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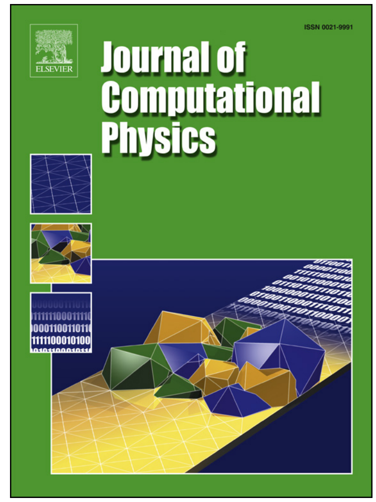

Time-accurate anisotropic mesh adaptation for three-dimensional time-dependent problems with body-fitted moving geometries

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Time-Accurate Anisotropic Mesh Adaptation for Three-Dimensional Time-Dependent Problems with Body-Fitted Moving Geometries

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Abstract

Anisotropic metric-based mesh adaptation has proved its efficiency to reduce the CPU time of steady and unsteady simulations while improving their accuracy. However, its extension to time-dependent problems with body-fitted moving geometries is far from straightforward. This paper establishes a well-founded framework for multiscale mesh adaptation of unsteady problems with moving boundaries. This framework is based on a novel space-time analysis of the interpolation error, within the continuous mesh theory. An optimal metric field, called ALE metric field, is derived, which takes into account the movement of the mesh during the adaptation. Based on this analysis, the global fixed-point adaptation algorithm for time-dependent simulations is extended to moving boundary problems, within the range of body-fitted moving meshes and ALE simulations. Finally, three dimensional adaptive simulations with moving boundaries are presented to validate the proposed approach.

Key words: Metric-based mesh adaptation, anisotropy, unsteady, moving geometry, moving mesh, connectivity change.

1. Introduction

Simulating complex moving geometries evolving in unsteady flows in three dimensions, which is more and more required by industry, still remains a challenge because it is very time consuming. To reduce the CPU time of numerical simulations while preserving their accuracy, anisotropic metric-based mesh adaptation has already proved its efficiency for steady problems [5, 37, 38, 46], and appears as a promising way to reduce the complexity of such simulations. However, its extension to the unsteady case with body-fitted moving geometries is not straightforward. Indeed, time-dependent simulations combine the difficulties arising from unsteadiness and geometrical complexity: global time-step driven by the mesh smallest height, evolution of physical phenomena in the whole domain, solution interpolation spoiling, and also three-dimensional meshing and remeshing issues with an imposed discretized surface. The introduction of body-fitted moving geometries in this process even raises new difficulties, due to the handling of the mesh movement and the deterioration of its quality, the specific numerical schemes imposed by moving geometries as well as fluid/structure coupling and contact handling.

There exist two main branches of mesh adaptation for unsteady problems: r-adaptation and adaptive remeshing.

In the case of r-adaptation also called adaptive moving mesh methods, the mesh is continuously moved to an adapted configuration. The movement of the mesh vertices is governed by an extra equation that is strongly coupled to the underlying physics equations and that is solved at the same time. Since the mesh movement is explicitly taken into account in the equations, there are no spoiling interpolation steps. Several approaches can be found in the literature, that differ by the adaptation criteria, the way the adaptation governs the mesh movement and the way the mesh movement is coupled with the physics equations. Recent works on the topic include Moving Mesh PDEs [8, 28], and Lagrangian methods with ALE rezoning [40]. A Monge-Ampère equation has also been used to drive the adaptation and has shown interesting results in 3D in [15, 17]. However, the solution of the extra moving mesh equation is often costly in terms of CPU in 3D, and the optimality of the adapted mesh is not achieved temporally as the same number of degrees of freedom is used through the whole simulation. Moreover, it is unsure how these methods can be coupled to moving boundary problems.

The other branch consists in performing frequent adaptive remeshings. Three different approaches can be distinguished in the literature. First [30, 33, 49, 52], an isotropic mesh is adapted frequently in order to maintain the solution within refined regions and introduce a safety area around critical regions. Another approach is to use an unsteady mesh adaptation algorithm [14, 16, 20, 48, 53] based on local or global remeshing techniques and the estimation of the error every n flow solver iterations. If the error is greater than a prescribed threshold, the mesh is re-adapted. In [27], the authors combine both approaches mentioned above. Local adaptive remeshing enabling the construction of anisotropic meshes has been also considered. In this case [46, 50], the mesh is frequently adapted in order to guarantee that the solution always evolves in refined regions. All these approaches involve a large number of mesh adaptations leading to a large increase in CPU time due to the generation of many meshes[1], and

[1] The generation of a mesh is usually more costly than a few flow solver time-steps.