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# COMPARISON BETWEEN METHODS TO CHARACTERIZE THE ACOUSTICAL PROPERTIES OF MUSICAL TONEHOLES

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## ABSTRACT

In woodwind instruments, lateral holes or toneholes, are used to reduce the effective length of the instrument in order to increase the number of notes that can be played. Over the time, instrument makers have noticed that details of the tonehole's geometry play a major role in the musical quality of woodwind instruments, a change in geometry impacts parameters such as: tuning, volume, and timbre. From the scientific point of view, it is of interest to link the tonehole's geometry to the acoustical properties of the produced sound. A single tonehole can be represented by a lumped T circuit comprised of a shunt and series impedance. In order to determine the values of these impedances, several methods have been developed, Keefe [1], Nederveen [2], Dubos et al. [3], Dalmont et al. [4], Dickens [5], Lefebvre and Scavone [6], these include theoretical, experimental, and numerical approaches. In this study a new method is proposed and compared to the method developed by Dalmont et al. [4]. The new approach is based on two measurements of the input impedance instead of the measurement of the input and transfer impedances of the method proposed by Dalmont et al. Also the tonehole position does not need to be at the middle of the main tube. Simulations of the experiments of both methods were performed to compare the effect of the uncertainty over the accuracy of the results. These results can be used for the design, and improvement of woodwind instruments.

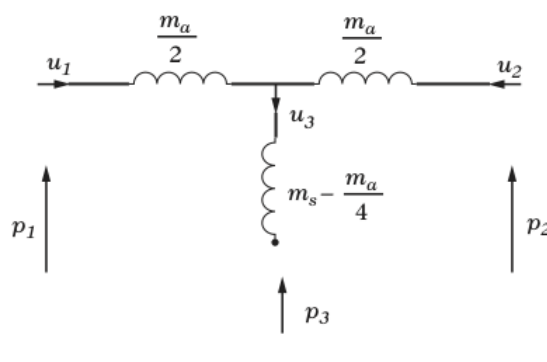
## 1. INTRODUCTION

The linear theory of the toneholes of wind instruments is based upon the idea to match the planar pressure existing at a short distance on both sides of the holes. The side hole is responsible for the creation of non planar pressure field, which can be modeled as acoustic masses (Fig. 1). One mass is in parallel, and can be regarded as a length correction to the hole chimney height. The other mass, in series, is negative and this effect is very small; it is limited to the behavior of the hole when it is closed [7]. The two masses are almost independent of frequency, and are combined with dissipative elements (related to boundary layers and radiation effects) into two complex

impedances:  $Z_s = j\omega m_s$  and  $Z_a = j\omega m_a$ . Therefore, the characteristics of a hole are two unknowns with a low variation with frequency, and are represented in Eq. 1.

$$Z_h = Z_s - Z_a/4 + Z_b + Z_r \quad (1)$$

Where  $Z_b = j\omega\rho\frac{h}{S_h}$  is the impedance of the plane wave mode in the hole,  $Z_r = \frac{8}{3\pi}j\omega\rho\frac{0.6b}{S_h}$  is the radiation impedance and  $S_h = \pi b^2$  is the cross sectional area of the hole.



**Figure 1.** Electrical circuit equivalent to an open hole at low frequencies, in this schema  $p_3$  is the value of the planar mode pressure at the input of the hole [8].

One of the classical procedures [1] measures each of the impedances separately, assuming that one is maximum when the other one is zero. Another classical solution [4] is the simultaneous measurement of two quantities: the input impedance of the main tube and a transfer impedance of the main tube through the hole, located at the middle of the tube. For the latter method at low levels, the order of magnitude of the accuracy (reproducibility) is 30% for the series impedance  $Z_a$  and 5% for the shunt impedance  $Z_h$ . There are several advantages of this method, in particular the non-disassembling of any part of the experiment during the measurement. We tried to study the sensitivity on several parameters: the precision of the length of the main tube, and that of the measurement of the input and transfer impedances. This leads to a correct prediction of the order of magnitude of the above-mentioned uncertainties of the results.

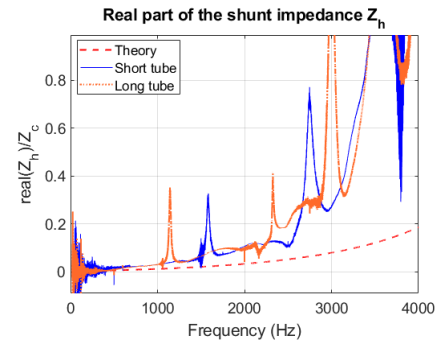
## 2. THE METHOD OF THE REVERSED TUBE

The present paper shows preliminary results of a new method. It is based upon two input impedance measurements of the same tube in two positions: after a first measurement, a second is done by reversing the tube direction. The impedance sensor is the one produced by the CTTM (*Centre de Transfert De Technologie du Mans* [9]). Since the main tube is cylindrical, the output impedance is not changed by the reversion. The tube opposite end to the measurement is open, and the radiation impedance is either experimental (thanks to a supplementary measurement with a cylinder without any hole by projecting the input impedance to the output) or theoretical. The measurement simulation shows that the best location of the hole is rather close to an extremity of the tube, at a distance allowing the non-planar pressure to be negligible. This is intuitive because a location of the hole at the middle would make the problem degenerated (the two measurements would lead to the same value with one equation for two unknowns). The drawback of this method is the disassembling of the tube from the impedance sensor between the two measurements. The mathematical treatment of the two input impedances lead to a second-degree equation of the series impedance  $Z_a/2$ , therefore there are two possible solutions for  $Z_a$  and also two possible values of  $Z_h$ . However, it is known that the real part of  $Z_h$  is positive (dissipation) and its imaginary part is close to a positive mass. Therefore, it is easy to eliminate one of the two solutions at every frequency.

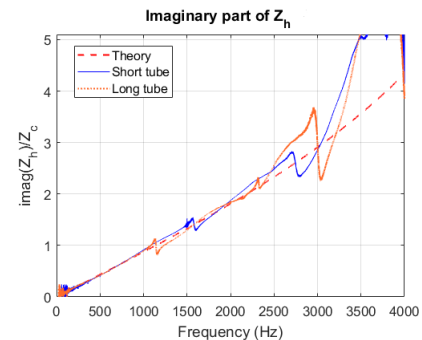
## 3. RESULTS

Measurements on two tubes with different lengths but the exact same hole geometry, are presented. The short tube has a total length of 11 cm and the long one has a total length of 15 cm, in both cases the hole is drilled at 4 cm of one of the ends. The lateral hole has a radius of 4 mm and physical height of 8.5 mm. Our first results do not provide any convincing results for the series impedance  $Z_a$  which is the impedance associated with the masses in series ( $m_a$ ) in Fig. 1. In the next months, we will try to modify this method. Results for the real and imaginary parts of  $Z_h$ , impedance associated with the mass in parallel, are shown in Figs. 2 and 3. Theoretical results computed from previous studies in cylindrical lateral holes ([2] and [3]) are superimposed to the experimental ones.

In Figs. 2 and 3 it is observed that the results tendency is good, except for accidents that are due to the anti-resonances of the measured tubes. Also, the shorter tube provides better results for a larger frequency range, since the first anti-resonance in around 1500 Hz, in comparison with the long tube which has a first anti-resonance at 1100 Hz. Frequency ranges around anti-resonances can be eliminated, in order to fit the results with a monotonic

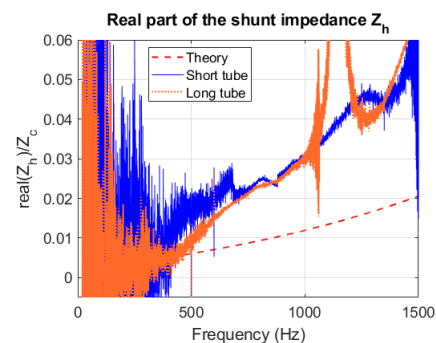


**Figure 2.** Real part of the shunt impedance ( $Z_h$ ) obtained by measurement for two different length tubes.



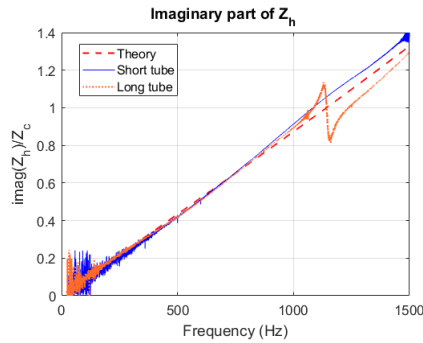
**Figure 3.** Imaginary part of the shunt impedance ( $Z_h$ ) obtained by measurement for two different length tubes.

function.



**Figure 4.** Real part of the shunt impedance ( $Z_h$ ) up to 1.5 kHz.

Figs. 4 and 5 show zooms of the curves up to 1.5 kHz. In Fig. 4 it is observed that the slope is greater than expected from the theory, this could be due to greater losses in the tested tube, this has to be further investigated since there are no previous studies for the tubes used in this study. In Fig. 5 it is observed that the slope is in accordance with the expected values from the theory, this means that the geometry of the hole is in accordance with previous studies in terms of dissipation for frequencies below 3 kHz. At these frequencies, the slope of the curve gives the value of the acoustic mass, then the equivalent length to the chimney height can be computed: the

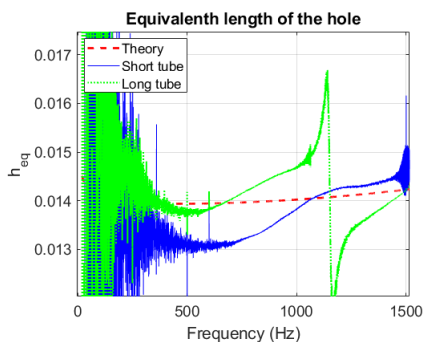


**Figure 5.** Imaginary part of the shunt impedance ( $Z_h$ ) up to  $1.5\text{ kHz}$ .

theoretical value is around  $14\text{ mm}$  for frequencies up to  $1.5\text{ kHz}$ , while the experimental values are presented in Fig. 6 and are computed with Eq. 2, it is observed that each tube has a different approximation in relation with the frequency.

$$Z_h = j\omega\rho\frac{h_{eq}}{S_h} = jkZ_{oh}h_{eq} \quad (2)$$

Where  $Z_{oh} = \rho c/S_h$  is the characteristic impedance of the hole.



**Figure 6.** Equivalent length of the hole ( $h_{eq}$ ), Eq. 2.

## 4. CONCLUSION

The observed real part of the shunt impedance shows that the measured dissipation at the hole is greater than the one predicted by previous theories proposed by several authors. Accidents observed in measurements linked with the anti-resonances will be dealt with in future simulations. The method is promising in the low frequency range, but improvements have to be sought for solving excessive presence of noise in frequencies below  $400\text{ Hz}$ , as well as the absence of results for the series impedance.

### 4.1 Acknowledgment

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## 5. REFERENCES

- [1] D. H. Keefe, "Experiments on the single woodwind tone hole," *The Journal of the Acoustical Society of America*, vol. 72, no. 3, pp. 688–699, 1982.
- [2] C. Nederveen, J. Jansen, and R. Van Hassel, "Corrections for woodwind tone-hole calculations," *Acta Acustica united with Acustica*, vol. 84, no. 5, pp. 957–966, 1998.
- [3] V. Dubos, J. Kergomard, A. Khettabi, J.-P. Dalmont, D. Keefe, and C. Nederveen, "Theory of sound propagation in a duct with a branched tube using modal decomposition," *Acta Acustica united with Acustica*, vol. 85, no. 2, pp. 153–169, 1999.
- [4] J.-P. Dalmont, C. J. Nederveen, V. Dubos, S. Ollivier, V. Meserette, E. te Sligte, *et al.*, "Experimental determination of the equivalent circuit of an open side hole: linear and non linear behaviour," *Acta Acustica united with acustica*, vol. 88, no. 4, pp. 567–575, 2002.
- [5] P. A. Dickens *et al.*, *Flute acoustics: measurements, modelling and design*. PhD thesis, PhD Thesis, University of New South Wales, 2007.
- [6] A. Lefebvre and G. P. Scavone, "Characterization of woodwind instrument toneholes with the finite element method," *The Journal of the Acoustical Society of America*, vol. 131, no. 4, pp. 3153–3163, 2012.
- [7] V. Debut, J. Kergomard, and F. Laloë, "Analysis and optimisation of the tuning of the twelfths for a clarinet resonator," *Applied acoustics*, vol. 66, no. 4, pp. 365–409, 2005.
- [8] A. Chaigne and J. Kergomard, *Acoustics of musical instruments*. Springer, 2016.
- [9] J. C. Le Roux, M. Pachebat, and J.-P. Dalmont, "A new impedance sensor for industrial applications," in *Acoustics 2012*, 2012.