In This Issue:

- THE HELMHOLTZ RESONANCE AND HIGHER AIR MODES OF THE HARP SOUNDBOX
- ON BODY RESONANCE C3 AND VIOLIN CONSTRUCTION
- THE RECIPOCAL BOW AS A WORKSHOP TOOL
- EFFECT OF SOUND POST ADJUSTMENT
- ACOUSTIC CONDITIONS FOR A SOLOIST'S CONCERT VIOLIN
- DOWN-HOME LUTHERIE: A Simple Technique for Measuring Loudness
- NEW VERSUS OLD: Playing-in Instruments through Vibratory Transmission of Music to the Bridge
- ACOUSTIC EXPERIMENTS WITH THE VIOLIN
- USE OF A BENT TOP TO REDUCE LONG-TERM VIOLIN DEFORMATION

Catgut Acoustical Society

To increase and diffuse the knowledge of musical acoustics and to promote construction of fine stringed instruments

Vol. 3, No. 3 (Series II) May 1997
FROM THE EDITOR...

I am very pleased to welcome Professor Robert T. Schumacher to the CAS Editorial Board as Associate Editor for Musical Acoustics. Bob will be responsible for the review process of papers relating to musical acoustics in the Journal. A thorough review process is key to maintaining and even enhancing the quality of the Journal’s contents, and Bob is exceptionally well-qualified to direct this function. As we note on page 49, this year he marks his 25th anniversary as a CAS member. A Professor of Physics at Carnegie—Mellon University since 1957, he has researched and written extensively on violin acoustics. Readers of this Journal will recall his paper (with S. Garoff) “Bowing with a Glass Bow,” in the November 1996 issue, with the remarkable images of the slip-stick bowed-string motion at the point of contact between bow and string. A number of his papers are included in the recent publication, Research Papers in Violin Acoustics 1975—1993, edited by Carleen Hutchins and Virginia Benade. (Look for the review by Neville Fletcher in this issue of the Journal.) A violinist, Professor Schumacher plays a violin made for him by Curtin & Alf (also CAS members).

Some readers have wondered about the section of the Journal designated “Violinmaker’s Forum.” We have used this designation to flag papers that should be of particular interest to practicing luthiers. Papers in this section may focus on using acoustical principles and research findings in the process of instrument making and may be somewhat less technical. Some papers will describe tools, jigs, and techniques that facilitate good construction. As we have said before, good craftsmanship is essential if instruments are to embody advances in knowledge of violin acoustics.

It may be important to know that all papers in the Journal pass through a formal process of written reviews by anonymous reviewers. Associate Editor John Randerson of Colorado Strings manages the review process for many of the papers that appear in the “Forum” section. In addition to working in his shop, John has written for this Journal and the Strad and is collaborating with Karl Roy on a book on violinmaking.

I encourage you to read the announcement on page 52 for ISMA ’98: Tone and Technology in Musical Acoustics to be held near Seattle, Washington in June 1998. Planning is underway, and the organizing committee would appreciate hearing from persons who want to participate or attend.

As always, we appreciate your feedback about the Journal so that it can be improved and better meet the members’ needs.

Good reading!

A. Thomas King

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<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>The Helmholtz Resonance and Higher Air Modes of the Harp Soundbox</td>
<td>by Alexander J. Bell</td>
</tr>
<tr>
<td>9</td>
<td>On Body Resonance C3 and Violin Construction</td>
<td>by Erik V. Jansson, Benedykt K. Niewczyk, and Lars Fryden</td>
</tr>
<tr>
<td>15</td>
<td>The Reciprocal Bow as a Workshop Tool</td>
<td>by Joseph Curtin</td>
</tr>
<tr>
<td>19</td>
<td>Effect of Sound Post Adjustment</td>
<td>by Oliver Rodgers</td>
</tr>
<tr>
<td>25</td>
<td>Acoustic Conditions for a Soloist’s Concert Violin</td>
<td>by Hajo G. Meyer</td>
</tr>
<tr>
<td>42</td>
<td>New Versus Old: Playing-in Instruments through Vibratory Transmission of Music to the Bridge</td>
<td>by Daniel Ling and Mead Killion</td>
</tr>
<tr>
<td>45</td>
<td>Use Of A Bent Top To Reduce Long-term Violin Deformation</td>
<td>by Charles W. Gadd</td>
</tr>
<tr>
<td>48</td>
<td>Paillette Indicators: an Alternative to the Blister Cup Indicators</td>
<td>by Åke Ekwall</td>
</tr>
</tbody>
</table>

**NEWS & CORRESPONDENCE**

Page 49

**RECENT PUBLICATIONS**

Page 51

**IN MEMORIAM**

Page 51

**MEETINGS**

Page 52

**BOOK REVIEW**

Page 56

**LETTERS TO THE EDITOR**

Page 58

**AUTHORS**

Page 60

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THE HELMHOLTZ RESONANCE AND HIGHER AIR MODES OF THE HARP SOUNDBOX

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The air modes of a rigid soundbox of the Salvi "Orchestra" Concert Harp are analysed. A Helmholtzian mode plus higher air modes are found. The Helmholtzian mode is modelled using an elliptical approximation. The resonant frequencies and profiles of the air modes are affected by the apertures in the rear and base of the soundbox.

The Helmholtzian Mode of the "Orchestra" Soundbox

The Experimental Technique

The experimental procedure was...
quite straightforward. The soundbox was buried under sandbags in a bath. Some 120 kg of sand was used. In initial testing, placing 5 kg masses inside the soundbox and on the soundboard did not affect the major resonances of the enclosed air. The rigid bass end of the soundbox was left exposed, so that a microphone (B+K 1/4 inch) could be passed through aperture No. 6 to various positions inside the soundbox.

The apertures at the back of the soundbox could be covered with tight-fitting lead plates, with the sand bags over them. All the experimental work was conducted in an anechoic chamber. A signal from a Heterodyne analyser (B+K 2010) was amplified and then sent to a small loudspeaker. This loudspeaker was placed either by an open aperture or inside the soundbox. Any air excitation was detected by the 1/4 inch microphone and the SPL and phase of any resonance could be measured using an accompanying measuring amplifier and phasemeter. Information on resonant frequency, Q-factor and phase was collected for enclosed air modes. This is presented graphically—see for example, Figure 2. Following the convention set by Jansson (1977), the phase is taken as π at the bass end of the soundbox.

The Helmholtz Resonators of Individual Apertures

The first stage of this investigation was to open each aperture in turn and determine whether the soundbox could support a Helmholtzian mode with one open aperture. For the bass end aperture (No. 6), a resonance was found at 75 Hz. Its characteristics (Figure 2) show as Helmholtzian with the entire enclosed air volume vibrating as a single unit. Similar modes were found when apertures 1, 2, 3, 4 were each opened in turn (Figure 2)—the frequencies and Q-values are given in Table 2. The treble end aperture (No. 5) was found to be unable to sustain a Helmholtzian mode when it was operating into the volume of the entire soundbox.

Theoretical work to confirm these values depend on the calculation of the aperture corrections. Kinsler and Frey (1982) cite:

$$2\Delta = 0.96 \times (\text{Area of Aperture})^{1/2}$$

The error on the theoretical values of the Helmholtz resonances is ± 5%, due mainly to the difficulty in determining the volume of the soundbox. Using this formula for aperture correction, we gain the theoretical values as given in Table 2. As four of the five cases are in agreement, this simple method seems to be a reasonable means of predicting resonant frequencies.

The Development of the Helmholtzian Mode

Clearly the soundbox can support a Helmholtzian mode when a single aperture is open, except for Aperture No. 5. The question remains whether there is a Helmholtzian mode when all the apertures are open. A programme of testing was conducted, where the apertures were systematically unblocked and the characteristics of the Helmholtzian mode were monitored using the loudspeaker and microphone. In all, some six stages were noted and some of the results are shown in Figure 1i to Figure 1iii. In each set of plots, the sketch of the soundbox shows which of the apertures are open. The mode with all the aper-

<table>
<thead>
<tr>
<th>Table 1 - The areas and lip-lengths of the apertures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture Number</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions of the Apertures</th>
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<tbody>
<tr>
<td>Number</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

CASJ Vol. 3, No. 3 (Series II), May 1997
Table 2 - The experimental and theoretical values of the Helmholtzian resonances of the individual apertures on the soundbox

<table>
<thead>
<tr>
<th>Aperture Number</th>
<th>Helmholtz Frequency Experimental Value (Hz)</th>
<th>Q-value</th>
<th>Helmholtzian Frequency Theoretical Value (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>75</td>
<td>10</td>
<td>84 ± 4</td>
</tr>
<tr>
<td>1</td>
<td>87</td>
<td>9</td>
<td>94 ± 5</td>
</tr>
<tr>
<td>2</td>
<td>94</td>
<td>9</td>
<td>96 ± 5</td>
</tr>
<tr>
<td>3</td>
<td>88</td>
<td>11</td>
<td>91 ± 4</td>
</tr>
<tr>
<td>4</td>
<td>86</td>
<td>10</td>
<td>88 ± 4</td>
</tr>
</tbody>
</table>

There are three features to note in Figure 1. The first is the obvious point that the resonant frequency increases as the number of open apertures. The second point is that the shape of the SPL plots changes as more apertures are opened. In the first case (Figure 1i), the SPL level rises by 10 dB from the bass end to the treble, while in the last case (Figure 1iii), the SPL drops by 20 dB from the bass end to the treble. This is predicted by Kinsler and Frey (1982, Section 8.10) who show that the attenuation of a branched pipe principally affects low frequency modes and varies directly with the cross-section area of the main branch. The third, and final, point is that the phase characteristics of the mode change as the aperture tures open was examined in particular detail. The characteristic of this mode was determined thrice, with the excitation loudspeaker beside three different apertures. There were only marginal differences in mode profile and Q when this was done.
Table 3 - A comparison between theoretical and experimental values for the Helmholtz resonance, with changes in the aperture parameters

<table>
<thead>
<tr>
<th>Change in Parameter</th>
<th>Experimental Value (Hz)</th>
<th>Theoretical Value (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>all apertures open and normal size</td>
<td>190</td>
<td>186 ± 9</td>
</tr>
<tr>
<td>closing Aperture 1 only</td>
<td>164</td>
<td>163 ± 8</td>
</tr>
<tr>
<td>closing Aperture 2 only</td>
<td>168</td>
<td>163 ± 8</td>
</tr>
<tr>
<td>closing Aperture 3 only</td>
<td>178</td>
<td>172 ± 8</td>
</tr>
<tr>
<td>closing Aperture 4 only</td>
<td>181</td>
<td>173 ± 8</td>
</tr>
<tr>
<td>closing Aperture 6 only</td>
<td>162</td>
<td>170 ± 8</td>
</tr>
<tr>
<td>increasing Aperture 1 to 190 cm²</td>
<td>206</td>
<td>208 ± 10</td>
</tr>
<tr>
<td>decreasing Aperture 1 to 64 cm²</td>
<td>186</td>
<td>185 ± 9</td>
</tr>
<tr>
<td>decreasing Aperture 1 to 43 cm²</td>
<td>182</td>
<td>175 ± 8</td>
</tr>
<tr>
<td>increasing Aperture 2 to 176 cm²</td>
<td>196</td>
<td>198 ± 10</td>
</tr>
<tr>
<td>decreasing Aperture 2 to 64 cm²</td>
<td>186</td>
<td>179 ± 10</td>
</tr>
<tr>
<td>decreasing Aperture 2 to 43 cm²</td>
<td>182</td>
<td>176 ± 8</td>
</tr>
<tr>
<td>increasing Aperture 3 to 150 cm²</td>
<td>193</td>
<td>196 ± 10</td>
</tr>
<tr>
<td>decreasing Aperture 3 to 61 cm²</td>
<td>187</td>
<td>183 ± 9</td>
</tr>
<tr>
<td>decreasing Aperture 3 to 40 cm²</td>
<td>186</td>
<td>178 ± 9</td>
</tr>
<tr>
<td>increasing Aperture 4 to 140 cm²</td>
<td>197</td>
<td>199 ± 10</td>
</tr>
<tr>
<td>decreasing Aperture 4 to 54 cm²</td>
<td>186</td>
<td>184 ± 9</td>
</tr>
<tr>
<td>decreasing Aperture 4 to 36 cm²</td>
<td>184</td>
<td>181 ± 9</td>
</tr>
<tr>
<td>increasing Aperture 6 to 120 cm²</td>
<td>199</td>
<td>193 ± 10</td>
</tr>
<tr>
<td>decreasing Aperture 6 to 46 cm²</td>
<td>186</td>
<td>177 ± 9</td>
</tr>
<tr>
<td>decreasing Aperture 6 to 30 cm²</td>
<td>184</td>
<td>173 ± 9</td>
</tr>
</tbody>
</table>

is opened. Initially, the phase only changes by 15° from bass end to treble, by the point when all the apertures are opened, the phase change is nearly 90° (86° to be precise).

The question arises as to whether the mode at 190 Hz is a Helmholtzian mode or a standing wave (of quarter-wave-length). If it were a $\lambda/4$ standing wave, we would expect to find a family of higher order modes (of $\lambda/4, 5\lambda/4$ etc.) and it will be shown below that we do not. This mode is affected by changes in both aperture area and volume. It will be shown below that this mode can be modelled as a Helmholtz resonance using an elliptical approximation for the apertures.

Predicting the Helmholtzian Frequency of the Multiapertured Soundbox

An adaptation of Cremer's method was used in this case. The participating apertures (No. 1-4 and 6) were modeled as an ellipse with the same area. The value of the minor axis was set as the average of the widths of these apertures (2.7 cm) and the major axis was determined to be 45.8 cm, giving the ellipse an eccentricity of 0.998. Using the two formulae, shown above, the resonant frequency was determined to be (186 ± 9) Hz, the experimental value being 190 Hz. This method of determining the Helmholtzian frequency was tested on some 21 modifications to the aperture profiles. The results are shown in Table 3; in 20 out of 21 cases, the calculated and experimental values agree to within the error margin.

The Higher Order Air Resonances in the Soundbox

Background and Experimental Technique

Although Meyer (1975) reported work on the guitar, Jansson (1977) was one of the first researchers to describe the higher order resonances of a guitar and violin shaped cavity. Firth (1977) reported a number of such modes on the clarsach soundbox, which he stated were not affected by the closure of any apertures.

The experimental technique for determining these mode characteristics is the same as for the investigation of the Helmholtz modes. The exception is with the transverse mode, where a small (telephone) loudspeaker was placed inside the soundbox.

The Experimental Results

The first five higher order air modes were monitored. These are labelled A1 to A5, following Jansson's notation. The developments of these modes as the apertures are systematically opened are shown in Figures 2-6.

Looking at the first trace (Trace i) in each of these figures, we see the characteristics of a family of standing wave modes operating along the length of the...
soundbox. All the modes show antinodal regions separated by deep nodal troughs. The peak-trough height is usually between 10 and 15 dB. The phase diagrams for these modes show changes of $\pi$, $2\pi$, $3\pi$, $4\pi$ and $5\pi$, though there is a small "overshoot" of—at most—$\pi/3$ for the A2 and A3 modes. This phase progression confirms that this is a family of $\lambda/2$ modes.

Morse (1936) has calculated the resonant frequencies of a conical horn of similar shape to the soundbox, which can be applied to the low-frequency analysis of this soundbox (below the frequency of the first transverse mode). The resonant frequencies of such a conical horn are in the ratio:

$$1.20 : 2.10 : 3.00 : 4.00 : 5.00$$

The frequencies of these air modes in the soundbox, when only the bass end aperture (Aperture No. 6) is open, are in the ratio:

$$1.23 : 2.08 : 3.03 : 4.00 : 5.00$$

and compare well with Morse's theory. Furthermore, the calculated length of the soundbox, obtained by taking the frequencies of the A4 and A5 modes give the length of the soundbox as 1.27 m, which is correct to a few centimetres.

As the apertures were opened, the modes A1 to A5 all changed in shape and frequency: this is in antithesis to Firth. As the changes are quite specific, each mode will be considered in turn.

**The A1 Mode (Figure 2):** The frequency and shape of this mode both change as the apertures are opened: the frequency rises from 168 Hz (at stage i) to 292 Hz (by stage iii). There is a long region of gradually diminishing SPL towards the treble end of the soundbox. Such attenuation could be due to the array of apertures acting as a High-pass filter. The Q-values of the mode also falls, from 10 to 6 over the stages, because of the increased losses through the open apertures.

**The A2 Mode (Figure 3):** Again, the frequency and mode shape both change, with a slight shift in the position of the nodal points. The resonant frequency rises from 283 Hz to 423 Hz. As the changes are quite specific, each mode will be considered in turn.

**The A1 Mode (Figure 2):** The frequency and shape of this mode both change as the apertures are opened: the frequency rises from 168 Hz (at stage i) to 292 Hz (by stage iii). There is a long region of gradually diminishing SPL towards the treble end of the soundbox. Such attenuation could be due to the array of apertures acting as a High-pass filter. The Q-values of the mode also falls, from 10 to 6 over the stages, because of the increased losses through the open apertures.

**The A3 Mode (Figure 4):** The effect of opening the apertures is not so pronounced on the A3 mode as on the pre-
vious two. The resonant frequency rises from 414 Hz to 530 Hz. The nodal positions only shift slightly. There is no attenuation of SPL to the treble end of the box, though there is a decrease in Q-value, from 23 to 10.

The A4 and A5 Modes (Figures 5 and 6): There are only slight increases in resonant frequencies as the apertures are opened. The A4 resonance changes from 545 Hz to 620 Hz, the A5 from 680 Hz to 720 Hz. There is no shift in nodal positions or change of mode cross-section. There is only a slight change in Q-value (A4: from 16 to 15, A5 from 36 to 30).

The Phases of the Modes: Modes A2, A3, A4 and A5 form a series of modes with phases of $2\pi$, $3\pi$, $4\pi$ and $5\pi$, showing that this is a group of half-wave modes. The frequencies of the modes can no longer be predicted by Morse's method.

A Transverse Mode: One transverse mode was identified. This occurs at 545 Hz in the bass end of the soundbox. As the nodal line is along the apertures, closing these apertures does not affect the resonant frequency or profile.

Enclosed Air Resonances on the Completed, Strung Instrument

Experimentation on a complete harp detected a very strong resonance of the entire soundbox at 187 Hz, which could be affected by closing Apertures 1 to 4. Investigation of SPL and phase showed it to be of similar form to the Helmholtz mode found on the rigid soundbox. This mode is the gravest of the resonant modes of the completed instrument and thus represents a very strong factor in the tonal quality of the bass strings of the harp.

Conclusion

Both Helmholtzian and Higher Order standing waves have been detected on a rigid harp soundbox. The Helmholtzian mode can be modelled using an elliptical approximation of the apertures. Both sets of modes are affected by the aperture configuration. The Helmholtz resonance is very strong on the completed, strung harp.

ACKNOWLEDGEMENTS

The author would like to thank Dr Ian Firth of University of St Andrews, Fife, Scotland for his guidance and academic support. He would

Figure 5 - The development of the A4 mode

Figure 6 - The development of the A5 mode
also like to thank Mr. Victor Salvi, of the Salvi group, for the harp and the soundboxes, and not forgetting the financial support.

REFERENCES
ON BODY RESONANCE C3 AND VIOLIN CONSTRUCTION

Erik V. Jansson, Benedykt K. Niewczyk, and Lars Frydén
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Royal Institute of Technology (KTH)
Stockholm, Sweden
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Previously, high quality, soloist violins have been found to have a prominent resonance peak between 500 and 600 Hz. The authors look for answers to two questions related to this peak: is the soundpost placed on a nodal line in order not to dampen the resonance and is the resonance made prominent by the design of plates and of ribs? With a small weight fixed to different positions of the experimental violin it is shown that maximum sensitivity is found at the upper and lower end blocks and at the c-bouts. The result indicates that clamping the chinrest beside the lower block is acoustically favourable and that the resonance is affected by the neck. In answer to the two questions, the experiments indicate that the soundpost normally is close to but not on a nodal line and the peak level can be affected by the soundpost. For the C3 resonance the back plate seems to be more important than the top plate.

In an investigation of 25 high, soloist quality violins belonging to the Järnäker foundation of the Royal Swedish Academy of Music, it was found that a dominant resonance peak in the 500 to 600 Hz range was one of their typical features (Jansson 1994). This resonance peak is also found in less good violins but not dominant, cf. Jansson, Niewczyk (1994). The resonance, called C3 by us, has four antinodes, one at each c-bout and one at the upper edge in center, and one at the lower edge in center (Figure 1). The vibration patterns are the same in the top and in the back, and the vibrations of corresponding parts are in phase, i.e. the assembled violin body vibrates as a very thick free plate. The C3 resonance stands out clearly in assembled violins with optimum position of driving, i.e., at a c-bout center of the violin (Alonso Moral, Jansson 1982a). The C3 resonance has also been found in numerical experiments (finite element calculations with a doubly symmetrical violin body consisting of ribs and two similar top plates without f-holes or bass bar, c.f. (Isaksson, Saldner, Molin 1995)). In the frequency range 450 to 500 Hz of the assembled violin body another resonance, T1 can be found. Corresponding resonance peak is found prominent in most violins, also less good ones. The top and the back plates form a breathing motion in mode T1 (Figure 1).

The violin has been investigated for a long time by Dr. Carleen Hutchins and co-workers. Thereby the terminology B1+ was introduced for the resonance corresponding to our C3 and B1- for our T1 (Schelleng 1971, Marshall 1985, Knott 1987, Hutchins 1989, 1990, Bissinger 1995). The vibration distributions are somewhat differently interpreted by our group and by Hutchins with co-workers. In a previous investigation in Sweden, it was hypothetically suggested that the soundpost is placed on a nodal line of the C3 resonance (Saldner, Molin, Jansson 1996). In the present report, we are interested in which proper-

Figure 1 - Typical vibration distributions for the T1-mode (left) and the C3-mode (right) as seen from outside

Lines are equi-vibration lines, point-dashed lines are nodal lines. Plus and minus signs mark phase (from Alonso Moral, Jansson 1982a)
ties of a violin affect the C3 mode. In conclusion we can say that the investigation was made to find answers to two questions: Is the normal position of the soundpost on top of a C3 nodal line and how do the ribs, the top plate and the back plate affect the C3 resonance? The results have preliminarily been reported in the quarterly report of our department (Jansson, Niewczyk, Frydén 1995). The present paper is the second in a series of papers on the fundamental function of the violin. The first paper includes an extensive report on the soundpost action (Saldner, Molin, Jansson 1996). The project work on the third paper is in progress.

Typical Violin Properties

A well developed method to measure violin properties is to hang the violin in rubber bands (Hutchins, Fielding 1968). The method is simple to use, the measurements are well reproducible, and the hanging causes negligible losses. This method was used to determine the C3 frequency of 18 violins by hitting each violin with a small impulse hammer, PCB 86M37, at the lower end block, and by recording the vibrations at the same end block with a small accelerometer, PCB 309A (PCB Piezotronics, Inc., 3425 Walden Avenue, Depew NY 14043-9910, USA). Frequency responses were registered by a HP 3562A FFT-analyzer. Thereafter, the nodal lines were sought. With the C3-resonant frequency known, the violin was laid with the topside down on top of the four supports close to the C3-nodal lines. The violin was centered above a loudspeaker connected to a sinewave oscillator (Beldie 1969, Hutchins 1973). The back was sprinkled with particles (colored sawdust) and the loudspeaker tone frequency was adjusted to resonance (maximum jumping of particles at antinodes). The level of the tone was adjusted so that the saw dust collected along the nodal lines. The method is a development of the classical Chladni method. The use of the Chladni method for assembled violin has been reported previously (Miller 1992). For two of the three violins, the Miller 1988 and the Klotz model, the typical C3 patterns was found in the back plate. The patterns presented in Figure 1 resembles of the vibration patterns (with plotted lines of equal vibration amplitude) for driving at the bridge (Saldner, Molin, Jansson 1996, Figures 5 and 6). Thus we have good reasons for believing that our presented modal shapes are correctly interpreted.

Without soundpost, the typical C3 mode was easily and clearly found (for detailed measurements see Figures 5 and 6 in Saldner, Molin, Jansson 1996). The distance between nodal lines of the C3 mode were 48 to 67 mm at the bridge (measured along a straight line between the lower corners). The typical maximum and minimum distances between the bridge feet are 15 and 40 mm, respectively (distance between inner and outer edges). Thus, the measured nodal line positions were outside the bridge feet. In addition, it was found that the maximum differences of the C3 peak level were approximately 15 dB, but the bandwidth differences were smaller corresponding to -6 dB, i.e. the differences in peak level is not only set by differences in bandwidth. The influence of the soundpost on frequency was small, 1% frequency difference between with and without the soundpost. A single observation should be mentioned. The soundpost had remained unmoved in one violin for two years. When it was taken out and reset, the C3 level was 8 dB lower. The difference may be an effect of "playing-in."

With the soundpost inserted, the nodal line at the soundpost side still remained outside the nearby bridge feet, but was moved slightly closer (it was placed between 18 to 28 mm from the centerline). The other nodal line was much less clear - the saw dust tended to slide off the back plate on this side (the side opposite to the soundpost). The experiment was repeated for two complete violins of soloist quality. Again only the single nodal line was easily found, now at 21 and 28 mm from the centerline at the soundpost side. Assuming that the soundpost is centered behind its nearby bridge foot, means that it is somewhat closer to the center than at the nodal line. Thus it can be concluded that the nodal line is typical for the violin. It is not its being that is a quality mark, but how it can be used.

Figure 2 - Sketch of excitation with impulse hammer (H) in pendulum arrangement and of recording transducer with magnet (M) and electrical coil (C)
The hanging causes negligible losses. However, in real playing the holding of the violin causes extra losses. Measurements by hitting the bridge by the impulse hammer and recording the response by the accelerometer waxed at the other side of the bridge (c.f. Figure 2, but accelerometer in magnet position) showed that the losses increased between 50 and 100% (the peak level lowered 6 to 12 dB), although the frequency shift was small.

**Perturbations of a Violin Body - Mass Added**

First experiments were made with simple mass perturbations as a control that the C3 mode really is a C3 mode. The violin was laid horizontally (with the top up) on two supports, and a mass of 43 g (less than a shoulder rest but slightly more than the average chin rest) was placed at various positions on the top plate. The experiments showed maximum sensitivity at the antinodes (at vibration maxima) of the C3 mode (at the c-bouts and in the center of upper and lower ends of the body, Figure 3). Thereafter, mass perturbations along the ribs were investigated. Weights of 12 g were placed at the c-bouts (without soundpost). Thereby it was found the nodal lines moved towards the mass. If masses were added at both c-bouts, both nodal lines moved away from the center line. For a mass added at the center of the violin, the nodal lines of the lower half moved towards the center line. The frequency shifts were much smaller for the center loading than for the c-bout loading, 1% and 10%, respectively. The same experiment repeated for a complete good-quality violin gave similar results, but the differences in frequency shifts were smaller and the nodal line at the side opposite to the soundpost was influenced more. It can be concluded that the influence of mass is qualitatively as expected from the C3 vibration patterns, it is large at the c-bouts and it can perturb nodal lines. Thus we have further support for interpreting the mode as the shown C3 vibration pattern. The results also indicate that clamping the chin rest beside the lower end block is acoustically more favorable than on top of it and that the neck influences the C3 mode.

**Figure 3 - Sketch of areas most sensitive to mass loading: full line hatching - marking areas of maximum sensitivity; dashed line hatching - marking an area of slightly lower sensitivity**

**Perturbations of a Violin Body - Changes at the Ribs**

The experiments were continued with an experimental violin with soundpost. The violin was tested laying horizontally on two supports. The plates were successively cut loose (without reglueing loosened parts) from the ribs in steps (overhead film was inserted in the loosened joint as “grease”) without shift of the soundpost (the soundpost remained in the same position during all steps). It was found that c-bout areas were the most sensitive to the perturbations.

The experiments were repeated in more detail for the c-bout loosening steps, with and without neck. It was found that the influence of the perturbations were large. It was also found that the neck (ca 150 g) lowered the resonant frequency approximately 10% but increased the admittance level (approximately 5 dB measured at the lower end block). Thus, it was concluded again that the perturbations of the ribs along the c-bouts including the corner blocks make maximum influence.

The experiments were ended with perturbations of the c-bout shapes. The ribs were loosened between the four corner blocks, pressed firmly towards the center and reglued. The shift was less than 2 mm at maximum and no changes in the C3-properties were noted. Thereafter experiments were made with the ribs cut loose all the way from 50 mm above the upper corner blocks to 50 mm below the lower corner blocks and regluing the ribs as close together and as far apart perturbations was possible (maximum difference slightly larger than 5 mm, but still a smaller variation than found between different violins). Differences of resonant frequency up to 10% (from the lowest to the highest frequency) and peak level differences up to 5 dB (from the lowest to the highest level) were noted (higher frequency and level with the ribs close together). Nodal lines were little changed in the bridge soundpost region.

In conclusion, we can say that the C3 resonant frequency shifted as expected by c-bout (waist) perturbations, but the maximum level shift was only a third of what had been found in real violins (a maximum shift of 5 dB and not 15 dB as was found in Jansson (1994) and Jansson, Niewczyk (1994)). The nodal lines were little changed. The perturbations of the “waist” was within the limits of real violins.

**Perturbations of a Violin Body - Thinning of Plates**

An experimental violin was carefully selected for the plate thinning experiments. At the start, the top plate was slightly heavy, 83 g. The second and fifth free plate resonances were found at 188 and 369 Hz, respectively (The first was unfortunately not measured). For the back, the mass was 109 g and the first, second, and fifth resonant frequencies were 138, 213, and 394 Hz, respectively. Again, the measures were on the high side. For the body assembled, the C3 resonance was at 560 Hz and the T1...
resonance at 506 Hz, c.f. Figure 4 where all results of the measurements on the assembled body are summarized. The level of the C3 is always higher at the lower end block than the level of the T1 resonances and the level difference identifies the two resonances when their frequencies are not known. The measuring point, at lower end block, in the middle of the violin, or at the bridge showed little influence on resonant frequencies. The stringing also showed little influence both on resonant frequencies and peak levels. The plates were thinned in three steps. The violin properties were measured with our standard method, c.f. Figure 2. A typical input admittance curve is shown in Figure 4. (Similar measurements has been presented earlier by Beldie, see (Cremer 1981)).

First the back was thinned to a mass of 99 g, i.e. -9%. The resonant frequencies were lowered to 125, 194 and 356 Hz, i.e. only slightly more than the mass, and an average of -9%. The C3 and T1 of the assembled violin was 544 and 494 Hz, i.e. rather small shifts, -3% on the average and a third of the frequency shifts of the free plate. The influence on the peak levels at the bridge foot was moderate, -5 and +1 dB, respectively. The Chladni patterns showed the typical nodal lines of mode C3. Thereafter the top plate was taken off, the bassbar was removed and the top was thinned. The top was refitted with a new bassbar.

The mass was decreased to 80 g (-4%) and the frequencies of the free top plate were 100, 181, and 363 Hz (an average shift of -3%). The frequencies of the assembled violin were 556 and 487 Hz, respectively. The frequency and level shifts were even smaller than in the first step. The Chladni patterns remained the typical ones of mode C3.

Finally the back was much thinned. The mass was decreased to 75 g (-24%, a rather thin back plate) and the frequencies of the free back were reduced to 88, 131, and 256 Hz, i.e. 30%. The frequency of the C3 is now much lower (-19%) but the level is little lowered. The Chladni patterns of C3 were now hard to find. The level of the T1 peak is

Figure 4 - Frequencies measured and peak levels of the C3 (hatched lines and squares) and T1 (full lines and circles) peaks in the four steps of plate thinning. Frequencies (a), peak levels measured close to the bassbar bridge foot (b), at the lower end block(c) and at the bridge (d)

a) Frequency

b) Peak level at bridge foot

c) Peak level at lower block

d) Peak level at bridge
Figure 5 - Frequency responses of the experimental violin with level (0 dB corresponds to 2 s/kg) and phase (normal top plate, too thin back plate and soundpost in normal position)

![Frequency and Phase Responses](image)

considerably influenced but the frequency little (-1%). The frequency response shown in Figure 5 (soundpost in normal position) was the violin condition (with back much too thin), which was liked the best by the player. The C3 peak level could be shifted much (more than ±5 dB) by shifting the soundpost position. The result, T1 and C3 levels equal, implies that the player was appreciating another property than a maximal C3 input admittance peak, a property most probably related to the tone quality received by his left ear.

A remark on the levels, frequencies and nodal lines. The measured frequency shifts are large for mode C3. The measured levels for mode C3 and T1 are the highest at the bridge foot and the lowest at the bridge top. The levels are little to moderately shifted in the four steps. The experimental results indicate that mode C3 is mainly affected by the back plate, most clearly shown in the resonant frequency. The Chladni patterns of mode C3 seems to be rather stable and typical as long as the plate thickness is not too much off normal (as the very thin back plate).

Our experiments are made after similar lines as M. Schleske (1996). It is therefore interesting to compare our results with his. Our findings is that the resonant frequency shifts of the corpus modes are normally about a third of those of the free plates. This result is in fair agreement with that of M. Schleske (1996, Figure 6), i.e., our and his sets of results supports one another.

Conclusion

In earlier investigations we have found the level rather than frequencies at resonances to be a quality measure (Alonso Moral, Jansson 1982b). But as the frequency is rather simple to measure accurately, we find it fair to use a frequency shift as a sign of general shift of properties.

In the introduction we raised two questions were raised which we have tried to answer with this investigation.

- Is the normal position of the soundpost on top of a C3-nodal line?
- In the investigation it was found that the answer is no. The soundpost position is close to a nodal line but slightly closer to the center of the violin. This was also true for two high, soloist quality of violins. The function of the soundpost seems to be to give the best sounding tone by optimizing another parameter in addition to a high level of the C3 peak in the admittance curve. It should be mentioned that the nodal lines of C3 remains the typical ones as long as the plates are not too much off normal.
- How do the ribs, the back plate, and the top plate affect the C3 resonance?

The investigation shows that all three may affect the C3 but that some may be more important than others. The experiments show that the c-bouts (the waist) of the ribs is an area which is especially sensitive for the C3 mode, both resonant frequency and peak level. The resonant frequencies of C3 seems to be more sensitive to the back plate than to the top plate. In addition the large shift by the much detuned back plate indicates that proper tuning is important. Thinner plates do not favor a high C3 peak in the input admittance. Soundpost/no soundpost makes little difference for the soundpost in normal position. The C3 peak level may, however, be considerably affected by the soundpost. In one case it was accidentally found that a soundpost being left in the same position for a long time gave a considerably higher C3 level than after resetting. Is this the secret of "the playing in" of a new instrument?

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**Forthcoming in the CAS Journal**

- Field and Field- Down Home Lutherie Part II: A computer-based Technique for Measuring Integral Loudness
- Oliver Rodgers - Constructing a Nodal Line Seeker
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THE RECIPROCAL BOW AS A WORKSHOP TOOL

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Good violinists impose their own sound on violins. Are they the best people to evaluate them? Playing a violin "backwards" may be the most objective way to test it.

The obvious way to test a violin is to give it to a good violinist, then sit back and listen, just as, I suppose, the obvious way to test a race-car is to give it to a race-car driver and see how fast he can go. The trouble is that race-car drivers can drive fast in almost any car, and good violinists will make almost any violin sound good. It’s their job.

You could say that if you want to hear how a violin really sounds, a good violinist is the worst person to give it to. Good violinists impose their own sound on an instrument. They tone down harsh notes, smooth out unevenness, and like a chef using salad dressing, blend everything together with vibrato.

As often as not, good violinists are not really interested in testing a violin; they are interested in demonstrating how well they can play it. What you hear is not so much the sound of a particular instrument as the sound of violin-playing, which is a kind of magic trick they do, using the violin as a prop. Bad violinists are even less useful.

More seriously, when someone plays a violin, there is an unconscious tendency to adjust to the instrument. Slight changes in bow-speed, pressure, point-of-contact, etc., effectively normalize the violin toward the sound concept of the player. This makes it difficult to evaluate an instrument independently of a given player’s response to it.

Of course, there is a lot to be learned from talking to violinists. They tell you things you don’t hear while they are playing, such as how much or how little work it took to make an instrument sound good. And this is, after all, a major difference between good and bad instruments.

The trouble is, when players talk about sound, they often resort to highly personal, more or less improvised language. Such words as bright, dark, smooth, harsh, or muffled seem fairly workable (though a client once told me, without apology, that he didn’t use the word dark the way other people do). But what about the player who says an instrument sounds a little too dry, or too moist, or too goosy? The fact is, when violinists talk about sound, it’s sometimes hard to know what they are talking about.

The problem has partly to do with how we hear. Each note on a violin is a complex mixture of fundamental and partials, but it is not these we hear. We hear notes, or more likely, we hear music. Is it possible to listen more analytically, more objectively? Musicians, after all, train their ears to hear not just the music, but the individual notes that make up the chords on which the music is built.

Though many research tools have been developed for analyzing violin sound, it is often difficult to connect the results of such analysis with the experience of listening to a violin. Response curves, input admittances, and radiativity charts mean something to physicists, but tend to induce in violinmakers a kind of ‘fight-or-flight’ response. What is needed, perhaps, are tools that bridge the gap between analysis and perception.

The Reciprocal Bow

The reciprocal bow evolved over the past few years in Gabriel Weinreich’s laboratory at the University of Michigan (Weinreich, 1996). It is a direct descendant of his well-known technique for measuring what he calls the “radiativity” of a violin—basically, the amount of sound radiated by the instrument in response to a given bridge motion (Weinreich, 1983). To measure radiativity, a swept sine wave is played over a loudspeaker situated somewhere near the violin—all this in an anechoic chamber. The sympathetic response of the violin to the test signal causes the violin’s bridge to vibrate. These vibrations are picked up by a phono-cartridge resting on the bridge, and the resulting signal is sent to a computer for analysis.

It can be shown by the Reciprocity Principle (for a technical explanation, see ten Wolde 1973) that the signal picked up at the bridge reflects the violin’s modification of the test signal as though it were applied directly to the bridge and listened to by a microphone positioned in place of the loudspeaker. Effectively, the violin is played backward. It absorbs sound, rather than radiating it, and the bridge, normally the input, becomes the output. If we think of the violin as a complex filter, removing or enhancing portions of the string signal until what comes out is violin sound, it happens that, under carefully specified conditions, the filter works equally well in both directions.

Imagine a beam of white light entering a prism, where it is refracted then
emerges a rainbow. If this same rainbow were directed back into the prism, it would re-emerge on the first side as a beam of white light.

One of the elegant things about Weinreich’s method is a minimal disturbance to the violin, which can be tested while fully set-up, suffering only the very light contact of a phonograph needle.

Some years ago, the idea came up of using, instead of a sine wave, a signal emulating the string signal—namely, the force exerted on the bridge by the bowed string. (I shall use the term string signal hereafter to refer to a signal proportional to this force.) Would one not then hear, listening through the bridge, the sound of the violin as though it were being normally played?

For example, imagine putting the test violin on-stage in a concert hall. A loudspeaker is placed at the back of the hall. A string signal derived from a violinist playing, let’s say, the opening bars of Bach’s Chaconne on a solid-body violin, is played over the loudspeaker. The signal from a phono-cartridge resting on the violin’s bridge drives a pair of headphones. Would not a listener wearing the headphones hear just what they would hear if the headphones were connected to a microphone situated at the back of the hall and the violinist were playing Bach on-stage using the test violin?

Weinreich used a computer to synthesize the string signal for a slow three-octave chromatic scale and a fast passage in thirds (Weinreich, 1996). The speaker (JBL Studio Monitor 4408) and a jig designed to hold the violin and a variable reluctance phono-cartridge (Grado Elliptical ZCE + 1) were placed in an anechoic chamber (actually a quasi-anechoic chamber). A monitor speaker was situated outside the chamber. The results were encouraging; different violins indeed produced characteristically different sounds. Even more exciting was that certain characteristics, more or less hidden when the instrument was played normally, became suddenly obvious.

Figure 1 shows a mock-up of one of several possible configurations for the reciprocal bow. A laptop computer with a sound-card generates the string signal. This signal can easily be stored on any digital medium—portable CD players and DAT machines seem like good candidates for a workshop system. The test-signal is run through an amplifier (not shown) and fed to the speaker (whose position in figure 1 is only for visual clarity—in use one would place it wherever one might naturally stand while listening to the violin being played in the normal manner).

Figures 2 and 3 show the jig a little more clearly. It is built to hold the violin securely, to allow for the violin’s easy placement and removal, and to stay out of the way acoustically. The clamp holding the neck does not touch the strings, so they remain undamped. The phono cartridge is balanced on a plane-blade resting in a V-groove cut in a relatively massive metal arm. The whole assembly can be moved back and forth so as to line up with variously positioned bridges.

The phono-cartridge used here cost about $50. It is the bottom of the Grado line of pick-ups. I called Mr. Grado himself to learn more about them, and he assured me that, for my purposes, his cheapest cartridge would do as well as his most expensive.

The cartridge feeds a pre-amp. Because the phono pre-amp on a normal stereo receiver introduces an equalization curve (compensating a complementary curve used in the recording process), a pre-amp with a flat frequency response was built by Colin Holmes in Weinreich’s lab. This pre-amp feeds a power amplifier, which drives either a monitor or a pair of headphones, and/or a tape recorder.

To get a good signal-to-noise ratio, one needs to play the string signal rather loudly over the speaker. For this reason, a monitor situated in another room is needed for simultaneous listening, though well-insulated headphones might do.

A few technical points: a stereo phono-cartridge generates two distinct outputs, reflecting motion of the needle along two different axes. For our purposes, we have combined the two outputs into a single one, reflecting the horizontal, or side-to-side, motions of the bridge. This means that any vertical motion of the bridge is invisible to the system, and so any sound the violin radiates due to such motion will not be heard.

Figure 1 - Configuration of the reciprocal bow using a computer to generate the string signal
As each of the strings exerts force on the bridge in all three dimensions—longitudinally as well as horizontally and vertically—all three dimensions should be taken into account. It would be interesting to listen to a violin in each of these ways—making audible the contributions of each type of bridge movement. But arguably, the horizontal forces are most important, and these are what we have worked with so far.

I should point out a whole range of an instrument’s characteristics not accessible to the reciprocal bow, at least not in its present form. I refer to any effects the motion of the bridge has on the vibrating string itself. A wolf-note, for example, arises when the bridge, due to a strong body resonance, moves so vigorously that the normal Helmholtz motion of the string breaks down. Because the strings are never actually stopped when using the reciprocal bow, no wolf-note will be heard—though the note at the corresponding pitch will presumably be colored by the prominent resonance which normally results in a wolf-note.

We have, to date, tested violins with the strings undamped. The presence of four continually-open strings presents some anomalies. The open strings resonate sympathetically, as they normally do, with the difference that the fingers of the violinist usually remove at least one open string from the mixture. With the reciprocal bow, the ring of the open A, for example, can be heard even during a passage apparently played on the A-string. A further complication arises when the strings of the violin being tested are not precisely in tune with the “virtual strings” of the test-signal. Beats, corresponding to the mis-tuning, are heard whenever an open string is played. Of course the strings can easily be damped with a piece of cloth, but this creates an equally artificial lack of open-string resonance.

Figure 4 shows another configuration of the reciprocal bow. Here the string signal is produced by a violinist playing a solid-body violin fitted with a commercially-made electronic bridge (Zeta VR204). If the violinist wears headphones connected via the phono cartridge to the violin being tested, he is effectively playing that violin by remote control.

Alternatively, the violinist is allowed to hear only the neutral string signal from the solid-body violin. Thus no adjustments are made to compensate for the characteristics of any particular instrument. Test passages such as scales and short musical examples are recorded directly from the solid-body violin. This provides a library of test signals—more natural-sounding than those generated by computer, yet still repeatable with a consistency beyond the powers of even the best violinist.

Figure 3 - Close-up of reciprocal bow jig
Figure 4 - Configuration of reciprocal bow using a solid body violin to generate the string signal

This said, some portion of the unevenness can be attributed to the violin's directionality. Different frequencies are radiated in different directions, especially at frequencies above about 1000 Hz (Weinreich, 1993). The acoustics of a normal room tend to sum up the total radiated sound for the listener. The anechoic chamber is less generous, offering only sound traveling directly from violin to listener, absorbing the rest. So the unevenness heard in an anechoic chamber demonstrates to some extent the directional properties of the violin.

For this reason, along with the fact that anechoic chambers are not readily available to violinmakers, it makes sense to use the reciprocal bow in a normal listening environment. For violinmakers, it would be most useful, I believe, in the space normally used for testing instruments. Of course, this re-introduces one of the problems of testing violins - they sound different in different rooms (while sounding the same, in principle, in any anechoic chamber).

One is struck, when using computer generated string signals, by the absolute, unnatural steadiness of the tone. Violinists, even when not using vibrato, introduce countless tiny fluctuations of pitch and intensity. While these fluctuations are essential to what we think of as violin sound, they make trying to hear the precise qualities of an individual note as difficult as trying to see the separate threads of a silk cloth that is fluttering in the wind.

The dead-even signal created by the computer makes it far easier, in my experience, to identify individual overtones. The reciprocal bow is therefore useful as a kind of ear-training tool. One develops an aural sense of how each note is a layering of overtones, how these overtones shift from note to note, and perhaps how, in the end, what we hear is not so much the differences between notes as the overall spectrum from which each note is derived.

Summary
I think of the reciprocal bow as a tool less for analyzing violins than for listening to them in an analytical way. Because the violinist is replaced by a prerecorded or computer-generated string signal, the subjective response of the violinist to the instrument is avoided. The reciprocal bow has the advantage over mechanical bowing systems of being relatively inexpensive, relatively simple to build, easy to control, and flexible enough to be used for many different experiments. I believe it is useful to the violinmaker both in learning to hear in a more objective way, and as a practical aid in comparing and adjusting violins.

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EFFECT OF SOUND POST ADJUSTMENT

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Harmonic analyses were made of the glissando tones of a violin when the sound post was adjusted in two steps from a position which favored the higher strings to one which was judged to be slightly favoring the lower strings. In the final sound post position a prominent resonance appeared at about 930 Hz, the nodal pattern of which is given. A plausible explanation is offered for its appearance and its effect on the overall tone of the instrument.

One of the more mysterious steps in making the final adjustments on a violin is the final positioning of the top of the sound post. Old texts on violin making have described the process and its results in various ways. Heron Allen (1885) indicates that the exact position depends entirely on the quality and peculiarities of the violin. The post should be moved back if the tone is "rough and harsh," and moved out toward the f-hole if the "low notes are weakened, the high notes shrill." Sacconi (1972) suggests that the post be located 1-2 mm behind the bridge foot and 2-3 mm to the inside edge of the bridge foot, depending on the thickness of the belly. Broadhouse and Ole Bull (post-1885) indicate that moving the end of the post toward the center favors the lower strings and that, if the upper strings are "dull and heavy," it should be moved a little inside and farther back. Alton (1964) says that if the post is too tight, the tone is "tense and hard," if too "forward, the tone is loud and shrill, without quality," if too "far to the right, the E tone is loud and coarse and the G dull," if too "far to the center, the E tone will suffer and the G will be loud and strong."

For a technically minded person, there is not a clue in any of the above prescriptions to what is happening to the vibrating system to produce the acoustical changes which any player can hear, even when the sound post is moved only a very small distance.

The author, working with an experienced violin maker and restorer, Pam Anderson, has used an available computer based analysis system to study the changes in the details of the sound of a violin when the sound post location was changed on one available instrument. The result is a small step toward understanding what is being altered in the mechanical system of a violin when the sound post is moved.

Test Violin

The violin used for the test was a 50 year old European cottage industry production violin made on a Stradivarius pattern which had been disassembled and the free plates tuned. Final frequency values were, for the top, 88, 170, and 350 Hz for the free plate modes 1, 2, and 5, and for the back, 118, 178, and 345 Hz. In its final assembled condition the tone of the violin was quite acceptable for amateur use.

Apparatus and Analysis Systems Used

The system for displaying the frequency analysis of the tones of the violin was the CONQT system described by Miller (1993) and in recent papers by the author (Rodgers 1993, 1994). A digital record is made of the bowed sound of the violin while one glissando, starting with the open string, is made over a 1.5 to 2 octave span on each string. The CONQT analysis system processes the digital data to develop a harmonic analysis of each test run which displays the strength of the sound output at quarter tone intervals on a three dimensional plot in which the vertical dimension is sound intensity to a linear scale, one horizontal dimension is the logarithm of frequency so that octaves are of equal length, and the other dimension is time. The single curve at the top of each CONQT display shows the highest sound intensities achieved at each quarter tone pitch during the run and, thus, the most prominent natural frequencies, or modes, of the violin. The test run for each glissando is limited to 4 seconds duration.

The tests took place in an anechoic room with dimensions 6 x 6 x 9 feet. The player was standing in one corner of the room with the microphone on the near opposite corner close to the ceiling. The position of the violin was always the same with the neck pointing down toward the far opposite corner. The test lasted 4 seconds and was always done with one down bow stroke. The strings other than the one being played were damped by the player's fingers.

Sequence of Experiments

Three sets of four runs were made, each set of four consisting of a glissando run on each string. The initial set, Set A, was with the sound post positioned in line with the bridge foot and very close to the foot so that the top strings sounded "loud and bright," especially on the E string. A second set, Set B, was made with the top of the post moved straight back from the bridge 1.6 mm. The third set, Set C, was with the top of the post moved back half
way toward the bridge from the second position and 1.0 mm toward the center of the instrument. The bottom location of the soundpost was not changed.

The violin in the third position sounded better than in either of the others. To the player, the shifts did indeed change the sound in the ways described in the reference cited above—the high notes became less brilliant in the first move, and the lower notes became fuller and louder in the second.

The results of the twelve runs are shown in Figures 1 to 4. In each figure only the G string run is completely displayed showing the detailed harmonics components of each note of the glissando as well as the peak amplitude plot just above it. For the other three strings only the peak amplitude curve is presented for easier comparison. It should be noted that it is not humanly possible to play a violin so that the intensity of individual notes can be compared between runs. Rather, one must concentrate on the peak frequencies revealed in the back plots, which are the important natural frequencies of the vibrating system. The test method is consistent in revealing peak frequencies. It should be further noted that the scale of each plot is automatically adjusted by the software so that the maximum experimental value of sound intensity on the run is plotted at full scale.

Analysis and Further Experimental Verification

Only minor differences can be seen between the three sets of runs, shown for each string in Figures 1 to 4. The peak amplitude plots for the three sound post settings on each string have been precisely lined up with each other for easy comparison. Note how differently each string excites the instrument.

The first significant feature, as always in violins, is the strong first mode of the air system at about 277 Hz (circle 1), shown only on the G string plots of Figure 1. This is a breathing motion of the air through the f-holes, commonly called A0. It is not as prominent in this violin as in most. The second air mode, longitudinal air motion from end to end, is usually visible at about 440 Hz (circle 2). It is unusually strong in this violin. A third strong resonance, usually called the B1 resonance, shows up at about 500 Hz. It, likewise, is not prominent in this display, although it does show prominently in the nodal line test, to be described later. In this mode the primary motion is of the bassbar moving as a unit parallel to itself. These resonances have not been appreciably affected by the sound post moves, as can be seen by comparing the three sets of peaks in Figures 1 to 4.

The next significant modes on this violin occur in a band between 900 and 1300 Hz. In the Position A runs, there are peaks at 1047 (circle 4) and 1175 Hz (circle 6) with a peak at 932 Hz (circle 8) showing only on the E string run. In the Position B runs, the peak at 932 Hz is of equal prominence with others on the E string run. In the Position C runs, the peak at 932 Hz is now the prominent one on all strings (906 Hz (circle 3) on the G string) and the peak at 1175 Hz has disappeared.

There are no clear patterns in the peaks above the 1200 Hz even within the sets of runs for one sound post position.

What can it be about those three vibrating configurations that can make

Figure 1 - CONQT sound analysis presentation of the G string for all three sound post positions. The graphs above the CONQT plot are obtained from the selection of peak amplitudes in that plot at each frequency, and are aligned with the CONQT plot's frequency axis. Only the peak amplitudes graphs are shown for sound post positions A and B; the CONQT plot is for position C. For peaks 1, 2, 3, 4, 5, and 6: f = 277 Hz, 440 Hz, 906 Hz, 1047 Hz, 1077 Hz, and 1175 Hz, respectively.
them so sensitive to a sound post adjustment? Is it plausible to attribute to the replacement of two peaks at 1050 and 1175 Hz by one around 900 Hz a noticeable change on tone character of the violin? A first step in answering that question must be to devise a way to determine in detail the plate deformation patterns when the violin is vibrating at those three frequencies. A second step is to examine the harmonic content of the individual tones of the instrument to see how reinforcement patterns of those tones have been altered by the shifts in the location of the top of the post.

In order to do the first step mentioned above, the author has developed a variation of the system described by Schleske (1996a) in order to reveal the nodal lines of the vibrating patterns of the 930 Hz mode in the violin when the sound post had been adjusted to Position C.

**Nodal Line Detection System**

The system basically consists of a shaker which can be tuned to the frequencies of interest and can excite the instrument while it is held in a very soft suspension system, in this case hung by a system of rubber bands at the scroll and steadied by other rubber bands stretched from the lower C bouts points. The shaker driver is the same type used for free plate Chladni tests. It excited a coil-magnet device to which is fastened a very light plastic soda straw size tube which was located to touch the violin top at an antinode for the vibrating configuration being studied.

The detection system is a simple throat microphone which was held one or two millimeters away from the surface of the violin and moved over the surface of the plates. A small audio amplifier and a headphone is adequate to detect the lines of minimum sound. An x-y oscilloscope was also used to provide, when desired, rough measures of amplitude and of the phase relationship between the electrical signal to the shaker coil and the signal from the throat microphone. The test is done in the same anechoic space used for the glissando tests. It was possible to define the nodal lines quite accurately by the positions which gave minimum signal. It was also possible to define roughly the points of maximum amplitude by moving the microphone to the location of the loudest sound.

After the detection system had been used on several violins, it became obvious that the phase relationships between the two signals was providing some interesting information. If the vibrating configuration that was being investigated was effectively only a single mode of the mechanical system, the two signals were in phase and described a single straight line on the scope when excited at and below and above the resonance. When more than one vibrating configuration was close to resonance it described a figure which enclosed some area. If the vibrating configuration was primarily of the air system, such as the Helmholtz mode, the response was very strong only when the microphone was held directly over the f-hole and quite weak over any surface, and the two signals were 90 degrees out of phase and described a circle or ellipse on the scope.

Three clear air cavity modes were detected by strong responses over, and only over, the f-holes. The lowest one was the A0 mode as a doublet mode at 275 and 284 Hz. These were clearly separate modes, probably due to the two lobe nature of the cavity. The A1 mode, in which there is longitudinal air movement from end to end, with a pressure node toward the center of the cavity and with pressure antinodes at the ends is usually only weakly detected. Here an air signal could clearly be detected at the

**Figure 2** - CONQT sound analysis presentation for the D string for all three sound post positions, as in Figure 1. For peaks 2, 7, 8, 9, 10, 4, 5, and 6: f = 440 Hz, 453 Hz, 932 Hz, 960 Hz, 1209 Hz, 1047 Hz, 1077 Hz, and 1175 Hz, respectively.
lower corners of the f-holes at 466 Hz. A third longitudinal air cavity mode could be detected at 1175 Hz with strong responses over the central region of the f-holes. This location is where the central antinode lies, with two nodes positioned in the air column at roughly one quarter and three quarters of the length. To the author’s knowledge this expected air mode had not previously been detected.

The mode configuration tests were not run for 8-9 months after the original sound post tests were made because of the time needed to develop the system. The instrument had been in the air conditioned lab all during a spring, summer, and early fall. A retest of the CONQT glissando runs in the third sound post configuration just before the tests for nodal line location revealed that the modes were all present at almost the same frequencies.

It was possible to excite a desired mode after learning enough about the deflecting configuration to be able to place the probe of the shaker at an antinode location appropriate for the mode being studied. Figures 5 and 6 sketch the nodal line patterns of both the top and the back of interesting modes at 932 and 905 Hz. In the figures the view of both top and back is of someone looking from outside of the instrument. An X indicates the location of the excitation point. A small circle shows the approximate sound post position. An X inside a circle indicates the location of a maximum microphone response.

The nodal line pattern of the 932 Hz mode of the Position C case, Figure 5, suggests a reason why that mode should be sensitive to the position of the top of the sound post. The major moving mass in this frequency range is the bassbar, which is ready to rotate more or less about its mid point as a rigid body so that the upper bout end of the bassbar deflects into the corpus when the lower end deflects outward. In the 932 Hz mode the bassbar is vibrating vigorously. Most of the left lower bout of the top is strongly vibrating in phase with the lower portion of the bassbar, as is, also, the upper right bout. The left upper bout is vibrating in phase with the upper part of the bassbar. The nodal line in the lower right bout passes very close to the sound post position. Thus about three quarters of the top area is vibrating in phase.

Why, then, should the 932 Hz mode become prominent when the post was moved toward the center by 1 mm from the positions of cases A and B? The position of the post probably serves to define the location of the lower nodal line in the top. The shift could conceivably cause a major reorienting of the mode so that there is appreciable motion in the right lower bout in phase with the left lower bout because the post is quite rigid and the post location on the back is not moving appreciably. The result is an unsymmetrical deflection pattern in the top in which three quarters of its area is moving in phase. This insures that the mode is a good radiator of sound.

The configuration of the vibrating mode at 905 Hz is included here as Figure 7 to illustrate how a very small change in exciting frequency will cause a strong change in vibrating configuration while still retaining the basic rocking bassbar characteristic. Note that the areas of positive deflection and minus (out of phase) deflection in the top just about balance, so one would expect little sound to be emitted from the top at this frequency, as is the case.

The B1 mode at 533 Hz was producer of sound. It was found that it could be excited by placing the exciting probe directly over the bass bar at any position along its length. The A1 mode, at 466 Hz could not be detected when the ex-
citing probe was close to the middle of the instrument. It was detected easily when the exciting probe was positioned anywhere in the middle of either the upper or the lower bout, where one expects to find substantial plate deflections from the cavity pressure variations. Thus, the important Hutchins delta between the A1 and the B1 frequencies in this instrument is about 60 Hz, indicating an instrument of a solo type with good projection (Hutchins 1989).

The plate vibrating configuration of the air mode at 1175 Hz is shown in Figure 7. The back plate is vibrating in the expected configuration with nodal lines more or less at the quarter points, responding to the air pressure changes in the corpus cavity which are maximum in the C bout region and at the upper and lower ends. The nodal lines in the top do not indicate a similar conformity to the internal pressure variations. The rigid bassbar and the sound post prevent similar local plate deformations in the top. As expected, there were strong signals when the probe was positioned in the air stream coming from the f-holes, the high velocities resulting from the peak air pressure variations right at the f-hole location.

The strong peak at 440 - 463 Hz with strong signals the full length of the f-holes was a surprise, since its deflection characteristics are not either those of A1 or B1. Based on experiments with other violins of similar design one can suspect that a back resonance which produces a pumping action may be the cause. The resonance is usually found at 500-600 Hz but it is known that the edge areas of this violin are unusually thin.

**Study of the Changes in Tonal Reinforcements**

Some time was spent at the computer with the CONQT runs reviewing the harmonic content of individual tones hunting for obvious changes in the ways various notes were reinforced by the changes in the harmonics between the various runs. The obvious reinforcement is the 930 Hz tone acting as a third harmonic of the low e flat on the D string, a note quite often thin sounding on ordinary violins. No other reinforcements were obvious.

**Conclusions and Recommendations for Further Work**

This report must be anecdotal for it reports some details of how sound post adjustment affected one particular violin. No generalizations can be made. However, further investigations of the configurations of vibrating modes on several violins suggest that the vibrating configuration described above at the 932 Hz mode is often found. It is logical to suppose that the rocking motions of the bassbar will dominate the modes and motions in the 900 Hz range. Whether one of them is often a strong radiating component in a good violin is a question that must wait for much more data of the type suggested by this investigation.

It is not too difficult for a violin maker who already has a shaker table for Chladni tests to set up a system on the workbench similar to the one described above for probing the details of vibrating modes of the violin corpus. However, one must have a way to identify from sound measurements which of the bewildering array of mechanical modes are producing appreciable sound in the violin under study and are worth investigating. A sound analysis system of roughly the complexity of that used by the author or the radiativity system of G. Weinreich (1993) is required. The author would like to talk with anyone interested in continuing the present work.

![Figure 4](image_url) - CONQT sound analysis presentation for the E string for all three sound post positions, as in Figure 1. For peaks 8, 9, 4, 5, and 6: f = 932 Hz, 960 Hz, 1047 Hz, 1077 Hz, and 1175 Hz, respectively.
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ACOUSTIC CONDITIONS FOR A SOLOIST’S CONCERT VIOLIN

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The author formulates and discusses six conditions, which must be fulfilled in order for a new violin to be suitable as a soloist’s concert instrument. These conditions are: projection, dynamic range, tone quality, articulation, vibrato, and ease of playing. Where possible a link is made to the physics of the violin and/or to the practice of the maker.

In order that a newly made violin can fulfill the requirements of a concert soloist, that instrument should have a number of properties which go quite a bit beyond the often heard property of a “nice sweet singing tone.” It goes without saying that such a tone is also one of the conditions, but during the last four decades most of the work on violin acoustics has focused on just this one single point. In practice however at least six conditions must be fulfilled before a real concert soloist will consider buying a newly made instrument and use it in the concert hall.

After a short introduction about the preoccupation in the recent past with mainly one aspect of violin acoustics, i.e., the spectral composition of the typical violin sound, we will, one by one, list the six main conditions for the achievement of our goal. Each of these conditions will be considered in some detail, and where possible those measures will be indicated which can be taken by the luthier in order to fulfill these conditions.

It goes without saying that the author is not capable of giving detailed causal relationships between all actions by the luthier and their consequences on the behavior of the instrument. Most aspects of this behavior are determined simultaneously by several factors. In some places the author may dare to offer guesses as to what actions might mainly determine certain results. However, he himself is—and the reader should be—fully aware that much of the craft of violin making remains an intuitive art which, besides requiring knowledge, is also based on feeling and experience.

Some Historical Observations

The situation regarding the acoustics of the violin until the third decade of this century can hardly be better described than by a quotation from an article by the well-known and acoustically successful Czech maker P. Spidlen (1980) in telling about the generation of makers born near the end of the last century:

The generally held belief was that tone quality would develop after a certain amount of time had passed and after the instrument had been well played in. The truth is that they didn’t know enough about the acoustics of instrument construction, knowledge that is absolutely necessary if one hopes to produce instruments that sound well.

It is only too natural that starting from this position, and with the introduction of early electronic equipment capable of analyzing the spectral composition of violin sounds, the first pioneers in this field concentrated mainly on just this. This history is clearly surveyed in an excellent article from the year 1983 “A History of Violin Research,” by one of the most prominent of these rather early pioneers, C. Hutchins. It is interesting to note that the amount of space devoted to the importance of the choice of wood for the acoustical properties of the instrument is, in line with the limited amount of research into that problem until that date, quite small indeed.

Here is a quotation from another prominent early pioneer, H. Meinel (1960): “The material of the resonance wood plays a definite role in the formation of the acoustic properties. But the importance of this effect must not be overrated.” (Italics by H.G.M.). Unintentional deviations in the hand-making of commercial violins, in particular an inaccuracy in maintaining the thickness, overshadows the effect of the wood quality.” As previously shown, (H. Meyer 1995), and as will again be pointed out below in detail, the present author certainly does not agree.

Projection

The first and foremost condition for a soloist’s concert violin is that it should be able to project its sound into the farthest corner of the concert hall. Projection in the first place depends on the total sound output in the so-called far field (i.e. at distances large as compared to the dimensions of the violin). Secondly, projection also depends on the spectral distribution of the total sound power. In fact, as the human ear’s sensitivity has a rather pronounced maximum between 3 and 4 kHz, (Olson 1967 p. 400), the amount of power in this spectral region is of considerable importance for an instrument’s capacity to project, (Schnur 1989, J. Meyer 1982).

While the relative spectral distribution does depend highly on the graduation of the plates and on the details of the setup, especially the bridge and the bass
bar. (Atwood, Croen 1996) the absolute power in the critical spectral region is also greatly dependent on the total sound output, i.e., a low acoustical impedance which in turn depends greatly on the right choice of wood, (H. Meyer 1995). The mass density and the sound velocities in the two main directions are especially of importance here.

While this article was in review, the author received a preprint of an article by Prof. G. Weinreich (1997) of the University of Michigan with the title "Directional Tone Color." He states there as a guess that the power to project might be connected with the property he mentions in the title, i.e., that from a good violin nearly every tone seems to reach the listener from a different direction. That hypothesis is in no way contradicting our assertion that projection is better the lower the impedance within the possibilities given by holding on to a suitable tuning scheme for the plates and using spruce (picea) and maple (acer) as materials (see also H. Meyer (1995)). To the contrary, it is the present author's conjecture that low values of the acoustical impedance (H. Meyer 1995) lead to relatively large deformations so that more plate modes will audibly contribute to the emitted sound. This in turn will probably also increase the directional variability.

In connection with what we said above under "some historical observations," it is interesting to note that Dünnwald (1991), in his article "Deduction of Objective Quality Parameters of Old and New Violins," discusses the concept of loudness, which is closely related to the ability to project. However, Dünnwald does not use loudness in the absolute sense. Instead, he uses it exclusively to compare loudness levels in the various spectral regions relative to each other. This corroborates our assertion made in the previous paragraph concerning the emphasis on the spectral distribution in previous work.

Dynamic Range

To enable the artist to fully express the emotional content of the music, his instrument should possess a very large difference in musical power between the loudest obtainable **fff** and the softest, barely audible **ppp**. Again, this means that the maximum output of the violin should be very high, whilst the pianissimo passages should come out easily and smoothly and, at the same time, contain a sufficient amount of harmonics in the 3-to-4 kHz region. The faculty of the violin to produce the **ppp** passage easily and smoothly depends primarily on the input impedance of the bow force, which should be small. This in turn depends on the properties of the bridge and on the input impedance of the violin body to the forces exerted by the bridge feet during bowing. This impedance is again largely determined by the choice of the wood (H. Meyer 1995), i.e., by its mass density and by its velocities of sound.

Tone Quality

The main determining factor of tone quality, the various aspects of which will be mentioned below, is provided in the first place by the amount of higher harmonics. The term "amount" must be interpreted here in two ways. On the one hand we must think of (a), the relative output in harmonics belonging to any single tone, i.e., the power contained in all harmonics as compared to the power in the fundamental. On the other hand, (b), the absolute amount of acoustical power contained in the harmonics is of great importance. This last is due to the fact that the human ear, being a highly sensitive and also quite non-linear detector is able to construct the fundamental (if lower than 2000 Hz) from the harmonics alone even if the fundamental were objectively absent, (Gulick, Lawrence, Gescheider, and Frisina 1989, p. 255). A third important property for tone quality is (c), the distribution of power among the frequencies within the total harmonic spectrum.

In accordance with what we have mentioned under historical observations, it might be said that this last consideration (c) has so far gained most of the attention. Although the present author in no way denies its importance, a certain perspective is called for. This is due to the well known empirical fact that, within reasonable limits, a great soloist can elicit "her/his" tone from any reasonably good violin, (Pickering 1993). This empirical observation was put onto a firm basis by Lottermoser (1968). He measured the distribution of the loudness in sones in the various frequency regions, each having the width of a musical third, of the same violins (the "Donaldson" del Gesu of 1739 and the "d'Evigle" del Gesu of 1735), when played on the one hand by Yehudi Menuhin and on the other hand by Ruggero Ricci. The differences are astonishingly large, in some frequency regions up to 10 sones, which on a logarithmic scale amounts to 30 phons in experienced loudness.

A direct consequence of the strength (in absolute terms) with which the harmonics are present is the ease with which flagollete (string harmonic) tones are produced. It goes without saying that any soloist wants to be able to play Paganini caprices—which are difficult enough in any case, and which contain considerable passages consisting of harmonics alone—with as much ease and conviction as possible. The lower the impedance of the violin body, i.e., the lower the ratio of the mass density divided by the geometrical average of the sound velocities in the two principal directions for the two plates, the higher will be the content of harmonics (see H. Meyer (1995) for a detailed explanation). In fact, such a lower impedance will allow the nonlinear force from the bow to excite more harmonics.

Another aspect of tone is formed by the auditive experience obtained from playing double stops. It was Tartini who reported in 1754 that a third tone is clearly heard when a double stop is played on a really good violin. This effect, which in musicology is called the Tartini tone and in physics is called a combination tone, occurs only when the sound level of the two primary tones is strong enough. In fact, although the violin exclusive of the strings is acoustically a linear system (Marshall 1985), it is the ear itself which is a highly non-linear organ which forms the combination
tones. As the sound level of these Tartini tones is about 40 dB weaker than the primary tones (Von Bekesy 1960), it goes without saying that these primaries must be strong enough in the first place.

As mentioned above, given the same force on the bow and assuming the same bridge, the primaries become stronger as the impedance of the violin body decreases. It should be noted here that the present author has the hunch, not more than that and certainly no proof, that with the low acoustical-impedance wood he uses, the amplitudes of vibrations of the top and back may be large enough to yield audible combination tones in the objective sense. His clients do comment in any case that the combination tones are more audible than they are accustomed to from instruments with less projecting power.

Prof. Dr. H. P. Wit of Groningen University has recently analyzed in his laboratory one (so far only one) double stop played by the author on one of his recently made violins. Preliminary results seem to indicate that a difference tone on a sound level of only about 30 dB below that of the primaries is clearly present.

The last aspect of tone quality to be discussed here is the so-called "evenness over the strings." It is the author's belief that the details of the graduation of top and back, which many makers nowadays control by plate tuning, are of prime importance here. Secondly the choice of strings can be very helpful indeed.

Articulation

A fourth important attribute which a solo-concert instrument must possess is the ability to articulate clearly. It is a fact that brilliant and impressive solo concertos contain rapid passages in abundance. The sensation for the listener is more impressive the more he is able to hear the various tones which rapidly follow each other as individual notes. As shown in a pioneering article by Rohloff (1964), the faculty of an instrument to articulate is highly dependent on the presence of partials in sufficient amounts in the region above 4000 Hz. That author compares correctly the violin with the human voice, where clearly articulated speech is dependent on the presence of sufficiently audible consonants.

From the point of view of physics, Rohloff's result can probably be explained. The vibrations of a violin while emitting a certain tone can be considered, according to one of the most fundamental theorems of physics, as being the sum of the vibrations of a number of normal modes, the frequencies of which are the fundamental and/or the harmonic partials of that tone. Now, according to another fundamental theorem of physics, any of these normal modes of vibration needs as much time to be excited into its fully vibrating state as it needs time to come to a stand-still after the excitation has been stopped. This so-called damping time \( \tau \) is directly related to the so-called logarithmic decrement \( \delta \) via the relation \( \delta = 1/\tau f \), where \( f \) is the frequency of each of these normal modes which constitute the emitted tone (Schelleng 1982). Although there is probably still some controversy as to the exact frequency dependence of the damping, it is at best constant with rising frequency, or it may rise somewhat. The order of magnitude indications we give in the following pertain to the low frequency region. For each normal mode, \( \delta \) is composed of at least three components: the damping due to the internal friction in the wood (\( \delta \approx .025 \)), the damping due to the loss of energy caused by the emitted sound (\( \delta \approx .022 \)) (Schelleng 1968), and the damping due to the varnish (\( \delta \approx .026 \)) (Schelleng 1968).

At frequencies between 2000 and 6000 Hz, the damping due to the internal friction appears to rise quite a bit (Schelleng 1985), whilst there is probably still a controversy as to the frequency dependency of the damping caused by the varnish. However that may be, we can safely assume a total decrement above 4000 Hz of .088 which at this frequency would lead to an excitation time of about 3 ms. It should be noted that if the ear were not so highly non-linear that it can construct the main frequency from the partials, the rise time of fundamentals in the d-string range (300 Hz) would be of the order of 50 ms, not enough to make a quick passage of 1/32nd notes at a beat rate of say 80 per minute (i.e., 20 ms per note) clearly audible. It is interesting to note that the properties of the ear are such that an interval of about 2 ms between two different sounds are no longer judged as being simultaneous (Gulick, Lawrence, Gescheider and Frisina 1989, p. 242).

Response to Vibrato

The expressiveness of a virtuoso's violin tone, and thus the faculty of the soloist-instrument combination to catch the ear of the listener and to hold it, depends greatly on the vibrato effect, i.e., on the amount of change in frequency and volume that a certain amplitude of displacement of the finger brings about. Extensive studies have been performed to obtain an insight into this effect (Fletcher, Sanders 1967, J. Meyer 1992). What is important in our context is that the vibrato effect is more pronounced the more "spiky" the response curve is, especially in the 1000 to 3000 Hz region (Mcltyre, Woodhouse 1978 p. 162). In its turn the "spikiness" of this curve is greatly determined by a low internal acoustical damping, i.e., a small logarithmic decrement characterizing the damping of the wood used in construction of the violin improves "spikiness" and hence vibrato. It should be noted that a strong vibrato effect gives the player the impression of a greater tone volume, quite important for expressive playing. The listener, receiving mainly sound reflected from the walls, gets the subjective impression of a fuller tone (J. Meyer 1992).

Ease of Playing

In the foregoing we have enumerated the requirements for a concert violin in so far as they are audible, mainly to the listener. Now we have to consider two last, but by no means less important points, the ease with which the player can produce the audible sounds and the sound the player himself experiences through his ears as well as due to bodily contact with the instrument.

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Summary

It may be said that the above enumerated conditions which have to be fulfilled by a violin in order to qualify as a soloist’s concert instrument are at least necessary but by no means sufficient. The final choice is the soloist’s with his personal preferences, sensitivities and idiosyncrasies. ■ CASJ
The authors describe a useful method for making quantitative measurements of the loudness of bowed stringed instruments using only simple equipment. Using repeated measurements they conservatively estimate that the reproducibility of the method is better than 10%. They report interesting subjective perceptions of loudness in the course of the work. They find that subjective loudness perception is oftentimes a non-linear function of the pressure amplitude incident upon the ear, and this finding is in accordance with known aspects of the physiology of human hearing. The perceived ability of a stringed instrument to project sound may involve the non-linearity of the bearing function in addition to the physics of the projecting instrument.

One of us (CWF) is a luthier, and in the course of her work during the past several years she produced Cello 17 (numbering sequential over her total oeuvre) finished in 1991 and Cello 24 finished in 1995. As is her practice, she recruited as many people as possible to play both instruments and to express opinions about their quality, and in particular she attempted to include in this group of players local professional string players, who might be expected to have a relatively wide experience with stringed instruments. One such professional after playing the instruments expressed the opinion that he thought that Cello 17 would project better, but he could not say with certainty because the test was taking place in a small room.

The question of the projection abilities of instruments is one that interests us but one we really did not understand, so we considered the question of how we might measure the projection abilities of our two cellos. We do not have easy access to the large hall conventionally used for making such measurements.

Our first experiment was primitive and qualitative. Our home/workshop/laboratory is a two-story house, the bottom half of which consists of two rooms of about equal size (ca. 500 sq. ft.) separated by a short hall containing a door. The experiment consisted of CWF (a cello player) playing orchestral passages alternately on the two cellos in one room with FHF listening in the other room with the door closed. CWF made every effort to play the instruments as much alike as possible, and at no time did FHF know which instrument was being played.

The experiment was quite successful in that the amplitude of the sound in the second room from Cello 17 was invariably distinctly greater than that of the sound from Cello 24, and as a consequence the definition of the musical passages was much clearer on Cello 17. Cello 17 was projecting down the hall and through the door more powerfully than Cello 24, and the tentative opinion expressed by the professional based on his playing was correct.

We then started thinking about how such measurements could be made in a more convenient and, especially, in a more quantitative way. Many years ago Saunders (1966) devised a simple procedure for making violin loudness measurements, which involved bowing by hand a series of notes on the instrument under investigation as loudly as possible and electrically recording the sound produced. This produced what Saunders called a loudness (output) curve. We investigated the question as to whether we could do something similar using only the quite simple electrical equipment that we had in the house and shop. To summarize, we developed a similar technique which produced results which we find of interest and which may have some practical value.

**Experimental**

Our experimental set up consisted of a microphone providing the input into an amplifier, the output of which was measured with an analog volt-ohm-meter. The microphone was a Realistic (Radio Shack) Stereo Electret Microphone System, Cat. No. 33-919A, Fre-
quency response = 30 – 15,000 Hz, Sensitivity = -72 dB, 0 dB = 1v/mbar at 1 kHz. The amplifier was a Realistic (Radio Shack) MPA-40 35 Watt Public Address Amplifier, Frequency response 70 - 20,000 Hz, and the volt-ohm-ammeter was a Micronta (Radio Shack) 43-Range Multitester. This obviously is not high technology equipment. As we stated in the title of this paper, this is a down-home study for which this inexpensive, down-home equipment was all that was available. However, we should further state at this time that the focus of the experiments is the comparison of different instruments always using the same equipment and the same technique, and for this purpose our equipment seemed to be adequate.

We had no way of determining the degree of linearity between input and output of our equipment, and we are forced to assume that it is adequate. The microphone was operated in its unidirectional mode. The amplifier was the one CWF used for the plate tuning procedure which is a routine part of her instrument production operation, and for the present measurements it was always operated at maximum gain. One of its outputs provides AC voltages in the range 0 - 70 v. This voltage was measured by the volt-ohm-ammeter set to read AC volts. The range of output voltages produced was 0-35 v. To read these the range scale of the meter was set to 0-10 v or 0-50 v, as appropriate.

We played the instrument to be tested at a fixed distance of 8 feet from the microphone and manually recorded the AC voltage generated by the sound. To be practical, with our setup the measurement requires two people: one to play the instrument and the other to read the voltmeter and manually to record its value. FHJ played the under-the-chin instruments; CWF played the between-the-knees instruments. The setup was such that the player could not see the meter or the figures being recorded, and our practice was to have no communication between the participants over the course of the complete measurement on an instrument. We played chromatic scales for three octaves starting at the lowest note of the instrument.

We started with the practice of playing and recording both the open string note and the corresponding stopped notes for the three notes of the scale for which this is possible (D, A, E for violin; G, D, A for cello and viola). We later decided that this added little to the experiment, but it also does not hurt, so the results reported here include this practice.

In the Saunders measurements referred to above, the bowing technique used was to play the notes as loudly as possible, which presumably involved a fairly rapid bow stroke. Note that Saunders also used a smooth, 4 second duration bow stroke to obtain what he refers to as response curves, which differ significantly from loudness curves. We were not sure that our simple equipment would respond quickly enough accurately to register the burst of sound produced by a rapid bow stroke, so we adopted the procedure of bowing smoothly from frog to tip.

The time required for a bow stroke was perhaps 3-4 seconds, and the player was at pains to attempt to bow as smoothly and reproducibly as possible with the goal that the output voltmeter would achieve and maintain a sensibly constant value. This was oftentimes not the case, and then considerable subjectiveness entered into the decision as to what value should be recorded. However, each of us when serving as reader/recorder attempted to standardize our subjectiveness. This variability in the output across the stroke of the bow is of interest in itself, as shall be mentioned later.

To reduce the effect of the random error in these measurements we executed and recorded the results of three bow strokes on each note, and these were averaged. Obviously executing more bow strokes per note would increase the precision of the average, but it would equally obviously increase the effort and time needed for the measurements. The voltages recorded by the reader/recorder were transferred manually into the spreadsheet of a PC computer for storage and data manipulation.

We should emphasize here that these measurements are surely very sensitive to the identities of the equipment, the room in which they occur, and, especially, the person bowing the notes. Pickering (1988) has treated this matter in some detail. We can say simply that Itzhak Perlman would produce absolute voltages different from those of FHJ. Therefore, comparisons of different instruments have a chance of being meaningful only when using the same equipment and personnel.

Results

a. Objective Results

The work that we have done on this project divides itself into two parts and periods. The first part was undertaken in September and October of 1995, initially quite tentatively for our own enlightenment, but then more seriously as the results proved to be of interest. Unfortunately, in the middle of October the work was interrupted by a long-scheduled remodeling of the room which was serving as our laboratory, and it was not possible to resume until March, 1996. In this latter phase of the work we concentrated on the matter of establishing the degree of reproducibility and reliability of these down-home measurements, and we shall present these results first even though they are out of chronological order.

As we said above, the initial impetus of this work was to investigate the projection ability of bowed stringed instruments, and this remains a major experimental focus. However, as a result of the work we have formed the opinion that whatever else may be involved in projection ability, it certainly includes loudness, and we concluded that we were really involved with loudness measurements.

To extract meaningful measures of the loudness of the instruments studied, we used the spreadsheet program of the computer to average the three voltages measured at each different note in the three-octave chromatic scale (forty notes including the open string/stopped string duplicates), and then these forty
average voltages were summed to obtain a loudness figure of merit (the Voltage Sum). The loudness figure of merit is thus based on 40 x 3 = 120 individual measurements, and we hoped that this rather large number of measurements would to a considerable degree compensate for the errors which are obviously inherent in the individual measurements.

We investigated the short-term reproducibility of our loudness measurements by making eight three-octave measurements over a relatively short period of time, namely, between 9 March 1996 and 15 March 1996. The instrument used was Violin 16, a mezzo violin (using the terminology of the Hutchins violin octet) constructed by CWF in 1990. It is a superb instrument which has been the favorite of FHF ever since it first appeared.

We give as Table 1 the results obtained in R38, which is an arbitrarily selected one of these eight runs. The designation G', A', etc. in the leftmost column represents G sharp, A sharp, etc. Do, Ao, and Eo represent the open D, A, and E strings. The voltages produced by the three individual bow strokes are given in columns 2 - 4, and their average in column 5. Column 6 is the standard deviation for the three individual voltages, and column 7 is the percent standard deviation for these.

At the bottom of the table is given the sum over all the notes of the average voltages, the Voltage Sum, which we take as the loudness figure of merit for the instrument. Similarly we give the average of the standard deviations over all the notes and the average of the percent standard deviation over all the notes. This latter quantity is a measure of the overall dispersion of the voltage measurements in the experiment. While for some notes there is a wide fluctuation in the voltage measurements obtained, the value of 12.1% for the average percent standard deviation is rather better than we initially feared might be the case.

We have calculated statistics for the 320 note measurements involved in all of the eight runs (960 individual meas-

<table>
<thead>
<tr>
<th>NOTE</th>
<th>VOLTS (AC)</th>
<th>STD. DEV.</th>
<th>% STD. DEV.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V(1)</td>
<td>V(2)</td>
<td>V(3)</td>
</tr>
<tr>
<td>G</td>
<td>11</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>G'</td>
<td>8</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>A</td>
<td>8</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>A'</td>
<td>9</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
<td>26</td>
<td>23</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>C'</td>
<td>7</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>D</td>
<td>11</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>Do</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>D'</td>
<td>7</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>F</td>
<td>13</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>F'</td>
<td>10</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>G</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>G'</td>
<td>7</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>A</td>
<td>10</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Ao</td>
<td>10</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>A'</td>
<td>8</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>30</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>C</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>C'</td>
<td>12</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>D'</td>
<td>13</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>E</td>
<td>7</td>
<td>8</td>
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<tr>
<td>Eo</td>
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<td>11</td>
</tr>
<tr>
<td>F</td>
<td>13</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>F'</td>
<td>15</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>G</td>
<td>15</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>G'</td>
<td>19</td>
<td>26</td>
<td>25</td>
</tr>
<tr>
<td>A</td>
<td>8</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>A'</td>
<td>15</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>C</td>
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</tr>
<tr>
<td>C'</td>
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<tr>
<td>D</td>
<td>8</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>D'</td>
<td>14</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>E</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>F</td>
<td>5</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>F'</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>G</td>
<td>10</td>
<td>12</td>
<td>9</td>
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</table>

Table 1 - Run 38 for Violin 16 (mezzo)

<table>
<thead>
<tr>
<th>NOTE</th>
<th>VOLTS (AC)</th>
<th>STD. DEV.</th>
<th>% STD. DEV.</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLTAGE SUM</td>
<td>443.0</td>
<td>1.5</td>
<td>12.1</td>
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<tr>
<td>A.V. STD. DEV.</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.V. % STD. DEV.</td>
<td>12.1</td>
<td></td>
<td></td>
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Table 2 - Voltage Sums (VS) for Violin 16 (mezzo)

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Chromatic</th>
<th>Diatonic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VS</td>
<td>VS/#Notes</td>
</tr>
<tr>
<td>R26</td>
<td>423.0</td>
<td>10.58</td>
</tr>
<tr>
<td>R33</td>
<td>473.0</td>
<td>11.83</td>
</tr>
<tr>
<td>R34</td>
<td>433.0</td>
<td>10.83</td>
</tr>
<tr>
<td>R35</td>
<td>439.0</td>
<td>10.98</td>
</tr>
<tr>
<td>R36</td>
<td>517.0</td>
<td>12.93</td>
</tr>
<tr>
<td>R38</td>
<td>443.0</td>
<td>11.07</td>
</tr>
<tr>
<td>R40</td>
<td>424.0</td>
<td>10.60</td>
</tr>
<tr>
<td>R41</td>
<td>470.3</td>
<td>11.76</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>AVERAGES</th>
<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>452.8</td>
<td>11.32</td>
<td>250.5</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>STD. DEVIATIONS</th>
<th>% STD. DEVIATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30.1</td>
<td>6.6</td>
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<td></td>
<td>0.80</td>
<td>6.6</td>
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<td></td>
<td>23.3</td>
<td>9.3</td>
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<tr>
<td></td>
<td>1.06</td>
<td>9.32</td>
</tr>
</tbody>
</table>

The average percent standard deviation using 320 sets of three bow strokes is 14.2%, and we conclude that crude though our procedure appears on the surface, it produces results that have a sufficient degree of consistency to make it potentially usable.

Each of the eight measurements in this series yielded an Voltage Sum, and these are given in Table 2. While the experiments involved making measurements on three-octave chromatic scales, the spreadsheet program enables us to extract Voltage Sums for the diatonic scales embedded in the chromatic scales, and values for Voltage Sum (Diatonic) are included in Table 2. The absolute values are, of course, different from the Voltage Sum (Chromatic) values, and to permit a comparison the Voltage Sums divided by the number of measurements (notes) involved in making them are also tabulated.

The most significant entry in Table 2 is the figure of 6.6 % for the percentage standard deviation of the eight chromatic Voltage Sum values. The probable error is defined as 0.67 times the standard deviation (Margenau and Murphy 1956, p. 511), so our probable error for the chromatic Voltage Sums is 0.67 x 6.6 % = 4.4 %. The probable error is the error, r, for which one half of the errors in n observations are greater than r and one half are less than r. We think that as a conservative estimate our chromatic Voltage Sum values may be looked upon as being precise to about 10%, and possibly somewhat less.

Examination of columns three and five of Table 2 shows that some differences exist in the values of (Chromatic Sum)/N and (Diatonic Sum)/N, but the averages of the two sets of values for the eight runs tabulated (11.32 and 11.38) are very close. However, the percentage standard deviation for the diatonic sums is somewhat greater than that for the chromatic sums, which is exactly what one would expect in view of the smaller number of samples included in the diatonic value. This matter of the diatonic values was investigated because only about half as much work is required to make a diatonic run. One sees that diatonic values might be valuable, although of somewhat lower precision than their chromatic analogs.

We now consider the work performed in the fall of 1995. As we shall see, there may be a discontinuity between the results obtained then and those obtained in the spring of 1996. This possible discontinuity is not at the present a matter of concern because we do not represent our loudness measurement method to have long-term stability. Whether it does or not will have to be determined by another study, and the answer to this question does not affect the validity of the short-term comparisons being presented here.

Some of the measurements made in fall, 1995 were not replicated to the extent that we would have liked before we were forced to shut down our operations because of the house renovations. To try to make replicate measurements at the time of writing (spring, 1996) would in effect require making all the measurements ab initio, which we are not in a position to do, in part because some of the instruments studied are no longer available to us. Thus we present

Table 3 - Voltage sums for Violin 16 (mezzo)

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Date</th>
<th>Voltage Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>R10</td>
<td>16 Sept 95</td>
<td>540</td>
</tr>
<tr>
<td>R21</td>
<td>11 Oct 95</td>
<td>534</td>
</tr>
<tr>
<td>From Table 2</td>
<td>March 96</td>
<td>453*</td>
</tr>
</tbody>
</table>

* Average of eight runs

CASI Vol. 3, No. 3 (Series II), May 1997
our fall results as they stand.

We wish first to give in Table 3 the results obtained in fall, 1995 on Violin 16 (Mezzo). One sees that at this time two measurements were made separated in time by nearly a month, and they gave closely agreeing values for the Voltage Sum, with an average of 537. One further sees from Table 3 that this is appreciably, and we think significantly, different from the value of 453 obtained as the average of the eight-run reproducibility study made in March, 1996.

We can only speculate about the cause for this difference, which we think is outside the range of random variations as determined by the March, 1996 study. Perhaps the most likely reason is that the configuration of the room in which our measurements were made was significantly changed by the remodeling that took place after the fall, 1995 series of measurements. A change in the acoustics of the room probably resulted.

Perhaps the second most likely reason is that during Winter, 1996 Violin 16 suffered an accident which punched a hole in one of its ribs. As a consequence its top was removed, the hole repaired, and the top replaced. As a final possibility, the weather in Tennessee in late summer and early fall is different from that in late winter and early spring. Whatever the reason, for the instruments other than Violin 16 only the values obtained in fall, 1995 will be inter-compared.

Because our study was initiated by our interest in the relative qualities of Cello 17 and Cello 24, we first consider the results obtained on them. More measurements were made on Cello 24, and we consider these first and present them in Table 4. A total of 12 runs were made on this instrument under different circumstances, and in Table 4 these are divided into three groups. The first group (six runs in the group R1 through R17) were made with the cello in its original configuration or restored to its original configuration. One sees from the table that the average Voltage Sum for these runs is 444 with a standard deviation of 17.6, which corresponds to a percent standard deviation of 4.0%.

This is of the same order of magnitude, although slightly better, than the percent standard deviation found for Violin 16 in the eight runs tabulated in Table 2.

CWF was not pleased with the performance of Cello 24 after the R1 measurement, especially compared with the results on Cello 17 to be presented shortly, and she responded with standard luthier behavior: she changed the sound post; she changed the bridge; and she changed a string.

Unfortunately, several changes were made simultaneously, and therefore individual effects cannot be disentangled. However, runs R3 and R4 in Table 4 were made with the modified cello. CWF formed the subjective opinion that the modifications worsened the performance of the instrument, and this is reflected in the lower values of the Voltage Sums given for R3 and R4 in Table 4. When the modifications were eliminated and the cello returned to its initial configuration the Voltage Sums obtained returned to their original values as did CWF’s subjective opinion.

In order to learn more about the behavior of our Voltage Sum quantity, we made an experiment where we deliberately reduced the response of Cello 24 by muting it. Runs R9, R16, R8, and R15 tabulated as the last group in Table 4 give the results of the experiment. The results are also plotted in Figure 1. Bar 1, the leftmost one in the plot, is the average Voltage Sum (444) from Table 4 for the unmuted cello. Bar 2 is the value obtained from the cello when muted with a conventional rubber mute weighing 9 grams. Bar 4 is the average of the two results obtained from the cello when muted with a 74 gram practice mute, and Bar 3 is the value obtained when the cello was muted with a conventional wooden mute which was loaded at its top with oil clay to make the total weight 40 grams. In this makeshift mute the center of mass was quite high above the bridge, and one really does not know the magnitude of the muting effect it will have. Regardless of this uncertainty, it is clear that the Voltage Sum decreases monotonically as the muting mass increases, which is what one expects and corre-

<table>
<thead>
<tr>
<th>Table 4 - Voltage Sums for Cello 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>R1</td>
</tr>
<tr>
<td>R6</td>
</tr>
<tr>
<td>R7</td>
</tr>
<tr>
<td>R12</td>
</tr>
<tr>
<td>R13</td>
</tr>
<tr>
<td>R17</td>
</tr>
<tr>
<td>Average of above runs</td>
</tr>
<tr>
<td>Std. Deviation</td>
</tr>
<tr>
<td>% Std. Deviation</td>
</tr>
<tr>
<td>R3</td>
</tr>
<tr>
<td>R4</td>
</tr>
<tr>
<td>R9 (9 gm mute in place)</td>
</tr>
<tr>
<td>R16 (40 gm mute in place)</td>
</tr>
<tr>
<td>R8 (74 gm mute in place)</td>
</tr>
<tr>
<td>R15 (74 gm mute in place)</td>
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<tr>
<td>Average of R8 &amp; R15</td>
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</table>

<table>
<thead>
<tr>
<th>Table 5 - Voltage sums for Cello 17</th>
</tr>
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<tbody>
<tr>
<td>Run</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>R2</td>
</tr>
<tr>
<td>R18</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

CASJ Vol. 3, No. 3 (Series II), May 1997
Table 6 - Voltage Sums for several instruments

<table>
<thead>
<tr>
<th>Run Number and Instrument</th>
<th>Date</th>
<th>Voltage Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>R11 Violin 22</td>
<td>16 Sept 95</td>
<td>374</td>
</tr>
<tr>
<td>R22 Violin 22</td>
<td>11 Oct 95</td>
<td>434</td>
</tr>
<tr>
<td>Average, Violin 22</td>
<td></td>
<td>404</td>
</tr>
<tr>
<td>R19 Scarampella Violin</td>
<td>26 Sept 95</td>
<td>400</td>
</tr>
<tr>
<td>R20 Bagatella Violin</td>
<td>26 Sept 95</td>
<td>331</td>
</tr>
<tr>
<td>R24 Viola 19</td>
<td>11 Oct 95</td>
<td>513</td>
</tr>
<tr>
<td>R23 Hutchins Alto Violin</td>
<td>11 Oct 95</td>
<td>632</td>
</tr>
<tr>
<td>R5 Hutchins Cello</td>
<td>5 Sept 95</td>
<td>482</td>
</tr>
<tr>
<td>R25 Chinese Cello</td>
<td>11 Oct 95</td>
<td>579</td>
</tr>
</tbody>
</table>

For Cello 24 in Table 4 one sees that the value for Cello 17 is 69 units (14%) higher than that for Cello 24. Placing the conventional mute on Cello 24 reduced its Voltage Sum by 16%, which is comparable with the amount that Cello 24 is louder than Cello 17. Thus, we can understand quantitatively why the professional player who played the two instruments thought that 17 would carry better and why we also thought that this was the case with our down-the-hall-and-through-the-door experiment: Cello 17 is appreciably louder than Cello 24.

A number of other instruments were measured, and the results obtained on these are given in Table 6. Violin 22 was made by CWF and is generally considered to be a very good instrument. From Table 6 one sees that its loudness figure is about equal to that of the Scarampella, and both are appreciably louder than the Bagatella. However, all three of these instruments are appreciably less loud than Violin 16, which is the mezzo violin in our collection. Considering the cellos, the cello made by Carleen Hutchins (SUS 203) lies midway in loudness between CWF Cellos 17 and 24. However, the loudest cello that we tested was an inexpensive Chinese student instrument borrowed from an Oak Ridge music store for purposes of testing.

Our viola testing was quite limited, consisting of one run each on Viola 19 made by CWF and the alto violin made by Carleen Hutchins (SUS 132). Both were loud, with the alto violin having the distinction of being the instrument which gave the highest value of all for the Voltage Sum (632 units). We have known subjectively that this instrument is loud for many years, for when it is played in a string quartet its player must take great pains not to drown out the other instruments.

We should say that we do not know whether loudnesses as measured by our Voltage Sums can be compared between different types of instruments, i.e., can the loudness figure for a cello legitimately be compared with that for a viol- in? While we see no physical reason why it should not, we shall not at this time try to voice a definitive answer.

In summary, we have made loudness measurements on ten different instruments, and the Voltage Sum values obtained ranged from 200 for the heavily muted Cello 24 to 632 for the alto violin. The Voltage Sums unequivocally reflect obvious loudness differences: the heavily muted cello does not sound loud, and its Voltage Sum reflects this. However, the Voltage Sums also give information about smaller differences in loudness that are not subjectively obvious.

FHF always knew that the mezzo violin (Violin 16) was very good, but he did not know that it would produce the highest score of the several violins tested. Similarly, while everybody concerned suspected that Cello 17 was louder than Cello 24, the difference that the Voltage Sums indicated was greater than was subjectively apparent. We really were unable subjectively to order Cello 17, Cello 24 and the Hutchins cello, and the result that the Chinese student cello was the loudest of the four,
and by a considerable margin, came as quite a surprise.

2. Subjective Results

We now turn to a matter that we find interesting and exciting, which is our subjective responses to the measurements as they were made. In particular, both investigators found many times that the loudness of a note as indicated by the output meter of the equipment came as a surprise to the recorder of the measurements. For example, one sees in Table 1 that approximately a four-fold difference exists between the voltages of the A' and B notes in the octave above middle C, but this difference (and many others similar to it) was effectively not detected by our ears. Furthermore, the player of the instrument usually had at best only a vague idea as to its loudness (remember that no communication between player and recorder was permitted), and the Voltage Sum obtained sometimes came as a surprise.

We began strongly to suspect that our ears were playing tricks on us. Beyond this, the player seemed to be able to receive little auditory feedback for the control of the bow stroke. The bow strokes were supposed to be smooth and even, and they were not so fast that in principle some control of the volume over the course of the stroke could not be applied to obtain a uniform response. In fact this was frequently not the case.

One sees from Table 1 for some notes a considerable variation in the voltages were obtained with the three different bow strokes, and in general the player was not aware of this. The results of all bow strokes were recorded, except in the case where the player stopped in the middle because of an obvious problem like an egregious scratch. Obtaining reproducible results with different bow strokes was much more a matter of the mechanical skill of bowing than of auditory feedback. In an early paper Hutchins (1973) refers to work where even when the player tried to be consistent, there were observable variations with consecutive bow strokes, so the problem we encountered is not limited to us.

This is not to say that no variations in volume are detected, for they are. One can certainly distinguish a p from an ff in playing an instrument, and we had no trouble detecting that Cello 24 played more softly when loaded with the practice mute than it did without it. Nevertheless, we reiterate that our electrical equipment indicated the presence of significant loudness differences that our ears were basically unable to perceive.

One knows that the emission audio spectra (response curve) of string instruments such as that in Table 1 contain peaks and valleys, but our subjective perception does not detect these loudness inhomogeneities. Hutchins, in her seminal review paper on violin physics (1962), observes in passing that it often comes as a shock to a musician to discover that his instrument is much louder at certain notes than at others. Thus our inability to distinguish loudness inhomogeneities has long been anticipated.

One can raise the question as to whether our equipment was giving us erroneous results. The specifications supplied with the equipment are such that this is not likely, but most important, these unperceived variations in aural sound occur in different parts of the spectra for different instruments, which would not be the case if systematic equipment errors were occurring.

As a result of our subjective experimental findings we formed the tentative hypothesis that our inability to distinguish loudness differences is, at least in part, the result of the operation of normal human hearing physiology. It comes as surprising news to us (from reading generated by our investigation) that human hearing has a feedback mechanism which maintains control of perceived sound. This mechanism operates to reduce the perceived sound when the sound incident on the ear rises above a threshold level. Thus our naive, ad hoc hypothesis is compatible with known hearing function. Handel (1989) gives valuable information on this subject, and useful and relatively accessible information on ear physiology and hearing is also given in the Encyclopaedia Britannica (1976).

Very briefly, sound information is transmitted from the eardrum to the inner ear by a system of three bones (the malleus, incus, and stapes), and to these are attached two pairs of muscles (the tympanic muscle attached to the malleus and the stapedius muscle attached to the stapes). To paraphrase the information given by Handel on pp. 467-468, when stimulated by high intensity sounds, the stapedius muscle contracts reflexively (the auditory reflex (sometimes called the aural reflex)) to change the coupling between the bones connecting the eardrum to the inner ear, and the effect is the attenuation of the low frequency (here defined as frequencies below 1000 Hz) vibration that reaches the inner ear. The strength and timing of the reflex is a direct function of intensity. The reflex is initiated at relatively modest sound levels (about 65 dB, or moderate speaking levels). The reflex can reduce the transmission of low frequency tones by a factor of 10 to 100. (Italicization ours.) The reflex is too slow to protect the inner ear structures against intense, rapid transients (gunshots are usually used as illustrations), and the reflex adapts to long duration tones, thereby decreasing the low frequency attenuation.

We assert that the sounds produced in our loudness tests fall into the loudness range where the auditory reflex can be operative, and this reflex washed out our perception of many loudness differences in our measurements. Even in FHFP's amateurish hands a violin makes at least as much sound as that of moderate speaking levels. The player of an under-the-chin instrument which is robbing away at a mean distance of 7 - 8 inches from his/her ear is subjected to a sound appreciably more intense than that of moderate speaking levels. The frequency range which is attenuated by the reflex (<1000Hz) covers the fundamentals of all the notes played in our tests except those in the range above high C. Our procedure of trying to bow smooth, even notes puts us in the range where the reflex operates; that is our sounds do not involve loud, rapid tran-
sients. The duration of our note (3 - 4 seconds) is probably not great enough for the onset of the adaptation of the reflex referred to above, although this is just our surmise.

We wish to mention that Handel gives several other pieces of information about hearing and loudness, but to conserve space we shall summarize them by saying that from several points of view it appears that in a large range of loudness, perceived loudness and incident loudness are not very linearly related.

This phenomenon, to the extent that it operates and applies, has significant implications for lutherie and music in general. For example, to return to instrument projection, which is where we started in this work, one frequently hears it said that while a given instrument may not sound like much to a listener under his/her ear, it carries across a hall, i.e., it has good projection characteristics. We have never heard a convincing explanation for the phenomenon, and Saunders in his 1962 paper states that the carrying power (projection) of a violin is much debated and little understood. He discusses the matter and reaches the unarguable but not particularly informative conclusion that carrying power depends on the power of the violin and the nature of the hall.

We make the suggestion that projection is primarily a matter of the degree of instrument loudness (such as would be measured by an objective technique like ours). The player perceiving the sound by ear is not privy to this degree of loudness because of the auditory feedback control referred to above. On the other hand, at the back of a large hall the loudness will be attenuated by the inverse square law and by absorption of the sound in the room, and the loudness may well fall below the auditory reflex threshold to a region where a greater degree of linearity between incident and perceived loudness exists in the ear of the hearer. Then differences in the source loudness of different instruments will be perceived by the listener at the back of the hall as a difference in projection ability. A similar rationale may be offered for the results of our down-the-hall-and-through-the-door experiment: the hall and door provide the attenuation needed to enable the listener beyond the door to distinguish the two cellos under test. We suggest that the concept of instrument projection is as much a matter of human physiology as of violin physics.

Conclusion

We think that the loudness measurement technique that we describe is a valuable one for obtaining quantitative and subtle information about the loudness of bowed string instruments. By extension it can constitute one of the measures of instrument quality. It is unpretentious and inexpensive enough that virtually any lutherist can use it, but if desired it can be elaborated to make the measurements easier. Since its development the policy in this workshop will be to measure the Voltage Sum for all instruments produced or worked on seriously. This information will be kept as part of the information file on the instrument.

We are very intrigued by our subjective loudness observations. It appears to us that the nonlinearity of human hearing has great implications for violin makers and musicians. We do not know how widespread the knowledge of this phenomenon is among such workers, and we have no immediate way of finding out.

We ourselves have never heard it referred to by luthiers and musicians. We can say that while the operation of the pupil of the eye has been known to us for most of our lives, knowledge about the existence of a similar mechanism in the ear comes to us only as a result of the work reported here. We have spoken of the matter to as many as possible of our scientist/musician friends, and the information is new to them. It does not appear that many people are aware of the phenomenon (not counting otologists and audiologists), although we would like to be enlightened on the subject.

But, in summary, from our experiments we have formed the opinion that the human ear can be quite an inexact instrument for perceiving fine gradations of loudness. We have developed a possible rationale for our findings. We think that luthiers and musicians would do well, first, to be aware of the ear’s limitations in this regard, and, second, to supplement the loudness perceptions of the ear with objective procedures such as that described here.

ACKNOWLEDGMENT

We wish to thank Dr. Richard De Persio and Dr. Dennis Earl of Knoxville, TN, otologist and audiologist, respectively, for providing us with information about the hearing function.

REFERENCES


ACOUSTIC EXPERIMENTS WITH THE VIOLIN

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In these experiments a small electromagnetic transducer is arranged to drive the violin bridge laterally, in the direction of string motion. The transducer is activated by an oscillating voltage of varying frequency and the resulting sound is measured by a sound level meter. The oscillating voltage input is generated by a Macintosh computer which also records the sound level and plots the result as amplitude vs frequency.

The results are used to characterize the frequency response of good and bad violins, to demonstrate the influence of the sound post and to show the effects of bridge compliance. Vibration patterns (Chladni patterns) of violin plates are shown and are used to explain the directional properties of violin tones. The paper includes the computer program used to generate the results.

The violin has come to us in its present form after more than a thousand years of evolution. The earliest instruments showed a great variety but the form seems to have crystallized about 400 years ago. If an inventor of the violin could be identified at all, it would be Gaspar da Salo, near Brescia, Italy. It is said that a few of Gaspar’s instruments, now 400 years old, are still played by proud owners.

Following the work of Gaspar and his pupil Maginni in Brescia, the center of violin making moved to the workshop of the Amati family in Cremona, where Stradivari, Guarneri, and other now famous makers learned their art. The reputation established by these artisans in Cremona is such that no modern maker dares suggest that he has made an improvement, though in fact some not altogether modest improvements have been made.

It is unfortunate that the Cremonese makers wrote nothing about their designs, their formulas or their techniques, yet on examining their work, one finds evidence of considerable ingenuity in what we would now call acoustic science.

The figure of the violin, together with its internal construction, seem calculated to produce a wide range of resonant vibrations. In outline we see two roughly circular plates of unequal size connected by a highly arched narrower neck. While the outward figure of the violin shows strict bilateral symmetry, the interior does not. On the left side, under the G string, we find a long bar called the “bass bar,” while on the right side, under the E string, there is a stiff “sound post” wedged between the belly and the back. The top and the back are made of woods having different acoustical properties, the back of heavy, dense maple and the top of much lighter spruce having a higher velocity of sound.

Professor Saunders (1941) measured the resonant properties of violins by applying electromagnetic forces to one of the strings and recording the sound output. My own method is somewhat simpler and is shown in Figure 1. Here a small speaker with its cone removed is modified so as to drive the bridge laterally, in the direction of string vibration. The experiments were made in a small, heavily curtained room equipped with a pair of rotating reflecting surfaces which shift the standing wave pattern. A similar device is often seen in microwave ovens, shifting the electromagnetic wave pattern to avoid “hot spots.”

In earlier tests, a sinusoidal exciting current was provided by an audio oscillator and the resulting sound recorded from the reading of a sound level meter. In a later version, the sine wave exciting current is provided by a Macintosh computer which records and plots the resulting sound level. The computer can also produce current waves of saw tooth form, simulating the input of a bowed string (see Cremer 1984 and Schelleng 1974). The computer program, found in the Appendix to this pa-
per, was devised by the author’s associate Rick McWilliams.

Figure 2 shows the frequency response of my violins, numbers one and two, as tested in my laboratory. As noted by Meinel (1957), violins of good tone quality show diminished response in the nasal range of frequencies near 1500 Hz. Unfortunately, my first violin showed prominent overtones in that range. Violin number two, on the other hand, emphasized bright overtones in the range near 2000 Hz. Needless to say, number one was a tonal disaster; number two, however, had a distinguished career in the San Diego Symphony. Of course, one would like to know the exact structural reasons for the difference, but these are elusive. The top and bottom plates of each violin were quite thin around the edges, as recommended by both Saunders and Hutchins, but number two was somewhat thicker near the center.

Figure 3 shows the frequency response of a 1718 Stradivarius violin as tested in my laboratory. The instru-
ment was kindly provided for the test by Robert Mann, Principal Violinist of the Julliard Quartet. Figure 3 also shows the result for a good modern violin having rather similar characteristics. The most prominent difference is the lowered amplitude beyond 3000 Hz in the case of the Strad. As will appear later, amplitudes in this range can be influenced by shaping the bridge.

As seen on Figure 3, the low frequency cut-off of the violin occurs at about 260 Hz, well above the open G string at 193 Hz. Of course, the input of the bowed string is definitely not a pure tone and most of the sound energy at G will appear in the second and higher harmonics. At higher positions on the G string the first resonant peak at C# (270 Hz) appears. This lowest peak, known as the "air resonance" depends primarily on the volume of the violin and the area of the f-holes. The amplitude of the peak, however, is strongly influenced by the flexibility of the violin box. Inferior violins, which are often too thick and rigid, show weak air resonance.

A still stronger influence on the air resonance is that of the sound post. Remove the sound post from a violin and the instrument becomes remarkably quiet on the lower strings. Figures 4 and 5 show the effect of the sound post as it appears in my test. Without the sound post the air resonance is not excited at all. The next peak is lowered somewhat in accordance with the well-known principle that removing a constraint will lower the frequency.

The first rational explanation of the action of the sound post seems to have been given by Schelleng (1971). Without the sound post, vibrations of the top and bottom plates tend toward bilateral symmetry, in on one side and out on the other, causing no change of interior volume. The sound post, by fixing the distance between the plates at a point off the center of the violin, removes this symmetry so that the vibrations are accompanied by changes of volume, pumping air in and out of the f-holes and thus exciting the air resonance.

The next prominent peak is the lowest plate resonance near A-440. Both

Heifetz's Guarnerius (see Saunders and Hutchins 1952) and Robert Mann's Stradivarius have this resonance at 440. Instruments that are too stiff often have this peak as high as 550 Hz, leaving a wide gap between the two lower peaks.

Figure 6 shows the vibration pattern on the back of a violin at the lowest plate resonance. Such patterns are easily obtained by sprinkling pumice powder on the surface. At this frequency the greatest motion appears in the region of the bass bar. Figure 7 shows the pattern at a higher frequency, 1320 Hz. At this frequency the vibration pattern has a high degree of antisymmetry, i.e., regions of outward motion on one side of the centerline are matched by equal regions of inward motions on the other side. For a listener in the plane of symmetry perpendicular to the back plate, the acoustic path lengths are nearly equal so that

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**Figure 4 - Influence of the sound post**

![Graph showing the influence of the sound post on sound resonance.](image)

**Figure 5 - Influence of the sound post**

![Graph showing the influence of the sound post on sound resonance.](image)
compression waves and expansion waves arrive at the listener simultaneously and no sound will be heard. This is not true, however, for a listener in the plane of the vibrating plate. Since the width of the plate is comparable to the wavelength, the positive and negative waves are shifted out of phase and a sound will be heard.

Good violins show diminished response at frequencies above about 3000 Hz. Such frequencies, no doubt, emphasize scratches or squeaks made by the bow. A simple way to reduce these unwanted frequencies is through modifications of the bridge. Violin makers and restorers put great store in properly fitting and shaping the bridge. Figure 8 shows the influence of the bridge as determined in my test. In the upper curve small wedges have been placed in the slots marked on the Figure 9, making the bridge quite rigid in lateral flexure. In the lower plot the wedges are removed, restoring the bridge to its normal flexibility. It will be noted that the normal bridge reduces the output at 5500 Hz by nearly 10 db. Evidently, the bridge, in the form said to have been perfected by Stradivari, acts as an effective low-pass mechanical filter.

In the experiments described above the input to the violin has been a pure sinusoidal force without overtones. Within the normal range the violin should also respond with a pure tone whose amplitude varies with frequency. The input from a bowed string, however, is by no means a simple wave but, as described by Schelleng, resembles more closely a saw tooth wave, containing many higher harmonics. Figure 10 shows the effect of input wave shape on the response curve. Note that with the saw tooth input the loudness is much more uniform than in the case of the pure tone input. Most surprising is the increased level of sound below the nominal cut-off frequency, sound which must appear in the second and higher harmonics.
Figure 10 - Effect of input wave shape on frequency response

REFERENCES

APPENDIX

VIOLIN TEST PROGRAM
```
' draw box and title
MOVETO 20, 15
PRINT "Fast test 6000",DATE$
MOVETO 20, 97
LINETO 490, 97
MOVETO 20, 150
LINETO 490, 150
FOR freq = 200 TO 900 STEP 100
x=25+135*LOG(freq/200)
LINE(x,40)-(x,250)
MOVETO x-12,38
PRINT USING "##";freq/100
NEXT freq
FOR freq=1000 TO 7000 STEP 1000
x=25+135*LOG(freq/200)
LINE(x,40)-(x,250)
MOVETO x-8,38
PRINT USING "##";freq/100
NEXT freq
MOVETO 10,250
STOP
WAVE 1,SIN
```

OPEN "com1:2400,n,8,1"AS 1 LEN=2000
freq=200
vol=200
dur=10
rain:
SOUND freq, dur,vol,1
garbage$=INPUT$(LOC(1),1)
LINE INPUT #1,garbage$
INPUT#1,V1,V2,V3
level 1=(.001*v1)
x=10 + 135*LOG(freq/200)
y=130 - 50*LOG(.001*v1)
cALL LINETO(x,y)
freq=freq*.01
IF freq<7000 THEN GOTO rain

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NEW VERSUS OLD: Playing-in Instruments through Vibratory Transmission of Music to the Bridge

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The authors vibrated several violins and a viola for 500 hours, by attaching a device to the bridges and playing an FM classical music station through it. Most players and listeners noted tonal changes and thought the changes were improvements.

The notion that old (particularly Italian) instruments have better tone and are easier to play than contemporary ones is widespread. Many comparisons of select old and new instruments have been made without any conclusive support for the view. In one recent comparison, the Tokyo String Quartet played some well known string quartet music with their own old Italian instruments (to which they were accustomed) and three quartets of modern instruments (to which they were not). The event was reported by Pickering (1994). The audience could see and thus possibly identify which of the instruments were being played and this may have been one of the many factors that influenced the outcome, one possibly favoring the old Italian instruments.

The music was, however, recorded by one of us (MK) and listeners were asked to identify the old and modern instruments from excerpts that were presented in random order through listening alone. One of us (DL) had a dozen experienced musicians attempt this auditory identification task and none was able to detect consistent differences between the old and new instruments. Most attributed their failure to the less than ideal quality of the recording rather than their auditory skills. The other (MK), however, was later able to identify almost all items on the test correctly from the same tapes.

The reasons for the apparent superiority in tone and playability of select old instruments is not known. Eban (1981) considered that it was due to their having been played on extensively and consistently, and noted that after being played for a while by a skilled player, an instrument is better than usual for a short time thereafter, but that an unplayed instrument will "go to sleep" even if the string tension has not been relaxed.

Hutchins and Rodgers (1992) point out that "violinists are well aware that continuous playing over a period of time tends to increase the ease of playing and the overall tone qualities of the instrument." They describe how one Jacob Augustus Otto, to speed an instrument's responsiveness, recommended its laborious bowing in fifths, each fifth for 1/4 hour daily over its complete range for a period of 2-3 months. In contrast, they themselves described a method they had devised for playing a classical radio station through violins for 1500 hours by means of coupling loudspeakers (minus cones) to the bridge. They reported that, for the 12 instruments studied, the A1 mode frequency remained constant, but the B1 mode—and hence the A1-B1 Δ (see Hutchins 1989)—decreased an average of 22 Hz.

One of us (Killion 1994) later described changes with playing in the tonal qualities of his instruments—a 95 year-old violin and a modern viola—and suggested the possibility of producing a "closet violinist," an instrument that would vibrate the bridge in much the same manner as that described by Hutchins and Rodgers. One of us (DL), unknown to the other, had already employed such an instrument—one that used a bone conduction vibrator from an audiometer—and had found that audible changes in the tonal qualities of violins subjected to such vibration occurred in a matter of a few days.

Together, we decided to study the phenomenon more closely, obtaining not only tape recordings of a sample of radio music played through the instruments before and after vibration but pre- and post-vibration ratings from competent violinists on both the sound of the instruments when they were played by someone else and the ease of playing the instrument themselves.

The need to rate both tone and playability was suggested by the work of Chiang and Houtsma (1982) who had found that listeners were less able than the players to decide on ratings. This is a preliminary report since various constraints, including the difficulty in obtaining sufficient judges allowed us to vibrate only four instruments, two restored violins made 20 and 50 years ago respectively, one new viola and one new violin.

Method

The instruments were played and listened to, each by at least five competent string players, two or more of whom were professional musicians, who rated them on a scale of 1-10. Each player understood that a rating of 1 would be given to the poorest instrument they had ever come across, a rating of 5 would
be awarded to an average instrument of acceptable quality, and 10 would be the rating given to the best instrument they had ever heard or played. The players rated the instruments twice, i.e., before and after the instrument had been subjected to 500 hours of vibration.

A Beltone 10 ohm B 70A Bone conduction vibrator (Radio Ear Corp, 1995) was used to vibrate each of the instruments. Its frequency response ranged from about 250 - 4000 Hz. It was coupled to the speaker output of a General Electric Spacemaker radio tuned to a 24 hour CBC FM stereo station. The vibrator was placed on top of the bridge, between the D and A strings, and was kept securely in place by means of two elastic bands that crossed around the instruments and over the top of the vibrators.

The radio was tuned to the station and the output level of the vibrator adjusted so that a strong vibration was felt in all four quadrants (back and belly). A brief sample of the introductory music (Respighi's Ancient Airs and Dances) from Bob Kerr's program, entitled Off the Record, was recorded at the start and at the end of the 500 hours vibration at this level.

The sample was recorded in stereo at a distance of three inches above the fingerboard near the f holes using a Dual type 33-919A electret microphone and a Sony model UL stereo tape deck. The output from the vibrating violin at the microphone in this position was in the order of 95 dB. The pair of recordings obtained from each instrument were then dubbed onto another audiotape for play-back to an audience to demonstrate the marked differences between pre- and post-vibratory samples.

Results and Discussion

The results (Table 1) showed that the listeners/players were, with one exception (f for the viola) in close agreement on the sound and playing quality of the instruments. Ratings for the two restored instruments—both rated as being of moderate quality—support the notion that some such instruments in the hands of a good player sound better to a listener than they sound to another person when he/she is playing the same instrument. Comparisons of the pre-and post vibration period judgments suggest that the poorer the instrument at the outset, the more likely it is to be rated as improved following 500 hours of vibration.

Simple overall ratings (like other perceptual measures of stringed instruments) fail to tell the whole story. In this study, certain musicians clearly remembered specific things about particular instruments—how particular strings sounded, whether there was a completely even tone across or on certain strings, whether it was easy or difficult to obtain rapid changes in dynamic range, how quickly the instruments responded, and so on. However, while some such features were recognized by certain players or listeners they did not necessarily affect the rating. Judgments were more broadly based and reflected a gestalt impression.

All participants were sure that the instruments had changed, and most thought the changes were for the better. Two of the instruments were played extensively after the vibration period was over, the new violin by an advanced student and the viola by a professional in orchestral and solo performance. In both case, further changes in tone and playability emerged.

Many questions remain to be asked about vibration as an artificial means of playing-in an instrument. Does artificial vibration make trivial or truly important contributions to violin tone? To what extent can it promote in new instruments the qualities generally ascribed to older ones? What type of stimulus is optimal? Is the vibration provided by using an orchestra as the energy source more effective than using a recording of a single instrument or would driving the vibrator with a low-frequency square wave be as effective? What frequency response should an ideal vibrator have? What levels of vibratory intensity are desirable? What is the optimal duration of vibration? Is there an advantage in placing the vibrator on the side rather than on top of the bridge?

There is no doubt that frequency change such as reported by Hutchins and Rodgers (1992) occurs in wood that is vibrated. It occurs not just in violins at moderate humidity but, as reported by Hunt and Balsam (1996), in beams of spruce vibrated at high humidity. Do changes from vibration such as those reported here and elsewhere occur in all parts of the violin or in one plate more than another? Does it affect the glue as well as the wood? Does it affect the purfling and or the varnish? Should makers make allowances for the effects of later vibration on their instruments when they are making them?

Follow up on some of these questions might well prove to be useful, but the number of variables associated with each question is such that effective well controlled studies will prove to be difficult. Comparisons of input and output using a spectrum analyzer would potentially yield more quantitative data and, perhaps reveal more of the nature of the changes that occur with vibration over time.

Considerable further study of the topic is merited. ■ CAJS

REFERENCES


CASJ Vol. 3, No.3 (Series II), May 1997
Table 1 - Judgments of playing and listening before and after 500 hours of vibration

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USE OF A BENT TOP TO REDUCE LONG-TERM VIOLIN DEFORMATION

Charles W. Gadd
218 Pheasant Run
Henderson, NC 28739

Using a bent violin top greatly reduced the tendency for string tension to cause the neck to angle upward, the mid-upper region of the top plate to fall, and the upper end of the fingerboard to droop. A separate five-year study implies that a bent top should be significantly less subject to creep—the slow plastic deformation of a material under continuous loading—because of the lesser amount of grain runout.

Use of a top which has been bent to shape while in the rough, prior to final planing, scraping, and graduating has been suggested in various publications, notably by W. Fulton. If this is done, grain runout in the central upper and lower regions of the plate (where arching slants most steeply as viewed from the side) is markedly reduced, and the wood cells will run more closely parallel to plate surfaces. This suggests that, aside from any effect upon tone, the pre-bending of the plate should result in greater long-term stability of the instrument, whether it be a violin, viola, or cello. Notably, there should be less fingerboard droop and consequent need to reduce bridge height or even reset the neck after a period of years.

Measurement of Plate Deflection

Plate deflection was measured as illustrated in Figure 1. A machinist’s dial indicator, reading in thousandths of an inch, was attached to the center of a light-weight but stiff metal bridge which could be positioned transversely across the violin and attached by small spool clamps to the edges of the upper bouts. Clearance holes were drilled through the fingerboard such that readings could be made of plate deflection as the strings were tightened or loosened. (This was done several times at each position to insure repeatability.) The combined compressive and flexural stresses setup by string tension resulted in the downward deflections shown. These will of course vary with different plate graduation, but in this study conventional graduations were employed, and minimum thickness around the upper end of both the carved and bent plates reached 2.4 mm. As expected, grain runout and consequently greater flexibility of the carved plates resulted in much greater deflection here. Differing thickness options which one has if the plate is bent are discussed below.

Creep Measurement

Generally, creep is related to stress relaxation (Gadd 1984), in that with creep, constant loading rather than constant deflection is imposed. Both develop rapidly at first and progressively more slowly with time. This is illustrated by Figure 2, which compares the shape of the relaxation curve from Gadd (1984) with that of two creep curves published in a U.S. Forest Products Wood Handbook (1974).

Long term creep of the top plate will be greatest in its mid-upper and lower areas where arching slope is greatest. In this study the principal objective was to determine, on a relative basis, the degree to which the geometry of an instrument might be stabilized by use of a bent plate. Rather than attempt to make complete instruments with both carved and bent plates but otherwise identical, and compare them after many years, it was felt it would be preferable to conduct a simplified test program employing small plate specimens.

Those chosen had longitudinal, verti-
Upper ordinate is fractional relaxation of original imposed stress. In the lower graph the Forest Products Laboratory plotted creep deflection as a fraction of initial elastic deflection. For example, after 500 days at 4000 pounds per sq. in. creep reached a value equal to the initial elastic deflection.

Figure 3 - Method of cutting specimens from a block to obtain 0 or 7 degrees of runout of grain

Pairs with and without runout were then mounted on opposite sides of the simple fixture of Figure 4, such that they were subjected to identical loading. Loading springs were selected which applied a stress of 1300 pounds per sq. inch (8960 kPa) along the central span where bending moment was uniform. Under the conditions of this type of test, long-term creep is seen in Figure 5 to be reduced by 65% at the end of 5 years.

Discussion

As pointed out in the Wood Handbook (U.S. Forest 1974), creep varies as a function of temperature, humidity, stress level, and seasoning. Further, the degree of grain runout varies over the instrument’s plate surface. However, it can be concluded that creep should be markedly reduced by use of a bent top and that long term stability of the instrument should definitely be enhanced.

Choice of thickness graduations

Elimination of grain runout of 7 degrees increased flexural stiffness by approximately 20%. Thus, if a plate is to be bent rather than carved, two avenues suggest themselves.

- The bent plate could be given the same graduations as a carved one in the areas of greatest runout, in which case one might expect a little greater strength of tone in the high-frequency part of the sound spectrum. This seemed to be borne out when listeners volunteered the opinion that a bent top violin by the author could be heard more easily at the back of a hall.

- The bent plate could be made thinner in these same areas, to bring stiffness here down to that of carved plates, with resulting tone similar to that of a carved plate. However, long term stability would be lessened.

REFERENCES


Figure 4 - Method of applying test loading to paired specimens

Figure 5 - Relative creep with and without grain runout

Ordinate is millimeters of curvature remaining in specimens after removal from test fixture at various times up to 5 years.
PAILLETTE INDICATORS: an Alternative to the Blister Cup Indicators

Äke Ekwall
Hantverkargatan 9
77730 Smedjebacken, Sweden

The author describes an improvement to a device for finding various resonance modes for the violin body.

As a common rule says that nothing is so good that it can't be better, I worked further with my blister cup indicator (Ekwall 1995). Its weakness is that static electricity sometimes is a source of irritation and a hindrance for best function. And of course a quicker survey could be good. So I searched for a better indicator. And now I mean to have found it.

Figure 1 shows my new indicator. It consists of a small stand of 0.3 mm soft steel wire and a paillette put over its hook. The paillette is made of about 0.1 mm thick plastic and has an 1 mm hole through its center. The stands can be fastened with a 4 mm ball of oil clay pressed on very carefully with a narrow wooden spatula.

When to decide the size and shape of the vibrating part I had to my disposal a bag with hundreds of paillettes in different sizes and shapes, all with punched hole for sewing on and all made of sparkling 0.1 mm thick colored plastic. I experimented out which shape and size reacted best for my wants. Those with circular shape worked best. The smallest circular ones, diameter 4 mm, with a central hole seemed to react for the smallest vibration. Their movements however where difficult to observe. A larger size gave lower sensitivity but was easy to observe. I had to weight these demands against each other. My best choice was a paillette in diameter 11 mm formed as something of a flower. (My next best choice was a star-shaped paillette in diameter 8 mm, with 5 tips.)

Of course it would be possible for the violinmaker to cut out the paillettes needed from stiff paper or from plastic. But I mean it is important that all indicators in a set of four really have the same behavior. For that reason the best possible precision is needed. In this respect the factory made paillettes are very fine—and ready for use.

I call my new device The Paillette Indicator. It is to be used in the same connection as the previously described Blister Cup Indicator.

REFERENCES
The Catgut Acoustical Society is again pleased and proud to add to the previous list of members who have been with us continually for 25 years or more.

Carl Hugo Agren (1968)  
Jont Allen (1972)  
Frank L. Cash (1972)  
Norman F. Edge (1972)  
Julian Emery (1972)  
Thomas L. Finch (1972)  
David Finckel (1972)  
Neville Fletcher (1972)  
Charles W. Gadd (1972)  
John Mather (1972)  
North Texas State University (1972)  
David G. Proctor (1970)  
Robert K. Rohe (1972)  
Robert T. Schumacher (1972)  
William E. Slaby (1966)  
Johan Sundberg (1972)  
Edward Wall (1972)  
Oscar A. Wehmanen (1972)

Last November, Anne Cole presented a recital entitled “Vertical Strings” in conjunction with the Violin Society of America meeting in Albuquerque, New Mexico. She first played the Alto Violin in a Dvorak Sonatina, followed by Cesar Franck’s violin Sonata played on the Tenor Violin and a Bridge Sonata played on the cello. Anne made the Alto and Tenor following CAS blueprints, and has played them for over 20 years. She extended special recognition to Carleen Hutchins, “who pioneered the way towards new horizons in traditional classical music. Craig Brown, my accompanist, has been open-minded and patient in dealing with the musical applications of the new additions to the violin family.”

Through the interest of Pamela Proscia, a group of professional musicians in New York are experimenting with various Octet instruments with the interest of composing for them.

Rachael and Peter Kyrsa plan to present some of the Octet instruments this coming summer at the Winnepesaukee Music Festival.

Our Russian contact, Marina Meleshkina, who has been central in the development of the Octet in Russia, is now married to Brian Markot and living in New Hampshire. She is continuing to maintain our relationship with the St. Petersburg Conservatory trying to secure funding for the Octet. The group in St. Petersburg has made a recording for a CD, but funds are needed to produce this. We now have available for sale at $15.00 the 15 minute VCR which the Conservatory made in 1995. This contains a description of the Octet made by the Russians themselves—what they think of the Octet’s potential along with excerpts from a 1994 Christmas concert, which was attended by Roderick Skeaping. Comments of Skeaping’s experience with the Octet fifteen years ago at the Royal Conservatory of Music in London, comparing them to what he hears now, are also included. The text is in Russian with an overlay of English and gives a fine picture of what the Octet represents and its challenge to the music of the future.

Gregori Sedoukh is independently working with the Treble violin in addition to his playing with the Octet and the St. Petersburg Philharmonic. He has composed a number of pieces for the Treble and plays them magnificently, as illustrated in a tape he sent recently. He is hoping to find funds to have this music published. He played the Treble for Mstislav Rostropovich, who had never before seen our instruments and “he was admired of your works.”

Dutch Public Television has made a VCR which was aired in Holland last spring. Under the direction of Joseph Wassink of Rotterdam, with the TV crew, Pieter Guyt and Piotr Kuken, the TV show on the making and testing of violins in Holland contains a commentary by Adrian Houtsma and a Dutch violinmaker and includes shots of the 112 Essex Avenue laboratory and shop with comments by Carleen M. Hutchins, as well as several musical excerpts from our Octet concert last March.

Here are some comments on the two big volumes RESEARCH PAPERS IN VIOLIN ACOUSTICS, 1975-1993, C. M. Hutchins, Editor, Virginia Benade, Associate Editor and published by the Acoustical Society of America that are now in circulation. We quote a few for your interest:

“Thank you for your epic work. I received my copy about a month ago and have been reading it at every spare moment since.”

CAS! Vol. 3, No. 3 (Series II). May 1997
As a relative newcomer to violin making, these collected papers contain a huge amount of immediately relevant information which I am sure will help me to make better instruments in the future."

"It was with great delight that I received and began to read the collection of Research Papers —. I was literally like a child with new toys at Christmas, torn between decisions about what to read first as so many of the papers related to problems I had previously encountered and questions arose in building my own violins. I certainly admire and appreciate the tremendous effort a project of this nature requires and hope that world Lutherie realizes what a treasure and inspiration you have been with your prolific production of research information and your seemingly tireless promotion of the work of others through the CAS.——"

"The two volumes are wonderful, a great idea, masterfully executed. I treasure them."

"Congratulations to Carleen and all who deserve it on the two beautiful volumes of reprints. It is already an enormous convenience to me, and a pleasure to find many papers that I did not know or had forgotten. And it is a particular pleasure to find some reproduced in a better form than the originals - particularly the ones from early CAS Bulletins. Someone went to a tremendous amount of loving labor, and it is much appreciated."

Congratulations to an excellent publication! We are really impressed by your fighting spirit which made the publication of these volumes possible. The selection of articles seems to cover most of the recent work in the field of violin acoustics. Layout and printing make them a pleasure to look into, and reading the back cover citations made us even more pleased. Even the very demanding photos of wood structure from the electron microscope are a pleasure to study the details of. We are looking forward to using the books in our daily work!"

Your "Research Papers.... is the best I ever saw. Congratulations!"

A number of people have joined the CAS after reading these books.

B art Hopkins, editor of EXPERIMENTAL MUSICAL INSTRUMENTS, in cooperation with the Ellipsis Arts experimental instruments, has produced a 96-page color book with 90 photographs and 73-minute CD, with a foreword by Tom Waits, - "GRAVIKORDS, WHIRLIES & PYROPHONES." This includes a description and photos of some very exciting and innovative instruments - from a Photon Clarinet to the Aquavision and 25 foot tall Bass Harp, as well as an article on the Octet instruments. For further information - Ellipsis Arts, P. O. Box 305, Roslyn, NY 11576; email elliarts@aol.com

C ongratulations to Harold Coletta, a violinist and CAS member for over 30 years, who was feted on his 80th birthday. Under the auspices of the New York Viola Society, he will join pianist Abba Bogin and violinist Israel Chorberg for an evening of solo and chamber works at Landon Gallery on March 27. Harold played the Alto Violin years ago for our first recording with Frank Lewin for the TV show "Doctors and Nurses."

B ill Berman, who has played the Alto violin under his chin for 24 years in orchestras and chamber music groups from Israel to New Zealand and in the Portland, Oregon Symphony, stopped by 112 Essex last fall or a nice visit. Others who have made their way to 112 include Brett Allen, Courtney Burroughs and Lillie Wang of Pennsylvania State on a research visit, Dr. Nicholas Cunningham, Knut Guettler of Norway, Young-Nam Kim and his wife, Myoung-Ock, Ceslovas Kulevicius of Lithuania, Eugene and Gina Levinson, Daniel Ling of Canada, Yoko Matsuda, Ted Mook, Pim Radstake of the Netherlands, Professor Kameshaar C. Wali of Syracuse University and his wife, Kashi, Paula and Edward Wall, Joris Wouters of Belgium.... The list goes on and it is always a joy to share in the research, ideas and work of interested and dedicated people.


If your paper is not among those listed above, please send a copy to the office so it can be included.
ISMA '98 - INTERNATIONAL SYMPOSIUM ON MUSICAL ACOUSTICS:

TONE AND TECHNOLOGY IN MUSICAL ACOUSTICS

A joint symposium is being organized by the Catgut Acoustical Society and the Acoustical Society of America. It will take place June 26-30, 1998, following the International Congress on Acoustics (ICA) to be held during the preceding week in Seattle.

The location for this joint symposium is SLEEPING LADY, a mountain retreat located about 2 1/2 hours from Seattle just east of the Cascades mountain range. The site offers excellent conference facilities in a spectacular setting, and is a perfect starting point for subsequent outdoor activities or a family vacation. Sleeping Lady accommodates about 120 people on a room-share basis (2-4 persons to a room); nearby town accommodations and camp sites are also available. For further details, consult their web-site: http://www.sleepingladyresort.com. Bus service from/to Seattle will be provided.

ISMA '98 will consider all areas of musical acoustics. Papers are invited in such areas as sound production in musical instruments, singing, music perception and cognition, computers and music, music performance and theories of music. Workshops are planned for luthiers and others interested in applying acoustical principles to the design of musical instruments.

ISMA '98 provides an opportunity for acousticians attending the ICA meeting to focus on musical acoustics and to interact with instrument-makers and fellow participants.

If you are interested in participating, please return a copy of the reply form as soon as possible. More detailed information will be forthcoming. An ISMA'98 Website site is available at: http://www.boystown.org/isma98/

Organizing Committee: Maurits Hudig, Douglas Keefe, Charles Schmid

Technical Program Committee: Joseph Curtin, Uwe Hansen, William Hartmann, Oliver Rodgers, Thomas Rossing (Chair)

Abstracts (200 words or less) must be received on or before November 15, 1997 at the Catgut Acoustical Society, 112 Essex Avenue, Montclair, NJ 07042, USA. Abstracts may be faxed: 201-744-9197 or CAS E-mail: CATGUTAS@msn.com

PLEASE PROVIDE THE FOLLOWING INFORMATION:
I plan to attend ISMA '98
I intend to present a paper on
Please send detailed information to
(name)
(address)

SEND TO:
Catgut Acoustical Society
112 Essex Avenue, Montclair, NJ 07042
FAX: 201-744-9197
E-mail: CATGUTAS@msn.com
RECENT MEETINGS, WORKSHOPS, SEMINARS

CAS members represented at the Third Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan, held in Honolulu, Hawaii, December 2-6, 1996, presented the following papers:

FUTURE MEETINGS

International Symposium on Musical Acoustics, University of Edinburgh, August 19-22, 1997. For information contact: Arnold Myers, University of Edinburgh, Reid Hall, Bristo Square, Edinburgh EH8 9AG, Scotland. TEL: +44(0)131-650 2423; FAX: 44(0) 131-650 2425; E-mail: A.Myers@ed.ac.uk


Joint 1997 Conference of the Australian Acoustical Society and the Fifth International Congress on Sound and Vibration, University of Adelaide, South Australia, December 15-18, 1997. For information, contact: Congress Secretariat: Fifth International Congress on Sound and Vibration, Department of Mechanical Engineering, University of Adelaide, 5005 Australia. TEL: 61-8-8303-5460; FAX: 61-8-8303-4367; E-mail: iscv5@watt.mecheng.adelaide.edu.au


7th International Congress on Noise as a Public Health Problem, November 22-27, 1998, Sydney, Australia. For information: The Congress Secretariat, Noise Effects '98, GPO Box 128, Sydney, NSW 2001. TEL: 612 9262 2277; FAX: 611 926 2323; E-mail: tourhosts@tourhosts.com.au

Summer String Institute of the California Lutheran University will hold a workshop May 19 - June 20, 1997. Co-sponsored by the Office of Continuing Education and the Department of Music, the courses will include basic bow making, violin building, repair and maintenance. For further information, contact the Office of Continuing Education, 60 West Olsen Road, Thousand Oaks, CA 91360-2787.

24th Annual VIOLIN CRAFTSMANSHIP INSTITUTE of the University of New Hampshire Continuing Education will take place June 2 - August 15, 1995. The workshops will include basic maintenance and minor repairs, intermediate and advanced violin repairs; bow rehairing and repair; violin building workshop. For information call UNH VIOLIN CRAFTSMANSHIP INSTITUTE 603-862-1088, or write to Violin Institute, UNH Continuing Education, Brook House, 24 Rosemary Lane, Durham, NH 03824-3528.

3rd Annual CELLO FESTIVAL will take place June 6-8, 1997 at the University of Connecticut, Storrs, CT. For information: 501 Linn Street, Ithaca, NY 14850. Tel: 607-277-5372.

10th Annual Princeton Workshop, June 22 - 29, 1997, offers string players the opportunity to play chamber music, attend concerts, master classes, workshops. For information: Mary Ann Thomas, Jerry Banks, Directors, 924 Riverside Ave, Trenton, NJ 08618. Tel: 609-599-2569. E-mail: PlayWeek@juno.com

11th Annual Stringed Instrument Restoration Workshop The Oberlin Conservatory of Music in cooperation with the Violin Society of America announces the workshop to take place June 29 - July 25, 1997. The workshop will include bow repair and a special week-long workshop led by Curtin and Alf demonstrating the techniques and materials used in copying Classical Period stringed instruments. For further information: Office of Outreach Programs, Conservatory of Music, Oberlin College, Oberlin, OH 440743. (216-775-8044). E-mail: anna_hoffman@qmgate.cc.oberlin.edu

Symposium '97 - The Association of Stringed Instrument Artisans will take place June 11-14, 1997 at the University of Vermont in Burlington. For information call David Vinopal, P. O. Box 341, Paul Smiths, NY 12970. Telephone: 518-891-5379.

1997 Summer Sessions of the Vermont Music Arts Center will occur July 6 - 26, 1997 at Lyndon State College, Lyndonville, Vermont. For information: Joan Miller, P. O. Box 240, Berkeley Heights, NJ 07922. Telephone: 908-464-6933.
Graduate Program in Acoustics: A two week program will be held June 4 - July 1, 1997 at Pennsylvania State University, University Park Campus. For information: Graduate Program in Acoustics, P. O. Box 30, State College, PA 16804-0030. Telephone: 814-865-6364. Fax: 814-865-3119. E-mail: acoustics@sabine.acs.psu.edu.

World Cello Congress II will be held July 1 - 7, 1997 in St. Petersburg, Russia. The Congress will honor the 70th birthday of Mstislav Rostropovich (who plays a cello made for him by CAS member Robert Spear of Accokeek, MD). The Congress will be a forum for the world's greatest musicians, conductors, composers, and instrument manufacturers from around the world. Telephone: 410-830-3451. Fax: 410-830-4012. E-mail: e&a7bre@toe.towson.edu. WWW site: http://www.towson.edu/~breazeal/cello.htm.


The CAS Journal acknowledges the assistance of the following persons as reviewers during 1996 and 1997:

Ronald Bagley
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Oliver Rodgers
Thomas Rossing
Robert Schumacher
Edward Shaw
Edward Wall
Gabriel Weinreich
James Woodhouse
BOOK REVIEW

The opinions expressed are those of the reviewer and are not necessarily endorsed by the Editorial Board of this journal.

RESEARCH PAPERS IN VIOLIN ACOUSTICS 1975–1993

Edited by Carleen Hutchins and Virginia Benade
Acoustical Society of America, Woodbury NY (1996)

These two massive (1350 large pages and more than 4 kg in weight) and beautifully produced volumes bear witness to the level of continuing interest in violin acoustics around the world. There is undoubtedly much that is of practical interest to scientifically minded violin makers, but the main readership will be found among those concerned with understanding the science behind the sound.

Two earlier volumes, also edited by Carleen Hutchins and published in 1975 and 1976 in the Benchmark Papers series, brought together key papers up to about 1975, and the present volumes bring us up to almost the present day. They provide ready access to virtually all the key literature in the field (all but two of the papers are in English), and will be essential additions to the bookshelves of all those concerned with the acoustics of string instruments.

A major question in any reprint collection such as this, once the key papers have been identified, is that of arrangement. The editors have chosen a presentation based upon violin anatomy, starting with the bowed string and building up through the behavior of the bridge, soundpost, plates and air cavity to the complete instrument. This core material is enclosed between an introductory section on sound radiation and concluding sections on materials, psychoacoustics, and some miscellaneous matters. Each major section is prefaced by a short essay by the editors, giving a historical introduction and an overview of its content, and noting a good selection of other important papers. The whole volume begins with a longer historical review of "350 Years of Violin Research" which reaches back to the mid-16th century and provides a welcome perspective.

This is certainly a reasonable approach, but unfortunately each section is arranged alphabetically by author, rather than following any logical pattern. Thus, the very first paper in Volume 1 is a nice but technical piece on the constant-Q spectral transform, whereas it might have been better to begin with Jurgen Meyer's paper on "The Sound of the Orchestra". The same is true of the excellent survey papers by Arthur Benade on "Musical Acoustics," by McIntyre and Woodhouse on "The Acoustics of Stringed Musical Instruments," and by McIntyre, Schumacher and Woodhouse "On the Oscillations of Musical Instruments," which are buried in the misleadingly titled Section J, "Acoustic Theory and Research Techniques," beginning on page 1147. I recommend that you read these papers first, before diving into the more detailed literature.

Clearly this is not a collection for the beginner, and it is assumed even in the introductory summaries that the reader knows most of the technical background. (Those without this essential are referred by the editors to the New Grove Dictionary.) The papers are, however, for the most part very well written and quite straightforward, and could be read with advantage by anyone interested in the subject and with a reasonable knowledge of acoustics.

It is a test of a compilation such as this to see whether the reviewer finds most of his own favorites among the contents, and also some good papers that have missed his attention. The books are a success on both counts. Only four pre-1975 papers are included, such as John Schelleng's classic "The Violin as a Circuit" and Carleen Hutchins' "Founding of a Family of Fiddles," and the remaining papers span the cited years, though with a surprising emphasis on recent papers—47 of the 121 papers are from the four-year period 1990-93, and there are actually two papers from 1994. Perhaps there has been a recent explosion of activity in the field. Original sources are primarily JASA, JCAS and Acustica, as one would expect, though a few less well known journals also feature.

It is perhaps invidious to pick out particular papers for mention, but worthwhile to highlight some of the developments in the field in the past 20 years. The important series by McIntyre, Woodhouse and Schumacher on bowed-string dynamics is mostly included, and this work is complemented by papers by Gough and others on nonlinearity and string resonances. We now have a fairly thorough understanding of this essential topic.

The main focus of studies of the violin itself has, however, long been on plate resonances. These are the design parameters that are most directly under the control of the maker, and fairly clearly distinguish the musical response of one violin from that of another. The period under review has seen the further development of holographic interferometry, introduced in the early 1970s, as a prime experimental technique for studying plate modes, and this has been supplemented by finite-element calculations on

CASJ Vol. 3, No. 3 (Series II). May 1997
typical instruments and by examination of the air modes in the cavity and their coupling to plate vibrations. Papers by Hutchins and her collaborators, and by the Stockholm group, are well represented in this section, and Rodgers, in particular, has related the findings to practical instrument making. It would be too much to claim that the subject is now well understood, since the relations between mode frequencies and subjective musical evaluation remain empirical, but the papers in these volumes make it clear that our stock of knowledge has expanded greatly.

Papers in the section on wood are mostly quite recent and reflect a growing interest in understanding the properties of this important material from a fundamental viewpoint. The damping properties at audio frequencies are perhaps the most important parameters to measure and control, since these tend to shape the overall spectrum of the violin response—variations in elastic moduli and density can mostly be accommodated by changes in plate profile, though the precise ways in which this should be done are not always entirely clear. Ultrastructure studies by electron microscopy, supplemented by acoustic measurements, are a direct way of approaching the understanding of damping behavior, and are beginning to yield useful information. But wood is a sensitive material, the properties of which vary with age, mechanical history, humidity, and temperature. The effects of surface treatments with filler and varnish are broadly understood, but there is much still to be codified in relation to best practice.

The section on psychoacoustics is something of a mixed bag. All the papers are good and interesting, but the relevance of some of them to violin acoustics is rather slender—the two excellent papers by Pollard and Jansson, for instance, deal primarily with perception of organ pipe sounds. The paper on vibration sensation and finger touch by Askenfelt and Jansson, however, appears to break new ground in an interesting way.

The collected papers conclude with some general works in a section rather strangely entitled "Acoustic Theory and Research Techniques", which would have been better arranged as the introductory section to the volume, and a brief selection on "The Future" of violin research.

The volumes end with brief biographies of all the authors involved—a veritable Who’s Who of the violin acoustics world. Included among the biographies is a welcome extended essay on the life and times of Art Benade, who was a dominant figure in the world of musical acoustics for several decades. The second volume also contains an extensive list of references to papers mentioned in the editorial notes, and a complete index to the CAS Journal 1964-1994. There is also an author index for the published papers, and a somewhat sketchy subject index, but I found both of these rather unsatisfactory because the referencing system is to paper codes rather than to page numbers. This makes it very troublesome to locate any particular citation, since the volume pages do not carry these codes. This is, however, a minor quibble about an otherwise excellent production.

In summary, the editors are to be congratulated on doing a fine job in selecting and assembling this definitive set of papers. These are two volumes that you cannot afford to be without!

Neville Fletcher
Emeritus Professor
Department of Electronic Materials Engineering
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Editor’s Note: In the next issue we will review these two volumes from a luthier’s perspective.
LETTERS TO THE EDITOR

The Journal contains a lot of good technical descriptions. But, if CAS is meant to be an international society, please, inspect better if everything is readable outside U.S.A. A poor example from the May (94) issue p: 24

...a Radio Shack speaker #40-1325A

It gives no information for a reader in Sweden. An address to Radio Shack perhaps could help. But better in such a case, I suppose, must be to give also the values concerning the speaker.

Åke Ekwall, Hantverkargaten 9, S-777 30 SMEDJEBACJKEN, Sweden

Editor: Point taken. We will ask authors to provide the necessary technical information as well as the commercial information.

I stated in my letter to the Editor that the violins are made "without tuning the unmounted plates as practiced by many today." That statement is absolutely true. To imply [as in the May 1996 CAS Journal] that not "tuning" the plates means they are not graduated is wrong. To many in the CAS tuning is synonymous with graduating; however, nothing could be further from the truth. I graduate the plates first, by working them on the inside in a very careful manner checking the bending quality by feel, and second, after they are mounted on the ribs the channel is developed and blended into the arch. It would be impossible to know the actual frequencies of modes 1, 2, and 5 unless one were to remove the plates and check them. I have a feeling that the great masters of the past did something more or less like I do, and they seem to have had pretty fair results.

I have no trouble with those who want to bend their plates and also "tune" them to a preconceived scheme such as bi-tri-octaves. It presents a challenge to the violin maker; however, I believe it has little to do with the assembled violin. Today even those who practice such methods are finally recognizing that after assembly there is work to be done. This is now touted as the next frontier and is presented by Carleen Hutchins as "Beyond Plate Tuning - A Measurable Result." You tap the four quadrants in the assembled violin; and if you don't like what you hear, you remove wood from selected places on the plates. Oops - there go the bi-tri-octaves!

Keep up the good work, keep on bending and protect the results with terpene varnish - you can't go wrong.

William Fulton, Idyllwild, CA

FAIDDLE AFTER A VIOL-PLAYER'S HEART: MONSTER PROGRESS REPORT, PART DEUX. In the last installment of this report, a sequel was promised for later. At present, enough impressions have been gathered to be of interest. I will take it in installments, namely strings, musical uses, playing impressions and problems, and finally a cry for help in finding literature to play!

String problem

Finding the right strings for my alto violin turned out to be a long and also mighty expensive process. To begin with, it was strung up with a massive steel string for the top (diameter 0.36 mm, usable but no more) and various perlon core strings for the others. Exactly which is not too interesting, since they all turned out to be too heavy. After much thinking, it struck me that maybe a solution could be found among viol strings, and so it turned out. The g string turned out to have the same length and pitch as a bass viol C string gripped at fret #7. Such a string, shortened and used as an alto violin g, would thus be working at design tension and should be comfortably playable, which it is. Analogously, the a' string has the same length and pitch as a bass viol top d' string gripped at fret #7. Consequently, a bass viol d' gut string was installed as a top string. The most problematical string was the second or d'. Here, a bass viol e string was too thick (it originally gives b natural at fret 7) and worked at too much tension when tuned up to pitch. In the end, the excellent string maker Damian Dlugolecki made two G'T (Graduated twist) smooth gut strings for the d' and g strings, and a standard bass viol top string from the same maker was used as a top string. Thus,
the final string set becomes, for \( a' = 440 \text{ Hz} \):

<table>
<thead>
<tr>
<th>String</th>
<th>Type</th>
<th>Diameter</th>
<th>Maker</th>
</tr>
</thead>
<tbody>
<tr>
<td>a'</td>
<td>GT gut</td>
<td>14 PM</td>
<td>Damian Dlugolecki</td>
</tr>
<tr>
<td>d'</td>
<td>GT gut</td>
<td>20 PM</td>
<td>Damian Dlugolecki</td>
</tr>
<tr>
<td>g</td>
<td>GT gut</td>
<td>26 PM</td>
<td>Damian Dlugolecki</td>
</tr>
<tr>
<td>c</td>
<td>Perlon,</td>
<td></td>
<td>Dominant, cello G, soft</td>
</tr>
<tr>
<td></td>
<td>over-spun</td>
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</table>

Thus, the best string set turns out to be very likely what a Viola Tenore would have had during the 17th century! The effect of this string set is nothing less than a revelation. All three gut strings have a round, warm and beautiful tone with quite lively harmonics. They are easy to bow, even though the ideal bow has not yet been found. They stay in tune quite well and blend well with the Dominant bottom string.

Musical uses

My alto has now seen some various musical uses. The first was an assortment of Italian madrigals by Claudio Monteverdi. Here, it was used as a support for various voices (mostly tenors) and was very successful. On this occasion the gut string set had not yet been installed, but, on the other hand, the alto was used at \( a' = 415 \text{ Hz} \), (a pitch where this fiddle is quite at home) so that the too tense perlon strings were somewhat relaxed.

Some 18th century music has also been played, in all of which the gut string set was used. In a concert suite in F by Georg Philipp Telemann for recorder, two violins, viola and continuo the alto played the viola part, which worked fine. With a bit of volume moderation balance was quite good, The continuo was harpsichord only, since we had no player for the bass line. If one is found we may have to adjust balance somewhat.

In a duo in g minor for recorder, violin, viola and continuo, also by Telemann, the viola part was played. This part is excellent for practice, since it can be fingered in many different ways. In a Quintet in F by J. C. Pepusch for two recorders, two violins and continuo the alto played the violin II part, which was quite feasible with some use of second and 3rd positions, and gave me a chance to air the now extremely nice top string. This piece was also tried with two fiddles as indicated, but the viola version is nicer—the alto adds a lot of color.

For private practice two particular pieces should be mentioned. One is a Haydn trio in C (originally a baritone trio), the viola part of which is excellent practice stuff, and the other is Carl Philip Emmanuel Bach’s remarkable trio for bass recorder, viola and continuo. Both of these use 1st, 2nd and 3rd position but in quite a kindly manner. So far I have had no opportunity to play any of these two with the full instrumentation but am looking forward to it.

General Playing Impressions

The initial impression of extreme “ergonomicity” remains. This fiddle fits human anatomy to perfection. Why an end pin should be considered necessary is beyond my comprehension. It sits on one’s calves perfectly, and a violine is a quite sufficient security blanket in case of slippery clothing.

Fingering the beast is another matter entirely. I myself have unusually small hands (I have been married twice, and both wives had bigger hands than I), which means that 1st position was quite difficult to get used to, particularly in extended groupings. On the other hand, all other positions are actually more comfortable (less cramped) and exact intonation is easier than on the standard viola/treble viol string length of about 360 mm.

As on any vertical instrument, shifting is quite simple. When one’s left thumb hits wood, 4th position is reached. Besides, like any good fiddle, this beast signals in no uncertain terms whether I am in tune or not.

Bow response is excellent. I am uncertain if I have found the right bow, but the one I have (standard, labeled “viola,” cheap) is probably too heavy. This also goes for my baroque (snakewood) bass-viol bow. The best so far seems to be to use my standard bow but to grip it baroque style.

Cry for help

For such a magnificent instrument, there seems to be quite remarkably little music to play. Whereas music catalogues contain pages and pages of music where a tenor viol is expected, the amount of music for viola is pitifully small. Of course the alto violin is a magnificent instrument (“viola tenore”) for early music. I am not referring to orchestral music (not my cup of tea) but to music of moderate difficulty requiring not too many players, i.e., chamber music. Any tips will be vividly appreciated. The most likely area to look seems to be 17th century Italian and German music. Has anyone written a good tutor yet?

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Åke Ekwall is a long-time member of CAS and is particularly well known for his investigations into the principles of violin design. These culminated in his two volume set, The Art of Drawing A Violin, published in 1994.

Carolyn W. Field is a graduate of Swarthmore College (BA 1948) and the University of Houston (MA 1973). She worked as a student and then colleague of Careen Hutchins between 1977 and 1989. Since 1989 she has made stringed instruments in her shop in Oak Ridge. She is in the process of completing instrument numbers 25-28.

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Charles W. Gadd made his first violin at age 15. While still at high school age he built an elaborate model of a royal coach of the Napoleonic era, winning a scholarship competition sponsored by General Motors. He was graduated from MIT, where he wrote a thesis on the vibrational characteristics of automotive engines. At GM Research until his retirement, he supervised work on strength of materials, vibration, and automotive safety.

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