Research Note
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Partial remeshing strategy for CFD simulations when large displacements are taken into account

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Abstract

This research aims at developing innovative and efficient strategies to run computational fluid dynamics simulations when large displacements of geometry are taken into account. The goal is to be able to follow the movement of a rigid body in a given three dimensional domain during the simulation, regardless of the displacement amplitude. In these notes the strategies concerning the mesh generation and update are described. This research is carried out within a collaboration between the Fluids-Machines Department of University of Mons and NUMECA International.

Keywords: Partial remeshing; moving body; large displacements; hybrid mesh

1. Positioning of the Problem

The present research is carried out in the domain of moving bodies and fluid dynamics. A typical application is the problem of store separation that aims at simulating the release of a load from a flying aeroplane.

Numerical simulations of such types of problems are more and more common due to the growing computational resources available [1], but multiple challenges raise in terms of both mesh generation [2] and computation [3] of the Navier-Stokes equations solution. Main concerns are related to the time required to get an accurate solution and to implement a robust algorithm. This implementation must be efficient in parallel environments to be able to take advantage of the large parallel machines.

Rigid bodies have 6 degrees of freedom in the space and the displacement is computed from the generalised forces acting on them (e.g. weight, thrust and aerodynamic loads integrated by the solver, etc.); for the sake of generalizability, mass, inertia tensor and center of mass are time dependent.

In literature, different approaches to solve the rigid moving body problem can be found and they can be divided in three main clusters [4,5]: chimera approach [6], mesh deformation [7,8] and remeshing [9].

To implement the strategy, it has been chosen to use CFD tools developed by *NUMECA International*: the mesh generator is *HEXPRESS/Hybrid* (*HH*) and it will be coupled with the solver *FINE/Open*. *HH* is a meshing tool

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suitable for complex geometries that produces hex-dominant conformal meshes in parallel, including high quality viscous layers starting from unclean geometries. *FINE/Open* is dedicated to complex internal and external flows, suitable for both compressible and incompressible conditions.

2. Strategy Description

The strategy under development can be numbered in the group of partial re-meshing strategies: the region where the mesh needs to be reconstructed should be as limited as possible. Two main elements can be distinguished:

- **Background mesh** The mesh of the computational domain
- **Moving mesh** Each moving object has its own mesh around it and the two move as a rigid body.

The steps of the algorithm are:

1. Generation of the background mesh
2. Generation of the mesh around each moving object
3. Detection for the overlapping region between meshes
4. Delete cells in the overlapping regions
5. Insertion of the moving meshes into the background mesh with holes
6. Generation of a conformal connection between the two meshes.

The key element of the strategy is that steps 1 and 2 will be done once at the beginning, so that two reference meshes are obtained; while steps 3 to 6 will be run at each time step during the simulation to adapt the mesh to new position of the body. For the generation of the conformally connecting mesh *Gmsh* [10] is integrated in *HH*. Visualisation of the proposed strategy is given in Fig. 1 for a 2D example.

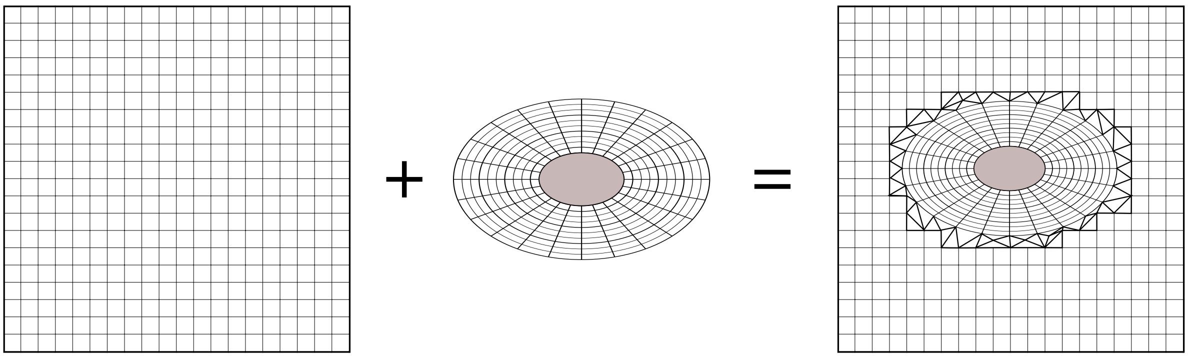

Fig. 1. Partial remeshing strategy: referencemeshes (left) and resulting mesh (right), example of overlap detection and conformally connecting mesh

2.1. Multiple moving bodies

It is necessary to focus on additional details to be able to handle more complex situations (e.g. multiple moving bodies, close to touch condition, etc...). As the strategy consists of cell removal and insertion, the algorithm should optimise the choice of cells to be deleted. If there is only one moving body in the domain, deleting the background-mesh cells is quite straightforward: the problem becomes more complex when multiple moving bodies overlap each other.

The notion of *priority* is introduced: the user has to define the priority level for each mesh.

Background mesh has priority 0 by default, as its cells will always be removed. Only one background mesh can be defined.

Moving meshes will have thus a priority greater than or equal to 1. Meshes will see their cells removed when overlapped by meshes with a higher priority. The same priority can be assigned to more than one mesh: in this case cells will be removed from both meshes or following a chronological insertion order.

A special treatment should be given to the boundary layer cells which should be kept as long as possible: the algorithm tries to remove external cells instead of boundary layer cells whenever possible. Boundary layer cells are removed when two meshes with the same priority overlap in the boundary layer region (e.g. two solid bodies are close to contact) so that the mesh is thoroughly re-generated in the gap between the solid boundaries; this approach should avoid degradation of the mesh quality limiting at the same time computational costs.

2.2. Advantages and limitations

The advantages of such a strategy are enumerated in the following list:

- **Moving mesh:** a high quality mesh (boundary layers) around each moving body is generated once for all and be kept without modifications as long as possible; this reduces mesh generation time.
- **Background mesh:** a mesh for the domain is generated at the beginning of the simulation, it will be updated through the overlap detection and conformal connection generation during the simulation.
- **Boundary layer cells:** this type of cells is very expensive to generate in terms of both computational time and computational costs; this approach tends to keep as long as possible this layer of cells around the body.

A first constraint of the strategy proposed is that the size of the moving mesh cannot be smaller then the size of the cells in the overlapping region. The detection of the overlapping region (e.g. the cells to be removed) is based on the identification of the vertices included in the surface surrounding the moving mesh and the deletion of all the cells sharing those vertices. If a mesh is smaller than the size of the cell to be removed, it is not ensured the detection of the this overlap (see Fig. 2 left).Then it is necessary to switch to a more sophisticated algorithm, though at the expense of the final mesh quality.

To obtain high quality meshes, cell densities between the two surfaces delimiting the "hole" should be similar: if they differ too much, then the quality of the resulting mesh will be degraded. This is due to the presence of cells of different size in a limited region (see Fig. 2 right).

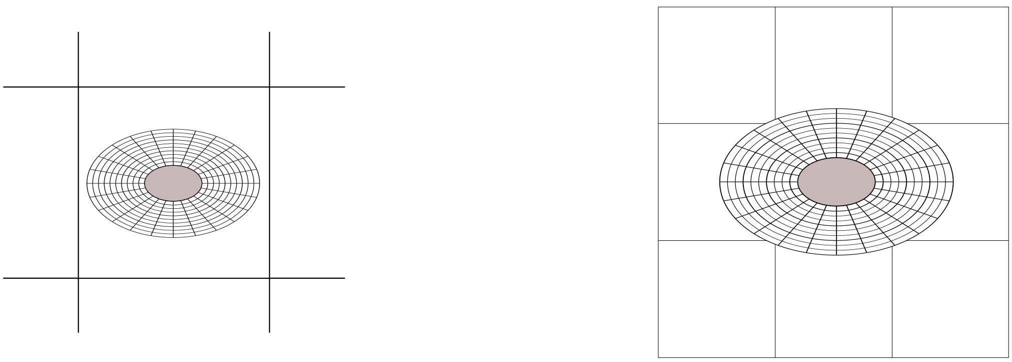

Fig. 2. Constraints on relative cell size between background mesh and moving mesh (*left*) and on cell density (*right*)

3. Preliminary Results

In the present section, preliminary results of the development of the strategy are presented. The main development directions are:

- Overlap detection: algorithm to mark the cells in the overlapping region and to remove them;
- Conformal connection using *Gmsh*.

Overlap detection and cell removal algorithm has been developed using two test cases differing for the cell size of the background mesh. An empty volume around the hexahedral mesh (moving mesh) is created by removing cells from the cubic mesh (background mesh), as show in Fig. 3.

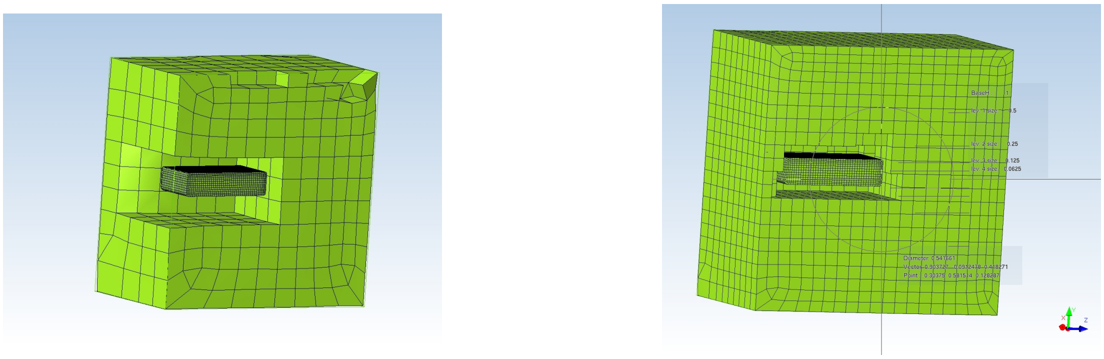

Fig. 3. Cube1 (left) and Cube05 (right) test cases for overlap detection and cell removal

This volume is then meshed by importing it into *Gmsh*; the result is given in Fig. 4. They can be recognised the faces externally bounding the volume and the hexahedral moving mesh as internal boundary.

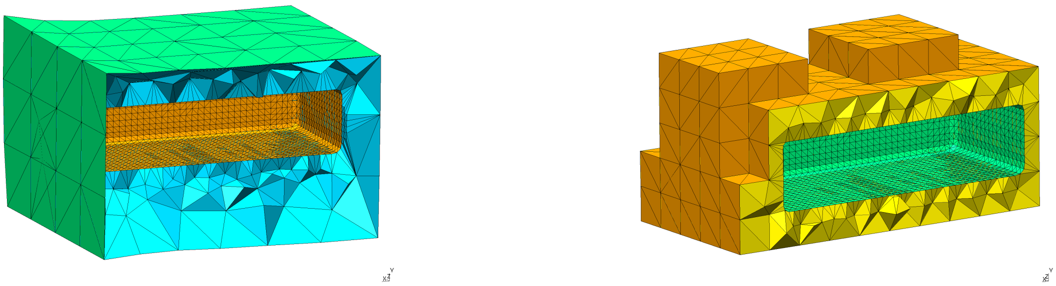

Fig. 4. Cube1 (left) and Cube05 (right) with mesh generated by *Gmsh*

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