Robust and Accurate Tracking of Free Surfaces: Stabilization and NURBS-Based Discretization Aspects

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ABSTRACT

Moving-boundary flow simulations are an important design and analysis tool in many areas of engineering, including civil and marine engineering, as well as production engineering [1]. While interface-capturing offers unmatched flexibility for complex free-surface motion, the interface-tracking approach is very attractive due to its better mass conservation properties at low resolution. We focus on interface-tracking moving-boundary flow simulations based on stabilized discretizations of Navier-Stokes equations, space-time formulations on moving grids, and mesh update mechanisms based on elasticity.

The kinematic condition, which can be interpreted as an elevation equation, as well as its stabilized GLS formulation, has been derived for specific classes of problems, including cases where surface nodes move along prescribed directors or spines [2]. The need for implicit solution of such stabilized problem results in a coupled system of equations for a) the equation governing the generalized elevation, b) the interior mesh deformation equations and c) the flow equations. The coupling between these three systems is enforced iteratively within the nonlinear iteration loop, placing certain restrictions on the size of the time steps taken.

In order to obtain accurate and smooth shape description of the free surface, as well as accurate flow approximation on coarse meshes, the approach of NURBS-enhanced finite elements (NEFEM) [3] is being applied to various aspects of free-surface flow computations. In NEFEM, certain parts of the boundary of the computational domain are represented using non-uniform rational B-splines (NURBS), therefore making it an effective technique to accurately treat curved boundaries, not only in terms of geometry representation, but also in terms of solution accuracy.

As a step in the direction of NEFEM, the benefits of a purely geometrical NURBS representation of the free-surface could already be shown [4]. The first results with a full NEFEM approach for the flow variables in the vicinity of the moving free surface have also been obtained. The applications include both production engineering, i.e., die swell in plastics processing simulation, and safety engineering, i.e., sloshing phenomena in fluid tanks subjected to external excitation.

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