than 7 and 8 were corrected using an average of the readings from these two gauges. Several consecutive loading and unloading runs were done. The results quoted

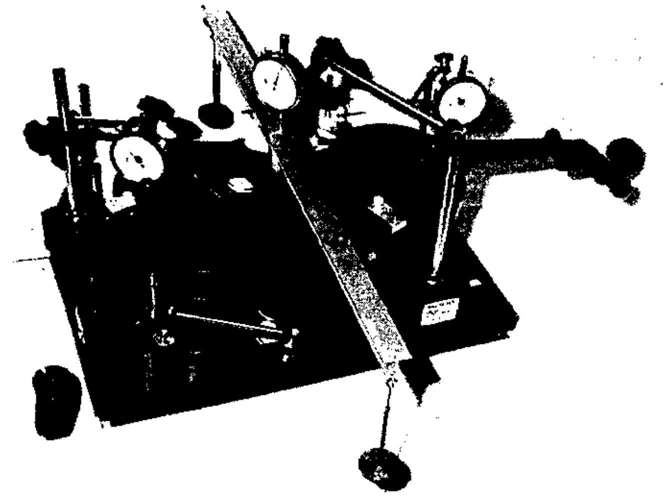


Fig.2 Experimental setup for load-deflection trials.

were typical of runs after the first loading when the system had settled down as indicated by the consistent zero readings.

The results for loading trials at the position of the left foot of the bridge are shown in Table 1 after correction for changes in zero during loading and unloading. The deflections shown at zero load were those remaining after the first loading and were not subtracted. Negative deflections indicate displacements inwards towards the centre of the violin while positive deflections indicate outward displacements.

Table 1

Deflections on loading at position of left foot.
R.T. 67.5°F R.H. 90%
(Deflections in 0.001 inches)

Load (lb)	Loading Point (3)	Sound Post (5)	Centre Back (6)	Centre Bout Width (7) + (8)
0	- 2.2	- 1.2	+ 1.0	- .6
0.5	- 2.75	- 1.3	+ .5	- .55
1.0	- 3.55	- 1.25	+ .7	- .3
1.5	- 4.4	- 1.3	+ .9	- .05
2.0	- 5.4	- 1.25	+ .4	+ .25
2.5	- 6.25	- 1.4	+ .35	+ .3
3.0	- 7.05	- 1.35	+ .1	+ .4
3.5	- 8.0	- 1.4	- .25	+ .5
4.0	- 8.9	- 1.75	- .3	+ .7
4.5	- 9.85	- 1.85	- .35	+ .95
5.0	-10.6	- 1.95	- .5	+1.4
5.5	-11.6	- 2.1	- .5	+1.3
6.0	-12.35	- 2.2	- .6	+1.35
6.5	-13.45	- 2.4	- .6	+1.55
Unloading				
6.0	-12.25	- 2.5	- .6	+1.4
5.5	-11.7	- 2.45	- .55	+1.2
5.0	-10.75	- 2.4	- .5	+1.1
4.5	-10.15	- 2.35	- .15	+ .95
4.0	- 9.25	- 2.25	+ .25	+ .8
3.5	- 8.35	- 2.2	+ .1	+ .6
3.0	- 7.35	- 2.15	+ .05	+ .5
2.5	- 6.7	- 2.2	+ .2	+ .3
2.0	- 5.8	- 2.15	+ .25	+ .25
1.5	- 4.75	- 1.95	+ .05	+ .1
1.0	- 4.15	- 1.85	+ .65	+ .1
0.5	- 3.15	- 1.5	+ .7	+ .25
0	- 2.35	- 1.35	+ 1.0	+ .05

The results are plotted in fig. 4 and represent relative displacements at the indicated gauge points.

The results for loading trials at the position of the right foot of the bridge are shown in Table 2. These results were also taken after the first loading and unloading, and have been corrected for change in zero so that they also represent relative displacements at the points indicated. The results are also plotted in fig. 5.

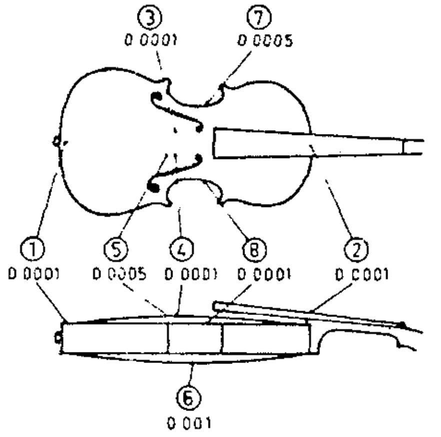


Fig 3 Gauge points for loading trials

EXPERIMENTS ON INSTRUMENT FITTED UP

Deflections at several points on the body of the instrument as a result of raising the string tension up to pitch and relaxing it were determined. The strings used were Pirastro Eudoxa except for a steel E string. The pitch was determined with a pitch pipe. Again the instrument was mounted on a surface plate with dial gauges as shown in fig. 6. The position of dial gauges is shown in fig. 7.

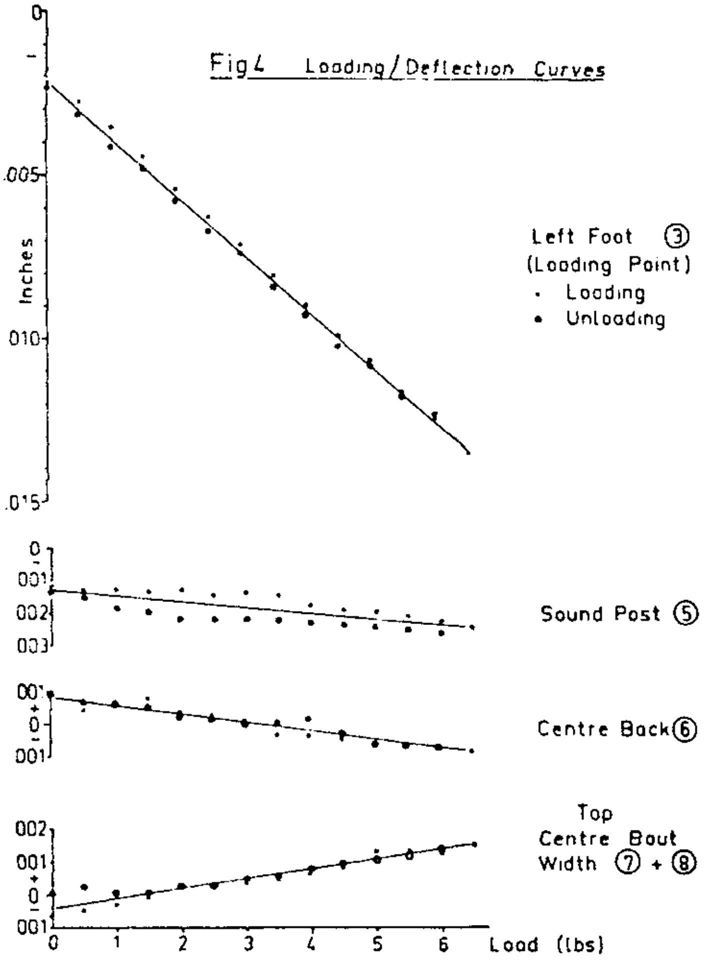
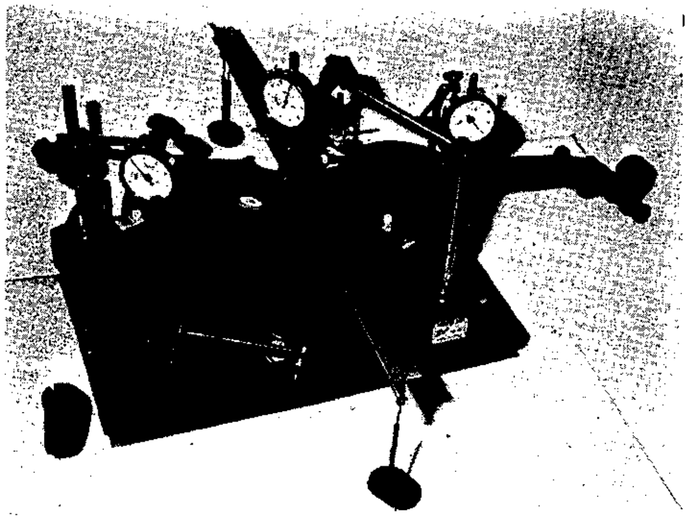


Fig 4 Loading/Deflection Curves



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2.0	- 5.4	- 1.25	+ .4	+ .25
2.5	- 6.25	- 1.4	+ .35	+ .3
3.0	- 7.05	- 1.35	+ .1	+ .4
3.5	- 8.0	- 1.4	- .25	+ .5
4.0	- 8.9	- 1.75	- .3	+ .7
4.5	- 9.85	- 1.85	- .35	+ .95
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3.0	- 7.35	- 2.15	+ .05	+ .5
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2.0	- 5.8	- 2.15	+ .25	+ .25
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1.0	- 4.15	- 1.85	+ .65	+ .1
0.5	- 3.15	- 1.5	+ .7	+ .25
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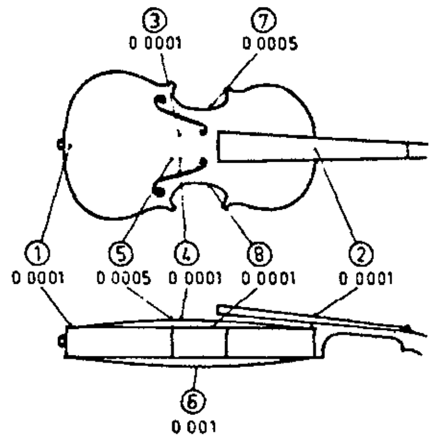

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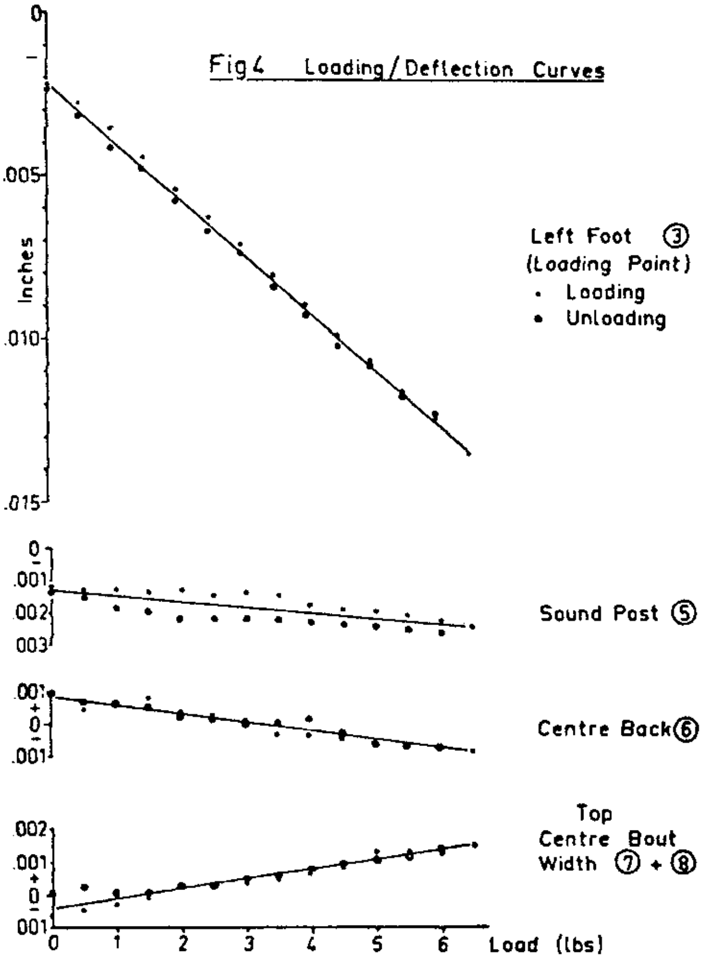


Fig4 Loading/Deflection Curves

Table 2

Deflections on loading at position of right foot.
R.T. 67°F. R.H. 85%
(Deflection in 0.001 inches)

Load (lb)	Loading point (4)	Sound Post (5)	Left Foot (3) *	Centre Back (6)	Centre Bout Width (7)+(8)
0	- 2.05	- 1.65	-	- .15	- .25
0.5	- 2.3	- 1.95	-	- .15	- .35
1.0	- 3.05	- 2.6	-	+ .1	- .6
1.5	- 3.95	- 3.2	+ .25	+ .5	- .9
2.0	- 4.65	- 3.75	.0	+ .65	- 1.05
2.5	- 5.35	- 4.3	.0	+ .7	- 1.25
3.0	- 6.15	- 4.95	+ .15	+ .85	- 1.4
3.5	- 7.1	- 5.4	+ .38	+ 1.1	- 1.6
4.0	- 7.8	- 6.05	+ .25	+ 1.35	- 1.75
4.5	- 8.35	- 6.8	+ .25	+ 1.55	- 1.9
5.0	- 8.95	- 7.5	+ .25	+ 1.7	- 2.05
5.5	- 9.6	- 7.95	+ .25	+ 1.95	- 2.2
6.0	- 10.1	- 8.15	.0	+ 2.15	- 2.2
6.5	- 10.75	- 8.3	-	+ 2.3	- 2.5
Unloading					
6.0	- 10.1	- 8.6	-	+ 2.2	- 2.45
5.5	- 9.75	- 8.3	+ .25	+ 2.1	- 2.25
5.0	- 9.1	- 8.1	+ .25	+ 1.9	- 2.15
4.5	- 8.55	- 7.7	+ .25	+ 1.45	- 2.0
4.0	- 8.1	- 7.1	- .45	+ 1.5	- 1.9
3.5	- 7.5	- 6.45	- .55	+ 1.15	- 1.75
3.0	- 6.9	- 5.8	- .4	+ .95	- 1.55
2.5	- 6.0	- 5.15	- .6	+ .55	- 1.35
2.0	- 5.3	- 4.6	- .7	+ .5	- 1.2
1.5	- 4.4	- 3.75	- .75	+ .35	- 1.0
1.0	- 3.45	- 3.2	- .75	.0	- .75
0.5	- 2.65	- 2.65	-	- .15	- .55
0	- 1.85	- 2.0	-	- .2	- .35

* Taken from another experiment with R.T. 64°F. R.H. 66%

With the strings under tension the gauges were set to zero. The surface plate was tapped before readings were taken. The string tension was relaxed and readings again taken. It was possible to re-tension and relax the strings in situ without disturbing the dial gauges as indicated by the constant readings obtained. The mounting of the instrument was remarkably stable.

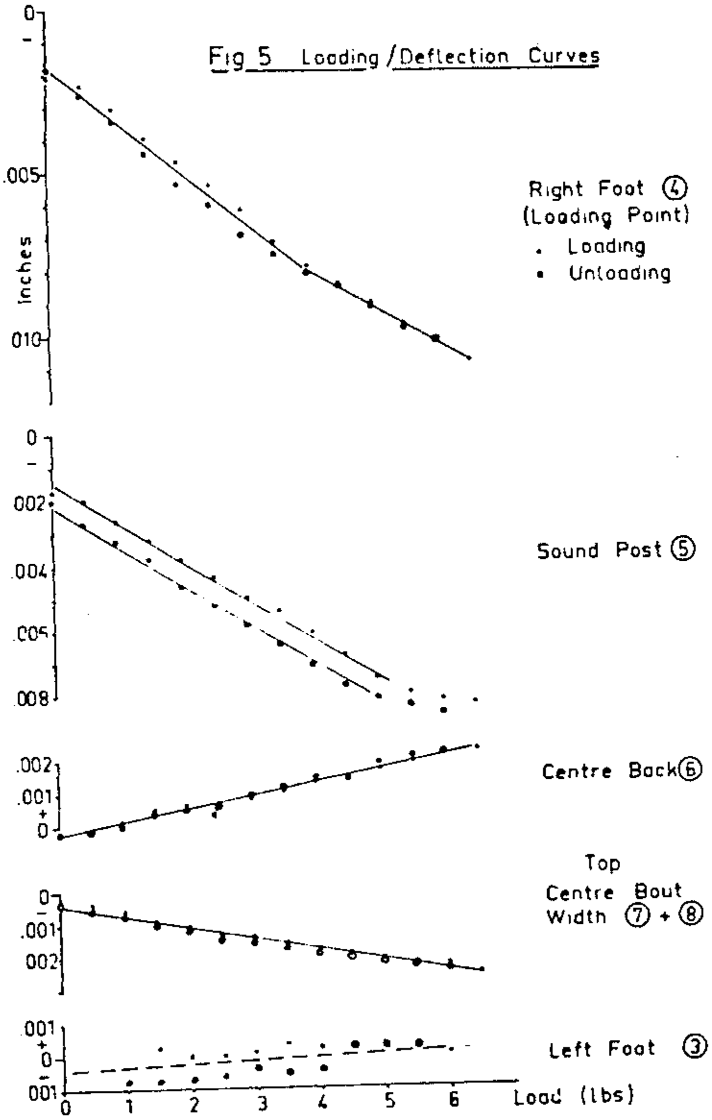
The number of positions that could be measured was limited at any one time by the size of the violin and the space around it. However, attempts were made to measure the change in length of the plates, displacement of the plate surface on the soundpost and bassbar side and change in tilt of the fingerboard.

The results are set out in Table 3. The position of the test points was measured from the inner notches on the ff holes and from the edges of the bouts where given.

DISCUSSION OF RESULTS

1. Loading Experiments

Loading experiments done separately at the two feet positions are somewhat unrealistic, but might be used to indicate the relative stiffness of the two sides of the instrument. This would be so if, to a first approximation,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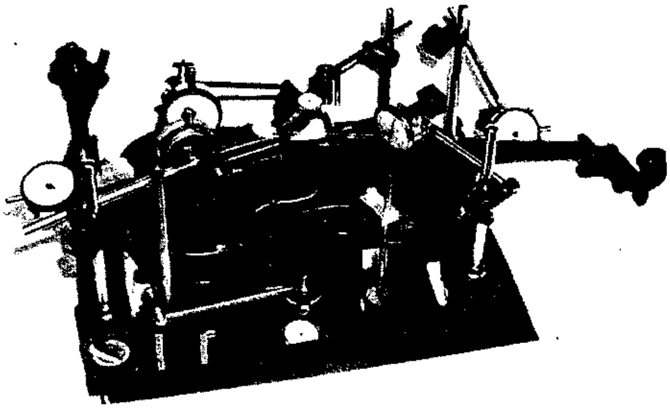
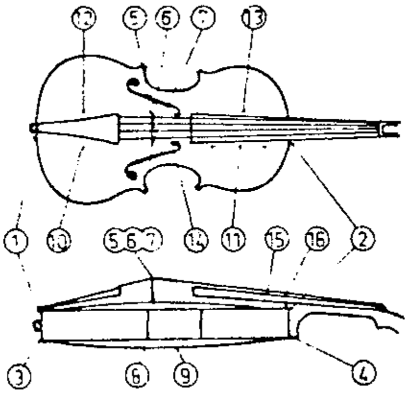


Fig 6. Experimental setup for string tension-deflection trials



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1.0	- 3.05	- 2.6	-	+ .1	- .6
1.5	- 3.95	- 3.2	+ .25	+ .5	- .9
2.0	- 4.65	- 3.75	.0	+ .65	- 1.05
2.5	- 5.35	- 4.3	.0	+ .7	- 1.25
3.0	- 6.15	- 4.95	+ .15	+ .85	- 1.4
3.5	- 7.1	- 5.4	+ .38	+ 1.1	- 1.6
4.0	- 7.8	- 6.05	+ .25	+ 1.35	- 1.75
4.5	- 8.35	- 6.8	+ .25	+ 1.55	- 1.9
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5.5	- 9.6	- 7.95	+ .25	+ 1.95	- 2.2
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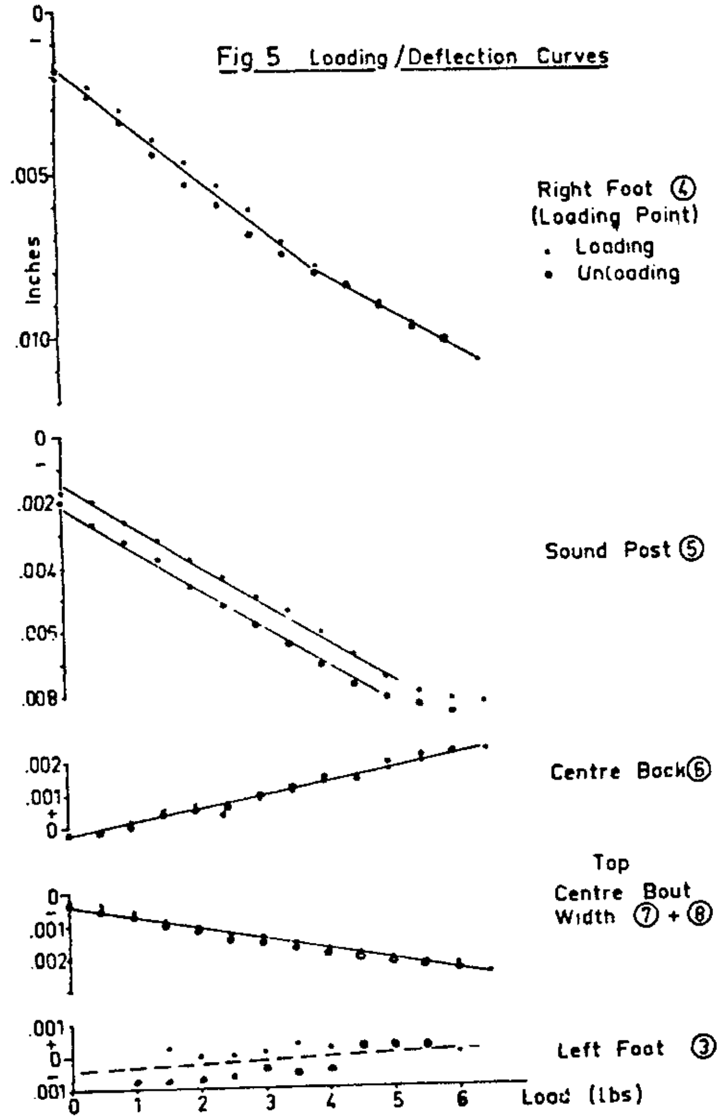
5.0	- 9.1	- 8.1	+ .25	+ 1.9	- 2.15
4.5	- 8.55	- 7.7	+ .25	+ 1.45	- 2.0
4.0	- 8.1	- 7.1	- .45	+ 1.5	- 1.9
3.5	- 7.5	- 6.45	- .55	+ 1.15	- 1.75
3.0	- 6.9	- 5.8	- .4	+ .95	- 1.55
2.5	- 6.0	- 5.15	- .6	+ .55	- 1.35
2.0	- 5.3	- 4.6	- .7	+ .5	- 1.2
1.5	- 4.4	- 3.75	- .75	+ .35	- 1.0
1.0	- 3.45	- 3.2	- .75	.0	- .75
0.5	- 2.65	- 2.65	-	- .15	- .55
0	- 1.85	- 2.0	-	- .2	- .35

* Taken from another experiment with R.T. 64°F. R.H. 66%



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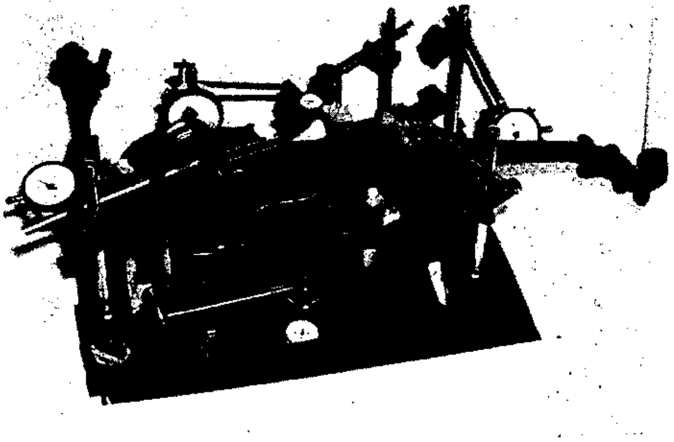

Fig. 6. Experimental setup for string tension-deflection trials.

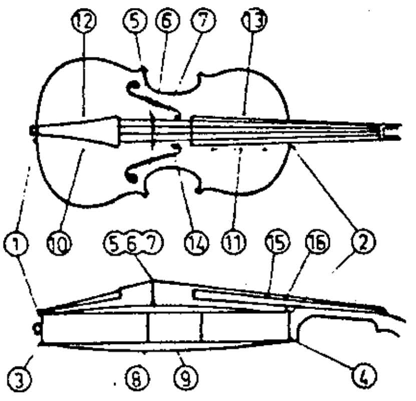

Fig 7 Gauge points for relaxation trials

Table 3

Displacements on Tensioning Strings of Violin up to pitch (Expansions - positive, contractions - negative) *R.T. 69°F.* **R.H. 75%.**
*** RT 64°F. R.H. 66%**

Position Measured (figure 7)	Displacement on loading (inches)	Average
Top Plate length (1) (2)	- .00104 - .00101 - .00116 - .00119	- .0011
Back Plate length (3) (4)	+ .00003 + .00006	+ .000045
Bridge Top (5)	- .0035 - .0069	- .0052
(6)	- .009 * - .010 *	- .0095
(7)	- .0058 - .0065	- .0062
Sound Post (8) (measured on back)	+ .0062 + .0053	+ .0058
Back at centre (9) (1.6" from soundpost)	+ .0018 + .002 + .0022	+ .002
Top/lower bout (10)		
2.5" from edge	+ .0017 + .00176	+ .00173
3.3" from bridge	+ .00171 + .00164	+ .00168
3.1" from bridge	+ .0017 * + .0023 *	+ .0020
Top/lower bout (12) (close to bassbar)		
3.1" from edge	- .00082 - .00084	- .00083
3.3" from bridge	- .00075	- .00075
3.25" from bridge	- .00167 * - .00175 *	- .00171
Top/upper bout (11) (close to finger board)		
3.1" from bridge	+ .0019	+ .0019
4.1" from bridge	+ .0034 + .0034	+ .0034
5.2" from bridge	+ .0036	+ .0036
Top/upper bout (14) in line with soundpost and bridge foot		
1.3" from bridge	- .0046 * - .0034 *	- .0040
Top/upper bout (13) (close to bassbar)		
4.65" from bridge	+ .00129 + .00137	+ .00133
5.0" from bridge	+ .0034 * + .0035 *	+ .00345

the two sides of the instrument could be considered independently.

Loading at the left foot depresses the top plate at this point as expected. The top at the soundpost is depressed but to a smaller extent, and the width of the centre bout is increased. However the results suggest that the back at the centre position moves inwards contrary to the movement of the soundpost, if assumed not to change length under these loads. Perhaps the increase in width of the top at the centre bout influences the shape of the back through the ribs and corner blocks. The back centre bout was not measured.

There is some evidence of hysteresis and creep but no detailed study of this was done. The amounts were small and may have been connected with the polythene supports. Teflon or high density polythene would probably have been better for this, and more work needs to be done.

Loading at the position of the right foot also showed a similar depression of the top plate, while at the soundpost the depression was almost the same. However the top at the centre bouts decreased in width and the back plate moved out at the centre.

Perhaps one could speculate that in this case the movement of the back outwards, in response to the force of the soundpost, caused the centre bout width to decrease causing in turn the width of the top to decrease also. As the results suggest, the left foot position, *as a consequence, might have risen slightly.*

The stiffness i.e. the slope of the load-displacement line, at the two loading positions was about the same.

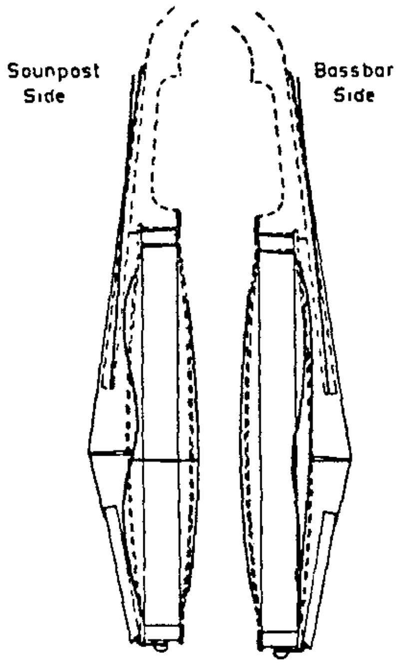

Fig 8 Distortion of design shape under string tension

2. <u>Tensioning and Relaxing Strings</u>

It would appear that from the results taken on the instrument used in these experiments, tensioning the strings brought about the following changes in geometry. The top was depressed *in the area of the bridge feet and at* the soundpost by about 0.006 to 0.010 inches. The top was also shortened in length by about 0.001 inches. On the soundpost side, the lower bout was raised about 0.002 inches and the upper bout was also raised up to 0.002 - 0.003 inches, giving this side a wave-like distortion to the arching. On the bassbar side the lower bout was depressed about 0.001 inches while the upper bout was raised about 0.0015 - 0.003 inches. This amounts to tilting the bassbar from end to end by the action of the bridge and the upper bout.

The length of the back plate did not alter significantly in these tests; if anything it increased slightly. The centre position moved with the soundpost but to a lesser extent, and no extensive survey was done on displacements of the back.

The tilt of the neck was measured by placing dial gauges at points (15) and (16) spaced one inch apart on the free part of the fingerboard. On tensioning the strings, the fingerboard was tilted towards the top-plate by about 0.002 inches per inch. If no bending occurs in the neck and it pivots about the top block, the string nut would be raised about 0.010 inches.

The deflections measured at the bridge are uncertain, to the extent that on relaxing the string tension, the position of the bridge top is moved and it has to be replaced under the gauges. It was not possible with the equipment available, to measure at the bridge feet which would have been better. However a comparison with figures 4 and 5 when the lines plotted are taken through zero, shows a measure of agreement with loads of 4 to 5 lbs. indicated corresponding to the displacements.

Fig. 8 shows a schematic of the distortion of the body looked at from the two sides of the instrument.

DISCUSSION

This paper is a presentation of some simple experiments to find out what happens to the body of a violin when it is strung and tensioned up to pitch. It might reasonably be expected that it will undergo elastic distortion. The final shape will be that about which body vibrations will take place. It might be possible that vibrations could become asymmetrical enough to affect the sound produced.

One question that could be asked concerning the effect of string tension on the violin is: do the two sides of the instrument react similarly to the static forces of the bridge?

As far as the top is concerned they do, in that at the bridge feet the top is depressed. However the displacements found at positions away from the loading points appear to be different because of the asymmetry of construction. Loading over the bassbar appears to cause the top to be flattened and widened at the middles bouts, whereas loading at the soundpost alone causes the width at the centre bout to be reduced, probably by transferring the force to the back and ribs.

Within the range of loads studied, the change in stiffness at higher loads on the soundpost side is probably due to the increase in support provided by the body through the soundpost.

The action of tensioning the strings distorts the instrument. This is no surprise in itself, but it is of interest that the distortion is not uniform. On the soundpost side there is a "wavelike" distortion superimposed on the arching. This can be seen to come from the combined action of the right bridge foot, the soundpost and the longitudinal compression of the top. On the left, the bassbar controls the distortion to the extent that the top is tilted longitudinally, being raised at the upper bout and depressed at the lower bout.

Whether this pattern of distortion occurs in all instruments is at least of academic interest One can speculate on the effect of other positions of the soundpost, variation in arching, the thicknessing of the channel region inside the purfling, the length and shape of the bassbar, for example, on the basic shape of the distortion and on the extent of the distortion at different places. As an example, moving the soundpost further away from the bridge might be expected to reduce the distortion on this side in the upper bout and increase it in the lower bout, perhaps to the point of reversing the tilt of the bassbar.

Part of the role of the bassbar might be to control the nature of the distortion of the top plate. The practice of springing the bassbar and the top plate at the upper bout could be examined in the light of these findings.

The stresses in the surface fibres of the top plate are not going to be uniform. Imposed on the stresses generated by the longitudinal compression of the top, will be the variations due to the distortions from the initial arching produced by the vertical loading of the bridge. The nature of the arching would have an influence on both of these effects.

The question posed at the end of the paper: what has all this to do with the vibration characteristics of the instrument? I do not know. The large number of vibration patterns recorded, do not at first sight appear to show a correlation.

A more sophisticated study could be done varying the parameters mentioned, and using different violins. Moire fringes by holography could map the plate surfaces completely and rapidly. Another technique that might be used to explore the behaviour of the body under load is photoelastic stress analysis.

CONCLUSIONS

Loading experiments on an unfitted up violin body at the position of the bridge feet in turn have shown that the deflections and hence the stiffness is about the same at the two positions.

However, deflections at other locations measured suggest a complex behaviour. Force at the left foot of the bridge increases the width of the top and possibly decreases the height of the arching of the back through the influence of the ribs and corner blocks.

A force at the right foot of the bridge seems to produce deflections through the connection with the back via the soundpost in that the width of the top is decreased and the left foot position is raised.

The deflections experienced after simultaneous loading at both feet would seem to be the result of complex interactions.

From the deflections measured on tensioning and relaxing the strings of a violin, the following distortion of the instrument might be deduced. The area of the top at both bridge feet, including the soundpost, is depressed. This is extended on the bassbar side to the lower end of the bassbar. Because of the string tension the neck is tilted and the top is shortened in length. This shortening, together with the rigidity of the bassbar, lifts the top in the region of the upper bouts and also raises the top on the soundpost side in the region of the lower bouts. The back is raised slightly and may be lengthened, but the distortion of the back is thought not to be as complicated as the top. Fig. 9 suggests a possible pattern for the distortion experienced by the two plates. Moire patterns could be used to determine this.

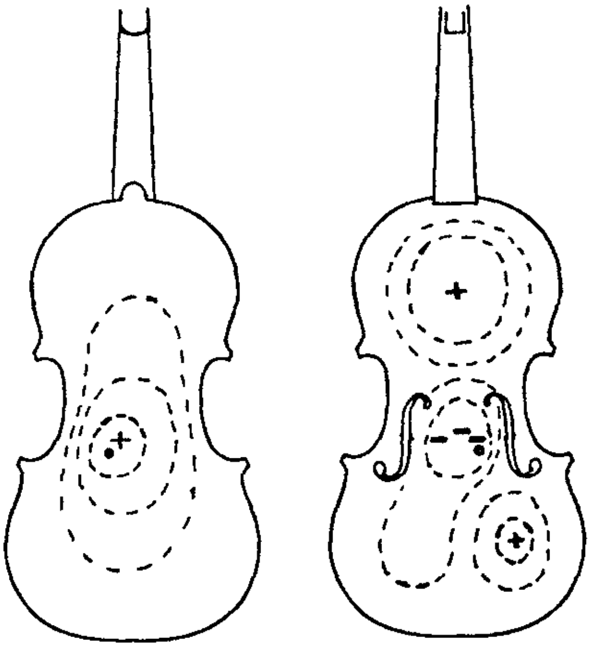

Fig 9 Probable distortion of top and back of a violin after tensioning strings.