APPLICATION OF CHIMERA COMPOSITE GRID SCHEME TO SHIP APPENDAGES

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SUMMARY

Modern computer hardware and software have made it possible to use computational fluid dynamics to determine the flow field around a bare hull ship. However, typical grid generation techniques and flow solution codes do not lend themselves well to applications involving hull appendages. A considerable amount of time and effort is required to model appended hull forms, and changes in appendage shape and/or configuration often require entirely new grids.

The chimera scheme of grid generation uses a system of relatively simple grids. The grids each define a particular component of the overall geometry, making the initial grid generation much simpler. The individual grids overlap and, once combined, cover the entire computational domain. Changes in geometry or configuration force modifications to one or a small number of individual grids, leaving the other individual grids untouched. For fully appended ships, these features allow computational grids to be generated quickly and easily.

1. INTRODUCTION

The predictions of detailed flow field around ship appendages and the associated hydrodynamics forces and moments are always challenging to marine designers. Through the rapid development of numerical capability of computational fluid dynamics (CFD) and computer hardware technology, comprehensive flow field computation around a bare ship hull has just now been considered feasible. Recently, the accuracy of computed results has been improved significantly. In addition, computational efficiency has been substantially enhanced through rapid development of effective geometry modeling/grid generation and advanced numerical algorithms of CFD technology.

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14. ABSTRACT
Modern computer hardware and software have made it possible to use computational fluid dynamics to determine the flow field around a bare hull ship. However, typical grid generation techniques and flow solution codes do not lend themselves well to applications involving hull appendages. A considerable amount of time and effort is required to model appended hull forms, and changes in appendage shape and/or configuration often require entirely new grids. The chimera scheme of grid generation uses a system of relatively simple grids. The grids each define a particular component of the overall geometry, making the initial grid generation much simpler. The individual grids overlap and, once combined, cover the entire computational domain. Changes in geometry or configuration force modifications to one or a small number of individual grids, leaving the other individual grids untouched. For fully appended ships, these features allow computational grids to be generated quickly and easily.

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However, it is important for a marine designer that an effective analysis tool is available to evaluate the flow field around an appended ship and the forces acting on a ship's hull and appendages. As an appendage is added to a bare hull, the effort of computational work is substantially increased. Two factors responsible for this increased effort are difficult surface geometry modeling at the hull/appendage intersection and cumbersome generation of a smooth, continuous, structured computational grid. These problems typically lead to considerably more work and time for a bare hull/appendage configuration than for a bare hull. This paper describes an effective method, the chimera composite grid scheme, to overcome these obstacles.

The chimera scheme allows for a system of relatively simple grids, each conforming to a single component of a complex surface, to be combined into a composite grid. A complex surface is surrounded using a collection of grids each of which resolves some segment of the flow, while the composite of all the grids covers the entire domain. The grids overlap each other in an unstructured fashion. Flow information is transmitted from one grid to another by means of the common, overlapping volume. The software codes necessary for implementing a chimera scheme for marine vessels have been integrated and implemented at the David Taylor Model Basin (DTMB).

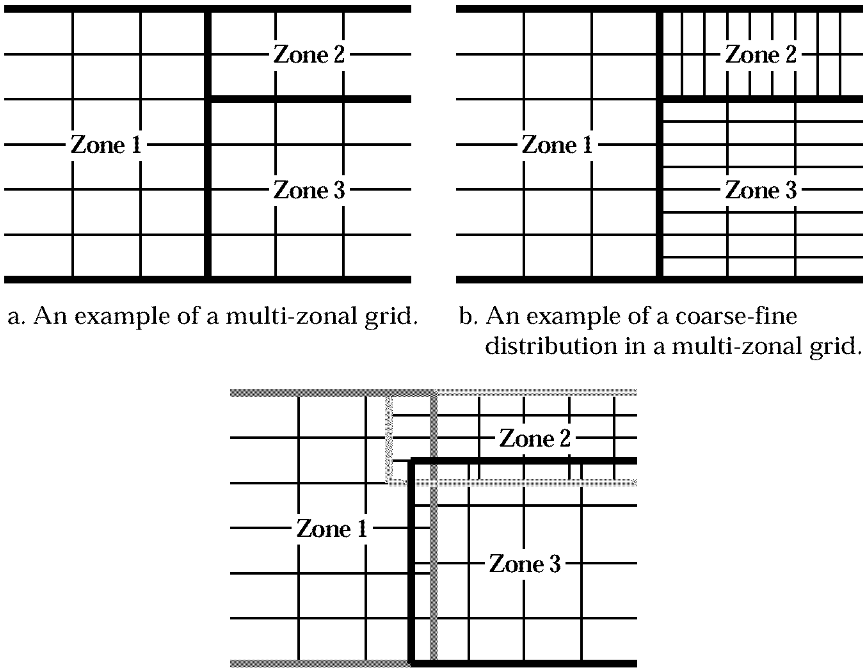
2. CHIMERA GRID GENERATION

2.1 Method

In multi-zonal grid generation, a single, continuous grid is formed by a combination of smaller grids, called blocks or zones. The zones abut each other, sharing common boundaries. Each of the grid points on these common boundaries typically coincide. (See Figure 1a.) To make a multi-zonal grid requires a great deal of planning and effort in order to ensure a smooth, cohesive grid. A change in the geometry of one zone can force the change of many zones throughout the grid. Similarly, a change in grid point distribution, such as adding additional points to increase resolution over an appendage, can require distribution changes over many zones in order to maintain the common, coincident boundaries. A more detailed description of multi-zonal grid generation techniques can be found in Lin, *et al.* [1].

These restrictions combine to increase the amount of effort and time involved in grid generation. In addition, the coincident, common boundaries increase the number of points in the grid. One method of increasing the number of grid points in one zone without adding unnecessary points elsewhere, is to use a coarse-fine distribution. (See Figure 1b.) Typically, every second or third point in one zone is coincident with each successive point in the bordering zones. This approach requires the use of interpolation routines to transmit data between the zones in the flow solver.

The chimera approach allows zones to overlap, commonly referred to as oversetting grids. (See Figure 1c.) Again, interpolation routines are used to transmit data between the overset grids in the flow solver. However, interpolation is not as simple as averaging points, as in the coarse-fine distribution. An extra step is added to the process in which stencils, instructions for the interpolation routines, are generated for the points which are overset. These instructions indicate the location of an point relative to the surrounding



a. An example of a multi-zonal grid.

b. An example of a coarse-fine distribution in a multi-zonal grid.

c. An example of a chimera grid.

Figure 1. Different grid distribution approaches.

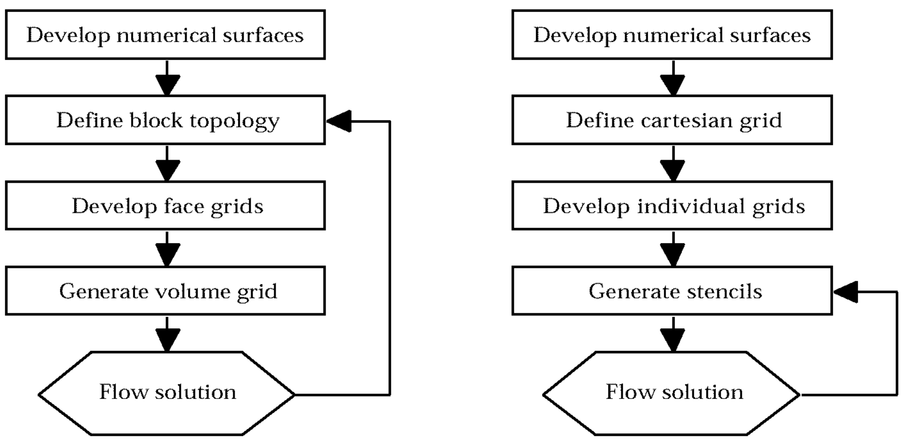
points on the overset grid. While the entire flow field must still be covered by grid points, it does not need to be covered by a single, cohesive grid. This method allows a great deal of flexibility in grid generation. A detailed description of chimera grid generation techniques can be found in Steger [2].

2.2 Advantages

The most important advantage of using the chimera scheme of oversetting grids is to reduce substantially the time and effort to generate a grid. This is especially true for three-dimensional configurations with increasing geometric complexity, such as a fully appended ship. The time and effort required to plan and generate complicated grids using solely multi-zonal grid generation techniques quickly becomes prohibitive.

In addition to time and effort, the number of points in a grid can become large in exclusively multi-zonal grids. The restriction of common, coincident boundaries often leads to unnecessary points away from areas of interest or complexity. Large grid sizes increase memory and disk space requirements, and can greatly increase the computation time required to reach a solution. As the number of appendages and the complexity of the geometry increases, the number of points, and the number of unnecessary points, grows rapidly.

Ship geometry almost always involves several appendages, from fixed appendages such as struts for propulsion shaft or bilge keels, to moveable appendages and control surfaces, such as rudders or roll stabilizers. To generate a proper computational grid around a fully appended ship geometry has been a tedious and cumbersome task using multi-zonal grid techniques. In the case of moveable appendages, a multi-zonal grid restricts the analysis by defining a set orientation with respect to the hull. Even with very careful planning while establishing the grid block topology, a significant portion of computational grid usually has to be redone. Sometimes, it is necessary to redo the entire grid. An brief overview of the analysis process for examining multiple appendage positions is shown in Figure 2. Figure 2a shows the typical process when using pure multi-zonal grid generation, while Figure 2b shows the typical process using only the chimera technique.



a. Multi-zonal grid generation method. b. Chimera grid generation method.

Figure 2. Overview of the analysis process for examining multiple appendage positions .

By using the chimera approach in conjunction with multi-zonal techniques, the task of generating a grid for a fully appended ship becomes considerably more feasible. Component grids for individual various appendages can be independently generated, while a main computational grid is developed around the ship bare hull. Then, appendage component grids can be overset to the ship hull main grid with different relative setting angles. No extra grid generation is needed for various setting angles of appendages on the hull, although new stencils must be generated. Fortunately, generating new stencils generally requires no more effort than re-running a computer program.

The chimera scheme does not require overset grid boundaries to join regularly. The composite of all overset grids must simply cover the entire computational domain. A coarse, cartesian background grid can be used that extends to the flow field outer bounds. Finer grids are generated in the areas of interest that may require better resolution, such as appendages. For simplicity, portions of an overset grid are allowed to overlap other grids freely, and may even fall interior to a solid body. These portions of grids are considered hole points, and are excluded from the flow calculation when the stencils are created.

All of these freedoms greatly reduce the time required to plan and generate a grid. In addition, the number of points is reduced since no more points are required just to maintain coincident boundaries. Furthermore, grid points are much more easily placed where they are needed without undue grid distortion. The quality of computational grids generated when using chimera techniques is therefore better.

In practice, single-zone chimera grids are rarely used. The individual grids used to create the chimera composite grid can be either single block grids or multi-zonal grids. The key to using the approach is to identify geometry for which boundaries or grid spacing requirements warrant an overset grid, while multi-zonal grids are used where the grid transitions smoothly from zone to zone. The goal is a smooth, useable grid generated with a minimum of time and effort. As such, forsakeing multi-zonal grids for purely chimera grids clearly would be counter-productive.

2.3 Disadvantages of the chimera approach

Drawbacks to using overset grids include having to interpolate data points along an irregular boundary. In addition, the bookkeeping can be especially complex if more than two grids overlap each other. Software is needed to interconnect the overset grids, create proper hole regions, define interface and hole boundaries, and determine the interpolation stencils for properly transmitting information between overset grids. Various algorithms have been devised for performing these tasks automatically.

The software *PEGSUS* [3] successfully performs these tasks with a minimum of interaction. The effective data structure and grid imbedding hierarchy in *PEGSUS* [4] facilitates generating final composite grids and necessary interface boundary data. Preparation of input data for *PEGSUS* is quite simple and straightforward. In use, the search mechanism has been highly reliable and quite effective. Sometimes, however, orphan points, points for which no interpolation stencils can be found, occur. Modification of the input parameters for the hole creation scheme in the *PEGSUS* input file is then necessary. There are several such schemes in *PEGSUS*.

Since the interpolation algorithm used in *PEGSUS* is a trilinear interpolation scheme, conservation at boundary interface is quite difficult to enforce. Possible enhancements involve the use of special interpolation schemes that maintain conservation. However, verification of this idea in practical use has proved difficult, since variations due to numerical dissipation and differing grid spacing at an interface tend to be larger than any variation attributed to loss of conservation. By the same token, the variation are not of major concern.

Oversetting grids does not eliminate the planning stage in grid generation. Care must be taken to ensure that the grid distributions of the common, overlapping volume in overset grids are not drastically different. Radical differences can lead to orphan points and poor interpolation results. Poor interpolation can in turn lead to increased computational time, due to poor solution convergence.

It should be pointed out that the use of the PEGSUS software is not a drawback, it is simply a step in the process. The drawbacks are the extra bookeeping, the interpolation difficulties, and the extra step of accounting for orphan points.

3. FLOW SOLVER

Once the proper interconnectivity of the composite overset grids has been established, it is relatively easy, although time-consuming, to adapt a flow code written for a multi-zonal grid for use with a chimera grid. Flags are used to indicate hole points to the solver. All these hole regions have been defined and flags generated using *PEGSUS*. The flow code has to be modified to read these hole flags and boundary data from the stencils. The flag array is simply a boolean array (on or off, 1 or 0), so it is not necessary to provide branching logic to avoid hole points and computer vectorization is not inhibited.

Points at hole boundaries or interface boundaries are updated by interpolating the solution from the overlapping grids which create the hole or overset points. Boundary interface arrays are supplied to store grid interconnect data. These arrays hold flow boundary values for the current grid, which are supplied from the other grids, and are relatively small arrays. The additional computer memory required by chimera approach is therefore not significant. However, detailed bookkeeping efforts are needed to modify a flow code to adopt the chimera oversetting scheme.

For the computational results shown in this paper, the software *OVERFLOW* Navier-Stokes code [5] was used. The code *OVERFLOW* was developed at NASA Ames Research Center as a general purpose flow solver. It has a built-in option for using chimera grids. A system which consists of solid wall surface definition, multiple zone grid generation, composite grid generation, flow solver, and various post processors has been established and implemented within the local computer network, connecting PC, Macintosh and IRIS workstations at DTMB. All computations were performed on the local IRIS workstations. A case study to demonstrate the computational process is discussed in the following section.

4. CASE STUDY

A typical submarine sail/sail plane configuration was selected as a test case, as shown in Figure 3. The sail geometry consists of a foil section with a flat cap. The sail is attached to a flat plate for this demonstration, not a body-of-revolution. The sail plane is a swept-back, tapered foil section which serves as a movable control surface. Viscous flow computation on various angles of attack for the sail plane with respect to the sail were performed and the results are discussed.

4.1 Solid Wall Surface Definition

The first step was the creation of the solid wall geometry, or database. We modeled the sail and sail planes of a submarine, ignoring the fillet at the bottom of the sail so it would rest on a flat plate. Splitting the sail along the plane of symmetry, only the half-body was modeled. The sail plane was modeled separately and extrapolated to extend inside the sail (to the plane of symmetry). Both the sail and sail plane have flat caps on their tips. Since this sail/sail plane configuration is a simple shape when generated in two pieces, it was easy to establish the database. A more complex shape such as a ship bow and stern would require more effort for creating a detailed database [6].

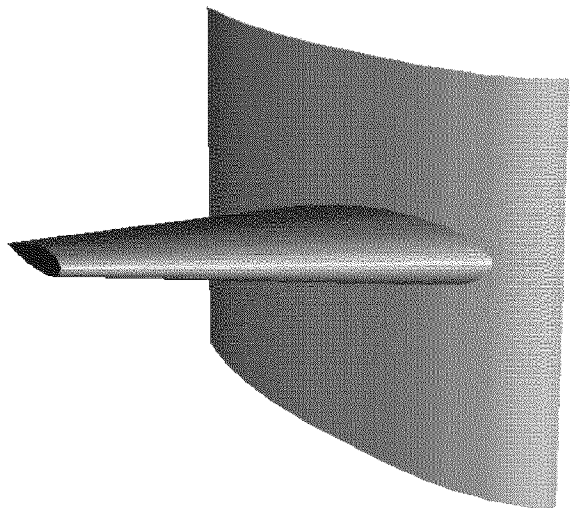


Figure 3. A typical submarine sail/sail plane

configuration.

4.2 Multi-Zonal Grid Generation

Multi-zonal computational grids conforming to the sail and sail plane database were generated using *GRIDGEN* [7]. The sail grid was generated without regard for the presence of the sail plane database or grid, and vice versa. The sail grid consisted of a zone outboard, a zone above and outboard, a zone above the cap, and a wake zone. (See Figure 4.) These zones conformed to the sail surface, the sail cap, the flat plate it rested on, the plane of symmetry and extended to the outer boundaries. The outer bounds were set at 3.5 sail chord lengths forward and to the side; 7.5 chord lengths behind; and 3.5 sail heights upwards. The sail plane grid consisted of a zone wrapping around the wing, a zone extending from the tip, and a zone wrapping around the tip zone. These grids conformed to the sail plane surface and extend a fraction of its root chord to the front, side, behind and out from the tip. The sail and sail plane grids were C-grids (the front of a C-grid is shaped like the letter "C", hence the name).

In retrospect, the sail grid should not have been used to cover the entire flow field. This is best accomplished using a cartesian grid, as mentioned earlier. Attempting to use a single grid to define the volume around a database and to cover the flow field produces a grid which does neither extremely well. Doing so introduces some of the very problems that the chimera approach attempts to avoid.

4.3 Composite Grid Generation

PEGSUS was the software used to reconcile these two overlapping sets of grids into one composite grid. Since the sail grids extend throughout the sail plane grids and inside the sail plane database, a boundary is established such that any point inside is flagged as a hole point, and is ignored by the flow solver. Several

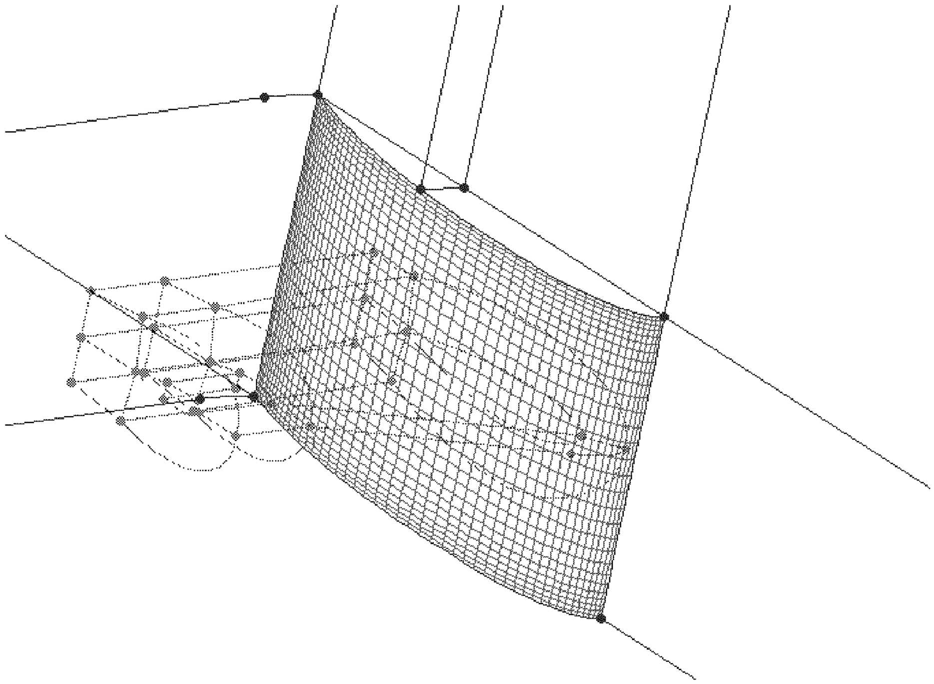
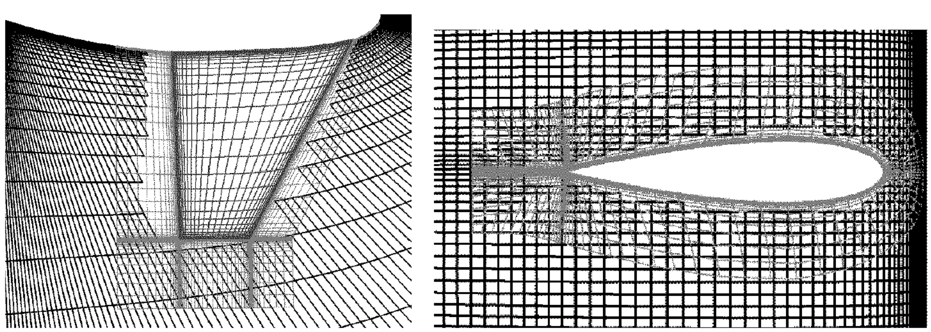


Figure 4. Grid zones comprising the sail and sail plane.

methods can be used to define this boundary, since the boundary represents the extent of interpolation and not a physical wall. In this case, we used a constant j-surface close to, but not on the sail plane database, where the j-direction is normal to the database surface. Figure 5 shows different views the hole created in the sail grid. The amount of overlap is user-specified in the *PEGSUS* input, in this case by declaring the index of the constant j-surface in the sail plane grid.

Adequate overlapping volume facilitates the search for interpolation stencils and proper transmission of flow information between overset grids. Relative grid distribution in the common volume must also be considered.

To generate computational grids for different angles of attack for the sail plane, no additional grid generation was necessary. The *PEGSUS* input was changed, and *PEGSUS* rotated the sail plane grid and recalculated the hole



a. Plan view. b.Profile view.

Figure 5. Hole created in the sail grid at 0° angle of attack.

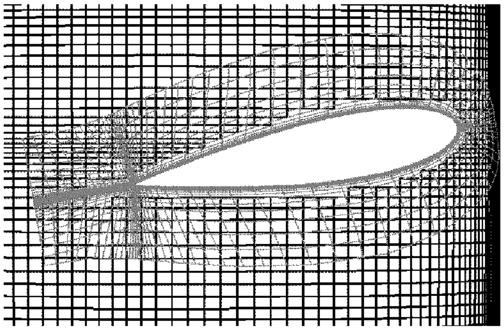


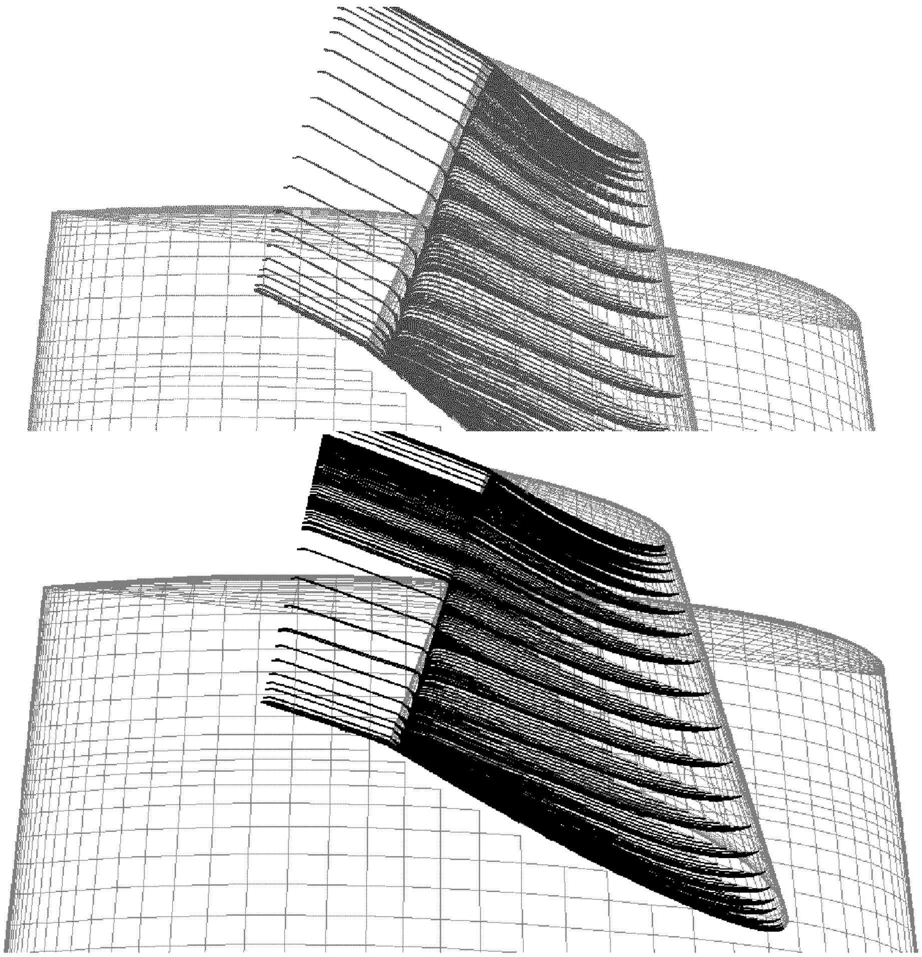
Figure 6. Profile view of hole created in the sail grid at +10° angle of attack.

points and boundary interpolation stencils. Figure 6 shows the sail plane at a 10° angle of attack. Seven composite grids were created in all, representing seven angles of attack for the sail plane, in ten-degree increments from -30 to +30 degrees relative to horizontal.

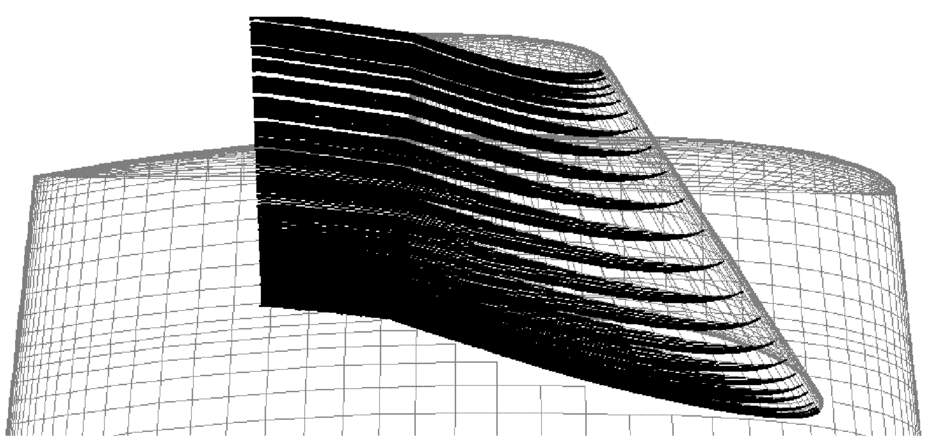
4.4 Viscous Flow Solution

Viscous flow computations were performed on each of these seven composite grids by using the *OVERFLOW* Navier-Stokes code. Although the number of time steps required for steady-state solution increased as the angle of attack increased, the numerical convergence was reasonably good and similar for each grid. Oil flow particle trace patterns on the suction side of the sail plane are shown in Figure 7 for six angles of attack. The horizontal case (0 degrees angle of attack) is unremarkable and is therefore not shown. Flow separation is indicated where the traces run together and merge into a line perpendicular to the flow.

For +10 degrees angles of attack, flow is attached everywhere except for a small portion at the trailing edge near the tip. A clear separation line in the root and tip region near the trailing edge is observed for ±20 degrees angle of attack . As the angle of attack is increased to ±30 degrees, a complete separation line is found across the span. These results seem quite reasonable.



b. Sail plane at -20°.



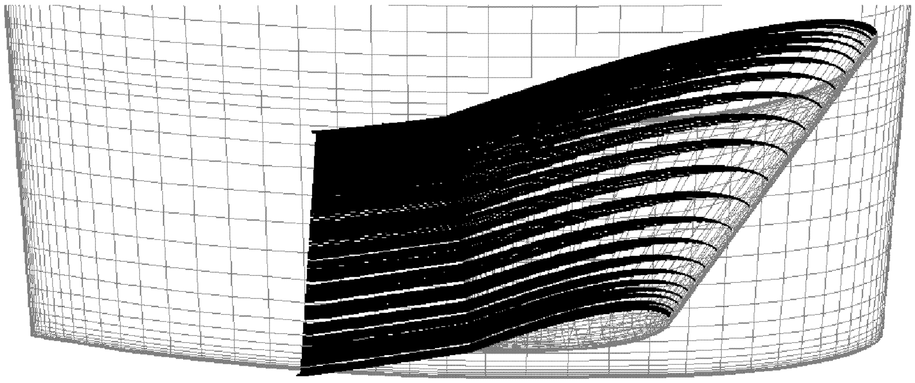
c. Sail plane at -10°.

Figure 7. (continued.)

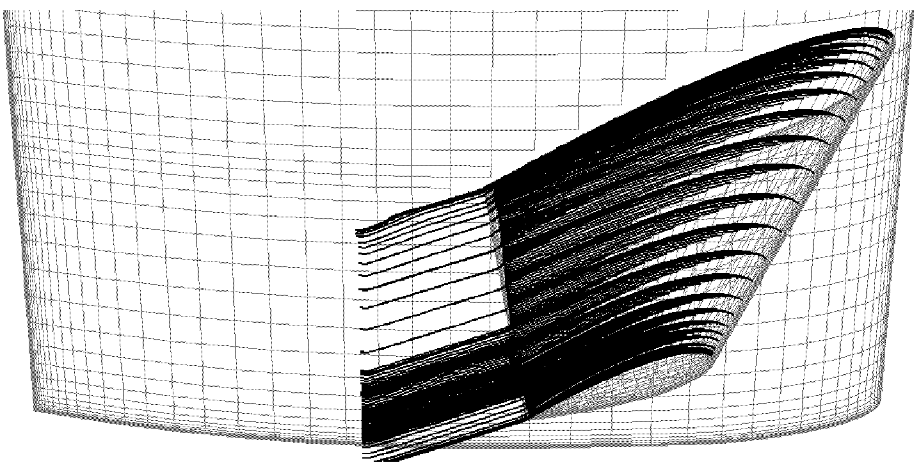
5. CONCLUSIONS

The chimera grid generation scheme can be used to predict a detailed flow field around fully appended ships. It uses a system of relatively simple grids, each of which define a particular component of the overall geometry. The individual grids overlap in an unstructured fashion and must combine to cover the entire computational domain. Changes in geometry or configuration dictate modifications to one or two individual grids, leaving the other grids untouched. These features allow computational grids to be generated quickly and easily for fully appended ships.

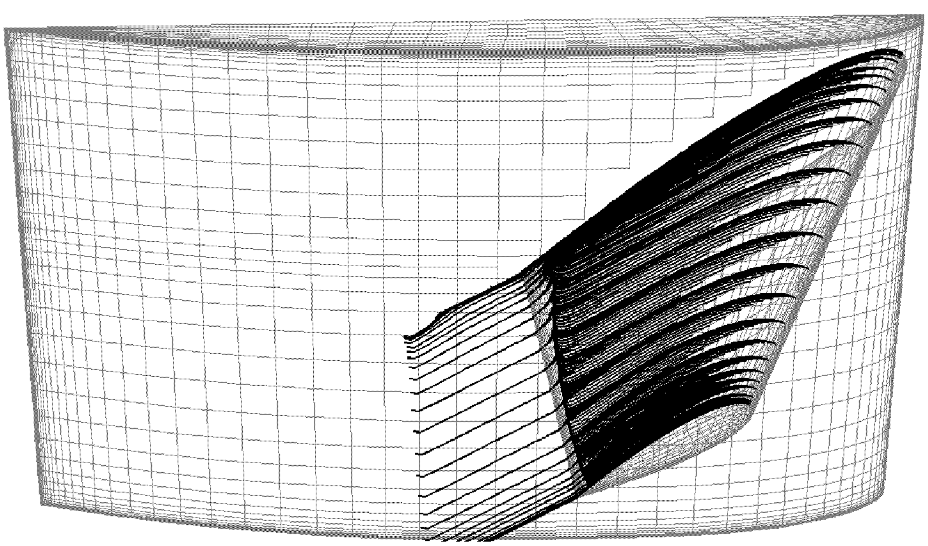
A case study is presented, analyzing the viscous flow around a submarine sail with a movable sail plane. Grid generation was simplified by using the chimera approach. No additional grid generation was needed for different angles of attack.



d. Sail plane at +10°.



e. Sail plane at +20°.



f. Sail plane at +30°.

Figure 7. (continued.)

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