Automatic Generation of a Panel-Based Representation of Ship Hulls for Wave Resistance Calculations

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Abstract

Wave resistance calculations are performed using a panel based description of the hull form. Because at present a fully automatic generation of such panel representations is not possible the panel generation takes up a considerable part of the time needed for a potential flow calculation. In this paper two algorithms are presented with the objective to facilitate the fully automatic panel mesh generation. An emphasis is placed on the stability of the algorithm and the applicability to all ship forms. Special consideration is given to the regularity of the panel mesh as required for CFD calculations.

Keywords

ship wave resistance calculation, automatic panel mesh generation, CFD

Introduction

In commercial shipbuilding an emphasis is placed in the initial design stage on precise and rapid predictions of the capabilities of the vessel leading to an increasing use of advanced computing techniques. These are utilized in iterative optimization processes to check, improve and compare multiple design alternatives.

In the field of fluid dynamics increasing ship speeds place an emphasis on the reduction of wave resistance. Codes based on potential flow theory are used to estimate and analyze the flow around the ship's hull as well as to determine the wave-induced resistance by calculating the strength of a source distribution on the hull and water surface.

The distribution of panels on the hull has a significant impact on the accuracy of the wave resistance prediction. Currently creating the panels on the hull surface is a labor intensive non or semi automatic task requiring a profound experience based knowledge. On average generating the panel meshes takes up about 30 to 90 % of the total time needed for wave resistance calculations. An overview over the steps performed for a CFD calculation is shown in figure 1.

To achieve a significant improvement in cost and workflow the main objective of the research presented is the development of fully automatic or at least semi automatic mesh generation tools with an automatic quality controlled panel placement. In this paper two algorithms are presented.

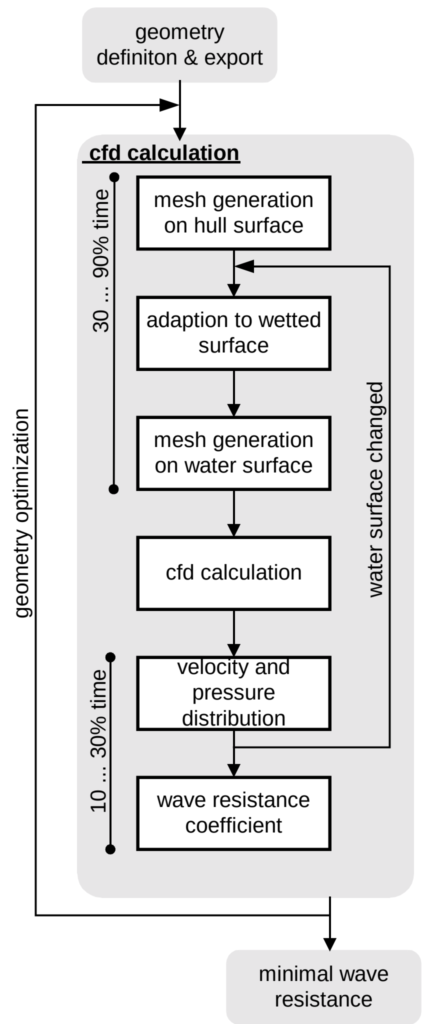

Fig. 1: The process of CFD calculations

In both algorithms panels are created so that boundaries as well as knuckles in the hull surface are treated correctly. Controls offer easy to use options for global and local mesh modifications. Shape optimization of generated panels and rational placement of new panels guarantee a high quality mesh.

As reference ship and for testing purposes the well known US Navy Combatant DTMB 5415 (url: Gothenburg) from the David-Taylor-Model-Basin and a twin-screw RoPAX vessel is used. The naval vessel was chosen because of a very prominent bulbous bow design, rapid changes of surface curvature in the bilge area and the presence of knuckles in the aft section. The RoPAX represents state of the art commercial ship design.

Requirements

Classification of Meshes

For potential flow calculations the meshes used can be classified in two categories, namely structured meshes and unstructured meshes, see figure 2.

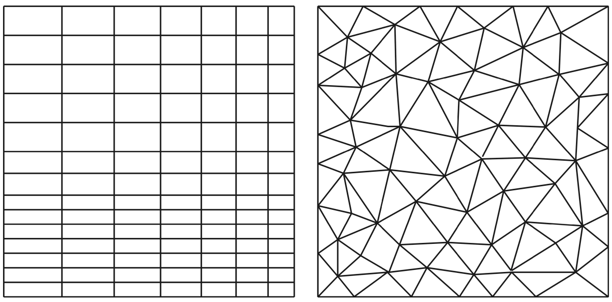

Fig. 2 Structured quadrangular mesh and unstructured triangular mesh (Zimmermann, 2003)

Today, structured meshes are used by many potential flow codes like shallo (url: HSVA) or kelvin (url: SVA) and offer efficient storage and management of the mesh structure with a comparatively easy mesh generation process. Applications like the napa npn (url: Napa) module for the generation of these meshes are available on the market. On complex surfaces high quality meshes can only be generated with block structured meshes which requires user interaction for the definition of the block boundaries.

Unstructured meshes are commonly used e. g. in finite element analysis and for visualization. With the use of triangular panels it is possible to adapt the panel distribution to local surface features permitting the meshing of complex surfaces without the need for a subdivision in multiple blocks. This allows for a fully automatic mesh generation process. There is considerable knowledge regarding the use of unstructured meshes in the fields of visualization, geographic information systems and finite element analysis. Experience with the application of unstructured triangular meshes for potential flow calculations is limited.

Geometrical Requirements on Meshes

The quality of wave resistance calculations is dependent on the accuracy of the potential flow solver used as well as on the quality of the mesh representing the hull form. Experience has shown that regular and uniform meshes yield more accurate calculation results.

Amongst other issues for a uniform high quality mesh it is essential that there are no gaps between or overlaps of adjacent panels. In regions with a rapid change of curvature as seen e.g. in the bow or stern regions panels of reduced size have to be used. If knuckles are present the characteristics of this form feature must be reproduced by an appropriate placement of the panels. It has to be guaranteed that the panels do not overlap the knuckle line.

For quadrangular meshes a ratio of the panel side lengths < 1:4 should not be exceeded. The area ratio of neighboring elements should be < 1:2 with a small angle between the normal vectors.

For triangular meshes all triangles should be close to equilateral with the direction of the surface normal for neighbor panels not differing significantly.

Data Import

As a platform and system independent standardized import format for the description of the hull surface the IGES standard is used. Most state of the art ship design software used in the shipbuilding industry is capable of exporting the surface description to this format using a surface patch based description (Knieling, 2002).

Currently, for import surface definitions of Type 128 (NURBS) are processed; further support of other surface definition types defined in the IGES standard as well as support of STEP AP 216 might be added in the future.

The number of NURBS patches used for the definition of a hull surface varies from only 3 patches for DTMB 5415 to up to several hundred for other models leading to the requirement of a flexible and adaptive internal surface representation. Tests with several models have shown that the topological integrity of the hull surface description can not be guaranteed, see figure 3; the algorithms developed must be capable of handling overlaps of or gaps between surface patches either using surface repair functions or intrinsically.

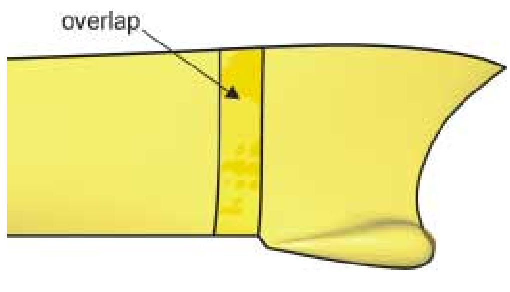

Fig. 3 Overlaps in the description of DTMB 5415

Internal Surface Representation

The calculation of intersections of the hull surface with arbitrary straight lines or planes is performed with algorithms that are based on a local iterative breakdown of the NURBS patch into triangles. For the algorithms presented an approximative internal representation of the NURBS patches by triangular meshes is therefore realised so that all following geometric operations are performed efficiently on the triangular mesh and not on the NURBS patches directly.

An accurate approximation of the hull surface is important for the generation of a high quality mesh. Therefore the initial mesh is generated using a structured approach. Quadrilateral elements are created with a given edge length. These elements are subdivided into two triangles.

A modified butterfly subdivision method is used for further refinement of the mesh (Cheng, 2002). Criteria for refinement are the area of the element and the distance between the midpoint of the element edges to the NURBS patches. In figure 4 examples of the initial meshing are shown. It can be seen that in regions of high curvature like the sonar dome or at the bilge smaller triangles are created. In these regions distorted elements may occur. For intersection calculations the shape of individual triangles is of no importance.

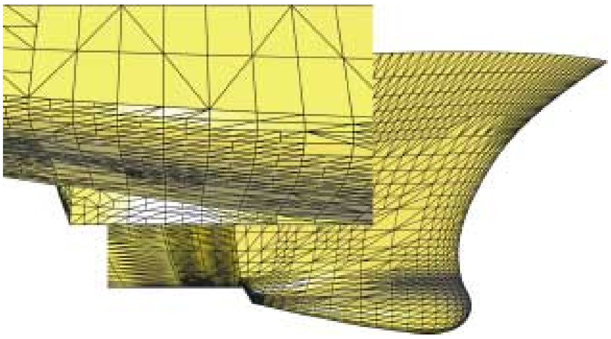

Fig. 4: Initial Meshing

Structured Mesh Generation

Multi-Block Meshes

Using a structured mesh generation technique a homogeneous element distribution on a complex surface without many distorted elements can only be achieved using a multi-block mesh based approach. Therefore a subdivision of the ship hull into separate regions, so-called blocks, is required.

In principle it is possible to subdivide the hull surface into separate regions automatically based on the surface curvature. Due to the large variety of possible surface shapes the subdivision is currently performed manually; intersection planes are placed by the user. As an example figure 5 shows the result of a block definition.

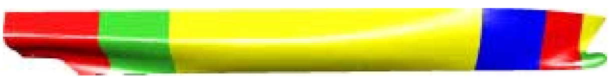

Fig. 5: Subdivision of the ship hull into regions

Knuckles

In order to accurately approximate the ship hull form with a panel mesh knuckles in the hull surface must be treated correctly, i. e. all edges of panels adjacent to a knuckle must be placed directly on the knuckle line. This can either be achieved by adapting of an existing mesh to the knuckles or by splitting the domain to be meshed using the knuckles as boundaries of the individual blocks.

Knuckles may occur either inside a NURBS patch by multiple definition of the same parameters or between adjacent NURBS patches. For the identification of the second class of knuckles the surface normals along the common boundary of adjacent NURBS patches are compared. This requires correct information about the topology, i. e. about the location of each NURBS patch in relation to the other surface patches. A complete and fault tolerant analysis of the topology is difficult to achieve if overlaps and gaps in the surface are taken into account. Therefore at the current state of development a group of particular NURBS patches without any knuckles has to be selected by the user and is meshed as described in the next section.

Meshing of a Single Region

The meshing of a user defined surface region without knuckles inside is done fully automatically; no user interaction is required. An overview of the mesh generation algorithm is shown in figure 6.

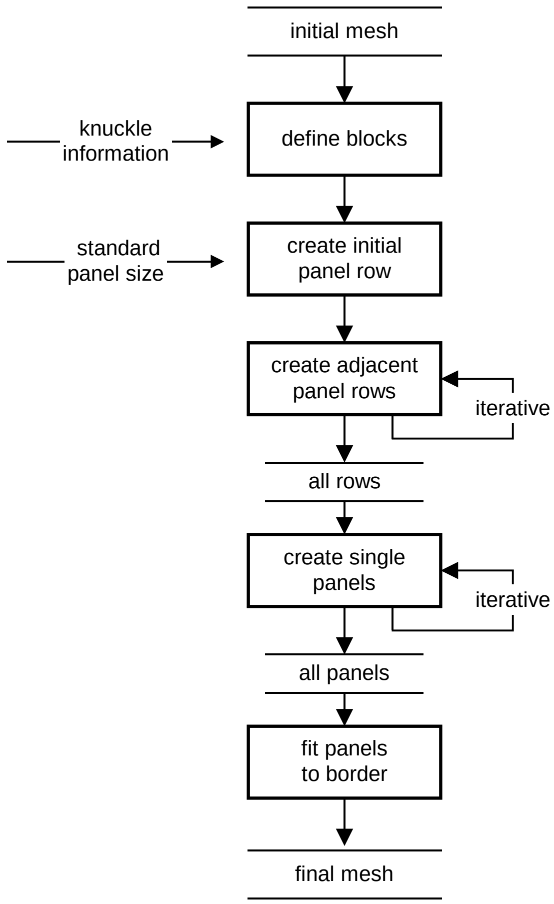

Fig. 6: Outline of Structured Mesh Generation

As mentioned above a high quality mesh possesses a high uniformity and a homogeneous element distribution. The high uniformity can be achieved by orienting the panels according to a global coordinate system. For this purpose a Cartesian coordinate system is chosen where the x-axis runs in the longitudinal ship direction. Depending on the position of an element relative to the hull surface one or more edges will be aligned with the global coordinate system. For the definition of individual element shapes and sizes values in these three directions can be given.

In contrast to the advancing front algorithm (Owen, 1998) the mesh generation presented here is based on an algorithm in which new panels are added to free edges of an existing element. The mesh is growing outwards hereby avoiding the problematic placement of the final elements needed in the advancing front algorithm to close the region. Therefore one or more panels are required at startup. Instead of a single panel it is advisable to use a complete row of elements at startup as experience has shown that this leads to a more uniform and homogeneous mesh. Subsequently further panels are added iteratively to the initial row of elements until the region to be meshed is completely covered with elements.

A new panel is connected to the existing mesh in two steps. For each endpoint of an existing edge the respective points of the new panel are determined. Consistency of the mesh is ensured by giving unique two dimensional coordinates to each corner points so that duplicate points can be avoided. In figure 7 the use of these two dimensional coordinates is explained graphically.

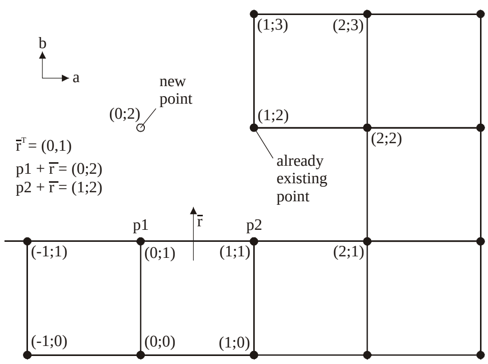

Fig. 7: Connecting of new Points to the existing mesh

A new cornerpoint of an edge or an element is created with the help of an intersection of the hull surface with a plane normal to the edge processed yielding an intersection contour in form of a first order spline curve. The new point is created with a specified distance to the point of origin. This distance depends on the desired panel size and shape.

For highly curved surfaces this approach leads to distorted or twisted elements. For elements where this holds true, i. e. where the length ratio of opposing edges is small, the algorithm replaces quadrangular panels with triangular panels.

In figure 8 the mesh of the sonar dome of the reference ship is shown. It can be seen that in areas of high curvature some panels are collapsed to triangular shape.

The propagation of the mesh, i. e. the creation of further elements, is stopped once the mesh overlaps the specified region completely. In a next step boundary compliance is guaranteed where all border points of the panel mesh are moved to the border of the mesh domain. This results in a uniform and regular mesh with distorted or badly shaped elements only at the boundary of the domain.

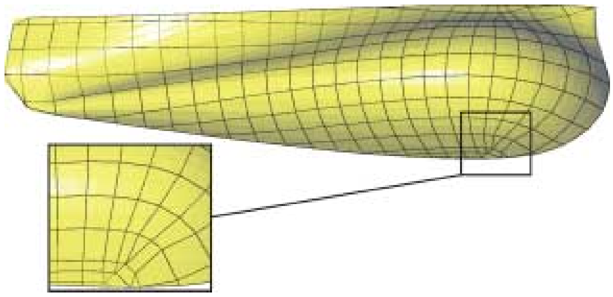

Fig. 8: Inserted triangular panels

Possible solutions for removing distorted panels are:

- removal of the distorted boundary panel and extension of the adjacent non-boundary panel
- extension of the boundary panel combined with a reduction in size of the adjacent panel
- transformation of distorted elements into triangular elements

Currently a complete solution for the treatment of border panels is not achieved. Further optimization of the mesh using a point relocation algorithm is planned. In figure 9 a mesh of the reference ship DTMB 5415 is shown.

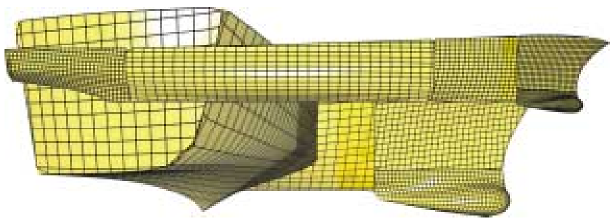

Fig. 9: Example of a fully meshed ship

Results

Using the mesh shown in figure 9 potential flow calculation were performed using the shallo code from HSVA. Compared with the results published by Larsson (2003) it can be seen that the pressure distribution is calculated correctly even with distorted elements present in the region of high surface curvature close to the sonar dome. The velocity distribution is very close to the numerical data available with minor errors close to highly distorted panels. This shows the importance of regularity of the panel mesh.

Unstructured Mesh Generation

In contrast to the structured mesh generation technique described above the second algorithm uses the low quality mesh used as internal surface representation directly and optimizes the mesh iteratively.

A very fine mesh is needed for the internal surface representation to obtain satisfactory optimization results, i. e. an initial mesh consisting of up to 40.000 triangles should be used.

An overview over the mesh generation algorithm is shown in figure 10. Again DTMB 5415 is used as a reference hull form.

A consistent mesh is generated by merging using the internal surface representation presented before. Utilizing the resulting surface mesh the algorithm performs subsequent operations reducing the number of panels until a user controlled mesh structure and panel size is achieved.

Merging

A single consistent mesh on the complete hull surface is obtained by merging the individual triangle surface meshes. Currently cocone, a surface reconstruction algorithm, reads the point set defined by the corner points of the elements on all surface patches (Dey, 2002). Surface reconstruction, i. e. shape, boundary and knuckle reconstruction, is then performed on this point set resulting in one consistent mesh. This method is used because surface reconstruction is a robust fault tolerant method handling overlapping surface patches or gaps between patches gracefully and does not require any further knowledge about the topological relations between the patches.

Experience has shown that this algorithm, albeit working perfectly for some meshes, does not give the results expected for others. Therefore development of a merging algorithm using advanced topology information has started and is currently in the early stages of development.

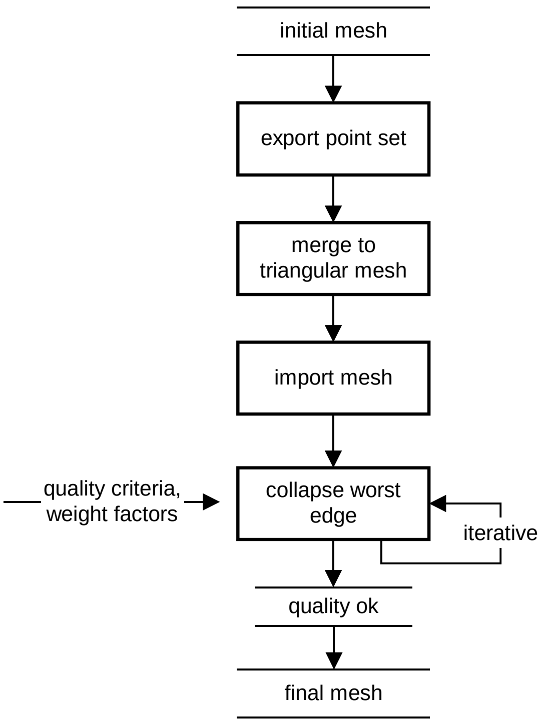

Fig. 10: The Algorithm for Unstructured Mesh Generation

Mesh Coarsening

The final step of the overall algorithm is a successive mesh coarsening operation. Mesh coarsening, i. e. an iterative reduction of the number of panels, is used thereby avoiding or reducing the extensive topological analysis needed for direct mesh generation as well as making the algorithm numerically more robust.

An edge collapse approach collapses an edge to a single point leading to an area of zero for the triangular elements connected and thereby eliminating them (Klein, 1998). The single point is selected so that boundaries and knuckles are preserved.

Edges to collapse are selected by the following geometrical quality criteria:

- All triangular elements should be as equilateral as possible
- The area ratio of neighboring panels should be close to unity
- The area of the panels should be inverse proportional to the curvature of the surface
- A user defined definition of a source-sink distribution allows for local modifications of the element size

Using a weightened approach a quality criterion is calculated for each edge. The quality index q of an edge is calculated from n different criterias as follows:

$$q = \sum_{i=0}^{n} \frac{w_i \cdot q_i}{n} \quad (1)$$

Weigt factors w_i allow for the emphasis of one criterion or the other; q_i is the quality of an edge for a single quality criterion.

Mesh coarsening is stopped when either a given minimum number of elements is reached or the mean or minimum quality criteria reaches a certain level.

Results

Using the geometric properties listed above a homogeneous mesh is obtained. User defined source distributions allow for control of the element distribution and size making work in-extensive adaption of the mesh structure to computational requirements not captured by the geometrical criteria possible. In figure 11 two sample meshes for the test case DTMB 5415 are shown. It can be seen that the complex geometry of the bow section is meshed properly; the knuckles in the aft body are not impaired.

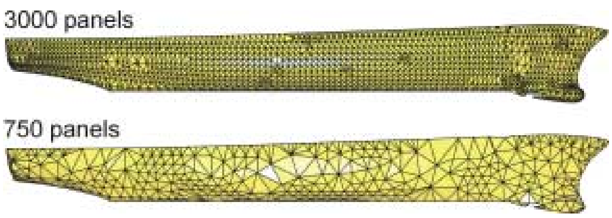

Fig. 11: Coarsed Mesh

Perspectives

In this paper two algorithms for semi or fully automatic mesh generation on arbitrarily shaped surfaces are presented. Albeit still in development these algorithms offer interesting perspectives for the automatization of the mesh generation process that may lead to a significant reduction in the turn around time needed for potential flow calculations. It has been shown that detection of and adherence to knuckles is possible using an unstructured algorithm. Furthermore a reliable and fault tolerant handling of inconsistent NURB surface descriptions is proposed.

For the structured mesh generation algorithm the placement of elements near the borders of user defined regions needs to be worked on; knuckles within individual NURBS patches need to be addressed. Also, investigation in the option to define regions depending on the surface curvature automatically is an issue that will be worked on in the future.

Extensive numerical validations are necessary for the unstructured algorithm to verify that these mesh types are suitable for potential flow calculations. It has to be clarified whether the use of geometrical quality criteria not only leads to suitable panel meshes but also produces accurate resistance predictions.

Further information about the project is available on http://www.schiffbauforschung.de/mesh_generation/.

Acknowledgement

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Links

Napa:
http://www.napa.fi

HSVA:
http://www.hsva.de/services/cfd/wave/index.html

SVA:
http://www.sva-potsdam.de/service/flow/ship_w/main.shtm

Gothenburg 2000 workshop:
http://www.iihr.uiowa.edu/gothenburg2000

University of Rostock, project information:
http://www.schiffbauforschung.de/mesh_generation/