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Construction of Hexahedral Block Topology and its Decomposition to Generate Initial Tetrahedral Grids for Aerodynamic Applications

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Making an initial tetrahedral grid for complex geometry can be a tedious and time consuming task. This paper describes a novel procedure for generating starting tetrahedral cells using hexahedral block topology. Hexahedral blocks are arranged around an aerodynamic body to form a flow domain. Each of the hexahedral blocks is then decomposed into six tetrahedral elements to obtain an initial tetrahedral grid around the same aerodynamic body. This results in an algorithm that enables users to produce starting tetrahedral grids for a variety of aerodynamic bodies. To construct an initial starting tetrahedral grid suitable for computational flow simulations, representing a solid surface geometry (fuselage or a wing section) attached to a plane-of-symmetry, a topology containing at least 5 hexahedral blocks is required. The resulting initial starting grid consists of 30 tetrahedral cells with 74 faces and 16 vertices, which is the same number of vertices as for the hexahedral blocks. A face-based global data structure is then produced for the tetrahedral cells. To represent multiple surface definitions a topology containing nine hexahedral blocks is required. When decomposed, the nine hexahedral blocks, produce a tetrahedral grid consisting of 54 cells and 24 vertices.

INTRODUCTION

Unstructured grid generation is a powerful computational tool used in the numerical modeling of physical phenomena on complex, irregular domains. Instead of requiring a uniform distribution of grid points, unstructured meshes allow grid points to be strategically placed in the computational domain. Thus, these grids are particularly effective in modeling irregular boundaries, multi-scale surface geometries, and rapidly changing solutions [1].

Unstructured grid technology has the potential to significantly reduce the overall user and CPU time required for CFD analysis of realistic configurations. To realize these potentials, improvements in automation, anisotropic grid generation, adaptation, and integration with the solution process are needed [2, 3]. Unstructured grid generation has advanced to the point where generation of a grid for most configuration requires only a couple of hours of user time. However, prior to grid generation, the CAD geometry must be prepared. This process can take anywhere from hours to weeks. It is the single most labor-intensive task in the overall simulation process. Much of this time is spent on repairing gaps and overlaps. Geometry preparation often may include further preparation in grouping of multiple surface definitions. Alternative procedures for surface grid generation which account for small gaps and overlaps and generate across multiple surfaces can minimize and potentially eliminate much of the geometry preparation. With improvements in the geometry preparation process, the overall grid generation task can be more fully automated. This can include automatic specification of appropriate element size, at least, for a given class of configurations.

Much research has been done to design sequential algorithms and techniques to effectively use triangular or tetrahedral unstructured meshes in the solution of large-scale applications [4, 5, 6]. Similar algorithms are developed for quadrilateral and hexahedral elements [7, 8]. Unfortunately, many of these applications cannot take advantage of an automated surface grid generation

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technique because of a lack of widely available software tools on surface grid generation architectures. This paper describes an essentially automated procedure for the development of initial starting tetrahedral grids applicable to aerodynamic configurations. The approach taken here is to construct hexahedral [9] blocks around a solid geometry to fill-up a computational domain and then to decompose each block into six tetrahedral cells. The resulting tetrahedral initial grid is then refined using an unstructured grid generator with geometry treatment (movement) capability.

The algorithm governing the block topology and its consequent decomposition of hexahedral cells into tetrahedral elements can designate whether the generated tetrahedral faces are surfaces or interior faces. This enables the algorithm to generate a suitable global face-based data structure that can be used by the grid generator. Thus, users can avoid the tedious and labor-intensive task of generating initial surface representation of the solid geometry. This procedure was used to generate numerous computational starting grids applicable to aerodynamic geometries.

Many researchers have taken a similar approach to the automatic generation of two-dimensional triangular cells around aerodynamic bodies [10, 11, 12]. In their work, a crude representation of the solid geometry and the flow domain is made by connecting a few edges. Figure 1 shows a sample initial starting grid for the automatic generation of two-dimensional triangular cells.

To construct an initial tetrahedral grid, a more complicated approach must be taken. Since an initial tetrahedral mesh employs several vertices, edges, and faces scattered in space, an automatic method is required to construct the initial tetrahedral grid.

INITIAL TETRAHEDRAL GRID

Construction of an initial starting grid with tetrahedral cells cannot be performed manually as in the case of two dimensions, where an initial grid can be constructed by connecting a few edges. This is due to two reasons.

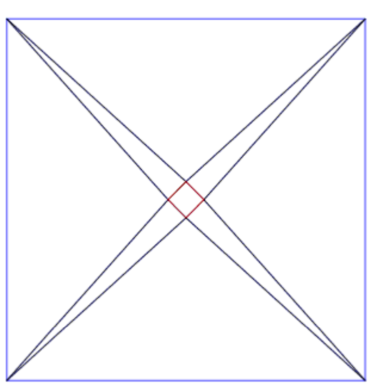

Figure 1. Typical initial starting grid for two-dimensional grid generation.

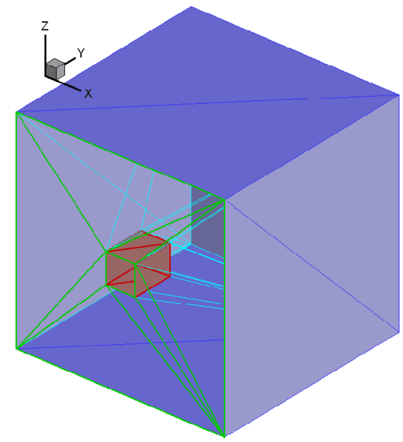

Figure 2. Sample initial starting grid for three-dimensional grid generation.

First, it is very difficult to arrange a set of vertices in three-dimensional space that would represent a set of tetrahedral cells, which represent a complex geometry. Second, the connectivity matrix for such a grid involves numerous vertices, faces, and cells that have to be defined (numbered) in a specific manner with respect to each other. For these reasons, it is obvious that alternative approaches must be considered when constructing an initial tetrahedral grid. An analogous initial starting grid for three-dimensional grid generation is illustrated in Figure 2. This may not be the case with many grid generators that start with a two-dimensional surface grid. Here, both surface and field grids are refined simultaneously, therefore it is essential to start with an initial tetrahedral grid.

One approach is to construct hexahedral blocks around the solid geometry to fill-up a computational domain and to then decompose each block into six tetrahedral cells. For example, to generate an initial grid around a solid geometry representing a circular cylinder or a wing section attached to a plane-of-symmetry, 5 hexahedral blocks are required. This approach has been used to generate three-dimensional initial grids suitable for numerous aerodynamic applications. The hexahedral block topology and its consequent decomposition into 6 tetrahedral cells, is incorporated in a computer program, and can produce initial starting grids for various aerodynamic configurations.

The simplest block topology is that of a single block. Although a single block, when decomposed into tetrahedral cells, does not constitute a suitable grid for aerodynamic applications, it is the basis for the decomposition of higher number arrangements of hexahedral blocks.

SINGLE BLOCK TOPOLOGY

Hexahedral blocks, as opposed to cubes, can have an unlimited number of shapes as long as they have six non-coplanar sides. Each side of an irregular hexahedral block can be made to fit a solid boundary while the other five sides can take almost any size and shape. Therefore, by arranging the sides of irregular hexahedral blocks around a prescribed solid geometry, and extending the opposite sides to a prescribed domain, a hexahedral grid can be obtained. This is very convenient since the eight vertices of each block lie on the surface geometry or the outer-boundary where the prescribed coordinates are known.

A single hexahedral block can be decomposed into six tetrahedral elements. Figure 3 shows the arrangement of tetrahedral cells that are decomposed from a single hexahedral block. Although, the intention is to do this for irregular hexahedral blocks, for simplicity and illustrative purposes, a regular block is decomposed. The six decomposed tetrahedral cells, shown in Figures 3 (a) to (f), constitute an initial tetrahedral grid. Examples of the final grid output for this initial grid will be given later in this paper. Here, for consistency, important notes as a result of the decomposition are pointed out.

By examining Figure 3 (f), it can be seen that this grid contains 18 faces, 8 vertices, and 6 cells. The number of resulting faces and their relation to one another is the concern of the grid generator, as they constitute the face data connectivity. The 18 faces referred to can be divided in two categories, 12 outer-boundary faces and 6 interior faces. The 6 interior faces are very important since adjacent tetrahedral cells share each one. The main objective of the block topology and their decomposition into tetrahedral cells is to provide grid connectivity for these faces, which would otherwise not be possible to obtain easily by hand. This is especially true when a more realistic domain containing a higher number of block arrangements is considered. To illustrate this point, a topology containing 5 hexahedral blocks is discussed in the following section.

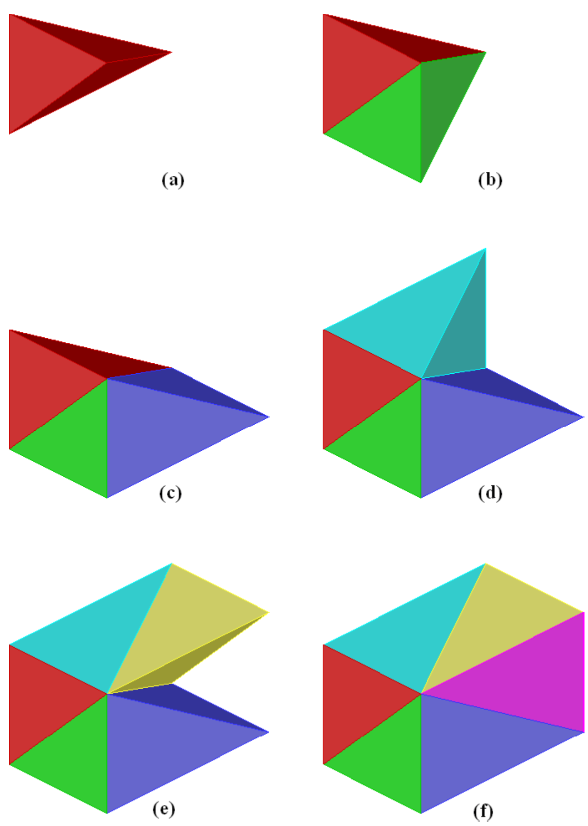

Figure 3. Decomposition of a single hexahedral block into six tetrahedral elements.

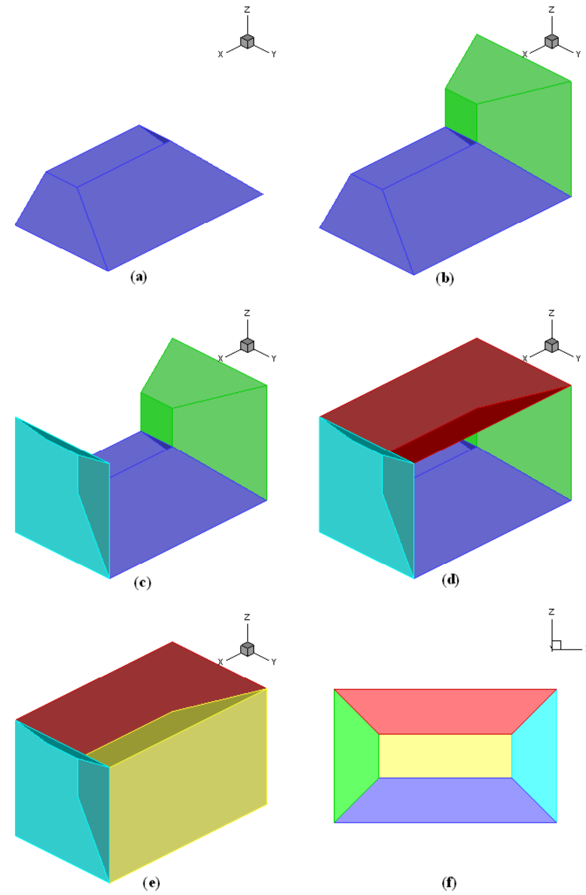

Figure 4. Five hexahedral blocks surrounding a cubical space representing a fuselage or a wing section attached to a plane-of-symmetry, where: (a) through (e) show block arrangements and (f) shows a view through the plane-of-symmetry.

FIVE BLOCK TOPOLOGY

To construct an initial starting tetrahedral grid suitable for computational flow simulations, a topology containing at least 5 hexahedral blocks is required. For aerodynamic applications to represent a solid surface geometry (fuselage or a wing section) attached to a plane-of-symmetry, an initial solid volume within a domain is required. It is then the grid generator's job, among others, to change the shape of the initial solid

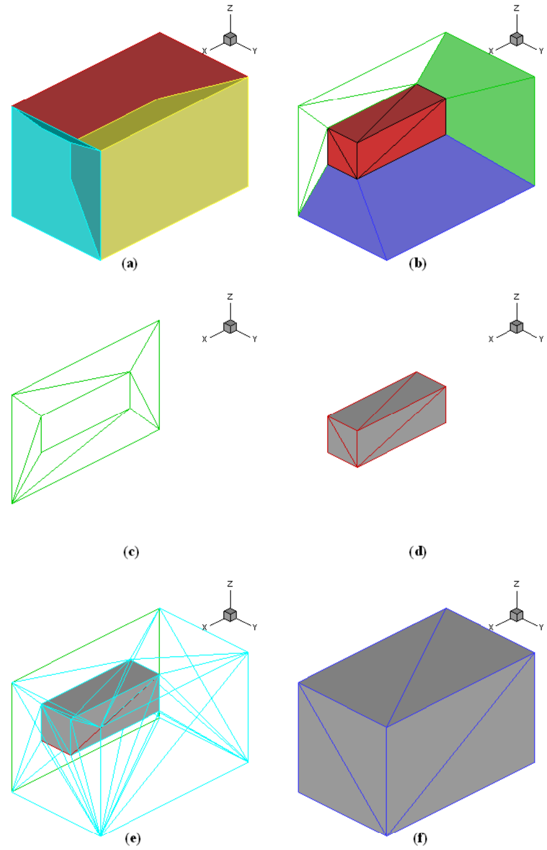

Figure 5. Initial tetrahedral starting grid from a 5-hexahedral block topology,: (a) original 5-block hexahedral cells, (b) some blocks are removed to show triangular grid faces, (c) plane-of-symmetry grids, (d) solid surface grids, (e) plane-of-symmetry and surface grids surrounded by interior cells (not shaded), and (f) outer-boundary grids.

volume to that of the final geometry (*i.e.* wing shape). This initial solid volume may take any shape as long as its coordinates lie on the geometry of the final shape.

For illustrative purposes, a simple cubical box is selected as the initial solid surface volume and five hexahedral blocks are arranged around this box. The topology for the five-hexahedral blocks is shown in Figure 4. By examining the irregular hexahedron shown in Figure 4 (a), it is evident that two sides of the hexahedron are parallel with the x-y plane. One of these parallel sides constitutes a rectangular face of the surface geometry and the other constitutes an outer-boundary face. Similarly, Figure 4 (b), in which two hexahedral blocks are arranged together, shows two of the faces of the solid geometry. By arranging the other hexahedral blocks, as shown in Figure 4 (c), 4 (d), and 4 (e), all of the five faces of the cubical solid surface geometry are constructed with the sixth face lying on the plane-of-symmetry. To better examine the initial solid surface geometry, Figure 4 (f) shows a view of the block topology through the plane-of-symmetry.

Each of the hexahedral blocks would now have to be decomposed into six tetrahedral elements as described in the previous section. By doing so, an initial starting tetrahedral grid is obtained. Figure 5 shows the initial starting grid of tetrahedral cells and their relation with respect to the original 5-block hexahedral topology. Figure 5 (a) shows the original block topology already displayed in Figure 4 (e). By removing some of the hexahedral blocks, the tetrahedral grids can be viewed and are displayed with relation to the remaining hexahedral blocks as shown in Figure 5 (b). This initial starting grid consists of 30 tetrahedral cells with 74 faces and 16 vertices, which is the same number of vertices as for the hexahedral blocks.

In addition to decomposing hexahedral cells, the block topology algorithm can designate whether the generated tetrahedral faces are surface or interior faces. When coupled with the face type character of a global data structure used in many grid generators, this feature can further categorize the face for a specific geometry treatment. As a result, the 74 triangular faces of the tetrahedral cells can be further assigned to represent various face types. There are, in this case, 8 plane-of-symmetry faces shown in Figure 5 (c), 10 surface geometry faces shown in Figure 5 (d), 46 interior faces shown in Figure 5 (e), and 10 outer-boundary faces shown in Figure 5 (f). Aside from the 46 interior faces, all other faces that lie on the surface geometry or the outer-boundary can further be defined for a variety of geometry considerations. Table 1 shows a set of geometry considerations and their designated face types applicable to aerodynamic applications. An integer value can be assigned to each grid face to designate the type of geometry treatment the face should receive.

The grid connectivity data can now be constructed and the various tetrahedral faces can be arranged as shown in Table 2.

Each row of the connectivity matrix contains the necessary information associated with each face. For example, face number 8 belongs to cell 0 and is shared by cell 21 and its space coordinates are defined by vertices 12, 13, and 16. The face type 4 designates that this face is a surface face and its refinement should

Table 1. Various geometry treatments and designated face types.

Face	Geometry Treatment	Face type
Plane-of-symmetry	Similar to both surface or outer-boundary faces	1
Outer-boundary	None	2
Interior	None	3
	Wing surface	4
	Wing tip	5
Surface	Fuselage	6
	Pylon	7
	:	:

consider the appropriate cubic spline or equation of geometry. In this case, as shown in Table 1, this corresponds to the wing surface geometry.

It should be noted that all of the grids referred to in this section have been generated for the sole purpose of illustration and the outer boundary to surface ratios are greatly exaggerated. The actual initial starting grids have a much larger outer-boundary to surface ratios (*i.e.* of the order of 30/1). To obtain a more realistic initial starting tetrahedral grid suitable for aerodynamic applications, there is no need to perform all of the operations discussed above. Rather, the coordinates of the 16 vertices, defining the location of faces and cells in space, can simply be modified to suit the problem at hand. For example, the eight vertex coordinates that define the solid geometry, shown in Figure 5 (d), can be changed to obtain an initial grid for variety of three-dimensional solid geometries. Similarly, the eight vertex points associated with the outer-boundary faces that constitute the overall size of the three-dimensional flow domain, shown in Figure 5 (f), can be altered to give any domain size of interest.

In fact, this initial grid with some modification of the vertices and face types has been used to generate numerous computational grids applicable to aerodynamic geometries. As an illustrative example, the following section describes the refinement of this initial grid.

GRID REFINEMENT

There are two issues that should be addressed about grid refinement. One is the way that grid cells are selected for refinement. The other is the actual geometrical procedure used to subdivide the tetrahedral cells

Table 2. Initial starting tetrahedral grid data connectivity.

I	NC1	NC2	NV1	NV2	NV3	type
1	0	5	10	13	9	4
2	0	6	10	14	13	4
:	:	:	:	:	:	:
8	**0**	**21**	**12**	**13**	**16**	**4**
9	0	27	13	14	15	5
10	0	28	13	15	16	5
11	0	2	10	9	1	1
12	0	3	10	1	2	1
:	:	:	:	:	:	:
18	0	24	12	4	1	1
19	0	3	2	1	5	2
20	0	4	2	5	6	2
:	:	:	:	:	:	:
28	0	30	5	8	7	2
29	1	6	10	5	14	3
30	3	2	10	1	5	3
31	4	1	10	5	6	3
:	:	:	:	:	:	:
73	28	21	16	13	5	3
74	25	22	16	5	8	3

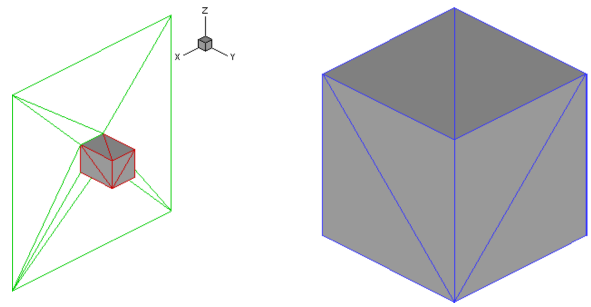

Figure 6. Initial starting grid for a cubic section attached to a plane-of-symmetry.

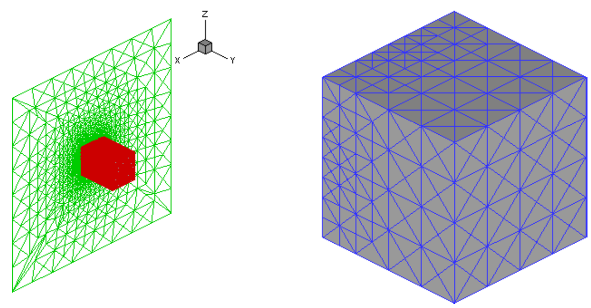

Figure 7. Final grid output of the cubic section grid after 10 cycles of refinement.

and the various surface geometry considerations. In the case of three-dimensional tetrahedral grids, there are a number of strategies for cell subdivision [13]. The most suitable methods attempt to ensure smoothness of the enriched grid (cf. Rivara [14]). In the present work, triangular faces of tetrahedral cells are subdivided. By subdividing a face of a tetrahedron, a new triangular plane perpendicular to the subdivided face is created within the cell, which splits the tetrahedron cell in two halves. Therefore, grid refinement criteria must consider the size and shape of triangular faces.

Both surface and interior field grid-faces were subdivided simultaneously in the same manner. To illustrate this sequence of grid generation, Figures 6 to 8 show the refinement for a sample three-dimensional grid. A simple cubic configuration (shown in red) attached on one side to a plane-of-symmetry (shown in green) and bounded by a larger cubic domain (shown in blue) was selected for illustrative purposes only. The

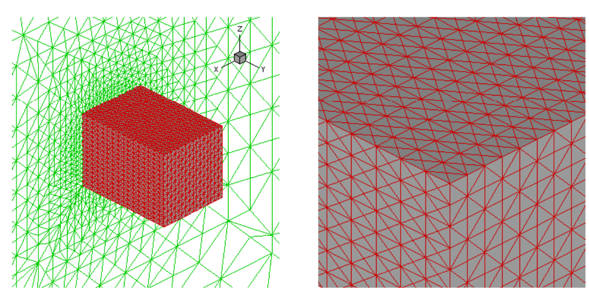

Figure 8. Close views of final Grid output for a cubic section.

interior field cells occupying the space between the small cubic surface and the outer boundary faces are not shown here.

Figure 6 shows the initial starting grid with 74 triangular faces forming a total of 30 tetrahedral cells. In fact this is the same initial grid that was discussed in the previous section, shown here with a better view of the solid surface. Ten refinement cycles are needed to reach the final grid output shown in Figure 7. The final grid consists of 16520 vertices and 83382 tetrahedral cells. These cells are formed by 4608 surface faces, 1942 plane-of-symmetry faces, 472 outer-boundary faces, and 163253 interior faces giving a total of 170275 triangular faces. This grid was formed in a relatively small domain for illustration and no geometry changes were considered.

The highly stretched skewed faces present in the initial grid have disappeared or at least are far away from the solid surface boundary after 10 refinement cycles. Close views are shown in Figure 8 to allow examination of the grid faces on the solid surface.

An important point to bear in mind while examining these grids is that the edges shown on the surface and plane-of-symmetry grid faces, are actually edges of one or many interior faces sharing that edge. The interior grid cells are not shown in the illustrative sequence of grid refinement for two reasons. One is the fact that they would cover the surface grids and would not allow viewing of the surface geometry. The second reason is the difficulties involved in the post - processing of large grid data, that is inherent in three-dimensional unstructured grid generation.

The interior field grids usually account for more than 90 percent of the total grid cells. This ratio gets worse as the outer-boundary increases for aerodynamic applications which require an outer boundary to wing chord ratio of at least 10 to 30. An attempt to show some of the interior cells was taken by cutting a slice through the domain near a side of the cubic section, and is shown in Figure 9.

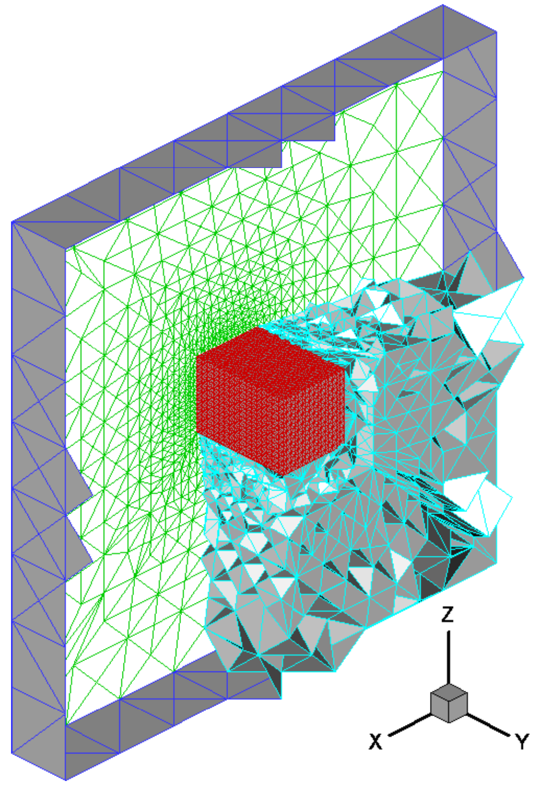

Figure 9. Final grid output showing a slice through the interior cells.

SURFACE GEOMETRY TREATMENT

The main objective of this paper is to describe the procedures involved in topology of hexahedral blocks for the generation of starting tetrahedral grids. Moreover, as a secondary objective, this section was added to show the final application of the tetrahedral grids as applied to aerodynamic configurations.

A more realistic refinement of the initial grid is obtained when the cubic section geometry is treated to represent an aerodynamic body. In this case, computational grid output for the ONERA M6 wing attached to a plane-of-symmetry and surrounded by interior and outer boundary cells is produced. The grid generation procedure is outlined by Figure 10.

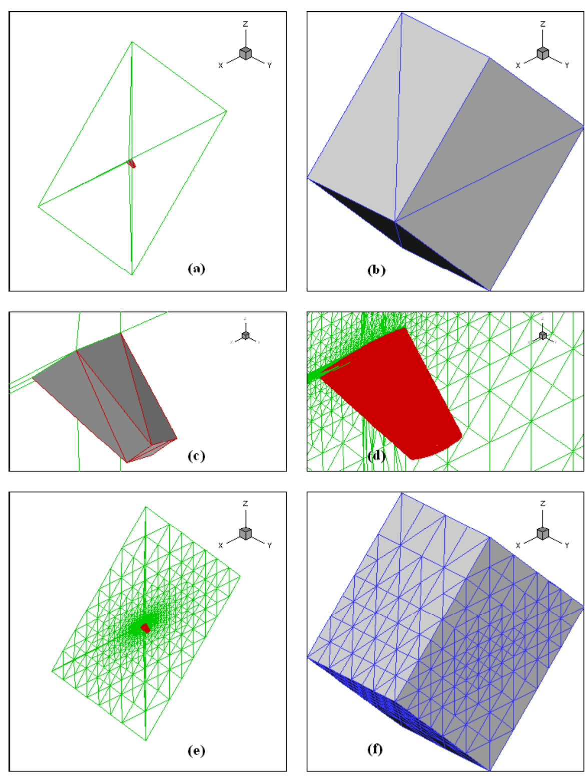

Figure 10. Computational grid output for the ONERA M6 wing AR = 3.8, where: (a) (b), and (c) show the initial grid while (d), (e), and (f) show the final grid.

The triangular faces of tetrahedral cells that fall on geometry surface shown by Figure 10 (c) are treated in the same manner as the interior faces, with some modifications to the algorithm. These modifications are essentially due to the way the surface faces are defined in the data connectivity matrix.

All of the faces that lie on the plane-of-symmetry, solid boundary and outer-boundary that may require geometry treatment (movement) are subdivided using a surface face subdivision approach developed to treat solid geometry. Each of these faces can be further designated to represent a specific three-dimensional geometric surface. In this case, the coordinates of the new node are translated to a new location on the prescribed ONERA M6 wing geometry. This point movement is shown in Figure 10 (d), where the newly generated vertices now lie on the prescribed surface geometry.

The space coordinates of a new surface geometry node is found through various means. Depending on the geometry shape, nodes are translated by means of empirical equations or cubic spline routines that match the geometry. For basic three-dimensional body shapes, this is done by selecting a point on the geometry that has the shortest distance along a radius of curvature. To automate the geometry movement, a library containing subroutines that can handle many body shapes, has been implemented in the program. The wing geometry subroutines are designed to be able

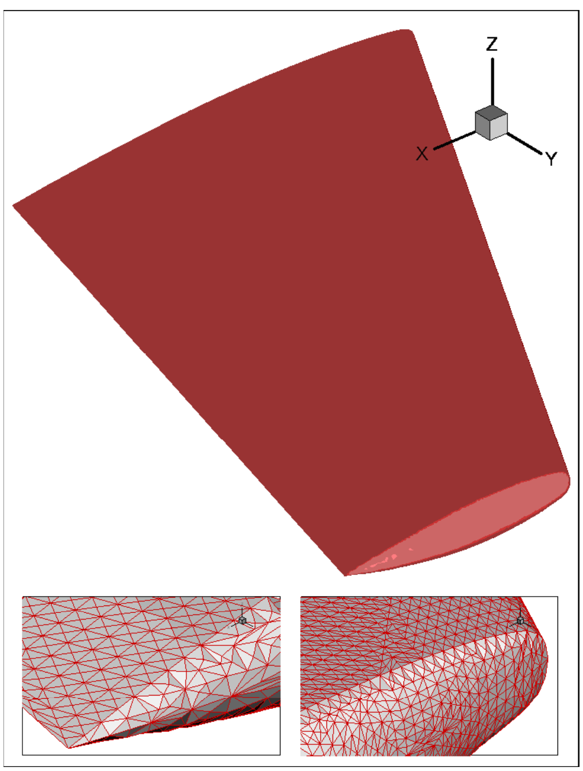

Figure 11. Final shape of the ONERA M6 wing and close views of the surface grids near the wing tip.

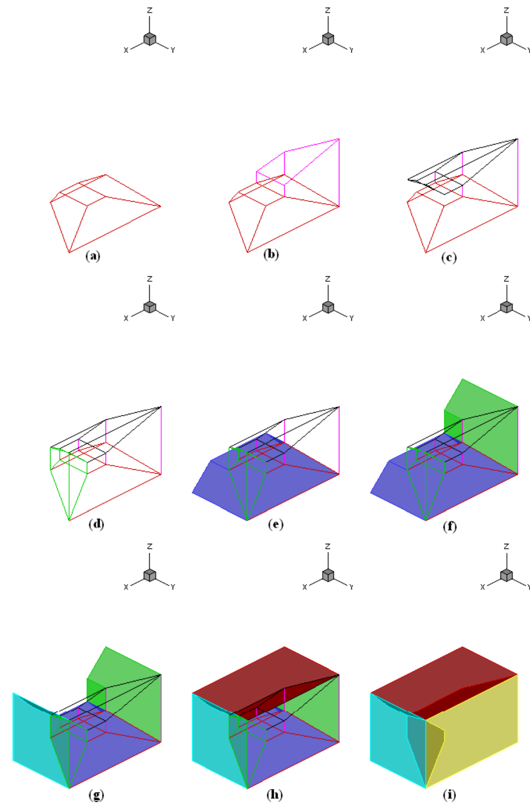

Figure 12. Nine hexahedral blocks surrounding two cubical spaces representing a wing-fuselage attached to a plane-of-symmetry, where: (a) through (d) show hexahedral block arrangements around the wing and (e) through (i) show five additional blocks representing the fuselage, plane-of symmetry, and the outer-boundary topology.

to handle single and multi element wings with taper, sweep, and tip considerations.

To examine the final geometry of the ONERA M6 wing as a result of geometry treatment, Figure 11 shows the final wing shape and close views of the surface grids near the wing tip.

The five hexahedral block topology discussed in this section is not adequate if additional surface geometries have to be considered. The following section will describe the procedure when an initial grid containing more than one surface geometry element is required.

NINE BLOCK TOPOLOGY

The sample initial grid produced in the previous section, with some modification of vertices, can be used to generate grids around a number of different body shapes. These shapes include circular cylinder, elliptic section, hemisphere, and numerous single wing sections. However, initial starting grids for multiple element airfoils, a combination of wing-fuselage, or a wing-pylon configuration require more hexahedral cells. For each additional body element, four new hexahedral blocks must be added to the hexahedral blocks of the previous section (i.e. 5 blocks). The nine hexahedral block topology and their consequent decomposition into tetrahedral cells are similar to that of a 5-block topology, and are illustrated by the grids shown in Figure 12.

For example, to construct an initial grid for a wing section attached to a fuselage and bounded by plane-of-symmetry or outer-boundary grids, the sides of four hexahedral blocks are arranged to form the solid wing geometry. This is shown in Figures 12 (a) to 12 (d), where a cubic solid body is formed as a result of arranging four hexahedral. By examining the topology shown in Figure 12 (d), one can see that the four surrounding hexahedral blocks form a cubic solid surface. This solid surface can represent a wing panel or any other body shape. To attach this wing panel to another geometry representing a fuselage, the five original hexahedral blocks, shown in Figure 4, are arranged around the topology of Figure 12 (d). By doing so, a nine-block hexahedral topology is constructed. The arrangement of the five original blocks around the topology of Figure 12 (d) is shown by means of Figures 12 (e) through (i).

The overall solid body formed by the nine-block hexahedral topology now represents a wing section

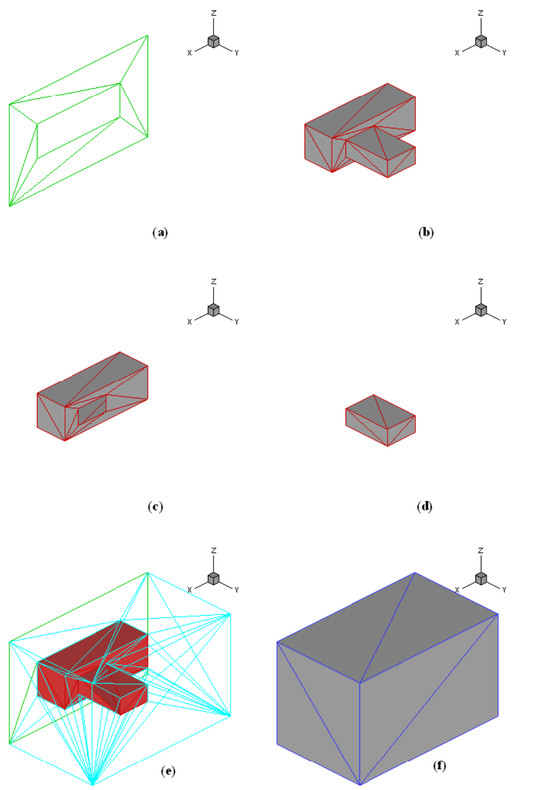

Figure 13. Initial tetrahedral starting grid from a 9-hexahedral block topology, where we have: (a) plane-of-symmetry grids, (b) solid surface grids, (c) surface fuselage representation (d) surface wing representation (e) interior grids, and (f) outer-boundary grids.

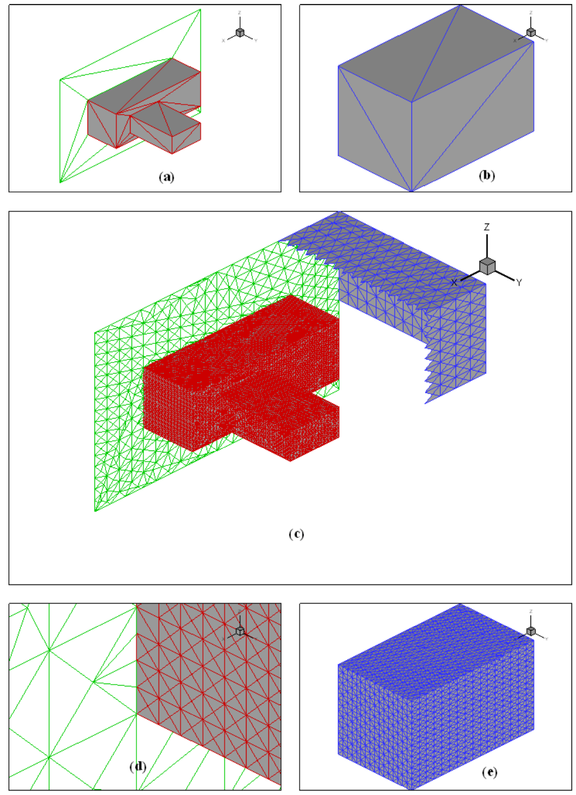

Figure 14. Sample grid output using 9-block initial data, where we have: (a) initial grid showing plane-of-symmetry and surface faces, (b) initial grid showing outer-boundary grids, (c) final grid output, (d) a close view near the plane-of-symmetry and surface faces, (e) final grid showing the outer-boundary faces.

attached to a fuselage. To use this topology as an initial starting tetrahedral grid, the hexahedral blocks have to be decomposed into tetrahedral elements.

When the nine-hexahedral blocks are decomposed into tetrahedral elements, an initial tetrahedral starting grid results with 54 cells, 130 faces, and 24 vertices. Again, the number of vertices remains the same as the number of vertices of the 9-block topology. This initial starting grid is shown in Figure 13 where the grids of various face types are plotted separately for ease of comparison with the previous initial grid (i.e. Figure 5). The various face types include 8 plane-of-symmetry faces shown in Figure 13 (a), 26 surface geometry faces shown in Figure 13 (b), 86 interior faces shown in Figure 13 (e), and 10 outer-boundary faces shown in Figure 13 (f) giving a total of 130 triangular faces. The surface geometry faces differ from the previous initial grid in that they represent two body shapes. The first one represents a fuselage and contains 16 faces and is shown in Figure 13 (c). The second body shape represents a wing panel with 10 triangular faces, and is shown in Figure 13 (d).

Although, the 9-block initial grid differs from that of the 5-block topology, there are many similarities.

For example, the number of plane-of-symmetry faces and outer-boundary faces in both cases remains the same. This is due to the fact that the same 5-block topology, constructing plane-of-symmetry or outer-boundary, has been used for both cases. The number of vertices and their three-dimensional coordinates remain the same when hexahedral blocks are decomposed into tetrahedral elements.

The initial starting tetrahedral grids that are shown in Figure 13 were constructed by decomposing a topology containing 9 hexahedral blocks. This initial grid can be used to generate computational grids for a number of two element bodies. However, for the sake of continuity and illustrative purposes, these grids were refined without modifying the outer-boundary vertices and without surface geometry considerations. The final refined grid results for this sample initial grid are shown in Figure 14, where the surface faces represent two distinct geometry elements.

CONCLUSION

The construction of an initial starting tetrahedral grid made the use of hexahedral block topology and their consequent decomposition into six tetrahedral cells. Hexahedral blocks were arranged around the geometry with one face on the solid surface and the opposite face on the outer-boundary to fill a domain. The blocks were then decomposed into tetrahedral cells to form an initial starting grid. Five hexahedral blocks were used to generate an initial grid containing 30 tetrahedral cells and 74 faces. This initial grid was used to generate several computational grids addressed in the present work.

Unstructured grid technology has the potential to significantly reduce the overall user and CPU time required for CFD analysis of realistic configurations. To realize these potentials, improvements in automation procedures, anisotropic grid generation, flow adaptation, and integration with the solution process are needed. Unstructured grid generation has advanced to the point where generation of a grid for any configuration requires only a couple of hours of user time. However, prior to grid generation, solid surface geometry must be prepared using CAD software or other graphics media. This process could take anywhere from hours to weeks for complex geometry. It is the most labor-intensive task in the overall simulation process.

Different approaches are used by researchers to overcome the difficulty of generating a suitable mesh around a complex geometry [3, 5]. However, in their work, a very well definition of surface geometry is first produced and then extended to three dimensions. Here, both surface and field grids are generated simultaneously, and there is no need for a well definition of the solid surface prior to volume grid generation. This novel feature of the current work enables the grid generator to become one step closer to full automation. The present approach adopts a very crude initial discretisation of the solid surface and the outer-boundary. Surface and field grids of increasing resolution are then generated simultaneously as the cell subdivision process continues.

Another novel feature of the developed program for the automatic generation of three dimensional unstructured grids is its ability to produce acceptable grids for complex configurations in a reasonably short CPU time without extensive use of grid quality measures. The grid generation algorithm selects the largest face of each cell and in turn the largest edge of the selected face for subdivision. This, inherently, controls the overall quality of the grids that are produced.

Three-dimensional unstructured cells can take various geometrical body shapes. These shapes include a tetrahedron with four faces and six edges, various hexahedral elements with six faces and twelve edges, or any higher order geometrical shape. The objective of the present work is to develop algorithm making use of hexahedral blocks to generate initial tetrahedral cells. This algorithm was developed to eliminate the labor-intensive surface grid generation performed by CAD software.

Hexahedral blocks represent irregular cubes, and can have an unlimited number of shapes as long as they have six non-coplanar sides. A single hexahedral block can be decomposed into six tetrahedral elements. The resulting tetrahedral elements may have a poor quality because they are a function of the original hexahedral shape. Further refinement of badly shaped tetrahedral elements and their geometry consideration is the task of the grid generator. Unstructured grid generators can move a grid point to match a specific solid surface geometry while enhancing the cell quality.

Each side of an irregular hexahedral block can be made to fit a solid boundary while the other five sides can take almost any size and shape. Thus, by arranging the sides of irregular hexahedral blocks around a prescribed solid geometry, and extending the opposite sides to a prescribed domain, a hexahedral grid can be obtained. The eight vertices of each block can be made to lie on the surface geometry or the outer-boundary where the prescribed coordinates are known.

Five hexahedral blocks were arranged around a solid body to represent a flow domain. The outer-boundary faces forming the flow domain can be set to match many prescribed geometries without any complications. This is because the movements of vertices defining the outer-boundary faces do not coincide with vertices of any other face. To increase the overall domain size, one can simply change the coordinates of the vertices defining the outer-boundary faces.

To generate an initial grid for a multi element aerodynamic body, nine-hexahedral blocks are required. When the nine-hexahedral blocks are decomposed into tetrahedral elements, they result in an initial tetrahedral starting grid with 54 cells, 130 faces, and 24 vertices. Again, the number of vertices remains the same as the number of vertices of the 9-block topology.

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