Study, design, planning process and manufacturing of a polyvalent bowsprit

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STUDY, DESIGN, PLANNING PROCESS AND MANUFACTURING OF A POLYVALENT BOWSPRIT

by

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DEDICATION

To my parents and sister,
For all the times you helped me to take the correct decision

ACKNOWLEDGEMENTS

After four years studying this degree, at two universities in different countries, I have learned one thing – I could never have done any of this, particularly the research and writing that went into this dissertation, without the support and encouragement of a lot of people.

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Finally, I would like to dedicate this work to my family: Angela, Pilar y Santiago. Without your unending support and love from childhood to now, I never would have made it through this process or any of the tough times in my life. Thank you.

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CHAPTER 1
INTRODUCTION AND MOTIVATION

Engineering Project is a wonderful and interesting part of the engineer's work. All products need a development since the first idea until the commercialization. Every part of the management has complex problems to solve, because we have not only to create the product, we should combine the simplest shape with the cheapest manufacturing, longest life product and the most safety and respectful elements with the environment.

In the next pages, I will try to give the best project example from a point of view of a beginner engineering. In that way, I will start with the main idea and the analysis and solution of every step. As you will notice, I will try to put as many illustrations and pictures as I can to do reading easier and more entertaining.

I will try to combine things that I like, for example, mechanical dimensioning with design and manufacturing of simple products that we can find in the market but it could be improvable or perfectible. So, I will perform a series of calculations, analysis of materials and use software that can be purchased and used with certain hours of use and work like MEFI, Inventor or WinUnisoft as well as the manufacture and use of specific equipment in a workshop. If I mix my personal hobby with the above along, which is the sailing field, I should realize a project about a part of a sailing boat. With the Obuda University's help, I have enough tools and a perfect environment to realize this work in the Manufacturing faculty.

My personal experience in the nautical field enables and helps me in this analysis. Since many years ago, sailing boats exist in the world using a natural resource to produce the motion. Nowadays we use the same energy of always: the wind. Every improvement in the field helps in the development of the boats. The emergence of new materials and building systems throughout the XX century has evolved this technology until today. In the last 50 years improvements in the field have grown exponentially, so I would like to create my own version of a product that you can find in the market: *a gennaker bowsprit.*

I would like to start with the historical development of this kind of booms to continue with the definition of the product and process to make it successfully.

The reader should keep in mind that the naval field has a lot of unusual terms to name all items, which I will try to explain the main meanings to understand the analysis.

CHAPTER 2

WHAT IS A BOWSPRIT

The **bowsprit** of a sailing vessel is a pole (or spar) extending forward from the vessel's prow. It provides an anchor point for the forestay(s), allowing the fore-mast to be stepped farther forward on the hull.[1]

2.1 HISTORICAL DEVELOPMENT

The origin of bowsprit is not known exactly. This boom comes from a simple stick, only one short piece. The main use was to provide support for a square spiritsail in the front of the boat.

Ocean-going vessels tended to tilt the bowsprit, known in centuries past also as a boltsprit, at a high angle, and hung one or two square spritsails from yards.

In the picture on the right we can see a ship example in XVII century. It was the most chosen option at that time.
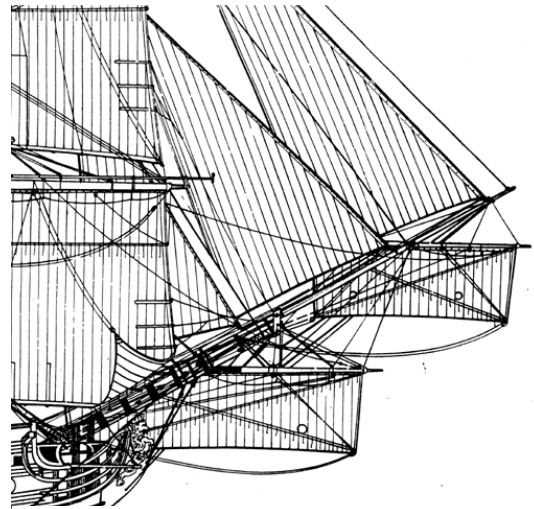
Figure 1: Configuration with two square spiritsails and three jibs (triangle sails)

In the 17th century and early 18th century a vertical sprit topmast was added near the end of the bowsprit and another square sail added to it; this was not a particularly successful design however, the mast tending to carry away in heavy weather. Fore-and-aft sails known as jibs hung from the stays proved more useful for speed and maneuvering, and the basic bowsprit was lengthened with a **jibboom** and then even further with a flying jibboom, resulting in bowsprits of tremendous length, up to 30 meters total.[2]

As we can see on the right, figure 2 shows a good example using the bowsprit to provide support for some jibs. Those kinds of sails are a triangle, influenced by "latin sail". This provides sailing against the wind with a certain angle. It was an improvement in the navigation techniques until nowadays (read Appendix A).

Figure 2: Common configuration in big ships in XIX century

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[1] http://en.wikipedia.org/wiki/Bowsprit (23/02/2015)
[2] http://en.wikipedia.org/wiki/Bowsprit (23/02/2015)

Figure 3: Classical vessel in a 2012 competition of "Classic boats". As we can see, the bowsprit is use to provide support for all jibs.

In the following years, with "yachting" interest at the beginning of XIX century, naval architects tried to design the best shapes to build the best hull ship. In that time architects thought the best was a "fish shape", with big head (bow) and slim tail (stern). It was based in all fisher and war ships. It had to be strong to face storms and big waves but fast to go to the port as soon as possible to be the first in selling fish.

Naval architects tried to find new shapes out of the common canon. Sometimes it was like swim against the tide because of criticism, but good results were shown quickly in important competitions.

In 1848 John Scott Russell proposed the opposite traditional canon, provided designs with sharp bows (prows) and broad or wide sterns.[3] Boaters did not have a clear opinion on performance and improvement but, three years after, schooner *America* was built with this principle and it was a clear change in the efficiency of new shapes. In the next 40 years the improvements were about reduce the wet surface and the displacement, but keels were still too long from bow to stern.

The next challenge was helped by the introduction of small boats in the market and the interest in yachting and competition. In 1891 the pioneer schooner *Gloriana* had deep and short keel. It reduces the friction and maximized the righting moment or

Figure 4: evolution in the shape of the boat. The picture below shows the actual configuration in most of the vessels.

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[3]http://www.fondear.org/infonautic/barco/Diseno_Construccion/Veleros_Evolucion/Veleros_Evolucion.htm (27/02/2015)

metacentric height. A larger metacentric height implies greater initial stability against overturning so the stability. But the keel and rudder were still together and if the keel is narrower, the rudder is more and more in the central part of the hull and it started to generate a problem in maneuverability.

The next evolution was separate keel and rudder. In that way, next shape of boats broken all builds before and it was consider a dangerous idea to face the sea. But triumph in competitions and success implementing this configuration gave the way to new generation until nowadays. The keel began to be more elongated as the airfoil in a plane. The best way to reduce drift was use as elongated blade as possible, with the weight in the lower part. In Figure 4 we can see the approximation of the hull evolution of boats in XX century. As we can see below Figure 4 there is a typical sailing yacht configuration nowadays. We have a long keel with a blub below, and the rudder separately in the stern of the boat. In the next picture below (Figure 5) you can see a kind of hull competition model. It is interesting because its keel is like a pendulum: with a hydraulic system we can move the keel to create more righting moment. You will realise that all aerodynamic parts in a sailing boat will be designed with airfoil shape, both in hull as in sails.
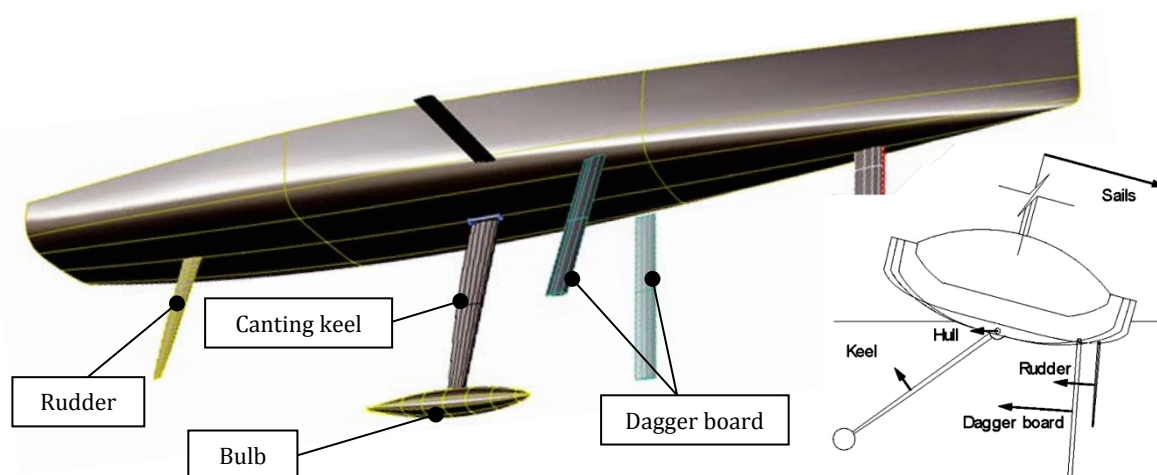
Figure 5: competition shape where the keel can rotate to maximize the righting moment.

The development of the rigging was accompanied by the hull development. Elongated keels get more stability, so then sails could have taller mast and longer sails therefore we got increasing sail area relative to the length of the boat. Shipyards started to put less but taller sails, getting simpler configuration; because it was enough as it was proved divided total sail area in few sails is much better.
In the 70's boats use to have two sails. The configuration was *mainsail* and *jib* but no bowsprit to provide support to the jib (it was directly fixed to the bow hull). It uses to have big jibs (called genoa) with big overlap between mainsail and genoa. But they started to research about improve *close hauled* course because it was one of the most important worries about the navigation and one of the most difficult part to study because of the challenges in aeronautic field. Sailmakers started to realize that the best option was to use sails like aircraft wings to generate easily sustentation. So shipyards started to design boats with very tall mainsail more similar than aircraft wing, and genoas became to be narrower because the jib's main goal is only acceleration and guide wind to this mainsail. Big mainsail and jib

(small genoa) configuration is the best option to sail close hauled. But what happen with the rest of courses? (See figure 7)

Figure 6: sail elongation benefits

With this configuration the problem is going to other courses with "more angle" to the wind. To improve the navigation in those courses, like beam reaching, broad reaching and running, the sails started to attending to other aerodynamic physical principle different from sustentation. Running course (downwind direction) works by sail pushing or towing (drag mode), so we will need bigger sails instead of slender jibs to get power and motion. In that case, sailmakers design deep sails similar than half balloon made of nylon. As much as compactible is better, and this is the main reason to use spinnakers and after some years, new generation of asymmetric spinnaker and gennaker: the new generation of sails.

The basic idea in the evolution of sailing technics is that each element has been divided to use it depending of the wind conditions and course. If we want to sail in some directions, we will use configuration mainsail+jib to get laminar lift on the sail surface or mainsail+gennaker to get big drag coefficient.

2.2 ACTUAL CONFIGURATION

For cruising sailors looking to enhance their boat's performance, recent developments in sail design and handling have made gennakers (also commonly known as multipurpose spinnakers or MPS') easier to use and great way to increase downwind speed.

Spinnakers have commonly been associated with race boats and shunned by most cruising sailors as unnecessary awkward and potentially dangerous to use. Certainly most of us will have watched with a sense of amusement and

Figure 7: basic sailing directions depending on the position of the boat respect to the wind

sympathy as a crew passes by wrestling a wayward spinnaker that has twisted around the rig or is dragging in the water "prawning"! The spinnakers of days gone by were also difficult to set up and required constant re-trimming, certainly not the user friendly experience that most cruising sailors are looking for.[4]

Developments in sail shapes to improve flying manners and dousing sleeves (also commonly known as snuffers) to aid launch and retrieval have significantly

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[4] http://www.northsails.com/SailBetter/Cruising/tabid/947/Default.aspx

improved the user friendliness of gennakers, making them more attractive and accessible for the cruising sailor. Most good gennakers will feature a tri radial construction for a smooth, stable, and easy to trim sail and the mould (design shape) will be optimized for your specific aspect ratio and forertriangle. The measurements required to assist with designing a well-fitting gennaker are simple and essential to ensure best performance. Sail shapes have also developed to such an extent that using a gennaker with autopilot is possible with boats that track well and have a powerful pilot to help keep a reasonably steady course.

A valuable addition to any gennaker is a snuffer dousing sleeve, which makes hoisting and dousing the sail a breeze, by gathering an encasing the sail in a nylon tube. Rather than wrestling with arms full of sailcloth blowing over the rail into the water, you just deal with an easy to handle tube with minimized windage. A simple control line quickly pulls the snuffer up or down the gennaker and enables just one person to hoist, set and lower such a sail. If you have an autopilot or device to lock off your helm, then the solo sailor can use the assistance of the snuffer to make using a gennaker relatively easy.

Nowadays the bowsprit is very important because it enables fixing a big gennaker as far as we can in the boat. The main goal is if the bowsprit is long will get less interference between gennaker and mainsail (we get more clear air). It is important too if we are gybing because we have to change the side of the sail (from broad port to broad starboard, see APENDIX A) it has to cross between forestay and gennaker luff. So if it is longer, we will be able to jibe easily because it will have more space.

Basically, these are the main points why we use a bowsprit:

- Gives the gennaker more clear air
- Facilitates rapid gybing
- Makes for fast and efficient gennaker handling
- Improves performance when gennaker sailing

In the picture below you can see a sailboat with the configuration of three sails in a catalogue picture. In the figures on both sides you can see the sail polar diagram (on the left, an asymmetric spinnaker and on the right, gennaker configuration).

Those last years the architects tried to create new bowsprits designs to improve asymmetric spinnakers and gennaker efficiency. So that, using this is going to be more common because we will get benefits in the navigation.

Not only in competition, even in cruising yachting will be usual to get a faster transportation and of course, a nicer and amazing experience in the navigation.
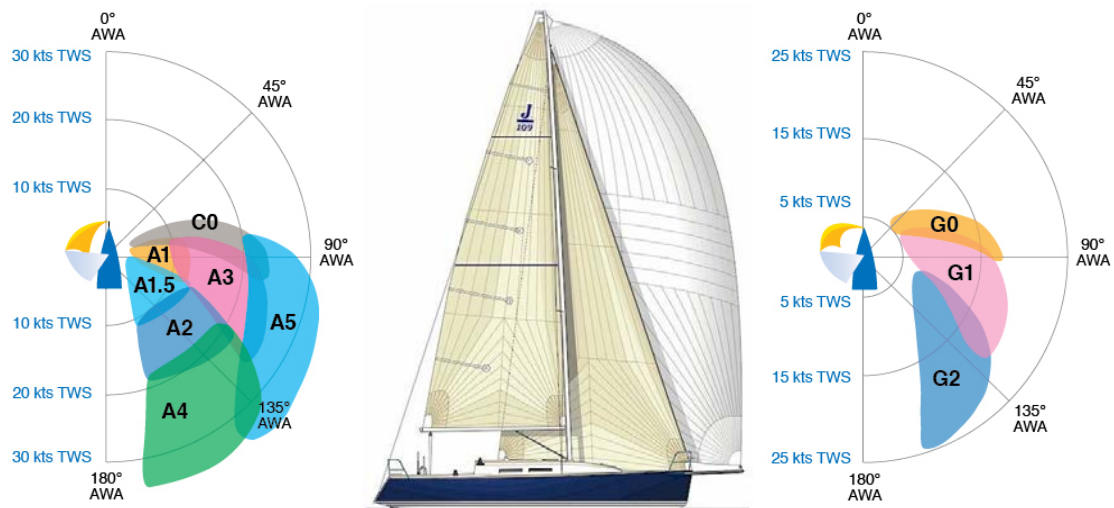
Figure 8: Polar diagram of North Sails catalog. It shows different kind of asymmetric spinnaker or gennaker, depending on the position of the boat respect to the wind, and depending on the wind speed (basically this is the two parameters to choose a sail)

As we can see, nowadays the range of sails is bigger. We can purchase various models that we can fix in a bowsprit:

- Asymmetric spinnaker: big dimensions and deep to sail in running.
- Gennaker: big dimensions but more laminar shape to broad reaching. 15% smaller than spinnaker and double area than jib or genoa.
- Code 0: design between a jib and a gennaker. Fewer dimensions than gennaker but laminar shape with tension in the luff. It generates big torque in bowsprits.

In Appendix B you can see a typical course broad reaching, in on a competition boat. As you can see, the jib is down on the boat ready to rise up when they will cross the buoy to go to the next one in a classical regatta.

In figure 9 we can see a removable bowsprit in a cruising boat, a clear picture where we can imagine the forces where are acting because of the gennaker guy traction.
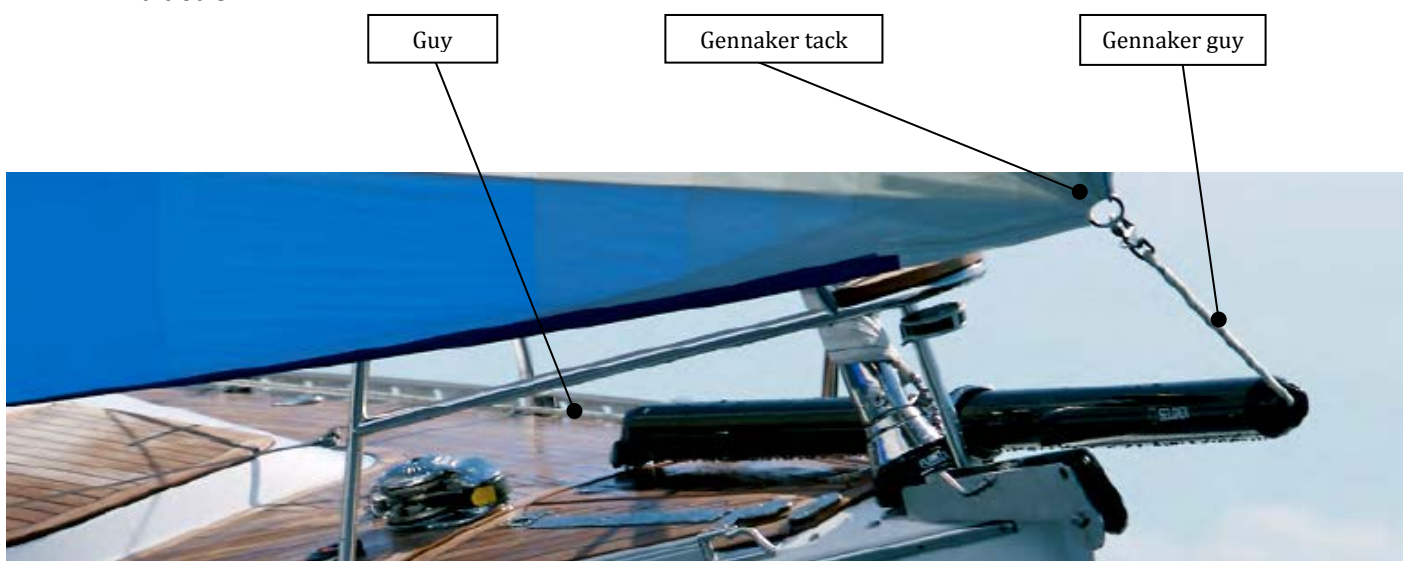
Figure 9: Seldén bowsprit and names of the main elements I talked.

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2.3 STUDY OF THE ACTUAL MARKET AND SIMILAR PRODUCTS

In this point, we will be able to have a perspective of what kind of products we could find in the actual market, what are the advantages and disadvantages, what could we do to improve the product and what is the "white space" or "holes" in the competence or in the catalogue of possibilities where we can include our bowsprit in the market.

First of all, we should study the main types of bowsprit we have available nowadays:

- **Removable bowsprits**: it is a type of booms that can be installed in most sailboats as they are built to be multipurpose. They are removable, making it easy to install just the time that will be used in addition to being able to save in a safer or where weather conditions are less aggressive place. Most sailboats no boom brings series, so this product is intended for a very common type of customer, as we found in the most general case (used by both cruisers who want to make the journey more exciting as sailors in most competitions).

  The main feature is its length and diameter as a function of these parameters can offer the product

Figure 10: Sparcraft removable bowsprit

  for different sizes of sailboats, from the smallest to the largest. Another important characteristic is the easy to be fixed abroad.

  Advantages:
  - o Does not matter what kind of boat. It is polyvalent
  - o If we remove it, we have free space onboard to use to other proposes like lie down on the bow or using the anchor.
  - o We can keep it inside of the boat and prevent theft and damage
  - o We save space (large of boat) because we can remove it in port and it is not part of the technical dimensions
  - o Easy to manufacture and commercialize like a complementary item.

  Disadvantages:
  - o It is not very aesthetic design sometimes
  - o The support is fixed making holes in the hull and sometimes
  - o Expensive

- **Extendable bowsprits**: this type of booms is intended for small and medium sailing yachts ranging mainly in competition. The sailboat hull design has to be done thinking of hosting this boom, so we can find sailboats standard mounting this type of booms.

  The company designs and manufactures these models must take into account that the choice of the boom is important because it is a specific element so normally designers will trust the experience of the best known brands of booms or have given better results in years. These are some examples of boats with an extendable bowsprit in the standard equipment: Beneteau34.7, XP33, VLC 35, elan310, J70, J109, etc.

Figure 11: Extendable bowsprit

They main characteristic is the easy to extend it (quick to use) because it is always prepared to be able to draw with a pulley mechanism, plus they do the most compact boat can pick it up completely so that no protruding part.

Advantages:
  o Easily fixation
  o Aesthetic design
  o We save space (large of boat) because we can extendable whenever we want to use.

Disadvantages:
  o We lost some space inside of the boat.
  o Only new boats and specific designs

- **Fixed bowsprits**: most of the times are riding bowsprits to medium and large sailboats competition type like IMOCA60. Usually models that hull design is done together with the bowsprit. Others however may be adaptations or modifications sailboats standard for high competition. They have the advantage that they are very sturdy and are always ready for use. In yachting is usually not performing the design of a fixed bowsprit so because they increase

Figure 12: bowsprit in a luxury yacht

the technical dimensions of the sailboat with the disadvantage of having a long portion interrupting maneuvering in port for example.

Advantages:
- o Rigid design
- o Aesthetic design
- o Always ready

Disadvantages:
- o Vessel length is greater in technical characteristics
- o Less preferable for maneuvering in port

Figure 13: bowsprit adaptation in a vessel

- **Rotating bowsprit**: is the new type of booms that has included a few years ago in certain competitions. It was introduced trough MINI TRANSAT oceanic regatta in sailing boats 6.5 meters, so it takes little capital to introduce new navigation techniques. This regatta has been very important because there are two divisions: production and prototype. Production boats use approved designs and comparatively conservative materials. The prototype division is more liberal with respect to dimensions, such as keel depth and mast height, and it allows for advanced technology such as "canting" keels, carbon-fibre masts, rotating bowsprit etc.[5] All these innovative changes have been implemented in larger sailboats after that.

It has the advantage of guide and opens the angle when we sail in running course or close the angle when we sail broad reach.

Advantages:
- o Orientable
- o Very long
- o Less forces acting along the tube.

Disadvantages:
- o Difficult to use.
- o It is mainly all the time mounted.

Figure 14: pogo 3 in Mini Transat. Very famous kind of boat because of the good results in this competition.

Analyzed the types of bowsprit that we can find, to begin with the production of any item I should choose an easy option to manufacturing which I can include in the market quickly.

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[5] http://www.classemini.com/?mode=jauge-classe-mini

Accordingly I must focus with the first product aforementioned; removable bowsprit (the most polyvalent) as it is a versatile product that can adapt to the characteristics of most customers and start the design development in that direction. Also, think that most normal sailboats are cruising sailboats that do not carry serial bowsprit like standard equipment because only a few high-performance units are beginning to be produced thinking in the use of gennakers. In that way it can benefit from two different perspectives: first, the current composition of the sail plan including using gennakers is becoming increasingly fashionable because of its use in large and medium races, ease of use and high performance, and secondly, sail industry is making an evolution in that field and improving performance, stability, ease, materials and design. The development of dousing sleeves and improvements in sail shape has combined to make gennakers a much more attractive option for the cruising sailor.

I use elements that we can get in the industry easily and economically with simple geometries and manufacturing techniques that do not require big investment and can order to other manufacturers and make the minimum investment at first, and slowly improving after. The next step would be to offer different settings and more sophisticated materials in the boom designed at first.

After that, I could move in another range of products that are manufactured sailboat house thinking extensible booms and expand the field of new builders of cruise-regatta. Could also be designed fixed bowsprits could be added to currently manufactured sailboats or in addition to the sale of new sailboats thinking in capturing those sailors interested in maximizing the results in competition.

As a complementary article, I could take a range of adjustable booms by looking at the system of Mini Transat vessels competition, as it is a system that could be installed in most sailboats, plus it seems a very simple system as it a bar used mainly in compression work with a fixation on one inboard end fitting and a system of ropes in the other outboard end fitting. Thus those fans who will capture their attention using this bowsprit or sailors who want to improve performance in navigation.

So that I will make an analysis of the current market, what it is the most important characteristics of this type of removable bowsprits and how it works those which one are on sale now to get an idea of the quantity and variability and how their characteristics, materials, prices are and whom they are intended.

2.4 ANALYSIS REMOVABLE BOWSPRIT

Extendable gennaker bowsprit sold as a kit for deck mounting. Just fit the two stainless steel pad eyes to the deck in line with the bow bracket. The bracket is a stainless ring through which the bowsprit slides into its "active" position. After the gennaker is doused, the bowsprit can slide back and be secured to the aft eye. If required, it can be quickly removed and stowed securely below. The gennaker tackline runs through the bowsprit, entering and leaving via well rounded holes, and then aft to the cockpit. An alternative is to fit an external tack block at the outboard end.

Setting up your boat for a gennaker is relatively easy, and there are a few simple pieces of equipment that you need and may have already fitted.

Firstly you need a spare halyard above or outside of your forestay attachment point at the mast to hoist the sail on. The gennaker tack may be attached to the stem of the boat wither with a short, fixed length strop (usually allowing the tack to fly at rail height) or you can set up an adjustable tack line with block at the stem and line leading back to clutch/cleat in the cockpit.

Adjusting the tack will allow for a little more range and performance from the sail by lowering the tack a little when reaching and raising for running squarer. However, it is by no means a necessity. Many gennakers feature a fixed tack strop, which might simply loop around a bow roller, or snap onto the stem fitting.

The final step is providing sheeting arrangements with block and line for sheets. Ideally your sheeting blocks should be positioned close to the stern (at least 80% of the way aft of the bow) to provide a good wide sheeting position and also correct lead to a winch for winding the sheet on.

In the searching for this bowsprit I use some time to check some deck hardware catalogues found in various nautical webpages on internet. I analyze this range of products I can find in the market and their characteristics. There is tree basically manufactures below, order by importance and status. Basically we can find:

- **SELDÉN**:
  It is a good situated Company hardworking, reliable and practical to take an active role within our mast production plan. Experience within metal working and composite fabrication. In their search for perfection, no detail is considered too small. This applies to everything, from the choice of materials to stringent testing of the finished product. Selden business philosophy can be summed up as quality thinking and system thinking, and a continuous quest to achieve the best possible function for each product. Selden has proved to be Number One in rig systems for dinghies, keelboats and yachts.

  1960: Per Seldén starts up with boat equipment and wooden masts.

  2006: Introduction of Seldén gennaker bowsprit.

Figure 15: Seldén bowsprit aluminum and carbon

  Products like masts, booms, reefing systems, sail hardware, blocks, rigging hardware, code 0 and gennaker furling, tracks and travelers, line management, etc. It has a nice webpage where you can get a lot of information, catalogues and technical characteristics. As you will see in the next chapters, I got a lot of information form this manufacturer which it helps me to continue with the design. They have a software calculator as well to get faster ideas if you know the characteristics of your boat and components.

Talking about bowsprits is expensive but very good situated in removable bowsprits because of their goals achieved in the general products of this brand. It offer some sizes depending on the displacement of the boat (it looks like available for boats at least 25 feet upwards) and two materials (aluminum and carbon).

Prices (small version kit ø72):

$476 [6] $506 [7] $594.99 [8]   593.10 € [9]

- **SPARCRAFT**:

    Sparcraft has been associated with engineering excellence and innovation in the marine industry for over 30 years, specializing in the design, engineering and manufacture of masts, booms and rigging systems of the highest quality.

    Sparcraft's products are consistently successful in international competition and are specified with confidence throughout the world and by the largest boat builders and charter companies.

Figure 16: As we can see, supplements like the ring and anchoring the reel to code zero.

Stock items like masts, booms, poles and bowsprits, furling masts, vangs riggings, headstay system, furling system and hardware are available.

Sparcraft offers a new range of bowsprits. Easily removed from the deck these innovative spars can be fitted on sailing boats from 25 to 57 feet. They have been specially designed for Gennakers/Code zero or asymmetric Spinnakers. The deck fixing device allows a free foredeck when arriving at the harbour or mooring.

Figure 17: the fixation is with screws attaching pieces to place with a click brackets.

This bowsprit is also expensive and the brand is not as well-known as Selden, but they have been achieved goals doing a good work in general and in this case a nice bowsprit design more elaborated it its fixation and to use different sails, but with simpler technical information. It only offers in aluminum material.

Prices (small version kit ø70):

$816 [10]   577.60€ [11] $899 [12]

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[6] http://www.pyacht.com/selden-bowsprit-kits.htm
[7] http://www.mauriprosailing.com/us/category/1-Selden-Gennaker-Bowsprits.html
[8] http://www.westmarine.com/buy/selden--asymmetric-bowsprit-kits-aluminum-gennaker-pole--P013741459
[9] http://www.nautic-outlet.com/es/tangones-y-botalones/2227-botalon-de-aluminio-selden-l-208m.html
[10] http://www.velasailingsupply.com/Facnor-Sparcraft-Bowsprit-Kits-s/4176.htm

- **VMG SOROMAP YACHTING**:
  It has a connotation of well-known sailing performance (velocity made good); it will be for them to bring us the most efficient product innovation, quality and competitive.

  This company carries out the design and manufacture of the following products:
  - o Sails: hardware, fabrics, saddlery, Laser cutting
  - o Masts: monohull and multihull, made to measure: new and old model, masts and booms anodized or painted
  - o Rigging: boating, Industry & Living, cables, turnbuckles, tensioners

  This is the most simplest and economic bowsprit we can find in the market. They define it like: Simple / Discrete / Effective / Economic. We can have the smaller version for boats less than 30 feet. Tubes ø60, ø70 and ø80 mm. Characteristics:
  1- Fixing with 4 screws
  2- Closed bracket with strap (very strong, not aggressive, discreet, quickly dismountable)
  3- Tolerance according to plan (delivery bilge fitting)
  4- Dismantled in the blinck of an eye (Velcro strap and pin ball)
  5- Asymmetric spinnaker or gennaker (hauling or not after tack)
  6- Possibility of sub barb (after dyneema prisoner)
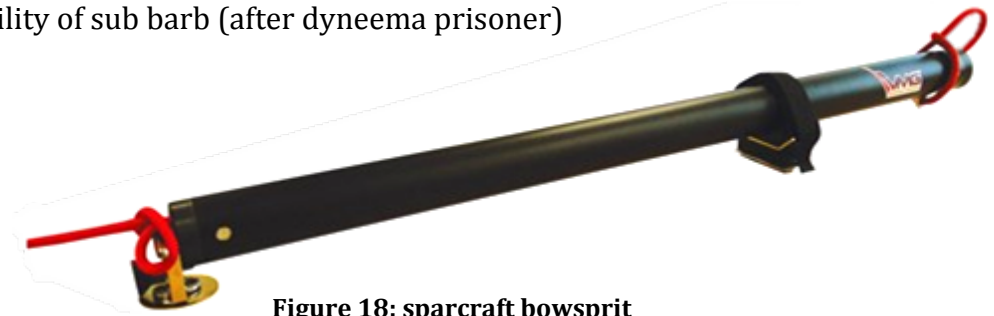
Figure 18: sparcraft bowsprit

  Prices (small version ø60):
  400,59 € [13]   359,90€ [14]

- **FORTE CARBON:**
  Forte was founded with the intention of making sailing more enjoyable with high-quality carbon products.

  The easy-to-install Forte Carbon Sprit Kit includes everything you need: a beautiful clear painted carbon fiber sprit, your choice of easy-to-mount deck hardware and a robust outboard end fitting.

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[11] http://www.sailonet.com/sparcraft-bowsprit-3292/sparcraft-bowsprit-diameter-70-227.html
[12] http://www.sailmagazine.com/boatworks/diy-bowsprit
[13] http://www.vmgsoromap.com/en/bowsprit/326-bowsprit.html
[14] http://www.accastillage-diffusion.co.uk/catalog/Alu-bowsprit,324576.html

Figure 19: ForteCarbon bowsprit

Forte offers four sprit kit sizes to accommodate your boat. The carbon fiber sprit tube will actually be engineered and built to your specific requirements. Because of this, the outside diameter (OD) of the tube is not set in stone; the laminate (wall thickness) may be a little thicker for heavier boats or boats carrying more sail area. [15]

Sizes**:**
- o *Small*: for boats from 15' to 27' long
- o *Medium:* for boats from 27' to 34' long
- o *Large*: for boats from 34' to 40' long
- o *Extra-Large:* for boats larger than 40'

This manufacturer seems to suit different projects depending on the particular case, but with the consequence of a high price.

As you can see, they offer you a small version to small boats, but let's check the price and see if it is worth:

Prices (small version 2" ID):

$1,675 [16] $1,591.99 [17]

With this overview of the booms available, I can make an analysis of what I liked and what I did not like:

I liked SELDÉN because it is a simple version but that is both functional, the use of elements that we can find in the market as the standard fitting, besides the possibility of finding carbon etc. Also has a catalog of information with many technical characteristics. No offer a version for small sailboats.

[15] http://fortecarbon.com/marine/bow-poles-sprits/
[16] http://www.sailmagazine.com/boatworks/diy-bowsprit
[17] http://www.defender.com/product3.jsp?path=-1|118|2358541|2692583&id=1017978

About SPARCRAFT, I liked the design and it is very well made, plus they have given importance to aspects such as easy disassembly. They have created a particular product with its special type latches. Nor do they offer to small sailboats.

About VMG bowsprit, the only thing I like is the price, but it is a very simple version. It uses a tube diameter less than the normal, offering it for a range of sailing too wide (under 30 feet) so it cannot be considered to offer a specific product for small sailboats.

The next, FORTE CARBON, I liked having the versatility in terms of specific product details. They are flexible when it comes to manufacturing. Only they use carbon, so that the product is of great interest but overly expensive. Although truly they offer a size small sailboats not worth acquiring since the price soars to more than double the rest of the competition.

I will try to make a simple but attractive and functional product, primarily to be cheap so you can compete without problems with good marks. I will try to find measures of standard materials and cheap ways to lower manufacturing costs.

I have observed that there is a gap in the market for smaller sailboats. I will examine the feasibility of creating a range of smaller dimensions and add a range for small sailboats and expand the sales pitch.

CHAPTER 3
DEFINITION OF THE WORK

My objective is simplifying the ideas in the market to get an interesting product with lower price (one of the main ideas is create a cheaper version) and the possibility to offer other range for smaller boats as I will analyze.

I will offer the product to the seller companies so I have to focus on making something similar, which is associated with other bowsprits that already exist and are well qualified.

Other basic idea is trying to purchase raw materials from suppliers (like normalized tubes and common materials) perform a process and assembly all parts with the similar quality assurance.

I define the basic elements I have to focus in:
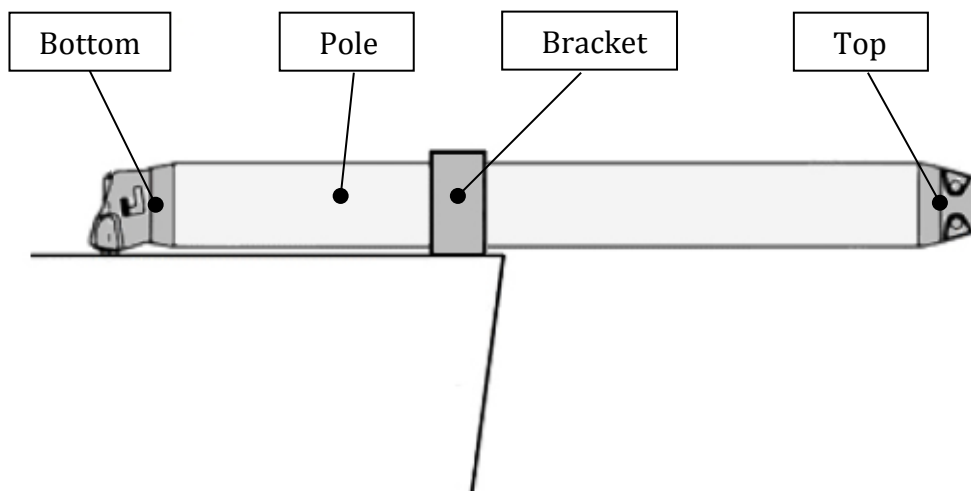
Figure 20: schematic showing the complete bowsprit kit

3.1 POLE

It is the main part. It provides the necessary length to the set. It is important to define common diameters to make easy finding tubes from suppliers. In this point, we can see than in nautical field almost every kind of mast, bowsprit, etcetera is made of aluminum, or sometimes composite materials (like carbon fiber-PVC)

I am going to keep in mind using aluminum like base material. I have the possibilities to find a lot of sizes of aluminum tubes to the best price, because is a common material in the industry. We will choose basically a simple geometry to guarantee the best price (circular hollow tube). I could study the possibilities to use other materials like complements of my product range.

3.2 TOP

Outboard end fitting part. It has to guide the guy rope for controlling the distance of the tip of the gennaker (gennaker tack).

It has to be very simple but functional, similar than Selden or Sparcraft (harboring the rope and providing support to other elements)

It is a piece of small symmetrical dimensions so a good method to manufacture it could be by molding or machining (less investment using machining methods like turning).

I must keep in mind that if the rope is guided through the interior, will be a large frictional force. Therefore, the chosen material must withstand the friction with ropes.

Another important aspect that is being used a lot is using bobstay. It is a strong stay between a bowsprit and the stem of a vessel for holding down the bowsprit

3.3 BOTTOM

Inboard end fitting part. It is the part that the boom fixed to the hull so that no slip is occurring. I will consider it as a fixed support.

It has to be something very simple too with a mechanism to open and close a latch that is set to a piece (pad eye) in the hull.

Figure 21: Spring-loaded locking and pad eyes

3.4 BRACKET

Bow brackets part. It provides the second support of the sprit. It allows the sliding tube to poke it easily.

In the picture you can see some formats available. It has to assurance that all boats has a space to place it, so it has to be a very polyvalent piece or provides many different brackets. Sometimes it is attached to the anchor bracket.

Figure 22: actual bow brackets in stock, by Seldén

CHAPTER 4
RESISTANCE STUDY OF THE POLE

The sizing of the item set must be the first par we should start with. First of all we should present the static situation I will face and after that I will give the possible solutions depending on the tools I have. In this way I will use some basics of deformable solid mechanics and I will be helped by a simple but interesting free software (MEFI) to get better and faster results. I will use EXCEL software to analyze the results, generate diagrams and get conclusions.

4.1 GENERAL ANALYSIS OF THE OBJECT AND POSSIBLE SOLUTIONS

Studying of a solid behavior usually is formulated with a series of simplification and generalization to make it easy.

Calculation hypothesis:

- Small displacements
- Small deformations
- Linearity, linear elastic behavior
- Sant-Vernant principle
- Homogeneous material
- Isotropic material.

The model of bowsprit we can start based in the cantilever beam with a punctual load in one side. I consider one bracket fixed and the other movable bracket like in the real case. Also we get only one hyperstatic grade (static_equilibrium equations are sufficient for determining the internal forces and reactions on that structure).

In the top part, the load will be produced by the sail. This load is in most of the cases perpendicular (or with a small angle) to the beam. I will consider perpendicular load to do the calculation because it gets the maximum flexion in the beam, so that the most critical situation we will have. Consider that this punctual force is caused by the traction of the rope produced by the sail sustainability and sail pushing, so it will have small modifications in the load direction depending on the course.
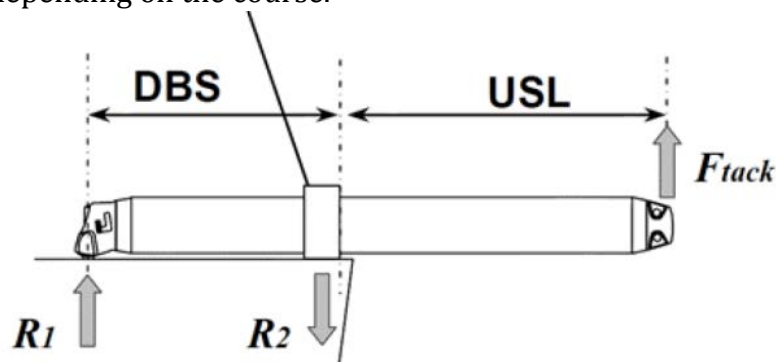
Figure 23: loads representation and distances in Seldén catalog

Figure 24: schematic realized in MEFI software witch I will use in the analysis.

We have to define the force. It is the variable parameter from I will get all behavior so then I could choose the characteristics of the tube and section.

But, how much is that load? That's not an easy data to calculate. It is the most difficult step in the design of a bowsprit. Hopefully, we have to ways to approximate a correct value and start with the dimensioning:

4.1.1 Calculation with technical characteristics

The goal is calculating the parameter from the tension that the rope produces in the top of the bowsprit. These are the parameters to take into account:

- Parameters external to the boat
  - Size sail
  - Wind speed
  - Shape of sail
  - Course
- Parameters of the boat
  - Displacement (weight of a ship)
  - Righting moment

If we want to get the exact value, we should combine all this parameters influenced in the force behave.
This way is very complicated because each sailmaker has their own methods to design and sometimes they have the software specific for them (Like North Sails, which is one of the most developed in the market and have developed many software to calculate all parameters and characteristics of the sails).

I would like to give an explanation about how is related all parameters above. We have to keep in mind that the force in the bowsprit is closely related with the force we will have to move the boat. For example, I could start fixing a displacement and righting moment given by the boat. In that way I could fix a maximum wind speed with a bearing (or course) which the sail is doing the max force. We should study the aerodynamic of that sail to know how much force is being exerted.

The North Design Suite is an integrated family of specialized software programs that brings unprecedented power and flexibility to sail and rig analysis. Each specialized program can interface with others within the suite, allowing North sail designers and engineers to virtually sail and test a boat in an infinite variety of conditions before construction. NDS significantly expands a designer's ability to

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test different sail and rig combinations and accurately measure results. Equally as important, NDS significantly reduces tuning and development time after launch.

North Design Suite Software Modules: [18]

- DESMAN™: rig and sail CAD modeling
- SPIRAL™: creates the 3-dimensional sail "mold"
- 3D LAYOUT™ : defines the structure of the sail
- FLOW™ : applies wind pressure to 3-dimensional sail mold and provides sail forces
- MEMBRAIN™ : balances wind pressure, sail shape and rig forces
- SAIL SCAN™ : compares actual sail shapes to Membrain predicted sail shapes where possible
- NORTH VPP™ : predicts yacht performance with special attention to sail shapes
- HULL VPP™: calculates lift and drag on hull and appendages
- VIRTUAL WIND TUNNEL™ : models air flow on upwind and downwind sails
- RACE MODEL™ : measures effects of sail/rig adjustments on rating and vice versa
- SPP™ : regression analysis to calculate hull forces without existing hull data
- ROUTER : predicts sail performance using historical weather over a specific race course or leg
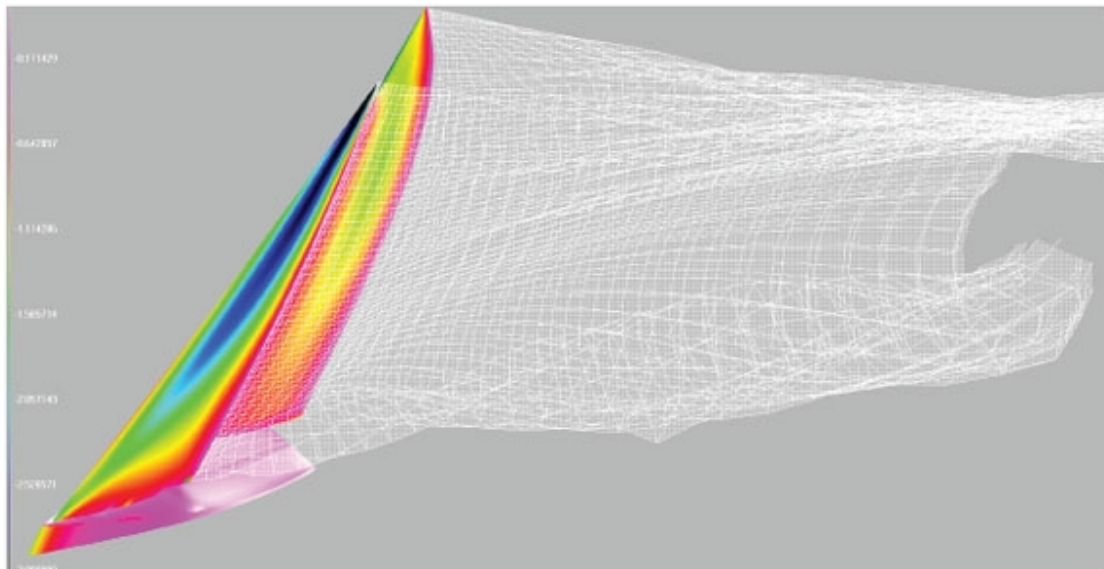
Figure 25: screenshot of one of the software that North Sails uses on analysis of the forces generated by the sails

The impossibility to get this software requires me to use other alternatives in the calculation of forces

But our problem goes beyond. We have to design a bowsprit polyvalent. So sometimes we will have boats with big displacement which this influence in how is easy to move the boat, and in that case we will have less force because if the boat is easier to move, we will have less reaction in the interaction between sail and

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[18] http://www.na.northsails.com/TECHNOLOGY/NorthDesignSuite/tabid/23145/Default.aspx

bowsprit. It is the same with the righting moment. In boats with big PAR we will have strong interactions in the CABO, between the sail and the bowsprit. But if we sail in a boat with less righting moment, this boat will be heeled easily and the sail will lose force and sustentation, so we will have less interaction forces because of the characteristic of the boat, independent with the sail. We can have the opposite: a heavy boat with big PAR and with a small gennaker. We could have strong interactions between sail and boat because the boat is going to produce a big reaction force that will impede the boat moves easily with the acceleration produced by the forces of the sail.

Finally, commenting that in internet we can find some approximate values of forces exerted per square meter of sail, but are values that cannot be used due to its complete randomness and widespread exercise we face.

Following this analysis, we can conclude to make our calculations in other ways. In the following section I will analyze data from other manufacturers showing me.

4.1.2 Calculation with table data of other bowsprits

From the collection of information I have done, I could say is the best way to continue with the sizing.

As I cited, there is four main manufacturers but I am going to focus in one of them specially, because it give me the most important data values. This catalog can be downloaded directly from Seldén web page in some languages. It has a kind of calculator where you put the boat specification and it gives you the approximation of the forces you will have as well as the best section recommended.

I will use other catalog (Sparcraft) to provide a comparison with the conclusions I am getting.

With all this tools I can start to do the analysis. Next page you can see an catalog Seldén extract with technical specifications. It shows the main values about distances, forces and tube sections.
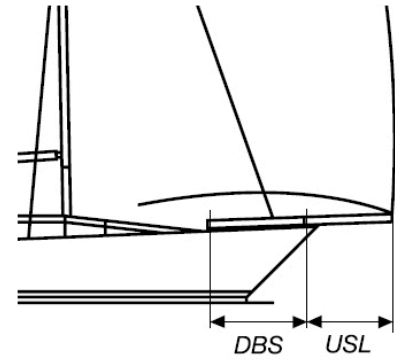
Let's study one by one to understand what I have.

Table 1: Seldén technical data table

Dimensioning for gennaker, Aluminium

RM 30° (kNm)	Approx. displ. (tonnes)	G072	G075	G087	G099	G120
8	1.7	1280				
10	2.1	1090				
12	2.4	960	1700			
14	2.8	860	1520			
16	3.1	790	1390			
18	3.4	720	1280	1640		
20	3.7	670	1180	1520		
25	4.5	570	1010	1300	1710	
30	5.2	500	890	1140	1510	
35	5.9		800	1020	1350	
40	6.7		730	930	1230	
45	7.3		670	850	1130	
50	8.0		620	790	1050	
55	8.7		580	740	980	
60	9.3		550	700	930	1850
65	10.0			660	870	1750
70	10.6			630	830	1660
75	11.3			600	790	1580
80	11.9			570	750	1510
85	12.5			550	720	1450
90	13.1			530	700	1390
95	13.8				670	1340
100	14.4				650	1290
105	15.6				630	1250
110	16.0				600	1210
115	16.1				590	1170
120	16.7				570	1140
125	17.3				550	1100
130	17.9				540	1070
135	18.5				520	1050
140	19.0				510	1020
145	19.6				500	990
150	20.2				490	970
155	21				480	950
160	22					930
165	24					910
170	25					890
175	26					870
Min. distance between support, DBS (mm)		580	600	700	800	1000
MSL at inner end (Kn)*		2.9	4.9	5.4	6.2	10

DBS   *USL*

* MSL = Max Service Load, based on minimum DBS.
MSL at bow bracket = MSL at inner end x (1 + DBS/USL).
DBS = Distance between support.
USL = Unsupported length.

Parameters explanation:

- RM: righting moment of the boat when is 30 degrees heeled, in kNm.

- Approx. displ.: approximated displacement, displacement or displacement tonnage is the weight of water that a ship displaces when it is floating, which in turn is the weight of a ship, in tonnes.

- Values G072, G075...: external diameter measure (72, 75 millimeters, etc.)

- DBS: minimal distance between supports given in millimeters. I will call L_1

- USL: unsupported length given in millimeters. I will call L_2

- MSL: max service load. Is the load we will have Inboard end fitting

With all these data, I have the necessary information to continue sizing calculations of the bar.

So I will make the approximation of the maximum force calculated in the static

state of the bar to values that have corresponding that force with other features relating to the ship. This is very important because in this way I will get a value of forces able to generalize and make a diagram that relates everything explained. With these diagrams I compare the actual values in current sailing to see if it matches.

4.2 CALCULATION USING BOWSPRIT TABLE VALUES

As I explained in the last point, technical characteristics give me enough information to calculate the parameters of the force. I am going to show where this formula comes from and how to get the rest of the values with the static equilibrium of the cantilever beam:
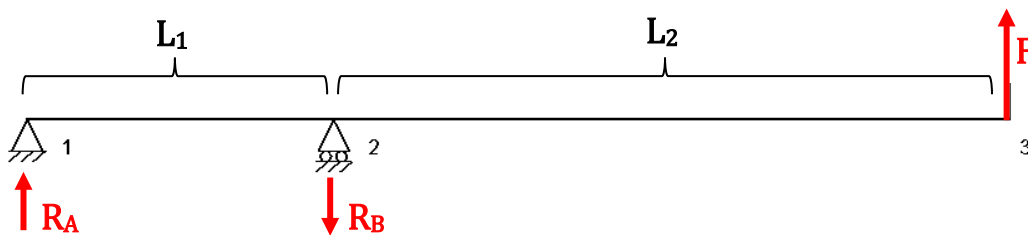
- Known data: R_A, L_1, L_2

- Identifying unknowns: R_B, F

- Static equilibrium equations:

$$\sum F_y = 0; \quad R_A + F = R_B$$
$$\sum M_z(A) = 0; \quad R_B L_1 = F(L_1 + L_2)$$

Basically we have two equations with two unknown quantity

- R_B cleared depending R_A:

$$F = R_B - R_A \quad ; \quad R_B L_1 = (R_B - R_A)(L_1 + L_2) \quad ;$$
$$R_B L1 = R_B(L_1 + L_2) - R_A(L_1 + L_2) \quad ; \quad R_A(L_1 + L_2) = R_B(L_1 + L_2 - L_1) \quad ;$$
$$R_B = R_A \frac{L_1 + L_2}{L_2} \quad ; \quad R_B = R_A \left(\frac{L_1}{L_2} + \frac{L_2}{L_2}\right) ;$$

$$\boldsymbol{R_B = R_A \left(1 + \frac{L_1}{L_2}\right)}$$

As expected, this formula is the same as that given in the catalog

- Substitute values first row and first column of catalog:

$$\boldsymbol{R_A = 2.9\ KN}$$
$$\boldsymbol{R_B} = 2.9\left(1 + \frac{0.58}{1.28}\right) = \boldsymbol{4.21\ KN}$$
$$\boldsymbol{F} = R_B - R_A = 4.21 - 2.9 = \boldsymbol{1.31\ KN}$$

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Using an excel software and writing Selden's table, we can generalize this formula to all data in the table and get the maximum force calculated by them to size the bowsprit.

In APENDIX C you can see Selden's table write on EXCEL (TABLE 8) and the values calculated F and R_B (TABLE 9).

As we can see, the force shows a natural progression increasing with the size of the boat (displacement). As well, we have some values of forces for a same dimension of boat because in those cases we can use one bowsprit longer or shorter, depending on how many long L_2 we want, or depending on the forces on inboard end fitting.

To generalize this progression, I do an arithmetic mean to get only one column of values (see TABLE 10, APPENDIX C). This table is linked with the approx. displacement and RM. First of all, I should do a representation about how much are RM and displacement linked in the next scatter diagram (Figure 26).
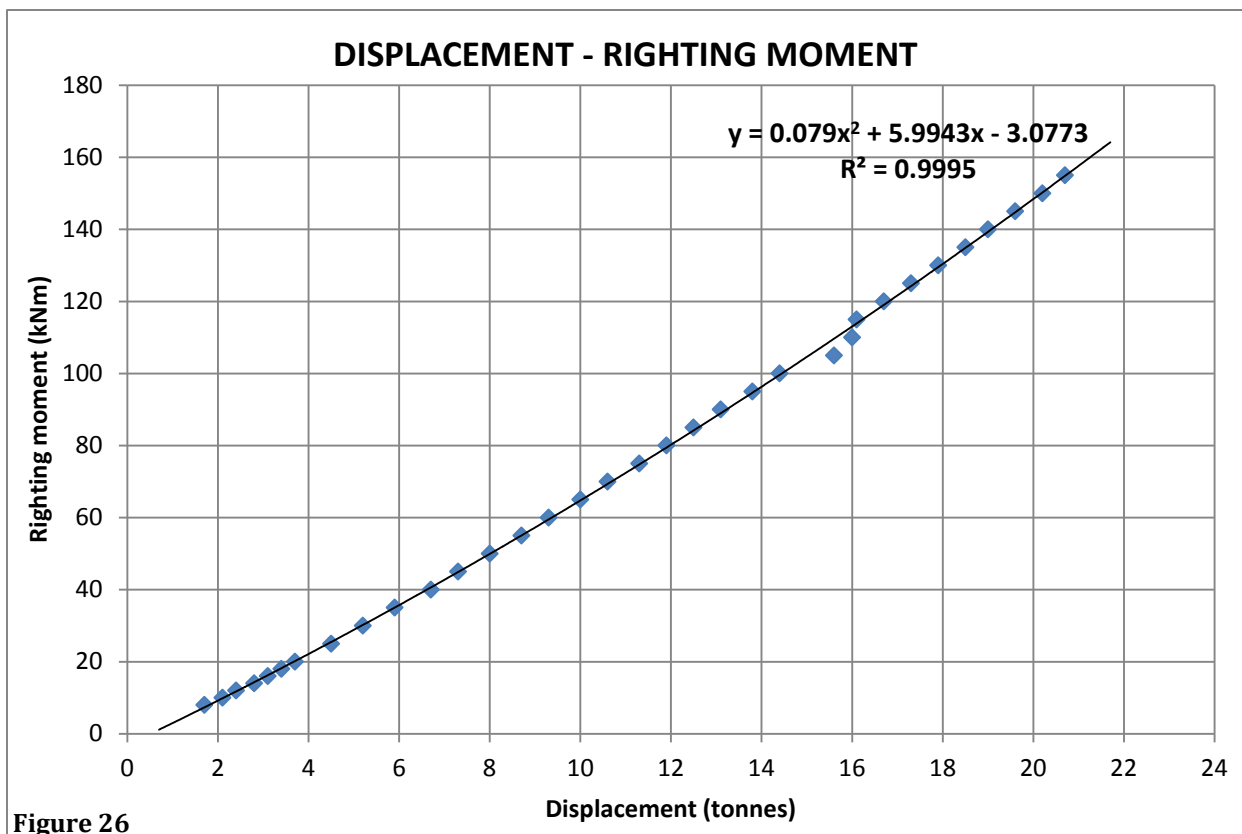
Figure 26

As you can see, there is a nice progression of points where we can do a regression curve. The best curve is a polynomial second grade curve with R^2 value enough to assert that there is an entailment as I told in my first hypothesis.

We can see as well two values near *Displacement = 16 tonnes* that shows a kind of deflection. Checking the data for the second time I realize that these values are given for Selden's table, so is not a written error or typo that I made. Moreover, this shows an error in the Selden's technical data.

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Therefore, I am going to use displacement value like "X" value in the graphics (is the most representative characteristic of the size of the boat) and use force value like "Y" parameter. The next graphic shows the relation between displacement and force for all value range (Figure 27):
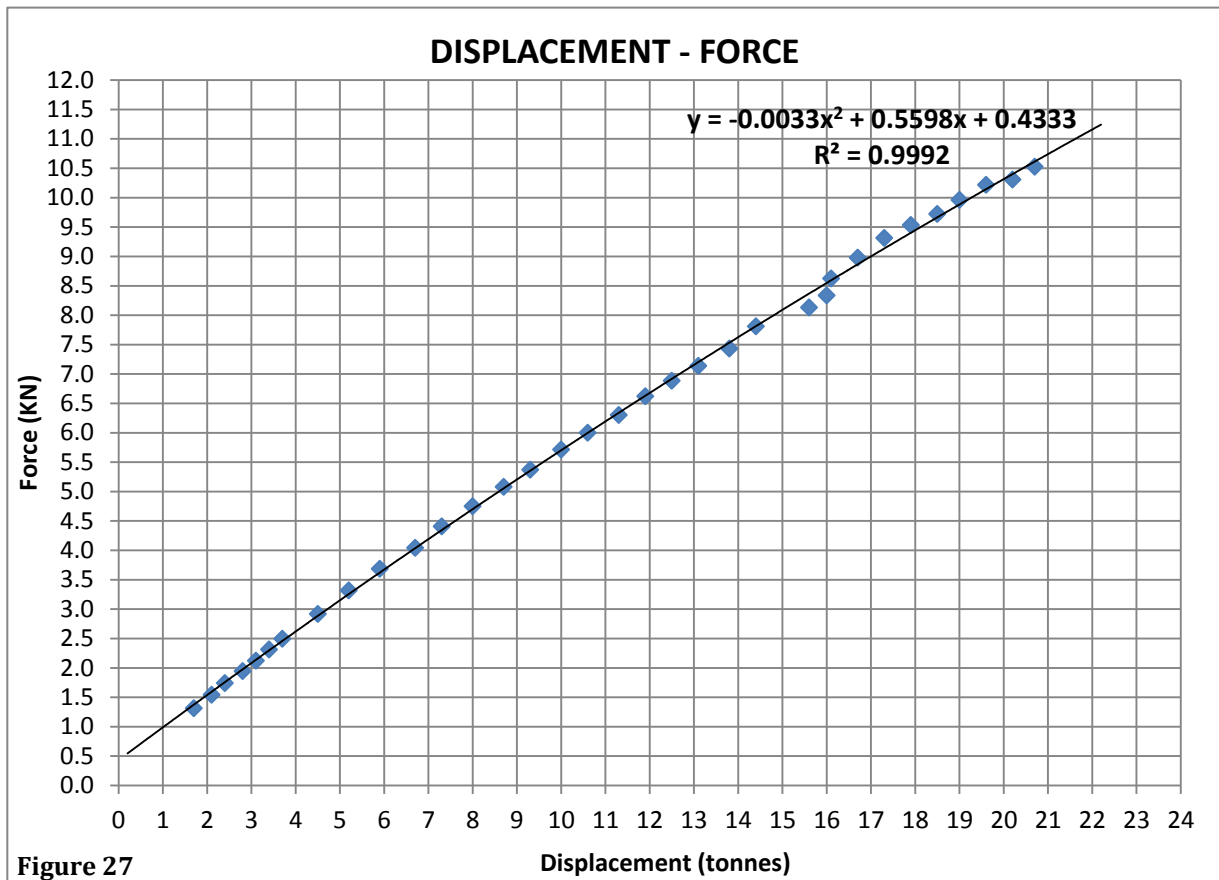
Figure 27

As we can see, there is a points progression and the best regression is another polynomial second grade function with $R^2=0.992$. You can notice the two deflection points near *16 tonnes* as well.

At the moment, I have a representation of the force in the top of the bowsprit linked with the boat size and the equation to get new values of force for a given displacement represent by:

$$y = -0.0033x^2 + 0.5598x + 0.4333$$

But, what happen with 1.7 tonnes sailboats downwards? There are a lot of small vessels between 0.5 and 1.7 tonnes nowadays, and most of them does not have bowsprit in the standard equipment.

In the next point I am going to analyze the possibility to complement another available range for the buyer who is in possession of a sailboat with small dimensions.

Thinking about smaller bowsprit could be a plus for my model because it could decreases the price and make it more advantageous compared to other manufacturers.

4.3 SEARCHING FOR NEW SOLUTIONS AND COMPARATIVE WITH REAL YACHTS

As a result of the above, I am going to find a set of new displacement data table including the small sailboats range.

The firs data displacement has jumps between 0.3 – 0.4 tonnes as we can see on the table 1 or in the representation below. I will use the downward values with jumps of 0.3 because I am working in smaller displacement values. So that I get this progression: *0.5 0.8 1.1 1.4*

To get the correspondent RM value, I am going to focus in the 15 first data because in that way I save the error of that two points deflected.

Figure 28

The chart is titled **DISPLACEMENT - RIGHTING MOMENT** with the y-axis labelled **Righting moment (kNm)** and the x-axis labelled **Displacement (tonnes)**. The fitted curve equation shown is $y = 0.1341x^2 + 5.3984x - 1.8523$ with $R^2 = 0.9998$.
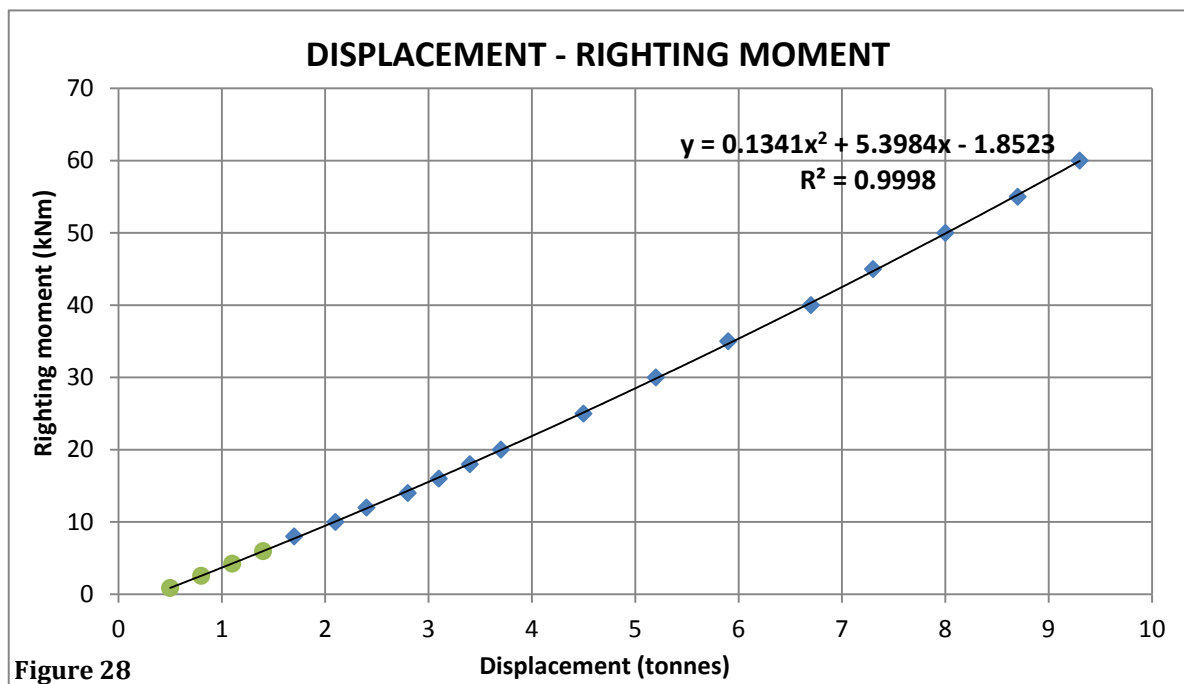
Table 2: New data points to small boats

Displacement (tonnes)	Righting moment (kNm)
0.5	0.9
0.8	2.6
1.1	4.2
1.4	6.0

The green points are the values on the right of the table, calculated with the quadratic curve given by Figure 28 with a very small *$R^2 = 0.9998$*

I am going to use these values to calculate the force in the top of the bowsprit in small boats. I use the polynomial formula given by Figure 27 to get new forces values linked to small displacement.

Displacement (tonnes)	Force (kN)
0.5	0.7124
0.8	0.8790
1.1	1.0451
1.4	1.2106
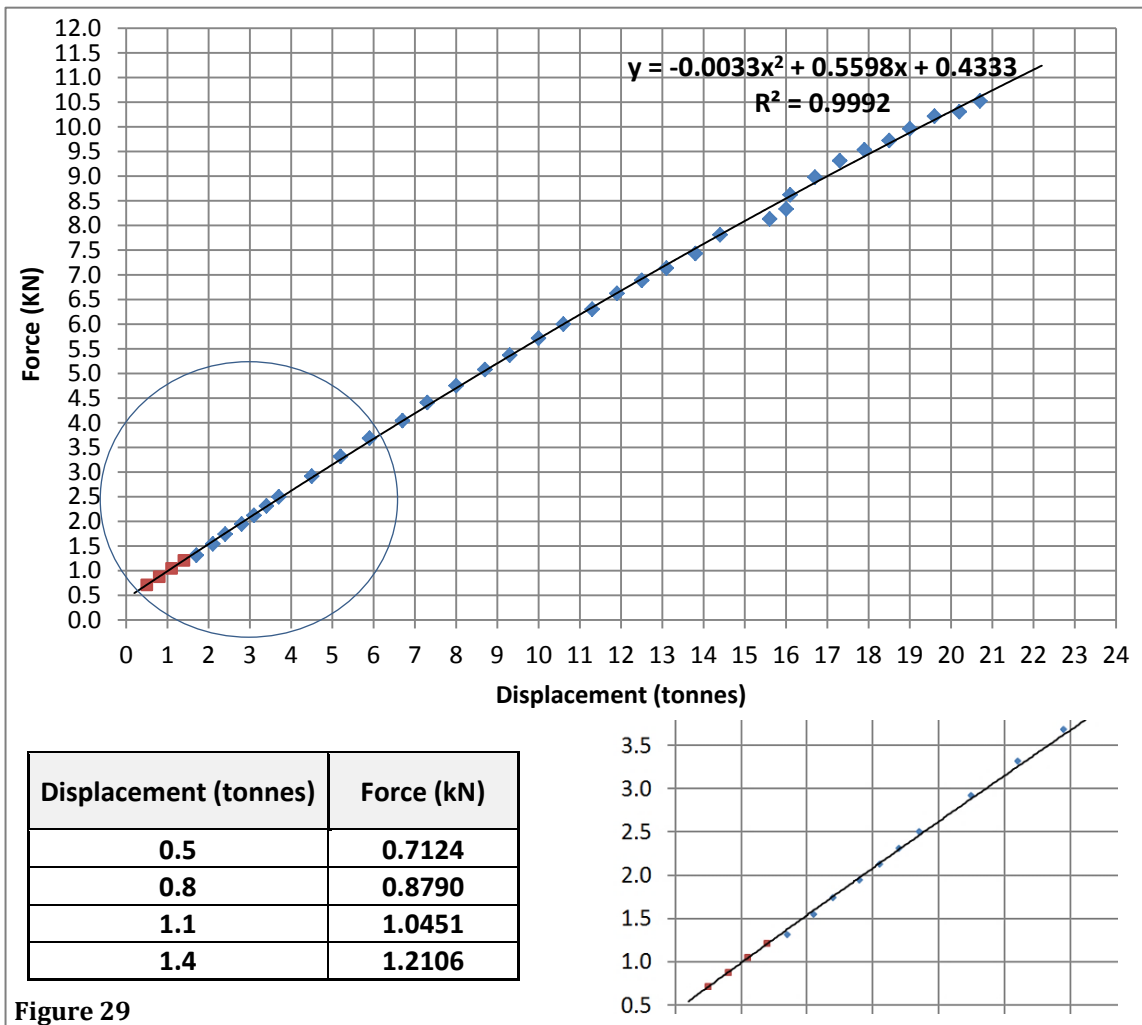
Figure 29

This new values (red points) are in the curve as we calculated, but we can observe in the zoom that the local tendency of the blue points are a bit different from the tendency of the red points or from the regression curve (figure 29).

I am going to focus again in the first 15 first rows of the table data to give a better solution in the calculation of the force and I save the error of those two points deflected as well.

As we can see in figure 30 and 31, I get a R_2 value very precise, almost perfect regression. We can see the polynomic changed so I do the same explained before to create a new table. The new force values are different from the values getting from figure 29. I will use this values later.

Displacement (tonnes)	Force (kN)
0.5	0.584
0.8	0.769
1.1	0.952
1.4	1.134
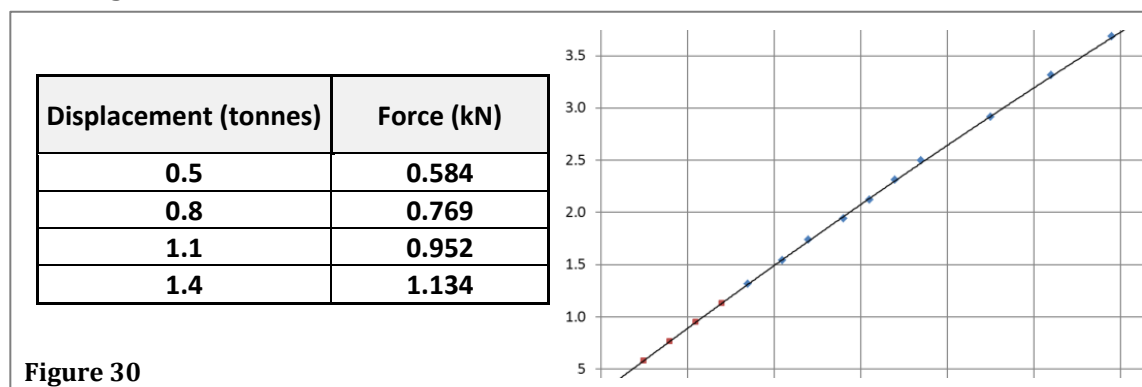
Figure 30

Figure 31
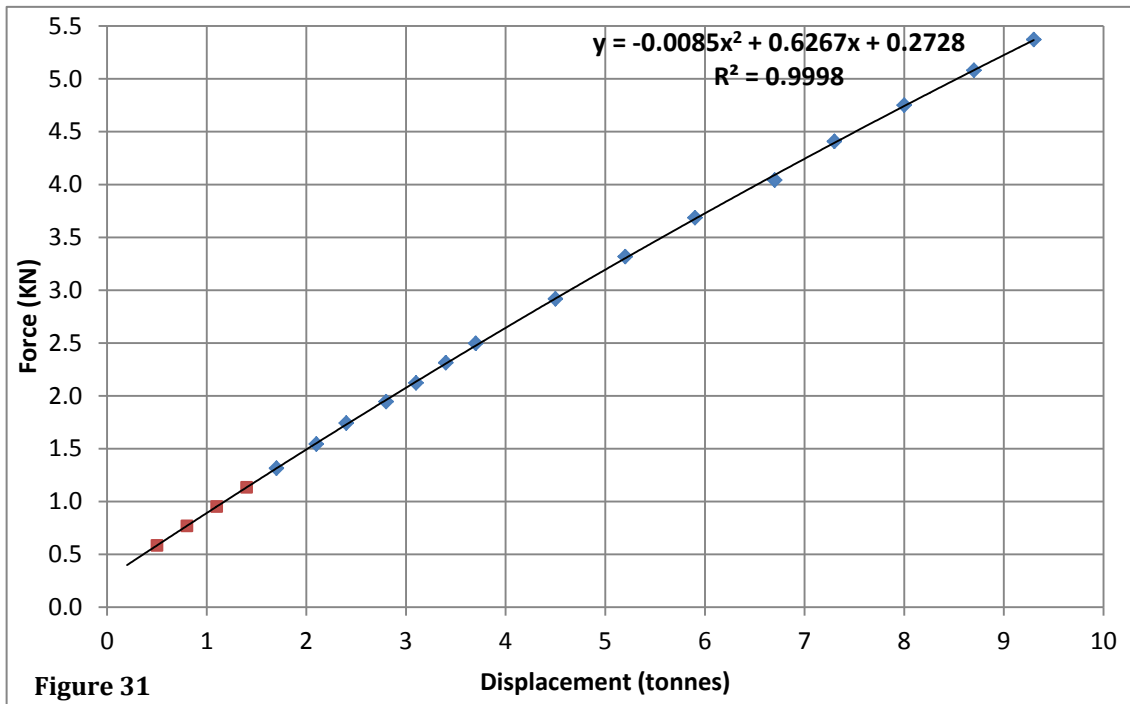
$$y = -0.0085x^2 + 0.6267x + 0.2728$$

Now I am going to present some real values and compare with the theoretical results. In APENDIX C you have the table with the technical characteristics collected from some catalogues. I consider the length of the boat, the displacement, the gennaker area (if it has) and finally the force in the top of the bowsprit according with the displacement.
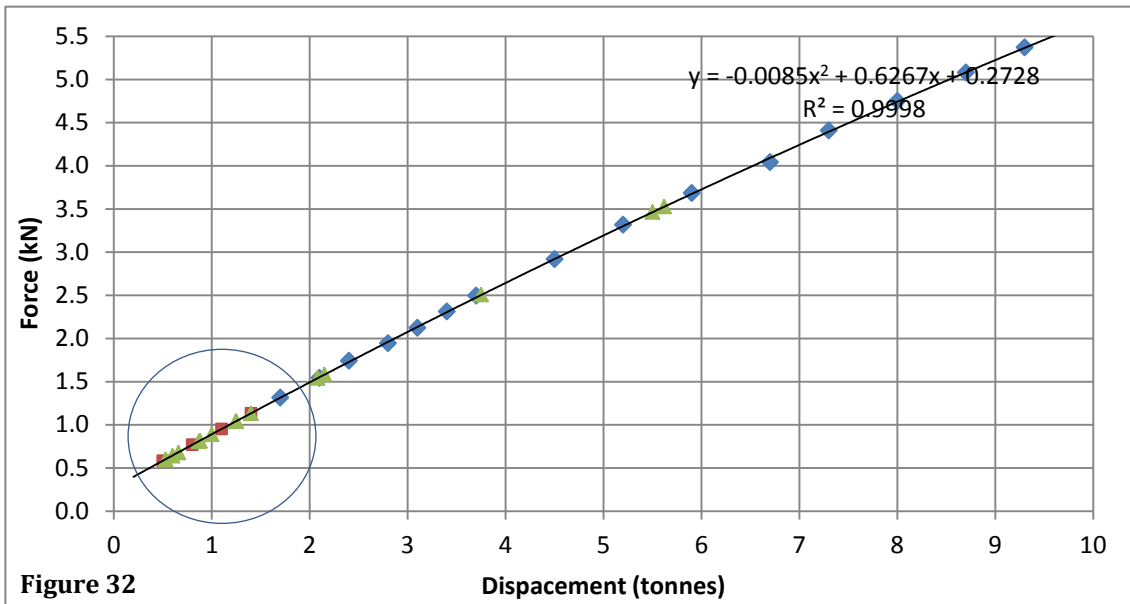
Figure 32

As we can see, we have the theoretical representation calculated with the formula cited. As you can see inside of the circle in figure 32 the green points are the small boats cited and they are just in the place I extended, so it is a clear sign to proceed to the design of smaller bowsprit.

I can consider other interesting relation between displacement t and gennaker area shows in next graphic.

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Figure 33
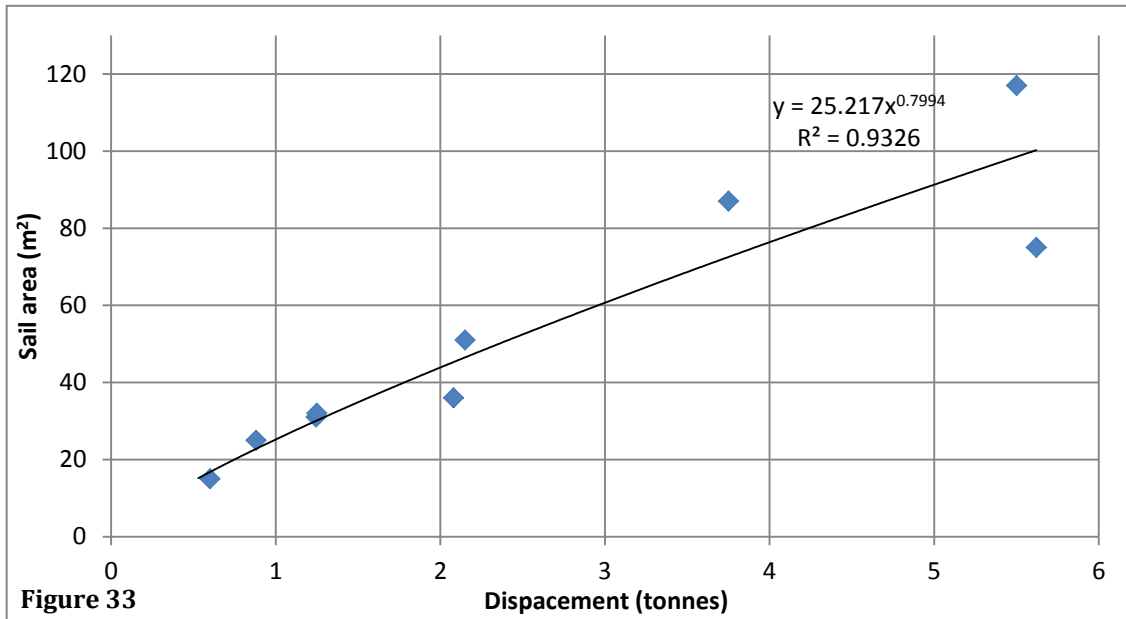
We can see the tendency of the values, of course are increasing but as we commented, I cannot have a perfect progression of points because a boat can have a bigger or smaller gennaker depending on where is located the displacement weight For example, if a boat has a big keel and big righting moment but the material of the hull is carbon, we will have a light boat with the displacement concentrated in the keel and we will be able to use a big sail area available, like MiniTransat boats.

The other manufacturer has the next values. The grey row is the new size of small bowsprit that I am going to design in next chapters.

Table 3: Sparcraft technical data table

Section (mm)	Boat Length (feet)	Maximum Asymmetric Sail (m^2)
60	*16-25*	*40*
70	25-36	60
80	36-40	82
90	40-47	102
100	48-57	130/150

I like this simple format of presentation data. I am going to mix both tables to get a nicer information table to put in the new catalog.

4.4 NEW RANGE PRODUCT DEFINITION AND SECTION CHARACTERISTICS

I am going to decide to use tubes with jump of 10 millimeters. I will start with 60 and I will increase to 70, 80, 90 and 100 like Sparcraft, and I am going to use the tables given by Seldén to do a similar distances configuration.

First of all I am going to define the section used after some trying. MEFI enables to create the equilibrium system with a random section and inertia and gets the

values of the reaction. If we choose the area section and inertia, we will get the maximum Von Misses value. This is the section chosen and the values calculated:
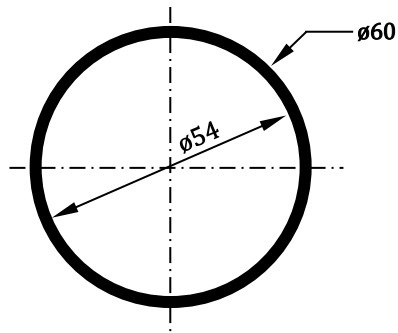
Int. diam. /ext. diam. /thickness = 60/54/3 mm

$r_e = 30 \ mm \ ; \ r_i = 27 \ mm$

$A = \pi \ (r_e^2 - r_i^2) = 537.21 mm^2 = 537.21 \cdot 10^{-6} \ m^2$

$I_z = I_y = \dfrac{\pi}{4} \ (r_e^4 - r_i^4) = 21879.73 mm^2 = 21.88 \cdot 10^{-8} \ m^4$

Second, use MEFI to present distance configurations I tried after some attempts. I fixed *L₁=0.5m*

So after some tries, I got similar forces in R_A because I have to give this value to the consumer, so it has to be almost similar in the *ø60* range tube. This is the configuration acquired:

Figure 34: configuration of length position bowsprit to get similar values in R_A and Von Misses

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Table 4: New table with the main values calculated with MEFI

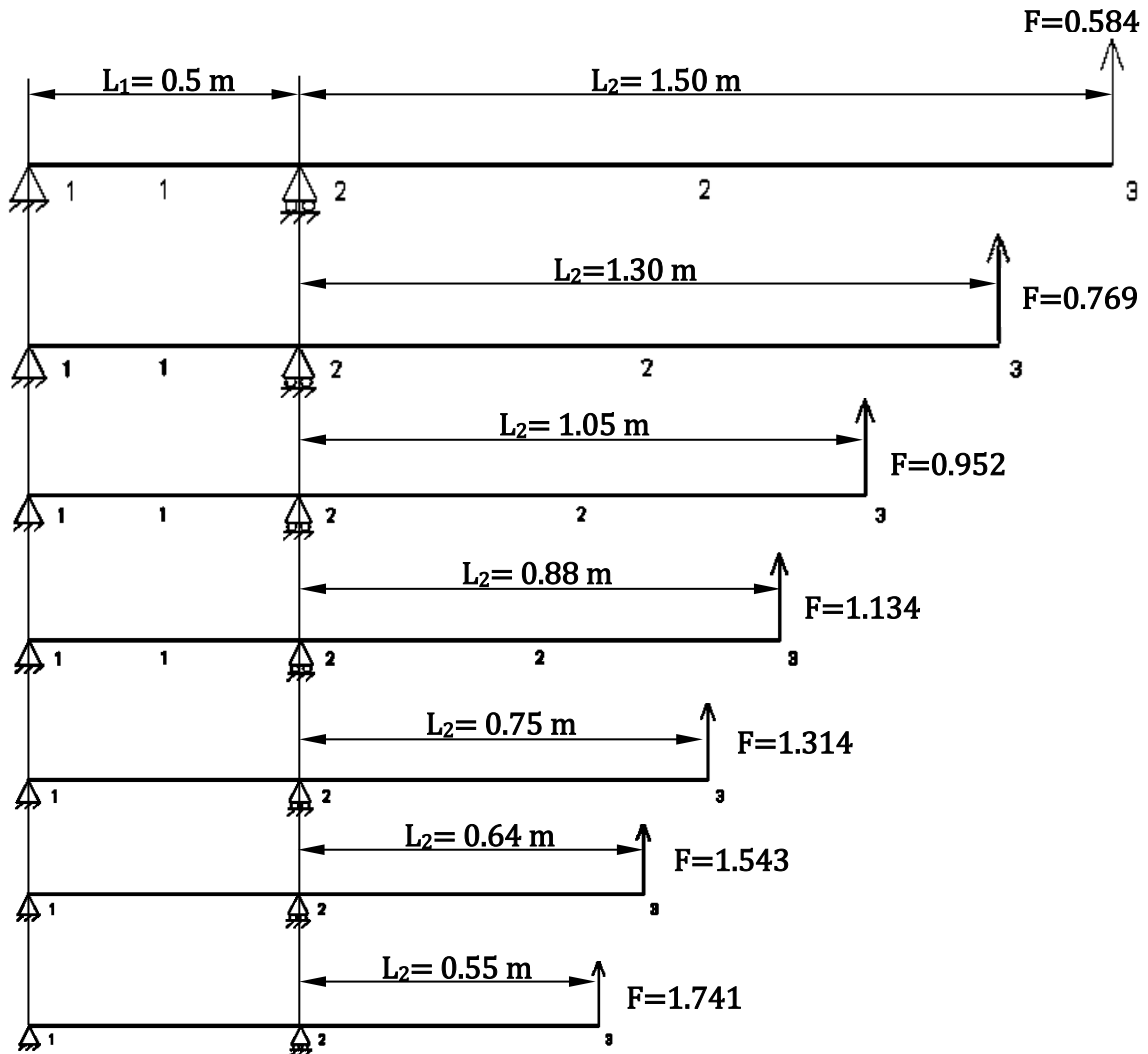|	F	R_A	R_B	Von Misses
Configuration 1	0.584	1.7520	-2.3360	1.4023e+05
Configuration 2	0.769	1.9994	-2.7684	1.6003e+05
Configuration 3	0.952	1.9992	-2.9512	1.6002e+05
Configuration 4	1.134	1.9958	-3.1298	1.5975e+05
Configuration 5	1.314	1.9710	-3.2850	1.5776e+05
Configuration 6	1.543	1.9750	-3.5180	1.5809e+05
Configuration 7	1.741	1.9151	-3.6561	1.5329e+05
Max values		~ 2		$\sim 1.6e+05$

As you can see, I get R_A value proximal to 2kN and von Mises stress or equivalent tensile stress (σ_v) is near $1.6 \cdot 10^5$ kPa.

I tried to make as more harmonious configuration as possible with the profile chosen considering the mechanical properties of aluminum, which, in most of the cases, its elastic limit (yield strength or yield point, σ_y) is between 150 and 400 N/mm^2 that is the same than between $1.5 \cdot 10^5$ and $4 \cdot 10^5$ kPa.

In APPENDIX you can see the table created by me. I have defined the profile and distances configuration for the first tube (because I will manufacture the top part attending to the internal and external diameter). The rest of tube sizes could be configured with the same distances and choosing the best thickness to ensure the strength of the tube. Those calculations are left open to future development in this project.

4.5 MATERIAL SELECTION

The right choice of material for a given application is a committed decision that requires extensive knowledge on the part of the design team, the properties of many materials to analyze the advantages and disadvantages to using a specific material in the manufacture of a product.

To make the right decision about what material is selected must assess the following:

- o Material properties.
- o Material availability
- o Material cost.
- o Quality material.

Wood, aluminum and carbon: three kinds of materials for the construction of masts are used. The wood is used exclusively for wood craft and carbon is used in high performance, being, then, the most common material aluminum.

4.5.1 WOOD

Wood was the material most used in masts at the beginning of the 20th century. The two types of wood most used in the first masts were oak and pine.

It has some major drawbacks:

- o It is not a lightweight material, especially when compared to modern composite materials.
- o Greater strength is achieved by using a single piece of wood.
- o Prone to rot if not treated properly.

4.5.2 ALUMINIUM

Aluminum is the most abundant metallic element present in the earth's crust and, within the group of non-ferrous metals, is the most widely used material in industry and in many other applications of everyday life.

Its lightness (2.70 g / cm3), good behavior in mechanical strength of many alloys, durability (aluminum is stable in air) and corrosion resistance (with proper surface treatment is resistant to both seawater, like many aqueous solutions and other chemicals), make this material ideal for this field.

Aluminum masts began to build after World War II. At present they are the most used for cruises and for a large number of classes. Aluminum has important advantages over wood, being lighter, stronger and immune to rot. Furthermore, an aluminum mast can be constructed in one piece.

The size of the mast to be built largely determines the process to be used.

Light masts, single or small cruise a standard sail section are made by aluminum extrusion through a die. The neck is cut to the desired length and accessories are attached. This is the cheapest way to build an aluminum mast, as it requires the use of expensive machinery and molds. For masts higher performance and larger you can use a similar system but with variations. The resulting conical shape has a top that allows the mast to be folded over.

The latest development in aluminum masts Alustartm is the use of an aluminum alloy developed for the marine industry. With a 20% increase in resistance, the thickness of the sheet used can be reduced; therefore, it can reduce the weight of the mast. The corrosion resistance, the bendability and weldability with other aluminum alloys is maintained. These masts are said to be stronger and lighter than extruded aluminum masts.

One feature that is taking strength today is the good availability to recycling once completed its useful life. Indeed, recycling can greatly reduce the energy required (up to 90%) if we compare it with the energy it would take to transform for use aluminum material extracted directly from the mines.

Anodized:
Aluminum, because of its chemical properties, has a high oxidation state. Thus, an aluminum piece that comes into contact with the atmosphere immediately reacts with oxygen in the atmosphere and rapidly forms a thin surface layer of an aluminum oxide, alumina ($Al2O3$). This layer is extremely resistant and is

chemically very similar to minerals as corundum, ruby or sapphire, second only to diamond in resistance.

Therefore, this fact, the formation of spontaneous and immediate way of the alumina layer is what gives the aluminum possessing properties excellent protection against oxidation and corrosion by chemicals.

Anodizing is an electrolytic chemical process that allows for artificially greater thickness of the protective oxide layer (even up to about 150 microns) so that better protection conditions are achieved with natural layers of alumina.

The electrolysis process begins by introducing the aluminum piece that works anode in an electrolytic medium, usually sulfuric. When making the electrical current passing between the poles the oxygen is released into the environment that will address the anode, which reacts with aluminum, will generate the oxide, alumina, covering the anode, and whose thickness is a function of time of current flow.

This process ensures that the aluminum piece is covered with an oxide layer of high hardness, ranging between 7 and 8 on the Mohs scale, in addition to being very stable and resistant to environmental corrosive agents. Layer generated through the electrochemical process is integrated in the metal itself, which cannot be scraped or peeled.

Advantages of anodized aluminum are the following:

- o Maintenance free
- o Anodizing is not affected by sunlight and therefore does not deteriorate
- o Increasing the surface hardness, it is resistant to abrasion and wear
- o The anodized surface layer is more durable than the layers obtained by painting.

However, the anodized aluminum used in construction must prevent contact thereof with mortars and concrete mixes, besides protect from attacks by acids and alkaline agents.

4.5.3 CARBON

Carbon masts were first used in the early 90. By using carbon fiber mast it can be constructed that is lighter and more rigid than an aluminum mast, which can significantly improve the performance of rigging. There are two major manufacturing methods employed in the construction of a carbon mast. The first is the use of a standard mold section to produce a uniform throughout the length of the mast section. This is the most economical type of carbon mast as molds used to make the standard section can be used more than once.

They can also be constructed as for a particular yacht. This type of mast, obviously more expensive as the mold must be constructed according to the specifications of the mast, and usually, this mold can be used only once.

The main problem of carbon is the additional cost of materials, as well as to increase labor needed. A carbon mast will cost about 7 times that of an aluminum mast.

4.5.4 TITANIUM

Titanium offers exceptional properties for sailing. Totally inert and stainless steel, slightly almost like aluminum, hard as steel, why do not you use the most?

Titanium is highly corrosion resistant against the marine environment and salt water. Their mechanical strength and other physical characteristics or ease of expansion accept different alloys with other metals, its low density and no toxicity and affordable cost when you consider his long life without having to make changes or maintenance, a material made of titanium perfect pleasure boats.

It is not used in the recreational boating industry because around him there are quite a few myths that should be clarified. Many people still think that titanium is a very exotic material and suitable only for very expensive and technologically advanced applications such as ball joints and bone pins and hips. But the fact is that titanium is used industrially for a variety of applications; in eyeglass frames, tools, climbing equipment, aviation, food industry....

Many construction professionals think that is very difficult turning and welding titanium, which is also false. The reality is you have to know its physical and technical characteristics of TIG welding equipment as well as the particulars to be taken into account in machining. It is a perfectly usable condition of knowing how material.

Regarding the price, it certainly is several times more expensive than steel, but this applies only to the additional cost raw material and not the total cost of a manufactured product, which makes possible much smaller price differences on the other They are no such side when you consider the savings without the possibility of maintenance and spare parts due to wear and oxidation.

Finally, although there is the possibility of finding titanium and its alloys in the market prices of raw materials to logic, this material is not magic and not be able by itself to solve all mechanical problems. The most interesting application areas are those in which need high mechanical strength and weight reductions, such as occurs in the rigging of the sailboats, or generally in any situation on a boat, motor or sailing, if we reductions weight and high performance.

It is a question of price. Titanium is more expensive than steel but not terribly expensive. The price depends on the type of titanium alloy used to get an idea, an alloy of grade 2 or grade 3 costs three times what it costs in stainless steel material 316. The price is therefore very similar to the price of alloys Copper / Nickel in its different proportions, or even cheaper than the famous *Monel* which costs about 4 times the price of stainless316 steel with a density of 8.9.

4.5.5 MATERIAL CONCLUSIONS

Today, aluminum remains the material of choice for excellence in this area, because it meets all the above specifications like properties, availability, cost and quality.

I chose this material to use in the pole. In future development of this project it could be interesting include other material like carbon fiber.

In the top and bottom parts, I have to consider the friction of the rope. There are many materials used today to make rope; synthetic fiber, natural fiber and wire. Main materials are polypropylene, Nylon, polyester and natural fibers. Accordingly, I should choose a more durable material than plastic. I am going to create the prototype in aluminum because as I told above, it meets with the basic specifications and is easy and fast to manufacture and doing a prototype part in the workshop.

But not only could the prototype part be made of aluminum, as well like last material chosen could be a good option. Other alternative could be stainless steel but we should study the behavior in contact because of the possible galvanic corrosion.

The material to fix the top and bottom with the pole it could be aluminum as well if I decide using rivets. It could be other material if is in screw shape.

CHAPTER 5
GRAPHIC DESIGN

The design is defined as the previous process of mental configuration "pre-figuration" in the search for a solution in any field. It is the most creative part, sometimes one of the most difficult because we have to create something that we cannot measure or calculate at the beginning.

In this chapter I am going to create the pre-production design doing the correct analysis, research, specification requirements, problem solving and presentation.

The basic manufacturing method to do the first prototype is use to be chosen by machining, in this case machining revolution (lathe) so I will make the prototype thinking about that method further work in a workshop where we have such equipment available

Next points you will see some first draws and 3D design make with Autodesk Inventor Professional 2015 software, and some renders with AutoCAD 2012 software, got with the free version for students in Autodesk web page..

5.1 DESIGN OF THE TOP

Our goal is design the simplest top but with same characteristics than the other manufacturers.

5.1.1 FIRST IDEAS

To fix the gennaker tack to the bowsprit, we need a rope (called guy) which we will modified the long depending of the sailing conditions. This rope will guide to the place where the crew are. So basically we need a piece to guide

Figure 35: simplest top

that rope from the gennaker tack to the cockpit. The simplest top is basically a ring where we can put a pulley as we can see in the figure.

But is preferable guiding the rope inside of the tube, because it provides less risk of entanglement and a cleaner product. With the rope inside we will get more integrated bowsprit and this will be an interesting goal for the buyers.

We are going to design a part which can be manufactured mainly by a lathe, in that way, we can define the main revolution surface showed in figure. But I cannot stop here. I need one place to fix a shackle where we could put a CODE 0 sail. In that way, we can think in putting a ring like figure 31 but we have to remember that our bowsprit will be through a ring (see
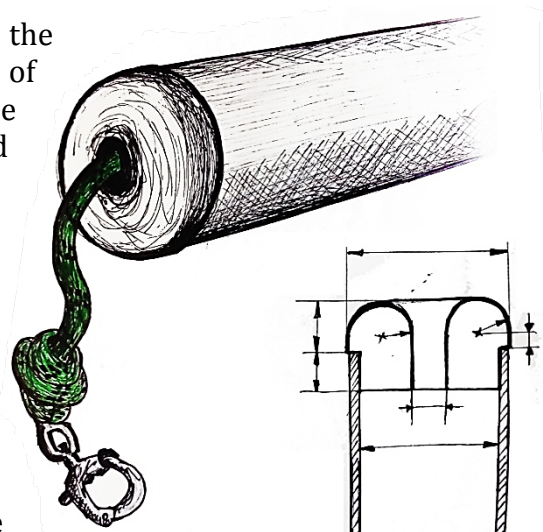

Figure 36: first sketch

BRACKETS in page 18). The outer bowsprit surface should be the internal diameter of the ring. In that way, we have to manufacture the hole based on the simple design in figure 32.

I only do not have to manufacture one, but two because we get more polyvalent and we can put a bobstay to counteract the force that code 0 furler does. Bobstay can be used when we sail in strong conditions or even with bigger downwind sails using the same bowsprit size. These two spaces are very important.

Other simplest possibility could be doing simplest holes to put a little rope, but I do not like this mechanism because the shackle must brook torsion (twisting) from the furler to the correct performance. Code 0 use to have this mechanism because setting up and getting down the sail is very fast.
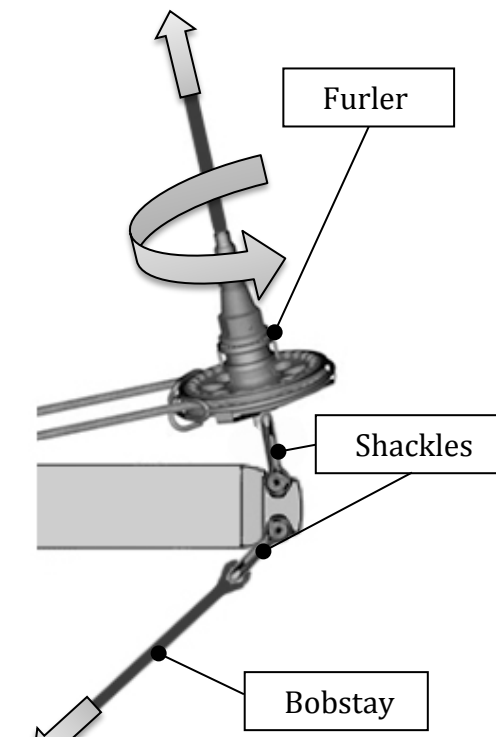
Figure 37: full configuration scheme

In figure 38 you can see a sketch, an approximation of what I want to design in CAD (Computer Aided Design). Take a look at the area manufactured by drilling or milling to generate the surface and hole where we will put the shackle.
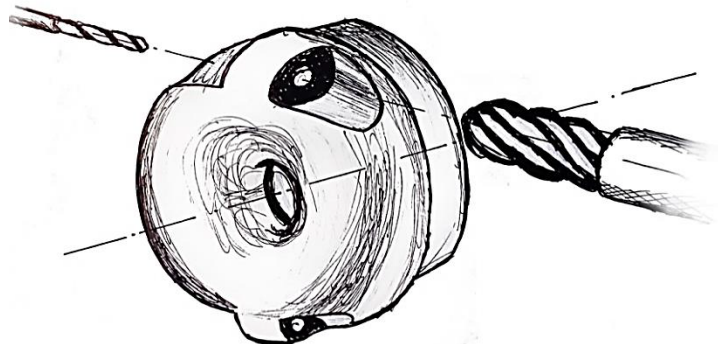
Figure 38 sketch done freehand, showing the geometry I will try to get

5.1.2 COMPUTER DESIGN: AUTODESK INVENTOR SOFTWARE

The Inventor 3D CAD software provides a set of professional tools for mechanical design, product documentation and 3D simulation.

Autodesk Inventor is based on parametric modeling techniques. Users begin designing pieces that can be combined into assemblies. Correcting parts and assemblies can be obtained several variants. As parametric modeler, it should not be confused with traditional CAD programs. Inventor is used in engineering design to produce and develop new products, while programs like AutoCAD are conducted only dimensions. A parametric modeling allows modeling geometry, size and material so that if the dimensions are altered, the geometry automatically updated based on the new dimensions.[19]

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[19] http://es.wikipedia.org/wiki/Autodesk_Inventor

The ability to download the student version (with a period of time for use of 3 years for free) is an option highly valued by students as it allows us to use this type of software to get used to what we can find in a real company.

The process begins by using an ".ipt" file (inventor part type) where I can make an individual piece.

First, I must draw the sketch of the revolution surface that defines the main body part. So that, define the basic geometry (in this case simply draw one side of the section) by drawing it with the tools available. Then I apply parameter values with the sizing tool (dimensions).

Once I have the main revolution surface, I must generate other sketch to do the mechanized areas (e.g. holes).

A very interesting option that I can do is to use a tool that allows you to copy as a mirror all that I made in one quadrant of the main body. Thus I have only to define one milled area. Automatically it will be copied to the other quadrants.

In this case, I draw the top part attending to the tube 60/54/3 mm so I have to be taken into account for the part to be inserted into the tube.
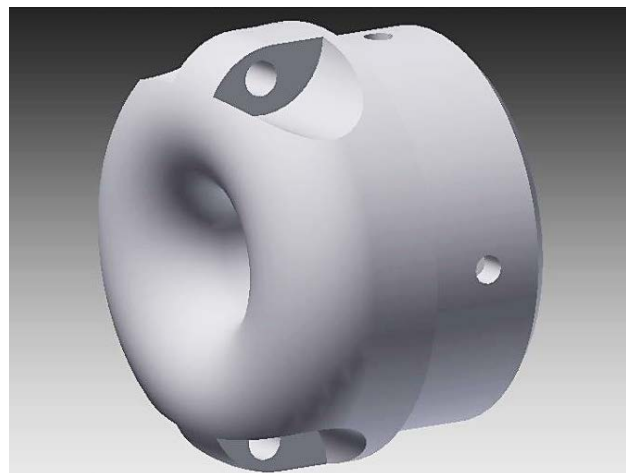
Figure 39: design of body top completed

After the draw is done, we can create an ".idw" file (inventor drawing) where I will place the technical drawing. I select the interesting views and section, selecting the perspective and DIN characteristics. In APPENDIX D you can see DIN A3 and A4 technical drawings.

I would like to focus in the milled parts because I did it according to the dimensions of the shackle selected, thinking in holding the shackle head and a specific rotational angle to adapt it to the different elements that we can place (it will not be placed perpendicular to the tube as you can see in figure 37).

In APPENDIX D you can see the shackle selected, according to DIN dimensions in other catalogues (nautical shackles). You can see as well the assembly part and the maximum angle without contact between top edge and shackle.
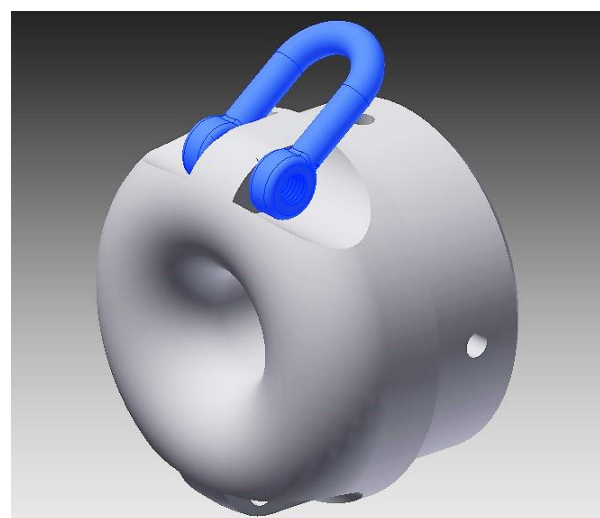
Figure 40: assembly part with body and shackle

5.1.3 COMPUTER DESIGN: AUTOCAD SOFTWARE

AutoCAD is a leader in software design programs, drawing, modeling, architectural drawing and engineering in 2D and 3D.

AutoCAD is used across a wide range of industries, by architects, project managers, engineers, graphic designers, and other professionals. It is supported by 750 training centers worldwide as of 1994.

As Autodesk's flagship product, by March 1986 AutoCAD had become the most ubiquitous CAD program worldwide. As of 2015, AutoCAD is in its thirtieth generation, and collectively with all its variants, continues to be the most widely used CAD program throughout most of the world.[20]

In my case, I will use this software for rendering the head because it has better qualities of quality when making a graphic presentation as realistic as possible compared with Inventor.

Rendering is one of the major sub-topics of 3D computer graphics, and in practice is always connected to the others. In the graphics pipeline, it is the last major step, giving the final appearance to the models and animation. With the increasing sophistication of computer graphics since the 1970s, it has become a more distinct subject.

In addition, once I have the piece measures, I do not make changes to the dimensions, so the use of AutoCAD will be the realization of digital photographs to present it in future catalog customers.

Clear differences are noticeable compared to inventor, especially when making modifications to the sketch (much faster inventor).

Like curiosity, comment that the design with Inventor has done

Figure 41: AutoCAD rendered image, showing almost a realistic perception.

with 2015 professional version, while the same version of AutoCAD has not been installed on my computer because it does not accomplish the minimum recommended hardware requirements. It was finally realized with the 2012 version and has even come to see a clear difference in the flow of the program (working much slower and consume more computer resources) although it is an older version.

In figure 41 you can see an example of a screenshot rendered image done in AutoCAD with soft shiny aluminum finish on a wooden table. In the appendix you can see more rendered with different materials.

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[20] http://en.wikipedia.org/wiki/AutoCAD

5.2 DESIGN OF THE BOTTOM

The realization of this part would do a larger project of established, so it is left open and just discussed for possible future development.

As discussed in the description of the parts of the boom, this part is going to take to fix the tube to the hull of the boat, so you have to have a simple mechanism yet robust and secure.

Some freehand sketches are shown in the following figure. There are possible bases, easy to manufacture in a similar way like the "top part".
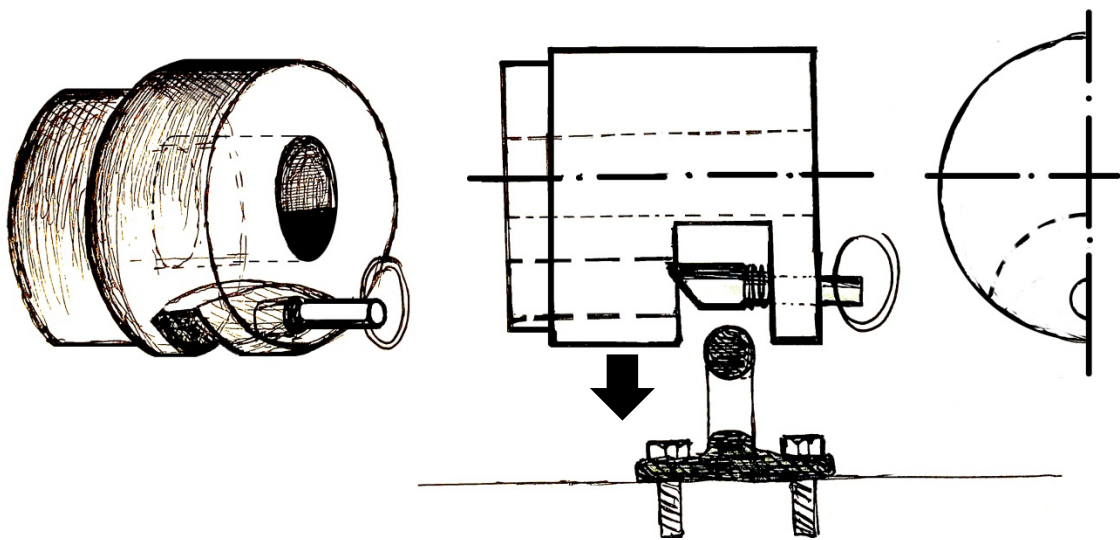
Notice the spring mechanism that could be used.

Figure 42: example of bottom part, simple to manufacture in a lathe with three machining processes after the turning: two drilling with different diameters and one milling.
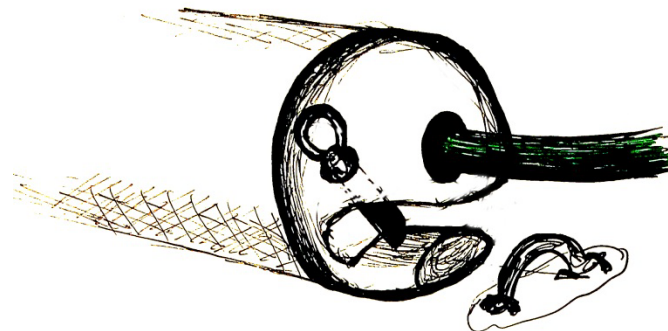
Figure 43: other alternative using the same main body than in top part but with an alternative of two milling processes: one drilled and one milling

CHAPTER 6
PROCESS PLANING

As I have already explained in advance, I will make prototyping by machining. I begin the main body by turning in a lathe and after, machining to do the holes. If I took a real situation, we should use a 5-axis lathe with controlled stop, to do all in the same machine automatically. In the case of unavailability of machine, which is very likely in most cases, should removing the main body by revolution, and placed manually on a milling machine to machine afterwards.

The tool used to perform a simulation of the process is called WinUnisoft, provided by EINA, University of Zaragoza. This tool offers the possibility to simulate turning processes (one axis), milling; tool selection and development of automation code (it can be used in real automatic lathes). The program offers a series of lathes that can be selected.

Sometimes it does not exactly match the code used by the program to that used by the real machine, so you usually have to make small changes in the parameters of the code.

For the simulation I am going to use a piece of a solid rod of the same diameter than the maximum diameter of the piece, precut and placed in the jaw chuck lathe

6.1 TOP MACHINNIGN

6.1.1 FIRST PART: FRONT

In this part, I will machine the front of the piece. The program can develop part machining for each file, so I cannot turn to the machined face and continue on the other side. Therefore, I do separately.
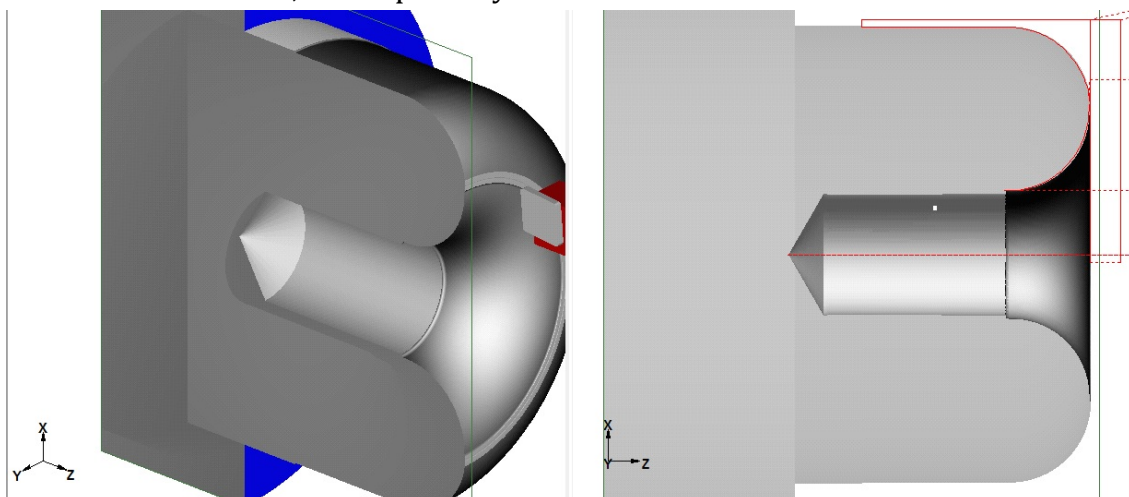

Figure 44: screenshot of front part process finished

Each process will go in a different file. In this case I have a lathe that perform the operations automatically and continuously, shall bear the same order which I will explain. In the workshop I will use a machine that will have to change the piece "by hand" between each process.

Start by selecting the dimensions of the billet machined. I also select the tools that we will use for inclusion in the code. Once all those parameters defined, I can continue writing the code and simulating. You can see the code in Appendix

6.1.2 SECOND PART: BACK

Once finished the first side, I have to manufacture the part that will be placed inside the tube. You can see I start with the inner hole made in first step.

Comment that the first written code is based on performing radial cuts. This option was changed because the machine should vary the speed progressively in each cut depending on cutting speed on the surface, so it would consume more energy and would be worse for the tool and the workpiece.

So each cut will be done along Z axis so we should only regulate a spin speed determined with each pass (in steps).
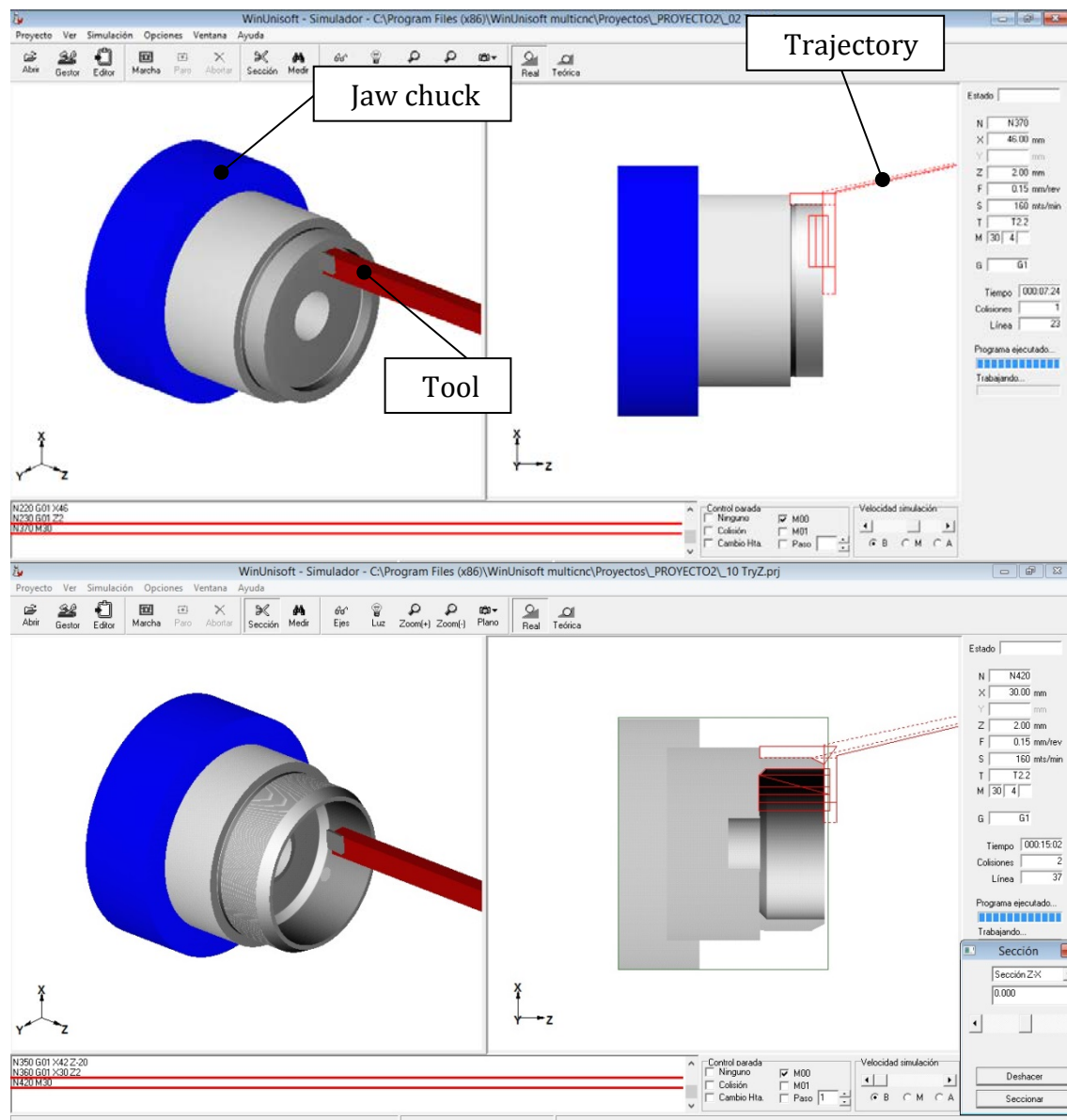

Figure 45: comparison between both methods; vertical (first pic) horizontal (second pic)

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6.1.3 THIRTH PART: HOLES

The software used can only perform simple machining turning on a flat surface, so that this part cannot be simulated with the tools I have. I will define the process that can be held in the following image. I use a vertical or horizontal milling machine, to make the hole in which it will put the shackle. Below I will make the holes with a drill.
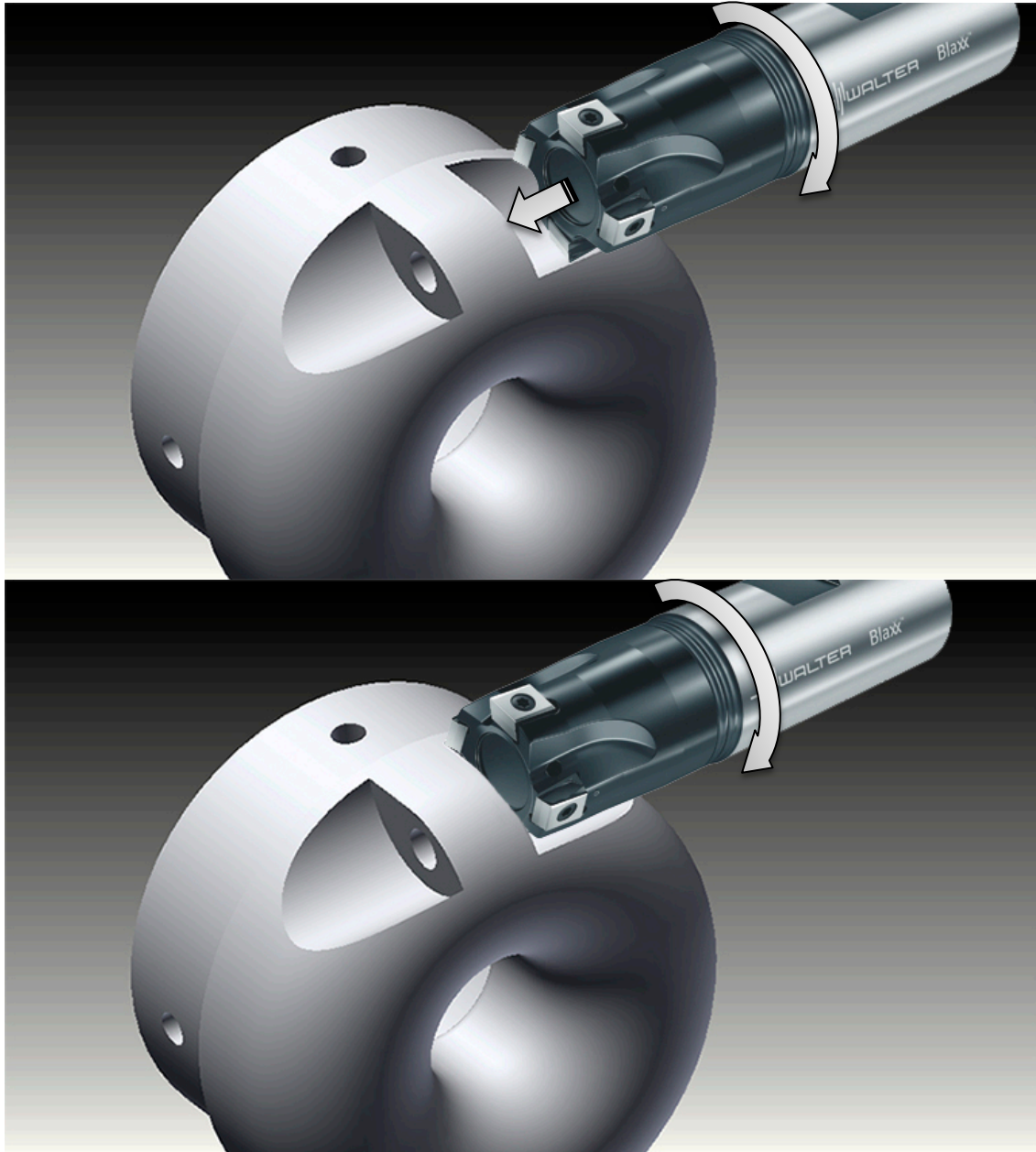

Figure 46: example of one possibility to manufacture that area

If you are more interested in the process, have a look to APPENDIX D to see more figures and the codes.

Once simulate the process, I am ready to go to the workshop to put into practice the prototype manufacturing.

CHAPTER 7
PROTOTYPE MANUFACTURING

7.1 WHAT IS PROTOTYPING BY CNC MACHINING?

It is a technique of rapid prototyping by machining. CNC machining and CNC computer is an automated cutting process turning and milling in which the material block is removed with a rotary tool. In CNC milling cutting tool moves in the three or five dimensions to achieve the desired shape in the workpiece. CNC milling cutting tool usually rotates about an axis that is perpendicular to the table containing the material to be cut. A router looks somewhat like a drill at first sight. A cutting tool projecting downward from the rotating spindle. Block material on a movable table below the knife is placed. While rotating the cutting tool, a computer controls the vertical movement of the blade (Z axis) and horizontal movement (X and Y) block material. The cutter is guided to move through the material, removing portions to create forms.

7.2 WHAT KIND OF MATERIAL IS GOING TO BE USED?

We can perform rapid prototyping of rigid materials including most metals: aluminum, stainless steel, copper, steel, brass, titanium, silver, bronze, etc.
And hard plastics and other materials: nylon, polycarbonate, polystyrene, acrylic, fiberglass, carbon fiber, PTFE, ABS, PVC, PMMA, PEEK, etc.

I am going to start using a kind of conglomerate of wood with glue. It is a very easy material to manufacture because is very soft and the tools do not work in heavy conditions. If this part of the prototyping is doing as the desired behavior, aluminum can be used for the next step in the manufacturing prototyping.

7.3 TRABAJO EN EL TALLER:

The objective of this part is to implement all the work done. The work is going to perform in the workshop of Óbuda University, specifically in "Donát Bánki Faculty of Mechanical and Safety Engineering", with the help of an engineer who works here. He is a professional in the field of manufacturing: István Burai.

The first day (9:00 to 13:00) we started with the study of a manual lathe with automatic feeding speed. We studied all component parts and how to do proper use of its operating mechanism. We did all the steps correctly for machining a cylinder, making a facing and then a series of turnings to see how the machine behaved.

Then I got used to the software we used to manufacture the part in the CNC machine. This software is TOPCAM, and once the process is well defined, we can

bring the program to the CNC machine and perform the piece. We selected the right tools to manufacture the first part. One observation is that selected steps will be different from those defined in Chapter 6, starting first from the back of the piece, because, to make the front, we can fix it easily in the jaw chuck.

The second day (9:00 to 16:00) we finished the program code, perform the screenshots that can be seen in Appendix F and codes, and then use tubes of a cluster of wood resins for the first two pieces manufacturing test. We make the part of revolution in CNC machine, leaving subsequent machining for the next day.

The third day (9:00 to 13:00) we made in the morning the holes for mounting the tube. Then we proceeded to make the shackle anchor regions in the vertical milling machine. The first prototype went wrong due to a small bug in one dimension. We discard it and finished the second piece, which was perfect as we can see in the photos of Appendix F. We then decided to make a prototype in a harder material (free machining steel) more realistic and similar to the aluminum process. Everything went correctly.

In the fourth day, I went to buy the aluminum. I went to the store to see the machinery used and the types of aluminum they work, as well as bar size and length needed to manufacture 3 or 4 top pieces. You can see in Appendix F, in the invoice, the dimensions of solid bar (65 x 200) and price.

The fifth day we manufactured the aluminum bar, as it is the final material we want to test the prototype. We performed 3 pieces. Everything went perfectly worked, so that it was the last step in prototyping. If we find fault with its use, such as cracks, fault rupture, material wear or corrosion, I should perform small changes in the design and use of other alloys or other tougher materials.

CHAPTER 8
CONCLUSIONS AND FUTURE WORK

After an exhaustive study market to design the bowsprit that can perform seemingly with the least possible cost, I would finishing designing the base part and a prototype to verify that it meets the requirements specified. Once I made the design of the whole kit, I should perform designs for larger sizes bowsprit. After a few prototypes built and tested in real sailboats and conditions, if everything went well, I should go into production of this, with appropriate safeguards for consumers.

I should look for providers of which I could serve the necessary materials to assemble the boom.

As already discussed, I would begin by buying aluminum tubes suitable dimensions and alloy which apparently can be adjusted to the features. The second step would be to produce heads that could instruct the manufacturer with capacity for proper machining.

I should study the total cost of the product due to the material cost and the costs of producing each piece. At that value, I should add the profit we want to get for every product sold. If the cost is too much, I should explore new methods of production or manufacture a more adaptable to each case so that each customer may have a range of configurations suitable for sailing. I may also consider making the top and the bottom part by other methods and materials, such as by molding.

As seen, this project is very close to a project that could be real, so I hope you could see the effort involved in performing any object in the industry, although it seems a very simple mechanism, it will always be behind many hours of work and study to improve gradually and offer customers what they want.

This project has been undertaken with the intention of improving the shipping industry, and to make it accessible to all, because I think that the naval field is a very exciting field for everyone, plus it favors transport and leisure sustainable and environmentally friendly as it sailing generates no environmental impact through the use of wind energy.
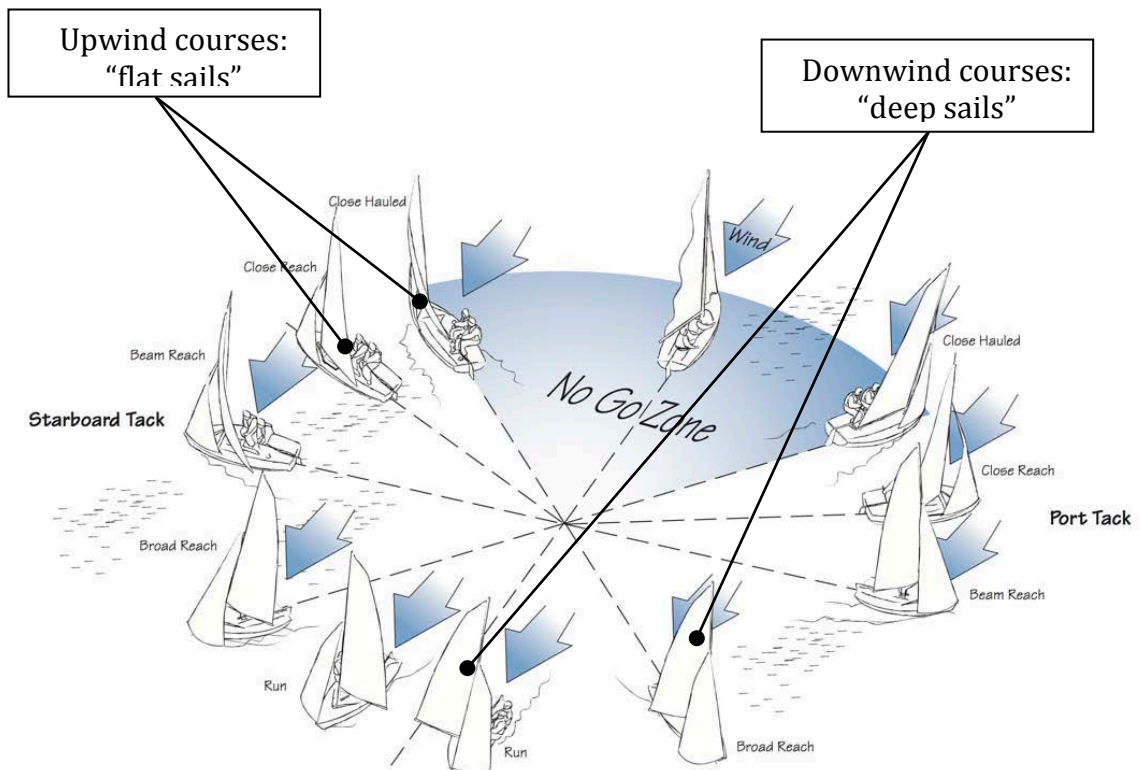
APPENDIX A
BASIC SAILING THEORY

Upwind courses:
"flat sails"

Downwind courses:
"deep sails"

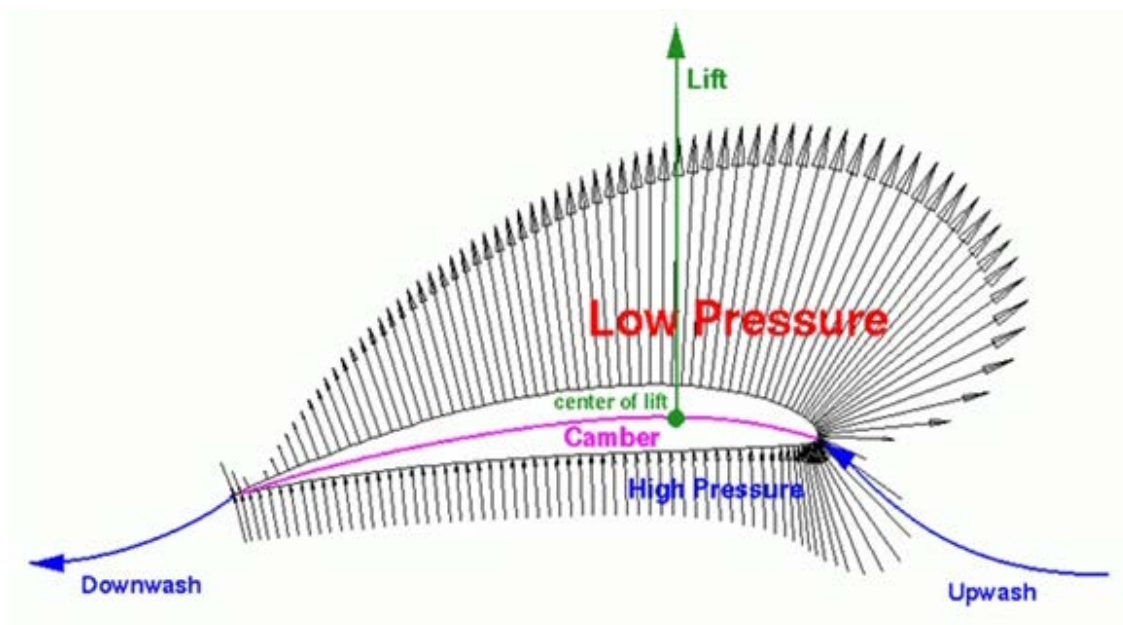**Figure 47: basic sailing directions**

Figure 48: Pressure vectors and flow over a cambered section

APPENDIX B
SAIL TYPES

Modern sails can be classified into TWO main categories:

- Upwind sails: Mainsail and headsail also known as the jib sail

- Downwind sails: Spinnaker

Special-purpose sails are often a variation of the two main categories like gennaker, code 0, etc.

Differences between sailing with spinnaker and gennaker:

- Spinnaker: sail used with spinnaker pole.

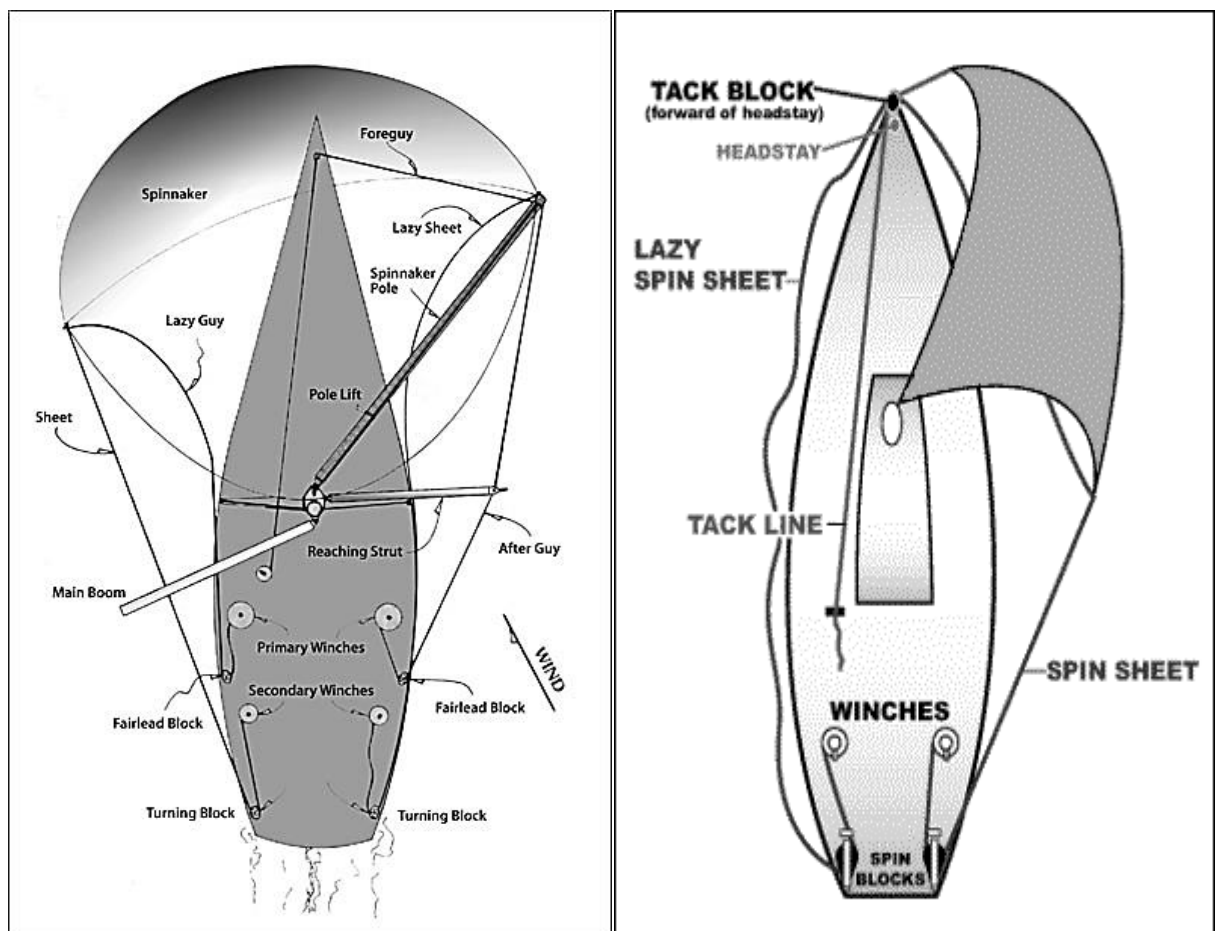- Gennaker : sail used with bowsprit

Figure 49: differences between spinnaker (left) and gennaker (right)

Figure 50: Competition boat using the configuration mainsail and asymmetric spinnaker

Figure 51

APPENDIX C

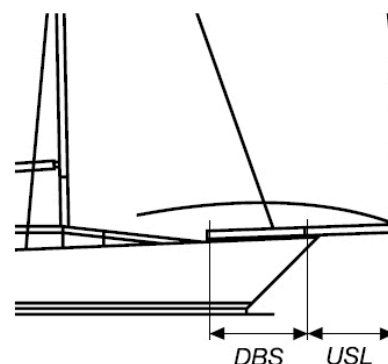# RESISTANCE STUDY TABLES

Table 5: VMG bowsprit table data:

Outside Ø (mm)	Indication of use, size boat (feet)	maximum offset (mm)	L min (mm)	Lengths standardbos (mm)			Reference		
								L1	L2
60	<30	700	700	1400	1700	3000	20BD00060	20BD00061	20BD00062
70	30 to 35	800	800	1600	2000	3000	20BD00070	20BD00071	20BD00072
80	35 to 40	900	900	1800	3000	4000	20BD00080	20BD00081	20BD00082

Table 6: Sparcraft bowsprit table data

section ø (mm) Alu.	Total length (mm - feet)	Minimum length inside (mm- feet)	Maximum length outside (mm)	Use example Boat length (feet)	Maximum sail area (m²)	
					Asymmetric spinnaker	Gennaker & Code O
ø 70	1600 - 5'3"	800 - 2'7"	800 - 2'7"	25-36'	60	37*
ø 80	1800 - 5'10"	900 - 2'11"	900 - 2'11"	36-40'	82	52*
ø 90	1900 - 6'2"	950 - 3'1"	950 - 3'1"	40-47'	102	65*
ø 100	2000 - 6'6"	1000 - 3'3"	1000 - 3'3"	48-57'	130 / 150*	105*

Table 7: Seldén bowsprit table data:

RM 30° (kNm)	Approx. displ. (tonnes)	G072	G075	G087	G099	G120
8	1.7	1280				
10	2.1	1090				
12	2.4	960	1700			
14	2.8	860	1520			
16	3.1	790	1390			
18	3.4	720	1280	1640		
20	3.7	670	1180	1520		
25	4.5	570	1010	1300	1710	
30	5.2	500	890	1140	1510	
35	5.9		800	1020	1350	
40	6.7		730	930	1230	
45	7.3		670	850	1130	
50	8.0		620	790	1050	
55	8.7		580	740	980	
60	9.3		550	700	930	1850
65	10.0			660	870	1750
70	10.6			630	830	1660
75	11.3			600	790	1580
80	11.9			570	750	1510
85	12.5			550	720	1450
90	13.1			530	700	1390
95	13.8				670	1340
100	14.4				650	1290
105	15.6				630	1250
110	16.0				600	1210
115	16.1				590	1170
120	16.7				570	1140
125	17.3				550	1100
130	17.9				540	1070
135	18.5				520	1050
140	19.0				510	1020
145	19.6				500	990
150	20.2				490	970
155	21				480	950
160	22					930
165	24					910
170	25					890
175	26					870
Min. distance between support, DBS (mm)		580	600	700	800	1000
MSL at inner end (Kn)*		2.9	4.9	5.4	6.2	10

DBS   USL

* MSL = Max Service Load, based on minimum DBS.
MSL at bow bracket = MSL at inner end x (1 + DBS/USL).
DBS = Distance between support.
USL = Unsupported length.

Table 8: Seldén table write on Excel

RM (KN)	Approx displ. (Tm)	L$_2$ (m)				
		ø72	ø75	ø87	ø99	ø120
8	1.7	1.28				
10	2.1	1.09				
12	2.4	0.96	1.70			
14	2.8	0.86	1.52			
16	3.1	0.79	1.39			
18	3.4	0.72	1.28	1.64		
20	3.7	0.67	1.18	1.52		
25	4.5	0.57	1.01	1.3	1.71	
30	5.2	0.50	0.89	1.14	1.51	
35	5.9		0.80	1.02	1.35	
40	6.7		0.73	0.93	1.23	
45	7.3		0.67	0.85	1.13	
50	8		0.62	0.79	1.05	
55	8.7		0.58	0.74	0.98	
60	9.3		0.55	0.7	0.93	1.85
65	10			0.66	0.87	1.75
70	10.6			0.63	0.83	1.66
75	11.3			0.6	0.79	1.58
80	11.9			0.57	0.75	1.51
85	12.5			0.55	0.72	1.45
90	13.1			0.53	0.7	1.39
95	13.8				0.67	1.34
100	14.4				0.63	1.29
105	15.6				0.6	1.25
110	16				0.59	1.21
115	16.1				0.57	1.17
120	16.7				0.54	1.14
125	17.3				0.52	1.1
130	17.9				0.51	1.07
135	18.5				0.5	1.05
140	19				0.49	1.02
145	19.6				0.48	0.99
150	20.2					0.97
155	21					0.95
160	22					0.93
165	24					0.91
170	25					0.89
175	26					0.87
L$_1$	Min distance between support, DBS (m)	0.58	0.6	0.7	0.8	1
R$_A$	MSL (max service load, based on minimum DBS) at inner end (KN)	2.9	4.9	5.4	6.2	10

R$_B$	MSL at bow bracket. We use the next formula:
	R$_B$ = R$_A$ · (1+(L$_1$/L$_2$)

F	Force formula, at top part:
	F = R$_B$ - R$_A$

Figure 52: MEFI software environment used for the structural design.

Place to write the code: point definition, lines, forces, materials, properties and boundary conditions

Schematic area to see the values graphically

Value of the maximum Von misses stress in the most unfavorable section

List of values calculated by the program

Table 9: calculated values (force F and reaction R_B)

ø72		ø75		ø87		ø99		ø120	
F (KN)	R_B (KN)	F (KN)	R_B (KN)	F (KN)	R_B (KN)	F (KN)	R_B (KN)	F (KN)	R_B (KN)
1.314	4.214								
1.543	4.443								
1.752	4.652	1.729	6.629						
1.956	4.856	1.934	6.834						
2.129	5.029	2.115	7.015						
2.336	5.236	2.297	7.197	2.305	7.705				
2.510	5.410	2.492	7.392	2.487	7.887				
2.951	5.851	2.911	7.811	2.908	8.308	2.901	9.101		
3.364	6.264	3.303	8.203	3.316	8.716	3.285	9.485		
		3.675	8.575	3.706	9.106	3.674	9.874		
		4.027	8.927	4.065	9.465	4.033	10.233		
		4.388	9.288	4.447	9.847	4.389	10.589		
		4.742	9.642	4.785	10.185	4.724	10.924		
		5.069	9.969	5.108	10.508	5.061	11.261		
		5.345	10.245	5.400	10.800	5.333	11.533	5.405	15.405
				5.727	11.127	5.701	11.901	5.714	15.714
				6.000	11.400	5.976	12.176	6.024	16.024
				6.300	11.700	6.278	12.478	6.329	16.329
				6.632	12.032	6.613	12.813	6.623	16.623
				6.873	12.273	6.889	13.089	6.897	16.897
				7.132	12.532	7.086	13.286	7.194	17.194
						7.403	13.603	7.463	17.463
						7.873	14.073	7.752	17.752
						8.267	14.467	8.000	18.000
						8.407	14.607	8.264	18.264
						8.702	14.902	8.547	18.547
						9.185	15.385	8.772	18.772
						9.538	15.738	9.091	19.091
						9.725	15.925	9.346	19.346
						9.920	16.120	9.524	19.524
						10.122	16.322	9.804	19.804
						10.333	16.533	10.101	20.101
								10.309	20.309
								10.526	20.526

Table 10: Sum of the forces obtained in the entire table: note that I will use the first 15 rows for dimensioning

Approx. displacement (Tm)	Rigging moment (KN)	Force (KN)
1.7	8	1.314
2.1	10	1.543
2.4	12	1.741
2.8	14	1.945
3.1	16	2.122
3.4	18	2.313
3.7	20	2.496
4.5	25	2.918
5.2	30	3.317
5.9	35	3.685
6.7	40	4.041
7.3	45	4.408
8	50	4.750
8.7	55	5.079
9.3	60	5.371
10	65	5.714
10.6	70	6.000
11.3	75	6.303
11.9	80	6.622
12.5	85	6.886
13.1	90	7.137
13.8	95	7.433
14.4	100	7.812
15.6	105	8.133
16	110	8.336
16.1	115	8.624
16.7	120	8.979
17.3	125	9.315
17.9	130	9.536
18.5	135	9.722
19	140	9.963
19.6	145	10.217
20.2	150	10.309
20.7	155	10.526

Table 11: New table (final version) with the values of the small section tube (ø60) for small-sized sailboats, written to add in the new catalog.

Maximum sail size (m²)	Righting moment (KN)	Displacement approx. (Tm)	Length out of hull, L₂ (m)					
			ø60	ø70	ø80	ø90	ø100	ø110
40	0.9	0.5	1.50					
	2.6	0.8	1.30					
	4.2	1.1	1.05					
	6.0	1.4	0.88					
	8.0	1.7	0.75	1.28				
	10	2.1	0.64	1.09				
	12	2.4	0.55	0.96	1.70			
60	14	2.8		0.86	1.52			
	16	3.1		0.79	1.39			
	18	3.4		0.72	1.28	1.64		
	20	3.7		0.67	1.18	1.52		
	25	4.5		0.57	1.01	1.3	1.71	
	30	5.2		0.50	0.89	1.14	1.51	
82	35	5.9			0.80	1.02	1.35	
	40	6.7			0.73	0.93	1.23	
	45	7.3			0.67	0.85	1.13	
	50	8			0.62	0.79	1.05	
	55	8.7			0.58	0.74	0.98	
	60	9.3			0.55	0.7	0.93	1.85
102	65	10				0.66	0.87	1.75
	70	10.6				0.63	0.83	1.66
	75	11.3				0.6	0.79	1.58
	80	11.9				0.57	0.75	1.51
	85	12.5				0.55	0.72	1.45
	90	13.1				0.53	0.7	1.39
130 / 150	95	13.8					0.67	1.34
	100	14.4					0.63	1.29
	105	15.6					0.6	1.25
	110	16					0.59	1.21
	115	16.1					0.57	1.17
	120	16.7					0.54	1.14
	125	17.3					0.52	1.1
	130	17.9					0.51	1.07
	135	18.5					0.5	1.05
	140	19					0.49	1.02
	145	19.6					0.48	0.99
	150	20.2						0.97
	155	20.7						0.95
	160	22						0.93
	165	24						0.91
	170	25						0.89
	175	26						0.87
L₁	Min distance between support (m)		0.5	0.58	0.6	0.7	0.8	1
Rₐ	Max service load, based on minimum L₁ at inner end (KN)		2	2.9	4.9	5.4	6.2	10

Table 12: Table with characteristics of commercial aluminum, for example like elastic limit (yield strength) or elongation values

Alloy type		Temper	Tensile strength (min) in <u>ksi</u> (MPa)	Yield strength (min) in ksi (MPa)	Elongation in 2 in %
ANSI	UNS				
201.0	A02010	T7	60.0 (414)	50.0 (345)	3.0
204.0	A02040	T4	45.0 (310)	28.0 (193)	6.0
242.0	A02420	O	23.0 (159)	N/A	N/A
		T61	32.0 (221)	20.0 (138)	N/A
A242.0	A12420	T75	29.0 (200)	N/A	1.0
295.0	A02950	T4	29.0 (200)	13.0 (90)	6.0
		T6	32.0 (221)	20.0 (138)	3.0
		T62	36.0 (248)	28.0 (193)	N/A
		T7	29.0 (200)	16.0 (110)	3.0
319.0	A03190	F	23.0 (159)	13.0 (90)	1.5
		T5	25.0 (172)	N/A	N/A
		T6	31.0 (214)	20.0 (138)	1.5
328.0	A03280	F	25.0 (172)	14.0 (97)	1.0
		T6	34.0 (234)	21.0 (145)	1.0
355.0	A03550	T6	32.0 (221)	20.0 (138)	2.0
		T51	25.0 (172)	18.0 (124)	N/A
		T71	30.0 (207)	22.0 (152)	N/A
C355.0	A33550	T6	36.0 (248)	25.0 (172)	2.5
356.0	A03560	F	19.0 (131)	9.5 (66)	2.0
		T6	30.0 (207)	20.0 (138)	3.0
		T7	31.0 (214)	N/A	N/A
		T51	23.0 (159)	16.0 (110)	N/A
		T71	25.0 (172)	18.0 (124)	3.0
A356.0	A13560	T6	34.0 (234)	24.0 (165)	3.5
		T61	35.0 (241)	26.0 (179)	1.0
443.0	A04430	F	17.0 (117)	7.0 (48)	3.0
B443.0	A24430	F	17.0 (117)	6.0 (41)	3.0
514.0	A05140	F	22.0 (152)	9.0 (62)	6.0
520.0	A05200	T4	42.0 (290)	22.0 (152)	12.0
535.0	A05350	F	35.0 (241)	18.0 (124)	9.0
705.0	A07050	T5	30.0 (207)	17.0 (117)[†]	5.0
707.0	A07070	T7	37.0 (255)	30.0 (207)[†]	1.0
710.0	A07100	T5	32.0 (221)	20.0 (138)	2.0
712.0	A07120	T5	34.0 (234)	25.0 (172)[†]	4.0
713.0	A07130	T5	32.0 (221)	22.0 (152)	3.0
771.0	A07710	T5	42.0 (290)	38.0 (262)	1.5
		T51	32.0 (221)	27.0 (186)	3.0
		T52	36.0 (248)	30.0 (207)	1.5
		T6	42.0 (290)	35.0 (241)	5.0
		T71	48.0 (331)	45.0 (310)	5.0
850.0	A08500	T5	16.0 (110)	N/A	5.0
851.0	A08510	T5	17.0 (117)	N/A	3.0
852.0	A08520	T5	24.0 (165)	18.0 (124)	N/A

APPENDIX D
DESIGN FIGURES

DESIGN OF THE TOP WITH INVENTOR
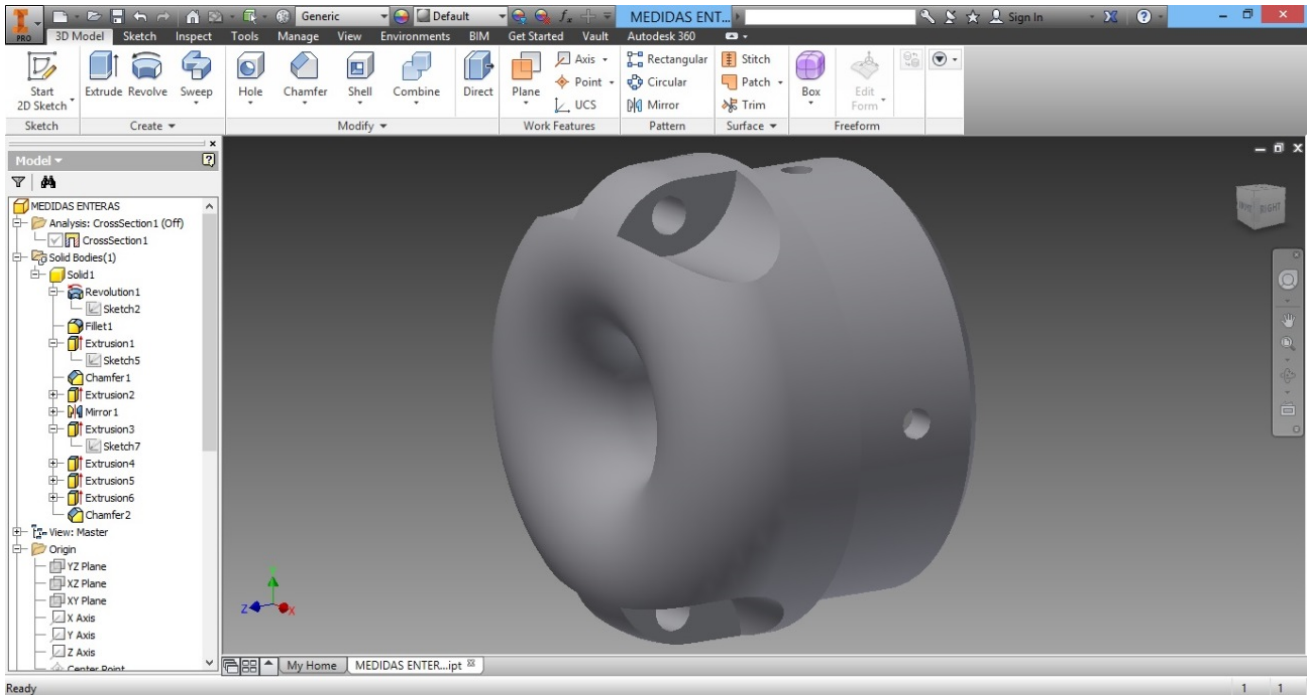
Figure 54: front side
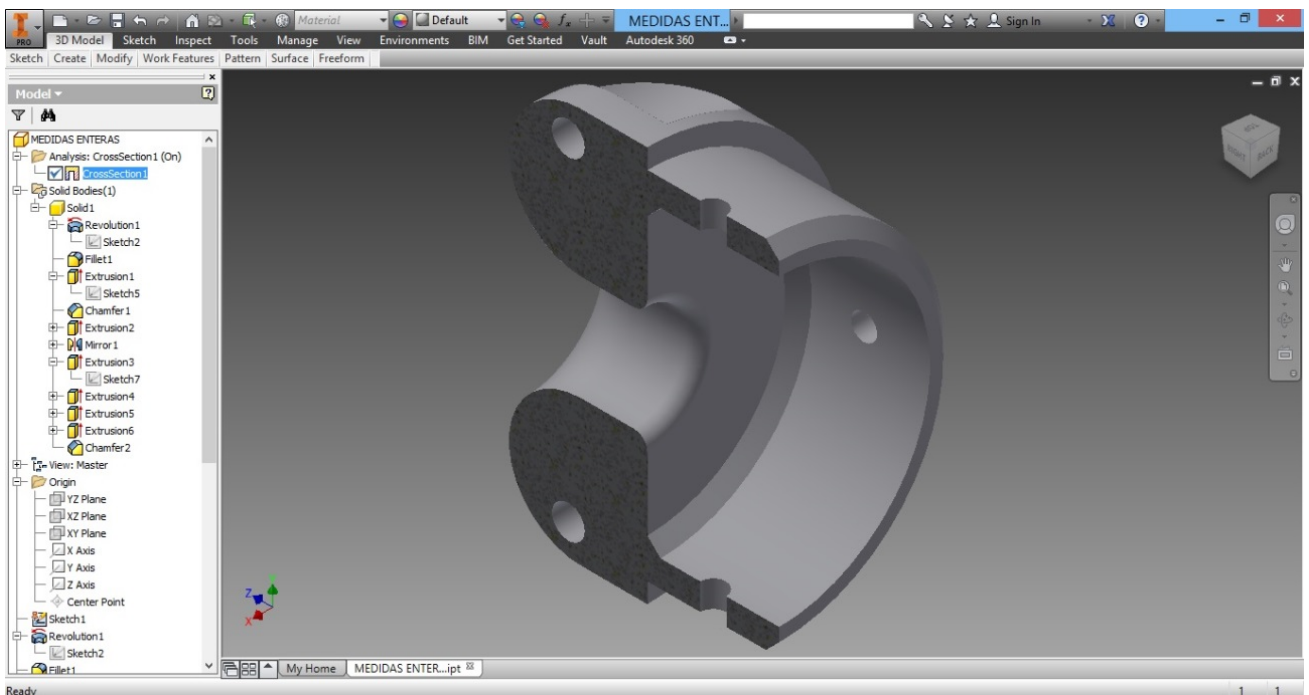
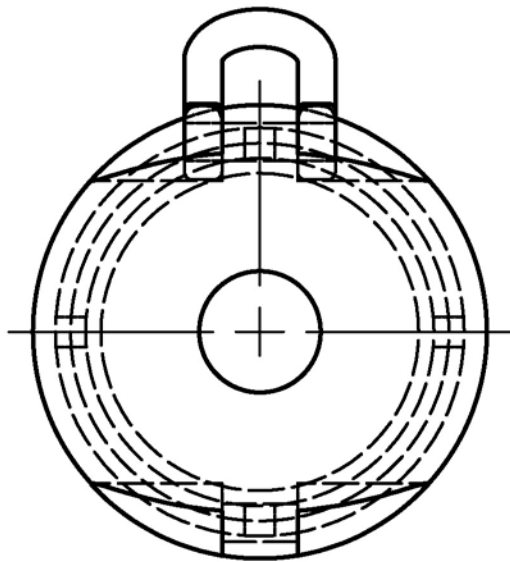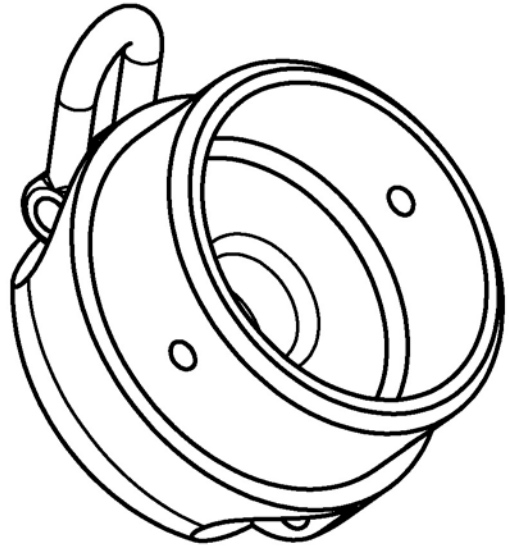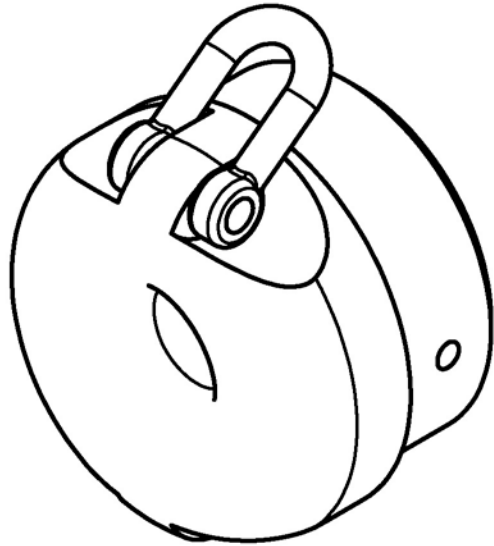**Figure 53: Back side, half view**
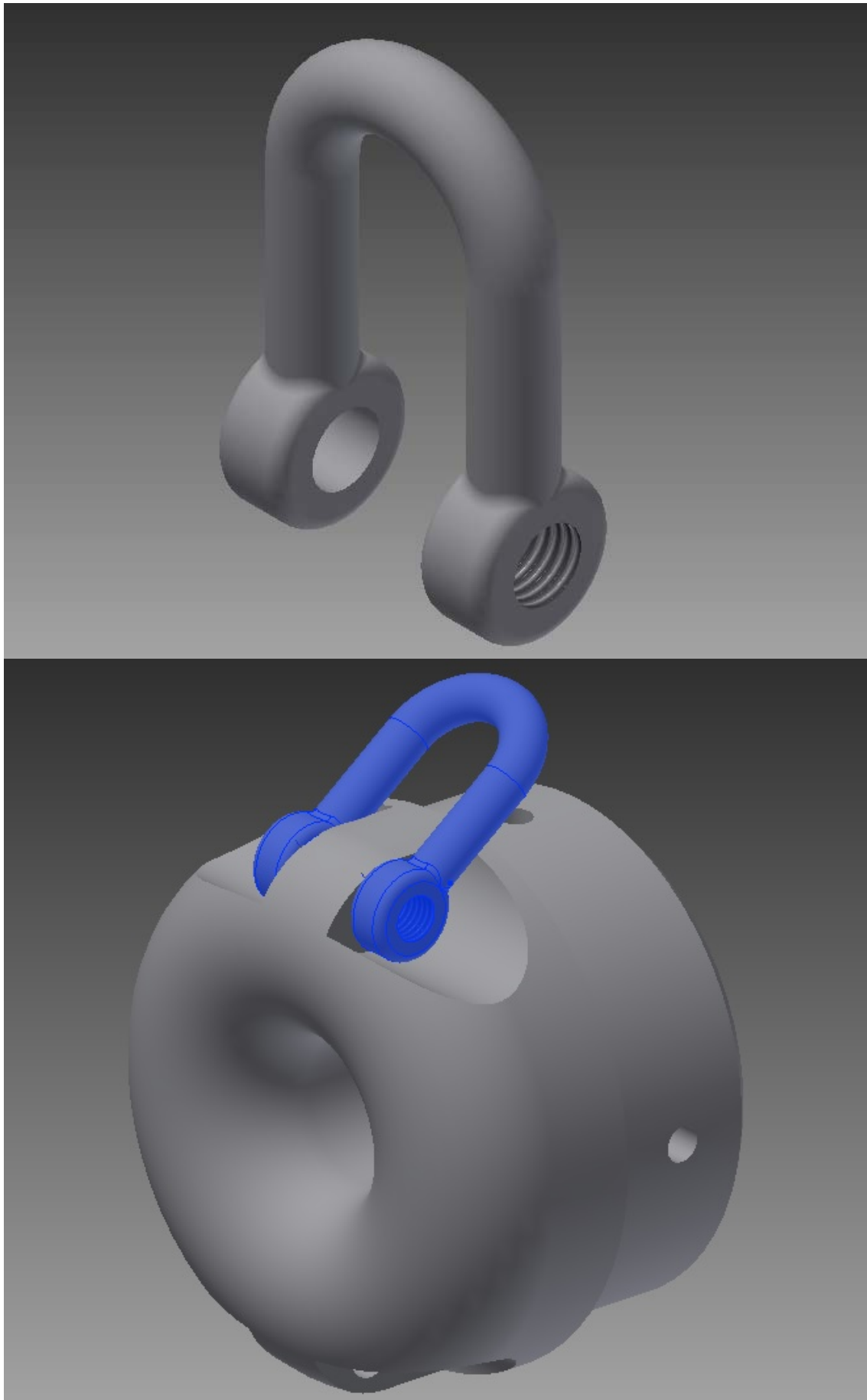
Figure 55: shackle and assembly in INVENTOR software

A-A (1 : 1)

R11
2X45°
R2
2X45°
60
46
54
21
4
41
Ø16
10

12
4,9
R10
Ø5

Obuda University

TITLE

TOP PART

SIZE		DWG NO	REV
A3		01_TOPDINA3	
SCALE		SHEET 1 OF 1	

A–A (1 : 1)

R11
2X45°
R2
2X45°

60
46
54

21
4
41

Ø16
10

A
A

12
4,9
R10
Ø5

53°

A–A (2 : 1)

15

M5

10

20

A

Φ5

R5

A

AutoCAD RENDERING

Figure 56: work screen in AutoCAD
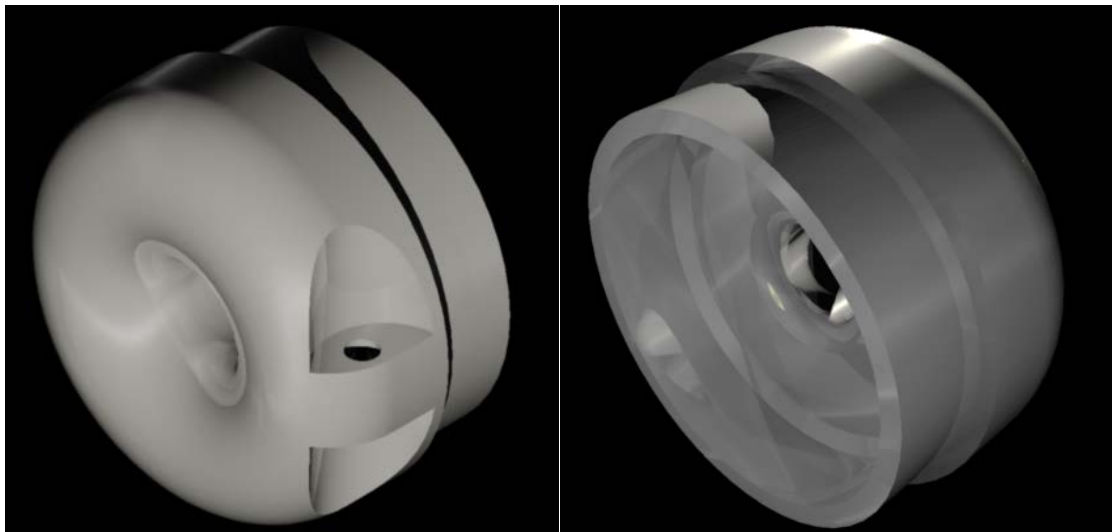
Figure 57: pre renderings in AutoCAD

Figure 58: AutoCAD rendering, fiber carbon material

Figure 59: AutoCAD rendering, light aluminum

APPENDIX E
SIMULATION PART

FIRST PART: FRONT
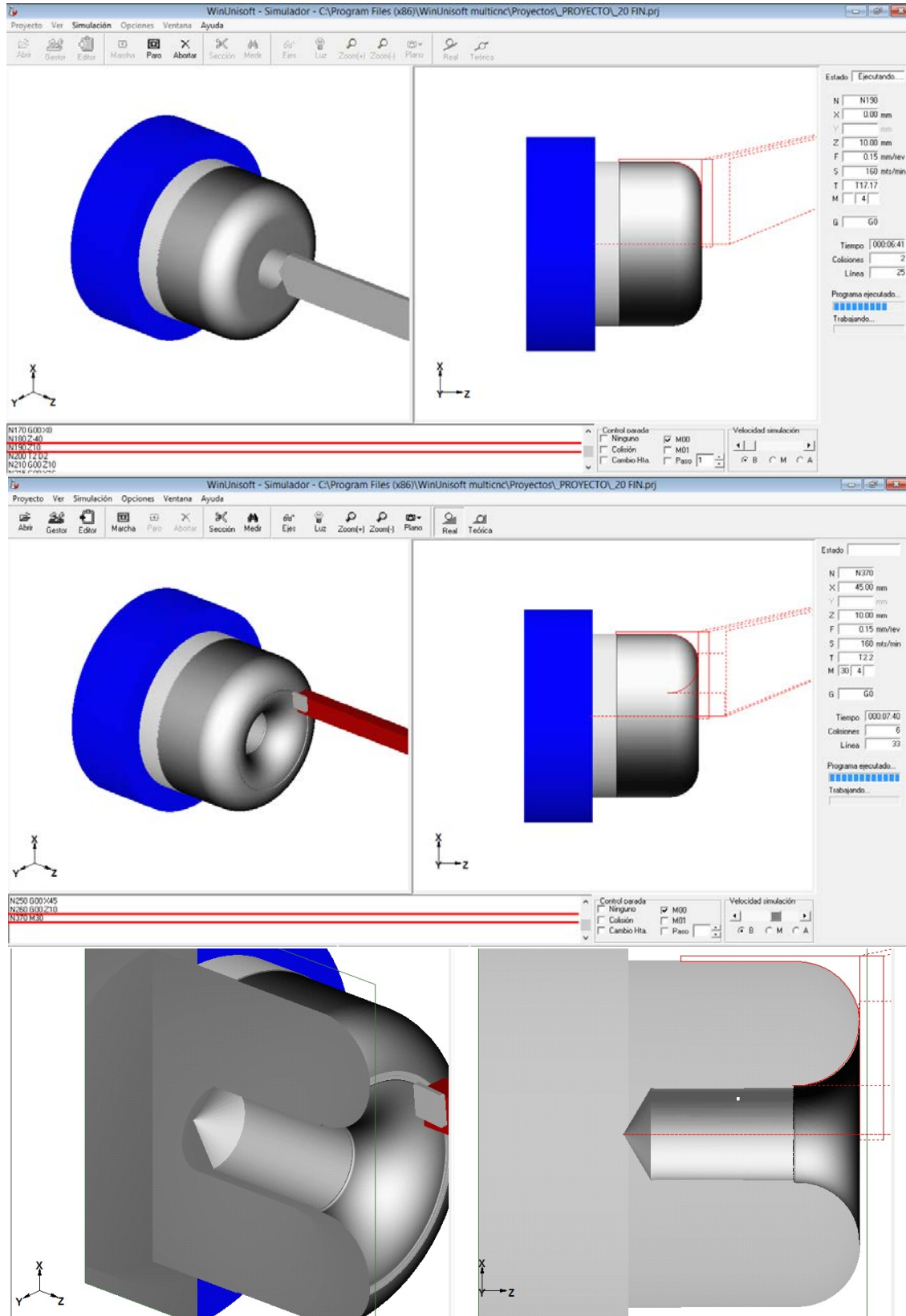
Figure 60 WinUnisoft Software

CNC CODE:

N010 (ORGX54=0, ORGZ54=49)

N020 G54

N030 G92 S2200

N040 T1 D1

N050 G90 G42 G95 G96 F0.15 S160 M04

N060 G00 X62 Z0

N070 G01 X-1.6

N080 G00 Z4

N090 G01 X62

N080 G00 Z0

N090 G01 X38

N280 G36 R11 X60

N120 Z-30

N130 X62

N140 Z4

N150 T16 D16

N160 G00 Z10

N180 G00 X0

N190 Z-3

N200 Z10

N150 T17 D17

N160 G00 Z10

N170 G00 X0

N180 Z-40

N190 Z10

N200 T2 D2

N210 G00 Z10

N215 G00 X16

N220 G00 Z-11

N230 G36 R11 Z0

N250 G00 X45

N260 G00 Z10

N370 M30

SECOND PART: BACK
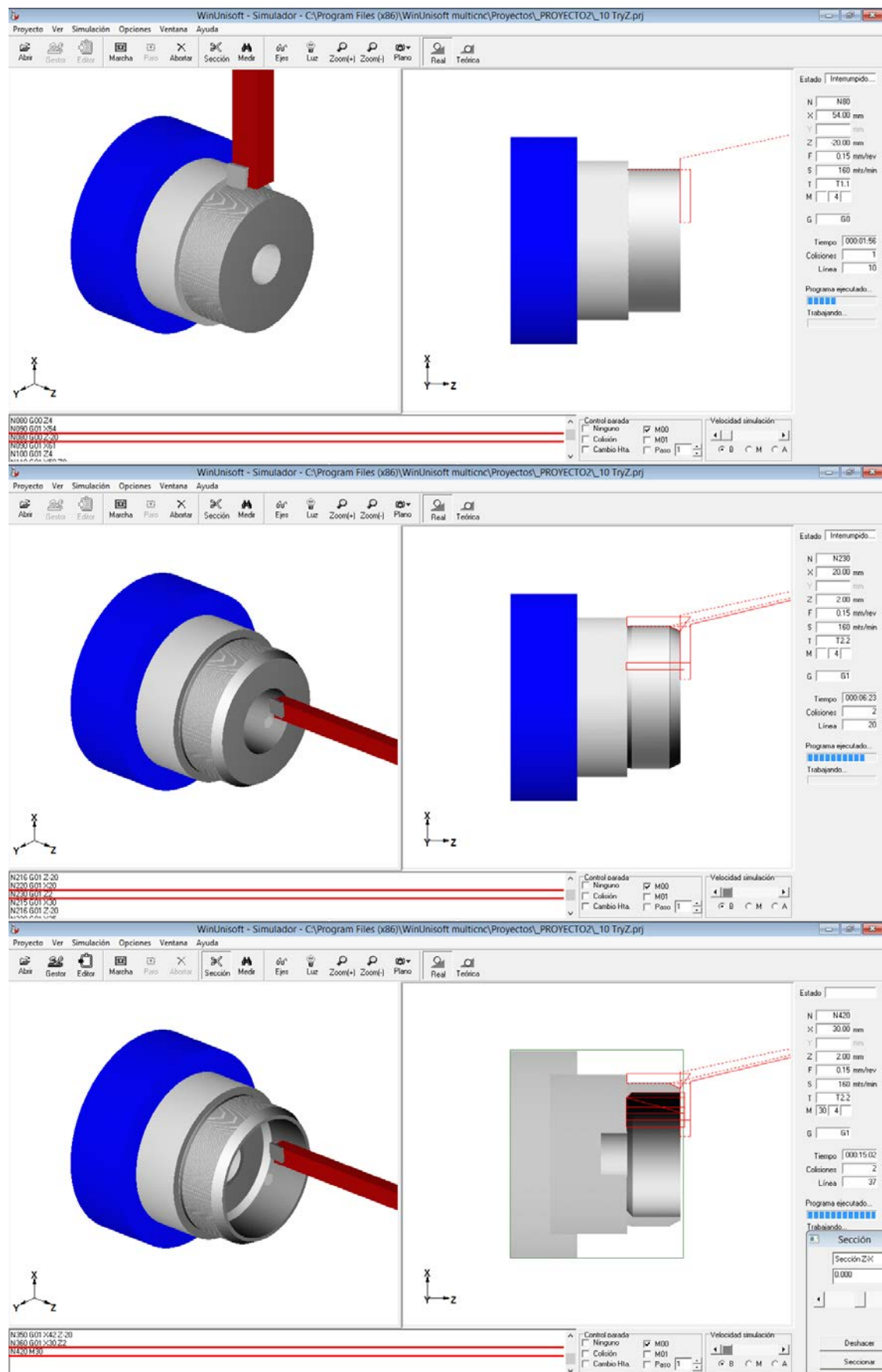
Figure 61: WinUnisoft Software

CNC CODE:

N010 (ORGX54=0, ORGZ54=49)

N020 G54

N030 G92 S2200

N040 T1 D1

N050 G90 G42 G95 G96 F0.15 S160 M04

N060 G00 X62 Z0

N070 G01 X14

N080 G00 Z4

N090 G01 X54

N080 G00 Z-20

N090 G01 X61

N100 G01 Z4

N110 G01 X50 Z0

N120 G01 X54 Z-4

N200 T2 D2

N210 G01 Z4

N215 G01 X25

N216 G01 Z-20

N220 G01 X20

N230 G01 Z2

N215 G01 X30

N216 G01 Z-20

N220 G01 X25

N230 G01 Z2

N240 G01 X35

N250 G01 Z-20

N260 G01 X30

N270 G01 Z2

N280 G01 X42

N290 G01 Z-20

N300 G01 X35

N310 G01 Z2

N320 G01 X46

N340 G01 Z-18

N350 G01 X42 Z-20

N360 G01 X30 Z2

N420 M30

THIRTH PART: HOLES
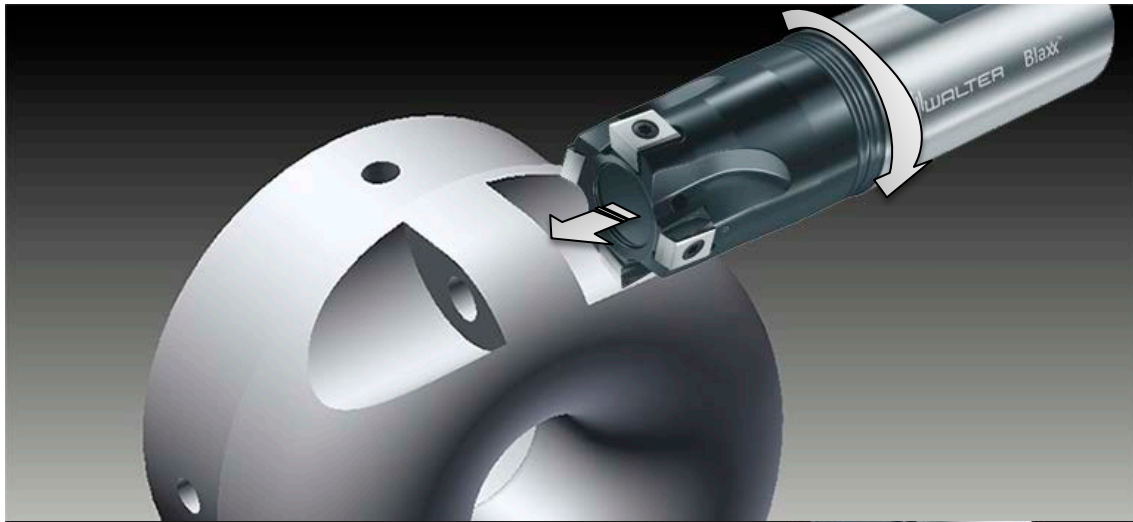
Figure 62: horizontal option
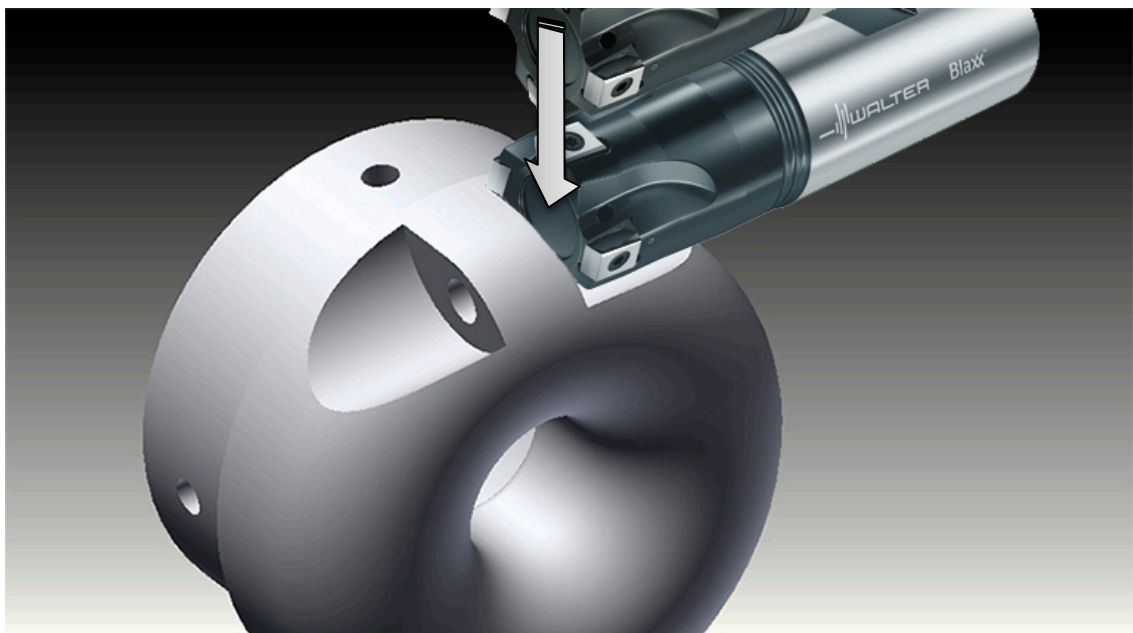
Figure 63: vertical option

APPENDIX F
PROTOTIPE MANUFACTURING

TOP CAM CODE: FIRST STEP (BACK)

```
N0010
N0015 (ORGX54=0, ORGZ54=49)
N0020 G54
N0025 G92 S2200
N0030 T0101
N0035 G90 G95 G96 S160
N0040 M3 M8
N0045 G00 X67 Z2
N0050 G01 Z0.3 F.2
N0055 G01 X-1.6
N0060 G01 Z2
N0065 G00 X65 Z2
N0070 G71 U1.5 R0.5
N0075 G71 P120 Q155 U1 F.3
N0080 G00 X200 Z200
N0085 T0101
N0090 S200
N0095 G00 X56 Z2
N0100 G01 Z0 F.12
N0105 G01 X-0.8
N0110 G01 Z2
N0115 G00 X43 Z2
N0120 G01 G42 X43.5 Z1
N0125 G01 Z0.04
N0130 G01 X54 ,C2
N0135 G01 Z-20
N0140 G01 X60
N0145 G01 Z-32
N0150 G01 X65
N0155 G01 G00 G40 X67
N0160 G00 X120 Z120
N0165 T0505
N0170 G00 X0 Z2
N0175 G01 Z-6 F.05
N0180 G00 Z2
N0185 G00 Z100
N0190 T0707
N0195 G00 X0 Z2
N0200 G01 Z-46 F.1
N0205 G00 Z2
N0210 G00 Z140
N0215 T0202
N0220 G00 14 Z2
N0225 G71 U1 R0.5
N0230 G71 P240 Q265 U-0.5 F0.2
N0235 G00 X48 Z2
N0240 G01 G41 X47.5 Z2 F0.12
N0245 G01 X46 ,R0.3
N0250 G01 Z-18
N0250 G01 Z-20 X42
N0255 G01 X16 ,R2
N0260 G01 Z-43
N0265 G01 G40 X15
```

TOP CAM CODE: SECOND STEP (FRONT)

```
N0005 G54
N0010 G92 S2000
N0015 T0101
N0020 M3 M8
N0025 G00 X67 Z2
N0030 G01 Z0.3 F0.2
N0035 G01 X14
N0040 G00 Z2
N0045 G00 X65 Z2
N0050 G71 U1.5 R0.5
N0055 G71 P065 Q085 U1 W0.05 F.35
N0060 G00 X35 Z3
N0065 G01 G42 X35.5 Z2 F0.12
N0070 G01 Z0
N0075 X60 ,R11
N0080 Z-13 X60.2
N0085 G01 G40 X65
N0090 G00 X120 Z120
N0095 T0202
N0100 G00 X16 Z2
N0105 G71 U1 R0.5
N0110 G71 P120 Q140 U-1 W0.05 F0.3
N0115 G00 X41 Z2
N0120 G01 G41 X40.5 Z1 F0.12
N0125 G01 Z0
N0130 G01 X16 ,R11
N0135 G01 X15.8 Z-13
N0140 G01 G40 X15
N0145 G00 Z2
N0150 M5 M9
N0155 G00 X120 Z120
N0160 M30
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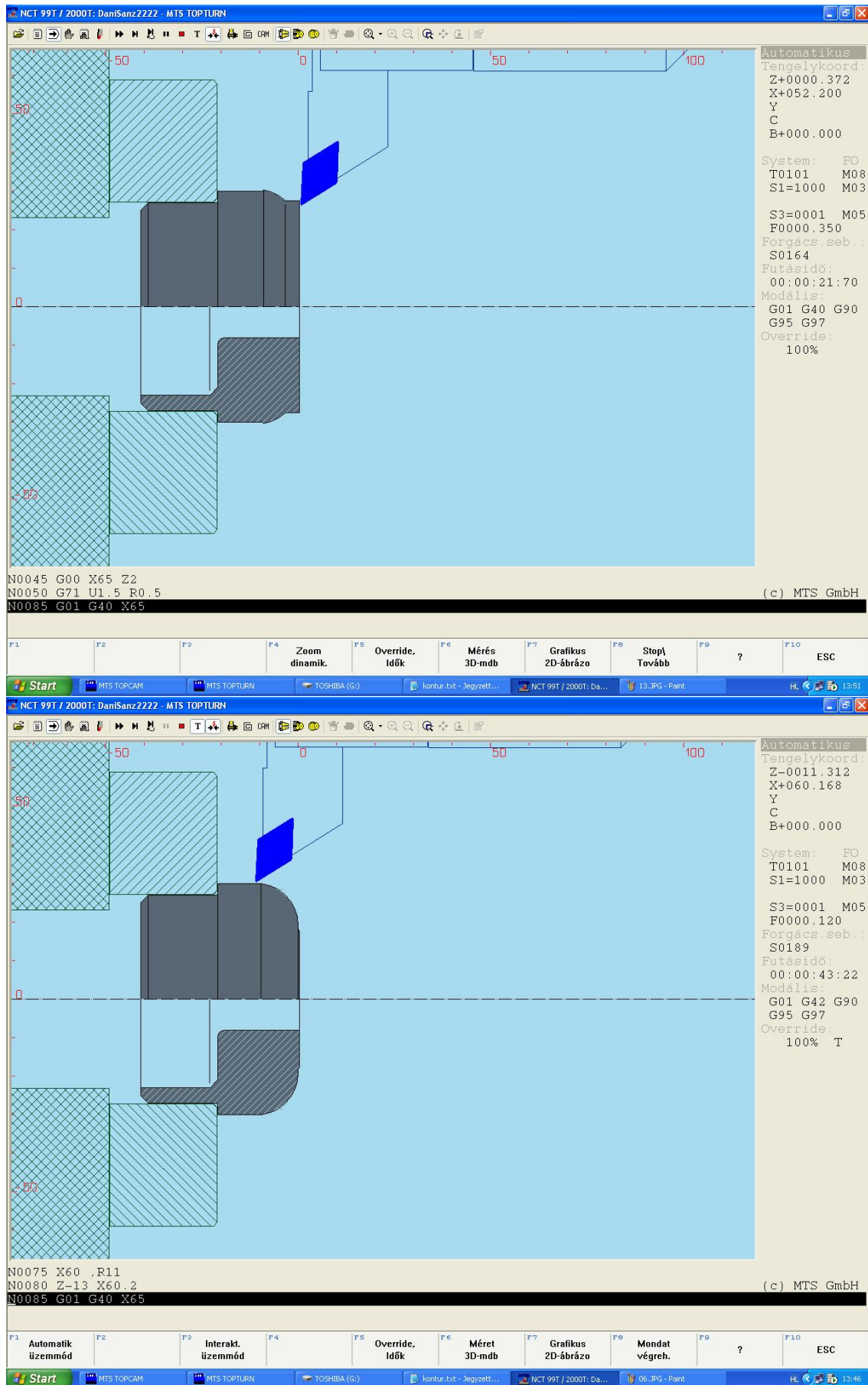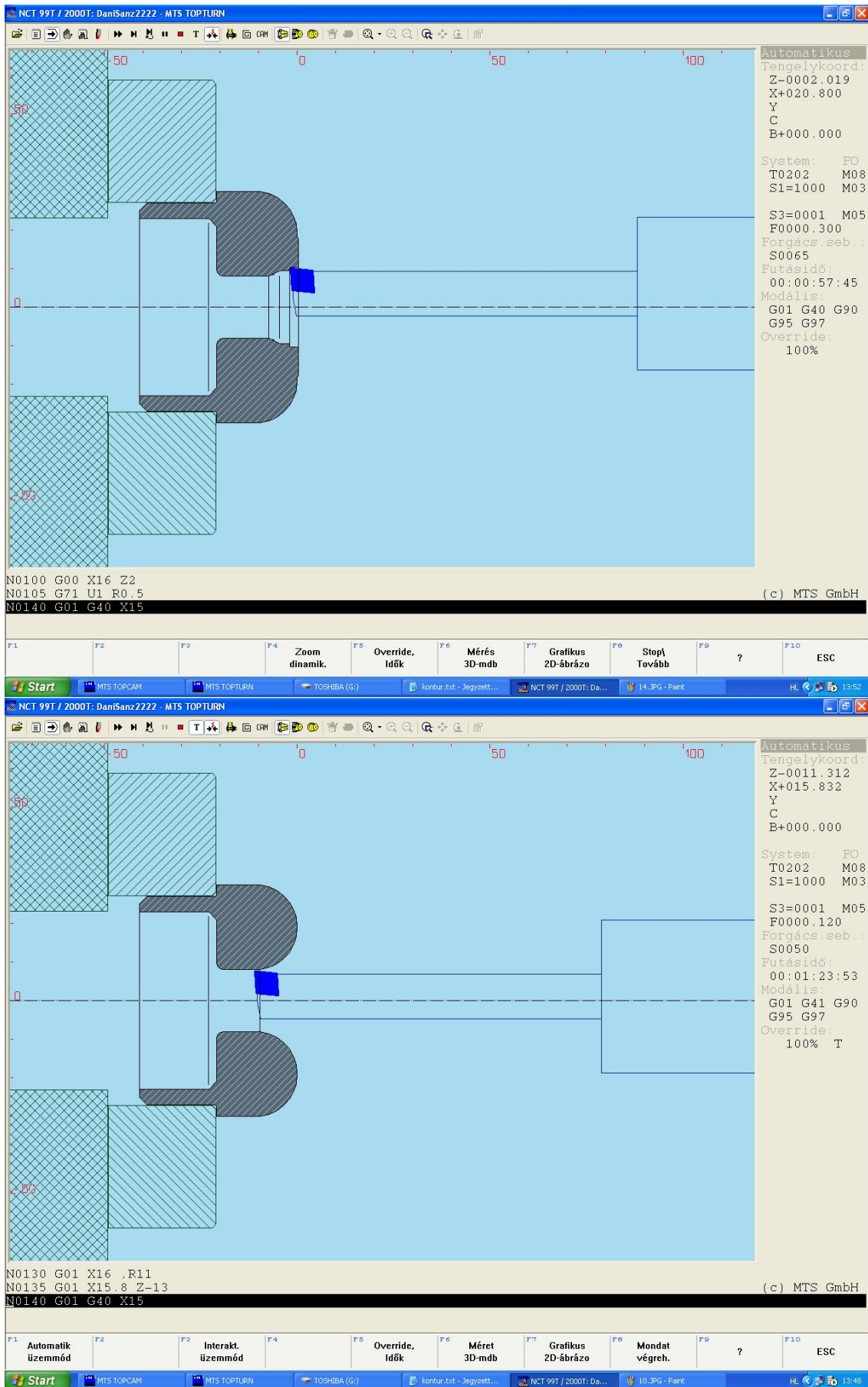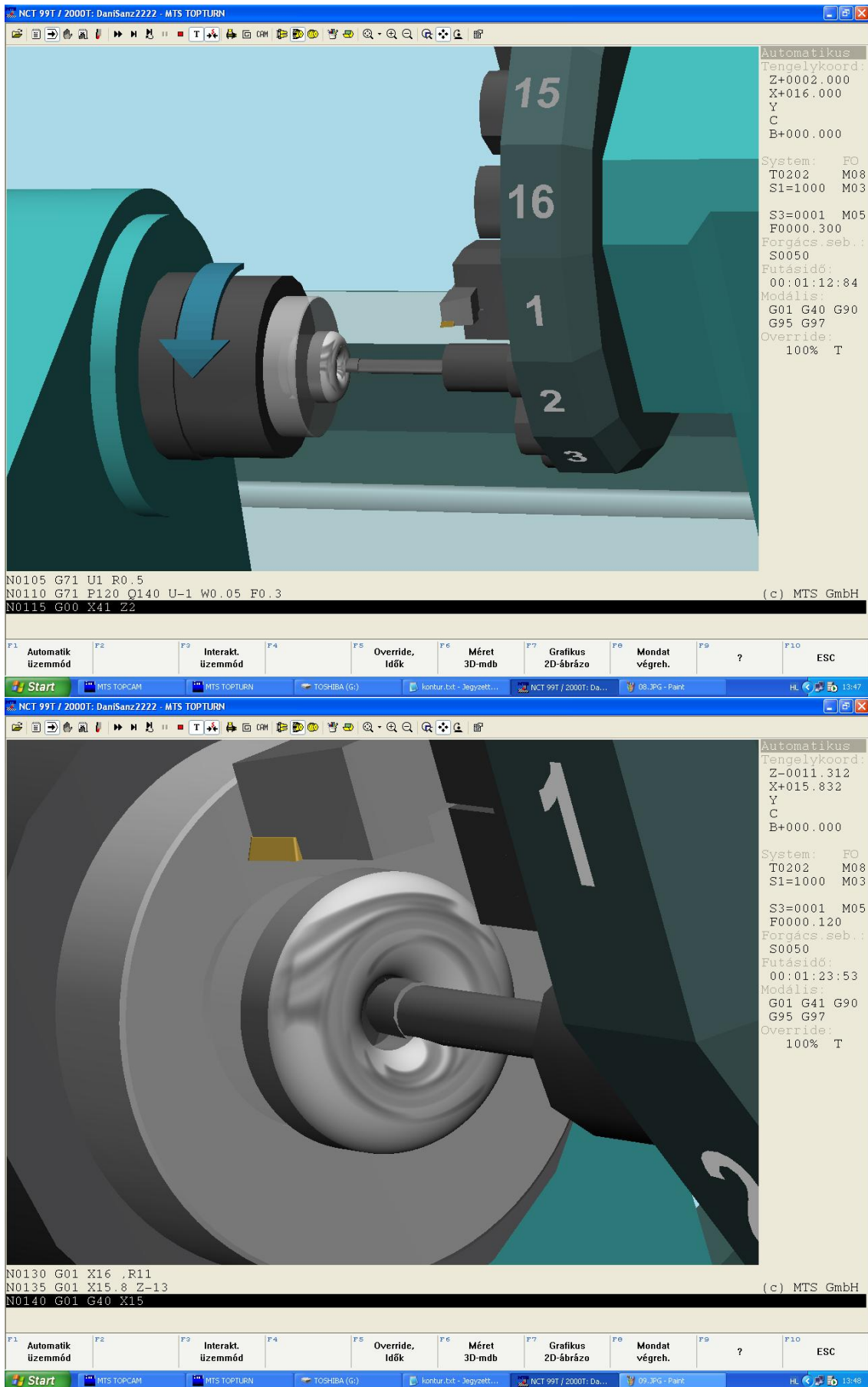
Figure 64: TOPCAM software

Figure 65: TOPCAM software
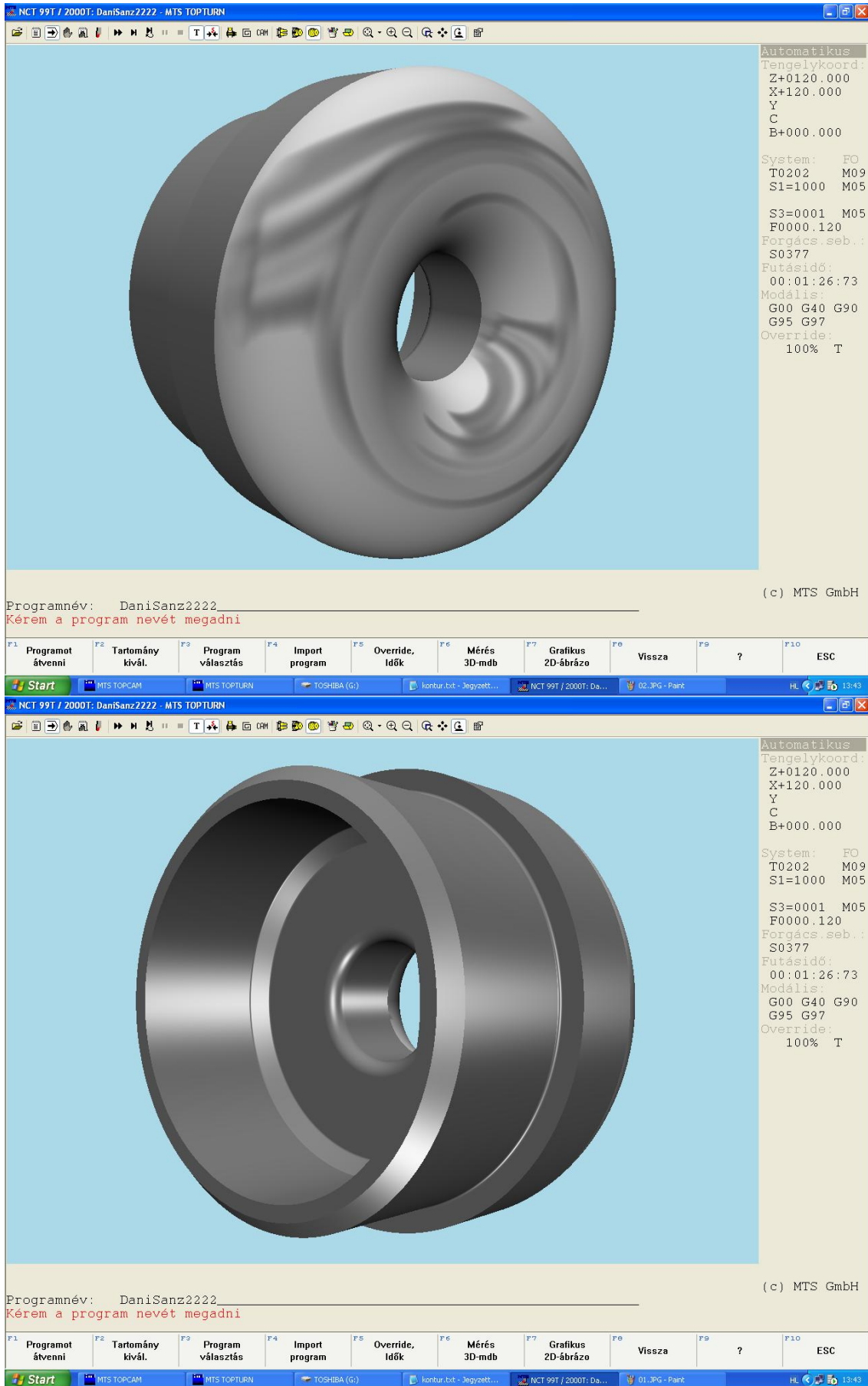
Figure 66: TOPCAM software

Figure 67: TOPCAM software
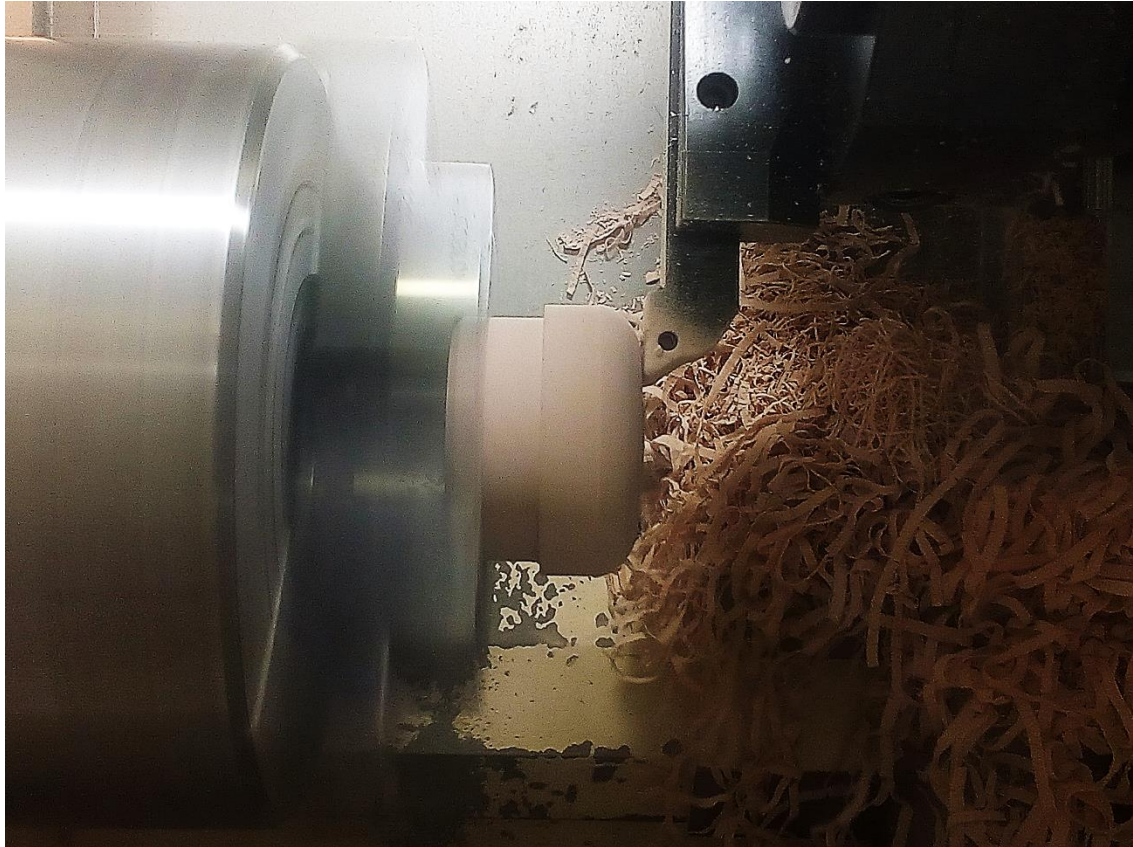
Figure 68: CNC machine

Figure 69: wood piece
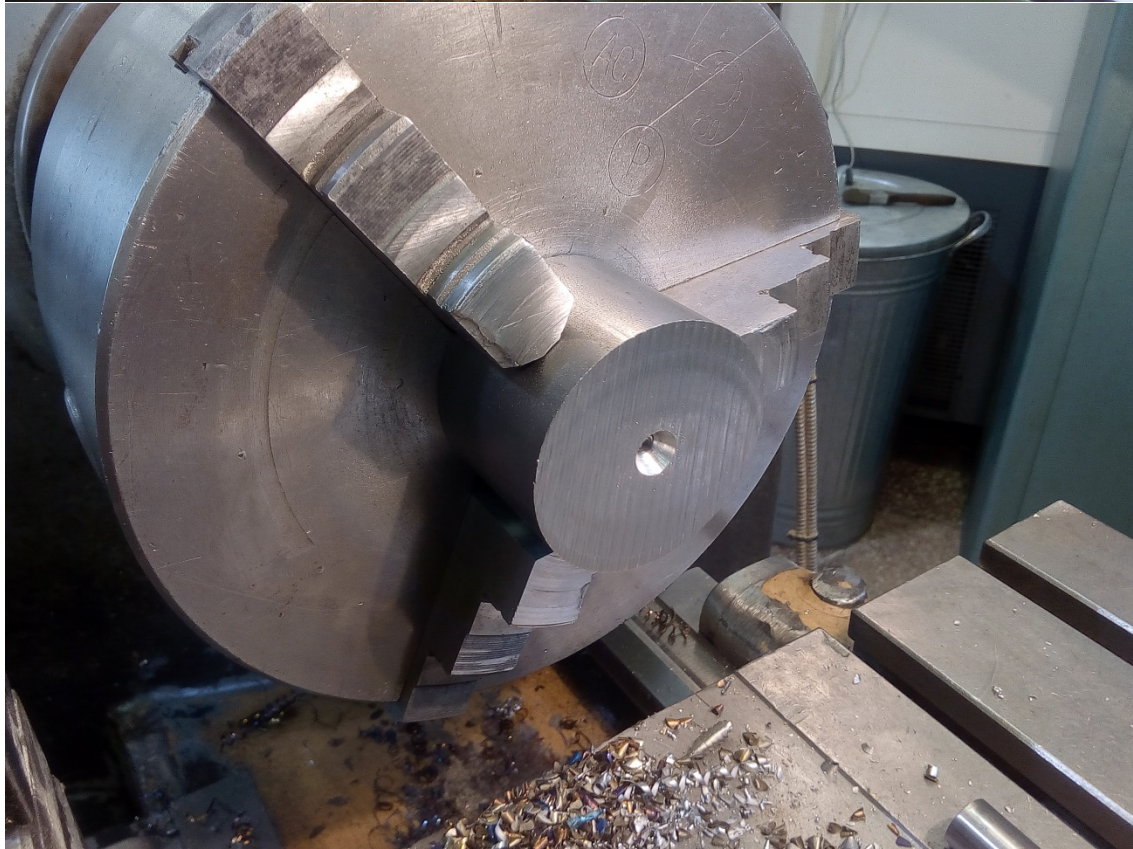
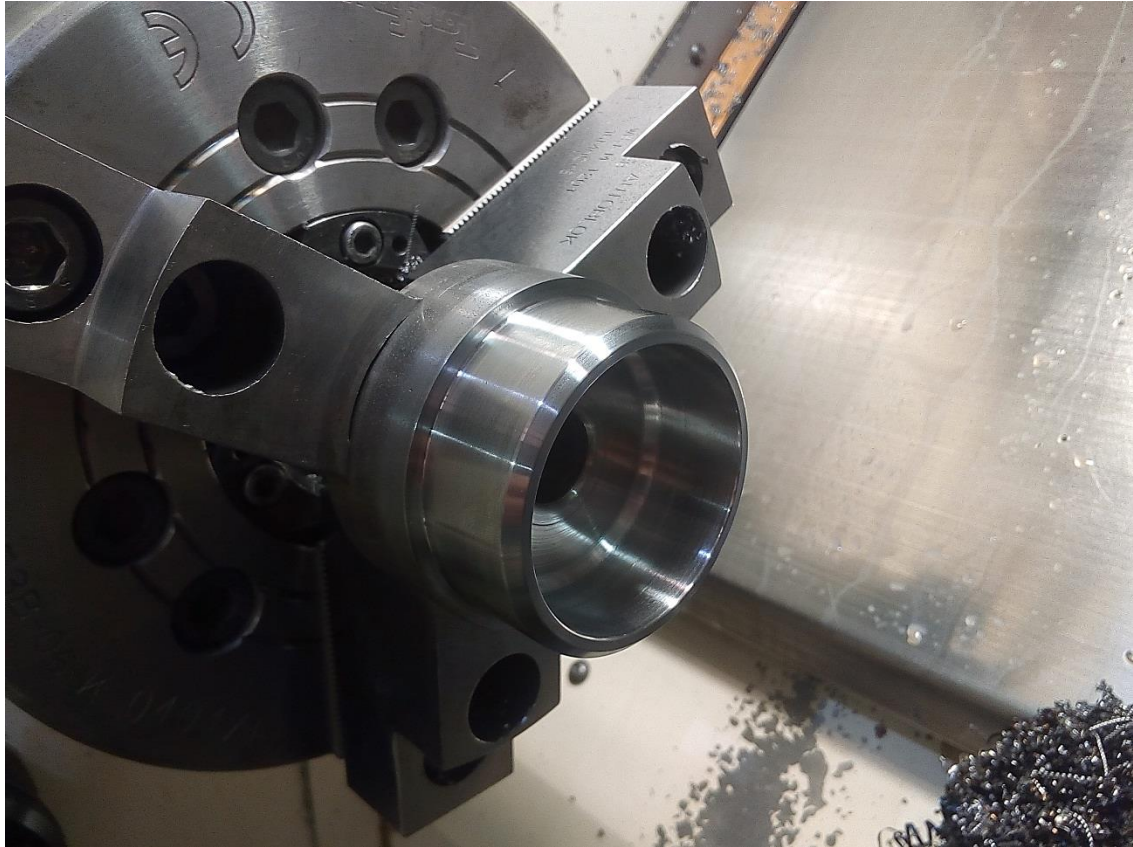**Figure 70: wood piece**

Figure 71: steel piece

Figure 72: steel piece
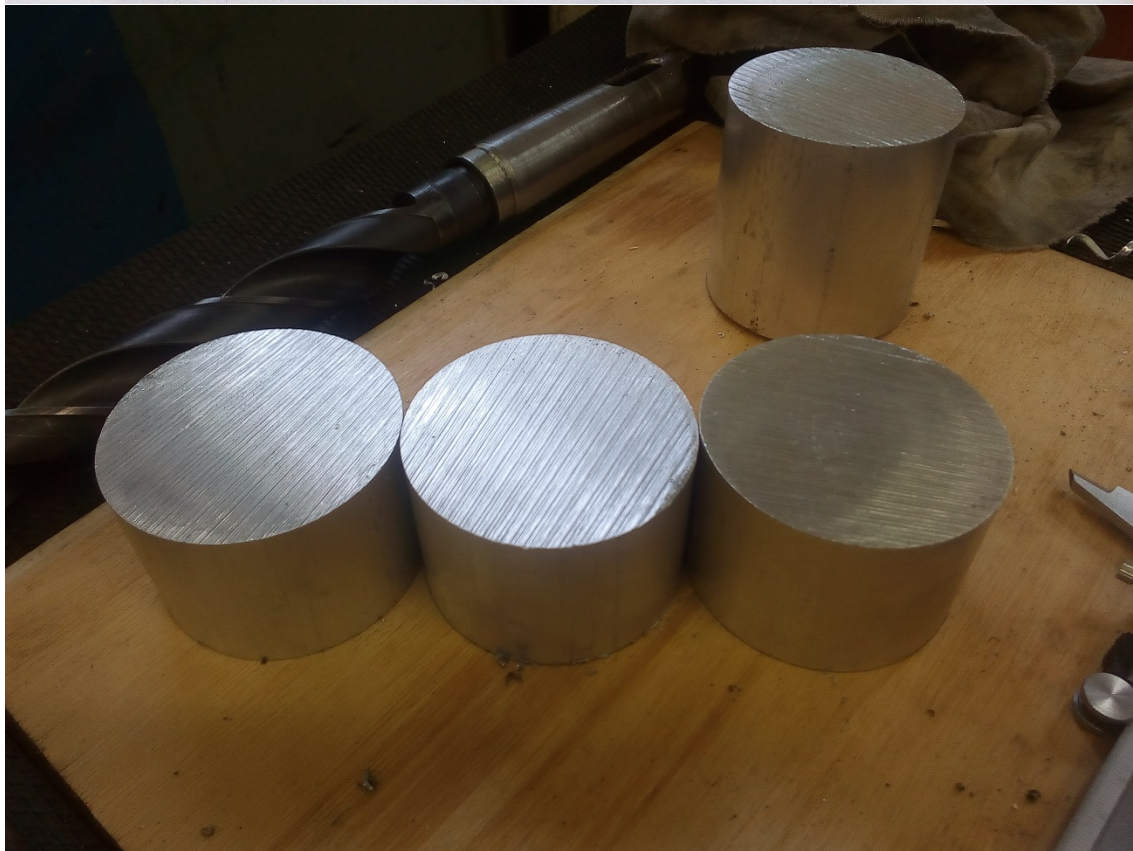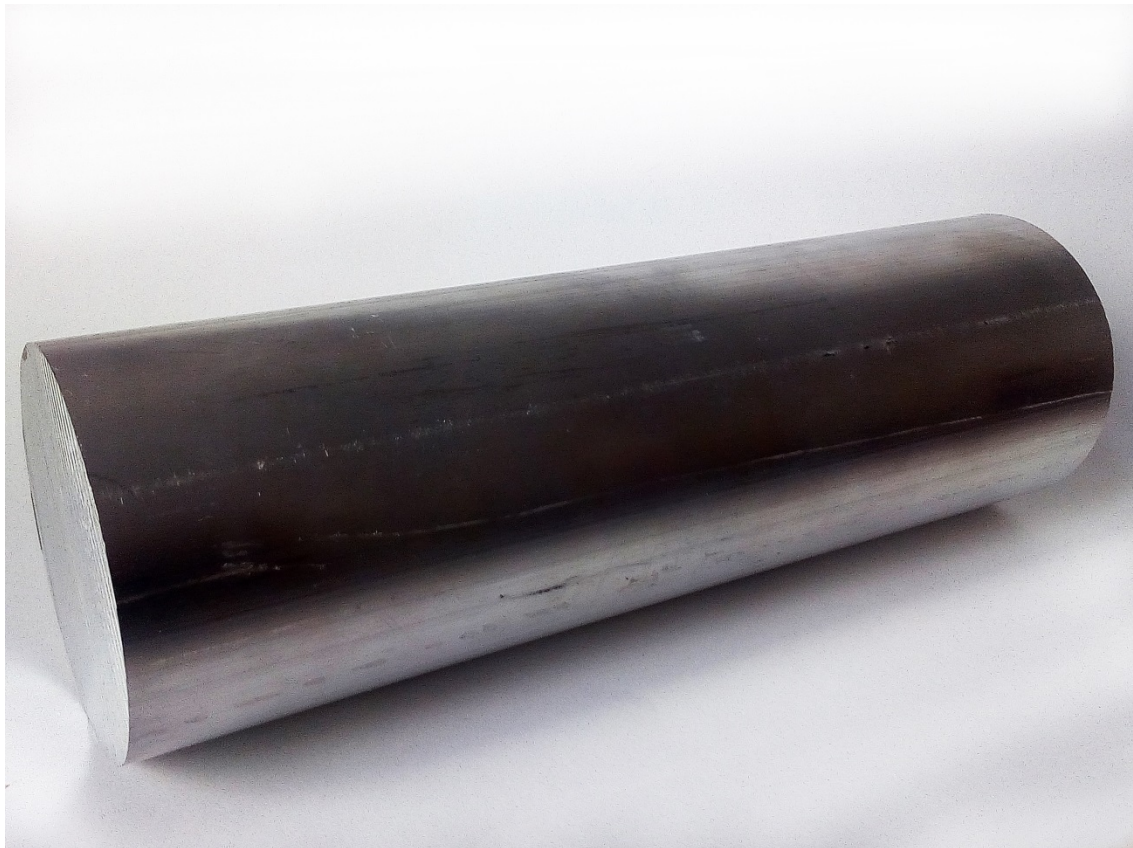
Figure 73:steel piece

Figure 74: steel piece

Figure 75: aluminum piece

Figure 76: aluminum piece

A M A R I
metal innovations

KÉSZPÉNZES VÁSÁRLÁS

X.- MAGYARORSZÁG
Magyarország

Szerződés sz.	:	289950.00
Teljesítés időpontja	:	26.05.2015
Vevőkód	:	120/50
Helység	:	Budapest
Számla kelte	:	26.05.2015
Ügyintéző	:	Hr.Kovacs Gyorgy
		+36 1 2323-443
		gyorgy.kovacs@amari.hu

Szállítási cim

Daniel Sanz Alonso
Mozsár u. 4.
H-1066 BUDAPEST

Rendelési adatok
26.05.2015

POZ.	MEGNEVEZES	MENNYISEG	SZAML.M.	AR	ERTEK
10	100693	1.00	Darab	2100.00	2100.00
	Roundbar	DB			
	EN AW 6082				
	T6				
	65.00 x 200.00				
	EN 755				
	extruded				
	27.00 %				567.00
					2667.00

FIZETVE

ARUERTEK		2100.00
MELLÉKKTG.		
TOTAL NETTÓ		2100.00
AFA 27.00 %		567.00
VÉGÖSSZEG HUF		2667.00

FUVAR   CSOMAGOLAS

FIZ. HAT. IDÖ:
FIZ. MOD: Keszpenz
     Vevő által
     Térítésmentes csomagolás

Adószám: 10724734-2-41; Közösségi adószám (VAT-ID): HU10724734; Cégjegyzékszám: 01-09-164673; Bankkapcsolat HVB Bank Hungary Rt., 1052 Budapest, Szervita tér 8. Számlaszám: 10900028-00000002-32210134 (HUF), 10918001-00000002-32210608 (EUR), SWIFT: BACXHUHB, IBAN: HU28 1091 8001 0000 0002 3221 0608. Szállításaink a hátoldalon lévő általános szállítási és eladási feltételeink alapján történnek. Késedelmes fizetés esetén késedelmi kamatot számitunk fel. 8 nappal az áru átvétele után reklamáció nem fogadunk el. A számla egy példányban készült, adattartalma megfelel a számviteli törvény és a 24/1995. (XI. 22.) PM rendelet előírásainak. A számla aláírás nélkül érvényes.

Figure 77: invoice

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