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 flute 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 of pipe sound and excites the resonator and 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.](image)

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.](image)

### Table 1: Pressure in the foot and jet velocities

<table>
<thead>
<tr>
<th>Pressure [Pa]</th>
<th>Velocity [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>low pressure</td>
<td>253</td>
</tr>
<tr>
<td>normal pressure</td>
<td>270</td>
</tr>
<tr>
<td>high pressure</td>
<td>292</td>
</tr>
</tbody>
</table>

**Brown’s equation**

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

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

\[j = 1.0, 2.3, 3.8, 5.4\]  

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:

\[
P = \frac{1}{2} \rho_0 U^2
\]

where \(P\) [Pa] is the pressure in pipe foot and \(\rho_0\) is the static density of air (1.19 kg/m\(^3\) 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.](image)

### 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
