Relationship between Transient Sound and Mouth Tone in Flue Organ Pipe

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Introduction

The study on the transient sound of flue organ pipes is a very complicated task. This is mainly because the duration of attack transient is quite short; moreover the transients of the same pipe may be different even if the blowing pressure is fixed. The relationship between the transient sound and the "mouth tone" of a flue organ pipe is investigated in this paper. An organ pipe made by an organ builder as well as a small organ model containing a very steady blowing system were used for acoustic measurements carried out in the anechoic room at the Fraunhofer IBP.

Mouth tone

The mouth tone was intensively studied by Castellengo[1] and she suggested a mutual relationship of the mouth tone to the transient of the flue pipe tone. The mouth tone can be defined as the sound that is emitted from a pipe when its resonator is filled with appropriate acoustic absorber. The expression of "mouth tone" was chosen because it is generated by the system just around the pipe mouth.

Mouth tone spectrum

At first, the pipe sound was measured. Since it consist of the attack transient and the steady sound, two different analysis methods were applied; a spectrogram was determined for the transient and a FFT spectrum for the steady sound, as shown in Fig.1. Next, steady mouth tone was measured after filling the pipe column with an absorber. Its FFT spectrum is superimposed on that of the pipe tone in Fig.1. The mouth tone sounds like a broad-band noise with some tonal components. The frequency of the largest peak in the mouth tone spectrum can be recognized between the 7th and 8th harmonics of the pipe sound. The component with the fastest build-up in the spectrogram of the transient can be observed in the same frequency domain, slightly over the 7th harmonic of the pipe sound. It is reasonable to assume that at the beginning the 7th eigenfrequency of the pipe resonator is excited by the strongest mouth tone component. After about 130-150 ms the frequency shifts down to the 7th harmonic of the pipe sound.

Such a tendency was already reported by Castellengo[1]. An acoustic pressure distribution is created around the mouth of a flue pipe when the jet starts to oscillate around the upper lip. This acoustic signal drives the pipe. The motion of the jet at the mouth is then affected by the pressure distribution due to pipe resonances as the result of a feedback. This means that the feedback enhances the sound whose frequency corresponds to the fundamental acoustic resonance of the resonator; however, the formation of such a feedback takes several fundamental periods. Since the system around the mouth responds much faster than the resonator, it is assumed that the mouth tone appears first in the transient of pipe sound and excites the resonator eigenmodes.

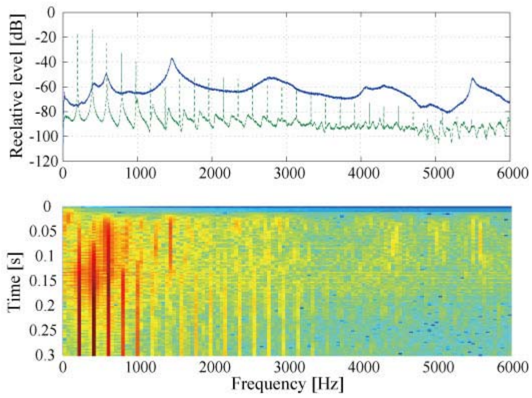

Figure 1: An example of mouth tone spectrum. Top: mouth tone spectrum (blue line) with pipe sound spectrum (green dashed line), bottom: spectrogram of the attack transient.

Effect of blowing pressure to mouth tone

Additional mouth-tone measurements were carried out with two additional blowing pressures. Blowing pressure was adjusted to high pressure (640 Pa), normal pressure (590 Pa) and low pressure (553 Pa). The results are indicated in Fig.2. Every peak frequency is proportional to the blowing pressure. The frequency of the largest peak around 1.6 kHz raises from 1602.9 Hz at low pressure, to 1608.3 Hz at normal pressure and to 1644.6 Hz at high pressure, while this peak becomes broader with the blowing pressure. The ratio of the each mode frequency to the fundamental tends to be constant with no relation to the blowing pressure. For example, the second mode frequency is about 2.5 times and third mode frequency is about 4.6 times of the fundamental.

Comparison between edge tone and mouth tone

Edge tone is the sound which is radiated from the structure consisting of a slit and a wedge when the jet emerging from the slit hits the wedge. The jet starts to oscillate around the wedge and acts as an acoustic dipole source. The frequency of the edge tone scales with the blowing pressure and different modes can be excited by increasing the pressure. Until around 1960, it was believed that the sound of flute-like instruments was generated by the resonating edge tone. This shows the deep relationship between the flute-like instruments and edge tone. Mouth tone is also generated by the oscillating jet; however, the source geometry is different. The wedge (the upper lip) is not free-standing any more; it is bounded from one side by the absorber filled pipe, thus the dipole source experiences an asymmetric acoustic load.

Moreover, transversal acoustic resonances of the lower part of the pipe and damped resonances of the absorber filled pipe may also appear in the mouth tone spectrum. The main peaks however, correspond to edge tone modes.

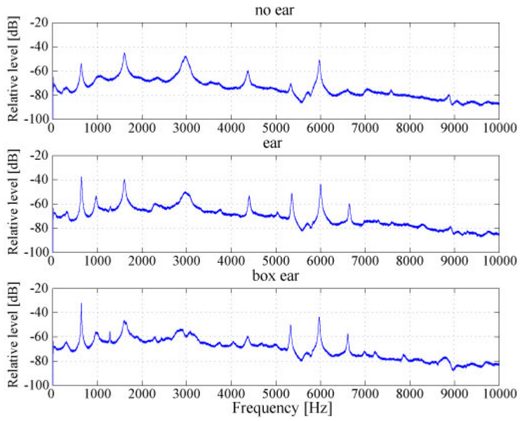

Figure 2: Mouth-tone spectra. Top: low pressure, middle: normal pressure and bottom: high pressure.

Table 1: Pressure in the foot and jet velocities

	Pressure [Pa]	Velocity [m/s]
low pressure	253	20.59
normal pressure	270	21.27
high pressure	292	22.12

Brown´s equation

Brown [2] derived the following relation between edge-tone frequency and jet velocity from his experiment:

$$f_j = 0.466 j(100U - 40)\left\{\frac{1}{100h} - 0.07\right\} \quad (1)$$

$$j = 1.0, 2.3, 3.8, 5.4$$

where f_j [Hz] is the frequency of the j-th edge tone mode, U [m/s] is the mean jet velocity, h [m] is the distance between slit and edge and j is a constant whose value depends on U and h, respectively. Edge-tone frequency is proportional to U with constant h and it jumps to the next mode with increasing jet velocity. The four j values given in Eq. 1 correspond to the first four edge tone modes for the investigated pipe geometry and jet velocity range.

For our case, mean jet velocity was calculated by the pressure in the foot using Bernoulli's law as follows:

$$P = \frac{1}{2}\rho_0 U^2 \quad (2)$$

where P [Pa] is the pressure in pipe foot and ρ_0 is the static density of air (1.19 kg/m3 at 22°C and 1 atm.). The jet velocity calculated by Eq. 2 is shown in Table 1. For that jet velocity range the edge tone must oscillate on the second or third mode, either with a j value of 2.3 or 3.8.

Comparison in frequency

Peak frequencies of the mouth tone were read out from the spectra and plotted in Fig.3 as a function of the jet velocity. The second and third mode frequencies of the edge tone, calculated by Eq. 1, are also indicated in Fig.3. The cut-up height (the distance from the jet exit to the upper lip) was used as h. Two dashed lines, labelled as II and III, show the second and third mode of Brown's equation, respectively. Coloured lines indicate the modes of the measured mouth tone. Mouth tone modes were estimated from the shape of spectrum. From Fig.3, the third mode of edge tone is very close to the fourth mode of mouth tone. In other words, mouth tone component around 4 kHz is corresponds to edge tone.

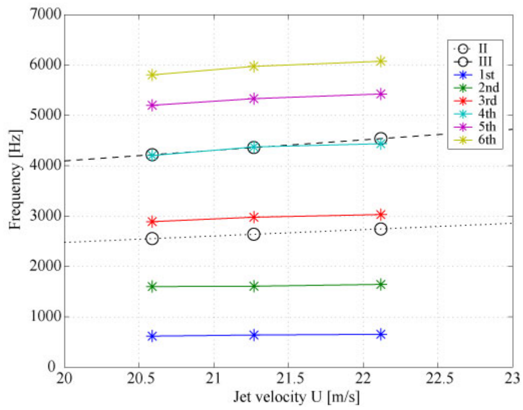

Figure 3: The change of the mouth-tone peak frequencies, and the related edge-tone frequencies of 2nd and 3rd mode.

Conclusion

It was confirmed that the fastest harmonic component in the transient was determined by mouth tone. The mouth tone component around 4 kHz must be an edge tone. The reason why the other peaks of mouth tone appear should be explained in the future.

References

[1] M. Castellengo: Acoustical analysis of initial transients in flute like instruments. ACUSTICA-acta acustica, Vol. 85, pp. 378 - 400, 1999.

[2] G. B. Brown. The vortex motion causing edge tones. Proc. Phys. Soc. London XLIX, pp. 493 - 507, 1937.