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Comparing the Use of Compressible and Incompressible Flow in the FE Model of Human Vocal Folds Self-Oscillation

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Abstract: In this study a three-dimensional (3D) finite element (FE) model of the flow-induced self-oscillation of the human vocal folds in interaction with air in a simplified vocal tract model is presented. The 3D vocal tract model of the acoustic spaces for Czech vowel [a:] was created by converting the data from the magnetic resonance images (MRI). The developed FE model includes fluid-structure interaction, morphing the fluid mesh according to the vocal-fold motion, unsteady viscous compressible/incompressible airflow described by the Navier-Stokes equations, airflow separation during the glottis closure, large deformations of the vocal-fold tissue and vocal-fold contact. The aim of this work is to analyze the effect of compressible and incompressible flow model on produced air pressure fluctuations and on vibrations of the vocal folds using the identical FE mesh and boundary conditions.

Introduction

Voice production should be modelled as a complex fluid-structure-acoustic interaction problem. Computational models of human voice production published in literature can be divided into three groups: reduced-order models, models of flow and finite element models. In previous works of the authors [1,2] FE model of flow-induced oscillations of the vocal folds in interaction with acoustic spaces of the vocal tract was developed. In this study a new FE model of phonation was constructed using four-layers vocal fold structure and in literature widely used M5 geometry of the vocal folds. The 3D FE model was developed using the program system ANSYS 15.0 (see Fig. 1.).

Results and discussion

Example of computed fluid pressure in point located 3 cm above the vocal folds for incompressible and compressible flow model is shown in Fig. 2. From the results we can see that for incompressible flow model vocal folds oscillating with higher fundamental frequency and after the vocal folds opening there is only one negative peak of fluid pressure. Whereas for compressible flow model fluid pressure oscillates several times from positive to negative values after the vocal folds opening. For compressible flow model we can see in the power spectral density spectrum of the pressure near the lips (see Fig. 2.), that some harmonics are enhanced by the resonant frequencies of the vocal tract and producing so called "formants". For incompressible flow model we can in the resulting spectrum observe only peaks of fundamental frequency and its harmonics.

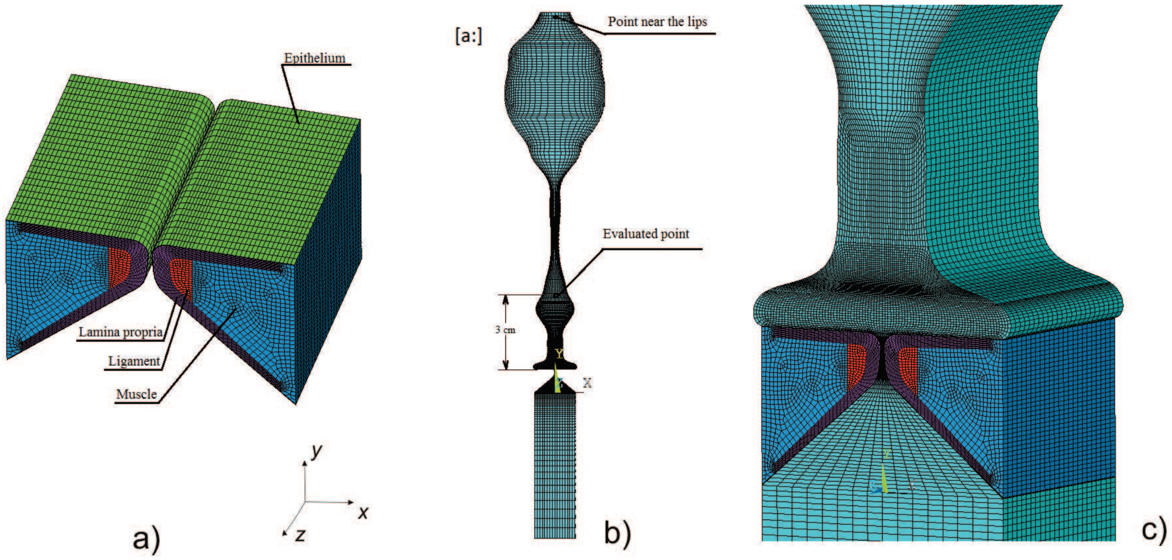

Fig. 1: a) FE model of the four layered tissue of the vocal folds b) FE model of the acoustic spaces of the trachea and the vocal tract for Czech vowel [a:] c) detail of the complete FE model of the vocal folds together with a part of the model of the vocal tract.

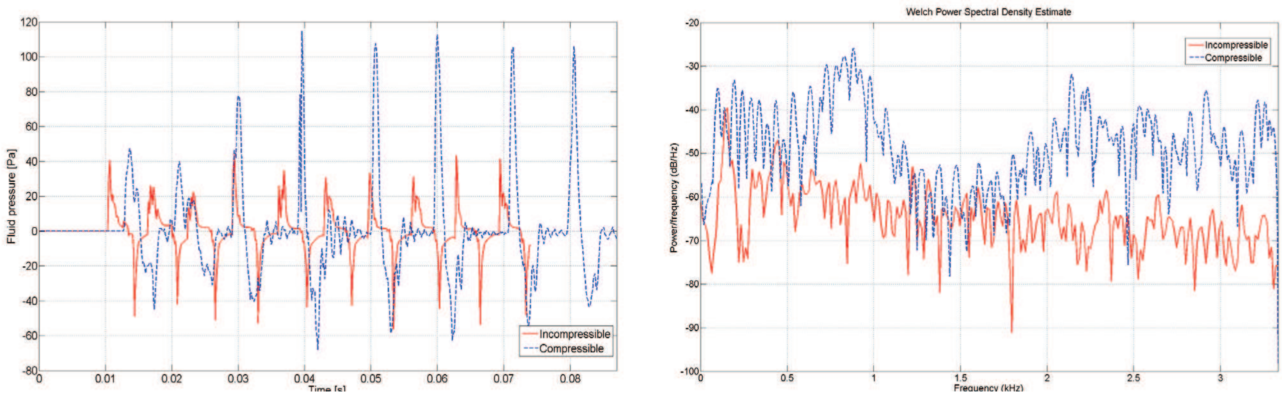

Fig. 2: Computed fluid pressure in point located 3 cm above the vocal folds (left) and power spectral density spectrum of the pressure near the lips (right) for incompressible and compressible flow model.

Summary

The developed model can be utilized to analyze the differences between use of compressible or incompressible flow model and to better understand the mechanisms of sound creation during phonation process.

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