Numerical simulation of the flow in the flue organ pipe

Seiji Adachi, Judit Angster and András Miklós
Fraunhofer Institute for Building Physics, Nobelstr. 12, 70569 Stuttgart, Germany, Email: seiji.adachi@ibp.fraunhofer.de

Introduction

Sound generated in a flue organ pipe is susceptible to the voicing adjustment. A small change in the configurations of the flue, lower and upper labiums, etc. often results in a great change in the sound. This research aims to assist the voicing process by clarifying the effect of the adjustment on the physical properties of the air jet emerging from the flue and thus on the output sound. To this end, the numerical simulation of the airflow in the flue pipe and the sound synthesis based on the physical modeling are performed. Two specific adjustments are considered in this paper: the height of the lower labium relative to the languid and the inner geometry of the foot hole.

Sounding mechanism overview

Sounding of a flue pipe is a self-excited oscillation[1]. Figure 1 schematically illustrates how the air jet coming out

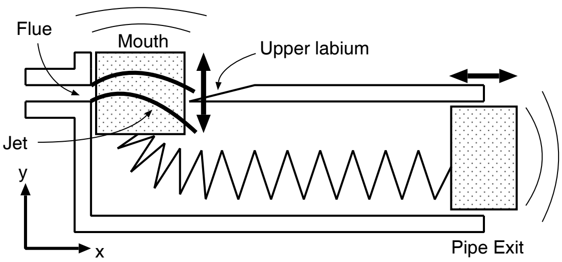


Figure 1: Schematic diagram of an organ flue pipe sounding in the first resonance mode.

from the flue and the aircolumn in the pipe interact with each other in the pipe mouth. The air jet is deflected by the sound (aircolumn oscillation) in the mouth. At the same time, a part of the airflow accompanying the jet comes into the pipe and excites the aircolumn.

The entire process of this self-excited oscillation is fairly modeled in [2]. Although the output sound can be synthesized with this model, several parameters such as the angle of the air jet coming out from the flue should be fixed in advance. Numerical flow simulation is performed for this purpose.

Flow simulation

To simulate the air flow in the flue pipe numerically, the same method as in [3] was used. This method discretizes space with the finite element method (FEM) and solves the incompressible Navier-Stokes equations. The flow is assumed to be two dimensional.

Because the purpose of the simulation is to find the angle of the air jet coming out from the flue, the calculation domain was prepared only for the pipe foot, the flue and an external downstream region. Neither the pipe nor the upper labium was considered here. The simulations were performed on two different geometries. The former one was made from the dimensions of a wooden flue pipe of D4, and the latter one was made from a modeled metal pipe foot that was used for the edge tone analysis in [4, 5].

In the simulation of the wooden pipe, two cases were considered: one with the lower labium placed 0.5 mm lower than the level of the languid and the other with the labium is on the same level as the languid. In both cases, the average flow velocity at the flue whose thickness is 0.8 mm is assumed to be 25.0 m/s.

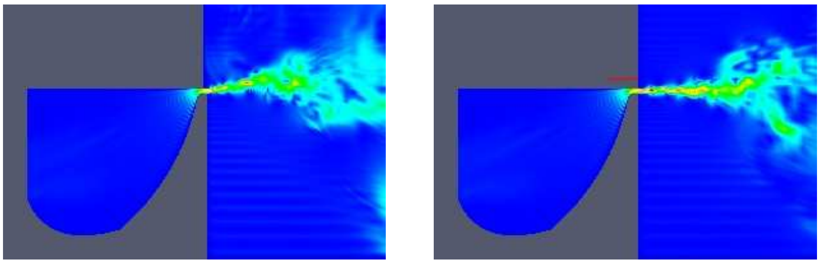
Two cases were also considered in the simulation of the metal pipe. Case 1 has larger curvature on the front side of the inner wall just above the foot hole, whereas case 2 has larger curvature on the back side. Due to this difference in the inner foot hole geometry, the flow in the foot is expected to change between these cases. The flue has a thickness of 2.0 mm and the average flow velocity at the flue is set to be 24.0 m/s in these cases.

Snapshots of the flow simulations for the wooden pipe with the lower and normal positions of the lower labium are shown in Fig. 2 (a) and (b), respectively. The flows were simulated in these cases for one second and the angles with which the jet coming out from the flue were found to be 6.4 and 3.9 degree outwards, respectively, from the horizontal direction in the figure.

Snapshots of the flow simulations for the metal pipe are shown in Fig. 3 (a) and (b). In Fig. 3 (a), the flow circulates clockwise, while in Fig. 3 (b) it circulates counterclockwise. This difference in the flow is probably caused by the Coanda effect that is the tendency of a flow to stay attached to a boundary surface (in the present cases, the inner wall of the pipe foot). It is, however, found that the jet angles in these two cases are the same. This implies that the output sound does not change between these cases. This result may somewhat contradict the fact that the edge tone changes between these cases as reported in [4, 5].

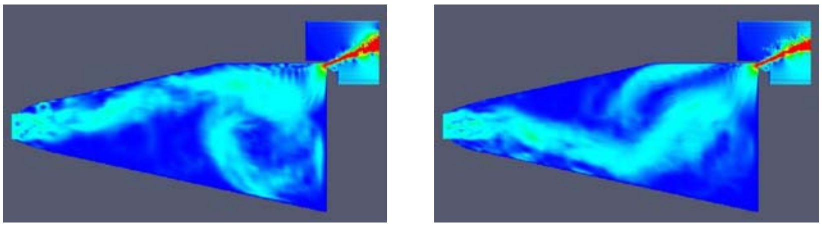
Sound synthesis

To estimate the change in the output sound of the wooden flue pipe due to the lower labium height, sound was synthesized using a physical modeling[2]. This model assumes Fletcher and Thwaites' theory[6] of the jet deflection by the sound. The original physical model is slightly modified here to incorporate the non-linear radiation impedance of the mouth due to the vortex shedding at the upper labium by the acoustic flow[7].



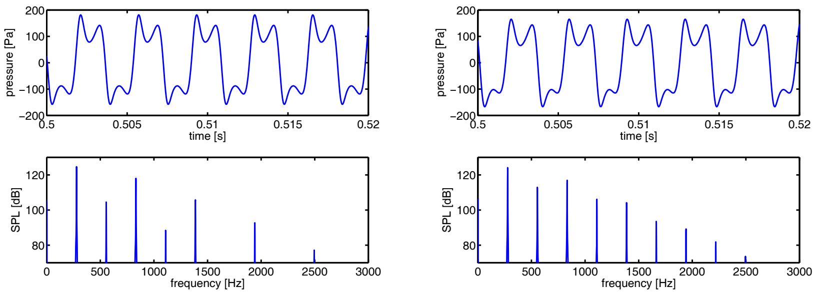
(a) Lower position (b) Normal position

Figure 2: The effect of the lower labium position on the jet angle. In (a), the labium is placed 0.5 mm lower than the level of the languid, whereas in (b), the labium is on the same level. The jet angle in (a) is 2.5 degrees larger outwards.



(a) Flow state 1 (b) Flow state 2

Figure 3: The effect of the foot hole inner geometry on the direction of the flow circulation in the pipe foot. In (a), the inner wall just above the foot hole on the front side (upper side in the figure) is curved, whereas in (b), that on the back side (bottom side in the figure) is curved. Due to the Coanda effect, the flow in (a) circulates clockwise, while that in (b) circulates counterclockwise.



(a) jet angle = 0 degree (b) jet angle = 2.5 degree

Figure 4: The waveforms and spectra of the sounds synthesized with the physical modeling technique in both cases where the jet is directed (a) straight towards the upper labium and (b) 2.5 degree outwards. In (a), the levels of the even harmonics are considerably depressed. This is because the jet strikes the labium symmetrically.

Figure 4 (a) and (b) shows the waveforms and spectra of the synthesized sounds in the cases where the direction of the jet is straight toward the upper labium (0 degree) and 2.5 degree outwards, respectively. Although the waveforms look very similar, the spectra are quite different: in Fig. 4 (a) the level of the even harmonics are considerably depressed, whereas in Fig. 4 (b) no such depression is observed. By listening to these output sounds, one can distinguish the difference.

Conclusions

By simulating the airflow in a wooden flue pipe, it was found that the angle of the jet emerging from the flue was 2.5 degree increased as the position of the lower labium was 0.5 mm lowered from its normal position. Using physical modeling sound synthesis, we found that the output sound also changes with the increase of the jet angle. This illustrates that the method described in this paper is beneficial to estimate the sound change caused by a voicing adjustment.

Acknowledgment: This research was conducted in the frame of the project "Physical model of the sound generation in flue organ pipes" founded by the European Marie Curie International Incoming Fellowship.

References

[1] Fletcher, N.H. and Rossing, T.D.: *The physics of musical instruments.* Springer-Verlag, New York, 2nd ed. 1998, Chap. 16

[2] Adachi, S.: Time-domain modeling and computer simulation of an organ flue pipe. Int. Symposium on Musical Acoustics, Proc. of the Institute of Acoustics **19** (1997), 251–260

[3] Adachi, S.: CFD analysis of air jet deflection — Comparison with Nolle's measurement. Proc. of Stockholm Music Acoustics Conference (2003) 313-316

[4] Pitsch, S.: Schneidentonuntersuchungen an einem Orgelpfeifenfußmodell. MSc thesis, Institut für Aero- und Gasdynamik, Universität Stuttgart (1996)

[5] Pitsch, S., Angster, J., Strunz, M. and Miklós, A.: Spectral properties of the edge tone of a flue organ pipe. Int. Symposium on Musical Acoustics, Proc. of the Institute of Acoustics **19** (1997), 339–344

[6] Fletcher, N.H. and Thwaites, S.: Wave propagation on an acoustically perturbed jet. Acustica **42** (1979) 323–334

[7] Verge, M.P., Hirschberg, A. and Caussé, R.: Sound production in recorderlike instruments. II. A simulation model. J. Acoust. Soc. Am. **101** (1997) 2925-2939