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Phonation energy budget from high-fidelity aeroelastic-aeroacoustic simulations

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Abstract

A rigorous accounting of phonation energy utilization is presented using high-fidelity computer simulations. Simulation results are used to compute terms of the integral energy equation for the volume containing air in the larynx. Flow work terms are decomposed to clarify power transfer mechanisms. Laryngeal acoustic efficiency is presented.

Introduction

Using a control volume analysis, the energy budget of air motion in the larynx has been defined [3]. Such an accounting reveals the power transfer mechanisms from the pulmonary system, vocal fold vibration, glottal jet dissipation, and energy exchanges between the airflow in the larynx and the acoustic fields in the trachea and the vocal tract.

Methods

To evaluate the energy budget, an aeroacoustic-aeroelastic simulation is setup using a swept-ellipse multilayer model [1,3]. The simulation is performed with the immersed finite element method [2]. A pair of vocal folds is placed within the vocal tract, represented by a stright uniform cross-section duct. The mouth opening is represented by an extended large region with non-reflective boundaries, shown in Fig. 1.

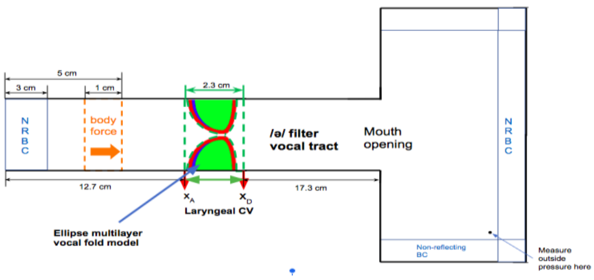

Figure 1: High-fidelity simulation setup of a pair of elliptical vocal folds placed in a vocal tract.

Results and Discussion

The power flows for the terms over several vibration cycle is shown in Fig. 2. The net pressure work, $2(p_A^+ Q_A -$ $pD{-}QD$, is balanced with the radiated wave pressure $\frac{\rho c}{S}(Q_D^2 + Q_A^2)$, and other outputs and losses $(\dot{W}_{VF}, \dot{W}_v, \dot{KE}, \dot{PE}, \dot{W}_f)$.

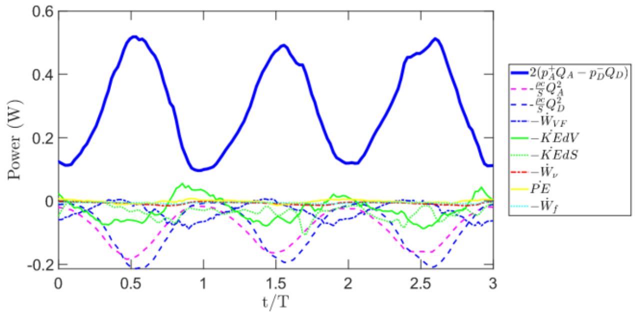

Figure 2: Power flow from the net pressure work (solid blue) to radiated pressure (dotted blue and dotted cyan) and other outputs and losses with input pressure of 1kPa.

Three pressure inputs (0.8, 1.0, 1.2KPa), forced/unforced flow symmetry, and infinite duct without mouth, are simulated for comparison of the energy utilization, shown in Fig.2. Overall, the acoustic output is within 20% of the pressure work input, the energy loss to viscous dissipation and skin friction, and potential energy to compress air are insignificant. Asymmetric cases generate higher work input, output, and losses. As the pressure input increases, the generated work is also higher.

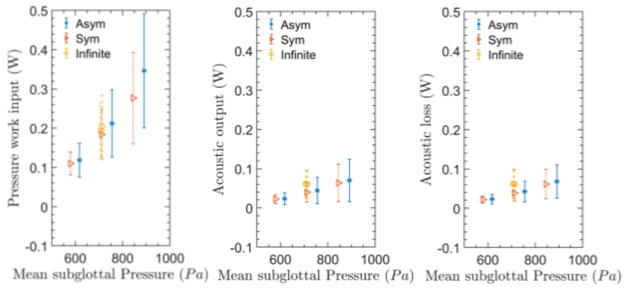

Figure 3: Pressure power input, acoustic output and losses with standard deviations vs. three pressure inputs, forced/unforced flow symmetry, and infinite duct without mouth opening.

Acknowledgements

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