Zipper Layer Method

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Summary. Based on the buffer layer method, a new method called zipper layer method was developed. This method maintains the capability of the buffer layer which can link two topologically different multi-block structured meshes together, while significantly improving the robustness. This method can both locally and globally connect two dissimilar structured meshes with tetrahedrons and pyramids to form a conformal mesh. The NASA Rotor 37 and an open rotor are used as test cases here to generate the zipper layer meshes. The numerical results on these zipper layer meshes compared well with those on the multi-block structured meshes.

Key words: mesh generation, hybrid mesh, zipper layer mesh

1 Introduction

It is well known that the hybrid mesh is a promising and useful alternative to structured and unstructured meshes. The original hybrid mesh uses prisms near the solid wall to maintain the orthogonality while using tetrahedrons to fill the rest of the volume. This method acquires some advantages of structured and unstructured meshes, however, hexahedrons are more preferable for most of the CFD applications. Therefore, it is natural to generate the hexahedrons near the solid wall while using unstructured cells such as tetrahedrons and/or prisms to fill the gap. The dragon mesh1 is one of the generic hybrid mesh which generates structured meshes for different components and then assemblies them together by using tetrahedrons. This method guarantees the high quality meshes in the structured mesh region and simplifies the mesh generation process. However, it causes hanging nodes in the meshes which is not suitable for all the flow solvers. In order to overcome this problem, Qin *et al.*1 use the combination of unstructured mesh layers to link the topologically different structured mesh together and named these layers as buffer layer. This buffer layer method successfully applied on the numerical simulation of turbomachinery flow field. It avoids the hanging nodes in the mesh by using pyramids layers, prismatic layers and tetrahedral layers to bridge the two structured meshes. This method further enlarges the scope of application of the generic hybrid mesh. Though the buffer layer method can link the structured meshes, it is still not robust enough when the linkage is in a small gap. Hence a new method called zipper layer method 3 is proposed in this paper to overcome the issues. Based on the general idea of the buffer layer method, the zipper layer method introduces an interface and then meshes the interface with unstructured cells to link two structured meshes.

2 Zipper Layer Mesh Generation Method

The generation process of the zipper layer method is totally dissimilar from that of the buffer layer method, though it still uses some of the ideas generated in the buffer layer method. The whole process can be divided into the following steps:

1. Identify the interface of the two multi-block structured meshes, find intersecting points of the two surface mesh edges, and merge the nodes or project the nodes to the edge when it is necessary;
2. Generate an unstructured surface mesh (triangles and quadrilaterals) including all the mesh points from both sides and the intersection points;
3. Insert nodes at the geometrical centres of the hexahedrons which need to be split on both sides of the interface, then generate unstructured

volume cells on both sides of the interface, including tetrahedrons, pyramids and hexahedrons;

4. Check the cell quality, fix the negative volume cells.

3 Dual Fast March Method and Node Movement

In order to indentify the node relation between the two meshes in Step 1 quickly, a method called dual fast march method is developed to locate the position in Mesh B for the nodes in another Mesh A. Based on the essence of the fast march method 4 applied on the single mesh, the dual fast march method is applied on the two different meshes at one time. Let Cell B contain Node A. Since the neighbouring nodes of Node A must be in the cells which are near the cell containing Node A, when locating these neighbouring nodes of Node A, the search region can be narrowed down to those cells near Cell B. As this method only searches the nearby cells, it can significantly decrease the search time than the brute force search.

In order to eliminate the sliver cells, node movement is adopted before the triangles on the interface are generated. The node movement is imbedded into the dual fast march method, so when locating the node position, the nodes are moved or projected to the edge. As shown in Fig.1, Node B is near Edge CD, so Edge CD becomes CBD to eliminate the small triangle which may be generated in the next procedure.

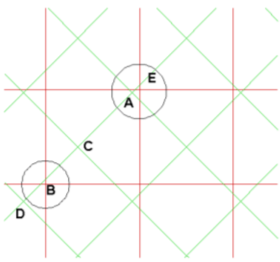


Fig. 1. Node movement

4 Generation of Interface Mesh and Volume Mesh

Before generating the unstructured meshes on the interface to form the interface mesh, some of the edges on both sides of the meshes are split by the intersection nodes. As shown in Fig.2, the cell's four edges (the red edges in Fig.2) are split by the intersection with another mesh (in green in Fig.2).

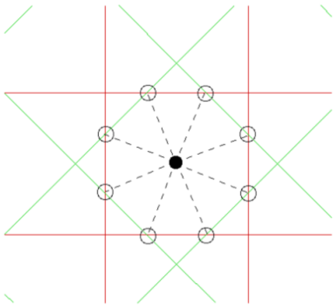


Fig. 2. Triangulation of the polygon

The interface mesh is formed by the newly generated edges and the original edges which have not been spilt. In Fig.2, the triangulation method is as follows:

1. Find the polygon which has more than four sides;
2. Insert a point into the geometry centre of the polygon;
3. Link the point with the two end nodes of each edge of the polygon to form triangles.

Fig.3 illustrates how a 2D interface mesh is generated. Fig.3 (a) and (b) are two topologically different structured meshes, whereas Fig.3 (c) is the interface mesh, and Fig.3 (d) is the magnificent view of Fig.3 (c).

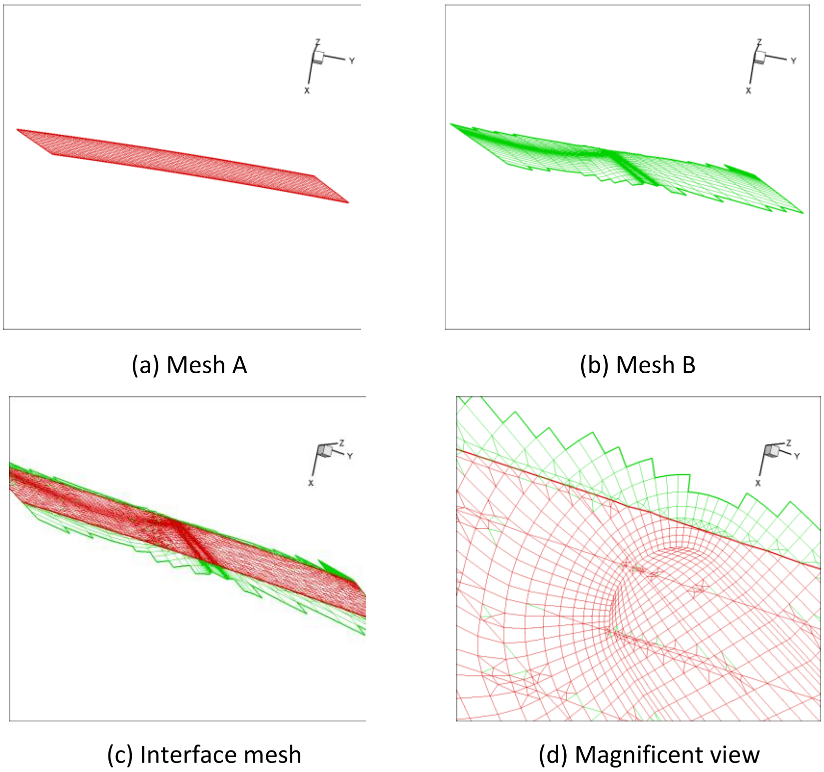


Fig. 3. Generation of interface mesh

The zipper layer approach adopts a similar cell splitting method as used in the buffer layer method, which is the major common ground between the two methods. However, in the buffer layer method, points are only introduced into each zone, while in zipper layer method, each split cell is treated as a single zone, and points are introduced into each cell. The general method is shown in Fig.4. First insert a point into the geometry centre of the cell, and then link the points of the triangles or quads to form tetrahedrons or pyramids.

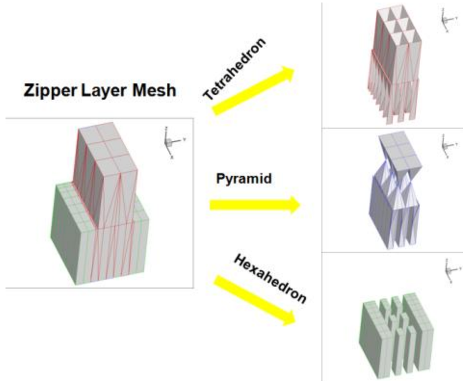


Fig. 4. Cell splitting required for zipper layer method to connect two non-matching structured meshes

5 Simple Test Case

This is a simple test case, as shown in Fig.5 to demonstrate the basic connection and capability of the method. On the left there is a uniformly distributed structured mesh; on the right there is a non-uniformly distributed mesh. The red surface highlights the interface surface where an interface mesh will be generated to link the top and bottom meshes, as shown in Fig.5. With the nodes on the interface surface and the intersection nodes, an interface mesh is then generated, as shown in Fig.6. Since the bottom mesh is smaller than the top one, all the top cells are split, while some of the cells at the bottom remain unchanged because they are 'contained' in the cells on the top. In order to form the volume mesh, the hexahedral cells are split based on the interface mesh in Fig.7. As can be seen from the figure, all the triangles on the interface mesh form the tetrahedrons, while the quadrilaterals formed by intersection nodes become pyramids.

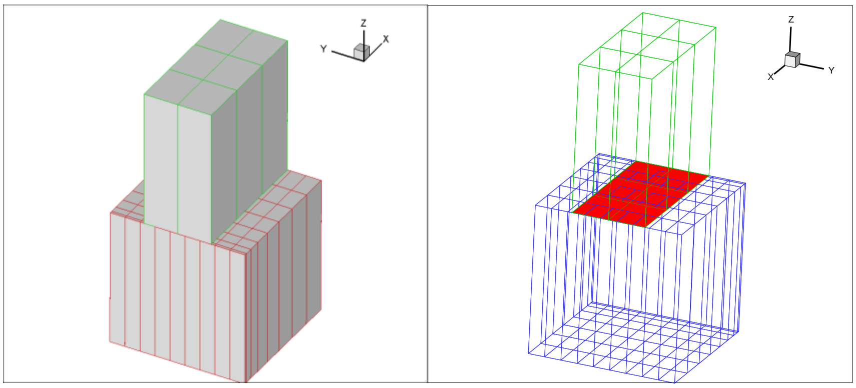


Fig. 5. Structured mesh(left) and interface (right, red plane highligts the interface of two different structured meshes)

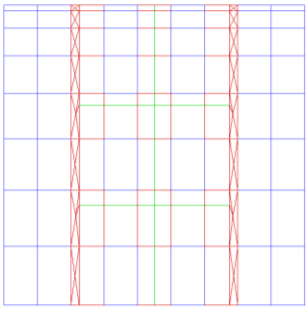
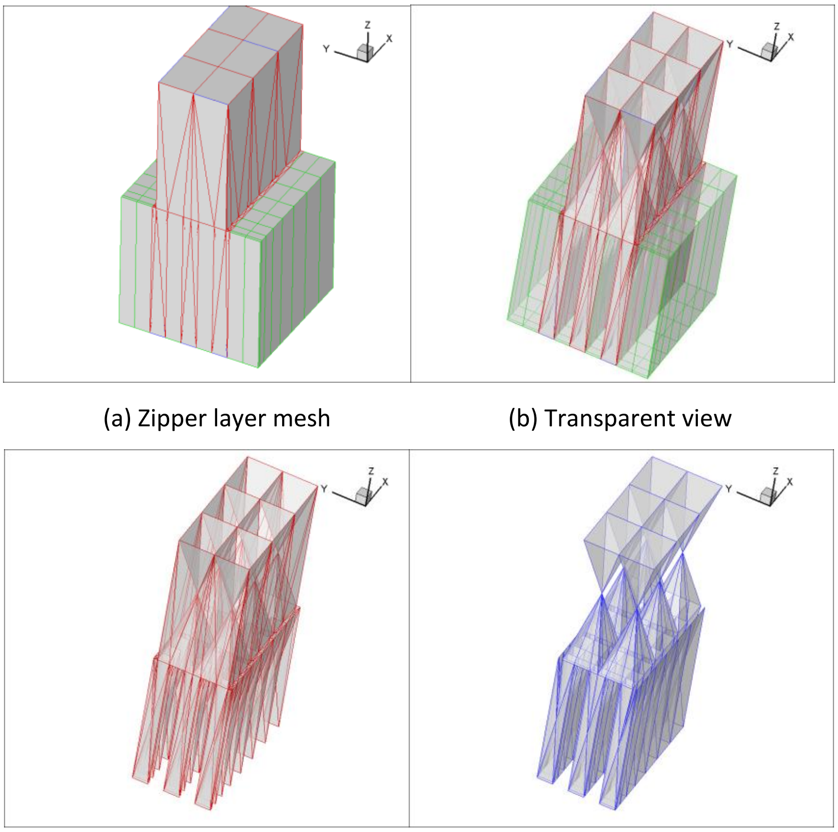


Fig. 6. Interface mesh (blue quads indicate the hexhedrons remain unchanged in the third step; while the rest of the quads form the pyramids)



(a) Zipper layer mesh (b) Transparent view

(c) Tetrahedrons (d) Pyramids

Fig. 7. Zipper layer mesh

6 NASA Rotor 37 Case

The NASA Rotor 37 case is used here as a test case to verify the method. Several grooves need to be added to the casing wall of the NASA Rotor 37 case for the casing design. However, it is difficult to achieve this for the structured mesh, since the tip gap is 0.356mm. Hence, the most efficient and simple way is to locally graft the groove mesh and the casing mesh for the NASA Rotor 37 case, which is called local zipper layer mesh here.

Fig.8 shows the local zipper layer mesh. As can be seen from the picture, the zipper layer mesh is introduced directly on the casing near the middle chord, and then the groove part is removed for the numerical comparison with the structured mesh. Both meshes use the same flow solver with 4 levels of multi-grid and CFL=2.

In Fig.9, the pressure ratios calculated on different meshes are compared. In order to verify that the local zipper layer mesh does not introduce too many numerical errors to the flow field, several zipper layer meshes are generated for comparison. The results on the local zipper layer meshes show the consistency to those on the multi-block structured mesh and the experimental data, while the result on the buffer layer mesh slightly under-estimates the pressure ratio. It indicates that the local zipper layer mesh introduces fewer numerical errors than the buffer layer mesh for the NASA Rotor 37 case. Fig.10 shows the comparison of the total pressure along the span. Both results on the zipper layer mesh and the multi-block structured mesh are comparable to the experimental data, while the result on the buffer layer mesh shows more discrepancy to the above two results and the experimental data.

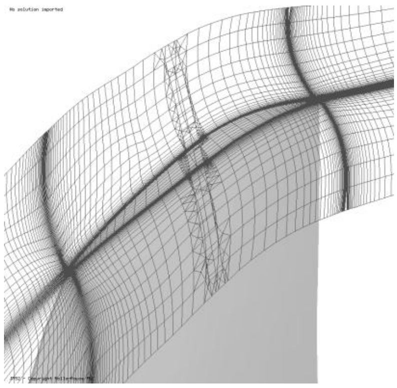
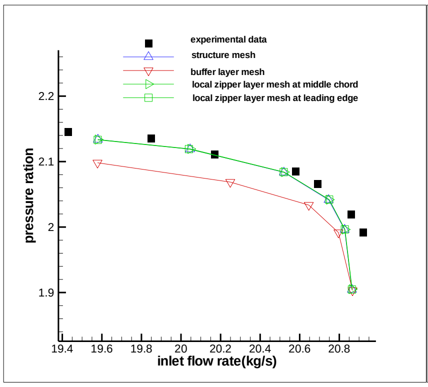


Fig. 8. Local zipper layer mesh for NASA rotor 37 case without groove



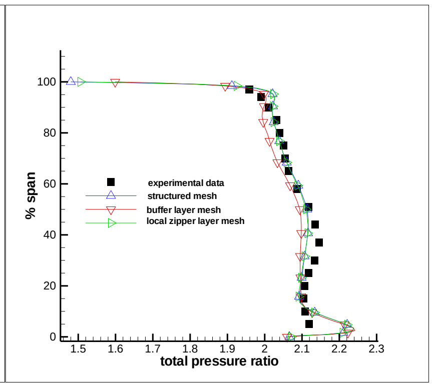
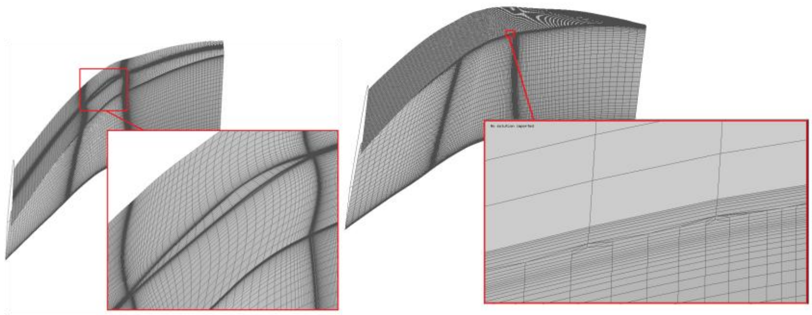


Fig. 9. Comparison of the total pressure ratios

Fig. 10. Total pressure ratios along the span

Different from the previous local zipper layer mesh which locally grafts the groove mesh to the casing, a more general way is to link the whole new casing mesh to the mesh from the blade side which is called the global zipper layer mesh here. As the global zipper layer creates more unstructured interface cells, it is therefore less efficient than the local zipper layer method. However, it makes the treatment of multiple components such as multiple grooves much more straightforward in programming.

To verify the global zipper layer mesh, the results on the multi-block structured mesh and the global zipper layer mesh were compared. Fig.11 shows the multi-block structured mesh and the global zipper layer mesh. Being different from the buffer layer method, the zipper layer method only affects the two layer meshes which can be seen in Fig.11. The original multi-block structured mesh consists of 5 H-type mesh blocks and 1 O-type mesh block for the blade. The upstream H-block is 40x59x84, the downstream H-block is 50x59x84, both the passage H-blocks are 74x16x84, the H-block mesh above the blade tip is 86x17x16 and finally the O-mesh block representing the blade is 203x12x84. The resulting mesh when all blocks are merged gives a mesh consisting of 810,228 hexahedral elements, which are then linked to 200x60x6 casing block. The zipper layer method effectively splits two hexahedral layers in the tip gap with unstructured cells, thus the total number of elements for this mesh increases to 1,070,609. Each mesh shown in Fig.11 was run from the choke to numerical stall condition and compared to the experimental data. Flow solver was run as a steady state calculation with a 4 level multi-grid approach and a CFL=2.0. The wall function and the SA turbulence model were used. All the solid walls were treated as non-slip adiabatic boundary. A subsonic inflow condition was specified at the inlet where the total pressure and temperature profile were set according to the data from the AGARD report [5]. A radial equilibrium subsonic boundary was used at the exit, which allows for a single pressure to be specified at a given radial point from which the exit pressure is calculated.



Structured mesh　　　　Global zipper layer mesh

Fig. 11. Original Multi-block structured mesh and global zipper layer mesh

Fig.12 shows the comparison of the total pressure ratios calculated on the zipper layer meshes, the multi-block structured mesh and the experimental data. The result on the zipper layer mesh matches well with those on the multi-block structured mesh and the experimental data. As compared in this figure, the local zipper layer mesh and the global zipper layer mesh show slight differences, which is probably due to the distinction of the casing block. In Fig.13 the total pressure ratios along the span at peak efficiency condition were compared. Though the result on the global zipper layer mesh shows a slight deviation from the structured mesh at 90%-95% span, two results are identical at the rest of the region. This indicates that the global zipper layer mesh only slightly changes the flow field locally. The uniformly distributed structured mesh on the casing side may account for the mismatch, which improves the flow resolution at that region and makes the result on the zipper layer mesh closer to the experimental result.

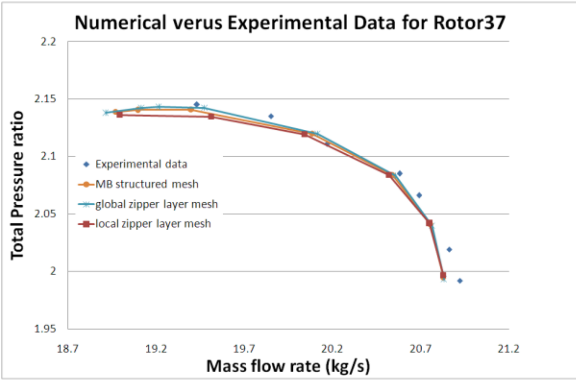


Fig. 12. Comparison of total pressure ratios

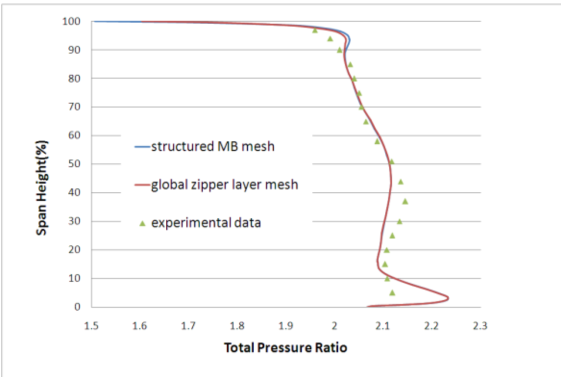
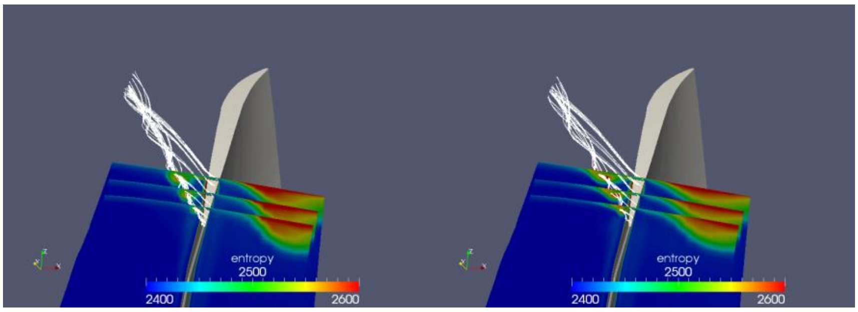


Fig. 13. Total pressure ratios along the span

In Fig.14, the stream line shows the path of the tip leakage vortex which is critical to the stall. The results given by different meshes are similar to each other. The static pressure at 98% span is also compared in Fig.15. The small mismatch is only observed at the leading edge, while most of the lines are identical.



(a) Multi-block structured mesh (b) Zipper layer mesh

Fig. 14. Entropy and tip leakage vortex

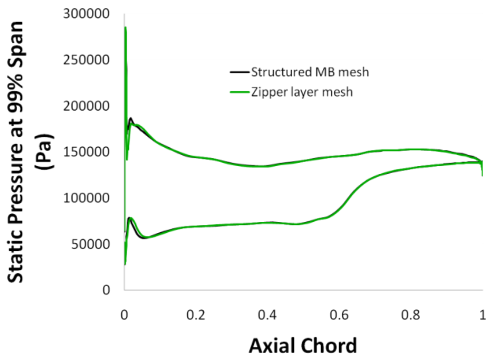


Fig. 15. Comparison of static pressure at 98% span

NASA Rotor 37 case with five grooves is generated by using the global zipper layer method. The five grooves have the same height, and the first groove starts form the place above leading edge. Fig.16 shows the zipper layer mesh of this configuration. As shown in Fig.16, the zipper layer mesh is in the tip gap which links two different multi-block structured meshes together. So far these types of configuration are deemed to be impossible to generate a merely multi-block structured mesh due to its complexity of geometry. The most challenging part is that the tip gap is very small, and the two meshes change dramatically from one topology to the other. However, by using the zipper layer mesh method, two meshes are smoothly linked together.

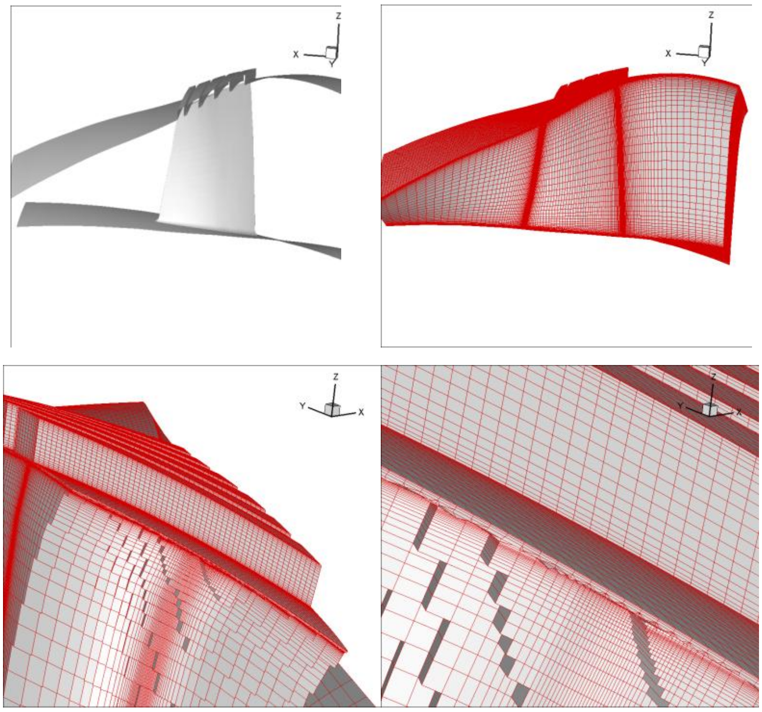


Fig. 16. Zipper layer mesh for NASA rotor37 case with 5 grooves

7 Open rotor case

The global zipper layer mesh method was also successfully applied on the open rotor case. As can be seen from Fig.17, the uniformly distributed mesh is smoothly linked to the clustered mesh. In Fig.18 the convergence histories are compared. The zipper layer mesh shows a superior convergence than the multi-block structured mesh, as the uniformly distributed mesh may help the solver converge more quickly.

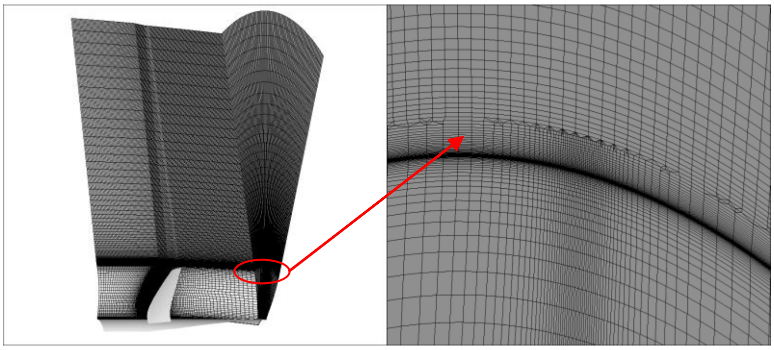


Fig. 17. Global zipper layer mesh for open rotor case

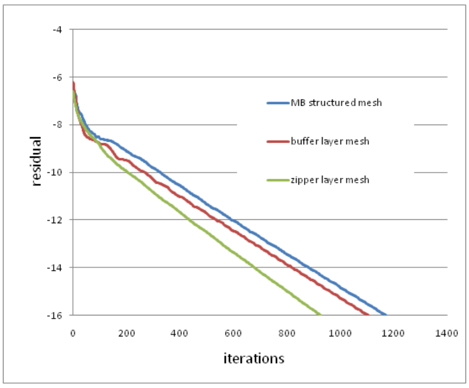


Fig. 18. Convergence history

8 Conclusion

A novel method for linking two dissimilar structured meshes is developed. This method maintains the structured mesh near the solid wall and links the different parts together. According to the numerical test, the addition of the zipper layer to a structured mesh has not degraded the quality of the flow solution, but rather gives as good as convergence and accuracy as the structured mesh.

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