AIR ANIMATIONS

Much of the low frequency vibrations, which give depth to a violin's sound, are radiated from the air inside the violin pumping in and out of the F-holes. These unprecedented animations by George Bissinger actually show these air flows for the signature modes.

VIOCADEAS composite violin surface – *f*-hole air motions animations

These first-ever composite animations of a violin's corpus signature modes and *f*-hole air motions were taken from separate zero-mass-loading laser surface mobility scans and *f*-hole "patch" nearfield acoustical holography (pNAH) measurements (*Violin f-hole contribution to far-field radiation via patch Nearfield Acoustical Holography***,** G. Bissinger, E.B. Williams, N.Valdivia, J. Acoust. Soc. Am. **121**, 3899–3906 (2007)), using impact hammer strikes at the bridge to excite violin motions.

Some quite new insights into how a violin radiates came from these pNAH measurements when they were combined with farfield measurements over a sphere in an anechoic chamber:

- *Directivity* – the violin's radiation from just the *f*-holes is more directional than from the violin as a whole, leading to more sound from the violin top hemisphere relative to the back. This is an especial help at low frequencies where the violin would normally tend to radiate pretty much uniformly in all directions.
- *Fraction of radiation from the f-holes exceeds 50% for the 1st corpus bending modes $B1^-$ and $B1^+$*. This surprising result comes via the large corpus volume changes associated with the B1 modes.
- *Driving A0.* These B1-driven large airflows through the *f*-holes are also capable of exciting A0, the low-lying cavity mode so essential to violin sound on the low strings, even though A0 is significantly below the B1 frequencies. (This behavior is analogous to that of a ported loudspeaker system where speaker movements effectively change the box volume, forcing air motions in the port. As the speaker output drops at low frequencies the port - which has its resonance tuned below the speaker falloff frequency – then boosts the total output above the speaker alone.) Experimental VIOCADEAS results show that A0 is stronger when the B1 modes are closer in frequency.
- *Falloff with frequency* – the *f*-hole contribution to the overall radiation falls off as frequency increases (a simple extended trendline drops to ~10% at 4 kHz).
- *Complex air motion* - Above about 700 Hz the bulk compression region is no longer valid and simple phase-antiphase *f*-hole air motions no longer hold. As an example the strong *f*-hole radiator at 1080 Hz is presented.
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INFORMATIONAL MATERIAL

<u>Signature modes</u> in the open-string, 196-660 Hz region are crucial to violin sound; they are seen in modal analysis results for every violin irrespective of quality:

1. *Cavity modes* A0 and A1: A0 ($f_{A0} \approx 280$ Hz), always the lowest frequency strongly radiating mode, is characterized as Helmholtz-like; A1, the 1st longitudinal mode with frequency $f_{A1} \approx 1.7 \times f_{A0} \approx 480$ Hz is only sometimes an important radiator, however A1 is *coupled to A0,* strongly affecting A0 volume dependence.
2. *Corpus modes* CBR, $B1^-$ and $B1^+$ - the lowest frequency corpus modes: CBR near 400 Hz, has shear-like in-plane relative motion between top and back plates, a ‡ out-of-plane nodal line pattern on top and back plates,

out-of-phase *f*-hole volume flows and thus relatively weak corpus and *f*-hole radiation; the 1st corpus bending modes $B1^-$ and $B1^+$ both radiate strongly from the surface *and* through the *f*-holes.

The pNAH experiment used a linear microphone array to scan a few mm above the surface over the *f*-hole and immediately surrounding top plate surface. The resulting 108 closely spaced readings of the nearfield radiativity (pressure divided by the exciting force) were then analyzed using mathematical NAH procedures to extract the volume flows at the *f*-holes and adjacent surfaces at frequencies up to 2.6 kHz. The *f*-hole air motions represented here take radiativity readings directly along the middle of the *f*-hole, with phases relative to corpus surface motions taken from pNAH analysis of the entire scan. The animations were adjusted so that the surface mobility and *f*-hole radiativity magnitudes were nominally the same to clarify how surface and *f*-hole air motions relate for each mode.

George Bissinger, April 2009