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RECENT ADVANCES IN UNSTRUCTURED GRID GENERATION PROGRAM VGRID3D

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INTRODUCTION

VGRID3D is a program for generation of unstructured grids over complex configurations. The grid elements (triangles on the surfaces and tetrahedra in the field) are generated starting from the surface boundaries towards the interior of the computational domain using the Advancing Front Method.

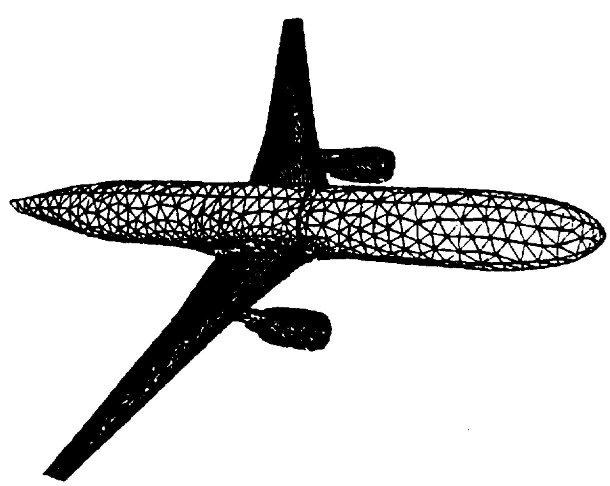
Over the past two years, many changes have been made and several new options are added to **VGRID3D**. Chief among these are:

- a restart capability that enables generation of a large, complex grid on a relatively small memory computer (like a workstation) in several restart runs,
- a menu-driven graphics version that helps a user visualize grid generation at every step during the process,
- a robust and user-friendly grid generator made possible by incorporating a wide experience base generated by the user community.

Several promising new developments are under way. These include

- structured background grid to provide a better control of the grid spacing, and
- development of an adaptive remeshing scheme that couples **VGRID3D** to an efficient Euler equation solver **USM3D**.

In this presentation, the grid generation process is briefly outlined first. This is followed by a description of the new developments augmented with examples.



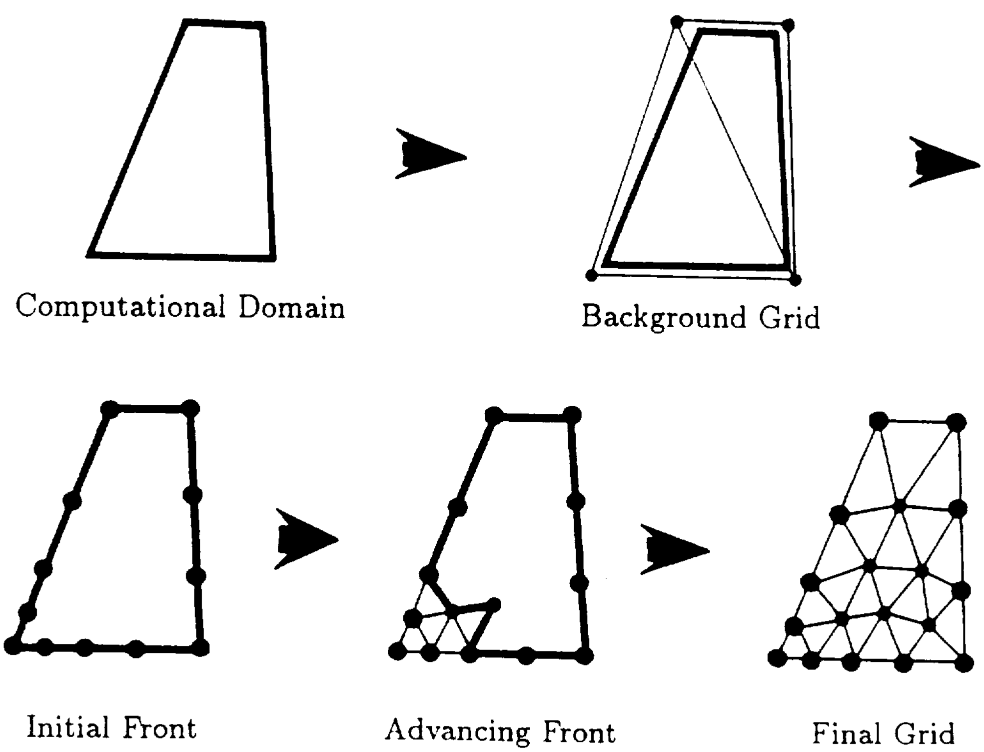
ADVANCING FRONT METHOD

The entire grid generation process using **VGRID3D** is summarized in the following main steps (Ref. 1,2):

1) The boundaries of the domain to be gridded are divided into a number of surface patches. These surfaces define the configuration of interest as well as the far-field boundaries of the computational domain.
2) A background grid is set up to define the local grid characteristics such as grid point spacing.
3) Each surface patch is, in turn, subdivided into a number of triangles to form the 'first' or 'initial' front.
4) The front is advanced in the field by introducing new points and forming tetrahedra until the entire computational domain if filled.

In the following figure the grid generation process is depicted in two dimensions.

Advancing Front Method



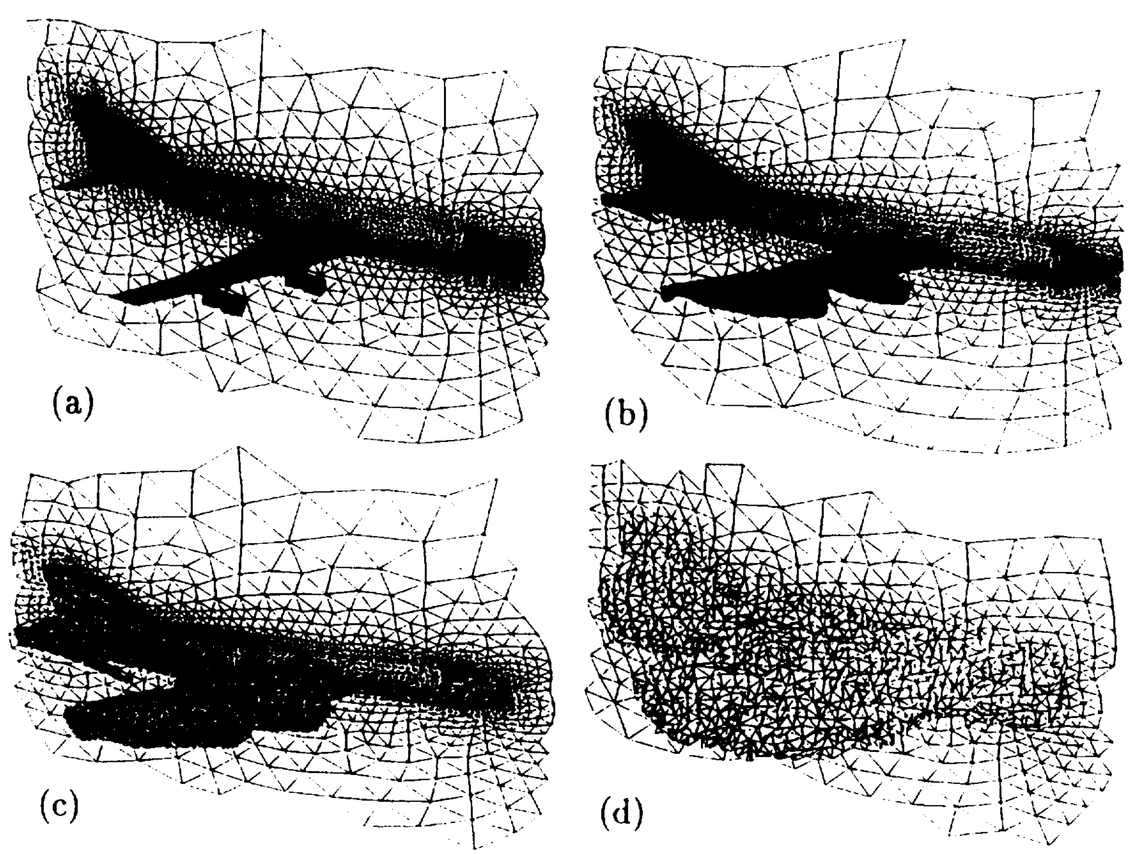
GRID RESTARTING

In the Advancing Front Method, the grid is generated in a marching fashion. Cells are formed on the current front by introducing new points in the field, which, in turn, reshape the front. Thus at any given time during the grid generation process, the computational region is divided into gridded and ungridded regions which are separated by the current front. Thus the grid generation process can be stopped and restarted without regard to the previously generated grid.

A grid restart capability has been incorporated in **VGRID3D**. The method is based on a local/global renumbering system. In each restart run, a user specified number of new grid points are introduced, the newly generated points and element connectivity are globally renumbered, the recent data are appended to the previously generated grid and the current front is locally renumbered for the next restart run.

The restart capability has resulted in a drastic reduction in the memory requirement for the grid generation, and now makes it possible to generate a large grid interactively on a large computer or in several restart runs on a smaller workstation. While conceptually simple, the restart capability has proven to be a powerful tool and has significantly enhanced the usability and productivity of **VGRID3D**.

The following picture shows several stages of an advancing front during the generation of grid around a Boeing 747 configuration using the restart capability.



INTERACTIVE GRAPHICS FOR VGRID3D

Interactive graphics has become an integral part of any three-dimensional grid generation process, whether for structured or unstructured grids. An interactive graphics version of **VGRID3D** has been prepared to help a user visually monitor each step of the grid generation process and intervene as necessary. Using this version, a user can examine the input to the grid generator, the background grid, the initial point distribution the surface triangulation for each patch comprising the configuration, and the selection and introduction of tetrahedra in the field. Although the interactive program is capable of generating a complete 3-D grid using a workstation, this task has been customarily left to a larger computer for speed and accuracy.

The interactive version currently runs on any Silicon Graphics IRIS 4D series of workstations, and is user-friendly and menu-driven. A version to run on SUN workstations is currently under development. In addition to the interactive version of **VGRID3D**, two other graphics pre-processor programs have been developed that help a user prepare the input to **VGRID3D**. The first of these is **PREGR1** which helps construct surface patch definition from geometry data given in either 'network' or 'cross-section' format. The second, **PREGR2**, helps construct and manipulate background grid which controls grid characteristics. Both **PREGR1** and **PREGR2** were originally written by Mr. Clyde Gumbert of NASA Langley Research Center. Current versions incorporate minor modifications that make them compatible with other programs in the unstructured grid software package. Availability of these graphics programs has greatly expedited the grid generation process.

GRID POST-PROCESSING

A grid with 'good' quality cells is essential for an accurate flow solution and for a stable convergence for steady-state problems. In the context of unstructured grids, a 'good' grid is one where the variation in size among the neighboring cells is smooth with a minimum number of distorted (high skewness) cells. Despite many precautions exercised in the grid generation process, the final grid almost inevitably contains some cells of undesirable geometric quality. For the advancing front grid generator, distorted cells can form either when the variation of grid spacing on the background grid is not sufficiently smooth, or when one or more fronts collide.

In order to alleviate this problem, a post-processing program called **POSTGR** has been developed. This program first provides an assessment of the grid quality based on the cell 'volume ratio' and 'included angles'. The volume ratio criterion is defined as the ratio of the actual cell volume to a corresponding 'ideal volume' of an equilateral cell which is based on an average of the actual cell edges. A volume ratio of less than 5 percent is considered distorted. The included angle is the angle between the adjacent faces of a tetrahedral cell. There are 6 such angles for any tetrahedra. Any cell with an included angle of less than 5° or greater than 175° is tagged as a distorted cell. The distorted cells are then removed along with an additional layer of surrounding cells, creating cavities in the volume grid. The cavities are next filled with new tetrahedra using the advancing front method. In practice several such cycles of alternately using the **POSTGR** and **VGRID3D** are used to remove most of the distorted cells.

This post-processing technique has proved to be very effective in improving grid quality and is being routinely used in the grid generation process.

NEW DEVELOPMENTS

Over the past two years, **VGRID3D** has been made robust and several options added to make it more user-friendly as described before. Further research is under way on several additional developments which should result in an overall improved grid quality, significantly reduced grid generation time, and expanded capabilities of **VGRID3D**. The developments include:

1) structured background grids which provide a better control of grid spacing with significantly less user interaction, and

2) an adaptive remeshing scheme to obtain the final solution more efficiently.

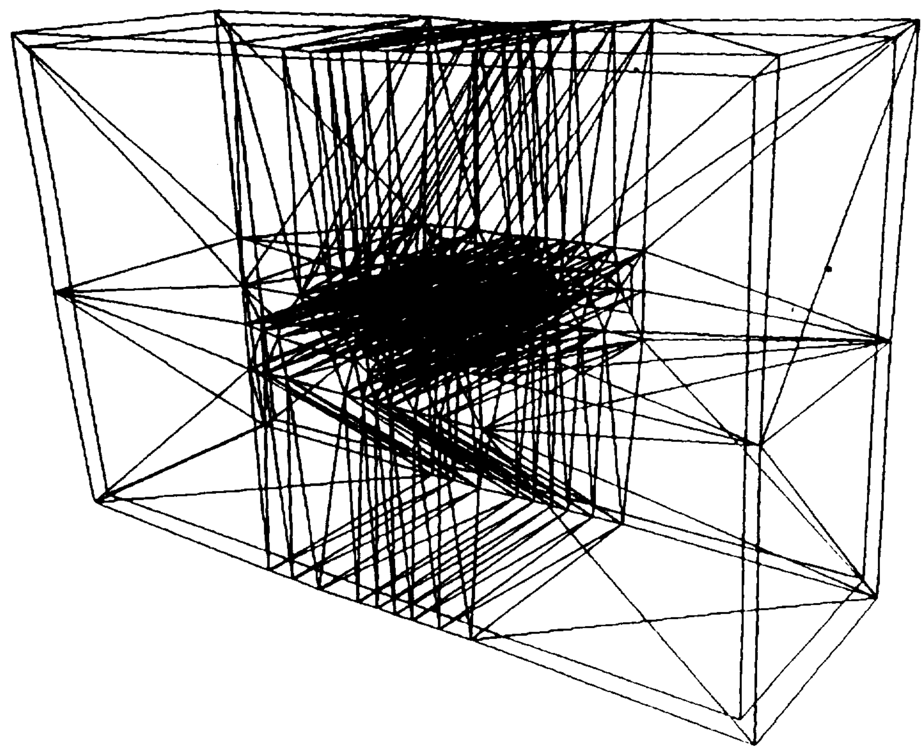
The above developments are at various stages of completion and have been successfully applied to focused applications which are presented here. The core technologies exist for both, but are not sufficiently mature to be installed in the production version of **VGRID3D**.

CONVENTIONAL BACKGROUND GRID IN VGRID3D

An important feature of a grid generation technique is its ability to distribute points smoothly throughout the computational domain with convenient user control. In the Advancing Front Method, the grid element size is controlled by parameters specified at the nodes of a secondary coarse grid called 'Background Grid'. The conventional background grid consists of a number of tetrahedral cells (an unstructured mesh in itself) which completely encloses the computational domain to be gridded. As the mesh front is advanced in the field, the information for the location of a new point is interpolated from spacing parameters prescribed at the nodes of a background cell which encloses the point.

This method of grid spacing control has several disadvantages. The quality of the final grid is dependent upon the smoothness in variation of the grid spacing from point to point in the background grid. An uneven variation in background grid spacing may result in many tangled fronts to the detriment of the grid generation process. Hence, a user needs to exercise caution in the construction of the background grid. Construction of the tetrahedral background grid is presently a manual process which is aided by a graphics pre-processor program **PREGR2**. Although **PREGR2** has simplified this procedure a great deal, there is currently no automatic way of modifying a background grid should the necessity arise.

Although the conventional method of grid spacing control using tetrahedral background grids has been successfully used to generate grids over several complex configurations, it is currently the most time consuming task in the entire grid generation process. A sample background grid is shown in the following figure for an ONERA M6 wing configuration and shows the complexity of the method of grid spacing control. For this reason research has been focused on alternatives. One such alternative is the so called 'structured' background grid which is described next.

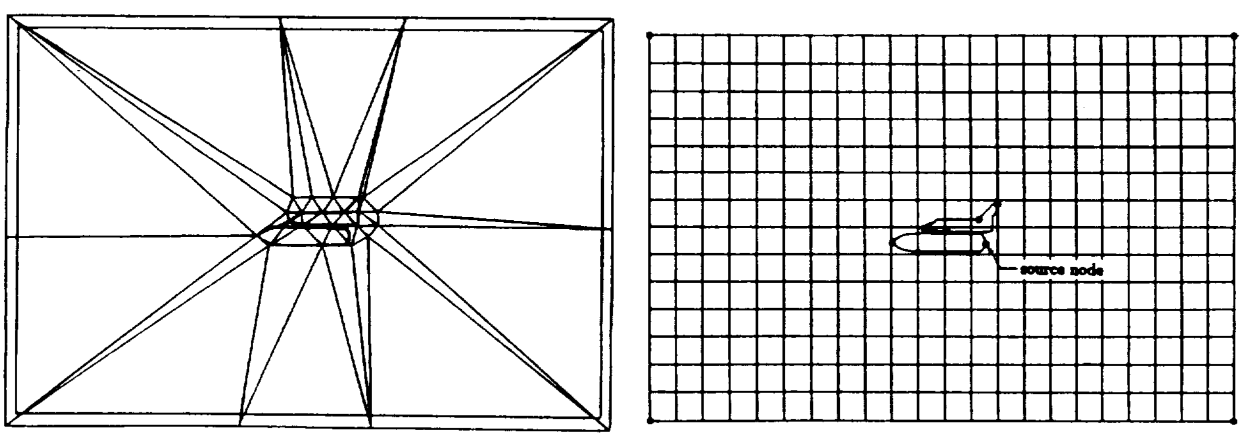


STRUCTURED BACKGROUND GRID

A new type of background grid has been introduced which resolves many of the problems and inconveniences associated with the conventional tetrahedral background grids (Ref.3). Some of the salient features of this new background grid are:

- The grid consists of uniformly spaced Cartesian cells, hence the name **structured**. Since a Cartesian grid can be generated automatically, the new method eliminates need for an involved graphics program.
- The desired grid spacing on the configuration is controlled by an arbitrary number of user specified 'source' elements. There is no restriction to the number and location of these source elements. Currently two types of elements are used: nodal and linear.
- The spatial variation of spacings at the nodes of the structured Cartesian grid is modeled as diffusion of 'heat' in a medium with 'source' elements acting as 'heat' sources, and solving a Poisson equation.
- During the grid generation process, the interpolation of spacing for any arbitrary location is now a simple matter of Cartesian interpolation, thus eliminating need for specialized data structure used in the conventional unstructured grid method.

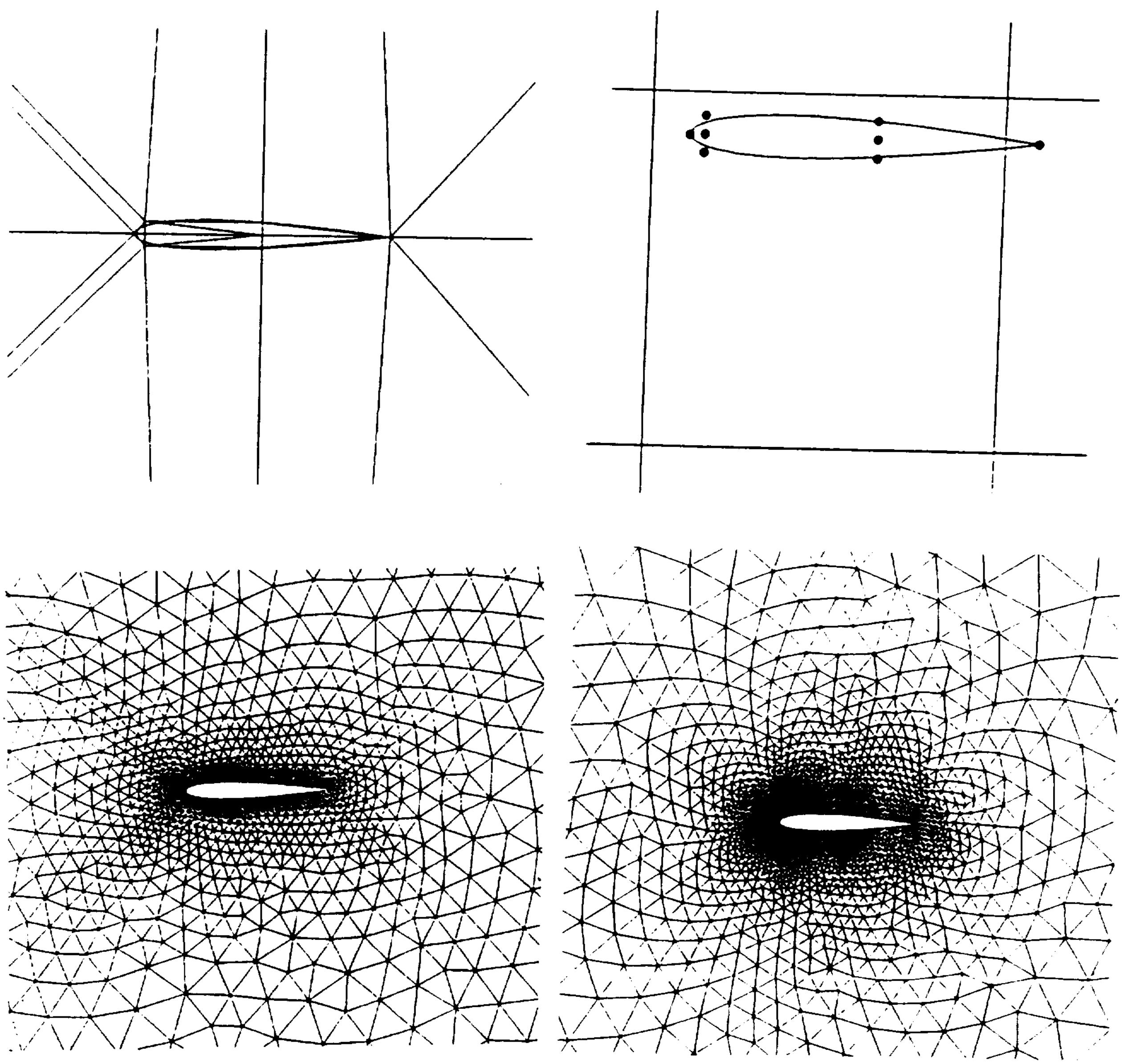
The figure below compares background grids obtained using the conventional and the new methods, in the symmetry plane of a Space Transportation System configuration. In the new method the grid spacing is controlled by specification of five source nodes on the body and four at the corners of the outer computational boundaries, while the conventional method required constructing 48 triangles and specifying grid control parameters at each of the nodes.



STRUCTURED BACKGROUND GRID - AN EXAMPLE

The use of structured background grid not only simplifies the preparation of the background grid information, but the quality of the final grid is significantly improved. The improved grid quality is illustrated in the following figure on a NACA 0012 airfoil. The top two frames depict partial views of the conventional triangular (left) and the new structured Cartesian (right) background grids are shown. The conventional background grid has 22 cells and 16 nodes. The structured grid is a 21 X 21 grid. The structured grid has 16 source elements for grid spacing control, 8 of which located near the airfoil are shown in the picture.

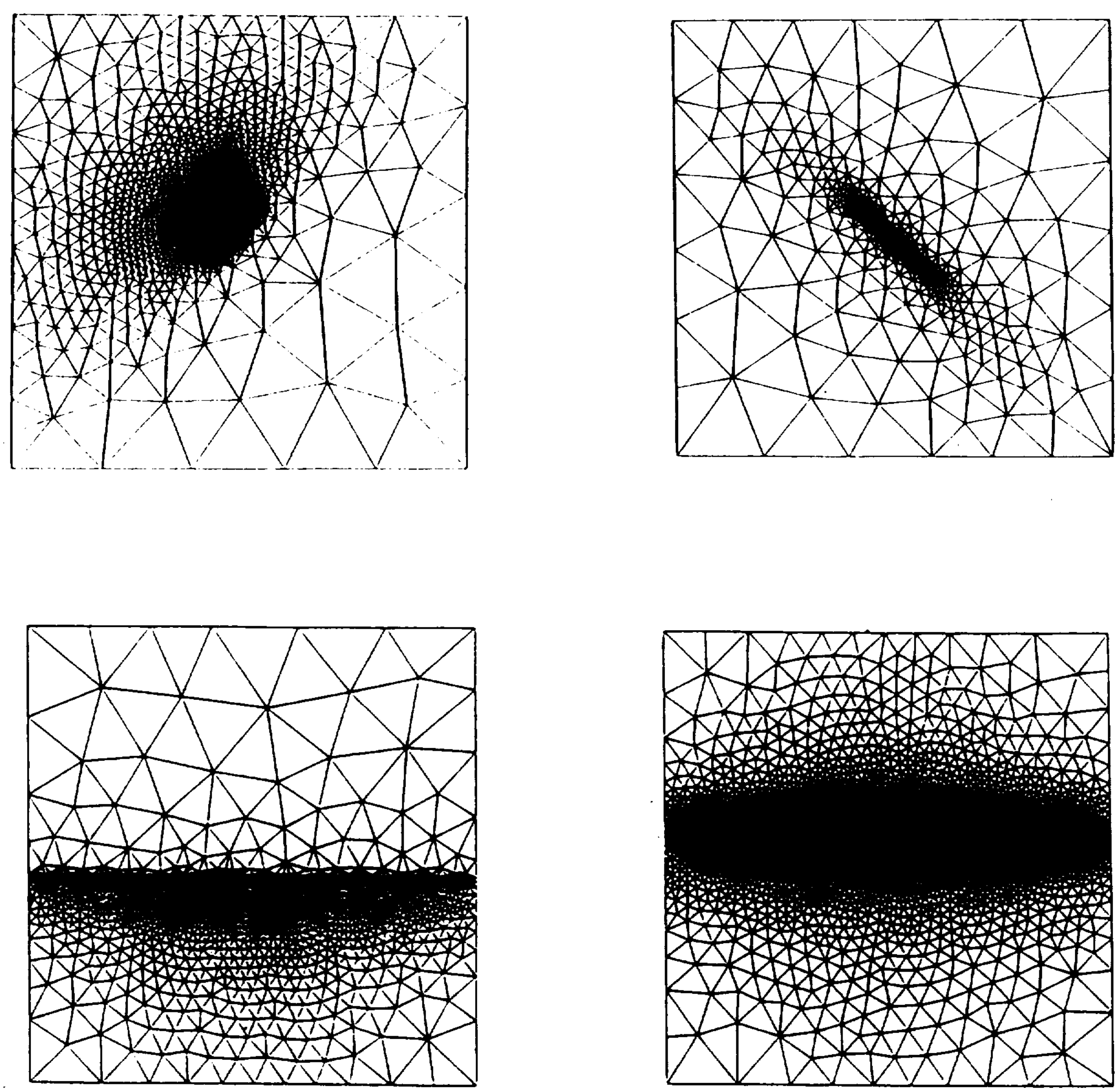
The corresponding field grids are shown in the bottom two pictures. These near field views clearly reveal the differences in grid quality near the airfoil. The conventionally generated grid lacks the desired smoothness in distribution, whereas the one generated with the new method exhibits an orderly progression of contours resembling concentric 'isotherms' around the airfoil.



DIRECTIONAL CONTROL USING STRUCTURED BACKGROUND GRID

In addition to symmetrical propagation of spacing parameter, the new method is capable of controlling the directional intensity of the sources. This is done by limiting the source intensities to certain zones and directions.

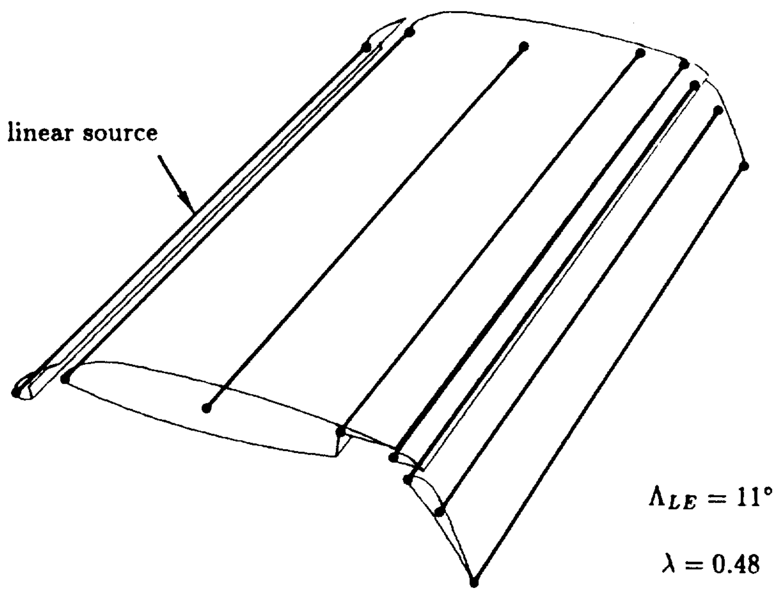
The figure below shows sample grids generated with various directional controls applied. The top two pictures show control exercised by controlling nodal sources, while the bottom two pictures show grids obtained by controlling propagation of linear sources.

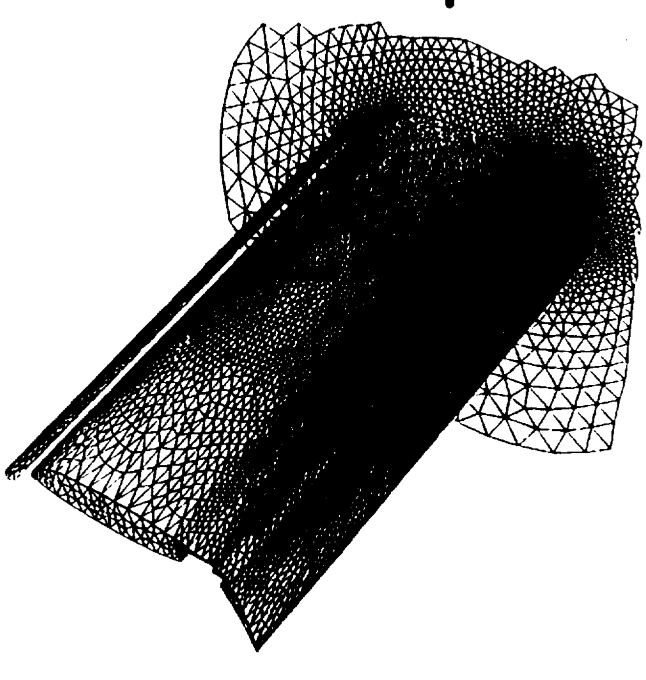


STRUCTURED BACKGROUND GRID IN 3-D

The technique of structured background grid has been recently extended to three dimensions (Ref.4). The figure below shows a multi-element wing with a leading edge sweep of 11 degrees and a taper ratio of 0.48. A 21 X 16 X 10 Cartesian background grid for this configuration includes 8 linear source elements on the wing section (top picture) and 8 nodal elements on the corners of the outer computational boundaries. All source elements have directional intensities for better control of grid point clustering. The resulting surface triangulation on the wing is shown in the bottom picture.

The smooth distribution of grid element size variation and the intended clustering of grid points along the leading and trailing edges is evident. Experience has shown that a reproduction of a grid with this quality using the conventional background grid would require many tetrahedral cells and require a substantial amount of users' time.





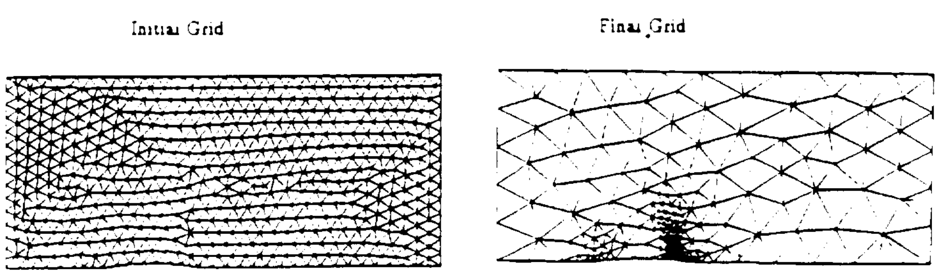
ADAPTIVE REMESHING PROCEDURE

Adaptation of the mesh to the dominant features of the flow offers the possibility of enhancing the solution quality while retaining control over the total number of grid points. Work is in progress in coupling **VGRID3D** to an efficient inviscid flow solver (Ref. 5), **USM3D**, in such a manner that the information produced by one is successively used by the other to allow the grid to adapt.

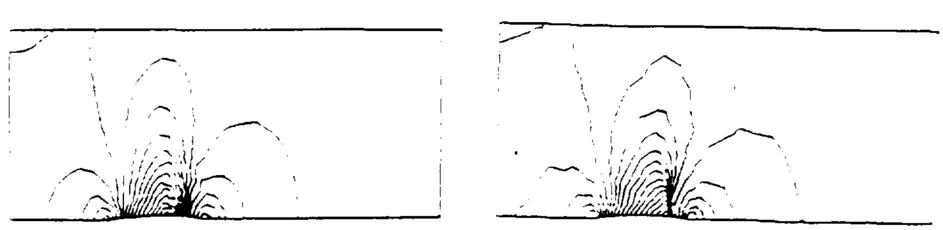
As mentioned earlier, in the Advancing Front Method the grid element size is determined by a user specified 'spacing parameter' on each node of a conventional secondary grid termed 'background' grid. In the adaptive procedure described here, the spacing parameter is calculated, instead, based on the local flow gradients. The steps involved for the adaptive remeshing procedure are (Ref. 6):

1) Obtain initial solution on a coarse grid.
2) Calculate the 'spacing parameter' at the nodes of the current grid, using the current solution as an error indicator.
3) Generate a new grid using current field grid as the background grid.
4) Obtain a new solution.
5) Repeat steps 1-4 until desired accuracy is obtained.

The adaptation procedure is demonstrated in the following figure on a circular arc bump in a channel at a $M_\infty = 0.85$. The top portion of the figure compares the initial and the final grids, while the bottom portion compares the C_p contours. A total of four remeshing cycles were applied. Clustering of grid points in the region of large flow gradients and coarsening of the grid in the smoother regions of the flowfield is evident in the adapted grid.



a) Side Wall

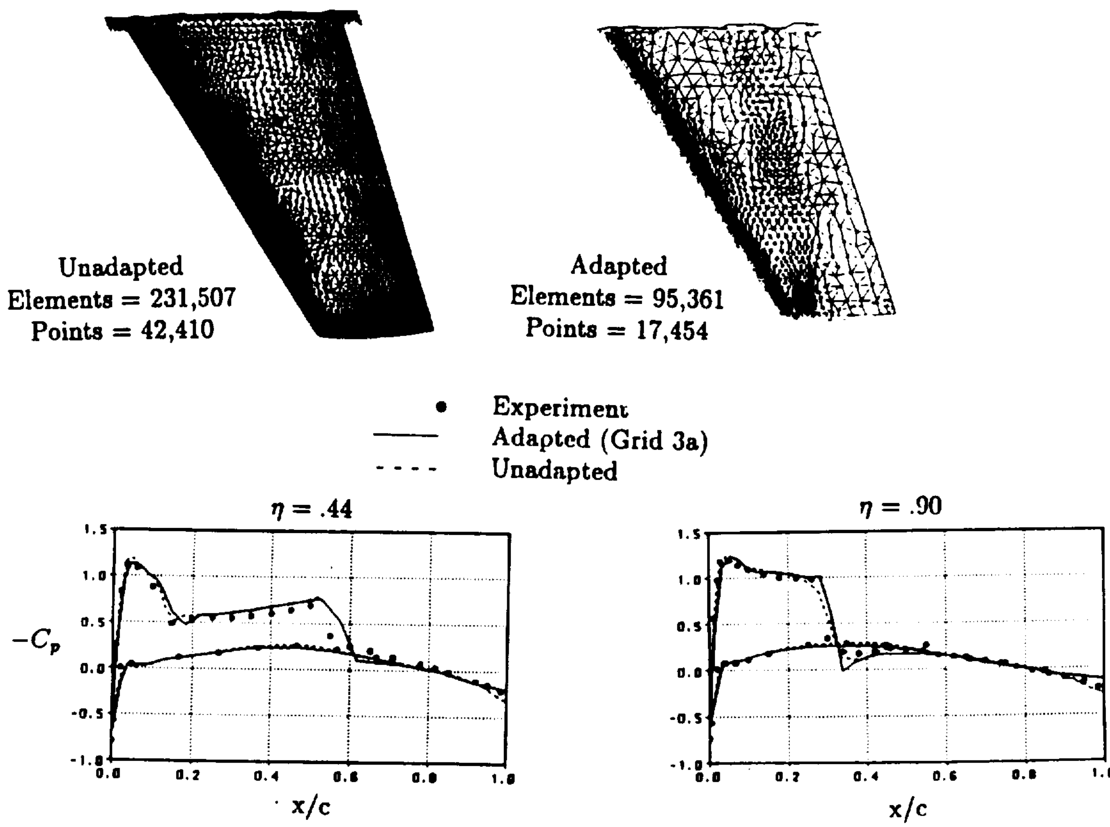


b) Pressure Contours

ADAPTIVE REMESHING ON ONERA M6 WING

To demonstrate a more complex example, flow over an ONERA M6 wing at a $M_\infty = 0.84$ and $\alpha = 3.06°$ is considered. The procedure was initiated with a coarse, almost uniform grid made up of 52,567 tetrahedral elements and 9,646 points. Three remeshing cycles were performed resulting in a grid with 95,361 elements and 17,454 points. The efficiency of the adaptive procedure is shown in the figure by comparing the results after the third remeshing cycle with an unadapted flow solution. The unadapted grid has 231,507 tetrahedral elements and 42,410 points. The top portion of the figure shows the upper surface triangulation for both the grids while in the bottom portion, the computed C_p distributions at two spanwise locations are compared with the experimental data. The adapted solution is in very good agreement with the unadapted one which has about 2.5 times the number of elements. Additional work is underway to quantify the efficiency of the procedure in terms of run times and solution quality.

Comparison Between Unadapted and Adapted Grids
ONERA M6 Wing, $M_\infty = 0.84, \alpha = 3.04°$



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