

# POLITECNICO DI BARI



**FACOLTA' DI INGEGNERIA  
DIPARTIMENTO DI INGEGNERIA MECCANICA E GESTIONALE  
CORSO DI LAUREA IN INGEGNERIA MECCANICA**

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**TESI DI LAUREA NELL'AMBITO DEL  
PROGETTO VELANTE**

**THESIS RELATED TO THE  
VELANTE PROJECT**

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## **Progetto Velante**

The “**Progetto Velante**” (Velante Project) starts in October 2007 as an initiative of a group of teachers of the Politecnico di Bari. In the beginning, the project was created following the line of the previous project, launched in 2005, called “Mille e una vela per l'Università” (which literally means “A thousand and one sails for the University”). This previous project had the goal of creating a competition between universities and engineering schools, for the design and construction of sailing boats made with sustainable materials by students, with the help of their teachers.

This initiative, through the development of a sailing boat, seeks to promote:

- Team work between students of different areas.
- The usage of sustainable materials (and procedures).
- Enhance the spirit of competitiveness among the students.

Under these premises the Velante Project has been active in the **Politecnico di Bari** since its creation.

As I have said, the components of the Velante Project work on the development of a sailboat. The type of sailboat chosen is one of the International One Meter (IOM) class. This boat is a radio controlled sailboat, and its hull cannot exceed a length of one meter (a simple requirement that names the whole class).

The Velante Project components will, thereby, design and construct a boat that necessarily fulfills the requirements and boundaries of the International One Meter class.

⇒ A brief description of the measures and requirements can be consulted on the [Appendix 1](#).

This thesis is related to the part of the work developed by me and my colleagues during the academic year 2011-2012 as a part of the Progetto Velante.

The thesis is divided in two main parts:

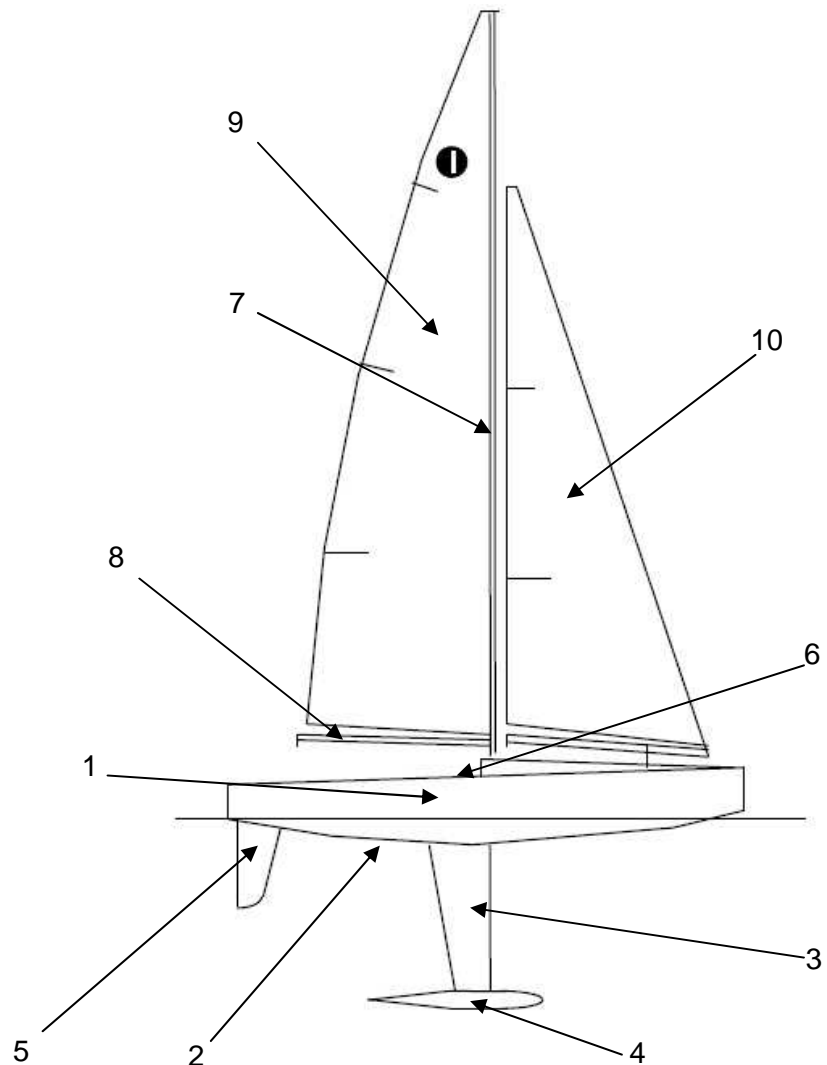
- The **first part** describes the different components of a sailing boat, and some specific components of a One Meter class sailboat. As well, it explains how we have managed to design and construct some of the parts, and also the procedures used.
- The **second part** is focused on the main part of my work here, the hydrodynamic analysis of the boat using both ANSYS programs and FLUENT software.

## DESCRIPTION OF THE SAILBOAT

First of all, I am going to make a quick description of the parts of a sailing boat similar to the one we have designed and constructed (within the Velante work group):

- 1 - Hull
- 2 - Keel
- 3 - Daggerboard
- 4 - Bulb
- 5 - Rudder
- 6 - Deck
- 7 - Mast
- 8 - Boom
- 9 - Mainsail
- 10 - Jib

⇒ Reinforcements



The boat shown above is a simplified example of a boat designed under the rules of the IOM Class. Although it is a simplified draft of the design, it represents the most important parts of a sailboat.

In the next paragraphs these parts are described the way they are in a typical sailboat. Later, I describe the reinforcements used in the construction of our boat and also, the specific elements installed in the boat in order to make it a radio controlled sailboat.

## **Description of the main structural parts of the boat:**

### ⇒ **HULL:**

The hull is the watertight body of a boat. Its shape and structure depend on the type of ship and its purpose.

The waterline is the line in which the hull meets the surface of the water. The part that remains above is called “dead work”, and the one beneath it “underbody”. Later, my study will be divided in two parts: first, the study of the underbody part of the boat and later, the study of the dead work part as well.

The shape of the hull is chosen to be a well-balanced hull between hydrostatic considerations, economic cost, and hydrodynamics. The design will determine the behavior of the vessel in water and its competitiveness.

### ⇒ **KEEL:**

When talking about the structure, a keel is a large beam upon which the hull of the ship is built. The keel extends all along the longitudinal structure of the ship, in the middle of it, and serves as the major source of strength of the hull. As an example, the keel can be considered as the spine of a human being. This is applied in the construction of all kinds of ships.

The secondary beams, that form the rest of the structure of the hull, are attached to the keel.

When it comes to sailboats, the keel has two main purposes:

- Use the forward motion to generate lift. When the wind comes from the sideways (abeam), the keel has to convert this motion into forward motion.
- Provide ballast to the boat.

Nevertheless, in our boat the ballast is provided mainly by the bulb, attached to the hull by the daggerboard.

⇒ **DAGGERBOARD:**

Is an essential part of the structure of the boat. In a sailboat one of its main functions is to hold together the hull and the bulb. Also, it provides extra stability, because it lowers the center of gravity of the whole boat.

In our boat, the daggerboard is thin and light. This is because its main purpose is being a connection of the hull to the bulb. Our daggerboard is fixed, and cannot be taken up or off the boat.

- ⇒ During the geometry analysis, the DAGGERBOARD denomination will refer to both the daggerboard itself and the bulb, to simplify the nomenclature.

⇒ **BULB:**

The purpose of the bulb is to provide enough ballast to the vessel. It is intended to be located as low as possible, in order to counteract the force of the wind collected in the sails and the torque. The bulb also lowers the center of gravity of the ship.

It is a very important part of our structure; without it the boat would not be able to resist the thrust of the wind and therefore would not succeed in sailing.

⇒ **RUDDER:**

A rudder is the device used to steer (drive) the boat. It controls the turns and the changes in the direction of the boat. Because of this, the dimension of it is very important when it comes to sail.

⇒ **DECK:**

A deck is a permanent cover of the hull. Like many other parts of a ship, its form and utilities depend on the type of vessel we are dealing with. For example, in a large cruiser, the deck has plenty of different levels and each one is used for a determined activity.

In our case, the main purpose of the deck is to provide a watertight enclosure to the hull, so it prevents it from flooding.

⇒ **MAST:**

The mast is the supporting element of the sails. It is large and vertical. Of course, it also has to support the forces produced by the wind on the sails.

⇒ **BOOM:**

A rigid spar which stabilizes the bottom of the mainsail. It can be wooden or metal made. The boom is fixed to the mast from one of its two tips. It is articulated so that it can rotate about the fixed tip within a quite wide angle. Thanks to the articulation the mainsail can be put into the position which best fits the conditions the boat is dealing with.

⇒ **SAILS:**

⇒ **MAINSAIL:**

As an engine provides the strength needed to a car or train, the mainsail is the main responsible of providing power to the movement of the boat.

Fixed to the boom in the bottom and to the mast in one of its edges, the mainsail is placed behind the mast (in the stern part of the boat).

The material traditionally used through History has been patchwork of wool, and later patchwork of linens until modern technology has made possible the use of synthetic materials, such as nylon. In addition, these new sails made by these new materials are seamless, made in one single piece.

⇒ **JIB:**

The jib is designed to be a complementary source of motion to the mainsail. It is triangular and sets ahead the mast of the vessel, and its tack is fixed to the bow of the deck.

It converts the pressure brought by the wind into motion force.

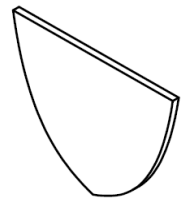
## **Reinforcements:**

The construction of the boat would not have been possible without the use of the elements described in this section.

### ⇒ **Timbers:**

Reinforcement timbers are wooden devices that are used to provide strength to the hull.

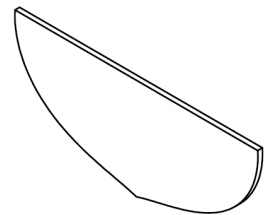
In our boat, there are nine different timbers alongside its length. They were made out of wooden sheets, and are 3 millimeters thick.



### ⇒ **Daggerboard reinforcement timbers:**

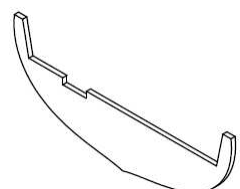
These timbers are special devices that act the same way as the timbers just described, but with the peculiarity that are added in the daggerboard proximities of the hull, giving more strength to it in one of the most demanding locations.

Like the normal reinforcement timbers, these ones are also made out of wooden sheets and have a thickness of 3 millimeters.



### ⇒ **Servomechanism reinforcement timber:**

The servomechanism reinforcement timber has two purposes. First, it has to provide additional strength to the hull, and it also has to serve as an anchorage point for the servomechanism. It is important that they do not move in any direction and that they are strongly fixed.





### ⇒ **Fixing structure of the mast:**

The fixing structure of the mast has been designed with the goal of fixing the mast to the hull without making any hole in it.

In order to achieve this, we have constructed a wooden structure that is fixed to one of the reinforcement timbers. This structure has a free space inside it in which the mast fits perfectly. By this, we also give an additional use to the timbers.

The bottom of the structure is properly designed to fit with the form of the hull.

### ⇒ **Fixing structure of the daggerboard:**

The device used to make the daggerboard fixed to the hull has the functions of:

- Fix the daggerboard to the hull and support its weight. We have to remember that the weight is the one of the daggerboard and the bulb together.
- Make the hole in the hull watertight. It is paramount that water does not enter the inside cavities of the hull.

To achieve these two purposes a wooden structure was designed and constructed, and attached to the daggerboard reinforcement timbers, thereby fixed to the hull itself.

With two resin layers we made the union watertight. We extended the layers in the inside part of the hull, very carefully.

### ⇒ **Use of epoxy resin:**

After all the reinforcements were put in the hull, we extended layers of epoxy resin to gain rigidity and make the unions stronger. The resin fills some little holes that existed between the timbers and the hull's surfaces.

The use of the epoxy resin is permitted by the IOM regulations.

In the case of the daggerboard reinforcement structure, the use of resin also made the union with the hull watertight.

## Other devices:

Because of the nature of our boat and the requirements given, we had to include some other less common devices in the overall structure. These devices are the ones responsible of moving the sails and the rudder, and make possible the driving of the boat from a remote controller.

These devices are the **battery** and the **servomechanisms**.

### ⇒ **Battery:**

The source of energy the servos need to function. Its electric energy will be transformed into mechanical by the servomotor.

### ⇒ **Servomechanism:**

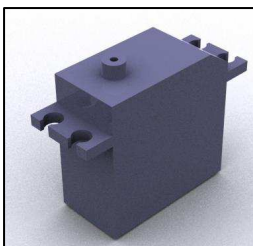
A servomechanism, or servo, is an automatic device that uses error sensing negative feedback to correct the performance of a mechanism. It has mechanical and electronic parts. This is a very general definition, since there is a vast amount of different devices, each one designed for a different application. For example, servos are usually applied in the field of robotics.

The ones we have used are the type of radio control servos. They are small actuators used for radio control. Most of them, like ours, are rotatory actuators.

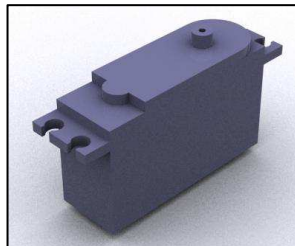
We have used two different radio control servos, one controls the sails and the other controls the rudder, since the necessities of these two parts are not the same. The difference between them is their range of rotation.

The one of the sails has a 360° rotation range. It can change the position of the sail's booms, depending on our needs in a determined moment in time.

The one of the rudder, though, has a range of 40° approximately (as the rudder is not supposed to turn more than about 15-20° to each side of its axis).



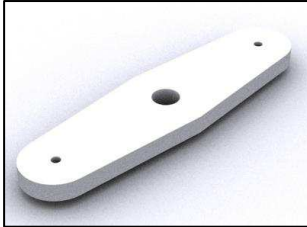
40° rotation servo



360° rotation servo

The servo is controlled with a **radio controller**. With this device we are able to control the rudder and the sails from as far as 100 meters from the boat.

- ⇒ In order to connect and transmit the movement from the servos to the sail's booms, we have used a **servo handle**, like the one shown below:



## CONSTRUCTION

Everything we have done in the design and construction of the boat has been developed under the restrictions of the IOM normative.

In the beginning of the academic year we carried out several activities related to the design and construction of some of the most important parts of the boat. I focused on the construction of the bulb, the daggerboard and the rudder. However, I also took place in the design and construction of some of the reinforcements of the hull.

Because of the IOM normative, the weight of both the bulb and the daggerboard together had to be **less than 2500 grams** (see “ballast ratio” in Appendix 1). Also, the rudder had a limited weight of 75 grams. For each of the three gadgets, a previous design was done with the SolidWorks CAD software, and during the construction we tried to be as accurate as possible. Nevertheless, some little modifications had to be made.

### Construction of the bulb:

Our first concern after having made the design was to obtain a suitable mold. We made one with the desired form of the bulb and then we constructed the mold in wood and filled it with filler. Later we divided the mold in two symmetric parts and by turning the bulb prototype several times we finally gave the filler substance the final form. This process is showed in the images below:



*The mold into which we will put the melted metal*

Once we had our mold, we began the construction of the bulb itself. The first decision was a suitable material which would fit the requirements given in the normative.

The main restriction was the density of the material used, that could not exceed  $11'3 \text{ g/cm}^3$ . We wanted a heavy and malleable metal to make the bulb. We decided to use **lead**, because it fulfills this premises, and its density is  $11'34 \text{ g/cm}^3$  ( $20^\circ\text{C}$ ), in the very limit of the normative.

In fact, in the regulation of the Appendix 1 it is directly indicated the use of lead for the bulb.

Lead characteristics:

- ⇒ Type => metal, carbon group
- ⇒ Density =>  $11'34 \text{ g/cm}^3$
- ⇒ State => solid
- ⇒ Melting point =>  $600'61 \text{ K}$  ( $327'46 \text{ }^\circ\text{C}$ )
- ⇒ Boiling point =>  $2023 \text{ K}$  ( $1750 \text{ }^\circ\text{C}$ )

The characteristics of our interest are the density and the melting temperature of the lead. Also, the fact that is a malleable and heavy metal. The melting point is reached at  $327'46 \text{ }^\circ\text{C}$ , easily obtained by means of a small melting device.

With the help of a small oven we could melt the pieces of lead we had. When it was melted (in liquid state), we poured the liquid metal into the mold, with lots of caution and trying to create a uniform surface. Once it was solid again and cold enough, we took it from the mold.

We had to repeat this operation twice, in order to obtain the two halves of the bulb needed. This process is showed in the images below:



*A view of the pieces of lead inside the little oven. The melting process takes about 7-8 minutes.*



*View of the lead cooling in the mold. The process was repeated twice.*

After the creation of the two parts that would form the bulb and before sticking them together, we had to work on the surfaces of both parts. This is because the surfaces have to be clean and smooth or they could give problems afterwards. We tried to make the surfaces smooth with handmade work, using sandpaper.

This two surfaces before smoothing are showed in the next picture:



*View of the two halves that will form the bulb.*

*In red, the areas into which we have had to work the most with the sandpaper*

Before the unification of the two halves of the bulb, we had to make a little cavity in the top of both parts where the union with the daggerboard would later be. This cost several handmade work.

Finally we joined the two halves of the bulb with the daggerboard (the construction of the daggerboard is explained in the next paragraph). Once we had the two pieces together, as shown in the photograph below, our remaining job was to polish the bulb and give resin to the daggerboard.

The finish of the bulb is very important because it is one of the elements of the boat that is more resistant to the flow of water. This means that its surface has to be perfectly smooth. In our bulb there were some areas where we had to polish afterwards. We marked them up with a blue pen as shown in the photograph below and worked with the sandpaper, as we had done before with the surface of both halves.



*View of the two halves united forming the bulb, already attached to the daggerboard.*

*In blue, the areas that were not smooth enough yet.*

To finish with our work with the bulb, we put a **layer of epoxy resin** and we painted it with blue spray.

## Construction of the daggerboard:

The materials used to make the daggerboard were: wood, carbon fiber and resin.

Initially, we made a piece of wood with the exact shape and measures of our design. We decided that the best way to reinforce the wooden daggerboard was to use **carbon fiber sheets**.

⇒ Main reasons to use **carbon fiber**:

- Its excellent specific strength. This means it is very strong for a piece that light. The specific strength is obtained dividing a material's strength by its density:

$$(N/m^2)/(kg/m^3) \Rightarrow N \cdot m/kg$$

Our piece has to be strong and light at the same time. It is going to carry the bulb and it has to act as a truly fixed union of the bulb and the hull.

- Its weight. Because of our requirements we need a light daggerboard. It will be light as a consequence of the specific strength.

**Carbon fiber** is often used in competition sailboats and other high-tech areas for this reasons. However, it is very expensive.

⇒ Reasons to use the **epoxy resin**:

The resin we have used is epoxy resin. This resin is one of the most used in the structural applications. It can glue a vast variety of materials by achieving a great rigidity. It is very stable to the changes of temperature and resistant to acids or solvents, as well as water erosion (our main interest).

After the first bath in resin of the piece, we worked with the sandpaper again to give it the final smooth required. With this repetition of the smoothing part, we obtain a quite good finish of the surface, smooth enough for our purpose. We decided to give the piece a last layer of resin afterwards, to cover those little areas where the resin layer was thinner than required. We cannot forget that the daggerboard is always underwater, and thus it has to be completely protected from the water erosion.



## Construction of the rudder:

The rudder's construction was made following the exact steps of the daggerboard's. We needed a piece that was to be strong, light and rigid, as the daggerboard is. The rudder is the responsible of the guidance of the boat, and has to be strong and rigid enough to resist the thrust of water.

It also had to be light, as the requirements indicated, less than 75 grams, and resistant to water erosion.

With the **carbon fiber** and the **resin** we succeeded in creating a piece of these characteristics.

Final appearance of the daggerboard and the rudder:



*Right, the finished rudder*



*Left, the prototype ready for the proving.  
In yellow, the daggerboard and the bulb.*



## **HYDROSTATIC PROPERTIES OF OUR VESSEL:**

In this section I am going to explain all the work developed during the study of the hydrostatic properties of the boat.

It has been the most important and extended part of my work here. I have learned to use the Fluent software and the ANSYS ICEM CFD programs, in order to obtain accurate and reliable results.

My work here can be divided in **two main periods**:

- ⇒ During the **first period** I worked with the geometry of the **underbody part** of the boat, preparing its geometry and then launching the Fluent software in order to obtain the calculations needed.
- ⇒ A **second period**, during which I worked upon the **overall geometry** of the boat, excluding the sails. This includes the geometry of the first period plus the rest of the hull.

Since it has been a long and quite a vast activity, both of the two periods can be divided in different parts. In each part I will try to explain clearly:

- First, all the work developed on the geometry of the boat with the ANSYS ICEM CFD program. This is a very important part of the work, because we prepare the geometry and generate the mesh, necessary for the Fluent software analysis.
- Second, the analysis of the mesh by the Fluent software and the obtaining of the results.
- Last, I will try to explain the results obtained.

## FIRST PERIOD. ANALYSIS OF THE UNDERBODY GEOMETRY

I was given the **underbody geometry**, previously designed with the program for assisted design SolidWorks. Our job consists in the study of the hydrostatic parameters of the geometry with the Fluent software, in order to improve the future design of the next boat.

Before launching the Fluent software, however, a lot of work upon the given geometry must be done. The geometry has to be “prepared” and “arranged” for the launching of the Fluent solver. This means I had to work on the geometry, creating a **mesh**, before trying to launch Fluent and having any results at all.

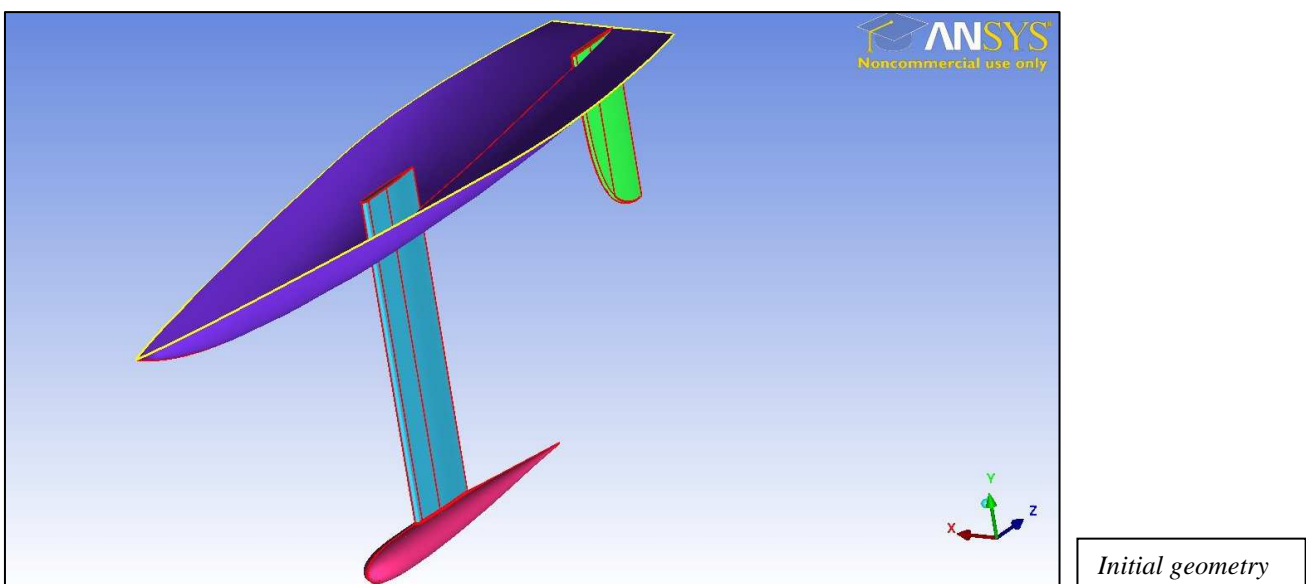
All the work carried out upon the geometry and the creation of the mesh has been developed with the **ANSYS ICEM CFD program**. A little introduction and explanation of the appearance and usage of the program can be found on the [Appendix nº 2](#).

- [Appendix nº 2 \(pages 56-59\)](#)

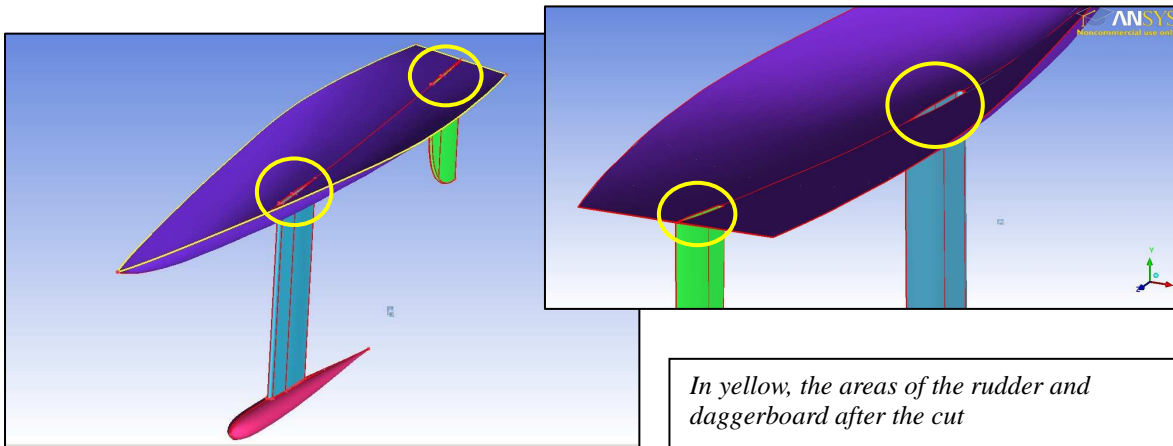
### Working with the ICEM CFD software:

As I said, during the first period of my work here I was given the underbody geometry of the boat. Water fluid would affect every part of the geometry I was to work with, so I had to create a mesh that would cover every part of the geometry.

The first thing that had to be done was the repair of the geometry, to make it suitable for the later creation of the mesh. This is the aspect of the geometry initially given:



My first concern was the elimination of the parts of the *daggerboard* and the *rudder* that were above the hull. Using the commands available in the geometry toolbar I was able to cut and eliminate these remaining parts.

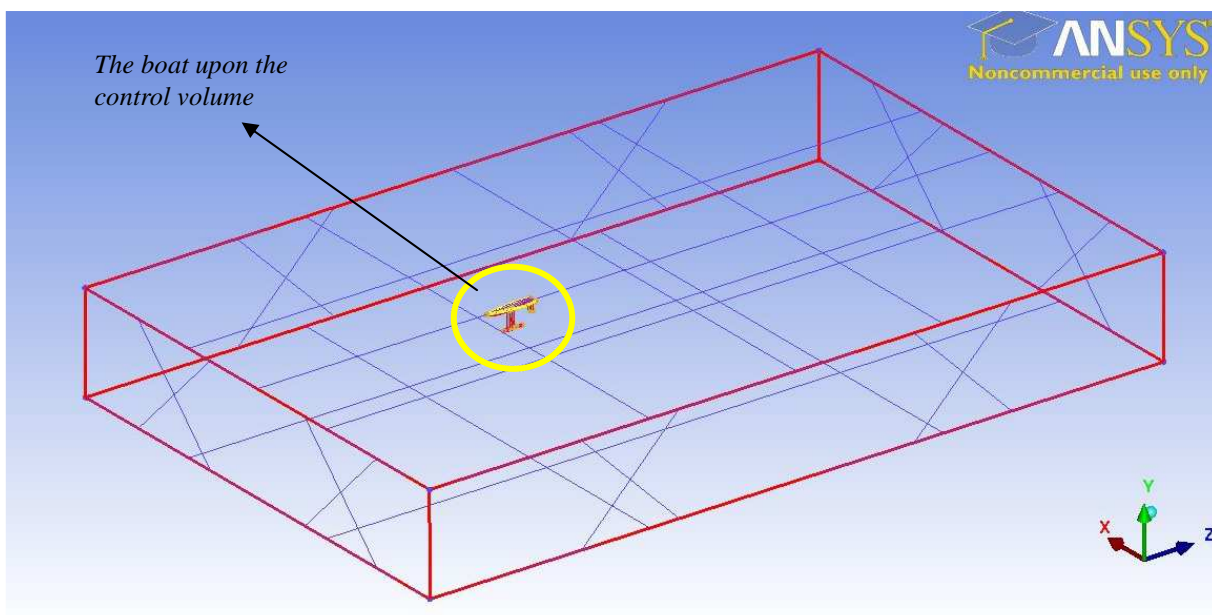


Once I had the geometry of the boat ready, the next step was the creation of a body that would form our **control volume**. This is the delimited space on which later we are going to make all the calculations, the space through which the virtual fluid will flow and interact with the boat.

The control volume had to be a rectangular body, so that the upper surface would match the upper surface of the boat's geometry (the fictitious surface formed by the waterline). The measures of the control volume were given:

Being:      “ L ” => the length of the boat  
               “ L' ” => the height of the boat

- Length: 5 times L from the bow and 10 times L from the stern.
- Width: 5 times L from each side.
- Depth: 5 times L' down the upper surface.



Once I had arranged the geometry and created the control volume I faced the **meshing process**. Since I started without any experience, the optimum parameters were found after several failed meshes and following wrong processes.

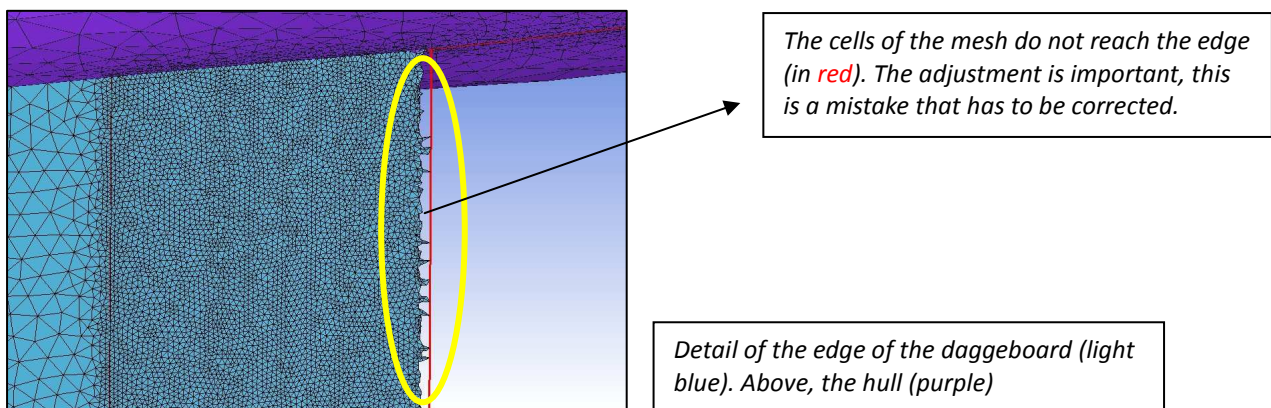
After trying several times, I finally reached suitable enough parameters to make a successful mesh. This does not mean that this is the only way to create the mesh, but it is accurate and precise enough for my purpose.

The main attempts to create the mesh can be divided into three different processes, described in the following paragraphs.

#### – **First approach to the meshing process:**

On my first approach of meshing the geometry I made several mistakes. The most important of all was that I computed the mesh with the command “Surface Mesh” instead of “Volume Mesh”, which would later prove to be more suitable.

This way, I computed the mesh with the command “Surface Mesh” and left the rest of the possibilities set as the default ones of the program. I found several problems, the most visible of them was that the daggerboard and the rudder were not entirely meshed.



**The mesh has to be as accurate as possible or it will not provide good results later.** The mesh must be adjusted to every edge of the surface, without exception. **Even the tiniest hole would give problems in the later simulation.**

⇒ I tried to fix this problem by enabling the command: “curvature/proximity based refinement”, as a way to take the grid until the end of the edge of the daggerboard and rudder.

Another problem was that the mesh was very coarse, and we want it to be dense, especially in the parts of the boat.

The way I tried to fix this last problem was by using the command “Mesh Curve”, introducing the parameters in “Curve Mesh Setup”. Here I could program the number of nodes each line was supposed to have, and thus I could make the mesh more dense where needed.

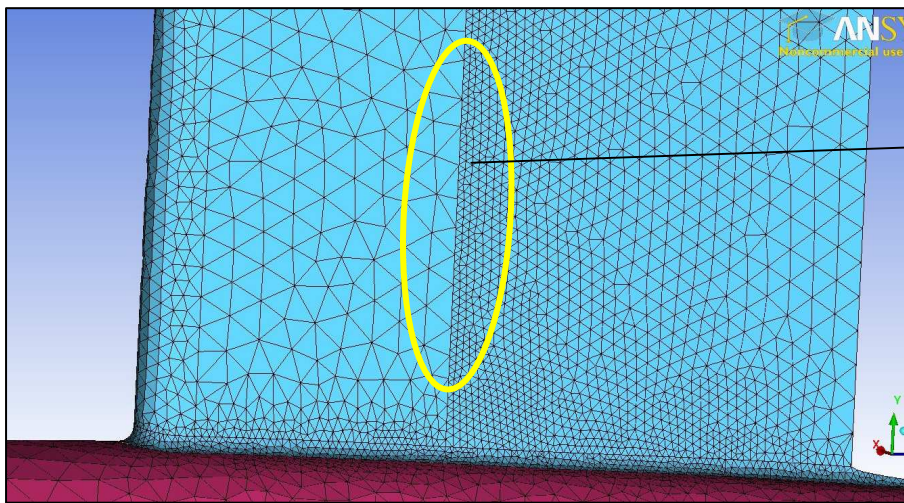
The other action I took was to program different parameters for each surface, modifying the ones of the surfaces of the daggerboard and rudder, in “Surface Mesh Setup”.

- ⇒ Maximum size of the cells.
- ⇒ All triangle.

Although with these new parameters the mesh looked fine, **basic things were wrong:**

- An inappropriate density of the mesh (in some areas too dense and in others too coarse).
- **The nodes didn't match up between the different surfaces.**

As an example:



*When two different surfaces are separately programmed, the nodes may not match in the edge.*

*Desigual density between surfaces forming the same part.*

*Detail of the daggerboard's mesh.*

- ⇒ I decided to mesh individually every curve of the geometry by myself (using the “Mesh Curve” command, as before). By meshing all the curves, I intended to give a solution for the big problem the unconnected nodes were. I divided the curves in a certain number of nodes (different for each curve), depending on the length of the curve (the longer the curve was, more nodes were necessary).
- ⇒ After meshing each curve, I completed the mesh with the “Mesh Surface” command.

**This was a long and weary process, and the results were not completely satisfactory.** What is more, I encountered new problems:

- I couldn't succeed in creating a mesh for the **bulb**, making its nodes connected with the daggerboard ones.
- The meshing of the **control volume** was not satisfactory. (It cannot be forgotten that the control volume has to be meshed as well).

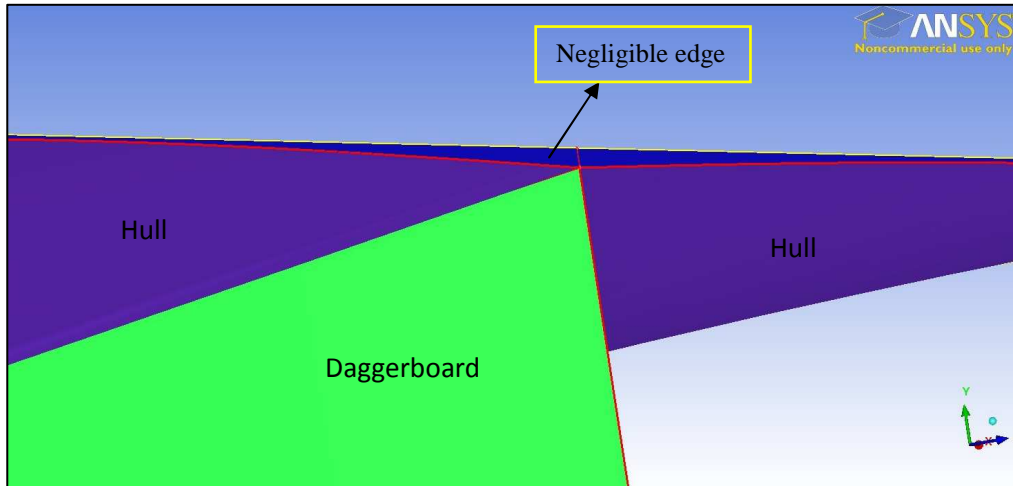
Nevertheless, although it was not a good mesh, the **Fluent software was launched** and I tried to obtain results with this mesh. As it was expected, **it was not possible** to obtain any result with the mesh.

This lead me to re-start and try to figure out a new way of creating the mesh, more simple and efficient. However, the fail in the launching of Fluent made us realize that the problem was also the geometry. In particular the problem was a tiny edge in the stern side of the boat.



- **Second approach to the meshing process:**

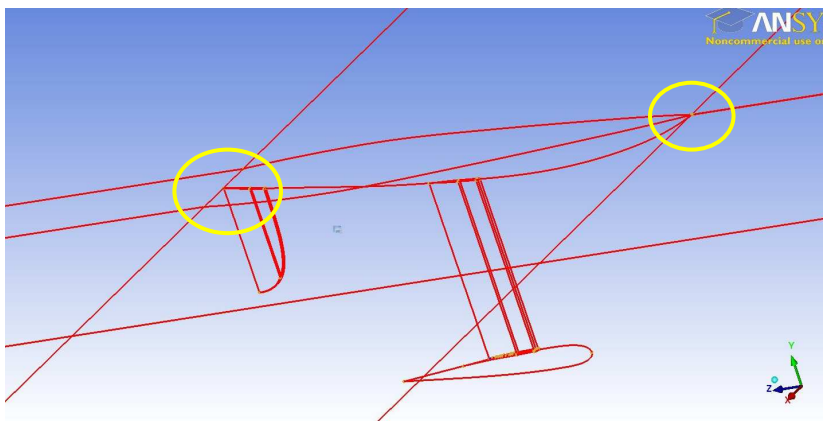
The tiny edge in the stern side of the boat's geometry was not easily visible and during the first attempt went unnoticed. The image below shows in detail the back side of the geometry:



Although it does not seem to be a big problem, when it comes to the realization of the calculations the Fluent software finds a lot of problems with this tiny surface and the mesh surrounding it. In fact, from a fluid-dynamic point of view the edge is completely negligible and does not make any difference in the analysis. Because of this, the best way to get rid of the problem was to delete the edge, changing the geometry from the beginning.

- ⇒ As I had changed the geometry of the boat, I also had to change the control volume, taking into account the different height of the hull's vertices. This is a detail I had also overlooked before. As the vertices both in the front and now back sides have a minimal but substantial difference in height, the generation of the upper surface of the control volume had to be changed as well. The rest of the measures of the control volume remained untouched.

The difference in height led to the creation of up to five surfaces that would form the upper surface of the control volume (called FREE-SURFACE), which was inevitable and would later cause some problems described in later paragraphs.



*View of the geometry of the boat and the edges of the different surfaces forming the FREE-SURFACE part (upper side of the control volume).*

*In yellow, the edges which vertices have a different height, what leads to the necessary creation of different surfaces.*

- ⇒ Now, the geometry is arranged and ready for the mesh generation step.

The first big change in the creation of the mesh was the **application of the “Volume Mesh”** command **instead of “Surface Mesh”**.

The “Volume Mesh” command is a much more “comfortable” function. There is no need to mesh all the surfaces separately and also has the possibility of changing a lot of parameters depending on the result expected. There are three different possibilities of volume meshes; my choice is “Robust Octree” (the Smooth Mesh will be necessary for further checkouts).

⇒ At this point, one of the main parameters I am going to change during this attempt is the **Edge Criterion**.

⇒ An explanation of the Edge Criterion can be found in => [Appendix 1](#)

I established an edge criterion of 0'05.

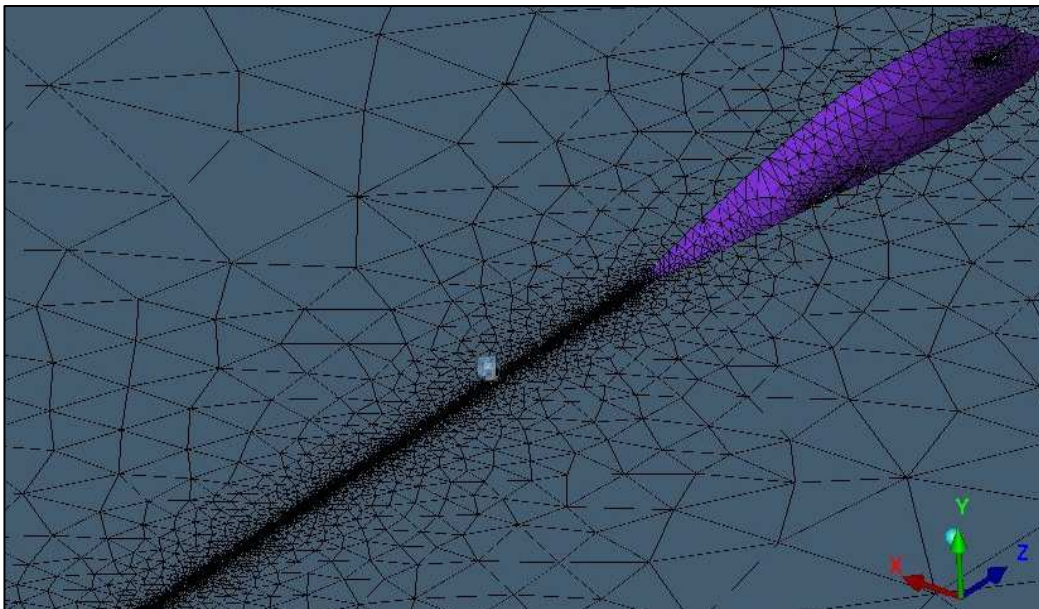
I also modified the “Global Mesh Parameters”:

⇒ enabling the *minimum size limit* and *global element scale factor*

⇒ Maximum elements = 1024

Again, with these parameters and this way of processing the mesh (Volume Mesh) I found several mistakes in the daggerboard and rudder’s meshes, similar to the ones found during the first approach.

There is another problem concerning the mesh of the control volume. The frontal part of the FREE-SURFACE mesh looks this way:

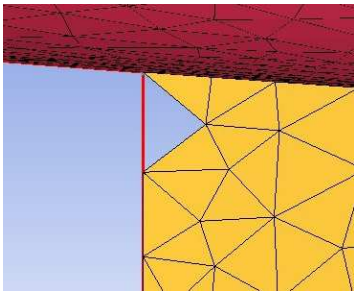


*View of the cells in the frontal side of FREE-SURFACE (in blue). In purple, the Hull’s mesh.*

The mesh is too dense in all the area going from the Inlet side of the control volume to the bow of the boat.

⇒ This is a consequence of the little surface I had to create because of the difference in the heights of the vertices.

What came next were a series of unsuccessful attempts trying to apply the solutions tried during the first approach (divide the curves into a certain number of nodes, mesh the wrong surfaces separately with Mesh Surface, etc).



⇒ However, these actions did not give a good solution. Sometimes, they even made the mesh worse (for example, creating holes in the mesh, or mixing different surfaces near the edges).

*Example of a hole in the mesh*

Because of this, I began trying a series of **new attempts**, such as:

- “Play” with the edge criterion. Decreasing or increasing it gave different adjusted better or worse the mesh to the edges. Generally, the lower it was, the better the adjustment. Nevertheless, an edge criterion lower than 0'025 was not suitable for the mesh. The most adjusted one seemed to be around 0'04-0'03.
- Eliminate the curves that delimited the surfaces before meshing (where needed). Such as the ones delimiting the different surfaces forming the upper face of the control volume.
- Determining the maximum size of the cells of the mesh for each part. For example, a maximum size of 10 for the size of the shells of the rudder. This proved to be a good way to fix the usual “next to edge” problems. It is changed in the “Part Mesh Setup” panel.
- Even change the tolerance from 0'0001 to 0'001 (ten times bigger), seeking a suitable mesh.
- It is possible as well to determine the minimum size of the shells, in “Mesh Surface Setup”, from 1 to 0'5.

In the end, it was clear that a lot of mistakes had been made and the accumulation of them made me think that the best way to achieve my goal was to re-start a third time, using the correct commands and the experience gained during this second process.



## Conclusions after the second approach:

In conclusion, a lot of commands are available for our use in the creation of the mesh, but not every path chosen is suitable for our purpose. The ones I used **during the second attempt proved to be more efficient and useful** than the previous ones. They were **less hardworking** and **quicker**, in the sense that I did not have the necessity of meshing each curve separately, which costs a lot of time and, what's more, enhances the risk of making mistakes.

Even if the user knows which process and commands are supposed to fit his or her interests, a certain “**discipline**” in the method has to be always carried out. The best example of this discipline is the **constant verification of the state of the geometry with the Build Topology command**. The Build Topology verification has proved to be necessary before every attempt of meshing the geometry. If it is not carried out, several mistakes may occur.

Another aspect that I had previously ignored is the **necessary division of the control volume in different parts**. This is something important because before launching Fluent each part will behave differently according to the type of surface we program them to be. For example, the front surface of the volume was named “Inlet” and the back surface “Outlet”, because the fluid will virtually enter from the first and go out from the second one. The **parts** are the following:

- **Inlet** – the flow will enter through it
- **Outlet** – the flow will exit through it
- **Left-Right** – side faces of the control volume
- **Bottom** – lower face of the control volume
- **Free-surface** – upper face, in contact with the edges of the hull, formed by different surfaces.

The type of surface assigned to each part, as well as the parts of the geometry of the boat, will be explained in later paragraphs.

- ⇒ Another thing that was useful for my operations with the mesh generator was the creation of a new part, called “**Curve-Punti**” that contained all the curves and vertices existing in the geometry, so that the rest of the parts would be formed only by surfaces. This proved to be useful in all the verifications of the geometry with the Build Topology command. Moreover, its use makes the operations and visualizations more simple and comfortable, which make the use of this operation a very recommendable work pattern.

With the combination of all these patterns described above, I faced the third approach of the meshing process. These series of attempts were finally successful.

- **Third approach to the meshing process:**

I start all over again from the arranged geometry (without the edge in the stern side). Before computing the first mesh, I apply the patterns described before. I unify all the curves and vertices in a single part (Curve-Punti), I verify the geometry with the Build Topology command every time something is changed, and divide the control volume in the necessary parts.

The command used was “Volume Mesh”, and I put into practice the parameters that in the previous process had given the best results. The most important of them:

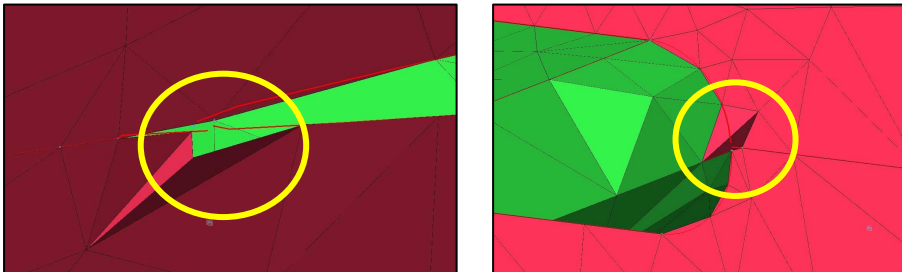
- Edge criterion => 0'035
- General tolerance => 0'3
- Specific tolerance between Free-Surface and the Hull => 1
- Maximum elements => 1024

And of course those parameters including the maximum size of the shells in parts such as the daggerboard and the rudder; or the elimination of the curves that separates the surfaces of the “Free-surface” part before meshing.

Once the mesh is created with these parameters and commands, there were two errors I had to amend before launching Fluent.

**1 – Daggerboard's Mesh:**

It is almost correct. The only wrong thing is the presence of a couple of nodes that do not adjust to the edge, as shown below. It is a minimal error but has to be corrected.



*Details of the edge separating the Hull from the Daggerboard.*

Such minimal errors are generally difficult to correct changing the global parameters of the mesh, and to do so could be dangerous as it could affect other parts of the mesh.

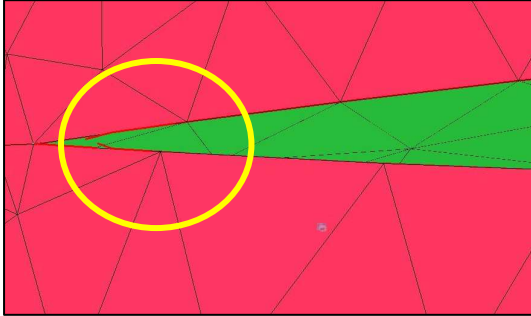
⇒ To amend this “impurities” I have used the commands included in **Edit Mesh**:

The “Edit Mesh” toolbar includes a lot of commands, the most suitable for my purpose was the “**Project nodes to curve**” tool. Using it, the problem is smoothly corrected and the results are quite good.

Nevertheless, the usage of the Edit Mesh commands is kind of a *last resort*. It was proved that if it is employed too many times or too deeply, the mesh may not pass the checkout and may fail.

As I did not use it in those terms, but only for those minimal mistakes, the mesh did pass the checking process afterwards.

An example of the appearance of the mesh after its correction:



The mesh is perfectly adjusted to the edge, and will pass the later checkouts.

## 2 – Frontal side of the “Free Surface”:

The problem regarding the excessive density of the mesh in the frontal side of the FREE-SURFACE remained unsolved since its apparition during the previous series of attempts.

The strange distribution of the mesh in this part of the geometry is an effect of the existence of the **thin surface** created to cope with the difference in height of the three vertices that form the limit of the bow.

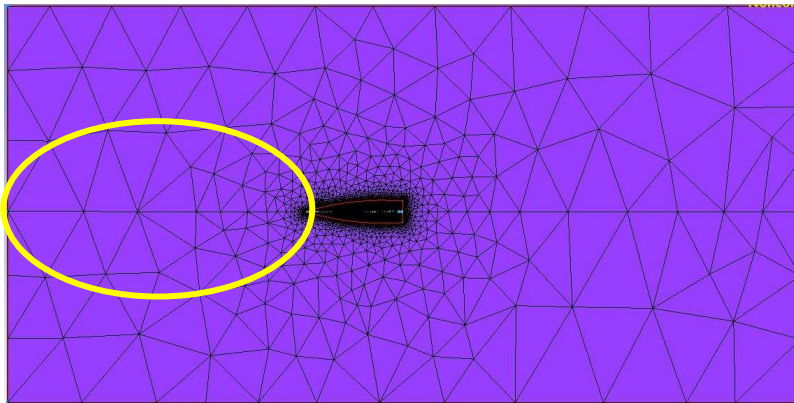
After trying in previous attempts other solutions (the problem exists since the division of the FREE-SURFACE part in different surfaces), I finally apply a change in the geometry itself.

The solution applied consisted in the **reduction of the length of the thin surface**. This way, I worked with the geometry of the control volume again, chopping the long and thin surface. The result was a rectangular and tiny element, non-visible unless the area is deeply zoomed.

Thanks to this, the remaining frontal side of the upper part of the control volume (the FREE-SURFACE) was then a normal single surface.

- ⇒ This solution was applied after the use of every other possible command, local or global, that I thought could amend the mistake without changing the geometry. The solution of this problem proved the necessary previous arrangement of the geometry, before meshing, and the occasional necessity of its change during the meshing process as well.

When we re-mesh the area, the result is the one expected:



*Top view of the control volume. Free-surface and Hull (darker)*

*In yellow, the area where the problem was, now with an appropriate mesh*

I finally had my geometry meshed. The following operations explained below would verify if everything was correct and would prepare all that was necessary for the launching of Fluent.

### **Last operations before the Solver launch**

Before launching the solver, the following operations have to be carried out:

- Creation of the boundary layer
- Smooth Mesh
- Existing Mesh
- Check Mesh

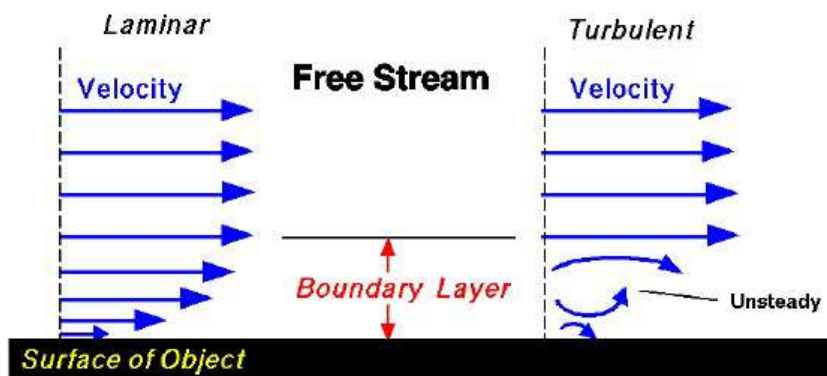
### **Creation of the boundary layer:**

In fluid-dynamics, the boundary layer is the layer of fluid in the immediate vicinity of a solid bounding surface where the effects of viscosity are significant.

The particles immediately next to the surface have a velocity equal to that of the surface. From that point, the velocity of the particles starts growing gradually until it reaches the velocity of the uniform flow, at a certain height which determines the thickness of the boundary layer. This is a consequence of the viscosity of the fluid.

The boundary layer can be either laminar or turbulent.

Simple representation of the boundary layer:



Velocity is zero at the surface (no-slip)

- ⇒ Although I tried with a couple of different values for the boundary layer height, the final mesh is created with a height of one centimeter (1cm).

Last verification of the mesh:

The three last operations have to do with the **checkout** of the mesh. I carried out the “Smooth Mesh”, which is an improvement of the mesh I had before, necessary for Fluent.

If an additional verification is required, the command “Check Mesh” informs of the unconnected vertices that could be remaining or other mistakes of the mesh.

**I finally have a suitable and accurate mesh to carry out the Fluent analysis.**

- ⇒ The last parameters I had to program before the launch of the Solver are the **Boundary Conditions** of the different parts of the mesh.

Every part has a specific type, and the description has to be accurate or all the work carried out with the mesh would be useless.

The Boundary Conditions are, for each part:

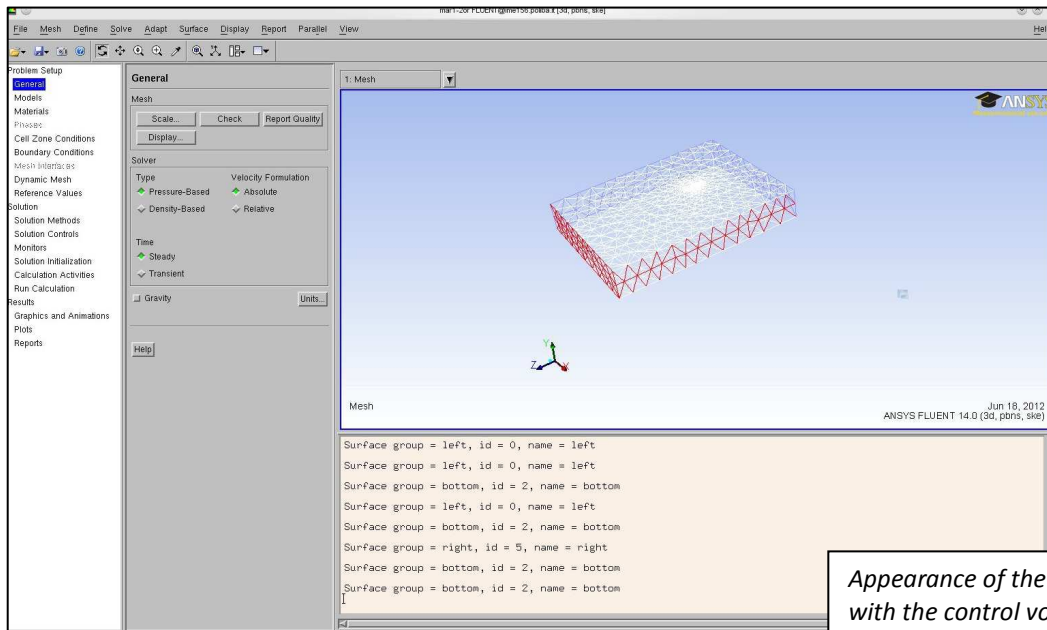
- INLET => Velocity-Inlet
- OUTLET => Outflow
- HULL, DAGGERBOARD, TIMONE (Rudder) => wall
- LEFT-RIGHT, BOTTOM, FREE-SURFACE => wall

Now, everything was ready for the launching of the Solver.

## FLUENT ANALYSIS

As I have explained in the “Geometry Analysis” section, the boundary conditions of the different parts of the geometry have to be set with the ICEM CFD program before the launch of Fluent. It is not a long procedure, every part will act as “wall” (every part of the geometry of the boat, and some parts of the control volume) except the INLET and OUTLET parts of the control volume that would be set as “velocity inlet” and “outflow” respectively.

I finally launch the Fluent software (fluent13 3ddp)



### Necessary operations before the initialization of the iterations:

First of all, the mesh has to be imported from the previous file. The first operation once the mesh is successfully loaded **is another checkout of the mesh**, this time with the Fluent software.

As there were no problems because the mesh was accurate and correct, my second concern was the establishment of the scale of the mesh, and adjust it to the correct values.

⇒ “Mesh Scale” => the geometry is given in millimeters (mm)

Then, I have to define the type of model I am to work with and the type of fluid. In this case, the model would be viscous and turbulent, with K- $\epsilon$  turbulence; the fluid, liquid water:

- ⇒ Define => Model Viscous (K- $\epsilon$  2 equations)
- ⇒ Define => Material => Fluid => Fluent database => Water Liquid
- ⇒ Define => Cell Zone Condition => Water Liquid

This way the type of fluid is defined along with all its properties, which are already in the Fluent database. The solver will apply the properties of the fluid chosen, under the conditions of the type of model we program. This is a very important part of definition, and it is not hard to forget.

The next step, again, is the definition of the **boundary conditions** of the control volume parts, this time from the Fluent software commands (although we have already done it in the other program, this is a necessary step):

⇒ Define => BC (Boundary Conditions) => **FREE-SURFACE** => Edit => Specified Shear  
(  $X = 0$   $Y = 0$   $Z = 0$  )

⇒ Define => BC => **BOTTOM** => Edit => Specified Shear  
(  $X = 0$   $Y = 0$   $Z = 0$  )

⇒ Define => BC => **LEFT-RIGHT** => Edit => Specified Shear  
(  $X = 0$   $Y = 0$   $Z = 0$  )

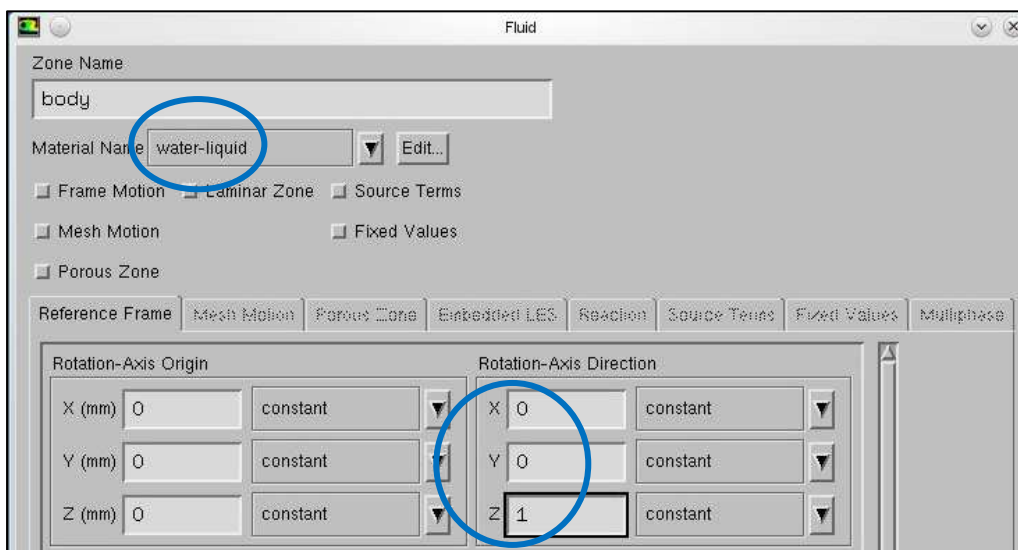
⇒ Define => BC => **INLET** => Edit => Velocity Inlet => 1 (m/s)  
(  $X = 0$   $Y = 0$   $Z = 1$  ) *the flow is in the Z axis direction (because of the geometry)*

Turbulence => 4% (intensity)

Turbulence length scale => 0'001 m (1 mm)

⇒ Define => BC => **OUTLET** => Edit => Outflow

⇒ When it came to the boundary conditions of the parts of the boat (Hull, Rudder and Daggerboard) I disabled the specified shear option. With this the program simulates that the velocity of the fluid in the surface of the boat is zero.



After all the work developed upon the geometry, the creation of the mesh and the setting of all the parameters, everything is ready for the beginning of the iterations.



When I launch the solver, I am looking forward to obtain accurate results of how the water liquid flows, at a velocity of 1 (m/s), affects the overall boat and which part of it offers more resistance to the flow and which less. The results will be both graphical and numerical.

⇒ Solve => Monitors => Residuals (Print, Plot) => Edit

In the edit command the “convergence” was disabled.

⇒ Solve => Initialization from => Inlet => Solution Initialization

⇒ Solve => Run Calculation => Calculate => Number of Iterations 1000x

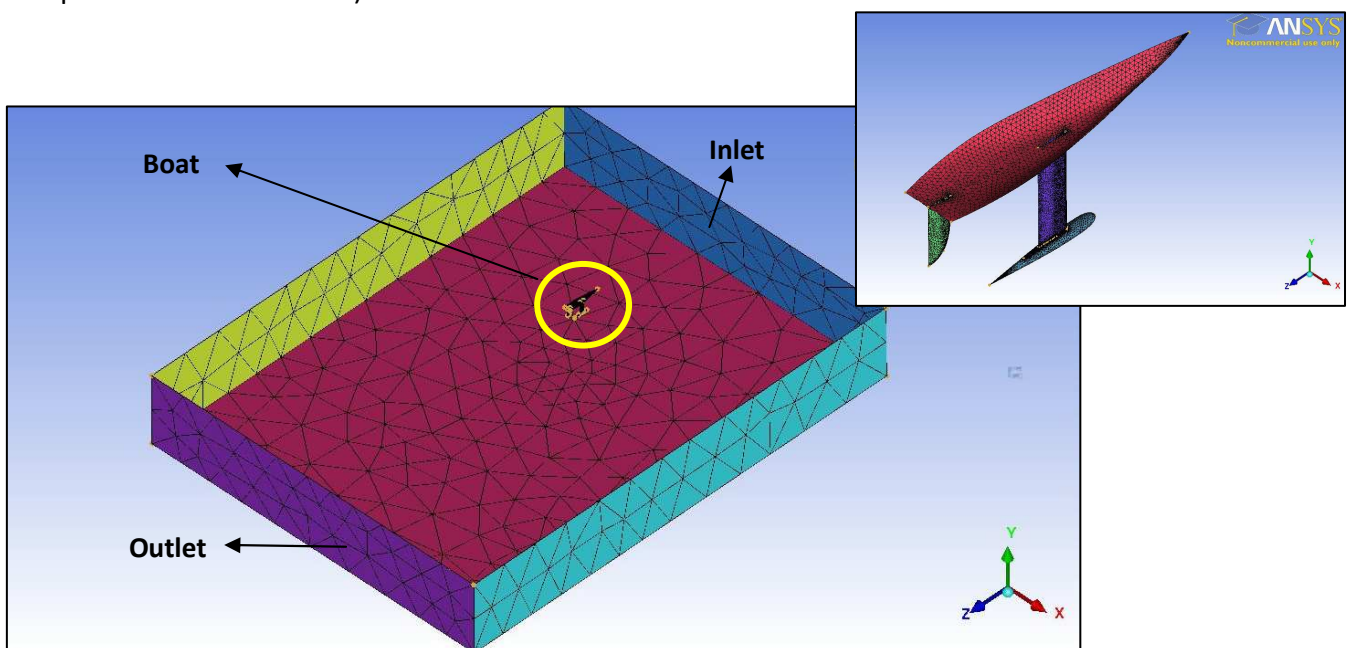
For the given mesh and number of iterations (1000), the obtaining of the results may last about an hour and a half. This is why it is very important to follow all the previous steps carefully and not forget to program any parameter that could change the results or make them wrong.

An inappropriate programming of the parameters, even those which do not seem important, may lead into wrong calculations, which for the user means a lot of wasted time.

⇒ I will carry out three different analysis:

- A unidirectional flow in **the Z axis direction** => **CASE nº 1**
- A unidirectional flow with a **30º inclination** (regarding the Z axis) => **CASE nº 2**
- A unidirectional flow with a **45º inclination** (regarding the Z axis) => **CASE nº 3**

Next, a clarification of the direction of the axis within the control volume (every part is visible except for the Free-Surface):





- **CASE Nº 1:**

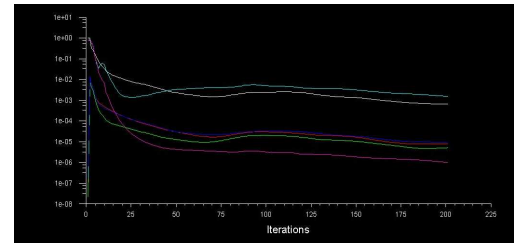
**1 m/s unidirectional flow ( X = 0 Y = 0 Z = 1 )**

The first analysis is carried out for a unidirectional flow going in the direction of the Z axis, from the inlet to the outlet of the control volume, facing the boat from the bow to the stern.

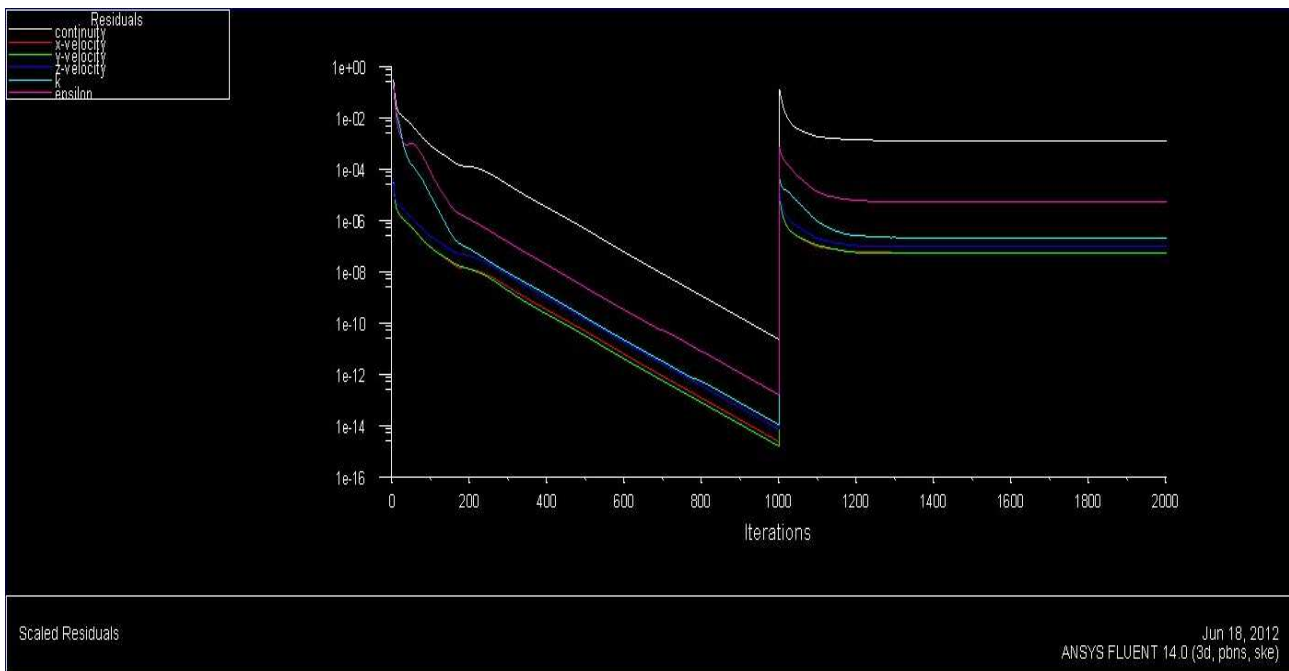
|      |            |            |            |            |            |            |            |         |     |
|------|------------|------------|------------|------------|------------|------------|------------|---------|-----|
| 187  | 7          | 0130e-04   | 7.7099e-06 | 4.7476e-06 | 9.8210e-06 | 1.8705e-03 | 1.2802e-06 | 1:05:50 | 813 |
| iter | continuity | x-velocity | y-velocity | z-velocity | k          | epsilon    | time/iter  |         |     |
| 188  | 6          | 9631e-04   | 7.7247e-06 | 4.7262e-06 | 9.7785e-06 | 1.8455e-03 | 1.2607e-06 | 1:05:44 | 812 |
| 189  | 6          | 9185e-04   | 7.7545e-06 | 4.7128e-06 | 9.7291e-06 | 1.8206e-03 | 1.2413e-06 | 1:05:40 | 811 |
| 190  | 6          | 8727e-04   | 7.7879e-06 | 4.7113e-06 | 9.6725e-06 | 1.7971e-03 | 1.2212e-06 | 1:05:34 | 810 |
| 191  | 6          | 8291e-04   | 7.8194e-06 | 4.7215e-06 | 9.6163e-06 | 1.7739e-03 | 1.2025e-06 | 1:05:40 | 809 |
| 192  | 6          | 7876e-04   | 7.8519e-06 | 4.7464e-06 | 9.5620e-06 | 1.7510e-03 | 1.1819e-06 | 1:05:32 | 808 |
| 193  | 6          | 7571e-04   | 7.8908e-06 | 4.7790e-06 | 9.5083e-06 | 1.7271e-03 | 1.1605e-06 | 1:05:26 | 807 |
| 194  | 6          | 7283e-04   | 7.9293e-06 | 4.8153e-06 | 9.4473e-06 | 1.7034e-03 | 1.1400e-06 | 1:05:18 | 806 |
| 195  | 6          | 7099e-04   | 7.9751e-06 | 4.8677e-06 | 9.3976e-06 | 1.6802e-03 | 1.1183e-06 | 1:05:11 | 805 |
| 196  | 6          | 6891e-04   | 8.0097e-06 | 4.9172e-06 | 9.3365e-06 | 1.6575e-03 | 1.0968e-06 | 1:05:07 | 804 |
| 197  | 6          | 6665e-04   | 8.0330e-06 | 4.9603e-06 | 9.2702e-06 | 1.6360e-03 | 1.0749e-06 | 1:05:02 | 803 |
| 198  | 6          | 6490e-04   | 8.0509e-06 | 5.0083e-06 | 9.2084e-06 | 1.6132e-03 | 1.0534e-06 | 1:04:57 | 802 |
| iter | continuity | x-velocity | y-velocity | z-velocity | k          | epsilon    | time/iter  |         |     |
| 199  | 6          | 6365e-04   | 8.0445e-06 | 5.0465e-06 | 9.1296e-06 | 1.5896e-03 | 1.0331e-06 | 1:04:52 | 801 |
| 200  | 6          | 6283e-04   | 8.0431e-06 | 5.0868e-06 | 9.0615e-06 | 1.5658e-03 | 1.0120e-06 | 1:04:46 | 800 |
| 201  | 6          | 6257e-04   | 8.0427e-06 | 5.1348e-06 | 9.0043e-06 | 1.5402e-03 | 9.9170e-07 | 1:04:44 | 799 |

View of the different iterations (blue). The outlet box where the software outputs the messages and the numerical results

During the iteration process, every single iteration is showed as the process goes on. In the right, the diagram at the 201 iteration.



- **Residuals:**



⇒ This diagram shows the decrease of the **mass continuity equation** throughout the iterations.

As it can be seen, the decrease is uniform from approximately the 200<sup>th</sup> iteration until the last (1000<sup>th</sup>). The reason for the big discontinuity from the 1000<sup>th</sup> to the 1001<sup>st</sup> is that after the first series of iterations I carry out the iterations (another 1000) with the **second order equations**.

This will be a pattern that repeats in each of the three different cases.

### - Numerical results:

Below, the output of the **forces** and **coefficients** that result after the iterations:

|                                   |   |   |  |
|-----------------------------------|---|---|--|
| bulbo                             | (0.0045893905 -0.056130498 0.053108183) | (-0.00010256423 -0.00025509154 0.085572521) | (0.0044868263 -0.056385589 0.13868072) |
| deriva                            | (0.036962395 -0.00013841219 0.34734051) | (-1.2935712e-05 0.00080368365 0.22073237)   | (0.036949459 0.00066527146 0.568072)   |
| hull                              | (0.0079023897 -12.047305 0.063975094)   | (-0.00056587498 -0.0085047612 0.34731621)   | (0.0073365147 -12.05581 0.4112913)     |
| timone                            | (0.015233216 -0.0067441484 0.096222923) | (4.4636673e-05 0.0025769994 0.067434632)    | (0.015277852 -0.004167149 0.1636575)   |
| Net                               | (0.064687391 -12.110318 0.56064671)     | (-0.00063673825 -0.0053791697 0.72105573)   | (0.064050653 -12.115697 1.2817024)     |
| Forces - Direction Vector (0 0 1) |   |   |  |
|                                   | Forces (n)                              |   |  |
| Zone                              | Pressure                                | Viscous                                     | Total                                  |
| bulbo                             | 0.053108183                             | 0.085572521                                 | 0.1386807                              |
| deriva                            | 0.34734051                              | 0.22073237                                  | 0.56807288                             |
| hull                              | 0.063975094                             | 0.34731621                                  | 0.4112913                              |
| timone                            | 0.096222923                             | 0.067434632                                 | 0.16365756                             |
| Net                               | 0.56064671                              | 0.72105573                                  | 1.2817024                              |
|                                   | Coefficients                            |   |  |
|                                   | Pressure                                | Viscous                                     | Total                                  |
| bulbo                             | 0.086707237                             | 0.13971024                                  | 0.22641748                             |
| deriva                            | 0.56708655                              | 0.36037938                                  | 0.92746593                             |
| hull                              | 0.10444913                              | 0.56704687                                  | 0.671496                               |
| timone                            | 0.15709865                              | 0.11009736                                  | 0.26719601                             |
| Net                               | 0.91534157                              | 1.1772338                                   | 2.0925754                              |

These results show the different forces on the different parts of the boat. It also gives information about the different coefficients used during the calculations.

In this case, the **direction vector analyzed is (0, 0, 1)**, the direction of the Z axis.

Certain parts are marked in blue:

- ⇒ The direction vector (upper rectangle).
- ⇒ The different parts of the geometry (bulbo = bulb; deriva = daggerboard; hull; timone = rudder; and **net**, the sum of all the previous ones).
- ⇒ The total forces and coefficients for each part (the sum of the pressure and viscous forces).

As it can be seen, the results are given divided by every part of the boat (specified in the left side of the result box). Down below, the program gives the sum of all the results for the overall geometry (net).

In the next page, the three different outputs for the three different direction vectors.

## Outputs for the different **direction vectors**:

⇒ **(1, 0, 0)**

|   |   |                |              |   |                |  |
|---|---|----------------|--------------|---|----------------|--|
| Reading "/home/tesisti/Velante/feb27-2order.dat"... |   |                |              |   |                |  |
| Done.   |   |                |              |   |                |  |
| Forces  |   |                |              |   |                |  |
| Zone  | Forces (n)                              |                |              | Viscous                                     |                | Total                                  |
| bulbo   | Pressure                                |                |              | Pressure                                    |                |  |
| deriva  | (0.0045893905 -0.056130498 0.053108183) |                |              | (-0.00010256423 -0.00025509154 0.085572521) |                | (0.0044868263 -0.056385589 0.1386807)  |
| hull  | (0.036962395 -0.00013841219 0.34734051) |                |              | (-1.2935712e-05 0.00080368365 0.22073237)   |                | (0.036949459 0.00066527146 0.56807288) |
| timone  | (0.0079023897 -12.047305 0.063975094)   |                |              | (-0.00056587498 -0.0085047612 0.34731621)   |                | (0.0073365147 -12.05581 0.4112913)     |
|   | (0.015233216 -0.0067441484 0.096222923) |                |              | (4.4636673e-05 0.0025769994 0.067434632)    |                | (0.015277852 -0.004167149 0.16365756)  |
| -----   |   |                |              |   |                |  |
| Net   | (0.064687391 -12.110318 0.56064671)     |                |              | (-0.00063673825 -0.0053791697 0.72105573)   |                | (0.064050653 -12.115697 1.2817024)     |
| -----   |   |                |              |   |                |  |
| Forces - Direction Vector (1 0 0)                   |   |                |              |   |                |  |
| Zone  | Forces (n)                              |                |              | Coefficients                                |                |  |
| bulbo   | Pressure                                |                |              | Pressure                                    |                |  |
| deriva  | Viscous                                 |                |              | Viscous                                     |                |  |
| hull  | Total                                   |                |              | Total                                       |                |  |
| timone  | Coefficients                            |                |              | Coefficients                                |                |  |
|   | Pressure                                |                |              | Pressure                                    |                |  |
| bulbo   | 0.0045893905                            | -0.00010256423 | 0.0044868263 | 0.0074928824                                | -0.00016745181 | 0.0073254306                           |
| deriva  | 0.036962395                             | -1.2935712e-05 | 0.036949459  | 0.060346767                                 | -2.1119531e-05 | 0.060325648                            |
| hull  | 0.0079023897                            | -0.00056587498 | 0.0073365147 | 0.012901861                                 | -0.00092387752 | 0.011977983                            |
| timone  | 0.015233216                             | 4.4636673e-05  | 0.015277852  | 0.024870556                                 | 7.28762e-05    | 0.024943432                            |
| -----   |   |                |              |   |                |  |
| Net   | 0.064687391                             | -0.00063673825 | 0.064050653  | 0.10561207                                  | -0.0010395727  | 0.10457249                             |

⇒ **(0, 1, 0)**

|                                   |  |                |             |   |               |  |
|-----------------------------------|--|----------------|-------------|---|---------------|--|
| Net                               | 0.064687391                                  | -0.00063673825 | 0.064050653 | 0.10561207                                  | -0.0010395727 | 0.10457249                             |
| Forces                            |  |                |             |   |               |  |
| Zone                              | Forces (n)                                   |                |             | Viscous                                     |               | Total                                  |
| bulbo                             | Pressure                                     |                |             | Pressure                                    |               |  |
| deriva                            | (0.0045893905 -0.056130498 0.053108183)      |                |             | (-0.00010256423 -0.00025509154 0.085572521) |               | (0.0044868263 -0.056385589 0.1386807)  |
| hull                              | (0.036962395 -0.00013841219 0.34734051)      |                |             | (-1.2935712e-05 0.00080368365 0.22073237)   |               | (0.036949459 0.00066527146 0.56807288) |
| timone                            | (0.0079023897 -12.047305 0.063975094)        |                |             | (-0.00056587498 -0.0085047612 0.34731621)   |               | (0.0073365147 -12.05581 0.4112913)     |
|                                   | (0.015233216 -0.0067441484 0.096222923)      |                |             | (4.4636673e-05 0.0025769994 0.067434632)    |               | (0.015277852 -0.004167149 0.16365756)  |
| Net                               | (0.064687391                                 | -12.110318     | 0.56064671) | (-0.00063673825 -0.0053791697 0.72105573)   |               | (0.064050653 -12.115697 1.2817024)     |
| Forces - Direction Vector (0 1 0) |  |                |             |   |               |  |
| Zone                              | Forces (n)                                   |                |             | Coefficients                                |               |  |
| bulbo                             | Pressure                                     |                |             | Pressure                                    |               |  |
| deriva                            | Viscous                                      |                |             | Viscous                                     |               |  |
| hull                              | Total  |                |             | Total                                       |               |  |
| timone                            | Coefficients                                 |                |             | Coefficients                                |               |  |
|                                   | Pressure                                     |                |             | Pressure                                    |               |  |
| bulbo                             | (-0.056130498 -0.00025509154 -0.056385589)   |                |             | (-0.091641629 -0.00041647598 -0.092058105)  |               |  |
| deriva                            | (-0.00013841219 0.00080368365 0.00066527146) |                |             | (-0.00022597909 0.0013121366 0.0010861575)  |               |  |
| hull                              | (-12.047305 -0.0085047612 -12.05581)         |                |             | (-19.669069 -0.013885324 -19.682954)        |               |  |
| timone                            | (-0.0067441484 0.0025769994 -0.004167149)    |                |             | (-0.011010854 0.0042073459 -0.0068035086)   |               |  |
| Net                               | -12.110318                                   | -0.0053791697  | -12.115697  | -19.771947                                  | -0.0087823179 | -19.78073                              |

⇒ **(0, 0, 1)**

|                                   |   |               |            |   |               |  |
|-----------------------------------|---|---------------|------------|---|---------------|--|
| Net                               | -12.110318                              | -0.0053791697 | -12.115697 | -19.771947                                  | -0.0087823179 | -19.78073                              |
| Forces                            |   |               |            |   |               |  |
| Zone                              | Forces (n)                              |               |            | Viscous                                     |               | Total                                  |
| bulbo                             | Pressure                                |               |            | Pressure                                    |               | Pressure                               |
| deriva                            | (0.0045893905 -0.056130498 0.053108183) |               |            | (-0.00010256423 -0.00025509154 0.085572521) |               | (0.0044868263 -0.056385589 0.1386807)  |
| hull                              | (0.036962395 -0.00013841219 0.34734051) |               |            | (-1.2935712e-05 0.00080368365 0.22073237)   |               | (0.036949459 0.00066527146 0.56807288) |
| timone                            | (0.0079023897 -12.047305 0.063975094)   |               |            | (-0.00056587498 -0.0085047612 0.34731621)   |               | (0.0073365147 -12.05581 0.4112913)     |
|                                   | (0.015233216 -0.0067441484 0.096222923) |               |            | (4.4636673e-05 0.0025769994 0.067434632)    |               | (0.015277852 -0.004167149 0.16365756)  |
| Net                               | (0.064687391 -12.110318 0.56064671)     |               |            | (-0.00063673825 -0.0053791697 0.72105573)   |               | (0.064050653 -12.115697 1.2817024)     |
| Forces - Direction Vector (0 0 1) |   |               |            |   |               |  |
| Zone                              | Forces (n)                              |               |            | Coefficients                                |               |  |
| bulbo                             | Pressure                                |               |            | Pressure                                    |               | Pressure                               |
| deriva                            | Viscous                                 |               |            | Viscous                                     |               | Viscous                                |
| hull                              | Total                                   |               |            | Total                                       |               | Total                                  |
| timone                            | Coefficients                            |               |            | Coefficients                                |               |  |
|                                   | Pressure                                |               |            | Pressure                                    |               | Pressure                               |
| bulbo                             | 0.053108183 0.085572521 0.1386807       |               |            | 0.086707237 0.13971024 0.22641748           |               |  |
| deriva                            | 0.34734051 0.22073237 0.56807288        |               |            | 0.56708655 0.36037938 0.92746593            |               |  |
| hull                              | 0.063975094 0.34731621 0.4112913        |               |            | 0.10444913 0.56704687 0.671496              |               |  |
| timone                            | 0.096222923 0.067434632 0.16365756      |               |            | 0.15709865 0.11009736 0.26719601            |               |  |
| Net                               | 0.56064671 0.72105573 1.2817024         |               |            | 0.91534157 1.1772338 2.0925754              |               |  |

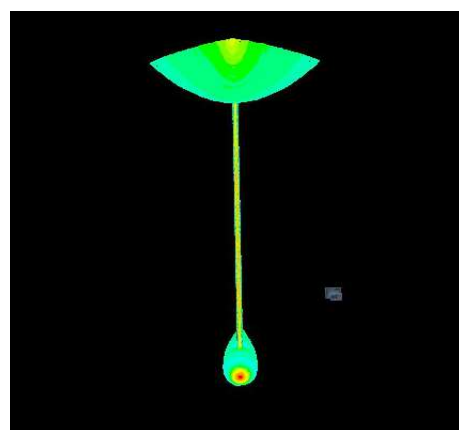
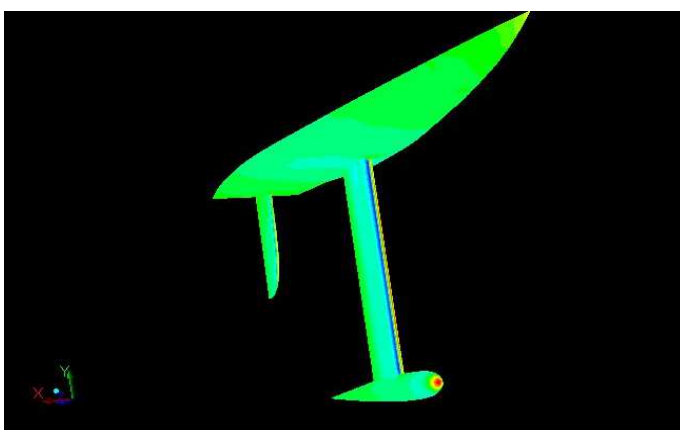
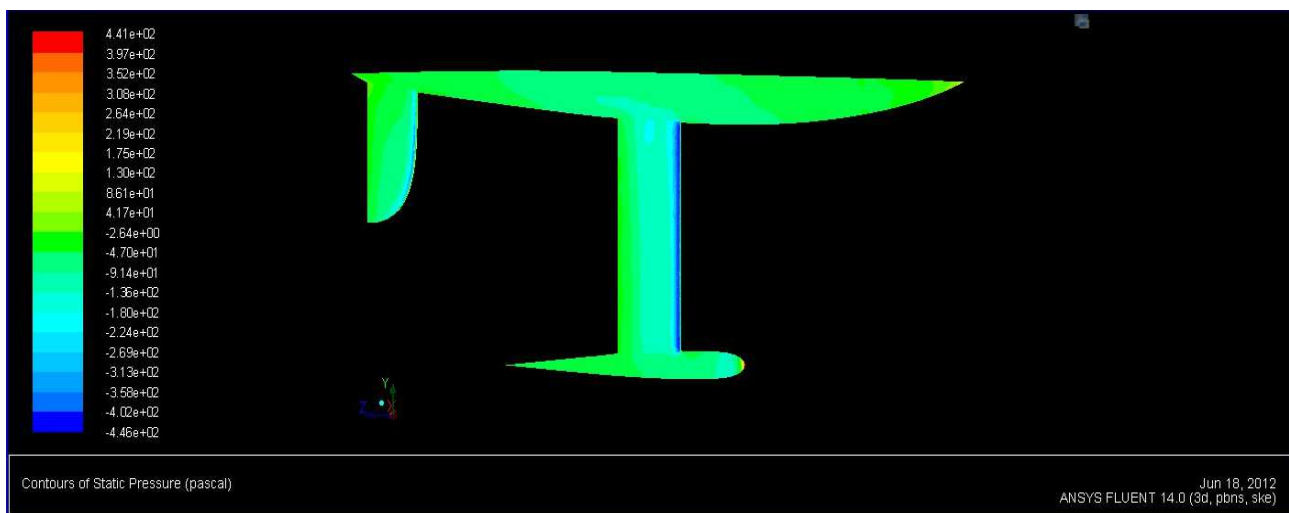
The results are given for three different direction vectors. In the simulation, the flow goes in the (0, 0, 1) direction.

It is thereby logical the forces in the direction vector (1, 0, 0), which total value is 0'064N whereas for the (0, 0, 1) direction vector is of 1'282N.

The results for the (0, 1, 0) direction vector are also good, all of them are close to zero except the value in the Hull, that is negative and makes the Net value also negative (-12'116N).

⇒ In the next diagrams, the geometry of the boat is reproduced in a contour map of static pressure:

- **Contour maps:**



*Contour maps of Static Pressure applied to the geometry of the boat (not the control volume)*

*Right, oblique and front view of the geometry*

This is a representation of the geometry of the boat in a map of contours of static pressure. The pressure is measured in Pascal and scaled in the left side of the upper view (the right view).



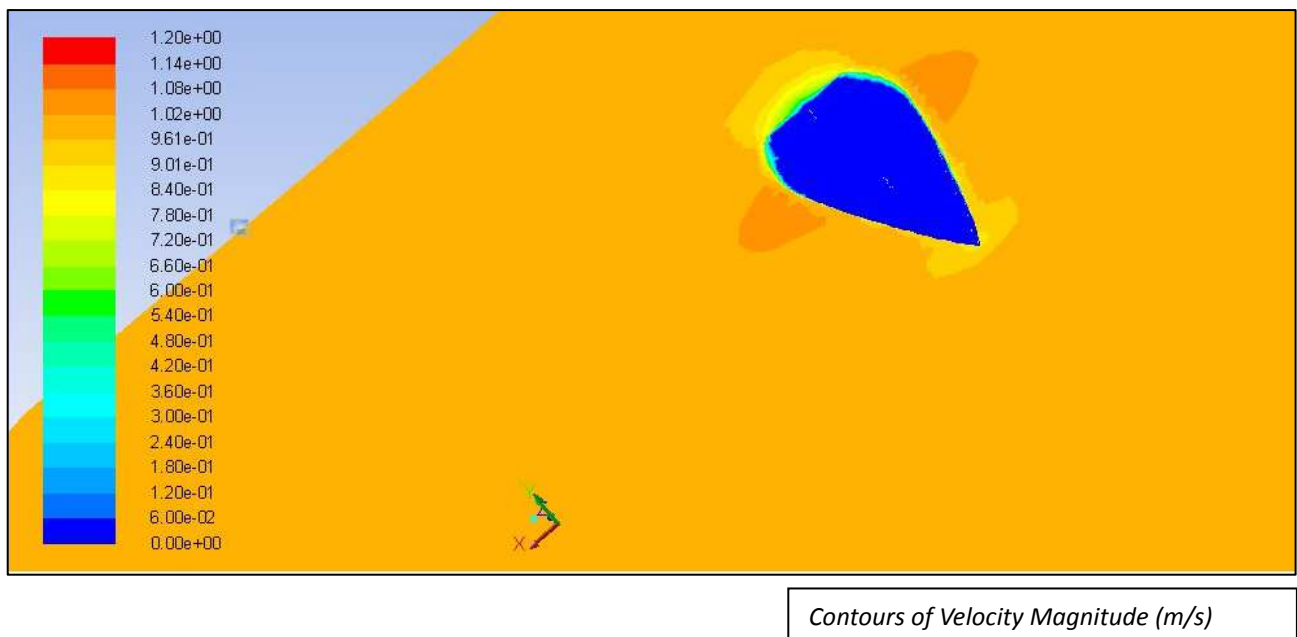
- ⇒ In the front view it is easily appreciable the direction of the flow of the water, which hits the bow side of the boat right ahead.

This is an easy way of observing and quickly analyze the parts of the boat in which the flow is causing more thrust. As expected, the bulb is one of the areas in which the pressure generated by the resistance to the flow is bigger (clearly visible red). As well as the bulb, the bow part of the hull also receives lots of pressure.

If any part was mistaken or badly designed this would be an effective tool to detect errors and excessive pressure, in any part of the geometry.

(I leave the control volume aside because its study does not interest me, it is only a way of making the analysis of the geometry of the boat.)

- ⇒ The next diagram shows the geometry of the Hull and the Free-surface parts in a **Velocity Magnitude contours map:**



- ⇒ The scale in the right this time represents the velocity magnitude of the flow in m/s.

The Fluent software offers a must more wider amount of possibilities that the ones that I have developed. Nevertheless, I have used the methods and procedures that I think are more useful for the analysis of the geometry of the boat from a fluid-dynamic point of view, among the rest of possibilities that the Fluent software provides.

- **CASE Nº 2**

**1 m/s unidirectional flow with an inclination of 30°**

The inclination in the direction of the flow is 30° regarding the Z axis. This means the flow will enter this time both from the **INLET** and from a **lateral side** of the control volume.

Because of this new situation, I have to go back to the ICEM CFD program and change the boundary conditions of the control volume. They will be all the same as before except for the former Left-Right part (that included both lateral sides of the control volume).

Thus, this time the right side will act as the INLET part => BC => “velocity inlet”, whereas the left side will necessarily act as the OUTLET part => BC => “outflow”

The original Inlet and Outlet parts (as well as the rest of the geometry) will continue having the same properties and functions.

After changing the boundary conditions (but not the mesh) in the ICEM CFD I launch Fluent again and start all the arrangements needed for the new calculation. These operations and steps will be the same of the previous case (Case nº 1): check and scale the mesh, establish the boundary conditions from the Fluent software (with the new parameters of the left and right sides)...

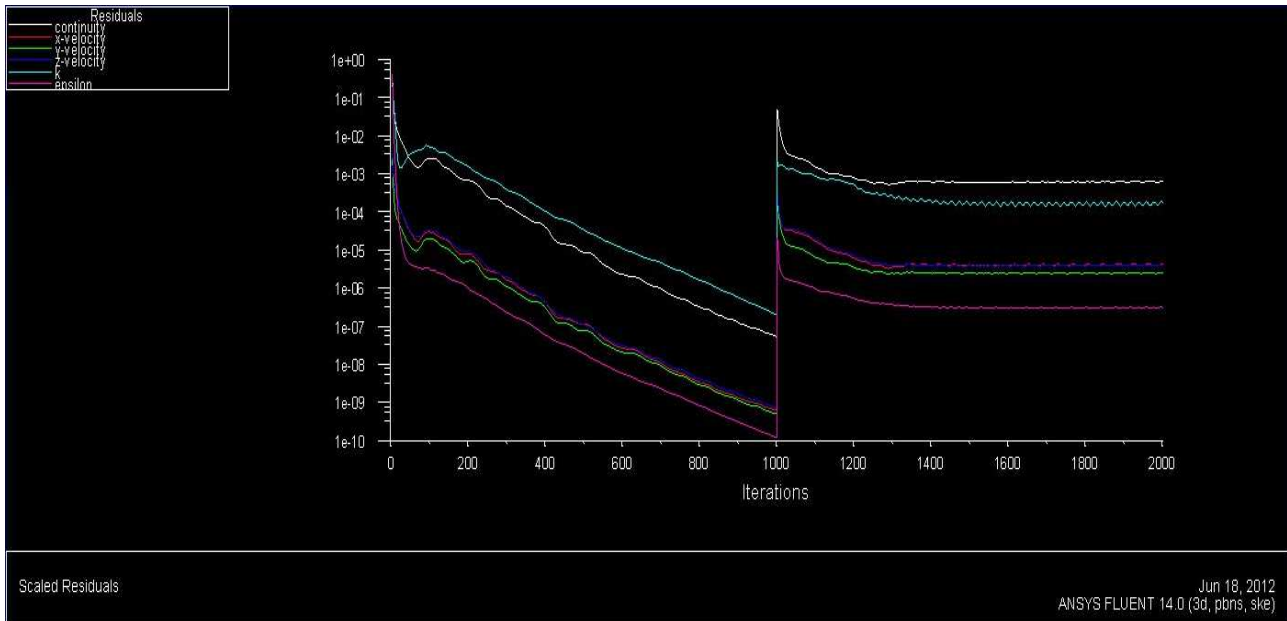
The only important peculiarity of the operations before the launch of the solver was the definition of the flow. This time, although the magnitude of the flow is still 1 m/s, I had to divide the vector into two components:

$$\Rightarrow V_x = \sin 30^\circ = 0'5 \text{ (m/s)}$$
$$\Rightarrow V_z = \cos 30^\circ = 0'867 \text{ (m/s)}$$

The direction of the flow is specified in the Boundary Conditions monitor of the Fluent software, the same monitor in which I had previously changed the BC of the Right and Left parts of the control volume.

- ⇒ Once all of this and the rest of the parameters (turbulence, etc) are arranged, I launch the solver again and wait for the results after the two series of iterations (2000 in total).

- **Residuals:**



*Diagram of the decrease of the mass continuity equation through the iterations*

- **Numerical results:**

Like in the previous case, the next diagrams show the outputs of the forces and coefficients under three diverse **direction vectors**:

⇒ **(1, 0, 0)**

|                           |  |            |           |                                    |            |           |
|---------------------------|--|------------|-----------|------------------------------------|------------|-----------|
| Net                       | 12.707173                              | -4.6873763 | 8.0197971 | 20.746406                          | -7.6528592 | 13.093546 |
| Forces                    |  |            |           |                                    |            |           |
| Zone                      | Forces (n)                             |            |           | Total                              |            |           |
| bulbo                     | Pressure                               |            |           | Viscous                            |            |           |
| deriva                    | (2.1377005 -2.7325296 0.25740179)      |            |           | (2.1325497 -0.57170385 4.1491735)  |            |           |
| hull                      | (16.093663 -0.00044716969 -0.45153902) |            |           | (0.45922074 -1.0130339 3.1515671)  |            |           |
| timone                    | (7.0360115 15.466068 0.055911023)      |            |           | (9.7747318 -2.8283317 21.751462)   |            |           |
|                           | (5.3023142 -0.025917892 -0.082070407)  |            |           | (0.17506544 -0.27430678 1.4258471) |            |           |
| Net                       | (30.569689 12.707173 -0.22029662)      |            |           | (43.111257 8.0197971 30.257753)    |            |           |
| Forces - Direction Vector | (1 0 0)                                |            |           |                                    |            |           |
| Zone                      | Forces (n)                             |            |           | Coefficients                       |            |           |
| bulbo                     | Pressure                               |            |           | Pressure                           |            |           |
| deriva                    | Viscous                                |            |           | Viscous                            |            |           |
| hull                      | Total                                  |            |           | Total                              |            |           |
| timone                    |  |            |           |                                    |            |           |
|                           | (2.1377005 2.1325497 4.2702502)        |            |           | (3.4901233 3.4817138 6.9718371)    |            |           |
|                           | (16.093663 0.45922074 16.552884)       |            |           | (26.275368 0.74974814 27.025116)   |            |           |
|                           | (7.0360115 9.7747318 16.810743)        |            |           | (11.487366 15.958746 27.446111)    |            |           |
|                           | (5.3023142 0.17506544 5.4773796)       |            |           | (8.6568395 0.28582113 8.9426606)   |            |           |
| Net                       | 30.569689                              |            |           | 70.385726                          |            |           |

⇒ (0, 1, 0)

|                                   |  |             |             |  |             |                                   |
|-----------------------------------|--|-------------|-------------|--|-------------|-----------------------------------|
| Net                               | -0.22029662                                | 30.47805    | 30.257753   | -0.35966795                                | 49.760081   | 49.400413                         |
| Forces                            |  |             |             |  |             |                                   |
| Zone                              | Forces (n)                                 |             |             | Viscous                                    |             | Total                             |
| bulbo                             | Pressure (2.1377005 -2.7325296 0.25740179) |             |             | Pressure (2.1325497 -0.57170385 4.1491735) |             | (4.2702502 -3.3042334 4.4065753)  |
| deriva                            | (16.093663 -0.00044716969 -0.45153902)     |             |             | (0.45922074 -1.0130339 3.1515671)          |             | (16.552884 -1.0134811 2.700028)   |
| hull                              | (7.0360115 15.466068 0.055911023)          |             |             | (9.7747318 -2.8283317 21.751462)           |             | (16.810743 12.637736 21.807373)   |
| timone                            | (5.3023142 -0.025917892 -0.082070407)      |             |             | (0.17506544 -0.27430678 1.4258471)         |             | (5.4773796 -0.30022467 1.3437767) |
| Net                               | (30.569689 12.707173 -0.22029662)          |             |             | (12.541568 -4.6873763 30.47805)            |             | (43.111257 8.0197971 30.257753)   |
| Forces - Direction Vector (0 1 0) |  |             |             |  |             |                                   |
| Zone                              | Forces (n)                                 |             |             | Coefficients                               |             |                                   |
| bulbo                             | Pressure                                   | Viscous     | Total       | Pressure                                   | Viscous     | Total                             |
| bulbo                             | -2.7325296                                 | -0.57170385 | -3.3042334  | -4.4612727                                 | -0.93339405 | -5.3946668                        |
| deriva                            | -0.00044716969                             | -1.0130339  | -1.0134811  | -0.00073007296                             | -1.6539329  | -1.654663                         |
| hull                              | 15.466068                                  | -2.8283317  | 12.637736   | 25.250723                                  | 4.6176844   | 20.633039                         |
| timone                            | -0.025917892                               | -0.27430678 | -0.30022467 | -0.042314925                               | -0.4478478  | -0.49016273                       |
| Net                               | 12.707173                                  | -4.6873763  | 8.0197971   | 20.746406                                  | -7.6528592  | 13.093546                         |

⇒ (0, 0, 1)

|                                   |  |            |              |                                    |            |                                   |
|-----------------------------------|--|------------|--------------|------------------------------------|------------|-----------------------------------|
| Net                               | 12.707173                              | -4.6873763 | 8.0197971    | 20.746406                          | -7.6528592 | 13.093546                         |
| Forces                            |  |            |              |                                    |            |                                   |
| Zone                              | Forces (n)                             |            |              | Viscous                            |            | Total                             |
| bulbo                             | Pressure                               |            |              |                                    |            |                                   |
| deriva                            | (2.1377005 -2.7325296 0.25740179)      |            |              | (2.1325497 -0.57170385 4.1491735)  |            | (4.2702502 -3.3042334 4.4065753)  |
| hull                              | (16.093663 -0.00044716969 -0.45153902) |            |              | (0.45922074 -1.0130339 3.1515671)  |            | (16.552884 -1.0134811 2.700028)   |
| timone                            | (7.0360115 15.466068 0.055911023)      |            |              | (9.7747318 -2.8283317 21.751462)   |            | (16.810743 12.637736 21.807373)   |
|                                   | (5.3023142 -0.025917892 -0.082070407)  |            |              | (0.17506544 -0.27430678 1.4258471) |            | (5.4773796 -0.30022467 1.3437767) |
| Net                               | (30.569689                             | 12.707173  | -0.22029662) | (12.541568                         | -4.6873763 | 30.47805)                         |
|                                   |  |            |              | (43.111257 8.0197971 30.257753)    |            |                                   |
| Forces - Direction Vector (0 0 1) |  |            |              |                                    |            |                                   |
| Zone                              | Forces (n)                             |            |              | Coefficients                       |            |                                   |
| bulbo                             | Pressure                               | Viscous    | Total        | Pressure                           | Viscous    | Total                             |
| deriva                            | 0.25740179                             | 4.1491735  | 4.4065753    | 0.42024782                         | 6.7741609  | 7.1944087                         |
| hull                              | -0.45153902                            | 3.1515671  | 2.700028     | -0.73720657                        | 5.1454156  | 4.408209                          |
| timone                            | 0.055911023                            | 21.751462  | 21.807373    | 0.091283303                        | 35.512591  | 35.603874                         |
|                                   | -0.082070407                           | 1.4258471  | 1.3437767    | -0.1339925                         | 2.3279137  | 2.1939212                         |
| Net                               | -0.22029662                            | 30.47805   | 30.257753    | -0.35966795                        | 49.760081  | 49.400413                         |

This time, the direction of the flow has an inclination of 30° regarding the Z axis. The results are very different in every of the three direction vector analyzed.

In general, the forces are bigger than the forces in the case nº 1. This is especially notable in the (1, 0, 0) direction vector, where the forces increase from almost zero in nº 1 case (0'064N) to 43'11N. The biggest increase is in the Hull and the Deriva.

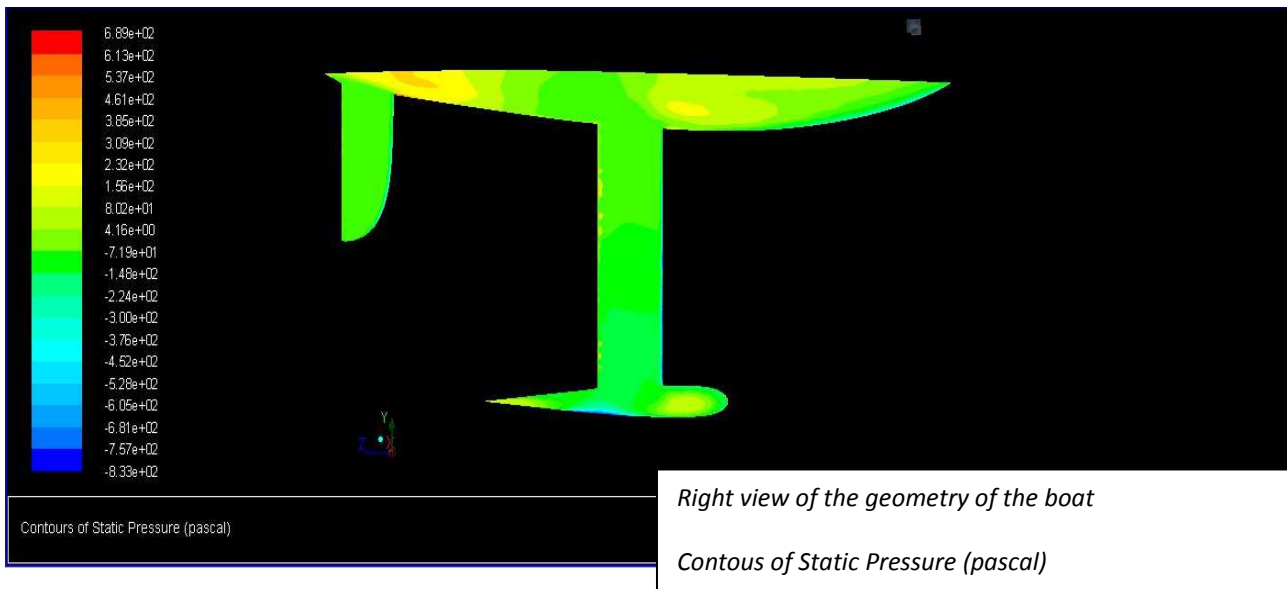
In the (0, 1, 0) vector the net forces result this time positive.

The increase is notable as well in the (0, 0, 1) direction vector, from 1'282N to 30'25N. The bigger increase is in this case in the Hull.

The inclination of the flow is thereby determinant for the response of the boat, the forces are much bigger. The Hull becomes a determinant part, as it suffers the biggest increase of the forces values.



- **Contour maps:**



- ⇒ In this case, the difference between the previous case and this one is easily appreciable. The reason is the change in the direction of the flow, as nothing else has changed.
- ⇒ The range of pressures is, however, wider in this case than in the previous, and it is concentrated in a discontinuous way along the surface of the Hull.

• **CASE Nº 3**

**1 m/s unidirectional flow with an inclination of 45°**

The inclination in the direction of the flow is 45° regarding the Z axis. Again, this means the flow will enter this time both from the **INLET** and from a **lateral side** of the control volume.

- ⇒ This time, I have everything arranged for the use of the same mesh and the same parameters in the Fluent software. The only thing I have to change is the direction of the flow.

In the BC monitor of the Fluent program I change the components of the flow vector. Its magnitude will continue to be 1 m/s:

- ⇒  $V_x = \sin 45^\circ = 0.7071 \text{ (m/s)}$
- ⇒  $V_z = \cos 45^\circ = 0.7071 \text{ (m/s)}$

I will carry out the same operations than in the two previous processes.

- **Residuals:**

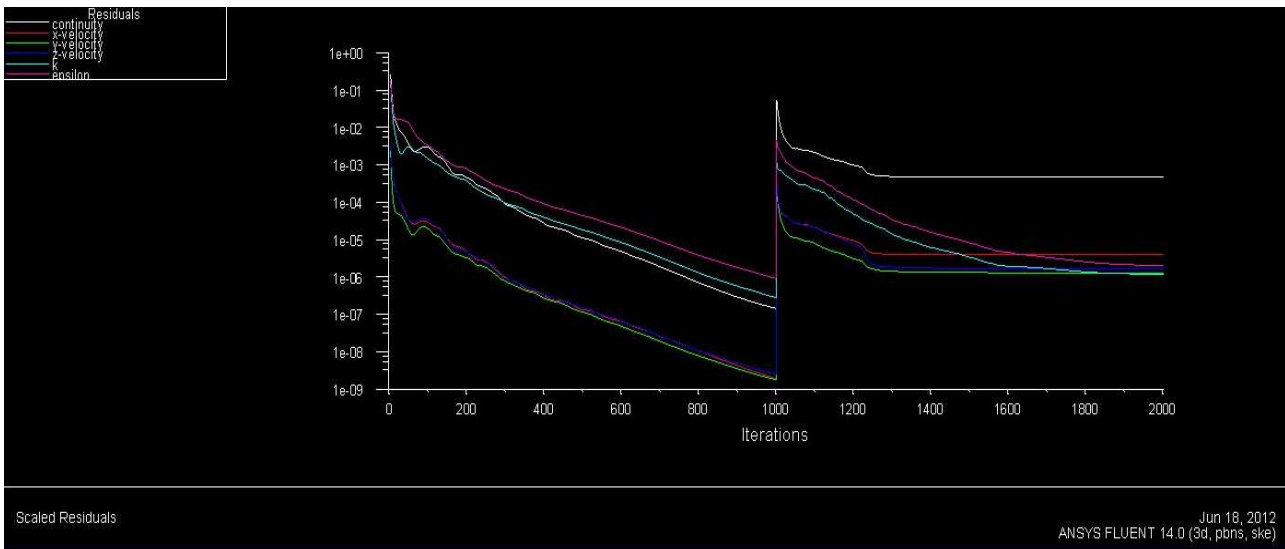


Diagram of the decrease of the mass continuity equation through the iterations

- **Numerical results:**

Outputs for the three different **direction vectors**:

⇒ **(1, 0, 0)**

Reading "/home/tesisti/Velante/mar1(45gradi).dat"...  
Done.

| Forces |                                       | Forces (n) |  | Viscous                                 |  | Total |                                       |
|--------|---------------------------------------|------------|--|---|--|-------|---------------------------------------|
| Zone   | Pressure                              |            |  |   |  |       |                                       |
| bulbo  | (4.5383292 -3.2544629 0.17846608)     |            |  | (0.064788881 -0.025942899 0.10288398)   |  |       | (4.603118 -3.2804058 0.28135006)      |
| deriva | (22.303278 -0.00089286061 -0.6187682) |            |  | (0.023060788 -0.017572546 0.069981257)  |  |       | (22.326339 -0.018465407 -0.54878695)  |
| hull   | (12.365868 13.023118 0.071258361)     |            |  | (0.19165833 -0.065418754 0.2976733)     |  |       | (12.557526 12.957699 0.36893166)      |
| timone | (7.797284 -0.058496331 -0.13557609)   |            |  | (0.0086582163 -0.014824488 0.036975621) |  |       | (7.8059423 -0.073320819 -0.098600469) |
| Net    | (47.004759 9.7092654 -0.50461985)     |            |  | (0.28816622 -0.12375869 0.50751416)     |  |       | (47.292925 9.5855067 0.0028943039)    |

| Forces - Direction Vector (1 0 0) |           | Forces (n)   |           | Coefficients |             | Total     |  |
|-----------------------------------|-----------|--------------|-----------|--------------|-------------|-----------|--|
| Zone                              | Pressure  | Viscous      | Total     | Pressure     | Viscous     | Total     |  |
| bulbo                             | 4.5383292 | 0.064788881  | 4.603118  | 7.409517     | 0.10577776  | 7.5152947 |  |
| deriva                            | 22.303278 | 0.023060788  | 22.326339 | 36.413515    | 0.037650265 | 36.451166 |  |
| hull                              | 12.365868 | 0.19165833   | 12.557526 | 20.189172    | 0.31291157  | 20.502084 |  |
| timone                            | 7.797284  | 0.0086582163 | 7.8059423 | 12.73026     | 0.014135863 | 12.744396 |  |
| Net                               | 47.004759 | 0.28816622   | 47.292925 | 76.742464    | 0.47047546  | 77.21294  |  |

The results on this direction vector are similar to the 30° inclination ones. The net force is a bit bigger.

⇒ (0, 1, 0)

|                           |                                       |              |              |   |              |                                       |
|---------------------------|---------------------------------------|--------------|--------------|---|--------------|---------------------------------------|
| Net                       | 47.004759                             | 0.28816622   | 47.292925    | 76.742464                               | 0.47047546   | 77.21294                              |
| Forces                    |                                       |              |              |   |              |                                       |
| Zone                      | Forces (n)                            |              |              | Viscous                                 |              | Total                                 |
| bulbo                     | Pressure                              |              |              |   |              |                                       |
| deriva                    | (4.5383292 -3.2544629 0.17846608)     |              |              | (0.064788881 -0.025942899 0.10288398)   |              | (4.603118 -3.2804058 0.28135006)      |
| hull                      | (22.303278 -0.00089286061 -0.6187682) |              |              | (0.023060788 -0.017572546 0.069981257)  |              | (22.326339 -0.018465407 -0.54878695)  |
| timone                    | (12.365868 13.023118 0.071258361)     |              |              | (0.19165833 -0.065418754 0.2976733)     |              | (12.557526 12.957699 0.36893166)      |
|                           | (7.797284 -0.058496331 -0.13557609)   |              |              | (0.0086582163 -0.014824488 0.036975621) |              | (7.8059423 -0.073320819 -0.098600469) |
| Net                       | (47.004759 9.7092654 -0.50461985)     |              |              | (0.28816622 -0.12375869 0.50751416)     |              | (47.292925 9.5855067 0.0028943039)    |
| Forces - Direction Vector | (0 1 0)                               |              |              |   |              |                                       |
| Zone                      | Forces (n)                            |              |              | Coefficients                            |              |                                       |
| bulbo                     | Pressure                              | Viscous      | Total        | Pressure                                | Viscous      | Total                                 |
| deriva                    | -3.2544629                            | -0.025942899 | -3.2804058   | -5.3134089                              | -0.042355754 | -5.3557646                            |
| hull                      | -0.00089286061                        | -0.017572546 | -0.018465407 | -0.0014577316                           | -0.028689871 | -0.030147603                          |
| timone                    | 13.023118                             | -0.065418754 | 12.957699    | 21.262233                               | -0.10680613  | 21.155427                             |
|                           | -0.058496331                          | -0.014824488 | -0.073320819 | -0.095504214                            | -0.024203245 | -0.11970746                           |
| Net                       | 9.7092654                             | -0.12375869  | 9.5855067    | 15.851862                               | -0.202055    | 15.649807                             |

⇒ (0, 0, 1)

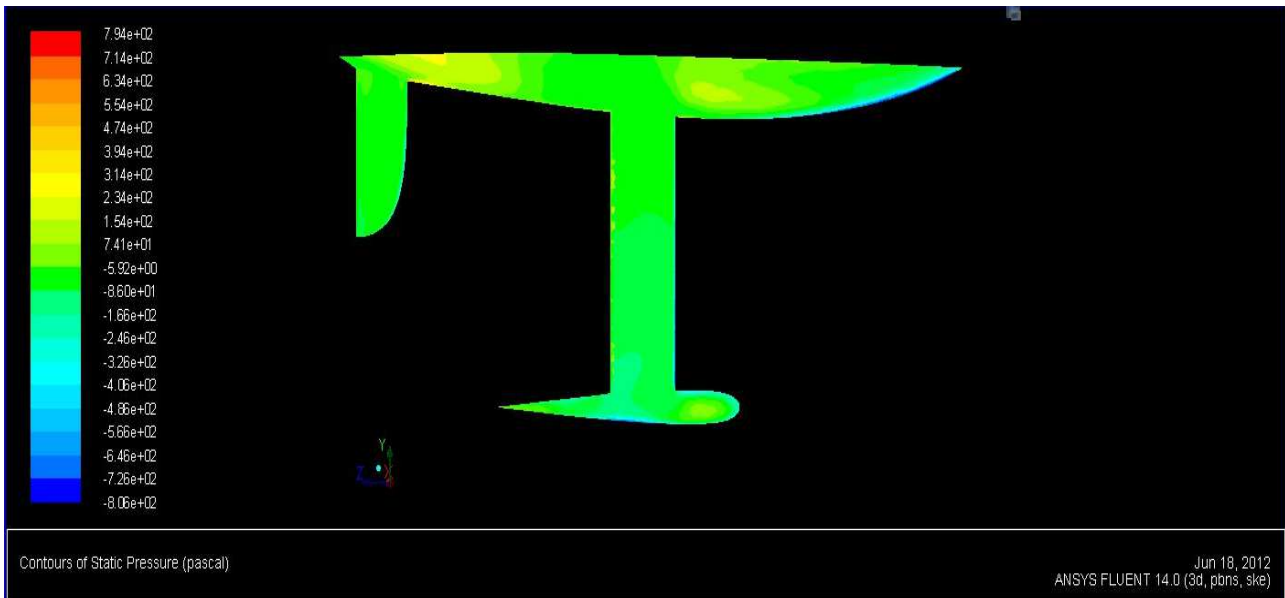
|                                   |  |             |              |   |             |                                       |
|-----------------------------------|--|-------------|--------------|---|-------------|---------------------------------------|
| Net                               | 9.7092654                                  | -0.12375869 | 9.5855067    | 15.851862                               | -0.202055   | 15.649807                             |
| Forces                            |  |             |              |   |             |                                       |
| Zone                              | Forces (n)                                 |             |              | Viscous                                 |             | Total                                 |
| bulbo                             | Pressure (4.5383292 -3.2544629 0.17846608) |             |              | (0.064788881 -0.025942899 0.10288398)   |             | (4.603118 -3.2804058 0.28135006)      |
| deriva                            | (22.303278 -0.00089286061 -0.6187682)      |             |              | (0.023060788 -0.017572546 0.069981257)  |             | (22.326339 -0.018465407 -0.54878695)  |
| hull                              | (12.365868 13.023118 0.071258361)          |             |              | (0.19165833 -0.065418754 0.2976733)     |             | (12.557526 12.957699 0.36893166)      |
| timone                            | (7.797284 -0.058496331 -0.13557609)        |             |              | (0.0086582163 -0.014824488 0.036975621) |             | (7.8059423 -0.073320819 -0.098600469) |
| -----                             |  |             |              |   |             |                                       |
| Net                               | (47.004759                                 | 9.7092654   | -0.50461985) | (0.28816622 -0.12375869 0.50751416)     |             | (47.292925 9.5855067 0.0028943039)    |
| Forces - Direction Vector (0 0 1) |  |             |              |   |             |                                       |
| Zone                              | Forces (n)                                 |             |              | Coefficients                            |             |                                       |
|                                   | Pressure                                   | Viscous     | Total        | Pressure                                | Viscous     | Total                                 |
| bulbo                             | 0.17846608                                 | 0.10288398  | 0.28135006   | 0.29137319                              | 0.16797384  | 0.45934704                            |
| deriva                            | -0.6187682                                 | 0.069981257 | -0.54878695  | -1.0102338                              | 0.11425511  | -0.89597869                           |
| hull                              | 0.071258361                                | 0.2976733   | 0.36893166   | 0.11634018                              | 0.48599722  | 0.6023374                             |
| timone                            | -0.13557609                                | 0.036975621 | -0.098600469 | -0.22134872                             | 0.060368361 | -0.16098036                           |
| -----                             |  |             |              |   |             |                                       |
| Net                               | -0.50461985                                | 0.50751416  | 0.0028943039 | -0.82386915                             | 0.82859454  | 0.0047253942                          |
| -----                             |  |             |              |   |             |                                       |

The same happens in the (0, 1, 0) direction vector, the net force is a bit bigger than in the second case.

The results for the (0, 0, 1) direction vector show a very notable decrease of the overall forces and coefficients.

⇒ All along the process of analysis with Fluent, it is very important to have a well-scaled mesh. When a result seems to be too big or too little, or there is a big change where it should not be, it is recommendable to check the scale of the mesh, before reaching wrong conclusions.

- **Contour map:**



*Right view of the geometry of the boat*

*Contours of Static Pressure (pascal)*

⇒ The results do not differ much from the results of the previous case (nº 2).

Fluent has turned out to be a **very efficient and potent software** for a fluid-dynamic analysis of a geometry. It has a vast amount of possibilities and options, and the range of work available is very wide.

Because of this, I think that my study of the program and my application of it has represented only a fraction of the potential resources the program offers. Nevertheless, this portion has proved to be valid and has helped me achieve the results I was seeking.

However, it cannot be forgotten all the tedious work the previous arrangement of the geometry has given me, although it did not seem like it in the beginning.

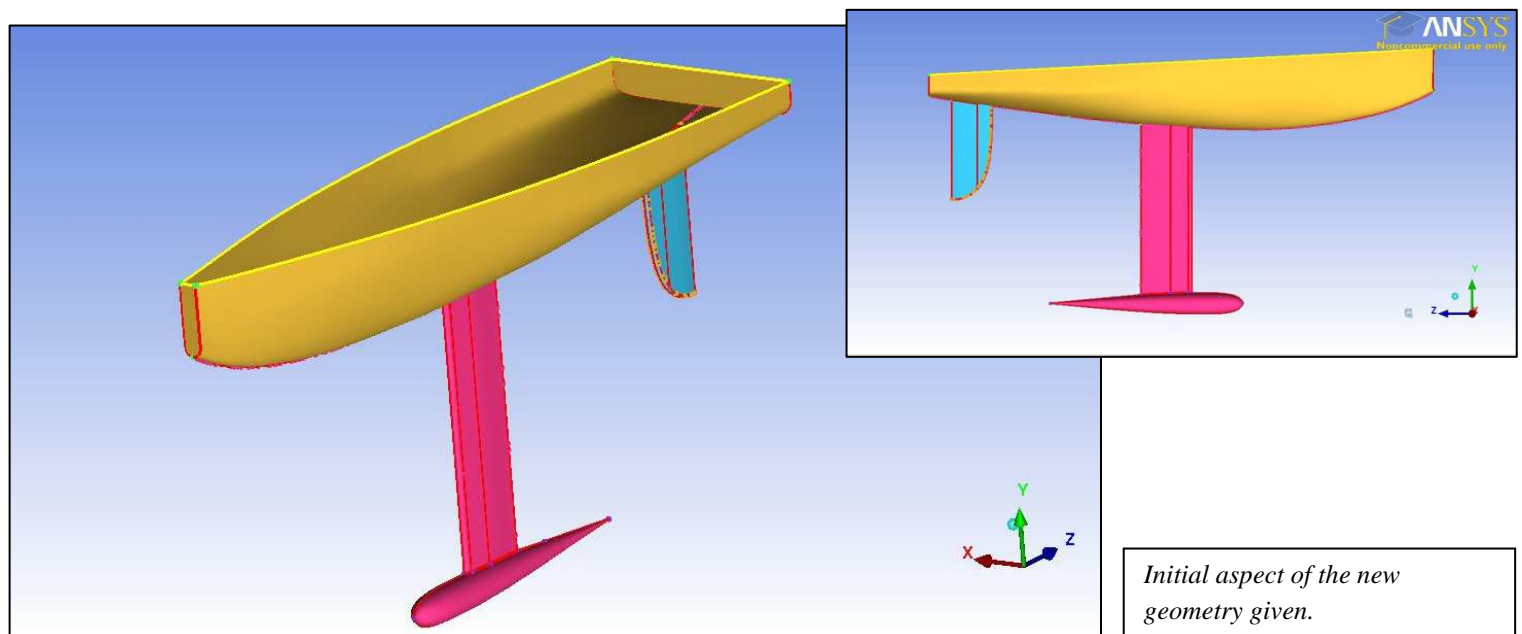
## SECOND PERIOD. ANALYSIS OF THE OVERALL GEOMETRY

During the second period of my study of the geometry, I carried out the study of the geometry of the whole Hull as well as the Daggerboard and Rudder. The geometry was no longer representative of only the underbody part of the boat, but also the some parts of the “dead works” (the whole of the Hull, leaving apart the study of the sails).

This way, I was given a new geometry file upon which a new mesh had to be built. The way I built the mesh was using the same ANSYS ICEM CFD program. It represents a new opportunity to create a mesh applying all the experience gained during the first period.

In the next paragraphs I explain the process followed towards the creation of a new mesh from the new geometry.

### Creation of a new mesh from the new geometry:



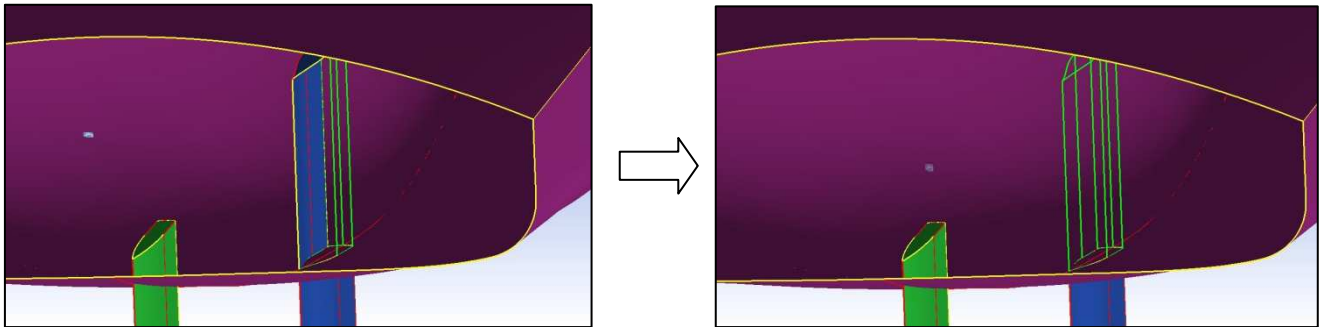
As well as during the first period, the first work is the preparation of the geometry for my purpose, the creation of the mesh.

The process was similar to the previous one: cleaning the geometry, creation of the control volume, creation of the mesh, correction of mistakes and the final checkout.

Most of the problems found were the same or similar to the previous ones, especially during the part of the creation of the mesh. Nevertheless, there have been other peculiarities to which new solutions have been applied.

### - Cleaning the geometry:

It was carried out using the same methods of the previous process. This time, the Build Topology command was frequently used from the beginning and the results were acceptable.



*The elimination process of the intern part of the rudder (green) and daggerboard (blue)*

The upper surface of the hull, visible in the images above, was also eliminated. However, the main difference from the underbody geometry was that the hull had an intern surface, which had to be eliminated as well. The frontal and back sides gave some problems with the Build Topology, but were finally corrected.

⇒ **For the creation or arrangement of the geometry a good pattern is to try to make things as simple as possible.** This means trying to use the simplest method or, if there is a certain spot of the geometry that gives problems, trying to reduce the amount of existing curves or surfaces (if possible).

After arranging the geometry, I made another Build Topology with a 0'3 tolerance (the same tolerance as in the first period). Everything was fine, so I proceeded to the creation of the control volume.

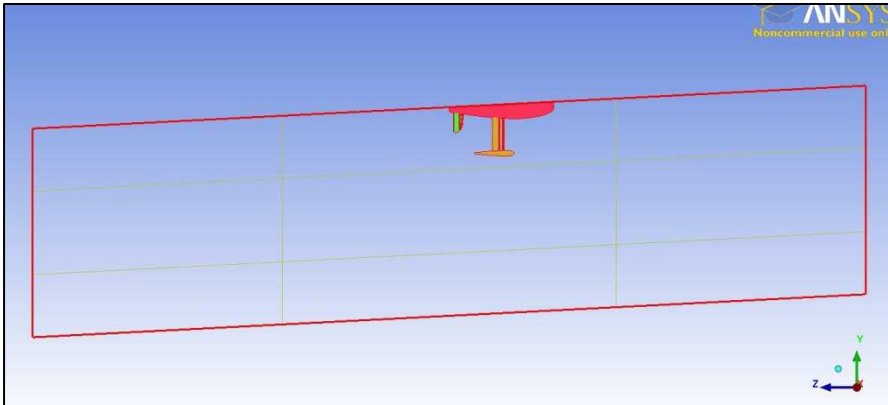
### - Creation of the control volume:

A similar control volume to the one in the previous period had to be done. The sizes were approximately the same as in the previous one.

This time, the difference was the disposition of the geometry. While in the previous geometry the superior curves of the hull had the same coordinate Y (they were contained in the same horizontal plane), this time the curves of the hull were inclined (contained in an oblique plane).

I had to calculate the inclination angle and with it, program the coordinates of the points that would later become the vertices of the control volume. The width of the angle was 2'9521°





In the image in the left the inclination of the control volume, as a consequence of the inclination of the hull's upper curves, can be easily appreciated.

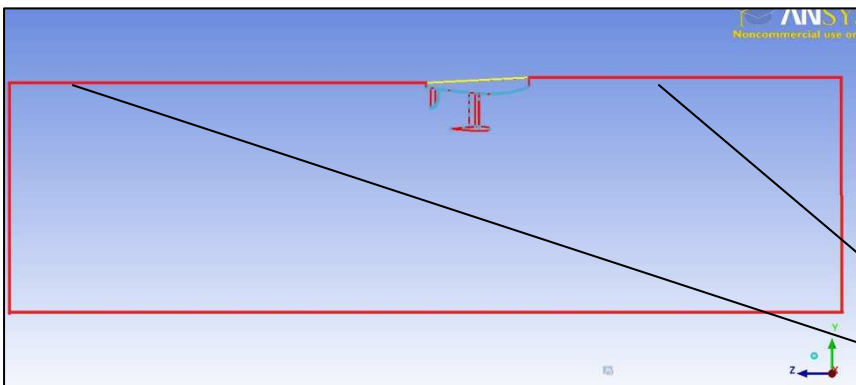
I created the control volume this way thinking that the inclination of the

upper and lower surfaces would not be a problem later.

However, I was wrong, since the flow of the later simulation had to go in the direction of the Z axis (not inclined). This way, I had to change the control volume appearance.

⇒ New appearance of the control volume:

A simple solution was found. The later attempt had been useful because the part of the surface in both of the sides of the hull had to be necessarily inclined. I changed the rest of it, with this result:



*Right view of the geometry.*

*Uniform height on both frontal and back surfaces:*

*Frontal => inlet height*

*Back => outlet height*

The control volume is similar to the one of the first period with the exception of the surfaces on the sides of the hull, that remain inclined.

However, this inclination did lead to a complication in the creation of the mesh, as there had to be different surfaces forming the upper surface of the control volume.

Before creating the mesh, I closed the control volume creating the surfaces needed. When everything seemed fine, after the Build Topology command usage, I started with the mesh.

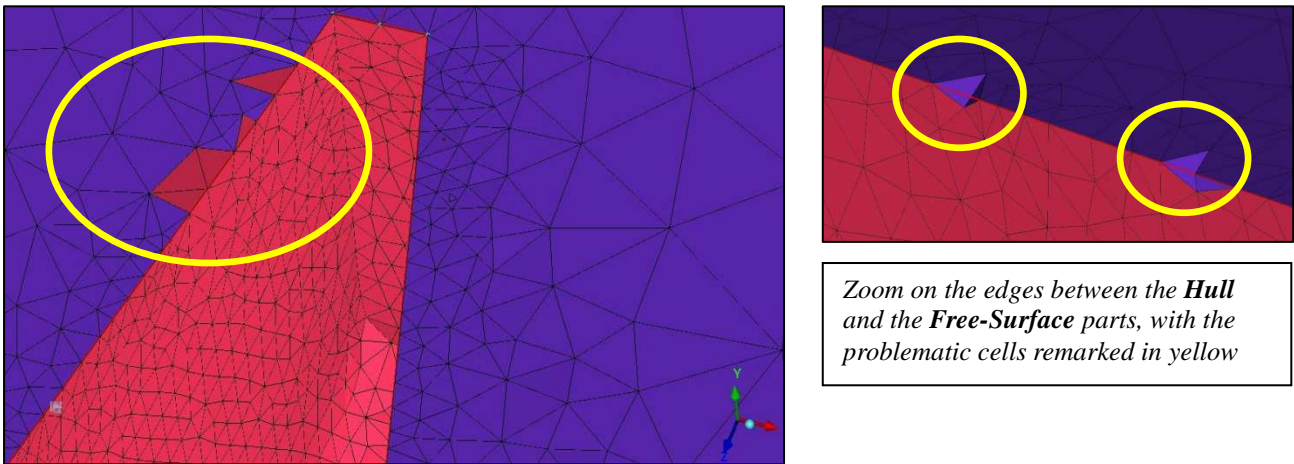


- **Creation of the mesh:**

Once the geometry was ready I started with the mesh. This time, I applied all the experience gained during the work with the previous model, using from the beginning the same commands and methods that had given a good result previously.

I thereby applied the Volume Mesh method, with the same parameters (the most important of them, the Edge Criterion = 0'04). I also programmed the daggerboard and the rudder cells to have a certain maximum size (changing it a couple of times before having good results).

Although the mesh seemed to be fine, a closer look to the areas where the Hull and the Free-Surface are attached revealed some classic problems. An example of them it is shown below:



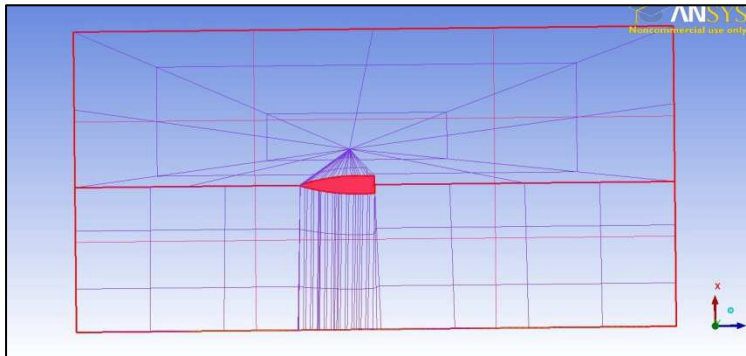
As it is seen above, some cells delimiting the edge formed by the union of the Hull and the Free-Surface give problems. An accurate mesh cannot have wrongly delimited edges, so the amend of these problems is necessary.

I tried three different solutions, being the third one the only successful:

- Usage of the Edit Mesh commands. None of them could correct them.
- Change of the cell size, in both the free surface and the hull parts. It was not successful either.
- Division of the upper part of the control volume (Free-Surface) into different surfaces.

As usual, the problem is because of the geometry. Although it seemed to be suitable for the creation of an accurate mesh, the geometry was the reason for the problems shown above. The reason was that the Free-Surface was not really accurate enough when it came to the problematic edges (between the Hull and the control volume).

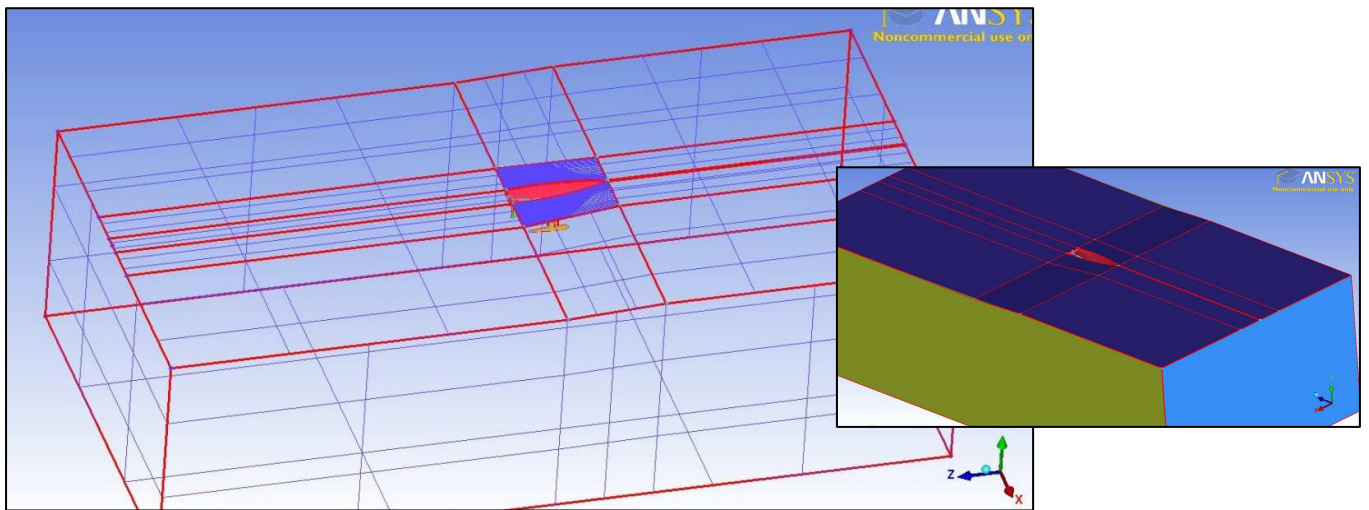
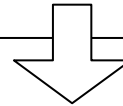
With a graphical view the solution is easily understandable:



*Above, it is shown the Free-Surface formed with **only two surfaces***

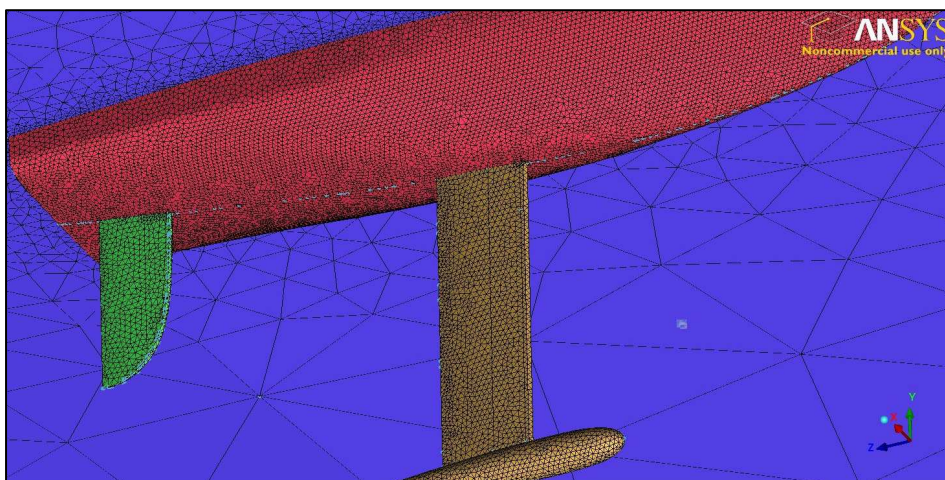
*Below, the same Free-Surface formed by **multiple surfaces***

*View of the control volume with opaque surfaces*



After this operation, I have to re-mesh the whole geometry. A recommendable pattern is the elimination of the lines that delimit the different surfaces of the Free-Surface, this way the mesh gives less problems. Although it may seem like a contradictory pattern, the point of having created so many surfaces was assuring that the mesh in the problematic edges was accurate.

- ⇒ The mesh is finally accurate and good, and it is ready to carry out all the checkouts. The problems in the edges are finally solved and the rest of the parts are the way I expected.



*View from the inside of the control volume of the mesh in the Hull (red), Daggerboard (yellow) and Rudder (green)*

There is only one operation left, the application of the **mesh density**.

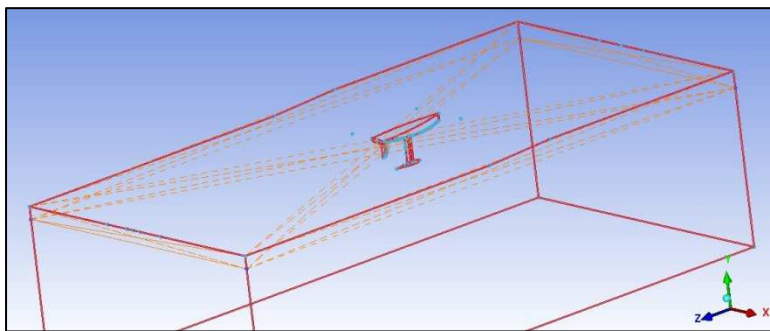
- **Use of the Mesh Density:**

Although the mesh is good enough to carry out the checkouts and to use it with the solver, the use of the mesh at this point would not be as accurate as it could be with a simple operation.

In order to make the mesh more dense in the interesting parts I apply the “Mesh Density” command. This command allows me to delimitate an area of the geometry in which the mesh has to be more dense (depending on the parameters given).

The result will be visible in the general view of the control volume, and will affect the specific delimited area, decreasing its density progressively from it as it continues to the rest of the body.

In this case, the interesting part of the control volume is the boat surface and the area that surrounds it:



*In orange, the delimited area in which the mesh will be denser*

⇒ The **maximum size** of the cells in the delimited area will be **50** (compared to 10 in the daggerboard, for example), and a **ratio** of **1'2**.

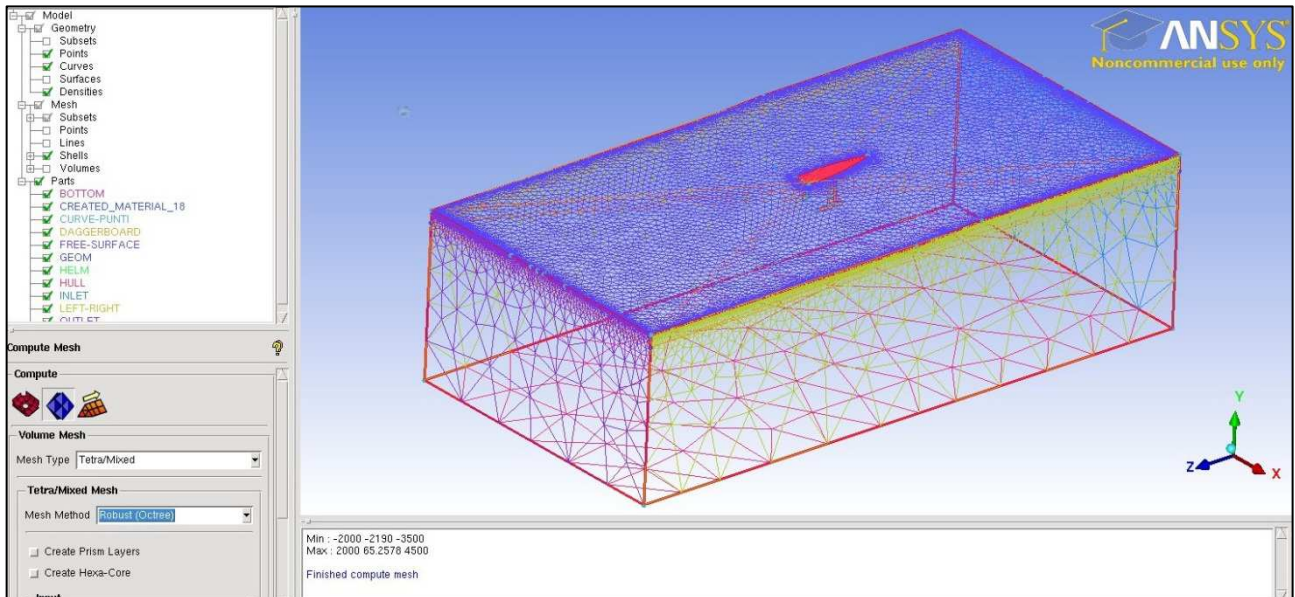
This way, applying the mesh density parameters, I re-mesh the geometry again. The mesh would be the same as the last one, with the only difference that the size of the cells in the delimited area would be now smaller, making the further study more accurate.

After the successful compilation of the mesh, I carried out the checkouts (Smooth Mesh, Check Mesh).

⇒ A general view of the appearance of the mesh achieved it is shown in the next page.



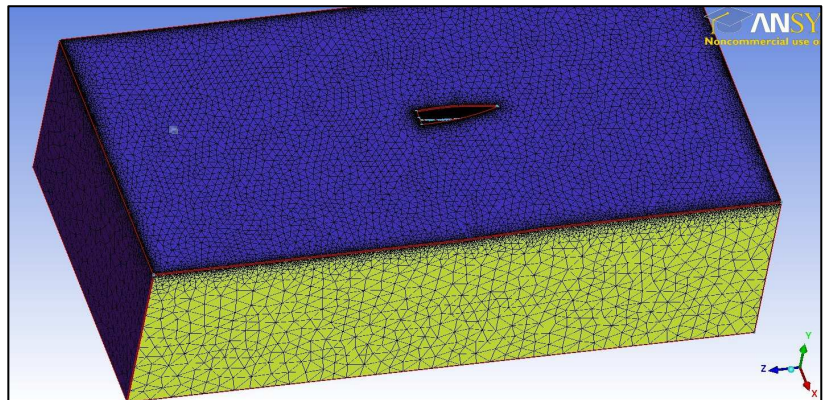
**The final appearance of the mesh**, in an overall view and after having made all the checkouts (Smooth Mesh, Check Mesh...), is shown in the image below:



*Upper image, final appearance of the overall mesh*

*Right, the control volume with opaque cells*

*The density mesh usage is easily visible*



**At last, everything is ready for the launch of the Solver.**

# CONCLUSIONS

My work within the “Velante” Project has involved various activities, from the manipulation of materials and the use of different procedures for the construction of a sailboat prototype, to the learning and use of the analysis software of Fluent or ANSYS ICEM CFD.

In the construction part I have learned more deeply what a sailboat is and how it works. Above all, now I am familiar with the IOM class sailboats and all the regulations it involves. I have found very interesting this competition, specially the idea of the design and construction of a sailboat without advanced tools or materials, except certain exceptions like the carbon fiber.

I have also found very interesting the possibility of making our own components of the boat, assemble them together and test them in the final proof that was the participation in a competition among other IOM class sailboats (in Bisceglie, Puglia, April 1<sup>st</sup> 2012).

The second part of my work has been the most interesting part of my stay here in Bari. It has offered me the possibility to learn the usage of both ANSYS ICEM CFD program and the Fluent software. I have found both programs useful for the development of my work.

The ANSYS ICEM CFD program has proved to be a good tool for the creation of a mesh. After a series of unsuccessful attempts, and with all the experience gained in the process, the creation of a suitable mesh for a geometry becomes a relatively mechanical process. Nevertheless, it can be longer than expected. The creation of a good mesh is absolutely essential for a later analysis with Fluent.

The work with Fluent has not been as intuitive as the work with the ICEM CFD program. It is a software that requires more knowledge and perhaps a previous learning, before achieving agility and skill with it. The software offers a great amount of possibilities. Among all the possible applications, I have used those which I have found more interesting and efficient for the results I was seeking.

As a final conclusion, I am glad for the opportunity of developing my thesis in the Politecnico di Bari, as it has offered me the possibility to participate in the process of the construction and design of a sailboat, as well as the learning of the two analysis programs. This is something I hardly could have done if I had remained in my University.

The final positive aspect is the development of my work in a different language, which I have found very enriching and challenging.

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- ⇒ Principles of yacht design – Larsson, Eliasson
- ⇒ [www.wikipedia.org](http://www.wikipedia.org)
- ⇒ ICEM CFD and FLUENT user manuals

## Appendix 1

### **BRIEF DESCRIPTION OF THE MAIN REGULATIONS OF IOM** **("International One Meter" Class boats)**

The **International One Metre (IOM)** is a class of Radio Sailing Boat used for racing under the International Sailing Federation Racing Rules of Sailing. It is a measurement-controlled box rule originally created by the ISAF-RSD (now the International Radio Sailing Association) in 1988 in an attempt to harmonize the different rules created around the world.

The IOM Class Regulation specifies a standardized sail plan and control of the other major performance dimensions (displacement, length, and draught) while allowing some freedom in the hull design.

In rough order of importance, the performance of a RC (Radio Controlled) yacht is a function of the following parameters:

| Parameter          | Restricted |  |
|--------------------|------------|--|
| Mono/multi-hull    | yes        | Mono-hull  |
| Sail area          | yes        | 3 rigs only<br>"A" approx 6000 sq cm<br>"B" approx 4100 sq cm<br>"C" approx 2700 sq cm |
| Bulb draft         | yes        | 420mm max  |
| Ballast ratio      | yes        | 62.5% max (2500g bulb max)   |
| <b>Hull length</b> | <b>yes</b> | <b>1000mm</b>  |
| Sail aspect ratio  | yes        | "A" rig approx 4.8   |
| Displacement       | yes        | 4000g minimum  |
| Rig plan           | yes        | Bermuda sloop, 7/8 fractional rig  |
| Beam               | no         |  |

- ⇒ It is interesting to note that, of all the major performance factors, only the beam of the hull has been left free by the IOM class rules. It is therefore primarily differing beams, and positions of maximum beam, which currently distinguish the different IOM designs.



In addition to performance factors, the class rules explicitly restrict certain materials and construction methods in order to keep the class **inexpensive and able to be built by an amateur builder**.

Radio control is restricted to two channels. It is interesting to note that the appendages and sails can be made of any material, and it is currently doubtful whether an amateur builder can realistically manufacture a fin to the same quality and standards as a professional builder. The rest of a competitive boat, though, can be built at home.

| Item              | Restricted |   |
|-------------------|------------|---|
| Hull materials    | yes        | Wood, glass fibre, resin  |
| Sail materials    | no         |   |
| Sail construction | yes        | "Soft" sails<br>Limits on panels, seams, reinforcements, battens, etc |
| Bulb materials    | yes        | Lead  |
| Spar materials    | yes        | Wood, aluminum  |
| Fin, rudder       | no         |   |
| Radio control     | yes        | 2 channels  |
| Rig construction  | yes        | Limits on shrouds, spreaders, stays, gooseneck, kicking strap, etc    |
| Rig materials     | yes        | Steel wire, polymer   |

## Appendix 2

### ANSYS ICEM CFD program DESCRIPTION

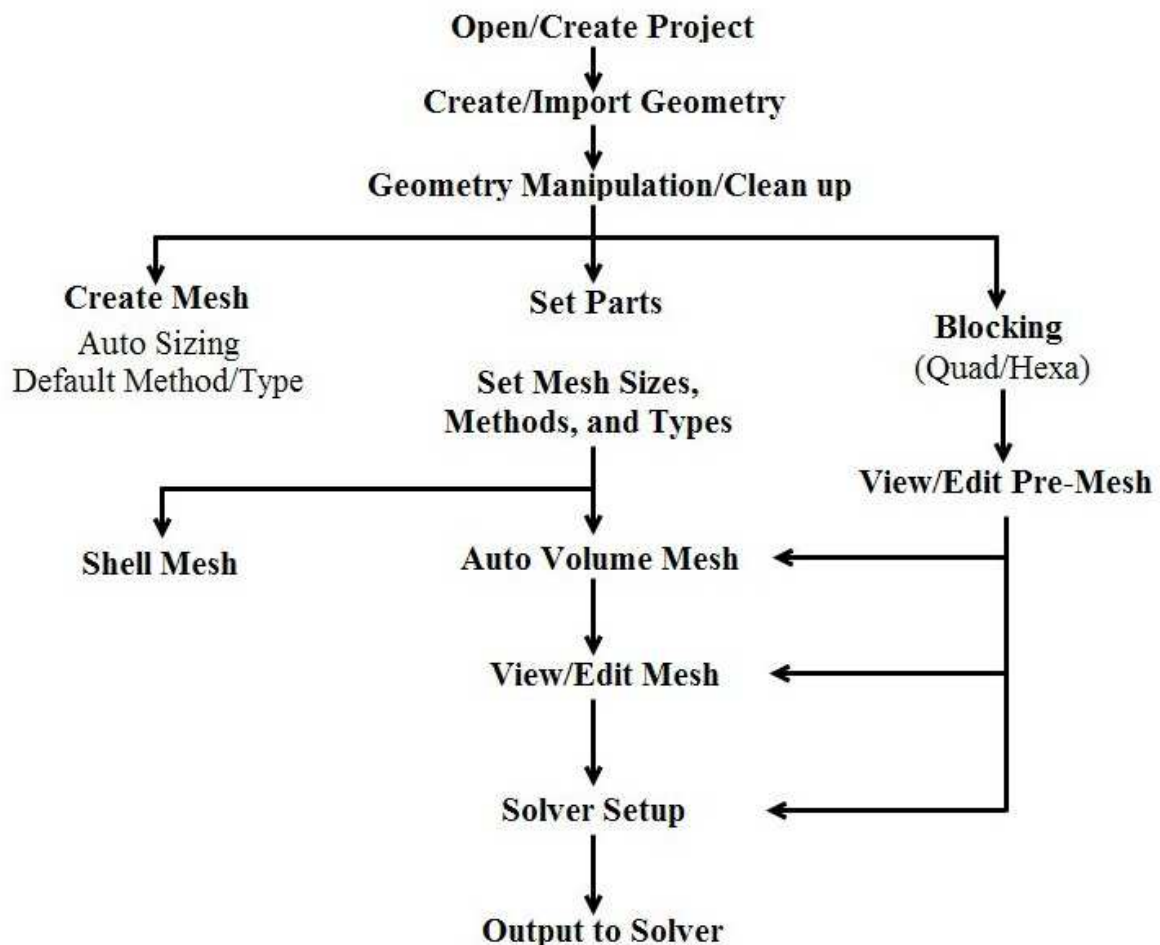
The ANSYS ICEM CFD meshing software starts with advanced CAD/geometry readers and repair tools to allow the user to quickly progress to a variety of geometry-tolerant meshers and produce high quality volume or surface meshes with minimal effort. It offers the possibility of an output to a wide variety of computational fluid dynamics and finite element analysis. The FLUENT software is one of those possible outputs.

ANSYS ICEM CFD provides a direct link between geometry and analysis.

However, creating the mesh does sometimes require more effort than the expected, what makes this previous description of the program not entirely true.

The next diagram explains the process followed from the load of the geometry to the final output of the further computational analysis programs:

**Figure 1 The Overall Process**



These are the steps followed in the process of meshing a geometry, before launching the later solver. As it can be seen, the path is quite delimited and does not have much possibilities.

Nevertheless, there is one point in which we have to make the choice of making the mesh with a default method, set parts of blocking. In both the first and second period of my work here, I have followed the central lead.

After the geometry manipulation and clean up, I had to set the appropriate meshing parameters that would make a successful mesh, which was not easy to do. A lot of parameters have to be taken into account if we want to create a good and complete mesh.

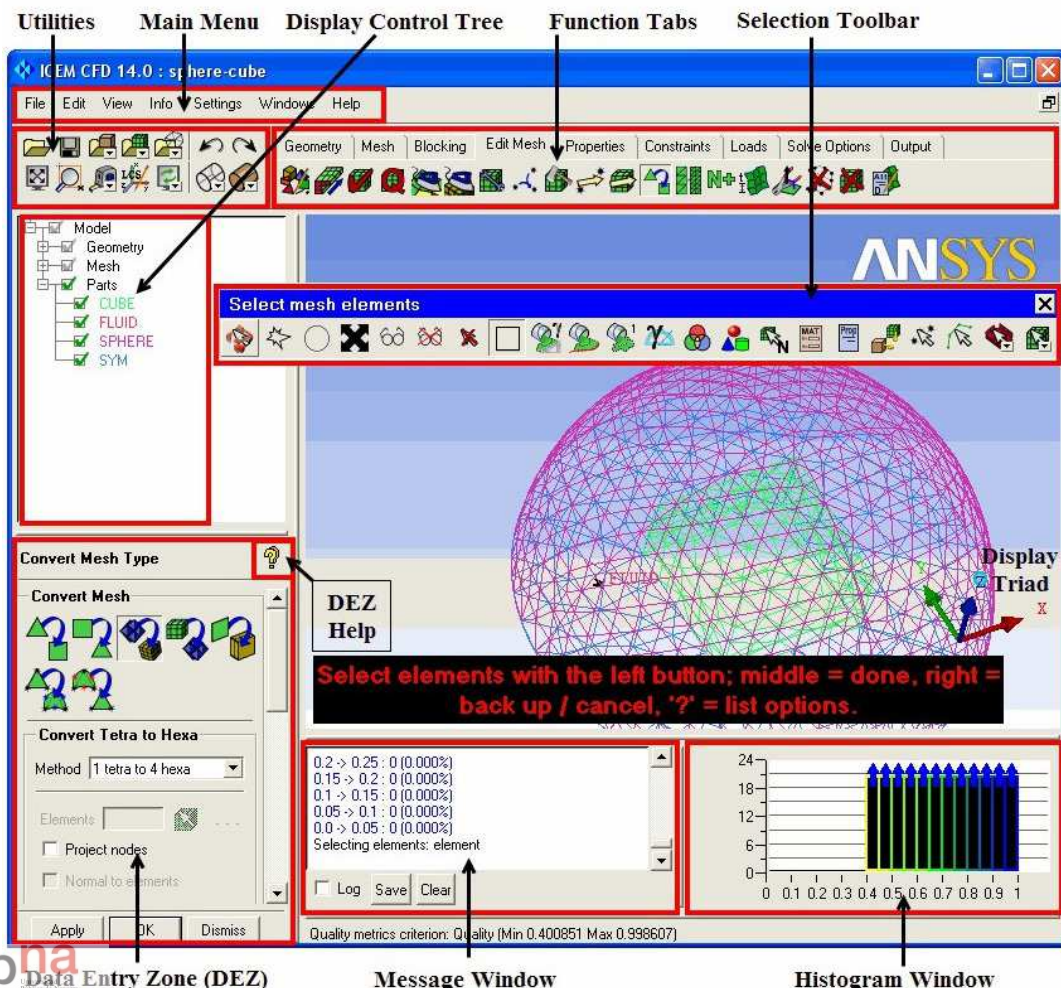
Once I had a good mesh and had found the appropriate parameters for my geometry, there was still work to be done. When checking the mesh “manually”, some little holes or imperfections were usually found. This is the part when the commands of Edit Mesh had to be used. This step is not supposed to be always needed to obtain a suitable mesh.

After checking the edited mesh, I was able to successfully launch the solver.

#### - About the appearance of the program:

The program is quite attractive and functional to work with. An example of the visualization screen and the displayed commands and toolbars is shown below:

Figure 2 ANSYS ICEM CFD GUI Components



I have found it to be a functional and intuitive program. With basic notions, anyone previously familiarized with CAD programs and to work with computational geometries can be able to manipulate the basic commands of the program. The basic commands are meant to be: the visualization box, the display control tree, the utilities (upper-left square of the screen) and the common commands of every computer program (save, load, import geometry...).

The rest of the commands require some time before knowing how to properly use them and when to, such as the ones that manipulate and change the geometry, or the ones that have to do with the tolerance of the geometry, or even the very important command that is Build Topology (with which I did check if the geometry was prepared for the meshing part), totally necessary before meshing.

When it comes to the meshing part, a lot of new parameters and possibilities come to play, and it is difficult to succeed in the creation of the mesh in the firsts tries.

The input of all the required data is in the Data Entry Zone (DEZ, lower-left part of the screen) where the different applications of every command are displayed as well. All the commands are displayed in the Function Tabs (upper part of the screen).

The message window is the way the program communicates with the user. When an operation is carried out, the results are shown there, as well as the process. When the results are also visible (most of the times, like the changes in the geometry or the meshes created), they also appear in the visualization screen.

In the next paragraphs I am going to explain some of the commands that are, in my opinion, important during any analysis or generation of a mesh carried out with ICEM CFD.

#### - **Build Topology:**

The Build Topology option creates a series of curves and points from surface edges and corners depending on the proximity of the surface edges to each other. If the curves are within a geometric tolerance, they are merged together as one. The curves are then displayed in a specific color to illustrate their connectivity in the surface data, which can be used to determine any gaps or holes in the geometry.

Build topology colors:

- Yellow: Single or free edge curves (those adjacent to only one surface)
- Red: Double edge curves (curves adjacent to two surface)
- Blue: Multiple edge curves (curves adjacent to three or more surfaces)
- Green: Unattached curves (not attached to any surface)

The use of the Build Topology command has proved to be very useful for the work developed with the geometry and the mesh itself. It works as a verify that the geometry is still valid after every operation the user makes. Without it, the user may occur into errors caused by a non-valid geometry.

The reason to this is that sometimes the visualization of the geometry or the mesh is not accurate enough and can mislead the user.

It is recommendable the use of the Build Topology function after every change in the geometry and before the compilation of any mesh.

The Build Topology command can be built attending to a specific tolerance. The user can decide which tolerance fits best to his or her purposes.

- **Tolerance:**

The tolerance is defined in units of the model, and controls how accurately you want to treat surface-to-surface proximity.

- **Mesh type:**

Specifies the type of surface mesh. If an individual surface is assigned a different type of surface mesh, then the local control will override the global setting:

- ⇒ All Tri => meshes the geometry with a pure triangular mesh. (the one used)
- ⇒ Quad w/one Tri => allows for a Quad Dominant mesh with one tri element per surface.
- ⇒ Quad Dominant => creates a quad mesh that allows for several transitional triangles.
- ⇒ All Quad => meshes the geometry with a pure quadrilateral surface mesh.

- **Checking/editing the mesh:**

The mesh editing tools in ANSYS ICEM CFD allow you to diagnose and fix problems in the mesh. You can also improve the mesh quality. A number of manual and automatic tools are available for operations such as conversion of element types, refining or coarsening the mesh, smoothing the mesh, etc.

The process typically involves the following:

- Check the mesh for problems such as holes, gaps, overlapping elements using the diagnostic checks available. Fix the problems using the appropriate automatic or manual repair methods.
- Check the elements for bad quality and use smoothing to improve the mesh quality.
- If the mesh quality is poor, it may be appropriate to fix the geometry instead or recreate the mesh using more appropriate size parameters or a different meshing method.