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Influence of Reed Motion on the Resonance Frequency of Reed-Blown Wood-Wind Instruments

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When vibrating, the reeds of wood-wind instruments displace an amount of air that shifts the resonance frequency of the instrument in the same way as does a mouthpiece cavity. In cylindrical instruments, this shift corresponds to an effective lengthening of the resonating tube. In conical instruments, the shift is strongly frequency dependent and it is essential for bringing first and second mode in tune.

BLOWN FREQUENCIES OF REED-EXCITED WIND INSTRUMENTS ARE well below calculated frequencies, even when corrections for boundary-layer effects and closed holes are applied. Most of the discrepancy seems to be connected with reed excitation; Backus[1,2] compared blown frequencies with "passive" resonances (obtained by weakly coupled external excitation) and he found the blown frequencies of clarinets and bassoons to be as much as a semitone flat.

The observed difference can be explained by taking into account air motion induced by the moving reed and reed damping. Both effects can be shown to lower the frequency.[1,3,4] Backus found experimentally the influence of reed damping to be less than about 15 cents. The influence of reed motion can be estimated when the area and the compliance of the reed are known. This influence, though also present on single-reed instruments (clarinet, saxophone), is more manifest on double-reed instruments (oboe, bassoon) and is best be illustrated for these instruments.

Double reeds were microscopically observed during a lowering of the pressure at the instrument side, and measurements were made of the static deflection C of the reed blades (defined as the change in distance of two opposing blades at the reed center). Illustrative results for an arbitrary (artificial) lip position, reduced to a unit pressure difference across the reed, are plotted in Fig. 1 for an oboe reed and a bassoon reed. The width B of the oboe reed is 7 mm over its whole moving length; the bassoon reed is 15 mm wide at the tip, which value decreases gradually, being about 11 mm at 20 mm from the tip.

The total volume of displaced air per unit pressure difference is found by integrating Curve C along the length of the reed, after

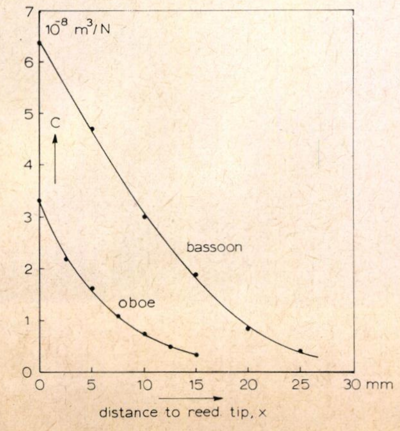

FIG. 1. Compliances of oboe reeds and bassoon reeds. C denotes the change in distance of two opposing blades at the reed center, as a function of the distance, x, from the reed tip, and per unit pressure difference across the reed.

multiplication with B and a factor of $\frac{2}{3}$:

$$A=\frac{2}{3}\int BCdx. \quad (1)$$

Numerical results are presented in Table I. The factor of $\frac{2}{3}$ was introduced in order to account for the fact that the deformation is a maximum in the center: It very closely resembles a part of the circumference of a circle and decreases towards the sides of the reed. For very slender segments, $\frac{2}{3}$ is the ratio of the area of a segment of a circle to its circumscribed rectangle.

The volume velocity U_r caused by the reed moving under

TABLE I. Some measured and computed quantities for oboe and bassoon.

Quantity	Oboe	Bassoon
Tube radius at throat, a_0 (mm)	1.5	2
Truncation, r_0 (mm)	110	280
A (10^{-14} m^5/N)	100	750
V/V_0	0.55	0.9

influence of an oscillating pressure difference p is given by

$$U_r=-Adp/dt. \quad (2)$$

We compare this with the volume velocity from a cavity of volume V at the same place:

$$U=-(V/K)dp/dt, \quad (3)$$

where K is the bulk modulus of air. From comparison of Eqs. 2 and 3, we conclude that the reed motion has the same influence as a mouthpiece cavity V of a magnitude

$$V=AK. \quad (4)$$

For a cylindrical tube, such a cavity acts approximately as a fixed increase in length, and notes of lower and upper registers are shifted with the same amount; this is in agreement with experience. As has been reported earlier,[5,6] the action of a mouthpiece cavity in conical instruments is different. This is shown from the resonance condition

$$(1-k^2r_0^2V/3V_0)\tan(kr_0-kr_1)=kr_0, \quad (5)$$

where k denotes the wavenumber; $V_0=\pi a_0^2 r_0/3$, the volume of the truncated part of the cone; a_0, the radius at the throat of the tube; and r_0 and r_1, the distances of throat and open end of the tube to the apex of the horn (Fig. 2).

When kr_0 is very small, a solution to Eq. 5 is $kr_1=n\pi$, with n integer. This solution is not applicable here, because $kr_0>0.3$ in conical instruments. Therefore, Eq. 5 has to be solved numerically for various values of k and V. Results for a bassoon are shown in

Fig. 3, where deviations, expressed in cents, from the zero-order approximation $kr_1 = n\pi$, are plotted against the sounding note. Curves are shown for four different values of V/V_0. Obviously, for $V/V_0 \approx 1$, the two octaves are reasonably well in tune. When V is too small, the notes are sharp; when $V=0$, the highest notes are as much as a whole tone sharp.

The mouthpieces of saxophones contain a cavity with at least a part of the required volume. In oboes and bassoons, a mouthpiece cavity is practically absent. In an earlier paper,[6] an attempt was made to ascribe a "mouthpiece-cavity effect" to the intricate diameter irregularities found near the staple of the oboe. I recently proved this explanation to be unsuccessful from computations of resonance frequencies for an oboe tube simulated by a number of short conical tube pieces.

An estimate of the influence of the reed motion is obtained, by use of the values for A, a_0 and r_0, as specified in Table I. In the same table are given the calculated magnitudes of the fictitious cavity due to reed motion, expressed in units volume V_0. Apparently, reed motion partly or completely accounts for the desired quantity. Because of the many approximations, these figures should only be taken as fair estimates.

We conclude that, although there are certainly other influences, the reed motion cannot be neglected as a factor in the tuning of reed-excited woodwinds. It shows the utmost importance of reed properties for intonation, which, after all, should not be a surprising conclusion for an experienced musician.

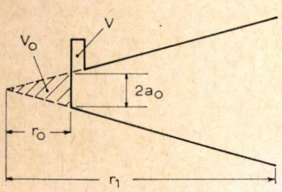

FIG. 2. Explanation of symbols used for a truncated cone, closed at the throat and provided with a mouthpiece cavity of volume V.

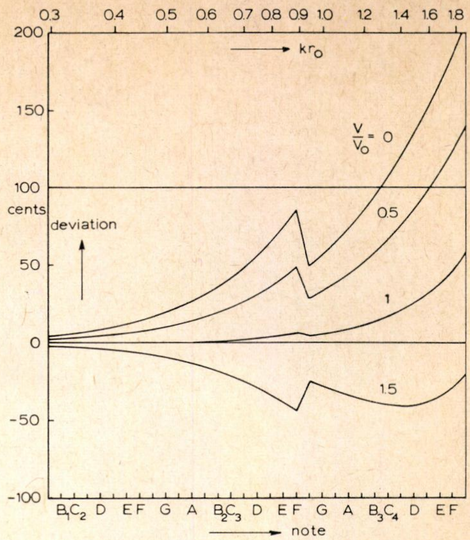

FIG. 3. Frequency deviation, expressed in cents, for a bassoon for various values of the mouthpiece-cavity volume.

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