11th. World Congress on Computational Mechanics (WCCM XI)
5th. European Conference on Computational Mechanics (ECCM V)
6th. European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

3D NUMERICAL SIMULATIONS OF HUMAN PHONATION

M. Kaltenbacher[1], S. Zörner[1], A. Hüppe[1] and P. Sidlof[2]

[1] Vienna University of Technology, 1040 Vienna, Austria, manfred.kaltenbacher@tuwien.ac.at
[2] Technical University of Liberec, 461 17 Liberec, Czech Republic, sidlof@it.cas.cz

Key words: *Multiphysics Problems, Human Phonation.*

The human phonation is a complex interaction of fluid mechanics, solid mechanics and acoustics. As the lungs compress, air flows through the larynx passing the vocal folds which form a narrow constriction, the glottis. The air flow forces the vocal folds to vibrate which in turn create a pulsating air stream, which is the main sound generating mechanism for phonation. Hence, our modeling approach is to resolve, within the larynx and adjacent regions, the physical details of the phonation process in space and time by means of partial differential equations (PDEs). Due to limitations in computer resources and current numerical methods, full coupling between all three fields for realistic 3D geometries is currently not feasible (see, e.g., [1, 2, 3]). However, as demonstrated in [4], where a driven vocal fold model is used (pure 3D fluid simulation with prescribed change of the fluid domain), a 3D computation is necessary for a physical correct computation of the flow structures.
Here, we concentrate on prescribed flow computations, evaluate the acoustic sources and perform acoustic computations of the generated sound. Thereby, we apply the program *OpenFoam* as well as our in-house research code *CFS++* for solving the 3D incompressible Navier-Stokes equations, and *CFS++* to compute the acoustic source as well as sound propagation. In detail, we have investigated Lighthill's analogy and its application towards the human phonation. It is a well-known fact that not all sources given by the Lighthill tensor cause propagating acoustic waves, audible in the far field. Actually, the second spatial derivative of the Lighthill tensor is the source term for the inhomogeneous wave equation. However, it can be shown that the divergence of the Lamb vector is the main acoustic source at low Mach numbers which radiates to the far field. In our current investigations, we could demonstrate this fact for human phonation computations. Furthermore, we found that the second derivative of Lighthill's tensor leads to stronger noise in the acoustic source structures, as shown in Fig. 1. For quantitative numerical assessment of aeroacoustic sound generation, special attention must be paid to the flow computation (especially discretization and turbulence modeling) and the type of acoustic analogy. In the last years, we have strongly investigated acoustic perturbation equations and compared these to Lighthill's analogy. In a recent study applied to the human phonation, we found that even outside the flow region, Lighthill's wave equation over-predicts

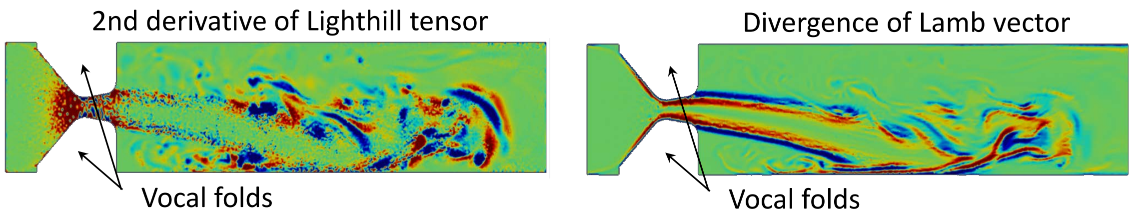

Figure 1: Visualization of different aeroacoustic source models on a cross section of the human larynx.

the acoustic sound pressure level (SPL). Figure 2 displays the SPL (Sound Pressure Level) at an observation point two centimeters away from the mouth.

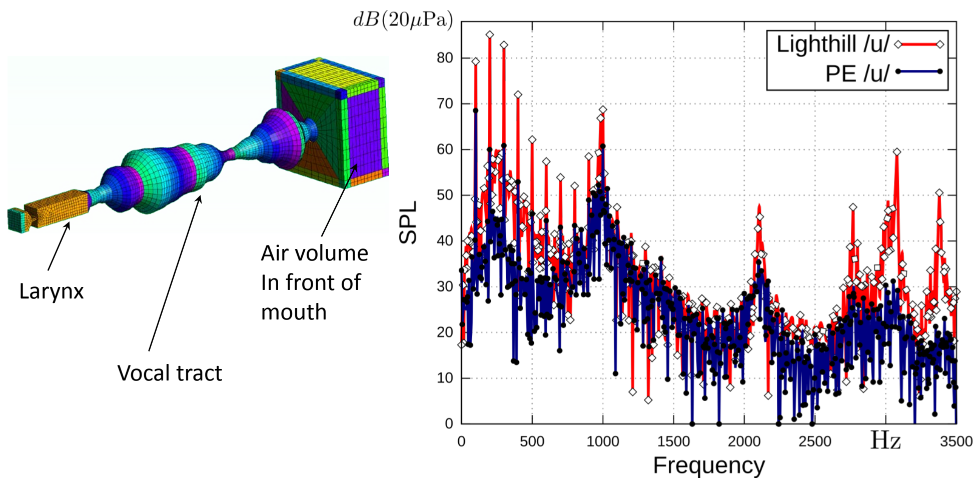

Figure 2: Acoustic sound pressure level two centimeters away from the mouth for the vowel u obtained by Lighthill's wave equation and perturbation equations (PE) (both based on the same CFD data).

REFERENCES

[1] G. Link, M. Kaltenbacher, M. Breuer, and M Döllinger. A 2D finite element scheme for fluid-solid- acoustic interactions and its application to human phonation. *Comput. Method. Appl. M.*, 2009

[2] F. Alipour et al. Mathematical models and numerical schemes for the simulation of human phonation. *Curr. Bioinform.*, 2011

[3] J. H. Seo and R. Mittal. A high-order immersed boundary method for acoustic wave scattering and low-Mach number flow-induced sound in complex geometries. *J. Comput. Phys.*, 2011

[4] W. Mattheus and C. Brücker. Asymmetric glottal jet deflection: Differences of two- and three-dimensional models. J. Acoust. Soc. Am. Expr. Let., 2011