



**HAL**  
open science

## Resonance frequencies in non-rigid compressed waveguides

Al Oualid Eliraki, Florian Vixège, Xavier Pelorson, Annemie van Hirtum

### ► To cite this version:

Al Oualid Eliraki, Florian Vixège, Xavier Pelorson, Annemie van Hirtum. Resonance frequencies in non-rigid compressed waveguides. Proc. 3rd Graz-Vienna Speech Workshop Connecting with Health Sciences, 2025, Vienne, Austria. <hal-05067487>

**HAL Id: hal-05067487**

**<https://hal.science/hal-05067487v1>**

Submitted on 14 May 2025

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.



HAL Authorization

# Resonance frequencies in non-rigid compressed waveguides

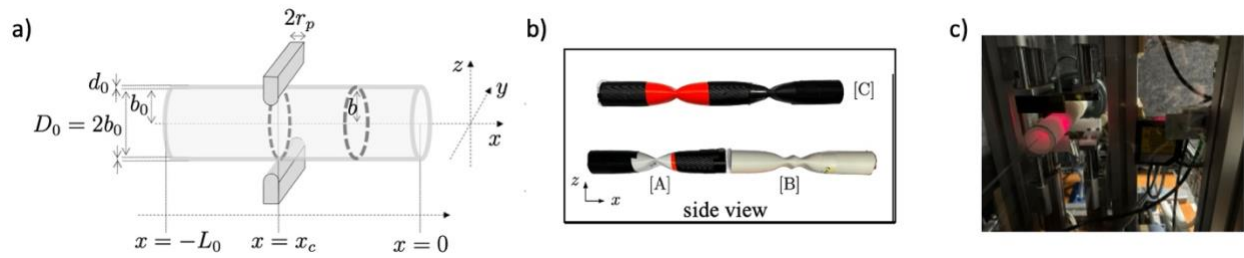
A. Eliraki, F. Vixege, X. Pelorson & A. Van Hirtum

University of Grenoble Alpes, CNRS, Grenoble INP, LEGI, 38000 Grenoble, France

*annemie.vanhirtum@univ-grenoble-alpes.fr*

*Background and objectives:* Voiced speech sounds are characterised by distinct resonance frequencies. The underlying physics is commonly examined using simplified waveguide geometries that replicate the constricted regions observed in human speakers. While such studies have successfully validated key aspects, such as the influence of constriction position and degree on resonance frequencies, they predominantly utilise rigid waveguides. This constraint limits the exploration of dynamic articulation and the subsequent production of varying vowels. To address this limitation, the present study investigates circular waveguides with wall properties ranging from rigid to elastic. An experimental analysis of resonance frequencies is conducted for both unconstricted waveguides and those featuring one or two constrictions, with systematic variation in the position and degree of constriction. An analytical model of the deformed waveguide geometry is employed, and critical geometrical parameters are validated against experimental data across different wall properties. The geometrical model is then employed to simulate acoustic wave propagation within the waveguides. Comparisons between modelled and experimentally measured resonance frequencies are presented, with particular attention given to the influence of waveguide wall materials on the observed acoustic phenomena.

*Materials and methods:* A circular uniform waveguide with length  $L_0$  is positioned along the x-direction. The waveguide's cross-section is deformed by squeezing it locally between a pincher consisting of two rounded symmetrical bars as illustrated in Fig. 1(a). The squeezing can be expressed as a function of two parameters, namely the constriction position  $x_c$  and the constriction degree  $P$ . The deformed waveguide is modelled by representing each cross-section within the deformed region as a stadium-shaped ring [1]. Three-dimensional rigid waveguides with one or two constrictions are generated based on the model considering a moderate constriction at  $P=77\%$  and a severe constriction at  $P=90\%$ . Three distinct constricted waveguide configurations ([A], [B] and [C]) are examined, based on the positioning and degree of one or two constrictions along the waveguide as shown in Fig. 1(b). In addition, uniform waveguides with different elasticity are obtained using both 3D printing and molding techniques. Concretely, and in order of increasing deformability, five wall materials are assessed: R (rigid, 3D printed); D (deformable, 3D printed); S (deformable commercial); DR (deformable, 3D printed); M (deformable, molded). Waveguides are mounted to the experimental setup illustrated in Fig. 1(c). The acoustic pressure is measured along its centreline. A compression chamber is connected to the waveguide inlet (at  $x = -L_0$ ) in order to repeatedly emits a 30-second linear frequency sweep so that the frequency range of 0.1 up to 15 kHz can be studied. A rigid Plexiglas rectangular baffle is attached at the waveguide exit (at  $x = 0$ ). Measured data (acoustic probe and source signal; wall displacement) are analysed as a function of the instantaneous acoustic source frequency by computing its amplitude and phase [1]. Acoustic waveguide resonances are identified at frequencies corresponding to peaks in the acoustic pressure amplitude (in dB). Pressure-pressure transfer functions between different probe positions are quantified.



**Figure 1:** a) Illustration of a cylindrical waveguide squeezed between two rounded parallel bars at constriction position  $x_c$  imposing constriction degree  $P$ ; b) Prototypes of modelled squeezed waveguides; c) illustration experimental setup allowing to squeeze deformable waveguides.

**Results and discussion:** The impact of various wall materials (R, D, S, DR and M) on the measured resonance frequencies for uniform, unconstricted waveguides with lengths  $L_0 \in \{175, 180\}$  mm is considered. Resonance frequencies across wall materials are mostly consistent, with standard deviations below 6% ( $< 75$  Hz) relative to the rigid wall reference (R). Nevertheless, resonances for deformable materials are generally lower, reflecting increased boundary compliance and energy absorption. However, for molded (M, most deformable) waveguides, the lowest resonance frequency decreases to 210 Hz, with an additional new resonance near 650 Hz. Measured microphone probe and wall displacement spectra indicate strong mode coupling between the acoustic quarter-wave frequency and wall vibration. The same observation holds for squeezed waveguides. This implies that mode coupling is observed for squeezed molded waveguides as well. Measured resonance frequencies are compared to modelled ones obtained using a plane wave model [1]. For frequencies up to 2.5 kHz, the model accurately estimates measured resonance frequencies across all parameter sets and waveguide configurations [A], [B] and [C]. For frequencies higher than 2.5 kHz, the accuracy declines due to the propagation of non-plane higher-order modes. The cut-on frequency of these modes for a uniform circular waveguide portion is approximately 4.4 kHz and decreases with increasing pinching effort, as the constricted section along the major axis increases. To illustrate frequency behaviour up to 10 kHz, modelled and measured pressure-pressure transfer functions are examined.

**Conclusions:** Acoustic resonances in deformable uniform and compressed waveguides are studied experimentally using an original setup developed to study vocal tract like waveguides dynamics. Experimental results are in close agreement with plane wave model results up to the cut-on frequency of higher order modes. Different degrees of deformability do not significantly affect resonances except for the most deformable waveguide (molded) for which vibro-acoustic coupling is observed affecting the lowest resonance frequency.

## References:

[1] Van Hirtum, A., Blandin, R., Pelorson, X. Validation of an analytical compressed elastic tube model for acoustic wave propagation, *J Appl Phys*, 118, 224905, (2015).