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An adaptive Fixed-Mesh ALE method for free surface flows

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Abstract

In this work we present a Fixed-Mesh ALE method for the numerical simulation of free surface flows capable of using an adaptive finite element mesh covering a background domain. This mesh is successively refined and unrefined at each time step in order to focus the computational effort on the spatial regions where it is required. Some of the main ingredients of the formulation are the use of an Arbitrary-Lagrangian-Eulerian formulation for computing temporal derivatives, the use of stabilization terms for stabilizing convection, stabilizing the lack of compatibility between velocity and pressure interpolation spaces, and stabilizing the ill-conditioning introduced by the cuts on the background finite element mesh, and the coupling of the algorithm with an adaptive mesh refinement procedure suitable for running on distributed memory environments. Algorithmic steps for the projection between meshes are presented together with the algebraic fractional step approach used for improving the condition number of the linear systems to be solved. The method is tested in several numerical examples. The expected convergence rates both in space and time are observed. Smooth solution fields for both velocity and pressure are obtained (as a result of the contribution of the stabilization terms). Finally, a good agreement between the numerical results and the reference experimental data is obtained.

1 Introduction

In the numerical simulation of physical phenomena many times one is faced with the need of simulating problems where the physical domain evolves in time. This is the case for instance in the numerical simulation of structural problems involving large deformations, multifluid flow problems or problems involving a free surface, amongst others. One of the main issues in such cases is to decide how to tackle with this movement. If a computational physics mesh is used, as for instance in finite elements simulations, a mesh which covers the physical domain is required (other possibilities which do not require a computational mesh exist such as meshless methods [56] or spectral methods [25], although these are perhaps not so common in day-to-day engineering practice).

This computational mesh needs to deal with the displacement of the physical domain. In many cases, the mesh can adapt to the shape of the domain by using Lagrangian formulations [17] which take into account large displacements and geometric non-linearities, or Arbitrary Lagrangian-Eulerian (ALE) formulations [38]. In most solid dynamics problems and even in fluid-structure interaction problems where the solid body is subject to large deformations but still has an anchor point [62], the simulation can be approached using these methods. In other cases, however, domain displace-