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Engineering Notes

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Enhancements of the Cut-Paste Algorithm in Overlapping Grid Generation

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I. Introduction

STRUCTURED grid-generation methods are widely used in computational-fluid-dynamics (CFD) computations. Compared to nonstructured grids, structured grid systems possess many advantages, such as high efficiency to generate, high accuracy for computational results, simple logic relationship, and good ability to simulate the boundary layer. Nevertheless, it is a great challenge to generate structured grid systems for complex geometries with complicate topology. In this sense, structured grid generation is still a tedious, experience-demanding task, despite the fact that graphic grid-generation software (Gridgen, IGG) has been developed.

To remedy the disadvantages in structured grid generations for complex geometries, the algorithm of overlapping grid[1] is developed, which allows grid blocks to overlap or overset. Its main idea is to construct relationships between grid blocks by hole cutting and has been applied to CFD computations for complex geometries[2–4] and for multiple moving-body problems.[5,6] However, most hole-cutting technologies depend on user-computer interactions.[7,8] Therefore there exist difficulties in efficiently, automatically constructing the relationships between grid blocks.

Because of their ability to promote automatic overlapping grid generations, the technologies of advancing front[9] and hole mapping[10] have become the core of some professional grid-generation software, such as PEGASUS. [Data available online at http://people.nas.nasa.gov/rogers/pegasus/uguide.html (cited Oct. 2003).] Furthermore, the cut-paste algorithm[11] has recently been developed based on these technologies. This new algorithm takes fewer iterations in cutting and pasting phases and generates small overlapping regions, which are far away from the body surface.

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II. Improvements and Enhancements

The traditional overlapping grid algorithm includes two steps: hole cutting and identifying donor cells. To improve the grid quality around the holes, the cut-paste algorithm employs cutting and pasting phases after hole cutting. This algorithm takes the body surface as the hole-cutting surface. Here we do not go into details about the hole-mapping technology and the cut-paste algorithm.

As introduced in the preceding section, the cut-paste algorithm can automatically generate the hole surface and the overlapping region. Furthermore, the location and the quality of the resulting overlapping region are satisfactory. However, this algorithm allows for improvements in hole-mapping and orphan point deletion.

A. Automatic Hole Mapping

The preconditions for the original hole-mapping method require that the surface be closed,[10,11] and therefore the corner cells of the Cartesian grid system are the external cells. If the body surface is not closed, then it is difficult to identify the properties of the grid cells. Figure 1 depicts the Cartesian hole mapping for a $\frac{1}{4}$-cylinder surface. The marked points A, B, C, and D are the corner cells. The boundary cells B and D are on the body surface. The original algorithm cannot automatically identify the cells A and C, which are the external cell and the internal cell, respectively. Therefore special treatments[5] should be carried out to close the body surface, or instead, developer must manually specify the classification of the grid cells. Obviously this original approach does not lead itself to automatic realizations.

A way to overcome this difficulty is to utilize the normal information of the body surface.

Define a criterion: The grid cell in the outer normal direction of body surface is an external cell; otherwise, it is an internal cell. We apply this criterion to each grid cell in the neighborhood of the boundary cells and accordingly mark the cell by internal or external. If a grid cell is always marked by internal (or external), it is an internal (or external) cell (see Fig. 2 for grid cells in convex and concave configurations). Moreover, according to the principle that the cells in the neighborhood of the internal (or external) cells are internal (or external) cells, all of the grid cells can be identified. Our numerical experiments indicate that this criterion is applicable to three-dimensional grid generations.

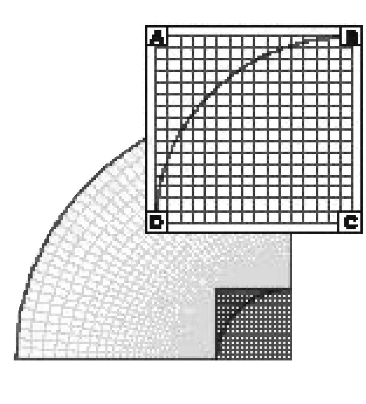


Fig. 1 Hole mapping for a $\frac{1}{4}$-cylinder.

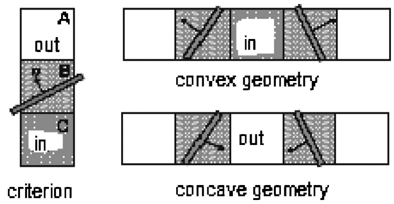


Fig. 2 Property of hole-mapping elements.

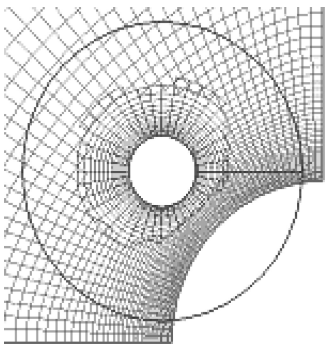


Fig. 3 Overlapping grids for cylinders.

Figure 3 demonstrates the overlapping grid system for an open $\frac{1}{4}$-circle and a smaller circle. The grid system is generated using the proposed criterion. As can be seen from the figure, the grid cells are successfully identified.

B. Deletion of Orphan Points

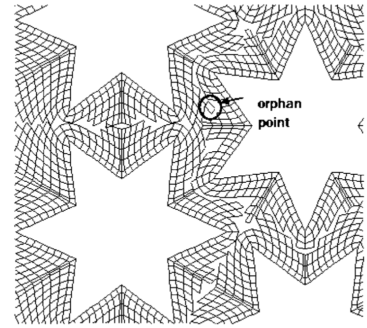
In propagating the hole surface outwards, some grid points will be isolated by other hole surfaces because of different propagation speeds, as displayed in Fig. 4a. The situation becomes worse when the surface geometry is complex. These isolated grid points will be viewed as the interpolation points and the vertices of the donor cells in the CFD computations. Therefore the orphan points must be identified and deleted to avoid considerable errors that can occur in the flow solver. The original cut-paste algorithm leaves this issue open, and we will propose a new approach to automatically identify and delete them.

In practical implementations, we consider an interpolation point once the propagation of hole surface is finished. If there are no external points in its neighborhood, we take this point as an orphan point and grant it with properties of internal points. Numerical practice indicates that this approach can efficiently eliminate orphan points to make the hole boundary clean and continuous. Displayed in Fig. 4b is the grid system after deleting orphan points.

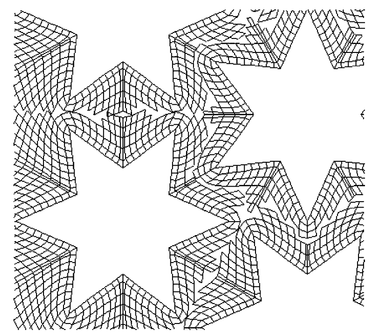
III. Applications

The enhanced algorithm has some promising properties. It can be applied to generate grid systems for open bodies as illustrated in the preceding section. It can also automatically construct the hole-cutting surface and maintain its continuity. Specially, the resulting overlapping region is small. These advantages make it suitable for the construction of DRAGON grids.[12] In Fig. 5 we display the DRAGON grid system with nonstructured grid overset.

The enhanced algorithm can be easily generalized to three-dimensional multicomponent geometries. We present two examples here. The first one is the overlapping grid system for a missile aft body with four rudders, as shown in Figs. 6a–6c. Its topology is so complicated that the grid system can hardly be generated by means of the traditional method of domain decomposition. The proposed method is also applied to CFD computations of the flowfield around

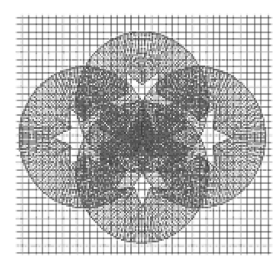


a) Before deletion of orphan points

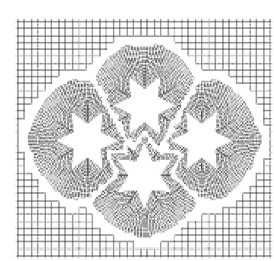


b) After deletion of orphan points

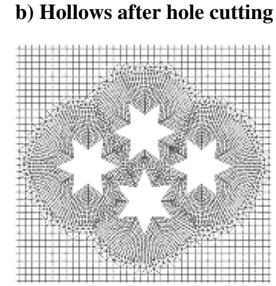
Fig. 4 Deletion of orphan points.



a) Oversetting grids

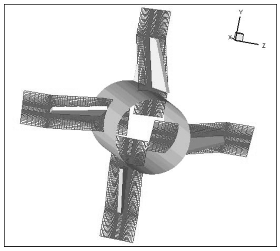


b) Hollows after hole cutting

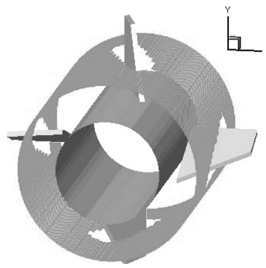


c) Grid system after embedding nonstructured grids

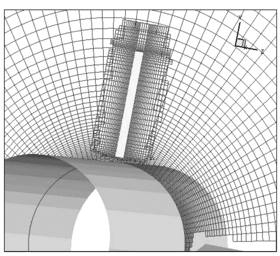
Fig. 5 Dragon grid generation.



a) Initial grid system for a missile aft body

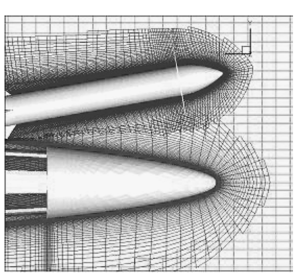


b) Grid system with hole cutting

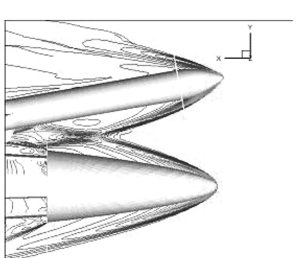


c) Overlapping grid system for a missile aft body

Fig. 6 Overlapping grid generation for a missile aft body.



a) Overlapping grid system for a submunition missile



b) Press contours for the flowfield

Fig. 7 Numerical experiments on a submunition missile.

a submunition missile. Displayed in Fig. 7a is the overlapping grid system automatically generated by our method. Figure 7b depicts the pressure contours with freestream Mach number 7. The interface between the bow shocks are accurately resolved, which demonstrates the feasibility and the efficiency of the overlapping grid system.

IV. Conclusions

The cut-paste algorithm is investigated and improved to ensure better properties in hole mapping and orphan point deletion. By utilizing the normal information of the body surface, the new algorithm can automatically identify all grid cells. The original algorithm is also enhanced by a reliable method to identify and delete orphan points. Numerical experiments illustrate that the enhanced algorithm can be applied to complex geometric configurations. Furthermore, as compared to the original algorithm, the new algorithm can be realized automatically by the computer code without computer-user interactions. Because of these advantages, it can be expected that our enhanced algorithm will cast impacts on DRAGON grid generation. Our next research work will combine the enhanced algorithm with the DRAGON grid scheme to develop a reliable, efficient grid-generation code for complex three-dimensional geometries.

Acknowledgments

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References

[1]Steger, J. L., Dougherty, F. C., and Benek, J. A., "A Chimera Grid Scheme," *Advances in Grid Generation*, edited by K. N. Ghia and U. Ghia, ASME FED-Vol. 5, June 1983.

[2]Murman, S. M., Rizk, Y. M., and Schiff, L. B., "Coupled Numerical Simulation of the External and Engine Inlet Flows for the F-18 at Large Incidence," *Aircraft Design*, Vol. 3, 2000, pp. 65–77.

[3]Pearce, D. G., Stanley, S. A., et al., "Development of a Large Scale Chimera Grid System for the Space Shuttle Launch Vehicle," AIAA Paper 93-0533, Jan. 1993.

[4]Rogers, S. E., Cao, H. V., and Su, T. Y., "Grid Generation for Complex High-Lift Configurations," AIAA Paper 98-3011, June 1998.

[5]Edge, H. L., Sahu, J., and Heavy, K. R., "Computational Fluid Dynamics Modeling of Submunition Seperation from Missile," AIAA Paper 99-3129, June 1999.

[6]Hall, L. H., and Parthasarathy, V., "Validation of an Automated Chimera/6DOF Methodology for Multiple Moving Problems," AIAA Paper 98-0753, Jan. 1998.

[7]Chan, W. M., "The Overgrid Interface for Computational Simulation on Overset Grids," AIAA Paper 2002-3188, June 2002.

[8]Chan, W. M., Gomez, R. J., Rogers, S. E., and Buning, P. G., "Best Practices in Overset Grid Generation," AIAA Paper 2002-3191, June 2002.

[9]Wey, T. C., "Development of a Mesh Interface Generator for Overlapped Structure Grids," AIAA Paper 94-1924, 1994.

[10]Chiu, I. T., and Meakin, R., "On Automating Domain Connectivity for Overset Grids," AIAA Paper 95-0854, Jan. 1995.

[11]Cho, K. W., and Kwon, J. H., "Development of a Fully Systemized Chimera Methodology for Steady/Unsteady Problems," *Journal of Aircraft*, Vol. 36, No. 6, 1999, pp. 973–980.

[12]Kao, K. H., and Lion, M. S., "Direct Replacement of Arbitrary Grid-Overlapping by Nonstructured Grid," AIAA Paper 95-0346, Jan. 1995.