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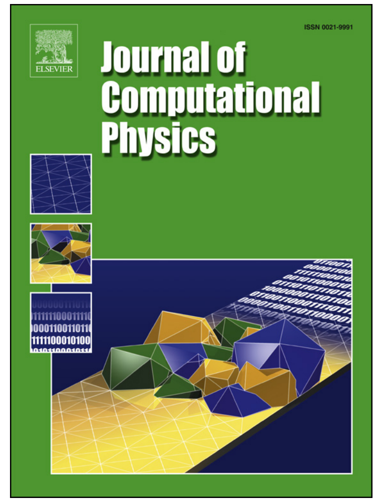

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Time-Accurate Multi-Scale Anisotropic Mesh Adaptation for Unsteady Flows in CFD

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Abstract

This paper deals with anisotropic mesh adaptation applied to unsteady inviscid CFD simulations. Anisotropic metric-based mesh adaptation is an efficient strategy to reduce the extensive CPU time currently required by time-dependent simulations in an industrial context. In this work, we detail the time-accurate extension of multi-scale anisotropic mesh adaptation for steady flows [35] (a control of the interpolation error in L^p norm to capture all the scales of the solution contrary to the L^∞ norm that only focuses on the larger scales) to unsteady flows when time advancing discretizations are considered. This is based on a space-time error analysis and an enhanced version of the fixed-point algorithm [3]. We also show that each stage - remeshing, metric field computation, solution transfer, and flow solution - is important to design an efficient time-accurate anisotropic mesh adaptation process. The parallelization of the whole mesh adaptation platform is also discussed. The efficiency of the approach is emphasized on three-dimensional problems with convergence rate and CPU time analysis.

Key words: Anisotropic Mesh Adaptation, Time-accurate, Multi-scale, Metric, Fixed-Point Algorithm, Unsteady Flows

1. Introduction

3D simulation of unsteady flows for complex geometries, which is actually the typical situation for real-life problems, still remains a challenge. Indeed, these computations are very time consuming. The use of anisotropic metric-based mesh adaptation, which has already proven its efficiency for steady problems [5, 9, 27, 41, 43, 55, 57], seems to be appropriate in order to reduce the CPU time of such simulations while preserving their accuracy. However, extension to the unsteady case is far from straightforward as such simulations have many difficulties arising from unsteadiness. To achieve an efficient time-accurate mesh adaptation scheme for unsteady flows, we have to overcome the issues described in the following discussion.

First of all, we have to remedy the problem of the latency of the mesh with respect to the solution, *i.e.,* the mesh is lagging behind the solution in time. Indeed, if a mesh is adapted for a solution at time t, once the solution progress in time again, it is clear that this mesh is not adapted for the next time-steps. Consequently, no error control can be guaranteed.

Theoretically, error estimates used for steady flows [5, 35] need to be extended to the unsteady case. In other words, for time-dependent simulations, the temporal error should also be controlled. A space-time error analysis is then required.

Moreover, after each remeshing, the solution on the current mesh has to be interpolated on the new adapted mesh to pursue the simulation. This stage becomes crucial in the context of unsteady problems and even more if a large number of solution transfers is performed, as the error due to this solution transfer accumulates throughout the simulation. In consequence, the error introduced by this stage can spoil the overall accuracy of the solution [2].

In regards to the meshing phase, a difficulty arises from the definition of the solver time-step dt (omitting CFL factor) which is homogeneous to the smallest element height of the mesh h_{min} when considering explicit time-integration schemes. Consequently, a single small-height element in the whole mesh is sufficient to considerably reduce the time-step and thus increase the CPU time of the simulation. This is a serious problem, especially in the context of highly anisotropic mesh adaptation, which involves highly stretched elements. On the solver side, specific time integration scheme can remedy to this issue such as the multi-rate approach [12]. On the meshing side, a remedy is to reduce this constraint as much as possible by generating anisotropic meshes controlling the highest h_{min} value [34]. This implies a substantial effort on the anisotropic mesh generator as the quality of the mesh must be very good. For example, if the mesh generator fails to generate the minimal height element for which a size of h_{target} had been prescribed, and instead build an element of height $h_{min} = 0.01 \times h_{target}$, then for explicit time-integration schemes, the number of solver iterations is multiplied by 100 for time-accurate simulations. Consequently, for a given mesh, *not a single meshing mistake is allowed although millions of tetrahedra are generated*.

State-of-the-art

Over the past few years, a rather large number of papers have been published dealing with mesh adaptation for *steady* numerical simulations, whereas only a small number have addressed *time-dependent* problems. For the unsteady case, three