Hydroelastic Simulations in OpenFOAM®: An Efficient Numerical Implementation of the Modal Equations

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ABSTRACT
To formulate equations of motion for a floating deformable structure, it is assumed that the structure may undergo large and nonlinear pseudo rigid-body translations and rotations (i.e. surge, sway, heave, roll, pitch and yaw) while local structural deformation remains small, linear and elastic. Using a modal superposition approach and the floating frame of reference, the equations of motion consist of six pseudo rigid-body equations and \( k \) equations in the modal space where \( k \) is the number of selected mode shapes. These mode shapes are usually computed using a finite-element software such as e.g. NUMEREX. In the formulation, the system mass matrix (\( M \)) as well as the quadratic velocity terms (\( Q_v \)) are nonlinear. An efficient numerical implementation of the modal equations is the subject of this paper which shows that it is not necessary to simplify further the \( M \) and \( Q_v \) matrices since all time-variant terms can be evaluated and updated very efficiently. In addition, the complexity of implementing support for various element types is significantly reduced. The theoretical description and the derivation are given followed by numerical examples.

**Keywords:** Deformable Body; Modal Superposition; Floating Frame of Reference

1. INTRODUCTION
To some extent global hydroelastic responses on large vessels such as whipping and springing can be studied using a free surface RANSE solver (Reynolds-Averaged Navier-Stokes Equations) which is casually referred to as the CFD method. This type of flow solvers can provide high-fidelity load distributions with far fewer assumptions than the traditional potential-flow-based models. The computation time, however, is known to be huge. Even on a modern HPC (High-Performance Computing) cluster a single run which covers approximately a few wave periods may need several days of computation on hundreds of processors. The need of a strong coupling (Matthies 2006) between fluid load distributions and structural responses in hydroelastic problems leads to even more demand on the computational resources. The computational complexity on the structural sides depends strongly on the model and the details which are needed. The structural model can be as simple as a Bernoulli-Euler beam, or a Timoshenko beam (Seng et al. 2012, Oberhagemann 2016) to a generic full 3D FE model (finite element model). Commonly, the latter requires a side-by-side execution of the flow solver and the 3D FE software (e.g. NUMEREX, ABAQUS, ANSYS) and a heavy communication to and from the flow solver to exchange necessary information such as interpolated fluid force and nodal displacement. The implementation, the control of the coupling algorithm and runtime parameters of such a heavily coupled system are very demanding; not only in terms of CPU time but also in terms of engineering skills and time for preparing the additional input data and simulation control

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