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Advances in Domain Connectivity for Overset Grids Using the X-rays Approach

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Abstract: Advances in automation and robustness of the X-rays approach to domain connectivity for overset grids are presented. Given the specification of surface grids for each component that make up a complex configuration, the determination of hole points with appropriate hole boundaries, and the location of interpolation stencils are automatically and efficiently performed. Improvements made to the original X-rays approach include an automated hole-cutter closure scheme, a two-level X-ray map with a uniform primary map and an adaptively refined secondary map, and an automated hole boundary adjustment procedure using a combination of wall-distance and cell compatibility functions. Results using the new scheme are presented for a number of static and relative body-motion test cases.

Keywords: Overset Grids, Domain Connectivity, Grid Generation.

1 Introduction

In recent years, structured overset grid technology has been successfully applied to a wide range of complex configurations [1]. An essential step in the grid generation process is domain connectivity. This typically involves the identification of grid points that fall inside solid boundaries (hole points), the adjustment of the boundaries of the resulting holes to provide accurate inter-grid communication, and the search for interpolation stencils for the fringe points at the grid outer and hole boundaries. A number of schemes have been available to handle this process. One of the most effective schemes is the X-rays approach [2] since its speed allows it to be efficiently utilized in problems involving relative body motion where hole-cutting has to occur at every time step.

In the original X-rays method, the user creates hole-cutters from component surface grids of a complex configuration. For each component, the bounding box of its surface grids in the X-Y plane, also called the image plane, is first determined. A uniform Cartesian grid is created on the image plane with spacing equal to the average grid spacing of the component surface grids. A ray is then cast in the Z direction from each point on the image plane, and the pierce points on the surface grids of the component are stored (see Figure 1a). Given an arbitrary point P in 3-D space, its X and Y coordinates are used to easily look up the appropriate cell in the X-ray image plane. The pierce points in Z are used to determine if P is inside the component (hole point), or outside (field point).

While hole-cutting in the original X-rays scheme is very fast, it also comes with a number of disadvantages. Preliminary work to reduce such disadvantages are described in Ref. [3]. New developments to eliminate the remaining disadvantages of the original X-rays method are presented in the next three sections.

2 Automated Hole Cutter Closure

In the original X-rays scheme, hole-cutter surfaces of a component used to identify hole points are manually specified by the user. If these hole-cutter surfaces do not form a closed set, new surfaces have to be constructed manually to close the open boundaries so that a valid X-ray map can be generated. The current work eliminates the manual closure of open boundaries by utilizing existing surface grids from other components to complete the closure.

Open boundaries on a component of a complex body can only occur at the junction between itself and other components. For example, the wing root is an open boundary of a wing component that occurs at the junction with the fuselage. If the fuselage and wing grids are created independently of each other, there are fuselage grid points that fall inside the wing that need to be removed by the hole cutting process. These hole points include fuselage surface grid points that fall inside the wing root. The current scheme utilizes two levels of bounding boxes of the open boundary (wing root) to clip out grid cells from the fuselage to complete the wing root closure, thus ensuring no new geometry is created in the hole-cutter closure process. Moreover, X-ray pierce points are constructed so that grid points from other components (fuselage) used for hole-cutter closure are guaranteed to be removed by the hole-cutter of the current component (wing).

3 Adaptive Secondary X-rays

In the original X-rays scheme, the X-ray image plane uses a uniformly-spaced set of rays to construct pierce points on a component surface grid. In situations where there is a very tight gap between neighboring components, an accurate representation of the boundary of the components is needed. This requires a very finely-spaced set of X-rays, resulting in prohibitively large X-ray file sizes. The current work solves this problem by using two sets of rays: a relatively coarse primary set, and a fine secondary set. The typically 5- to 10-times finer secondary set is introduced only where higher geometric resolution is needed: around the projected boundary of the component on the X-Y plane, and where the geometry surface normal is almost perpendicular to the ray-casting direction. Figure 1b shows a two-component system (rotor and hub) with a tight gap. The finer secondary X-rays provide a much more accurate representation of the boundary of each component. With a 5-times finer resolution, the adaptive secondary X-ray file size is only a factor of 2 larger than the original. A uniform factor of 5 refinement would have grown the file size by close to 25 times.

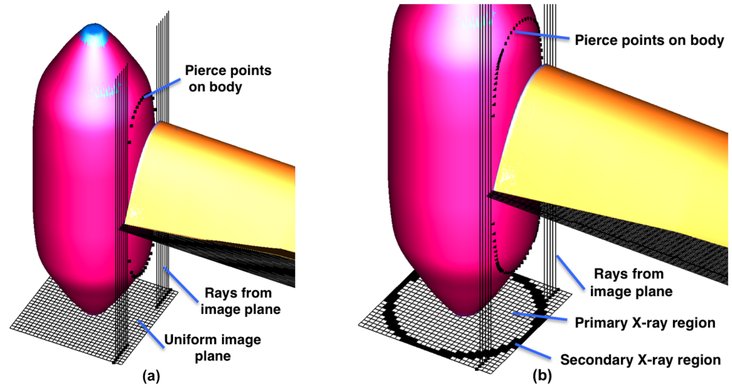

Figure 1: Rotor-hub system with tight gap. (a) Original X-rays with uniform image plane. (b) New X-rays with adaptive image plane.

4 Automated Hole Boundary Adjustment

In the original X-rays scheme, a hole boundary is offset from the solid wall boundary by a constant distance that is manually specified which tends to be tedious and error-prone. Moreover, there are situations where a spatially variable offset is preferred such as where multiple-components are in close-proximity. The current work uses a wall-distance function to determine an initial estimate of a spatially-varying hole boundary offset (see Figure 2) where the wall-distance function at a point is defined to be the closest distance from the point to any surface with a solid wall boundary condition. Determination of this function for hole-cutting comes for 'free' since it is already computed for standard turbulence models in the flow solver. Further refinement of the hole boundary location is iterated by a cell-attributes (volume, aspect ratio, orientation) compatibility function between the fringe point and its interpolation stencil. Details will be presented in the final paper.

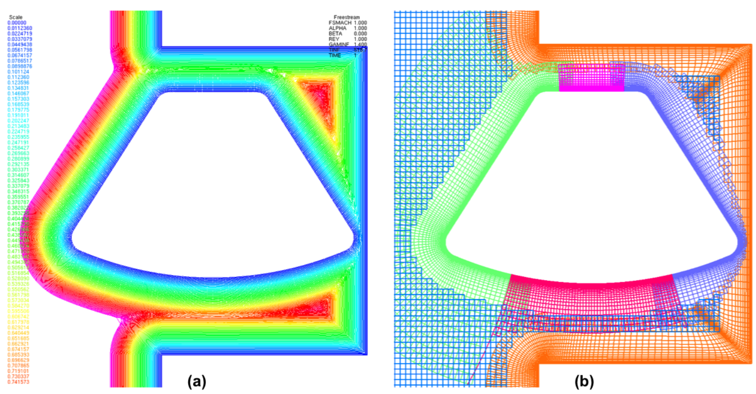

Figure 2: Capsule-cavity system. (a) Wall-distance function (small values in blue, large values in red). (b) Hole boundary estimate using wall-distance function alone.

5 Summary

New developments are presented which improve the original X-rays method. Open boundaries in the hole-cutter surfaces are automatically closed using existing surface grid cells. Tight gaps between components are efficiently resolved using adaptive secondary X-rays. A spatially-variable hole boundary offset estimate is generated using a wall-distance function, with further refinement using a cell-attributes compatibility function. Details of the algorithms and more test cases will be presented in the final paper.

References

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