Prediction of overblowing behavior of an organ flue pipe

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Introduction

In a normal situation of an organ, foot pressure, which is air pressure supplied to a pipe, is generally fixed in a range from 500 to 900 Pa. A pipe, however, makes sound with foot pressure in a much broader range. If the pressure is changed from a few tens Pa to nearly 10 kPa, a pipe sounds in several different oscillation regimes. This phenomenon is called overblowing behavior.

Figure 1 shows such an example observed in an E4 organ flue pipe[1]. When foot pressure is moderate, the

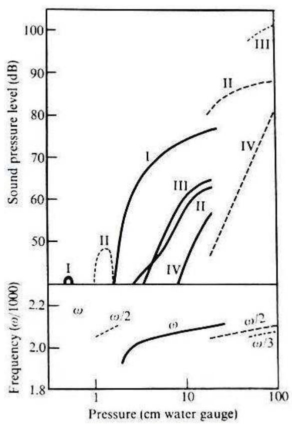


Figure 1: Overblowing behavior in an E4 organ pipe.

normal oscillation regime in the first resonance mode appears. The upper panel represents sound pressure levels of the harmonics. The lower panel represents sound frequency divided by the mode number. When the pressure is increased, regimes in the second and third modes are generated. These are called overblows. When the pressure is decreased, other oscillation regimes in the first and second modes are found. These are underblows.

The purpose of this research is to simulate overblowing behavior of an organ flue pipe. How accurately overblowing behavior can be simulated would be a barometer of how much we understand the sounding mechanism of the flue instrument.

Sound production of an flue pipe makes a feedback loop. As shown in Fig. 2, a jet comes out from a flue and oscillates in a pipe mouth while it is traveling between a flue and an upper labium. The displacement of the jet perpendicular to the traveling direction is denoted by $\eta(t)$. A part of the flow $U_{\mathrm{jet}}(t)$ comes into a pipe and excites it acoustically. As a result, pressure $p(t)$ and volume flow $U(t)$ are generated in the pipe mouth. The lumped air in the pipe mouth oscillating with $U(t)$ deflects the jet and make it oscillate with the same frequency. In phys-

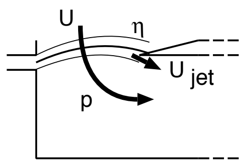


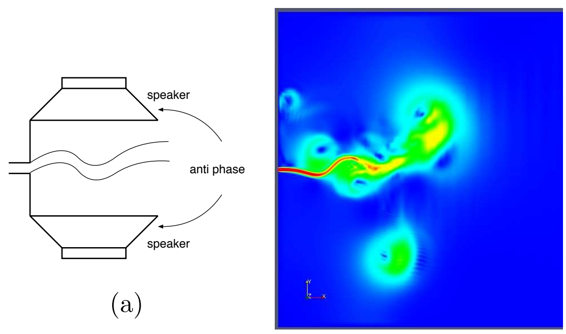
Figure 2: Flows and pressure near the pipe foot.

ical modeling sound synthesis, these processes should be adequately modeled.

Flow simulation

Coltman examined the motion of a jet deflected due to sound experimentally[2]. In his setup, a pair of speakers driven in anti-phase generate an acoustical cross flow in a channel where a jet travels. The same experiment was performed numerically in this paper with the method shown in Adachi[3]. The incompressible Navier-Stokes equations were solved in a two-dimensional domain representing the pipe mouth using the finite element method. Sound field, that is the oscillating lumped air, was realized by a special boundary condition. Instead of the pair of speakers in Coltman's experiment, oscillating acoustic velocity on the upper and lower boundaries were imposed.

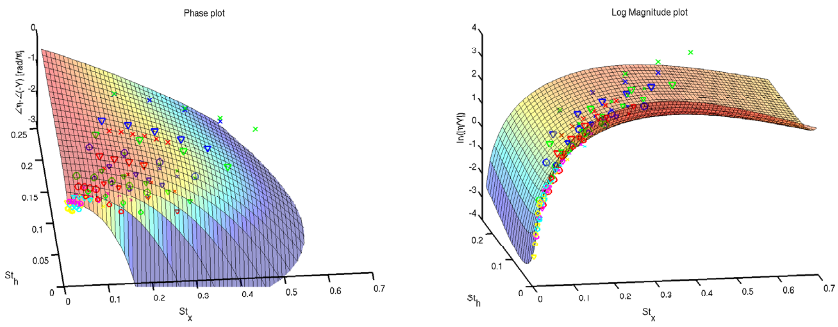
In the simulation, several parameters were specified as follows: The flue thickness h was set to 0.25 or 0.5 mm. Tophat (or constant) velocity profile at the flue was assumed. The initial jet velocity V_0 was from 5 to 60 m/s and The sound frequency f was changed among 200, 500 and 800 Hz. Figure 3 shows an example of a jet numerically simulated.



(a) (b)

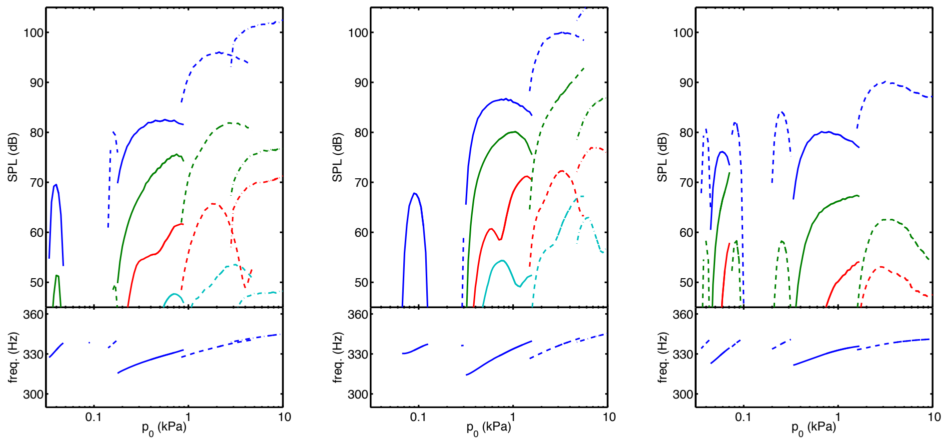
Figure 3: (a) Schematic illustration of a jet deflection experiment. (b) An oscillating jet numerically simulated.

From the simulated jet, displacement η normalized by acoustic displacement Y was measured at several differ-



(a) Phase (b) Amplitude

Figure 4: Data of η/Y obtained in numerical simulations and fitting surfaces as functions of two Strouhal numbers St_x and St_h.



(a) New model (b) Fletcher's model (c) Coltman's model

Figure 5: Overblowing behaviors simulated in physical modeling technique with (a) the new jet deflection model, (b) Fletcher's model and (c) Coltman's model.

ent distances of x from the flue. The phase and amplitude of η/Y are plotted in Fig. 4 as functions of two Strouhal numbers St_x and St_h, which are defined by $St_x = fx/V_0$ and $St_h = 3\pi fh/2V_0$, respectively. The data of the phase and amplitude were fitted to surfaces also shown in Fig. 4 (a) and (b). The surfaces provide η/Y as functions of St_x and St_h. A jet deflection model was thus developed from the numerical experiment.

Overblowing behavior

Using a physical model of an organ flue pipe[4], overblow behavior of an E4 organ flue pipe was simulated. The behavior simulated with the new jet deflection model is shown in Fig. 5 (a). For comparison, behaviors simulated with Fletcher's model and Coltman's model were also shown in Fig. 5 (b) and (c).

In Figs. 5 (a) and (b), the normal oscillation regime, two overblows in the second mode and the other in the third mode, and two underblow regimes are successfully simulated. We find that the foot pressure range for each oscillation regime in Fig. 5 (a) is more accurately simulated than in Fig. 5 (b), when the figures are compared with the experimental result shown in Fig. 1. In Fig. 5 (c), too many underblows and no overblow regime in the third resonance mode are observed. We can therefore conclude that the new jet deflection model developed in this research has better performance than the other models. We should, however, note that the simulated sound pressure levels are still much larger than those found in the experiment in the underblows.

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