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AUTOMATIC MESH GENERATION FOR NAVAL AND OFFSHORE HYDRODYNAMIC SIMULATIONS

Summary

A very general and robust procedure for hydrodynamic mesh generation of ships and offshore structures is presented. Method is very robust and can deal with most of the usual floating body types. Only the basic information about the structure is needed so that the intervention from users side is reduced to the minimum, which was the main objective. Once the model settled down, any additional change of the mesh is immediate. The developed software is already in use within the Bureau Veritas sea-keeping suite HYDROSTAR, and has brought enormous benefit to the users.

Key words: *hydrodynamic mesh, ship, offshore structure, interpolation, cosine rule*

AUTOMATSKO GENERIRANJE MREŽE OPLAKANE POVRŠINE BRODOVA I PLOVNIH OBJEKATA U HIDRODINAMIČKIM SIMULACIJAMA

Sažetak

U članku je prikazana općenita procedura za stvaranje hidrodinamičke mreže za brodove i plutajuće platforme. Metoda je jako pouzdana i upotrebljiva na skoro svim vrstama plutajućih objekata. Samo minimalne informacije o strukturi su potrebne tako da je intervencija sa strane korisnika svedena na minimum, što je i bio glavni cilj. Nakon što je model definiran, bilo kakvi dodatni zahtjevi za promjenu mreže su trenutni. Razvijeni numerički programi su već u upotrebi unutar numeričkog paketa HYDROSTAR (Bureau Veritas) i pokazali su se izuzetno korisnim.

Ključne riječi: *hidrodinamička mreža, brod, plutajuća platforma, interpolacija, pravilo kosinusa*

1. Introduction

Even if the meshing is not purely computational task, very often it takes the biggest part of the calculation procedure. There is a clear need for automatic and general software able to reduce this “waste of time” to the minimum. Here we present an efficient meshing procedure for ship like bodies and off-shore type structures (semi-submersibles, TLP, ...). The developed numerical codes are completely automatic and very robust. Only the basic information about the structure is needed. Once the model settled down, any additional modification (changing draught, mesh size, main dimensions, trim, heel, ...) is immediate.

Even if the software is mainly devoted to the sea-keeping hydrodynamic simulations based on the so-called Boundary Integral Equation method, the similar procedure can also apply to other numerical methods.

2. General

The main feature of an efficient hydrodynamic mesh generator should be generality and robustness. This means that the intervention from user side should be set to the minimum. The main objective of the present paper is to show that this can be possible using quite simple meshing rules. Since the logics for meshing the ship type bodies and offshore type bodies is quite different, two cases are treated independently, even if some features are common.

2.1. Ship like bodies

The minimum requirement for the ship geometry definition is the sectional offset as shown in Figure 1. By using only these information (plus some minor general data for ship type identification), the mesh generator should be able to produce the mesh shown in a same figure. Even if, at a first look this seems quite impossible in general case, we will show here how this can be done in a quite efficient way.

The overall procedure can be divided into the following five main steps:

1. Identification of the ship type and subdivision into different parts (fore, aft, midship,..)
2. Cutting of all parts at the required draught.
3. Meshing of the main cylindrical (midship) part
4. Meshing of the fore and aft parts (bulbs, skeg, mirror, ...)
5. Special requirements (accounting for trim and heel, interior and exterior free surface meshing, above waterline panels, flattening of the panels, definition of the quadratic patches, ...)

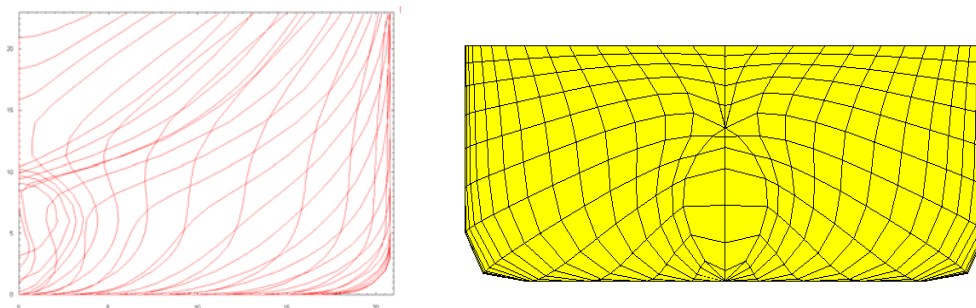


Fig. 1 Body offsets and ship mesh **Slika 1.** Linije broda i hidrodinamička mreža

2.1.1 Midship part

First point is the basic one and serves to clearly separate the different parts of the ship by keeping the same number of panels throughout the whole ship. In order to achieve this, the additional sections are created in fore and aft part (Fig. 2). These two sections define the

limits of the midship part, which is now cut at the required draught (Fig 2). The next step is the fine subdivision of each section according to the modified cosine rule, which we briefly explain below.

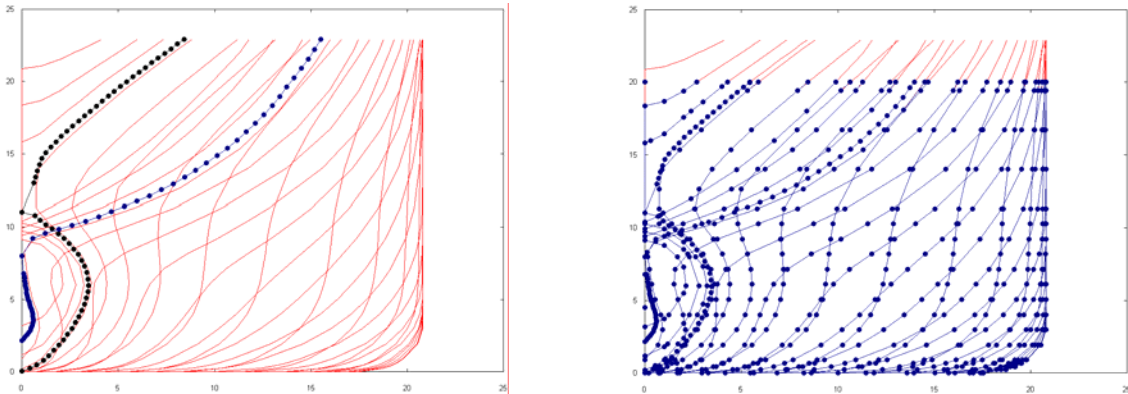


Fig. 2 Creation of the additional sections and cutting at the required draught
Slika 2. Kreiranje dodatnih poprečnih presjeka i vodne linije

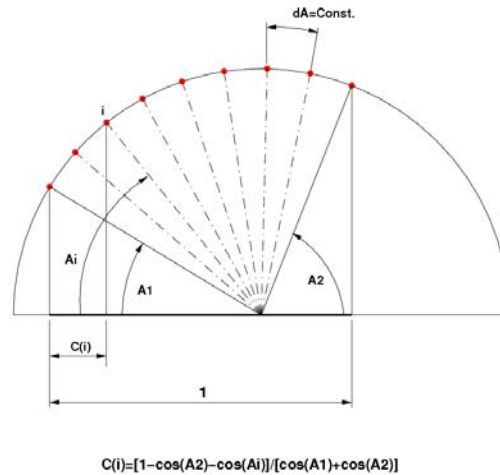


Fig. 3 Refinement principle

Slika 3. Princip usitnjavanja

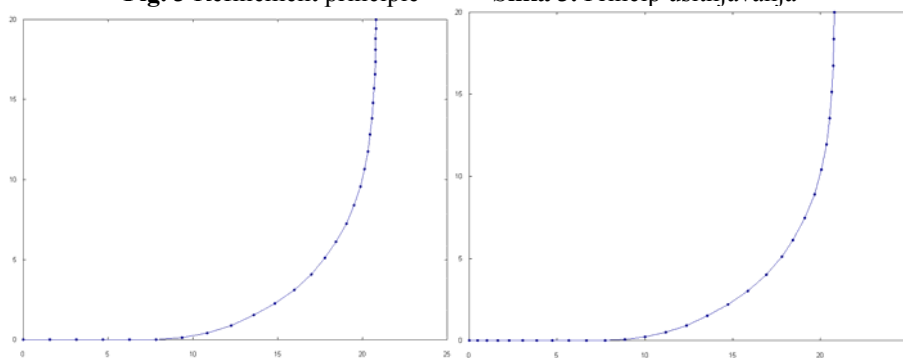


Fig. 4 Examples of section refinement close to the ends **Slika 4.** Primjeri usitnjavanja mreže prema krajevima

As shown in Figure 3., we only need to define two angles (A_1 , A_2) which are used to define the part of the half circle which will be subdivided into the required number of points with equal angular spacing. Projecting these points on the straight line, which gives the mesh more or less refined close to the ends, does the subdivision of the «real» section. Two typical examples are shown in Figure 4. The first one ($A_1=90$, $A_2=15$) gives the mesh finer close to the free surface while the second one ($A_1=15$, $A_2=90$) gives the finer mesh close to the centreline. It is clear that by “playing” with these two angles we can obtain almost any type of refinement (uniform subdivision is obtained with $A_1=90$, $A_2=90$). Note that this option is

very useful in hydrodynamic type of problems where more refined mesh is needed close to the free surface and close to the sharp corners.

Once the original sections subdivided, the midship part is subdivided longitudinally using the equal spacing (Fig. 5), and this represents the final grid of the midship part.

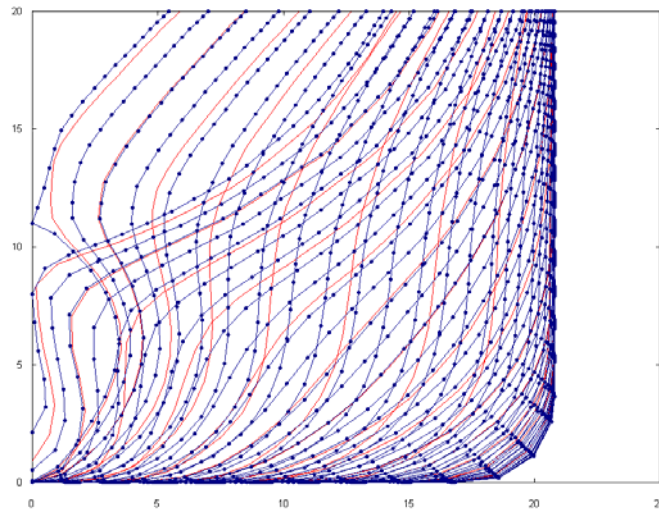


Fig. 5 Refinement and longitudinal subdivision **Slika 5.** Usitnjavanje mreže i uzdužna podjela

2.1.2 Fore and aft parts

As we may expect, in order to get the final mesh uniform, the special treatment is necessary for the fore and aft part. Below, we briefly explain the procedure for the typical bulbous fore part. The main difficulties are associated with the need to keep the mesh uniform and to not have very small panels. The first step is to identify the part belonging to the bulb and the part belonging to the bow stem. The two parts are meshed separately according to slightly different rules. The number and the distribution of the points at each part are done according to the last (first) midship section. Three main steps (identification – sectional refinement – longitudinal subdivision) are shown in Figure 6. Note that this task is far from trivial and several subroutines are needed in order to keep the procedure general for all possible draughts.

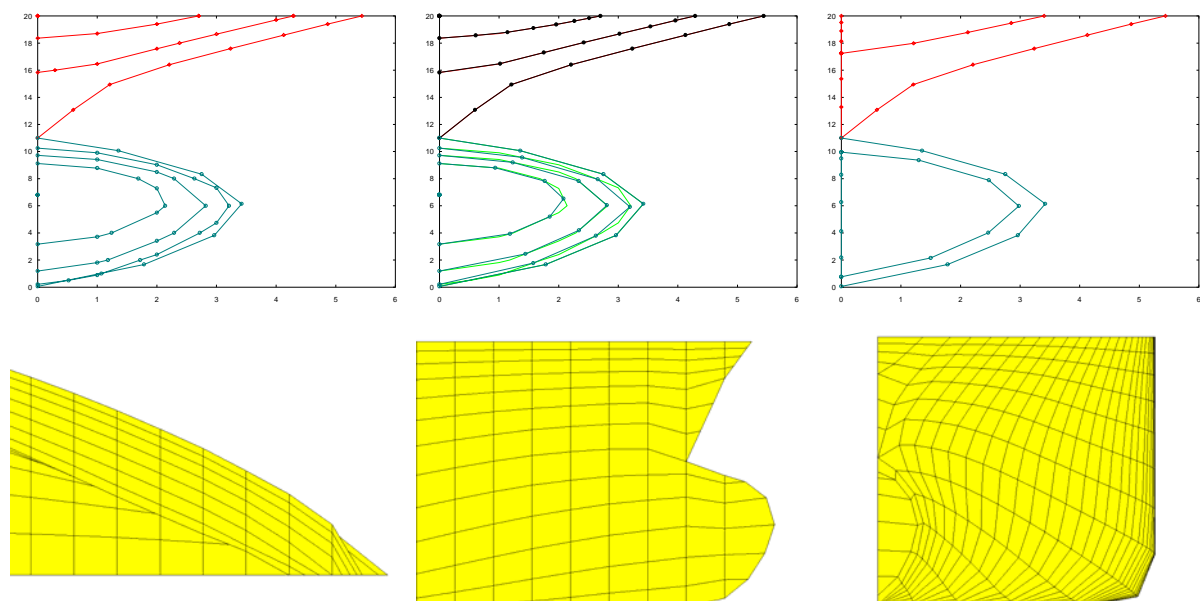


Fig. 6 Main steps and final mesh for the bulbous fore part **Slika 6.** Osnovni koraci i konačna mreža za bulb

Slightly different procedure applied for the aft part with the final result shown in Figure 7.

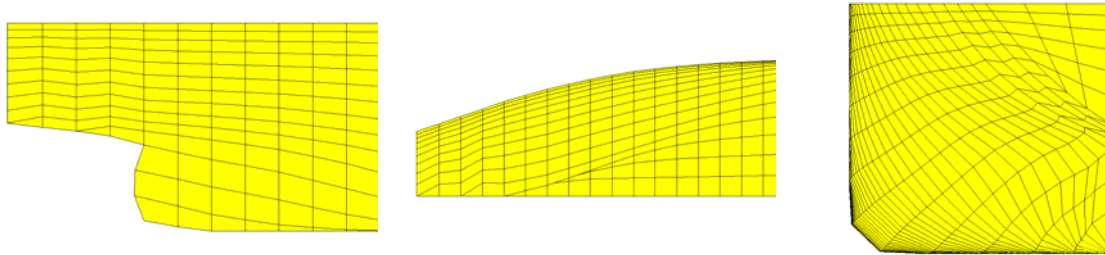


Fig. 7 Typical aft part of the ship

Slika 7. Tipični krmeni dio broda

2.1.3 Meshing of the interior free surface

When using the potential flow sea keeping solvers based on the Kelvin type Green functions, an important numerical problem appears. It is called irregular frequency phenomena and is usually solved by adding the additional unknowns on the interior free surface. It is therefore necessary to have an automatic mesh generator of the interior free surface too. Due to the flexibility of the method we do not necessarily need to match the interior mesh to the ship mesh, which makes the procedure of meshing easier. However, two options were implemented. The typical results are shown in Figure 8.

2.1.4 Meshing of the exterior free surface

For some purposes (visualization, non-linear calculations, linear Rankine type methods, ...) it is necessary to mesh the part of the exterior free surface too. This can be done in two ways: the exterior surface follows the ship shape at the waterline or exterior surface is completely independent and thus can be made regular (except close to the waterline where the matching is required). Two types of meshes are shown in Figure 9.

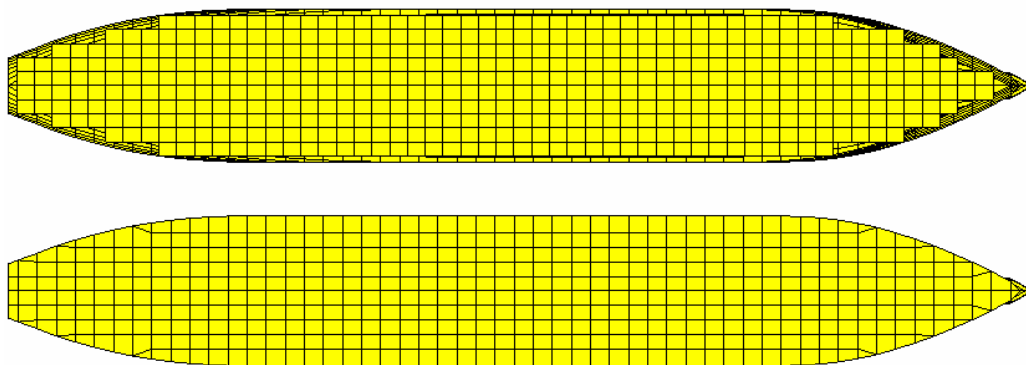


Fig. 8 Two methods for meshing of the interior free surface

Slika 8. Dva postupka generiranja mreže unutarnje slobodne površine

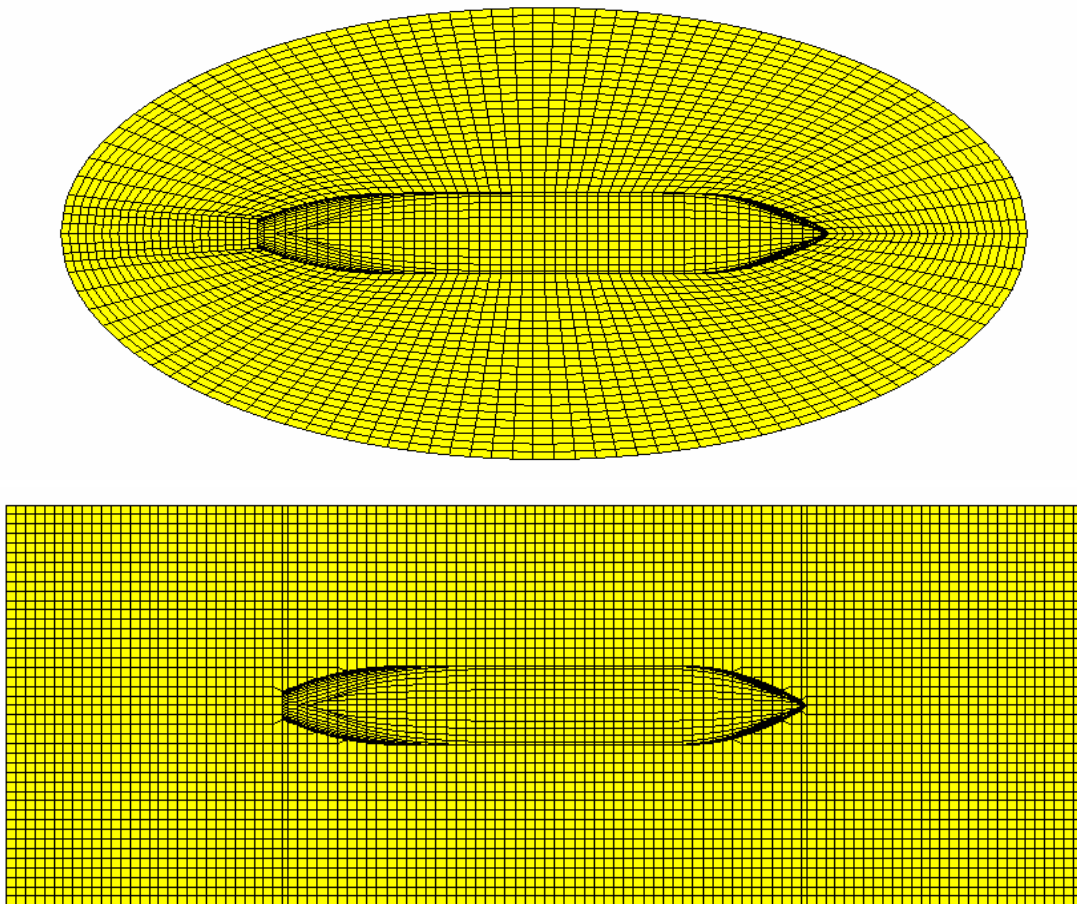


Fig. 9 Two methods for meshing of the exterior free surface
Slika 9. Dva postupka generiranja mreže vanjske slobodne površine

2.1.5 Other ship types

Even if all ships do not look like the previous one, they are in general less complicated, from meshing point of view. However, some cases may be very tricky and we consider here the most typical ones. The first one is the ship with knuckles for which is necessary to follow exactly the knuckle along the ship. The method, which we use, is quite similar to the meshing of the bulbous parts except that is now applied for each section having the knuckle point. One example is shown in Figure 10.

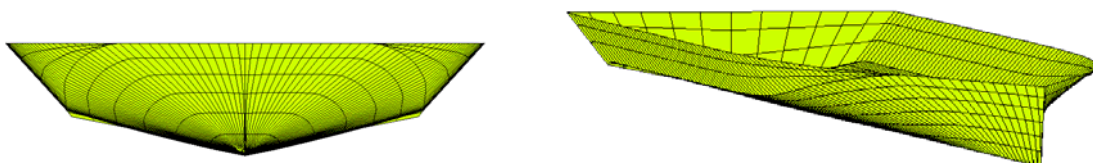


Fig. 10 Meshing of the ship with knuckle
Slika 10. Generiranje mreže izlomljene forme broda

The second interesting case is the ship with skeg. The procedure of meshing in this case consists in meshing the skeg separately, and then attaching it to the main ship part. The typical example is shown in Figure 11.

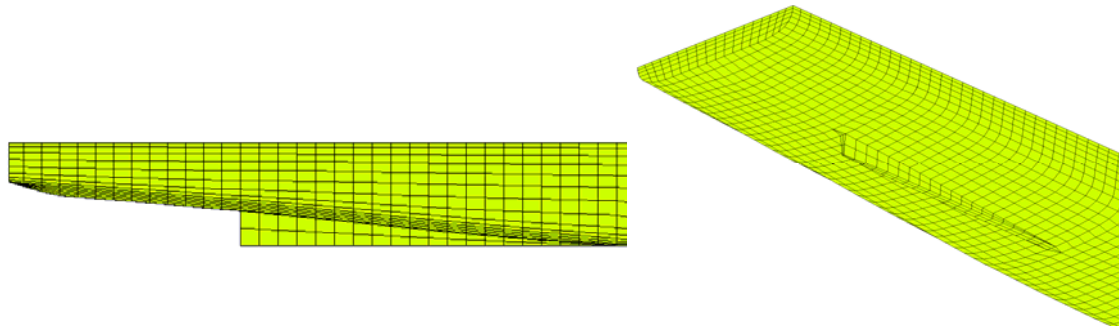


Fig. 11 Meshing of the ship with skeg **Slika 11.** Generiranje mreže broda s izdancima

Sometimes there is also need for modelling of the multihull ships. Within the present approach this can be done quite easily (Fig. 12) since the each hull is treated separately so that we just need to apply the correct offsets to each part.

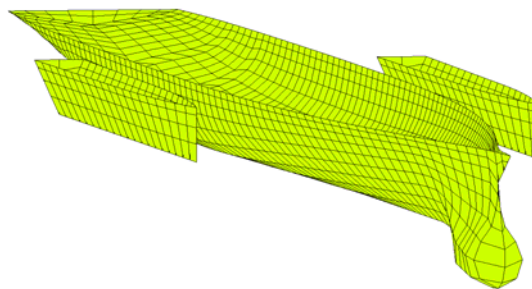


Fig. 12 Meshing of the multihull ship **Slika 12.** Generiranje mreže višetrupnog broda

2.1.6 Some special requirements

For some purposes we also need the meshing of the ship part above the waterline. Indeed, this possibility is of great interest for non-linear hydrodynamic calculations. The method applied here is similar to the case of the ship with knuckle, because the waterline level “plays” the role of the knuckle. One typical result is shown in Figure 13.

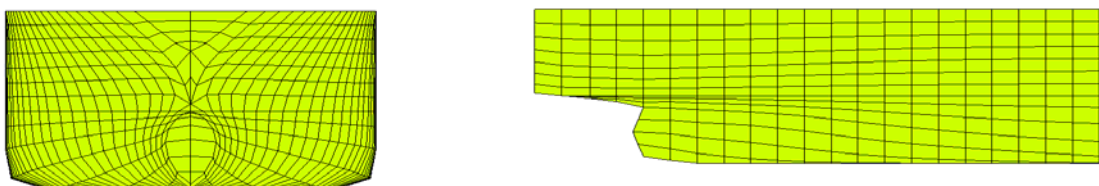


Fig. 13 Meshing of the above waterline ship part **Slika 13.** Generiranje mreže nadvodnog dijela broda

Another requirement of the hydrodynamic codes is related to the flattening of the distorted panels. Indeed, in the cases when the quadrilateral panels become very distorted some numerical problems may appear in the calculations. To avoid this, there is a possibility to subdivide these panels into triangles. The typical example is shown in Figure 14.

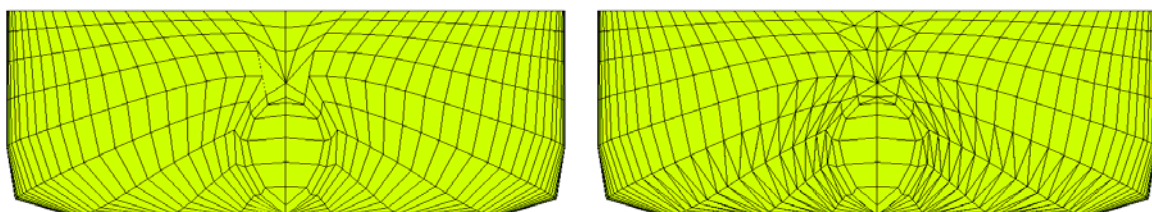


Fig. 14 Ship mesh before and after flattening **Slika 14.** Mreža broda prije i nakon zaravnjenja

The good mesh generator should also be able to treat the ships when they have a trim or heel angles. The present approach is also applied to these situations. Instead of trying to cut the mesh according to the trim and heel angles, the procedure adopted here consist in complete re-meshing of the ship. Indeed, the cutting of the quadrilateral panels may sometimes be quite complicated and also very small panels can appear. The complete re-meshing of the ship appear to be much more efficient especially within the adopted methodology. Few examples are shown in Figures 15 and 16.

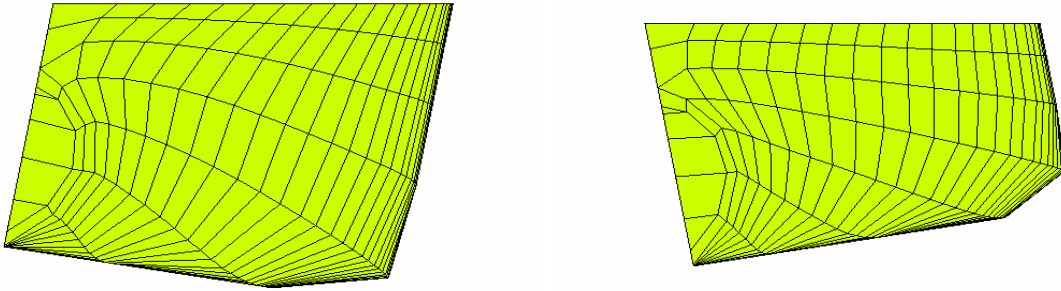


Fig. 15 Ship with positive and negative heel angle **Slika 15.** Brod s pozitivnim i negativnim kutom nagiba

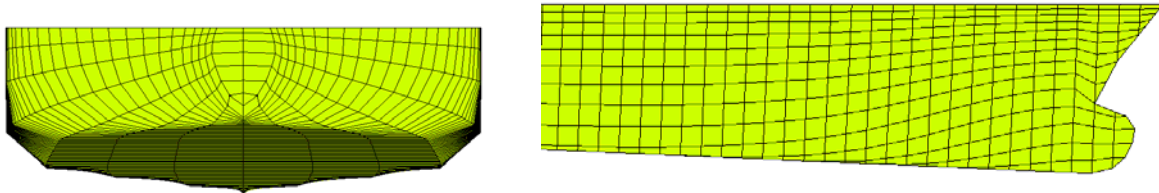


Fig. 16 Ship with positive and negative trim **Slika 16.** Zatežan i pretežan brod

Very often (convergence studies, rapid pre-design calculations, very precise non-linear calculations, ...), there is a need for meshes with different number of panels, going from less than hundred to few thousands. The present software offers this possibility in an extremely robust and efficient way. The “operation” takes only few seconds. In Figure 17 few examples are shown. We can see that the mesh still follows the original body offset but the number of panels dramatically change.

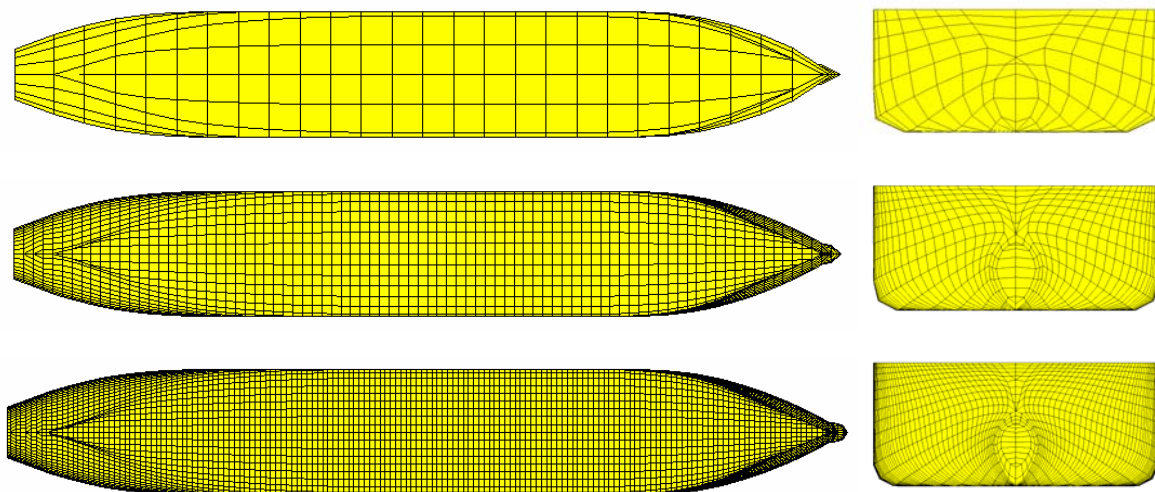


Fig. 17 Overall mesh refinement **Slika 17.** Globalno profinjenje mreže

2.1.7 Quadratic patches

A more advanced hydrodynamic methods use the higher order representation both for the potential distribution and for the surface representation. The main advantage of these methods lies in the fact that we can keep the same accuracy with the reduced number of unknowns. Most often the quadratic patches are employed. These patches are defined (Fig. 18) with 9 points for quadrilateral patches and 6 points for triangular patches.

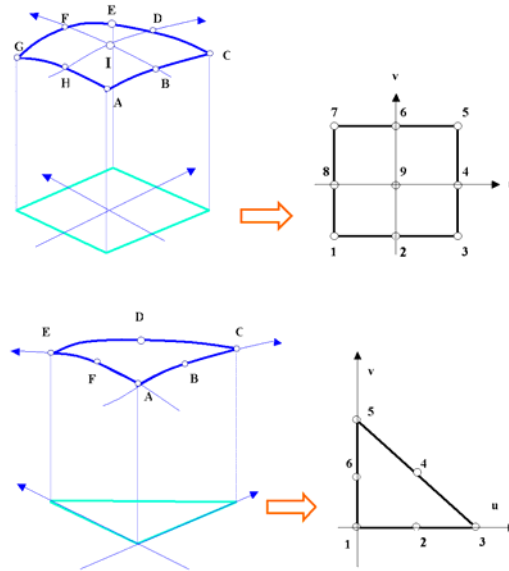


Fig. 18 Quadratic and triangular patch definitions **Slika 18.** Definicija kvadratnih i trokutnih ploha

The simplest method for meshing consists of creating the larger flat panels as before, and then projecting the additional points to the ship surface by the same interpolation technique, using the original body offset data. In this way, nothing really is changed except that we create approximately 4 times more panels.

The second method is to define the local curved-coordinates over the surface of each part of ship hull separated as described above. On each surface, an even number of flat panels in two curved directions are generated. The 9-node patch is defined by a group of 4 (2x2) panels. One result of this meshing procedure is presented in Figure 19. We can see that in this case, the longitudinal subdivision of the ship surface is not necessarily done with constant X values for each section.

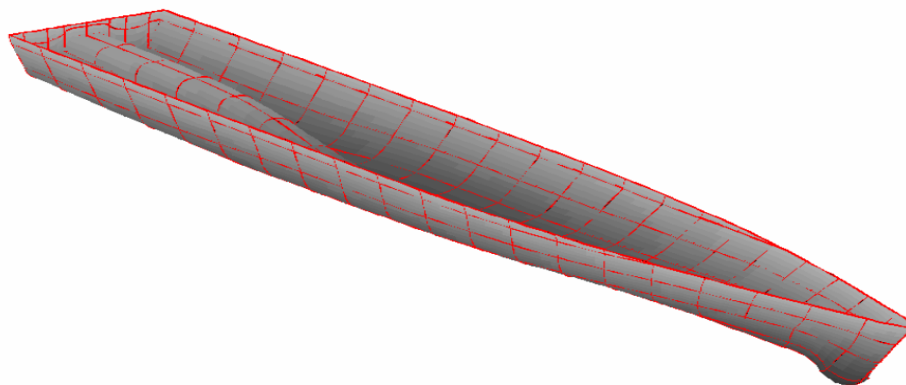


Fig. 19 Ship mesh using the quadratic patches **Slika 19.** Mreža broda sastavljena od kvadratnih ploha

2.2. Off-shore type bodies

Off-shore type structures, such as semi-submersibles, TLP's, ..., usually have more regular shapes but are composed of many different separate parts. We can expect that the meshing procedure will be simpler but this is not necessarily the case especially due to the need for perfect matching between the different parts.

Here we adopt the following quite general procedure, which consists in defining four generic surface types shown in Figure 20. Almost all types of offshore structure can be defined using these four surfaces. The only problem is the connection between the different parts, which should be done carefully. In most of the cases this can be done manually, so that the only information we should give to the program are the coordinates of the nodes and the surface types with the corresponding information shown in Figure 20.

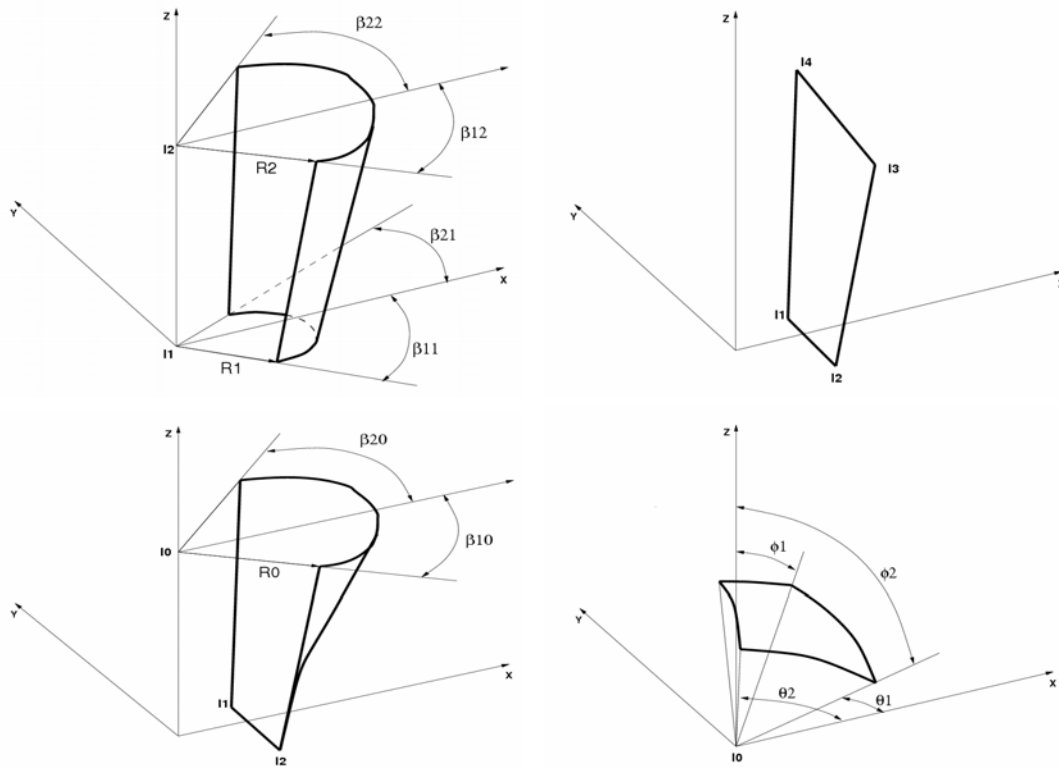
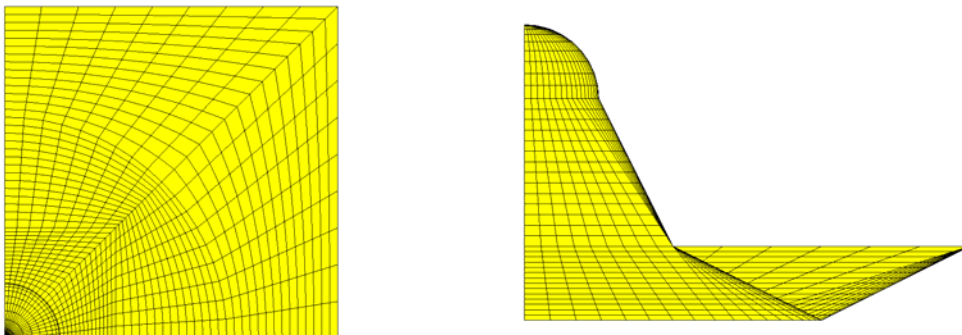


Fig. 20 Four generic surfaces (cylindrical, flat, flat-cylindrical and spherical)

Slika 20. Četiri generičke plohe (cilindrična, ravna, ravno-cilindrična i sferična)

Maybe the most general case of the surface mesh is shown in Figure 21. It is composed of the spherical, cylindrical and flat parts.



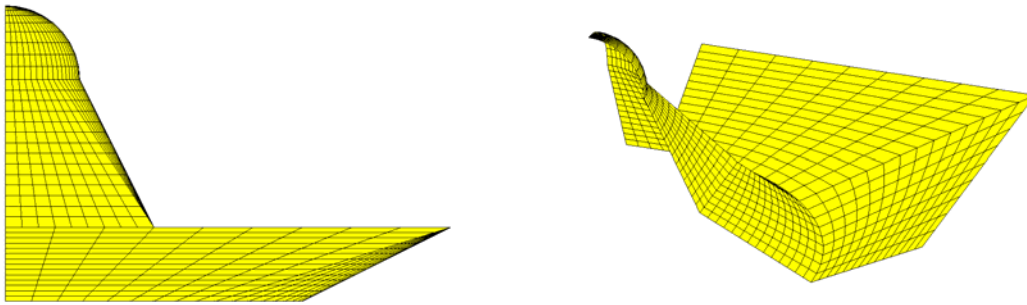


Fig. 21 General geometry meshes

Slika 21. Opće geometrijske mreže

Let also note that an additional flexibility of the method is introduced concerning the modified cosine rule. Indeed here we allow each side of the generic surfaces to be refined according to this modified cosine rule, so that any type of refinements can easily be obtained (Fig. 22).

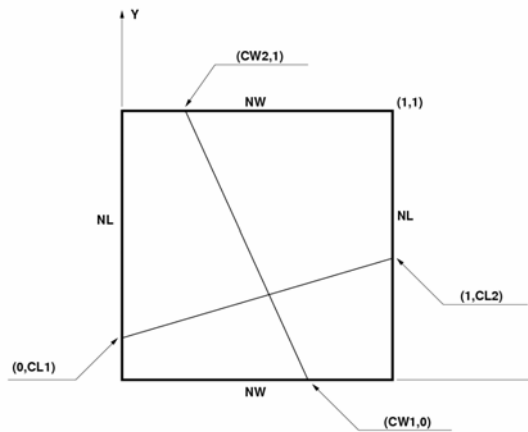


Fig. 22 General modified cosine rule

Slika 22. Opće modificirano kosinus pravilo

With this in mind, we can imagine the meshing of almost any type of the complex structures. Indeed the procedure can easily be made completely parametric, so that any additional change in the definitions (draught, mesh refinement, different dimensions, ...) is done immediately. In Figure 23 we show how this parameterisation can be done for a general Tension Leg Platform (TLP). Only 7 basic information data are needed and mesh is automatically defined. Few final results of the hydrodynamic mesh are shown in figure 24, where only the quarter of the mesh is presented due to the double symmetry of TLP.

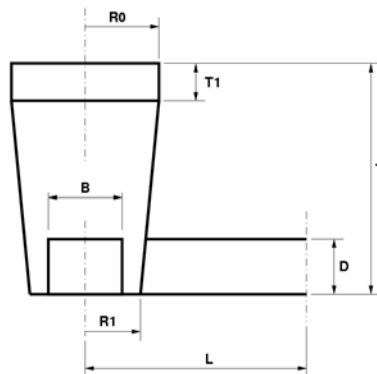


Fig. 23 Parametric representation of an TLP structure

Slika 23. Parametarski prikaz konstrukcije sa zateznim nogama

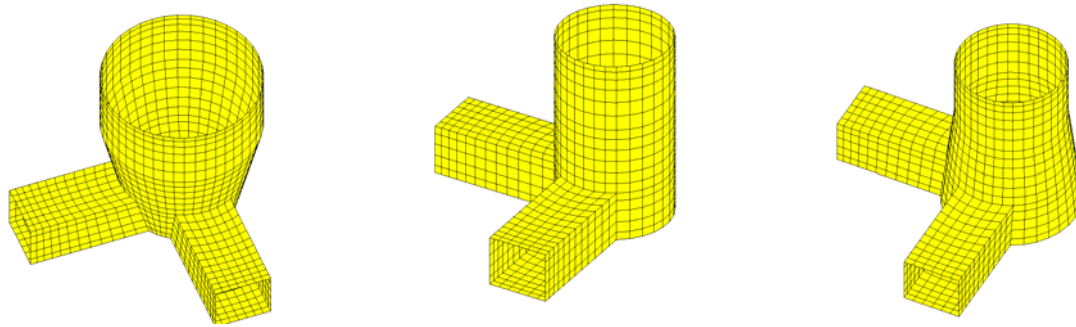


Fig. 24 Mesh of different TLP Platforms Slika 24. Mreža različitih platformi sa zateznim nogama

3. Conclusion

A very general and robust method for parametric meshing of almost any type of floating bodies for sea keeping calculation purposes is presented. Two separate numerical codes were developed:

- **SM (Ship Mesh)** for ship type bodies
- **OSM (Off-Shore Mesh)** for off-shore type bodies

The developed software is very efficient and requires the minimum intervention from users side. Once the basic model settled down, any additional modification is immediate. Two codes are already in use within the Bureau Veritas HYDROSTAR sea keeping package, and they have dramatically reduced the time devoted to meshing.

Even if both tools are completely independent, they can easily be implemented into more sophisticated interactive graphical tools as a separate routines.

Acknowledgement

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