Fluid–Structure–Acoustic Interaction Simulation Motivated by Human Phonation

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Abstract

This presentation focuses on the fluid–structure–acoustic interaction (FSAI) problem with particular emphasis on its application to human phonation, [1]. The problem involves the coupling of three physical subsystems: a complex airflow, the vibration of an elastic structure represented by the vocal folds, and the surrounding acoustic field. The general mathematical model of the FSAI problem is introduced and possible simplifications of the fully coupled formulation are discussed.

The fluid–structure interaction (FSI) is governed by the incompressible Navier–Stokes equations coupled with a geometrically nonlinear elasticity model, which is suitable for large deformations and, more importantly, significant rotations of the vocal folds. The fluid formulation employs the Arbitrary Lagrangian–Eulerian (ALE) method to treat the time-dependent fluid domain, and SUPG stabilization is applied within the finite element discretization to ensure numerical stability in convection-dominated regimes. Special attention is devoted to the inlet boundary condition, which is imposed in a penalized form, [4]. This approach can be interpreted as a generalization of classical Dirichlet and Neumann boundary conditions and has proven to be more robust and physically appropriate for modelling inflow conditions in phonatory flows. The influence of structural prestressing—mimicking the prephonatory configuration of the vocal folds—is also investigated and shown to be significant, [2].

An aeroacoustic model based on a perturbation approach is briefly introduced as a reasonable approximation of the full compressible Navier–Stokes equations that retains the essential sound-generation mechanisms, [3]. Finally, numerical simulations of flow-induced vocal fold vibrations and the subsequent propagation of sound through the human vocal tract are presented.

References

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