KARALIT
Simplicity without compromise

KARALIT CFD

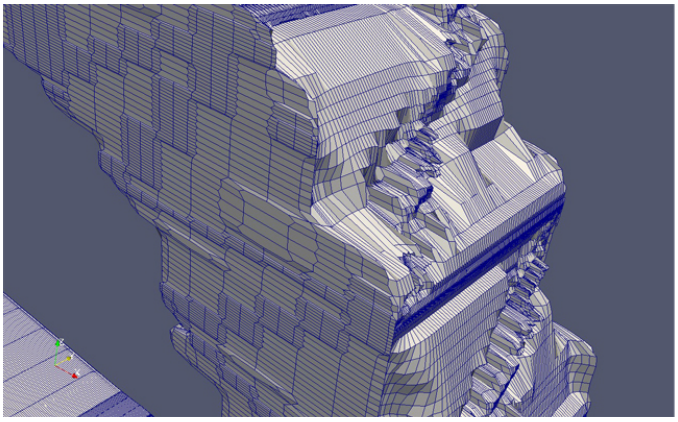
The Immersed Boundary method versus the Cut-Cell method

INTRODUCTION

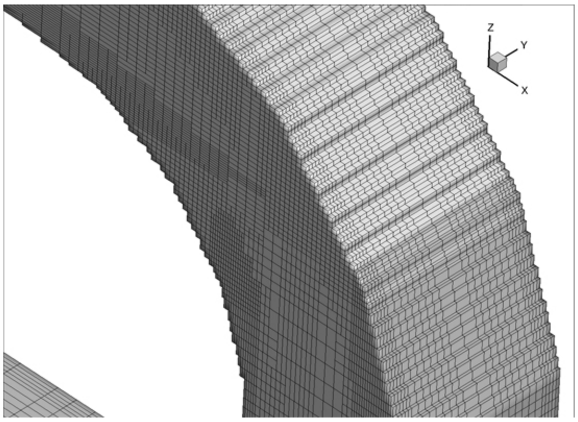
KARALIT CFD is a computational fluid dynamic software based on Immersed Boundary Method. IBM methods makes easier grid generation than usual method avoiding problems related to not conformity between bodies geometry and Cartesian grids.
Grid complexity and quality are not significantly affected by the complexity of the geometry when carrying out a simulation on a non-boundary conforming Cartesian grid.

DESCRIPTION

This document describes the difference between the IB method and the Cut-Cell method.



Curved pipe with a square cross section: Cut-Cell

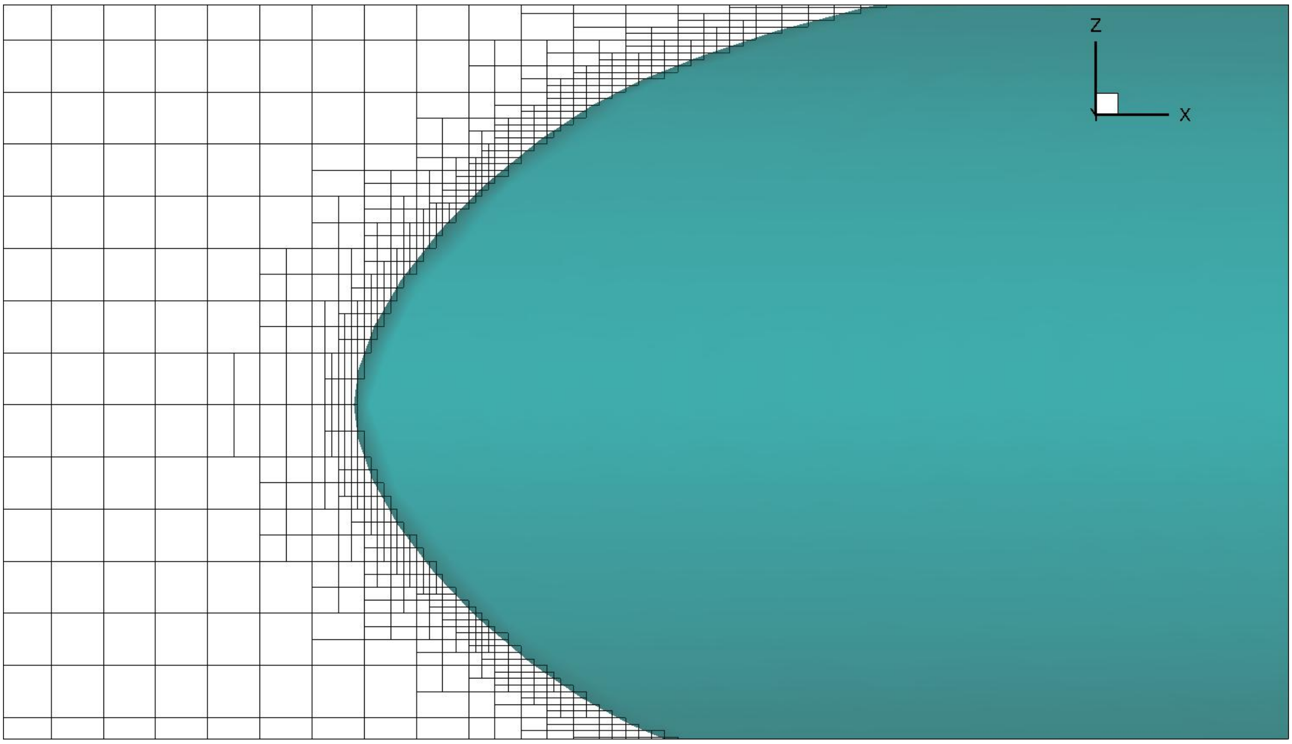


Curved pipe with a square cross section: KARALIT CFD

Immersed Boundary versus Cut-Cell method

The Immersed Boundary (IB) method is a mathematical technique that makes use of non conformal Cartesian grids, i.e. grids where no node is located on the bodies' surfaces. All cells are kept entire, even though those near the solid boundaries may partially lie inside the solid region.

The following figures shows an IB grid near the nose of a wing:



Only the cells whose center lies in the fluid domain region are solved by the equations. The Boundary conditions are applied at additional nodes located on the surface, and not on grid nodes. This is what the IB mathematical technique is all about.

That explains why the IB method is not "Stair Step", which is a common misunderstanding. The latter sets the BCs at the cell nodes, without introducing the location of the body, so that the stair step shaped domain represents the approximation of the body's surface.

The IB method greatly simplifies the grid generation process, which is completely automated and extremely quick. Moreover, Cartesian grids produce the least discretization error, and so the most accurate solution on equal terms (grid spacing at the bodies' surfaces and overall cell count).

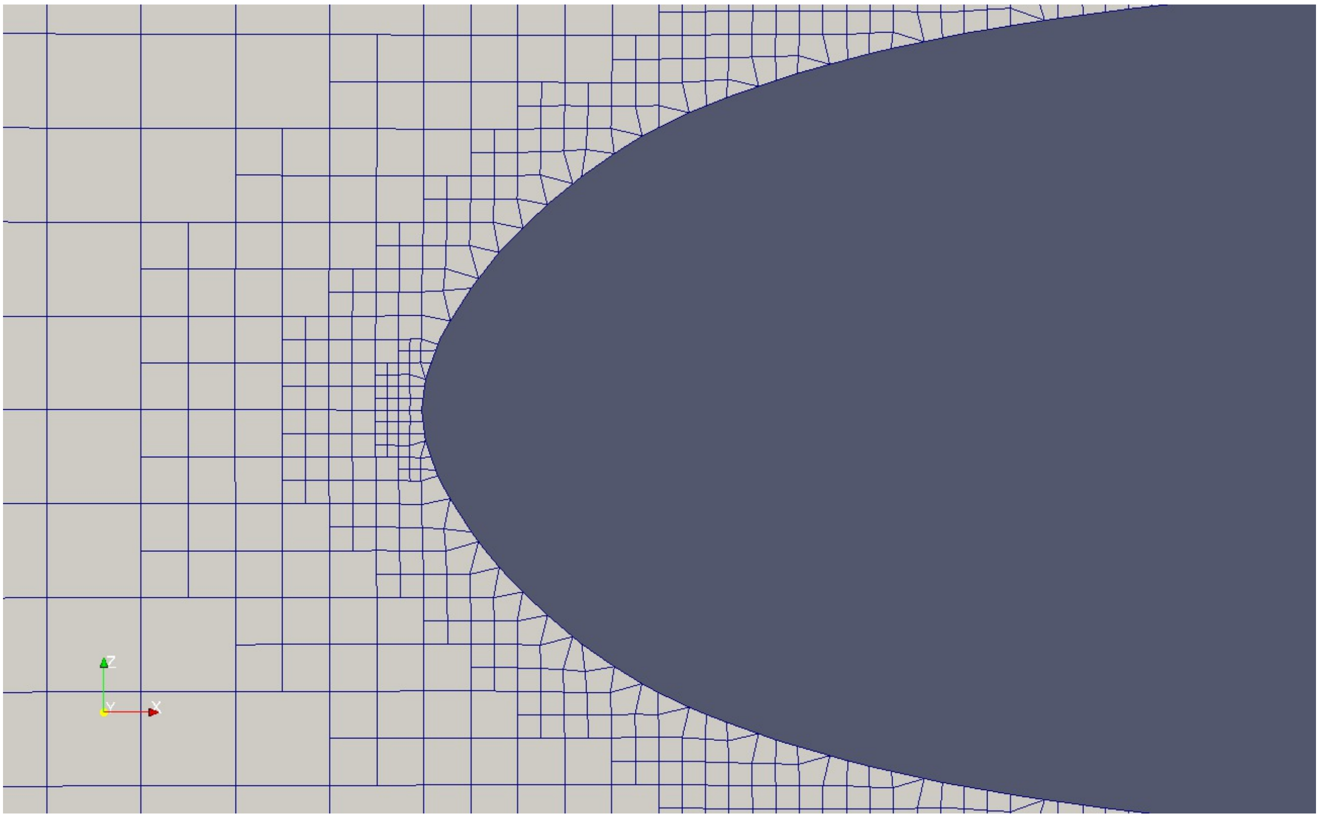
The IB method, whose development started in the beginning of 2000s, represents a disruptive innovation with respect to the standard Body-Fitted (BF) method. In the latter the mesh is conformal to the bodies' surfaces and it is therefore curvilinear. The boundary nodes of the mesh are located on the bodies' surfaces. At these nodes the boundary conditions are applied. Body-fitted mesh generation is a highly interactive and time consuming process that starts from meshing all surfaces first, and then filling the volume with hexahedral and/or tetrahedral cells. The cells near the bodies are often highly distorted, thus degrading the accuracy of the discretization schemes used to solve the equations.

Some CFD vendors claim they use the IB method. They use the so-called Cut-Cell (CC) method instead.

The CC method makes use of a grid which is similar to the grid used by the IB method, the nodes near the bodies' surfaces are however forced to lie on the surfaces, i.e. the portion of the cell inside the body is trimmed. So the grid generation process creates the surface where the Cartesian grid intersects the body geometry, and creates the volume mesh by cutting and merging the cells near the surface.

In this respect, a CC grid is BF with a Cartesian grid almost everywhere but near the surfaces. It can also be seen as an IB grid which is forced to be BF near the surfaces.

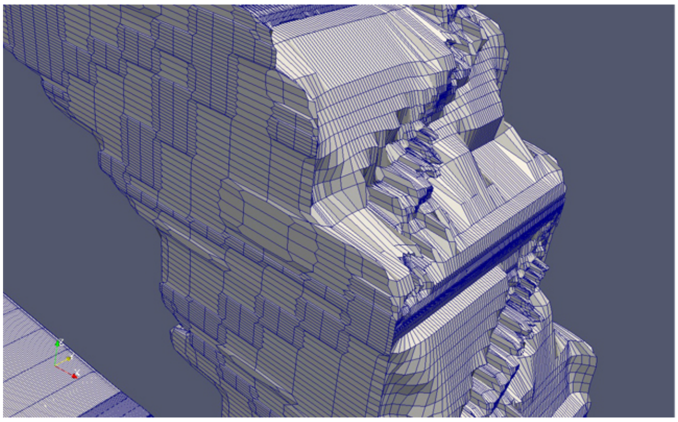
The following figure shows how a cut-cell method re-shapes the cells near the body:

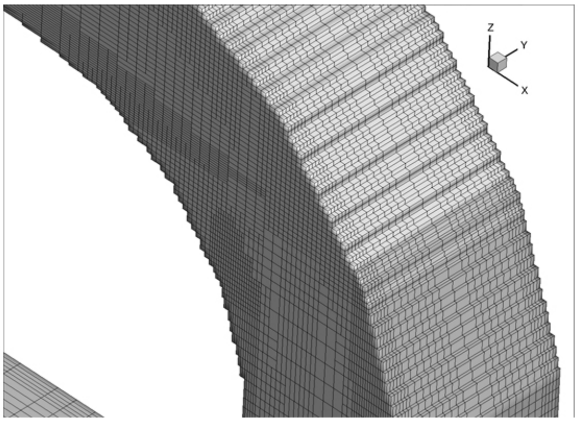


The disadvantages of the CC method are related with the process of cutting the cells. Care must be taken in order not to produce cells which are too small and that may become potential sources of numerical instabilities and possible failure of the computation. So, the cut cells near the boundary must be adjusted, modified and/or merged. In case of very complex geometries, this process may even fail in preserving the geometrical representation of the bodies, by introducing some sort of wavy pattern that was not present in the original geometry.

In the case shown, the leading edge of a wing, the geometry is smooth and the CC method successfully complete the cutting cell process, preserving the wing surface. However, it can be clearly seen that the cells near the surface are not Cartesian anymore and somewhat distorted.

When the geometrical surface definition is complex, or when sharp edges are present, the CC process may even fail. The following figure shows an example of such failures for the case of a curved pipe with a square cross section and, on the right, the same geometry processed with KARALIT CFD:





CONCLUSION

These are the main advantages of the IB technique compared to the Cut-Cell technique. The IB method developed by KARALIT has a number of additional strengths that most of the CC methods do not have:

- The grid generation process automatically finds all wet surfaces and the fluid domain, with no need to eliminate from the CAD output superfluous portions of solid bodies.
- The STLs may penetrate into each other.
- It can deal with overlapping STL elements.

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