Coupled isogeometric boundary element and finite element analysis for the efficient simulation of fluid-structure interaction problems

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ABSTRACT

An isogeometric boundary element (BE) formulation for Stokes flow is presented in this work. The key idea of the boundary element method (BEM) is to express the solution of a partial differential equation (PDE) in terms of boundary distributions of their fundamental solution. Thus, a three-dimensional Stokes problem can be solved efficiently on its two-dimensional spline boundary. Special care has to be taken for the boundary integration of the singular fundamental solutions. To this end, various techniques like special quadrature rules, semi-analytical integration and a nonsingular BEM formulation [1] are investigated and compared.

Beside its application to pure Stokes flow problems in rigid boundaries [2], the BEM is further used to model the interaction between fluid flows and deformable structures. The motion of the structural boundary is described with well-established nonlinear finite element (FE) surface models for membranes [3] and shells [4]. A monolithic scheme is presented to couple the formulations for boundary element (Stokes flow) and finite element (membranes and shells) analysis. A common curvilinear surface parameterization is used for BE and FE analysis to admit general surface shapes and deformations. Therefore, the discretization and integration on the boundary surface is sufficient to solve a volumetric fluid-structure interaction (FSI) problem. Geometry and PDEs are spatially discretized using C^1-continuous NURBS basis function for interpolation, while the temporaly discretization is realized with the generalized-α scheme.

The behavior of the coupled system is illustrated by several numerical FSI examples considering interior and exterior Stokes flow. These include flow within and outside of bubbles, droplets and liquid-filled balloons and moreover filling processes of cavities (including mechanical contact). The presented coupling formulation provides an efficient method to model industrial applications from melt engineering and additive manufacturing among others.

REFERENCES

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