



HAL
open science

The effect of the tonehole lattice cutoff frequency on sound production for conical resonators

Tom Colinot, Erik Petersen, Philippe Guillemain

► **To cite this version:**

Tom Colinot, Erik Petersen, Philippe Guillemain. The effect of the tonehole lattice cutoff frequency on sound production for conical resonators. Forum Acusticum, Dec 2020, Lyon, France. pp.3181-3184, 10.48465/fa.2020.0055 . hal-03234048

HAL Id: hal-03234048

<https://hal.science/hal-03234048>

Submitted on 26 May 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

THE EFFECT OF THE TONEHOLE LATTICE CUTOFF FREQUENCY ON SOUND PRODUCTION FOR CONICAL RESONATORS

Tom Colinot¹

Erik Alan Petersen¹

Philippe Guillemain¹

¹ Aix Marseille Univ, CNRS, Centrale Marseille, LMA

tom.colinot@univ-amu.fr

ABSTRACT

The effect of the tonehole lattice cutoff frequency of a conical resonator on sound production is explored using numerical synthesis: time-domain integration, as well as harmonic balance method combined with continuation (MANLAB). The tonehole lattice cutoff frequency f_c separates the passive response of the resonator into two bands. Below f_c , an acoustical wave traveling down the main branch of the duct, upon arrival at the first open tonehole, either radiates into the surrounding field, or reflect back into the main bore of the instrument. However, above f_c , the wave is no longer evanescent and is able to propagate farther into the lattice. In this work, three resonators are designed to have drastically different cutoff frequency behavior: two resonators with cutoff frequencies at 700 and 900 Hz and a simple cone with no tonehole lattice are proposed to compare the effect of the cutoff frequency on sound production. Numerical synthesis shows that some sound production features are almost unaffected by cutoff behavior, such as oscillation thresholds and values of the control parameters leading to the production of certain registers. However, the spectral centroid, an indicator of tonal brightness, seems greatly influenced by the cutoff frequency behavior. The severity of the cutoff, which relates to the overall height reduction of impedance peaks above the cutoff frequency, has a greater impact on the spectral content of the produced sound than the frequency at which cutoff occurs. Thus, taking into account the cutoff frequency behavior in the development of an instrument can be a way to control its spectral features without affecting the main sound production characteristics.

1. TONEHOLE LATTICE CUTOFF FREQUENCY FOR A CONICAL DUCT

Conical woodwinds, such as the saxophone or the oboe, feature a resonator into which several side holes, called *toneholes*, are drilled. By plugging or opening these holes, the musician changes the resonance frequencies of the duct, which allows the instrument to produce different notes. This is the primary use of toneholes. However, they also act together to influence the timbre of the produced sound. One of the determining characteristic of this secondary action of the toneholes is the called the *tonehole lattice cutoff frequency*. The cutoff phenomenon emerges

from the regularity of the structure of the toneholes. Starting from the first open tonehole, downstream holes form a lattice, through which acoustical waves can or cannot propagate depending on their frequency. At low frequency, the first open hole acts like a termination of the main duct: the waves do not propagate farther down the tube. Therefore, at low frequencies, the resonances of the resonator are mostly determined by the shape and length of the main duct, until the first open hole. In the case of a conical woodwind, it is a cone frustum. The validity limit of this low frequency approximation is called the tonehole lattice cutoff frequency, above which some of the acoustical waves propagate past the first open hole and into the lattice. Above the cutoff, the acoustical behavior of the resonator is more complicated, as it is determined by the complete geometry of the main duct and all the subsequent open toneholes. Notably, the resonances are weaker and can become irregularly spaced. The value of the cutoff frequency depends on the distance between the toneholes and their dimensions. It only admits an unambiguous definition in the case of a cylindrical lattice where all holes are identical and evenly spaced [1], in which case the cutoff frequency can be approximated by

$$f_c^{cyl} = \frac{c}{2\pi\ell} \frac{1}{\sqrt{2(b/\ell)(S/s)}} \quad (1)$$

where c is the speed of sound, ℓ is half the distance between two holes, b is the height of the hole's chimney, S is the cross-section of the main bore and s is the cross section of the hole. For a conical resonator, such geometrical periodicity is impossible, but approximations exist to the cutoff frequency, which are coherent with the structure of the input impedance [2]. Following these approximations, one can design conical tonehole lattices with a given cutoff. As an illustration of the effect of the cutoff frequency on the acoustical characteristics of a resonator, figure 1 compares the impedance of a single cone frustum with that of two conical resonator whose toneholes lattices are designed to have a cutoff frequency of 700 and 900 Hz, respectively. These resonators are designed so that they all have the same first resonance frequency, and the main bore before the first open hole is identical except from its length. Note that the impedance is normalized by the characteristic impedance at the input of the resonator $Z_c = \rho c/S$, where ρ is the density of air and S is the cross-section at the resonator's input. Figure 1 shows that the impedances

of the resonators that feature toneholes start to differ from that of the single cone frustum around their cutoff frequencies, with their impedance peaks becoming lower and less evenly spaced.

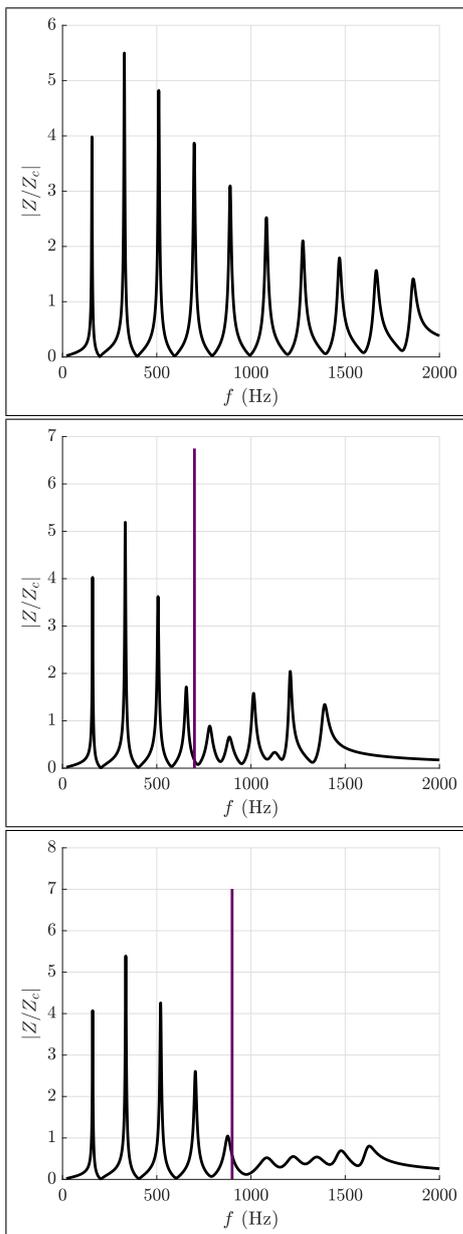


Figure 1. Input impedance magnitude of three resonators. Top: single cone frustum, middle: cutoff at 700 Hz, bottom: cutoff at 900 Hz.

2. SOUND PRODUCTION

For each of the three resonators, time domain synthesis [3] is used to produce sound clips across the control space defined by the two parameters γ and ζ [4], defined as

$$\gamma = \frac{p_m}{p_M} \quad (2)$$

$$\zeta = Z_c w H \sqrt{\frac{2}{\rho}}, \quad (3)$$

where p_m is the pressure in the musician’s mouth, p_M is the static pressure necessary to close the reed channel completely,. For every couple (γ, ζ) in a grid spanning the intervals $[0, 1.3]$ and $[0.2, 1]$, several sounds are synthesized, each one corresponding to a different evolution of the blowing pressure parameter γ . This way, if two oscillating regimes are stable for the same value of control parameters, they both have a chance of appearing. From each sound, which has a duration of 3 s, low-level signal descriptors are extracted. The procedure distinguishes a non-oscillating regime, a first register (whose frequency is close to the first impedance peak), a second register (whose frequency is close to the second impedance peak), and a quasi-periodic oscillation. Figure 2 shows that the three resonators from figure 1 produce the same type of oscillating regimes depending on the control parameters, except for very minor differences.

Then, the spectral centroid is extracted from the signals. It is computed as

$$C = \frac{1}{N_h} \frac{\sum_{h=1}^{N_h} h f_0 |S(h f_0)|}{\sum_1^{N_h} |S(h f_0)|} \quad (4)$$

where f_0 is the signal’s fundamental frequency, $|S(h f_0)|$ is the amplitude of the h th harmonic, and $N_h = 20$ for this study. Figure 3 shows the spectral centroid for the three resonators of figure 1. The spectral centroid values are similar between the simple cone with no cutoff and the resonator whose added tonehole lattice has the lowest cutoff $f_c = 700$ Hz. The resonator whose cutoff is highest $f_c = 900$ Hz leads to overall lower spectral centroid values. This result can appear surprising, as the lowest cutoff leads to earlier resonances being weakened. However, it can be interpreted by looking at figure 1, on which the resonator with $f_c = 700$ Hz has higher peaks above cutoff than the one with $f_c = 900$ Hz, where peaks above cutoff are extremely attenuated. This goes to show that if the cutoff phenomenon can have a clear effect on the sound produced by an instrument, the mere frequency where cutoff occurs does not suffice to characterize the phenomenon completely. The example chosen here illustrates that some form of cutoff efficiency, to be understood as the attenuation of resonances above cutoff, plays a great role in shaping the resonator’s sound.

3. REFERENCES

- [1] E. Moers and J. Kergomard, “On the cutoff frequency of clarinet-like instruments. geometrical versus acoustical regularity,” *Acta Acustica united with Acustica*, vol. 97, no. 6, pp. 984–996, 2011.
- [2] E. Petersen, T. Colinot, J. Kergomard, and P. Guillemain, “On the tonehole lattice cutoff frequency of conical resonators: applications to the saxophone,” *Acta Acustica*, vol. 4, no. 4, p. 13, 2020.
- [3] W. L. Coyle, P. Guillemain, J. Kergomard, and J.-P. Dalmont, “Predicting playing frequencies for clarinets:

A comparison between numerical simulations and simplified analytical formulas,” *The Journal of the Acoustical Society of America*, vol. 138, no. 5, pp. 2770–2781, 2015.

- [4] T. A. Wilson and G. S. Beavers, “Operating modes of the clarinet,” *The Journal of the Acoustical Society of America*, vol. 56, no. 2, pp. 653–658, 1974.

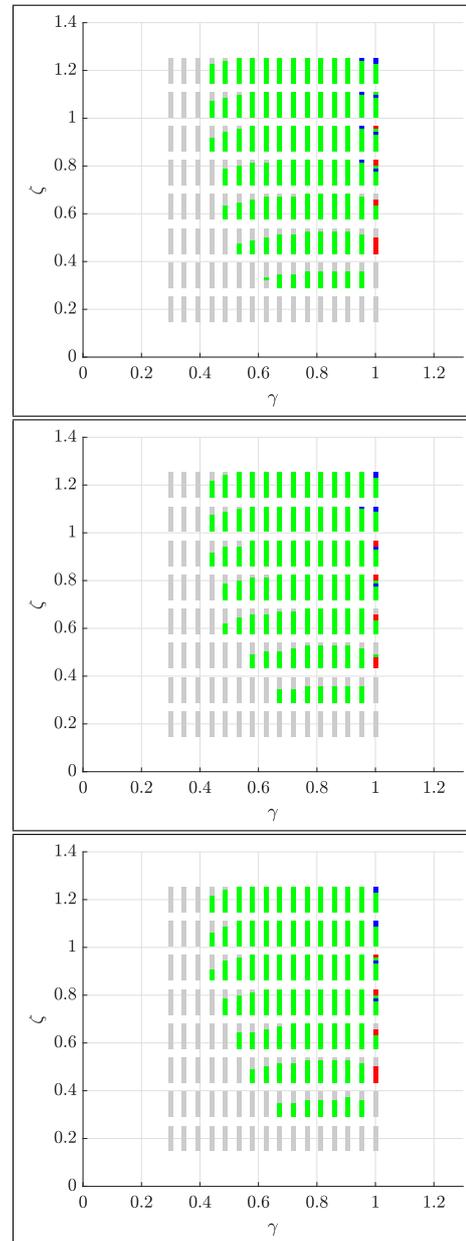


Figure 2. Register of the produced sound as a function of control parameters γ and ζ . Each column corresponds to a single (γ, ζ) couple. In a given column, the lowest point correspond to the shortest attack time and the highest to the longest. Top: single cone frustum, middle: cutoff at 700 Hz, bottom: cutoff at 900 Hz.

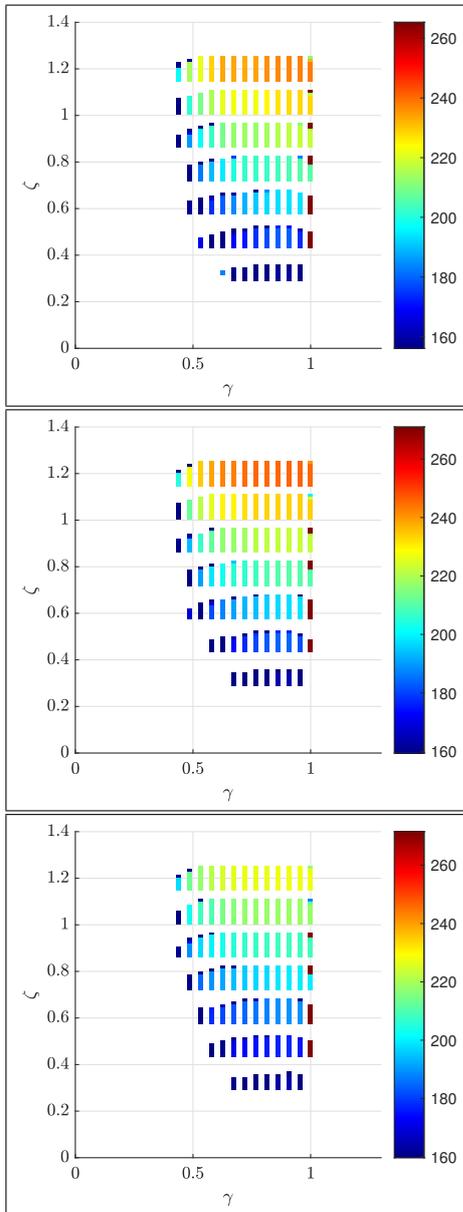


Figure 3. Spectral centroid (Hz) of the produced sound as a function of control parameters γ and ζ . Each column corresponds to a single (γ, ζ) couple. In a given column, the lowest point correspond to the shortest attack time and the highest to the longest. Top: single cone frustum, middle: cutoff at 700 Hz, bottom: cutoff at 900 Hz.