Computational study of flow–induced oscillation of a simplified soft palate

M. Khalili*, M. Larsson† and B. Müller*

* Department of Energy and Process Engineering
Norwegian University of Science and Technology (NTNU)
Kolbjørn Hejes vei 2, NO-7491 Trondheim, Norway
e-mail: {mohammadtaghi.khalili, bernhard.muller}@ntnu.no

† Sportradar AS
Ferjemannsveien 10, 7014 Trondheim, Norway
e-mail: m.larsson@sportradar.com

ABSTRACT

The purpose of the present study is to conduct a numerical investigation of the flow physics underlying the aeroelastic oscillation of a flexible plate in a channel in order to obtain a better understanding of the mechanism of Obstructive Sleep Apnea Syndrome (OSAS) and snoring. OSAS is a sleep related breathing disorder caused by repetitive collapses of the soft tissues in the upper airways during sleep. A simplified 2D model of fluid-structure interaction (FSI) for the soft palate in the upper airways is developed. In recent years, FSI models have been successfully applied to a wide range of physiological systems in the human body, including the vocal tract [1] and soft palate [2].

The interaction between the inspiratory airflow through nose and mouth with the soft palate is modeled as compressible viscous flow over a cantilevered flexible plate. The fluid motion defined in an Eulerian frame and the flexible plate motion defined in a Lagrangian frame are solved in an arbitrary Lagrangian–Eulerian (ALE) formulation and their interaction is handled using an explicit, two–way coupling strategy where forces and deformations are exchanged between the flow and plate at the end of every time step.

The compressible flow field is computed by means of a high order finite difference method. Strict stability and high order accuracy are obtained by employing summation by parts (SBP) difference operators, which are 6th order accurate in the interior and 3rd order accurate near the boundaries [3]. To achieve high accuracy and easy parallelization, the 4th order explicit Runge–Kutta method is applied for time integration.

The motion of the plate is obtained by solving a two dimensional model in which a thin flexible plate is clamped at its leading edge and is free at its trailing edge [4]. The plate motion is considered under the constraint of inextensibility. This inextensible plate model is described by another set of equations with an additional momentum forcing which is the result of the interaction with the surrounding fluid. The numerical method for computing the structure equation is based on the finite difference method. A staggered grid procedure in the single Lagrangian coordinate is employed. The plate tension is defined at the interfaces of the grid cells and other variables are defined at the primary grid points in the centers of the grid cells. The mesh adapts to the fluid-structure interface in each time step after the force acting from the fluid on the plate has been used to compute the new deformations of the structure and new grid velocities. The multi block structured grid approach is employed to accommodate geometric flexibility without loss of accuracy at block boundaries.

In the present study, an improved version of the structural model is proposed in comparison with [2] to better model the behaviour of the soft palate. The primary aim is to efficiently simulate the interaction between a flexible plate and a compressible viscous fluid flow with comparison of the results for the two structural models. We investigate the performance of this coupled

fluid–structure system for a range of plate and flow parameters and explore the effects of the oscillatory mode on vortex shedding.

REFERENCES

[1] M. Larsson and B. Müller, "High order numerical simulation of fluid-structure interaction in the human larynx," *Progress in Computational Fluid Dynamics, An International Journal*, vol. 12, no. 2/3, pp. 164–175, 2012.

[2] M. Khalili, M. Larsson, and B. Müller, "Interaction between a simplified soft palate and compressible viscous flow," *Journal of Fluids and Structures*, vol. 67, pp. 85–105, 2016.

[3] M. Svärd and J. Nordström, "Review of summation-by-parts schemes for initial–boundary-value problems," *Journal of Computational Physics*, vol. 268, pp. 17–38, 2014.

[4] W.-X. Huang, S. J. Shin, and H. J. Sung, "Simulation of flexible filaments in a uniform flow by the immersed boundary method," *Journal of Computational Physics*, vol. 226, no. 2, pp. 2206–2228, 2007.