Advances in Discrete Surface Grid Generation: Towards a Reliable Industrial Tool for CFD

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ABSTRACT

Recent advances in Discrete Surface grid generation are described. Specific aspects include: automatic preprocessing/improvement of the given DS grid, definition of sharp edges, strict enforcement of continuous topology, introduction of a visibility horizon based on the geometrical features in the DS, improved 2D cross-checks, and better adaptive background grid element size definition. The aim of this effort is to obtain a reliability similar to that of the standard Advancing Front Method operating on analytical surfaces, but resulting in a much better quality of a global surface mesh.

Key words: Discrete Surface Meshing, Unstructured Grids, Advancing Front Method, CFD

1. INTRODUCTION

The application of unstructured grids has enhanced considerably the automation of grid generation procedures and enabled the routine simulation of problems characterized by complex geometry and/or complex physics. While geometrical complexity is increasing, there is also a big request for faster turnaround time. As an example, we cite the situation in the automobile industry. Presently, the customer expects a complete simulation in a matter of days. For the near future, companies are demanding a time of one day for the design study of a new car model, including data preprocessing and mesh generation. Given that the flow simulation and post processing do run overnight, in order to obtain results the next working day the preprocessing must take at most a few hours. This request makes any kind of 'hands on' work for the given surface data the ultimate bottleneck. We surmise that the use of a Discrete Surface (DS) representation for grid generation offers a big potential for complete automation, as well as better (automatic) adaptation for complex geometries.

Over the last years Löhner [Löh96, Löh97, Löh00] successfully developed a DS grid generation technology based on the Advancing Front Method. While the results obtained are encouraging, there is still a need for considerable human intervention and technical insight to obtain surface grids for complex geometries. These DS surface grid generation algorithms were integrated in PAMGEN3D/ PAMFLOW. The present paper describes recent developments and improvements in DS grid generation, with the aim of achieving a robust tool for daily industrial use.

2. DISCRETE SURFACE REPRESENTATION

Surface representation and discretisation are two very important issues in any flow simulation. They define the fidelity of the model, as well as the grid resolution employed. Many domains to be gridded are defined by a surface grid, i.e. discrete data. The increase in complexity and the demand of a faster turnaround time increase the need of mesh based domain definition, i.e. DS-based grid generation.

An advancing front method for gridding discrete surfaces was developed by Löhner and first presented in [Löh96]. In principle, the procedure follows the same steps as the classical advancing front procedure:

- The side forming the smallest new surface triangle is taken out from the active front;
- The new point which defines the ideal triangle is placed on the given surface mesh (in this case the discrete surface);
- A set of close points (possible other candidates to form the new triangle) and sides are collected in 3D;
- Validation and exclusion tests for these close points and sides are made;
- For the new point selected, checks are performed to make sure the new triangle does not cross the

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  front;
- The front, as well as all data structures associated, are updated.

While the simplified procedure works properly on smooth surfaces, extensive research efforts were devoted to enhance the reliability of the DS gridding procedure for complex and dirty surfaces.

3. RECENT ADVANCES

The new developments/improvements are based on the ideas presented in [Löh00] and are applied in the version 2002 of PAMFLOW/ PAMGEN3D. The main improvements are given as follows:

- Automatic preprocessing/improvement of the given DS grid;
- Definition of sharp edges;
- Strict enforcement of continuous topology;
- Introduction of a visibility horizon based on the geometrical features in the DS;
- Improved 2D cross-check; and
- Better adaptive background grid element size definition.

3.1 Sharp Edges

A so-called sharp edge marker is given for the DS. It identifies important geometrical features that are necessary for the stability of the DS gridding. These edges are identified by the angle between the normal of the two adjacent faces. This angle, defined by the user, should be $\alpha_s = O(20-30)$ degrees. These sharp edges are included in the initial front for the surface grid generation in the form of discrete lines.

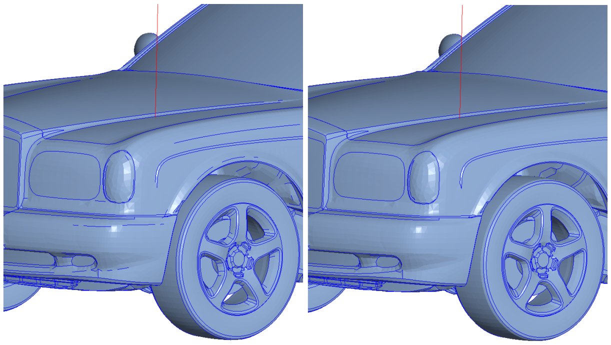

Figure 1 Car: Sharp Edge Definition
Left: Simple Sharp Edge Criterion;
Right: Sharp Edge Crawler Definition

The definition of discrete lines based on the simple angle criterion can be improved considerably by a so-called 'sharp edge crawler' that eliminates and adds edges at the end-points of discrete lines. Starting from any given end-point of discrete line, the sharp edge angle criterion is relaxed (e.g. by $\alpha_r = 1.2 \cdot \alpha_s$), and all edges whose angle falls below this value are eliminated from the discrete line. This process is repeated until no original sharp edge can be eliminated. Once the elimination process is completed, new sharp edges are added. Again starting at any given end-point of a discrete line, new edges are added if a more restrictive sharp edge criterion is met (e.g. by $\alpha_r = 0.8 \cdot \alpha_s$). As before, this process is repeated until no new edges can be added to the discrete lines. The improvement obtained from the sharp edge crawler technique can be seen in the discrete surface definition of a complete car, given by 237,167 triangles.

3.2 Automatic preprocessing

The actual DS implementation in PAMFLOW/ PAMGEN3D demands a water-tight DS grid. As typical preprocessing tools do not assure this condition, we developed some automatic preprocessing tools for DS mesh improvement:

1) Non Water-Tight Faces:
Most of the time non water-tight areas are given by single faces (see face ABC, Figure 2). The face and the neighbour faces are nearly planar and are detected by a comparison of their face normal:

- Three neighbour faces and all three angles are bigger than 150 degrees (Triangle ABC) (see Figure 2): The triangle node with an overlapping neighbour face is marked (Node D). If successful, the side opposite to this node is swapped (Side AB).

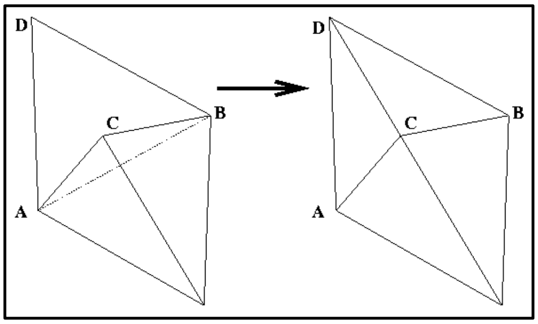

Figure 2 Non Watertight Faces

2) Degenerated Triangles:

- Angle > 179 degrees (see Figure 3): Mark the side opposite to this node (Side AB) and check if the other adjacent neighbour (triangle ADB) is not degenerated; if successful, swap diagonal (AB).;
- Angle < 1 degree (see Figure 3): If the side opposite to this node (side AA) has a neighbour face, collapse this side and remove both triangles.

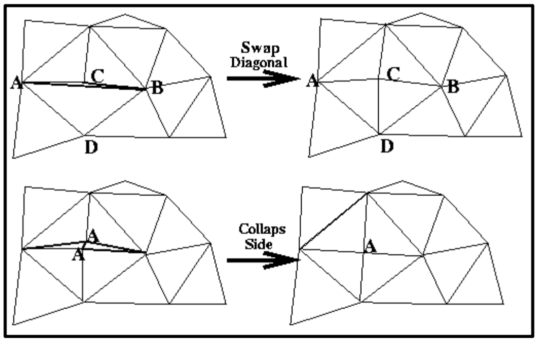

Figure 3 Degenerate Triangle

3) Improvement of Geometry Lines Given by Sharp Edges:

- Remove all lines defined by only one sharp edge segment. (see Figure 4, Case A);
- 'Single edge holes' in a sharp edge line are closed (see Figure 4, Case B);

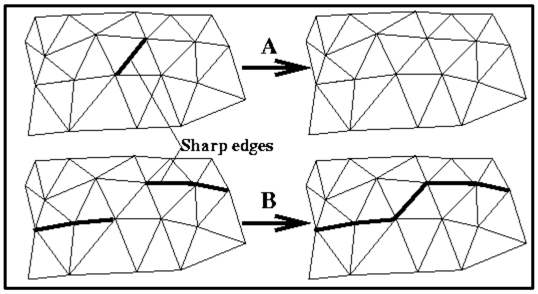

Figure 4 Improve Internal Geometry Lines

3.3 Visibility Horizon and Continuos Topology

The list of possible close points/sides for the check is reduced by several tests. Perhaps the most important validation test is based on the neighbour to neighbour search on the given DS. The starting face for the search is given by the underlying DS face at the side midpoint of the side being removed from the active front. The direction is given by the close point. The close point is removed from the list if it can not be reached on the given DS. The success criteria are given by the shape function values for the close point and its relative face normal distance. A typical neighbour to neighbour search will not stop at internal geometry lines (given by sharp edges). Therefore the internal geometry lines were meshed first (i.e. with a higher priority) to enhance the meshed area around these lines. However, this did not circumvent those cases where a close point was chosen from 'behind' an internal geometry line. We introduced a visibility horizon for the neighbour to neighbour search. All neighbour to neighbour edges given by internal geometry lines are marked. In this way, the neighbour to neighbour search can recognize them. The neighbour to neighbour search stops at these internal geometry lines. The close point is marked as unreachable and removed from the list of candidates. A more stringent test was introduced to enforce the condition of a continuos topology on a DS. An additional success criteria is added: the face found by the search must be identical with the underlying DS face of the close point. If not, the close point/face is excluded from the list. These two topolody enforcement criteria greatly enhance the robustness of DS surface gridding for complex configurations.

3.4 2D Crossing-Checks

The close points are sorted according to the quality of the triangle they would form if chosen. The first of these points that forms a new triangle that does not intersect any of the close sides is then chosen. The direct cross-check on a 3D surface is not a trivial task, especially on a non-smooth surface like a DS. Therefore Löhner [Löh96] introduced a 2D cross-check. The local transformation from 3D to 2D is defined by the underlying DS face given at the actual side midpoint. Before the check the close points/sides are transformed into 2D.

In its original implementation, the side-crossing check was carried out only with the transformations obtained from the DS face corresponding to the side being removed from the front. However, there may exist a noticeable change between the normal of the DS face corresponding to the side being removed and the normal of the DS face at the position of the new point. Therefore, a second 2D-cross is performed based on the normal of the DS face corresponding to the new generated triangle. If this test fails, the next close point in the remaining list is chosen and the two previous cross-checks are redone.

It was found that further tests were required to reduce the number of possible front crossings to a minimum. The 2D cross-check is also performed with the normals of the DS faces corresponding to the mid-point of the new sides. Without these tests, a close point may lie in the plane of this transformation 'behind' the new side. If the new side is subsequently removed from the front, this close point will be excluded from every further test and by this a possible front crossing may happen. A typical case where this happens is shown in Figure 5. Note that the new triangulation is coarse in comparison to the surface curvature.

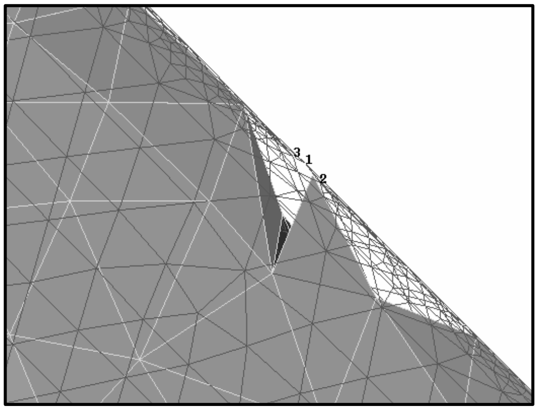

Figure 5 Requirement of Extra 2-D Cross Checking

This additional validation test improves noticeably the stability of the DS gridding, especially for coarse grids.

3.4 Adaptive Background Grid

In the latest version of the mesh generator we implemented an analysis of point and line distances on the surface patch. The sizes obtained are compared with the given size values in the background grid and, if necessary, interpolated back onto the background grid. This improves the mesh quality in critical areas, where one may have tiny patches with a low curvature surface. Without the new size adaptation, one would generate very big and stretched faces.

4. RESULTS

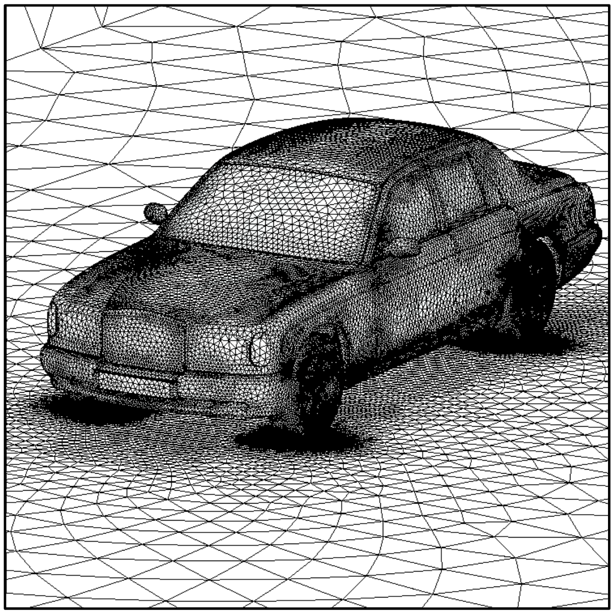

Figure 6a Car 1: Surface Grid

4.1 Car 1: The first case considered is the surface mesh for a complete car, including underhood and underbody. The (discrete) surface definition consisted of 237,167 triangles.

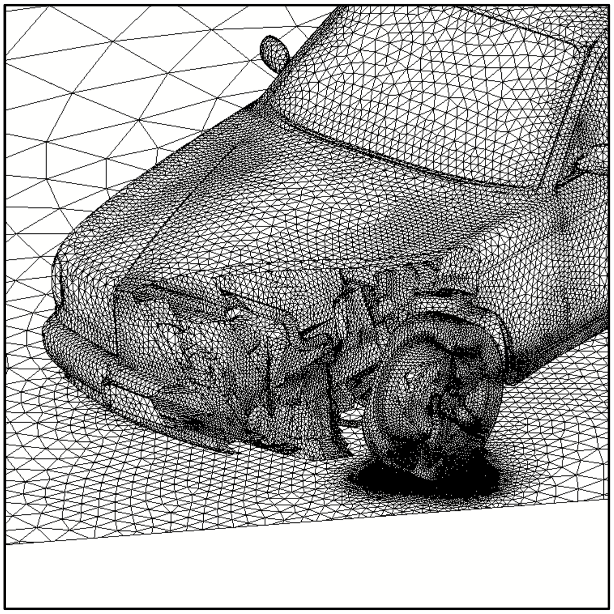

Figure 6b Car 1: Surface Grid (Detail)

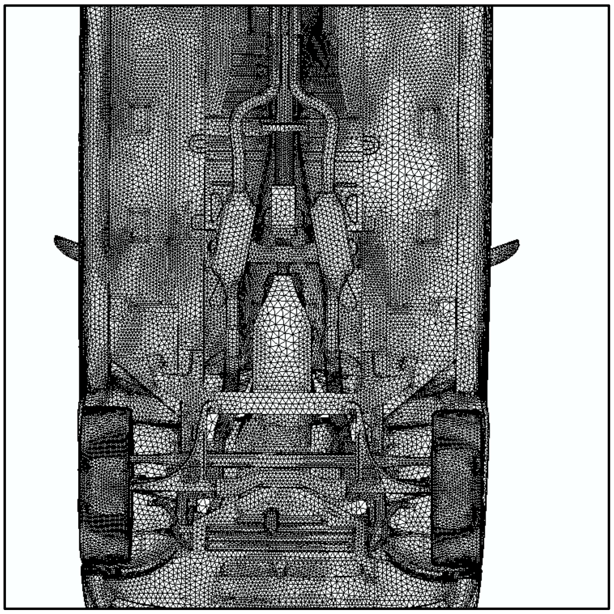

Figure 6c Car 1: Surface Grid (Bottom)

The given discrete dataset resulted in 287 discrete patches, of which 45 where defined as duplicate surfaces, for a total of 332 patches. An adaptive background grid with 10 levels of refinement/adaptation was used to obtain a good first size estimation for the complete domain. Further background grid refinement/adaption was done to take into account the line/point distances on surfaces (for a more detailed description of the background grid technique applied, see [Löh97]). Finally, 10 surface sources where added for the wheels and the wake to capture zones with flow separation. The generated mesh, including surface duplication, had 482,204 triangles, is shown in Figures 6.

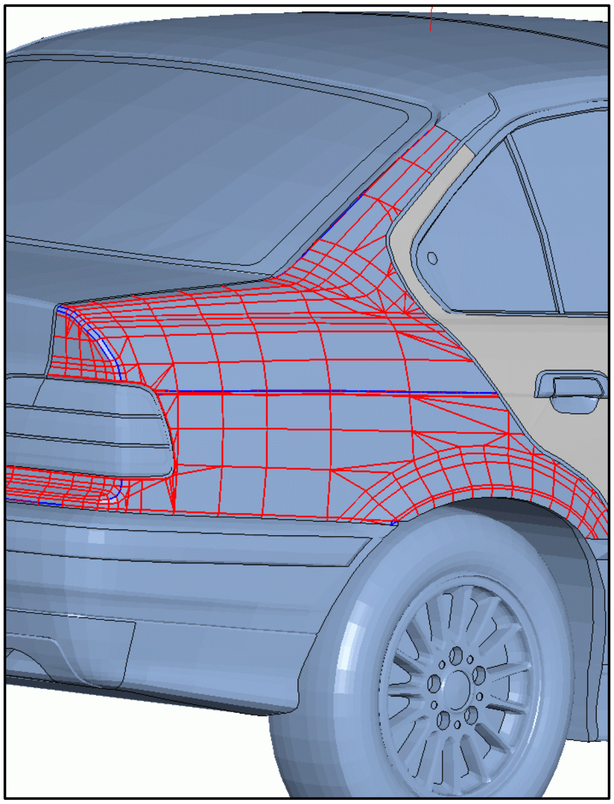

Figure 7a Car 2: Discrete Surface Definition (Detail)

4.2 Car 2: The second case considered is the external surface mesh for a complete car. The (discrete) surface definition consisted of (only) 61,412 triangles. A portion of the discrete data is shownn in Figure 7a. While the data set is not as large as the one of the previous example, it contained a significant number of highly stretched ($> 1 : 10^4$) elements. This lead to problems for the surface generation before the improvement described in this paper were implemented. An adaptive background grid with 9 levels of refinement/adaptation was used to obtain a good first size estimation for the complete domain. The final surface mesh had approximately 376,000 triangles, and is shown in Figures 7b,c.

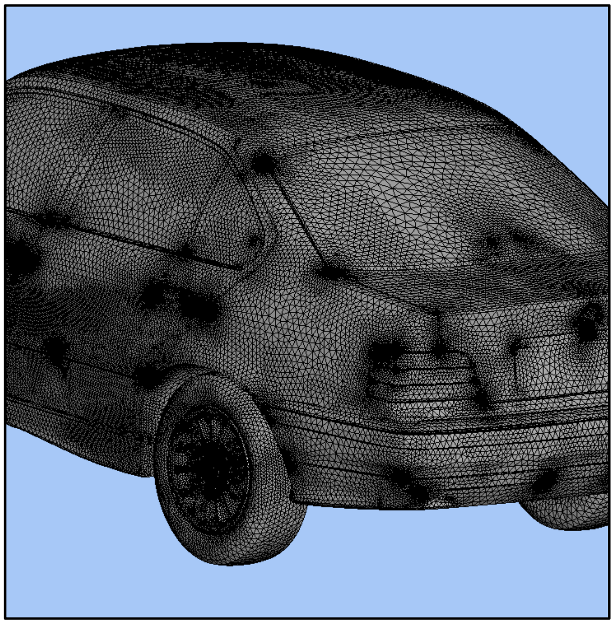

Figure 7b Car 2: Generated Surface

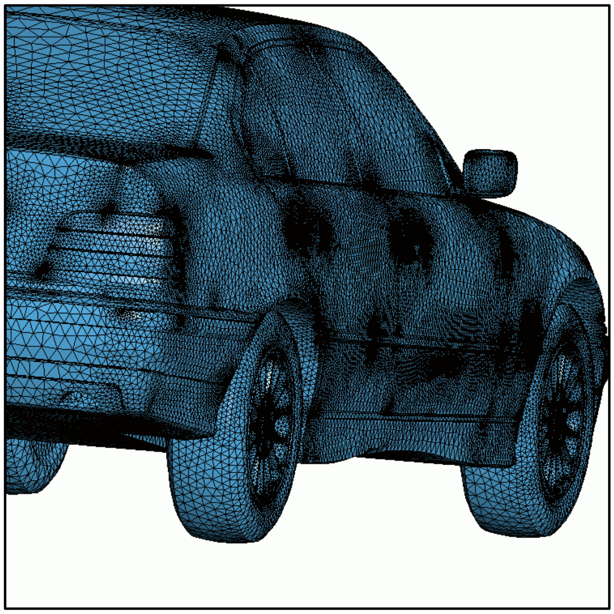

Figure 7c Car 2: Generated Surface

4.3 Thrachea: The third case is concerned with the air flow in the bronchii and lungs. The segmented image, together with the cuts at the extremities of the smaller branches, is shown in Figure 8a. The mesh sizes were automatically obtained from an adaptive background grid with 6 levels of refinement. This produced the surface mesh shown in Figure 8b. One can discern the smaller elements in regions of higher curvature and smaller vessel diameter. The volume mesh had approximately 1 million elements. The results obtained for steady airflow can be seen in Figures 8c,d, which show surface pressures and iso-surfaces of constant absolute value of velocity.

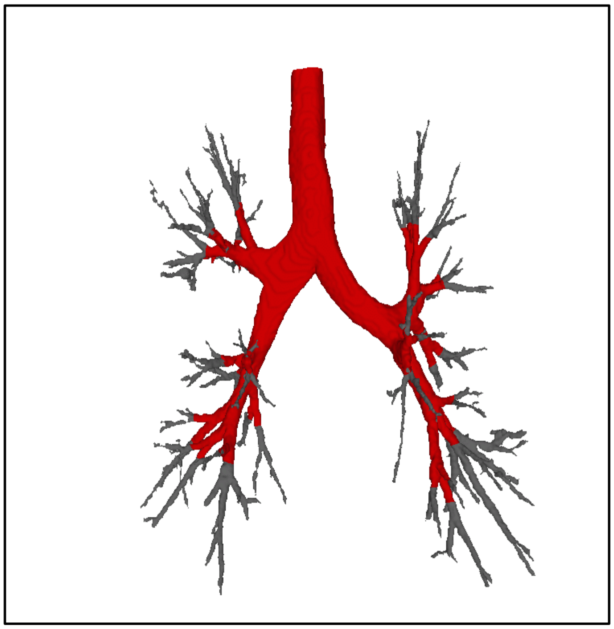

Figure 8a Trachea: Segmented Image

Figure 8b Trachea: Surface Grid

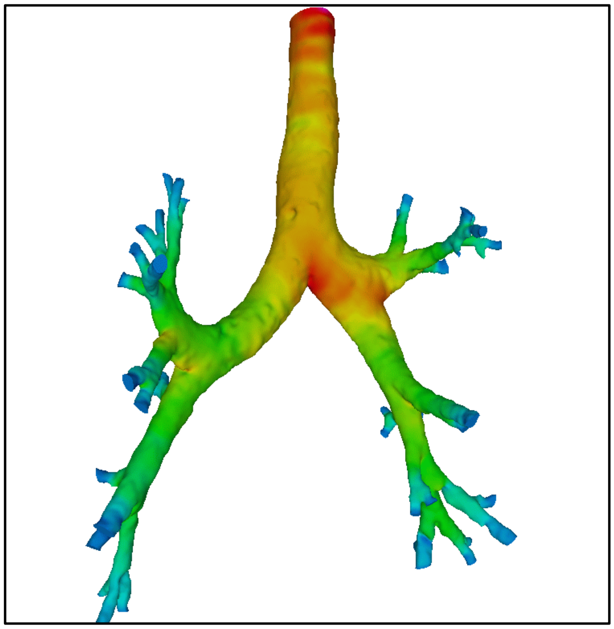

Figure 8c Trachea: Surface Pressures

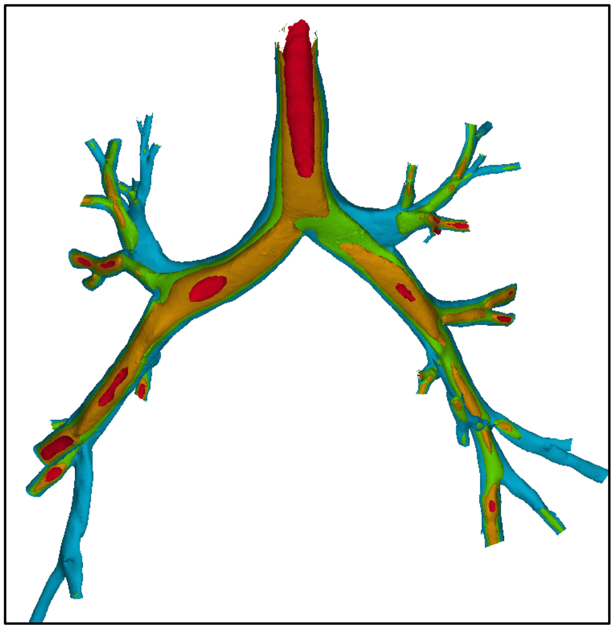

Figure 8d Trachea: Iso-Surfaces of Abs(Velocity)

5. CONCLUSIONS AND OUTLOOK

The combination of several advances in discrete surface meshing, namely:

- Automatic preprocessing/improvement of the given DS grid;
- Definition of sharp edges;
- Strict enforcement of continuous topology;
- Introduction of a visibility horizon based on the geometrical features in the DS;

- Improved 2D cross-check; and
- Better adaptive background grid element size definition,

has resulted in a very robust and reliable DS grid generator.

By using the automatic background grid one can obtain a very good adapted surface mesh with small amount of human intervention. The new surface mesh is adapted automatically to most of the given geometrical features, like curvature, distances of lines and points. One needs around one to three tries to obtain a very good surface mesh which is adapted to the user's wishes for the simulation.

The time used for the DS gridding is around one order of magnitude higher than for a simple analytical surface mesh generation, but includes a lot of automatism to obtain a very good surface mesh.

Future work will be devoted to improvements in the automatic preprocessing of the given DS data, the extension of the new implementations to discontinuous topologies (e.g. cracks), and anisotropic mesh generation for DS.

6. REFERENCES

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