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Domain Connectivity Among Systems of Overset Grids

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1. Introduction

The ability to accurately simulate unsteady flowfields about geometrically complex and moving component configurations is becoming increasingly important in the analysis of modern aircraft and launch vehicles. Although significant progress has been made in recent years to apply mature computational methods to this class of problems, there are still obstacles which prevent computational fluid dynamics from making more of a direct impact on the design process. Currently available software for unsteady multiple body aerodynamics is very complex, and requires a large amount of human interaction and expertise. This, combined with limited computational capacity, greatly restricts the degree to which such problems can be studied. The primary objective of this research is to achieve algorithmic improvements which not only reduce computational demands associated with unsteady multiple body aerodynamics, but significantly reduce the corresponding demands on human resources. The research carried out in the past six months has focused on the usability and efficiency of domain connectivity among systems of overset grids.

Geometrically complex problems are often addressed via an overset grid approach. Geometrically complex domains are decomposed into a number of much simpler overlapping sub-domains. The approach simplifies grid generation problems, since each component can be generated independently and grid boundaries are not required to match neighboring grid in any special way. For the same reasons, an overset grid approach can be applied to problems involving motion between vehicle component parts without any additional algorithmic complications. Moving body computations have been carried out time-accurately in three-dimensions for, among others, the separation sequences of the Space Shuttle's solid rocket boosters [1,2], and aircraft store separation sequences [1,3,4]. The approach has also been successfully applied to many non-aerodynamic problems ranging from applications in biomedical fluid mechanics [5] to environmental flow simulations [6].

The price that must be paid for the geometric and computational freedoms provided by an overset grid approach lies in the need to facilitate intergrid communication. The intergrid communication process is simply the interpolation of needed intergrid boundary conditions from solutions in the overlap region of neighboring grid systems. Intergrid boundaries are the outer boundaries of minor grids, and the boundaries around holes created by neighboring body components. For example, the outer boundary points of the symmetry plane of the V-22 fuselage grid illustrated in Figure 1 are intergrid boundary points. Corresponding boundary conditions must be interpolated from the overlap region of neighboring grid systems. Hence, a generalized procedure for identifying intergrid boundary points and suitable donors for the

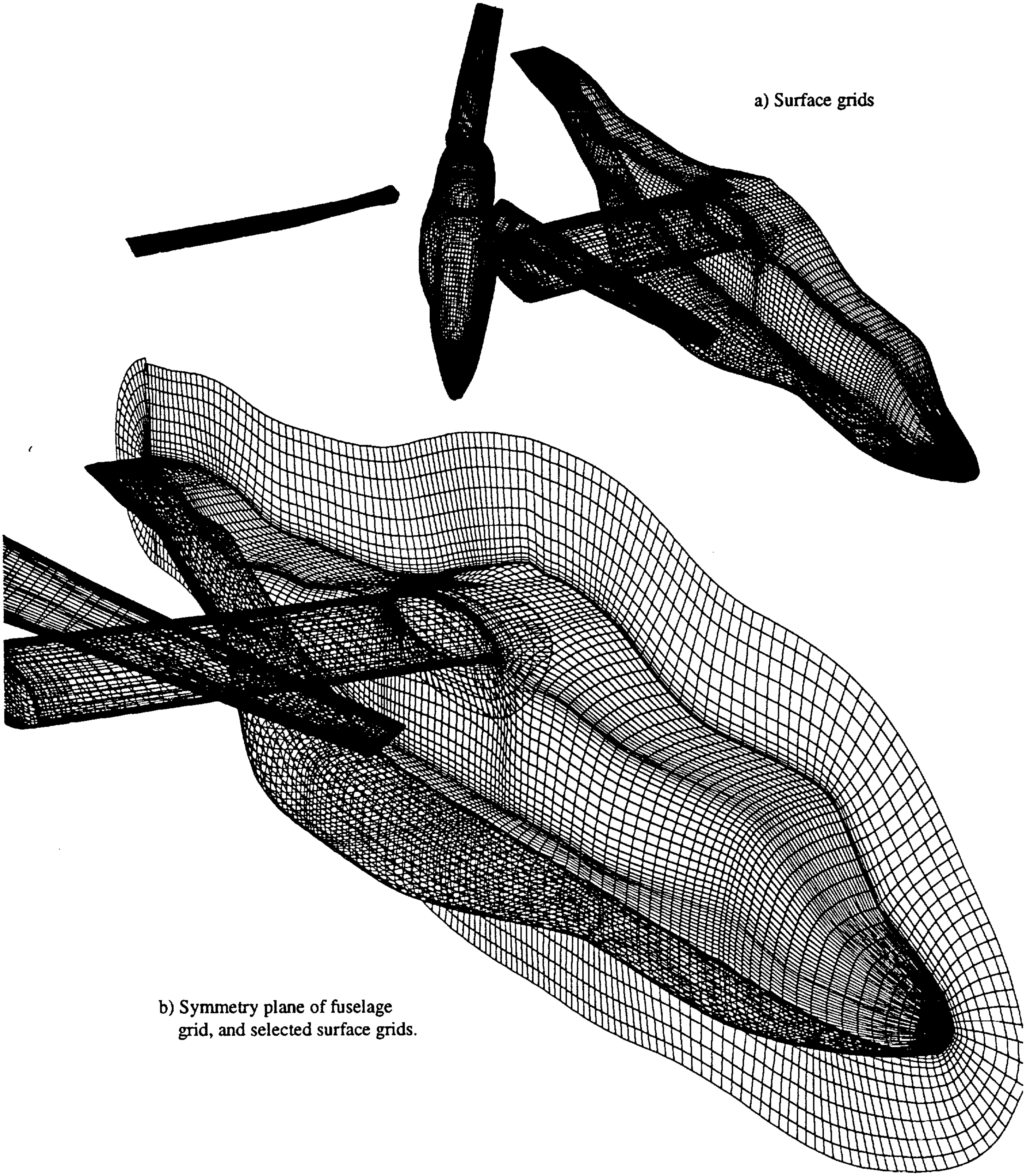
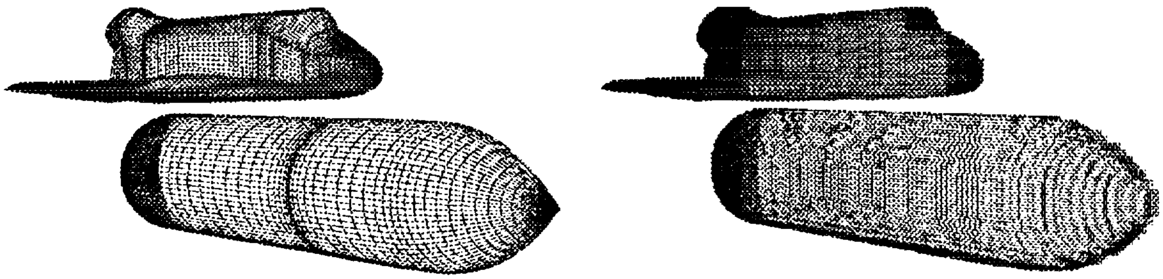


Figure 1. Overset grid discretization of the V-22 Tiltrotor aircraft.



(a) True hole surface.

(b) Approximate hole surface.

Figure 2. Comparison of true hole surface and approximate hole surface.

required interpolations is needed. Algorithms for performing this task exists [7,8]. Recently, an entirely new approach to the intergrid communication problem has been set forth [9] in the code "DCF3D", and is particularly well suited to moving body problems.

The research carried out in the past six months under NCC 2-783 has focused on usability and efficiency of domain connectivity among systems of overset grids. The most significant advance has been the development of "hole-map" technology. Hole-maps replace DCF3D's method of hole-cutting via analytic shapes, because of its potential for automation and comparable computational efficiency.

2. Methodology of hole-map

Hole-map technology is based on an idea of the late Professor Joseph Steger that takes advantage of the same search-by-truncation incentives that exists in the inverse-maps employed in DCF3D. Given a system of overset grids, and knowing something of the topology and flow boundary conditions, it is possible to generate approximate hole surfaces associated with each component grid. For example, Figure 2(a) illustrates the no-slip surfaces of the space shuttle external tank and orbiter grid systems. Figure 2(b) illustrates an approximation of the same surfaces defined with respect to a uniform Cartesian system of points. The approximate surfaces shown in Figure 2(b) can be used to carry out inside/outside tests for the determination of IGBPs far more efficiently than the PEGASUS style tests associated with the actual hole surfaces. Given the X,Y,Z coordinate of a point in the orbiter, for example, the position of that point within the external tank hole-map can be identified by simple truncation. Once this is known, the field or hole status of the X,Y,Z point in question is determined by the corresponding status of the hole-map element that bounds it. Following details the hole cutting procedure implemented in DCF3D utilizing the hole-map technology.

1. Generate a Cartesian box bounding given hole surfaces.

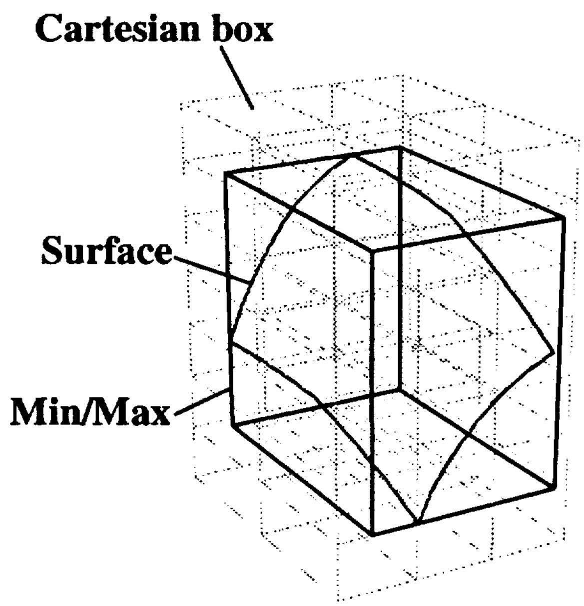


Figure 3. Method of finding hole boundary in a Cartesian box

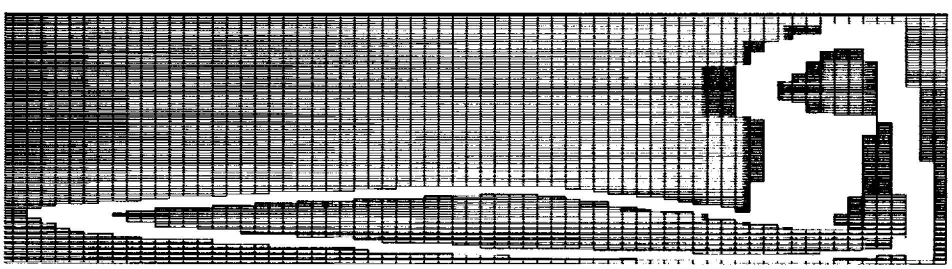


Figure 4. A typical hole boundary.

- Size of the Cartesian box is min/max of hole surfaces.
- Resolution of Cartesian box is based on the resolution of the given hole surfaces.
- Hole surfaces can be given as ranges of grid index (J,K,L) or set of offset distances from no-slip surfaces. The offset distance can be given as a global parameter for all the holes or a local parameter for a particular hole.

2. Find hole boundary in the Cartesian box – Hole boundary in the Cartesian box are determined by bounding each quadrilateral surface patch with a min/max box and marked all the cells (IBLANK=0) in this min/max box as part of hole boundary (see Figure 3). A slice of a typical hole boundary is shown in Figure 4. The white spaces designate the hole boundary.

3. Identify points inside hole boundary in a Cartesian box – The points inside the hole boundary are identified by walking along the hole edges (white spaces in Figure 4) and blanking out any points between edges by assigning IBLANK=0 to those points.

4. Hole cutting by truncation

   - Identify cell in the hole-map that bounds the given X,Y,Z point by truncation.
   - Carry out inside/outside tests by checking the status (defined by value of IBLANK) of the hole-map element that bounds the X,Y,Z point.

3. Results

Hole cutting through hole-map algorithm is tested for several testcases on a SGI 4D-210 workstation running on 25 MHz MIPS R3000 cpu. Figure 5(a) and 5(b) shows hole boundaries cut in the shuttle external tank and orbiter grids, and a wing and store grid combination using hole-map technology. The following table shows the CPU time usage for these two cases.

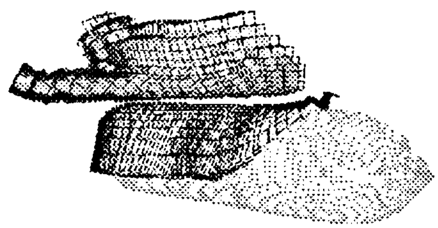
	# of Points	IGBPs	CPU (static)	CPU (dynamic)
ET/ORB	588,240	7,641	139.2	27.7
Wing/Store	256,863	3,114	79.4	11.3

The same wing/store case was also carried out using DCF3D with analytic shape cutters. The CPU time usage is 85.0 and 10.3 seconds for the static and dynamic mode respectively. Thus, the performance of hole cutting using hole-map is roughly the same as that of analytic shape cutters.

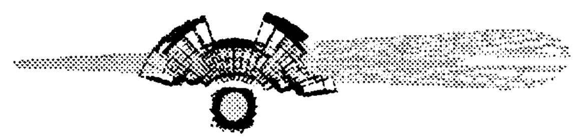
Another testcase is a 25-grid 1.3 million point discretization of the V-22 tilt-rotor aircraft (see Figure 1). Figure 6 illustrates the true hole surface and the approximate hole surface for this configuration. Figure 7 shows different shots of the hole boundaries computed through hole-map technology. As can be seen from the figure, the hole boundaries properly enclose each component grid. The hole-map is also capable of creating a hole at the fuselage/wing junction for the wing collar grid. The CPU time for cutting holes alone is 95.3 seconds with a total of 104 holes.

Although more testcases are needed to completely test out the hole-map technology, it can be seen that the hole-map creation is efficient and flexible enough for a complex testcase, like V-22, to be run on workstations.

4. References



(a) ET/ORB hole boundary.



(b) Wing/Store hole boundary.

Figure 5. Hole boundaries.

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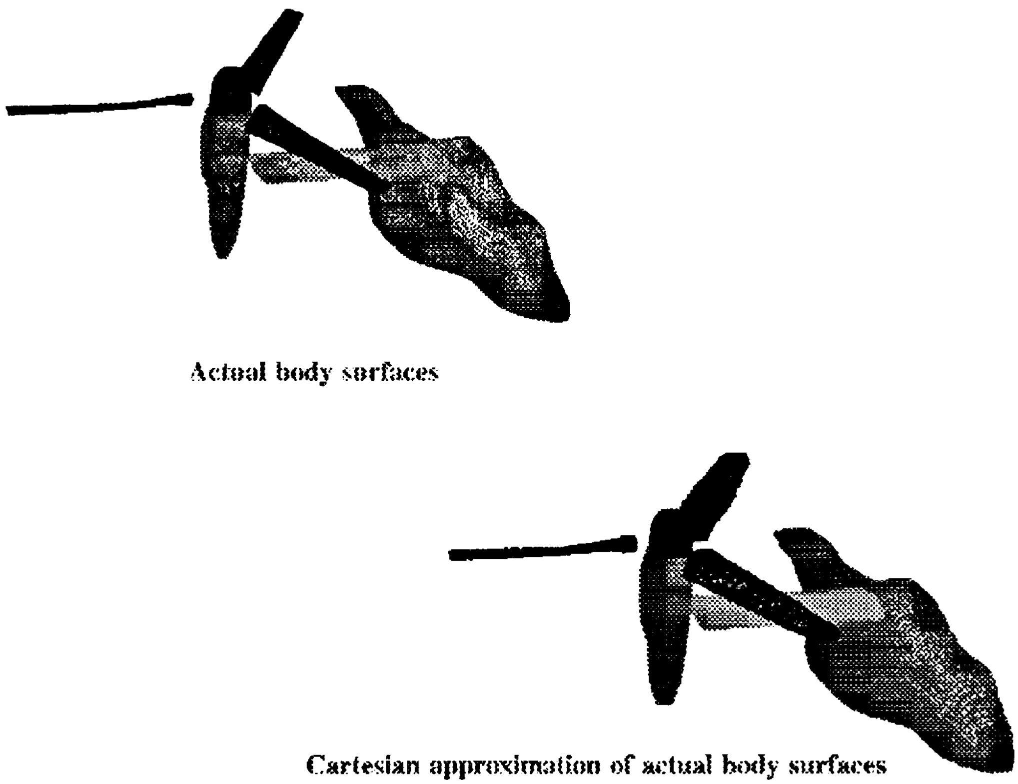

Figure 6. V-22 actual hole surface and approximate hole surface

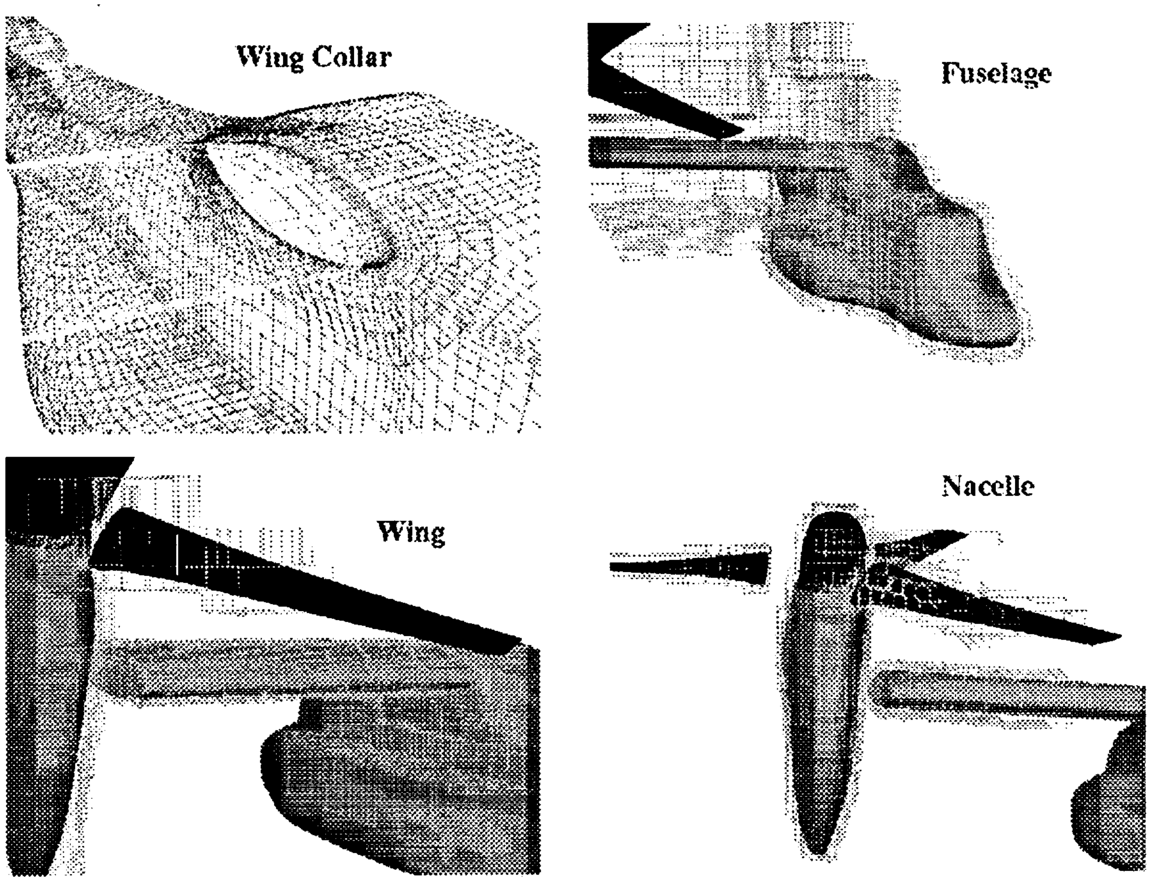

Figure 7. V-22 hole boundaries.

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