Study of the input acoustic impedance of a vibrating cylindrical shell: consequences on clarinet-like instrument

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Introduction

The influence of the wall vibrations on the acoustic behavior of wind instruments is a widely debated matter, although no clear results have been obtained. Musicians and manufacturers of wind instruments often state that the construction materials play an essential role in the acoustic quality of the instrument. Many scientific studies have aimed to address all phenomena related to wall vibration effect, but there are many difficulties to evaluate and quantify the role played by the instrument's material on its acoustic response. In this work a vibroacoustic model of a clarinet-like instrument is proposed to evaluate the wall vibration effect on the acoustic behaviour of a wind instrument.

Vibroacoustic model

The body of the instrument is assimilated to a simply-supported thin-walled cylindrical shell. The coupling between the shell modes of the body of the instrument and the acoustic modes of the air column (see figure 1) is deduced with an analytical vibroacoustic multimodal model [1].

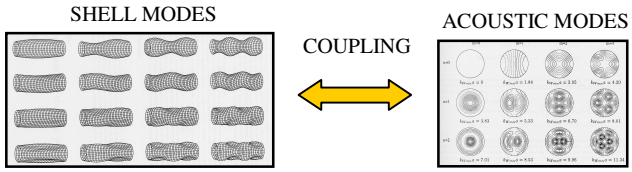

Figure 1: Vibroacoustic coupling between shell modes and acoustic modes

The acoustic behaviour of the body of the instrument (resonator) can be described by its input acoustic impedance considering only the interaction between the first breathing mode and the plane mode. Wall vibration effect can be evaluated as a correction (C) of the acoustic input impedance of a non-vibrating resonator (Z^r):

$$Z = Z^r(1+C).$$

Note that for a perfectly circular cylinder, acoustic impedance is affected only by shell modes having the same symmetry as the plane mode. When considering the usual materials of woodwind construction, the wall vibration effect is negligible (all the curves in figure 2a are nearby the same).

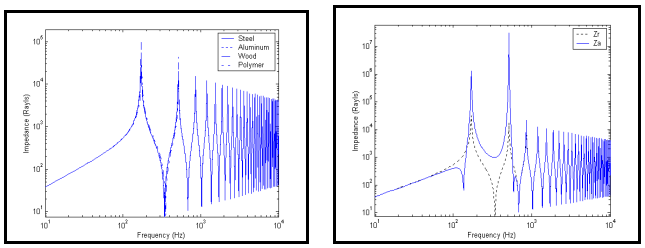

Figure 2: a) Acoustic input impedance of 4 vibrating shells made of steel, aluminum, wood and polymer. Only the breathing shell mode has been considered. Differences are very small. **b)** Acoustic input impedance of a rigid cylinder (Zr) and a wall vibrating cylinder (Za) made of wood (E= $0.212 \cdot 10^9$N/m^2 and density ρ =300kg/m^3). For Z^a, the materials are chosen in a way that the second acoustic resonance and the first mechanical resonance coincide. Tube length l=0.5; radius: 0.5mm and thickness: 14.5mm

For a fixed value of the geometrical parameters of the cylinder, it is shown that for low enough values of Young's modulus (E) and density (ρ) the wall vibration effect can be much important. As a consequence, acoustic input impedance can be strongly affected as shown in figure 3. Three phenomena underlay this singular behaviour: a mechanical resonance, a spatial coincidence effect and an acoustic resonance. When two of these phenomena take place simultaneously, the

perturbation effect becomes significant and the acoustic resonances and antiresonances of the tube can be significantly altered.

Numerical simulations

Simulations in the time domain provide the periodic oscillations corresponding to the main oscillation regime of the instrument. The implementation of this method [2,3] enables us to obtain a numerical solution in the time domain of the inner pressure field of the instrument when oscillating. Through the simulations in the time domain, the behaviour of instruments made of different materials is analysed.

Main wall vibration effects

Change of timbre

The spectral envelope is an important feature of timbre perception. Steady state spectra of the simulated signals of vibrating resonators made of several materials are different from the rigid case only when E and ρ are low enough.

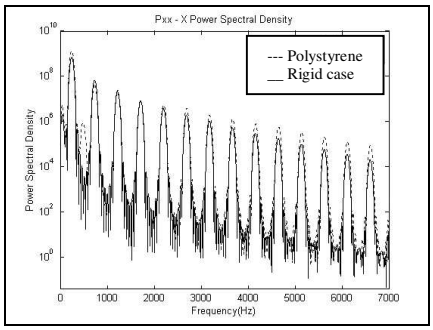

Figure 3: Spectra of steady state inner pressure simulated by polystyrene and rigid resonators.

Modification of the attack time

The starting transient is substantial in discrimination of musical sounds. Wall vibrations may alter the formation of stationary waves inside the instrument, and its oscillation regime. When E and ρ are small enough, this effect can be observed (figure 5).

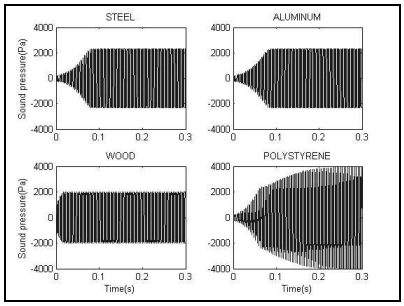

Figure 4: Transients simulated with steel and aluminum resonators are the same but differ from wood and polystyrene resonators.

Wolf note

In some circumstances, the instrument may emit sounds in quasi-periodic regime called Wolf Notes by analogy to bowed strings (cello). Transition through Wolf note has been observed in organ tube with flute mouthpiece and the interaction between ovalling shell modes and plane acoustic mode[4]. Numerical simulations of some vibrating resonators present the same behaviour. Therefore, wall vibration effect could explain this change of oscillation regime of the instrument.

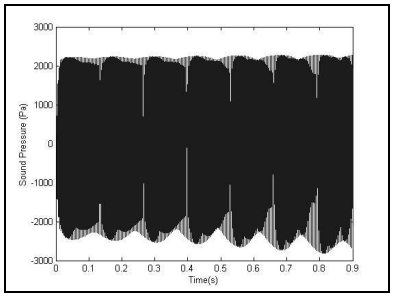

Figure 5: Simulation in the time domain of an instrument emitting a Wolf Note

Conclusion

Wall vibration effect is only visible in simulations in the time domain when E and ρ are low enough

References

[1] F. GAUTIER and TAHANI 1998 Journal of Sound and Vibration **213**, 107-125. Vibroacoustic behavior of a simplified musical wind instrument.

[2] R. T. SCHUMACHER 1981 Acustica **48**(2), 73-84. Ab initio calculations of the oscillations of a clarinet.

[3] C. J. NEDERVEEN, J. P. DALMONT Mars 2004 Journal of Sound and Vibration **27**(1-2) 227-239 Pitch level changes in organ pipes due to wall resonances.