THE FUNCTION of F-HOLES in the VIOLIN
(revised and corrected)

The most noticeable thing apart from the difference in pitch, about the paper in the STRAD (April 2001, 408) was the similarity between the plots for the harmonic content of the notes played on the G and E strings respectively. This is not surprising since both sides of the central area of the top plate on which the bridge stands, are active; the centre of rotation is variable and not necessarily unique, somewhere between the two feet of the bridge and not exclusively at the right foot as many body and plate modes are activated simultaneously and to varying extents by the fundamental and harmonics of the note being played.

The f-holes perform a function more complex which the paper attempted to point out, than the opening needed for the Helmholtz resonance.

To consider this function first. The frequency of the Helmoltz resonance depends on the volume of air in the body of the violin and the total area of any openings. If the volume is 1945, increased the frequency goes down, 10% reduces it by about a semitone; if the f-hole area is enlarged the frequency goes up, 20% raises it about a semitone, and vice versa. So small variations in volume and f- hole area are not going to have a large effect. The area of an f-hole can be expressed in terms of an equivalent ellipse for the purpose of calculation (J.W.Strutt (Lord Rayleigh). The Theory of Sound, Dover, Vol 2, 176) as used by Helmholtz (On the Sensations of Tone, Dover, 1954 86).

To be more specific, the volume of air acts as a spring together with the walls of the body. If the walls are rigid, the air alone, provides the spring action. The body of the violin is always somewhat compliant and lowers the frequency of the Helmholtz resonance. Fitting the soundpost increases its stiffness, enough to raise the Helmholtz resonance by about four semitones. Variation in soundpost stiffness would have an effect as would variation in body stiffness. For a violin used in these studies the stiffness of the air/body at the main air resonance with no soundpost (250 Hz) was 98 N/m and with the soundpost fitted (283 Hz) 125 N/m.

In addition to a spring element, for a resonance to occur there has to be a mass element. And on all real systems there is some damping. The mass element is provided by the plug of air situated in the f-holes. This is difficult to define and will extend beyond the two surfaces of the top plate. It is this air plug when vibrating that radiates sound and will require an energy input to maintain the vibration (and radiation) otherwise it would decay at a rate determined by the damping and the energy lost through radiation.

It is possible to calculate the mass, m, of the air plug in the f-holes that is excited at the main air resonance using the expression $m = k/(2\text{pi } f)^2$ where "k" is the stiffness and "f" is the main air resonance frequency. From the mass and the density, d, of the air, 1.205 kg/m^3, the volume of the air plug using $v = m/d$ and hence the length that vibrates in the f-hole from the area of the f-hole. As an example, for f = 285 Hz, and k = 108 N/m the value of m = 34 mg. The volume for two f-holes becomes $v = 34 \times 10^{-6}/1.205 = 28.2 \times 10^{-6}$ m^3 and hence, using the area of one f-hole of 685.7 mm^2, the length is $14.1 \times 10^{-6}/685.7 \times 10^{-6} = 20$ mm. The stiffness , k, includes that of the 2 litres of air in the violin and the stiffness of the body. The air plug clearly extends on both sides of the f-hole. The thickness of the plate at the f-hole will affect the damping as it vibrates. A thick, rough edge will give maximum damping and hence peak width but a lower peak height. A thin edge will raise the height of the peak and reduce the width. The sides of the f-holes are usually cut normal to the plane of the violin.

As for the other function of the f-holes, the most obvious one is that they detach the central region on which the bridge stands from the sides of the top plate attached to the centre bout. It has long been considered necessary for this region to be supported by the bassbar and the soundpost. A violin whose plates are not too thin is able to support the bridge when fitted up without the presence of the bassbar or the soundpost. So that while both these items help to support the forces, their major purpose may be otherwise; the bassbar to restore the stiffness and tuning lost on cutting the ff's and the soundpost to adjust the evenness of output across the strings.

The bridge has not always been located between the notches in the ff's as accepted to-day. It has been placed to varying distances below them in times past, but the soundpost, it is thought, remained near its present position. The reasons for moving the bridge to these lower positions has been commented on briefly by David Boyden (The History of Violin Playing, O.U.P. 1975, 34) that by so doing, the longer string gave more space in the higher positions and a more viola like tone was obtained. If the higher pitches were to be maintained, the longer string length would require a higher tension with greater demands placed on the gut strings of the time. It might have benefitted the G string of the day which was unwound.

The spacing of the ff's has been variable, with the upper eyes not less than the width of the bridge feet. The bassbar was placed under the bass foot of the bridge. The bassbar and the soundpost influence the motion of the region of the top plate between the f-holes. The right foot of the bridge would provide a pivot for the motion of the of the bassbar area while the soundpost would excite the back. The central area between the f-holes has often been made thinner than the rest of the top plate.

The nodal lines of vibration modes are influenced by the position of the soundpost, tending to pass through its position. It is desirable to have the nodal lines near the margins of the plates for maximum radiation. A top plate glued to rigid sides showed some major changes in nodal patterns when the f-holes were cut (Jansson E. et al "Resonances of a Violin Body Studied by Hologram Interferometry and Acoustical Methods" Physica Scripta, Vol 2, 1970, 243-256). The main difference was the immobilisation of the plate area between the f-hole and the plate edge at the C-bout. The margins of both plates are effectively clamped as the glue joint between the plates and the sides must remain intact. Any flexing must occur in the margins away from the joint and possibly in the sides. The inner edge of the f-holes then becomes an effective "free" edge of the plate in this region. Some resonance modes are modified in the vicinity of the f-holes. The soundpost creates an "island" at the treble f-hole in association with the main air resonance and nodal lines along the top tend to pass through the ff's.

The unique shape of the soundholes must allow the bridge the maximum freedom to function in transferring the string vibrations to the top plate with some latitude in bridge placement as seen in early paintings. Other shapes while allowing the main air resonance, would appear to be more restrictive. Early instruments showed crescent shapes, both inward and outward facing. Turning the top half of an outward facing C shape and adding the finials reduced the possibility of cracks and freed the central area while connecting it to the rest of the plate area.