Faculty of Mechanical Engineering.

Raúl Rodríguez Rodríguez

FIREWALL AND DRIVER'S SEAT FOR FORMULA STUDENT RACE CAR FEST11

Author applies for academic Master of Mechanical Engineering

Tallinn 2011

TABLE OF CONTENTS

0. Preface

This Master's Thesis was carried out at the Faculty of Mechanical Engineering of Tallinn University of Technology during the spring semester of 2011. It is my final project (in Erasmus program) of my degree, Mechanical Engineering, carried out in Barcelona (Catalonia, Spain) at Universitat Politècnica de Catalunya (ETSEIB-UPC).

My supervisor and examiner was Lecturer Risto Kõiv, from the Department of Machinery. I would like to thank him for all guidance and support. Thank you very much also to all the Formula Student team members for their valuable help and their patience with me.

Finally I would like to thank all my family and friends, especially to Rocío. Without you this project would not have been possible.

Tallinn, Estonia 2011

1. Introduction and task definition

Universities from the whole world participate in Formula Student events, the most prestigious student design competitions. After overcoming all the difficulties, engineering students acquire a valuable experience even more useful for future mechanical engineers interested in the world of motorsport and car races and the automobile industry in general.

In Tallinn, the TTÜ/TTK Formula Student Team, founded in 2006, presented its project in Silverstone, UK, in 2007 and made his first appearance in a Formula Student competition in 2008 with the FEST08 car in Silverstone again, finishing in a respectable 13th position among 72 participants.

After that, the team recalled as FS Team Tallinn, built the FEST09 obtaining the 1st position in the Baltic Open 2009. For the 2009/2010 season, the FEST09 was improved and recalled FEST10 highlighting a 7th position in the UK competition and the 1st and 2nd position in the Baltic Open 2010 with FEST10 and FEST08.

For the present 2010/2011 season the FS Team Tallinn is very ambitious, and its main goals are getting a lighter and more aerodynamic car. For this reason, a lot of pieces need to be redesigned and manufactured again. This process will culminate with the construction of the new FEST11 car. The task of this thesis is the design of the driver's seat and firewall.

As a part of a Formula Student race car, the design and manufacture of firewall and driver's seat is a great challenge related to driver's ergonomics and performance, weight, strength and stiffness optimization, firewall and seat design, choice of materials and manufacturing technology. Furthermore is needed to coordinate the different stages of the design with team members responsible for the development of other parts of the car that have some interaction with the seat and firewall (mainly the frame and fuel delivery system).

In this kind of seats is very important to put driver's centre of gravity as low as possible taking into consideration driver's ergonomics, hand room and visibility. To achieve these aims a foam seat is made and then scanned to get a rough 3D CAD model. After that more finalized model needs to be made in CAD according to the scanned model, taking into consideration the manufacturing possibilities. In the same way, a firewall CAD model will be designed to fit perfectly with the frame and the seat. The last model will be obtained from the CAD models using a 5D CNC milling machine. Then the moulds will be made from the milling models. At the end a carbon fiber seat and firewall will be manufactured with these moulds.

2. General concept of firewall and seat

2.1. Goals

The functions of the driver’s seat and firewall are isolating the driver from the engine and provide to him a comfortable driving during the competition. Furthermore the seat and firewall are key pieces for driver’s security.

In comparison with the previous cars and according to the general team goals, the next improvements are wanted:

- Get a lower driver’s centre of gravity in order to have more stability.
- Improvement of the seat shape to obtain a better support for the driver.
- Correct geometry to take out the seat and the firewall easily.

2.2 Restrictions

The seat and firewall designing is not free, there are some restrictions that have influence in the process.

1. Geometrical restrictions:
   First of all, it is indispensable to take into consideration the other parts of the car that restrict the space and geometry for the seat and firewall. The most important is the frame, because it defines the cockpit space and it was designed first. Consequently, the design needs to be made according to the frame shape in order to fit the seat and firewall into it. A part from the frame, it is also needed to coordinate the designing process with the different stages of the steering wheel and the fuel delivery system.

2. Manufacturing restrictions:
   It is also necessary to take into account the consequent restrictions of the manufacturing process. This means that the firewall and seat geometry needs to be designed considering the characteristics and limitations of the 5D CNC milling machine (used to obtain the milling models) and the moulds.

The most important of these restrictions is the necessity of achieving and adequate geometry to be able to take out the final pieces from the moulds. That is why is desired to get smooth surfaces without sudden changes of direction and complicated shapes in order to avoid problems during the different manufacturing stages.

3. <u>Rules restrictions:</u>

The other main restrictions are given by the Formula Student rules. The specific rules that affect the seat and firewall are related to the driver's seat position and security matters.

- <u>Driver's position:</u> The most important rules establish the minimum distance from the helmet to the frame, the minimum and maximum angles between seat belts attachment and the driver's shoulders and thermal insulation needed to protect the driver from the engine. In the next figures one can see some of these restrictions.

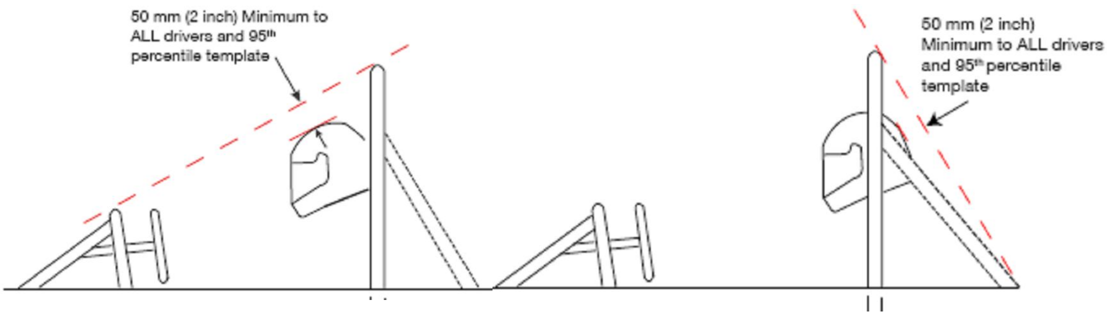


Figure 2.1: FS restrictions for the driver's seating position [1]

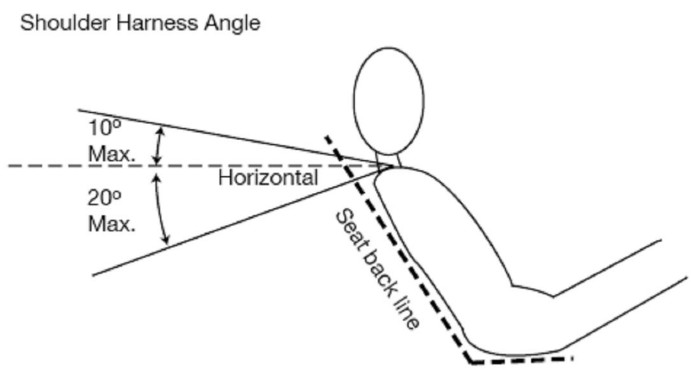


Figure 2.2: FS Shoulder Harness Angle [1]

- Driver's visibility and security time: The seat position and shape are also restricted by the rules which talk about the driver's visibility and the security time needed by the driver to exit the cockpit:

- The driver must have adequate visibility to the front and sides of the car. With the driver seated in a normal driving position he/she must have a minimum field of vision of 200º (a minimum of 100º to either side of the driver). The required visibility may be obtained by the driver turning his/her head and/or the use of mirrors.

- All drivers must be able to exit to the side of the vehicle in no more than 5 seconds starting with the driver in the fully seated position, hands in driving position on the connected steering wheel and wearing the required driver equipment. [1]

- Firewall and driver's insulation: Related to the firewall and the thermal insulation required for the driver, these are the main rules:

- The firewall must separate the driver compartment from all components of the fuel supply, the engine oil and the liquid cooling systems and it must protect the neck of the tallest driver.

- It must be a non-permeable surface made from a rigid, fire resistant material.

- The firewall must seal completely against the passage of fluids, especially at the sides and the floor of the cockpit. [1]

- Template: Furthermore, in order to ensure that the opening giving access to the cockpit is of adequate size, a template will be inserted into the cockpit opening. It will be held horizontally and inserted vertically until it has passed below the top bar of the Side Impact Structure.

During this test the steering wheel, steering column, seat and all padding may be removed but the firewall may not be moved or removed. Consequently this rule has a lot of influence on the design, and it will be crucial to decide if the seat and firewall will be made in one piece or in two pieces. [1]

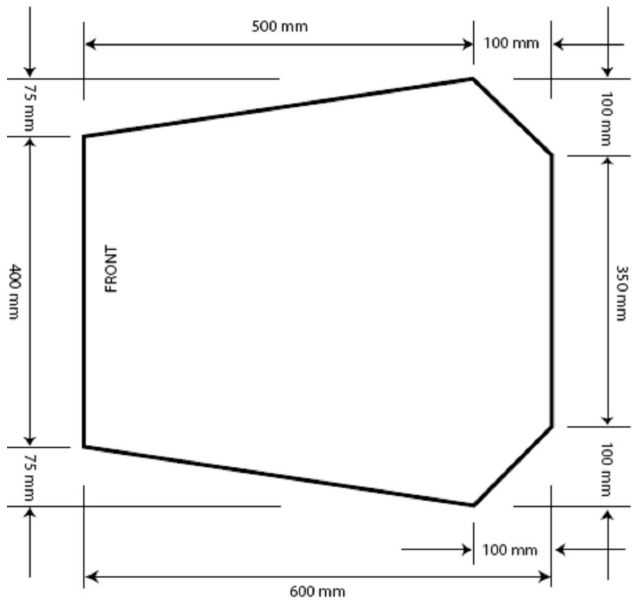


Figure 2.3: Template for the cockpit space test [1]

4. Economic and technological restrictions:

Finally, the design and manufacturing stages are conditioned by the technology and tools available to the team (mainly located at TTÜ and TTK) and the costs of the different processes and the team budget. Consequently, it will be wanted to make every operation in the most efficient way as possible but always trying to reach the best quality.

2.3. Options and solutions

At the beginning, it was thought that it would be better to make the seat and firewall together in one piece than make them separately in two different pieces in order to make them stronger. Moreover, making the firewall and seat in one piece, if the template fits with them inside the cockpit it would not be necessary to take the seat out for the Formula Student template check.

Despite of the advantages of manufacturing the firewall and seat in one piece, it was decided to give priority to the seat design, not taking into account if it would be finally made separately or not, in order to achieve the main goals of the project that are a lower driver's centre of gravity and a good support during the driving.

After finalizing the seat design, it will be checked in the CAD software if the template fits with the seat inside. If it fits, the seat and firewall will be built together, if it does not fit, they will be made in two different pieces to be able to remove the seat for the template check.

3. Driver’s seat

3.1. Goals

As it is said in the general description, the main goals for the seat are provide a good driver support and put his centre of gravity as low as possible.

- Geometrical requirements:

Furthermore, it is needed to fit the seat correctly into the frame, having an adequate geometry to be able to put the seat inside the cockpit and take it out when it is needed.

- Seat shape and aesthetics:

It is also wanted to get an ergonomic shape to be comfortable enough and good aesthetics because it’s piece of the seat that everybody can see. Consequently, it will be also a goal to obtain a symmetric seat with a smooth surface.

3.2. Options and solutions

The process for the seat it was quite clear at the beginning, giving always priority to the fact that obtaining a seat with the best quality possible is the most important.

- Designing and manufacturing process:

In summary, the different stages for the obtaining of the seat that were decided at the beginning are the next:

- A foam seat would be made with the help of a wooden frame and after that it would be scanned.
- The scanned model would be used to help the designing process with CATIA V5 in order to get an ergonomic shape.
- From the CAD model the milling model would be obtained and after some modifications if they are needed, the final mould for the seat would be manufactured.
- Finally, the seat will be manufactured using the mould.

The process detailed before was planned in order to reach the best results optimizing the available resources.

The combination of the foam model, the CAD model and the milling model makes possible to design the seat correctly, being sure before the manufacture stage that it satisfies the required characteristics. Consequently, with this kind of process it will be needed to manufacture the seat only once, saving money and time.

- Material selection:

The main choice was about the material selection. One option was making the seat with foam, like in the first car (FEST08), and the other option was making it with carbon fiber. Making it with carbon fiber it is possible to get a stronger and smoother seat than using foam. In addition, the aesthetics of the seat are better using carbon fiber.

Despite the fact that making the seat with carbon fiber it will be more expensive and manufacturing the mould and the seat will be more difficult, this material was chosen because using it the seat will have much better quality than using foam and the goals of the project will be reached.

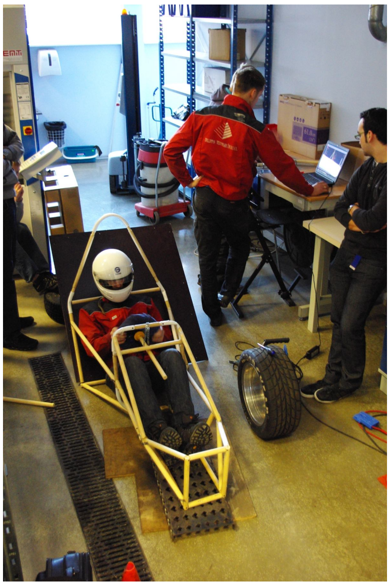
3.3. Wooden frame and mock up

The first step before starting the seat design is the construction of a car frame prototype, in this case a wooden frame.

The wooden frame is needed for the first stages of the seat design. First of all, it is needed to make a previous analysis of the driver's space and visibility. Second and more important, the wooden frame is indispensable to obtain a foam model of the seat with correct dimensions to fit into the cockpit.

Furthermore, the wooden frame is, together with the steering wheel prototype, indispensable to develop the foam model and find the best seat position, trying to put driver's centre of gravity as low as possible but with enough visibility for a good driving.

Picture 3.1: Wooden frame



Picture 3.2: Previous driver's space and visibility analysis with the wooden frame

3.4. Foam seat development and analysis of driver's position

- Function:

In order to get a guide for the 3D design, it is necessary to make first a foam seat with more or less the right dimensions and ergonomic shape that would be scanned after being finalized.

This foam prototype is indispensable to make easier and quicker the CAD design process and, even more important, to assure that the seat will be design according to the main goals: an adequate geometry to be comfortable and provide good support to the driver. In addition, this foam model is not only essential for that purpose, it is also needed to analyze and check the other main goal for the seat: find the best position for it, putting the driver's centre of gravity as low as possible keeping at the same time a good visibility.

In summary, the foam model is a very simple, but also cheap and effective solution for the first stage of the designing process.

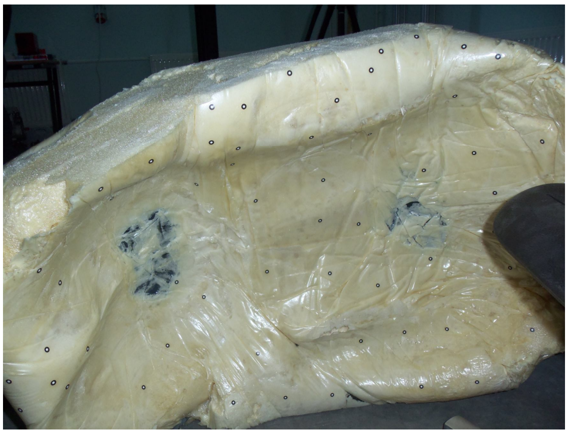
- Foam seat manufacturing and developing process:

The procedure to get an adequate foam seat to be scanned requires some steps and hand-operations.

Firstly, it is needed to mix between 3 and 4 litres of two components in order to obtain polyurethane, taking care of putting the same quantity of each one. After mixing and shaking the mix, a reaction takes place and the foam starts to rise. Very quickly, while the foam is expanding, it is put into a bag which is into the wooden frame.

Immediately, the tallest team driver sits down during 10 minutes approximately, the time needed by the foam to become hard and strong in order to get the ergonomic shape for the foam model that is wanted. This process is repeated several times and then the best foam seat is selected.

Finally, the model selected is extracted from the bag, and the excess of material is cut with a knife and a handsaw.



Picture 3.3: Foam seat selected after the process

The next stage is the analysis of driver's position and the modification of the foam seat following the advices and feelings of the different drivers.

For that purpose, the model is put into the wooden frame in different positions, and the team drivers sit down on it with the steering wheel prototype.

After that, the drivers give their opinion about the seat and its position and the foam seat is modified trying to satisfy their desires.

Consequently, after every modification the drivers check the foam seat again, showing the right way to cut it in order to achieve a good subjection and enough hand room for a good driving. This process is quite difficult due to the big difference in terms of height between the team drivers (189 cm the tallest and 172 cm the shortest).

Picture 3.4: Seat foam modification process

Finally, after checking that the visibility was enough for a good driving, it was decided to put the driver more horizontal than in the previous cars to put the centre of gravity lower.

When the drivers were satisfied with the foam seat shape, it was tried to scan it. However, because of the characteristics of the foam surface, that was too much reflective, there was some problems and the 3D scanner was not able to get all the required information about the foam seat geometry and it was impossible to obtain and adequate scanned model of it.

For this reason, the foam seat was painted to avoid reflexions and other problems with the 3D scanner.

Picture 3.5: *Foam seat finalized and painted*

Picture 3.6: *Driver checking the foam seat finalized*

3.5. Design

3.5.1. Scanned model

- Function:

After the last operation, the foam seat is painted and ready to be scanned in order to obtain a 3D guide model.

Due to the fact that the foam model was obtained and modified to be as close as possible to the characteristics wanted for the real seat, the scanned model will be a key factor for the CAD design, making it much easier and effective, because it will be only needed to follow the scanned model surface making some modifications (the hand room and the bottom of the seat mainly) taking care to fit it into the frame.

- Technology used:

With the purpose of getting the scanned model, the foam seat was taken to a laboratory in the Department of Machinery of the Tallinn University of Technology, where a 3D scanner was ready to be used.

To be more precise, the type of 3D scanner used was a non-contact active scanner. This kind of scanner works emitting light and then detecting its reflection. Working in this way, the machine can get a reference of the object that it is being scanned and the information is sent to the software installed in the computer connected to it.

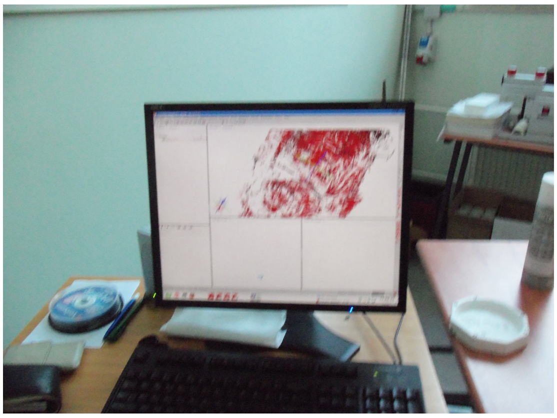
- <u>Scanning process and dots of reference function:</u>

Before starting to scan the foam seat, some adhesive dots were fixed to it in order to get some references in the 3D model that would be obtained.

The most important of these references is the vertical axis of symmetry of the seat. For this reason, two dots were fixed vertically in the middle of the foam seat. After the scanned model is finished, these points will be found easily in the computer. The location of the vertical axis of symmetry with these points is indispensable to start the 3D CAD design.

In that case, a single scan is not enough to produce a complete model of the foam seat. For this reason, multiple scans from different directions are required to obtain the information needed about all sides of the foam seat in order to get a complete model of it.

Picture 3.7: 3D Scanner



Picture 3.8: Scanning process

When this process is finished, a scanned model that could be exported to CATIA V5 is obtained. After that, is time to start the CAD design of the seat with this software using the scanned model as a guide.

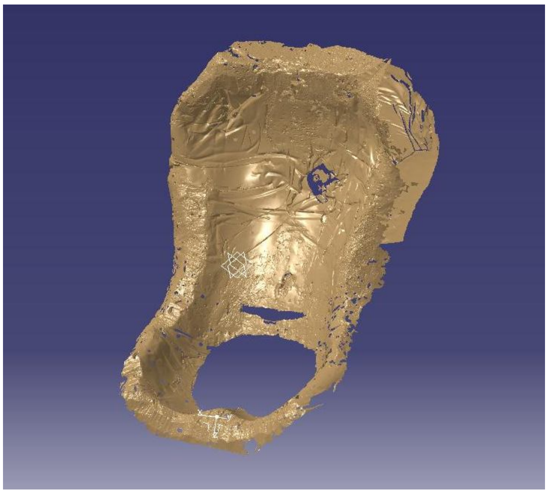


Figure 3.9: Scanned model in CATIA V5

3.5.2. CAD Design

- Function, goals and general description:

The CAD models design is probably the most important part of the seat and firewall creation due to the fact that the milling models will be created based on them, and after that the moulds for the real seat and firewall will be manufactured. For this reason the CAD models need to reach the main goals of the project.

The CAD design starts with the seat and not with the firewall for some reasons. The most important is the fact that the seat is the key factor to reach the main improvements in comparison with the previous cars (lower driver's centre of gravity and good support for the driver), so it makes sense to give priority to its design.

Furthermore, after finishing the seat design, it will be checked if the template fits into the cockpit with it inside and after that will be decided if the firewall design will start as a part of the seat or as an independent piece, and it could be done easily.

Following the scanned model, the design process tries to achieve the desire characteristics for the seat, which are and ergonomic shape and smooth surface to be comfortable for the driver but providing at the same time a good support during the driving.

It will be also needed to design the CAD model of the seat fitting it perfectly into the CAD model of the frame and, at the same time, leaving enough space for the engine and the fuel delivery system.

- Drawing process:

 - Symmetry plane:

 First of all, it is needed to find the two dots of reference fixed in the vertical axis of symmetry of the foam seat before scanning it. Then it is possible to create a vertical plane that will work as a symmetry plane. This plane will be indispensable during all the designing process to make the work easier and get a symmetric seat. In the next figure one can see the symmetry plane highlighted with a red circle.

Figure 3.10: Symmetry plane created

 - Seat Body design:

 After that, starts the drawing process to get the body of the seat model. Firstly, a guide curve is created over the previous symmetry plane, following the shape of the scanned model but always making it without abrupt changes of direction in order to get a smooth surface later.

When the guide curve is made, is time to create some planes, perpendicular to the guide curve in order to make several profiles, using also the first plane during the drawing process to get symmetric sketches. Finally two guide curves, parallel to the main one, are created.

With this guides and profiles, within the Shape/FreeStyle CATIA environment and using the Net Surface tool, the body of the seat model is obtained. To get the best result it was necessary to try different combinations of profiles and guide curves until having a satisfactory result.

- <u>Assembly file:</u>

When the seat body is created, the next step is inserting the seat body into an assembly file with the frame and the engine CAD models. This point is very important, because after putting the seat in the position that was decided in the previous stages, the CAD model of the seat can be cut and adjusted to fit perfectly into the frame.

Furthermore, the assembly allows to work in parallel with other team members that can check how much space they have to design their components, mainly the fuel delivery system and the steering wheel.

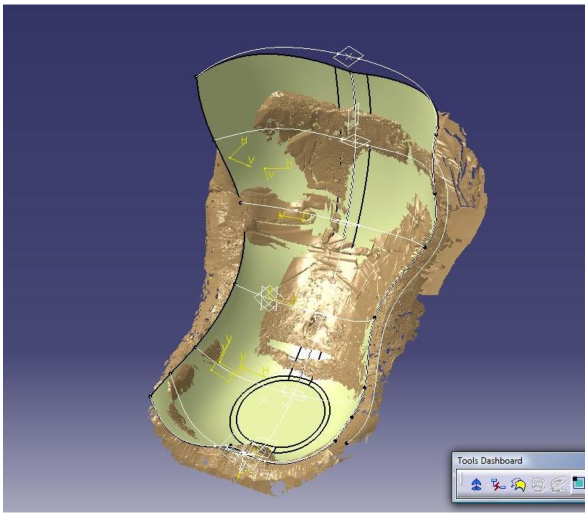


Figure 3.11: Seat model body overviewed with the scanned model

- <u>Seat sides design:</u>

Afterwards, with the help of the assembly file, the sides of the seat can be made. To design this part, is needed to take into account that the drivers will need enough hand room during the driving to turn the steering wheel without problems.

During the design of the two sides, it is also necessary to be sure that the two sides arrive just until the lateral surfaces of the frame in the correct way in order to assembly the seat into the cockpit in the best conditions, fixing it completely to avoid movements and vibrations during the driving.

The process is similar to the previous one. A 3D guide curve is made, and after that some profiles, which are perpendicular to it, are drawn taking into consideration the hand room needed. Again, with the Net Surface tool the side is created. After that, the side is cut with the body surface and the frame planes to fit it in the right way. Finally, the other side is obtained applying symmetry with the reference plane.

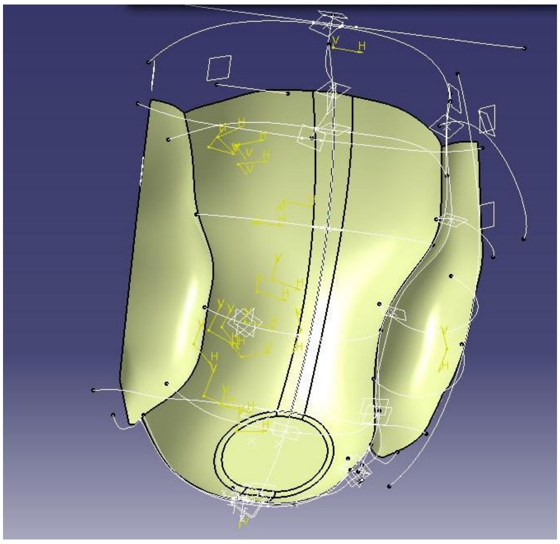


Figure 3.12: Seat model with sides

From that moment is not necessary to overview the scanned model and it is enough using the assembly file with the frame and the engine. Moreover, hiding the scanned model the CATIA V5 software works faster so it is decided to continue the CAD design without it.

- <u>Top and bottom of the seat design:</u>

After the sides of the seat are finished and the scanned model is hided, it is time to design the top and the bottom of the seat. These parts are needed to fix better the seat to the frame and firewall in order to give more stability, support and consequently stiffness to the seat.

The process to create it in CATIA V5 is very similar to the previous ones. Firstly, guide curves and profiles are drawn again. It is necessary to be focused drawing the guide curves, especially with the bottom of the seat, to assure that the surface will go through the floor of the car defined by the frame model. After that, the surfaces are created with the Net Surface tool after trying different combinations and selecting the best one. Then the surfaces are cut properly to join the rest of the seat surfaces created before. Finally some edge fillets are made around the seat.

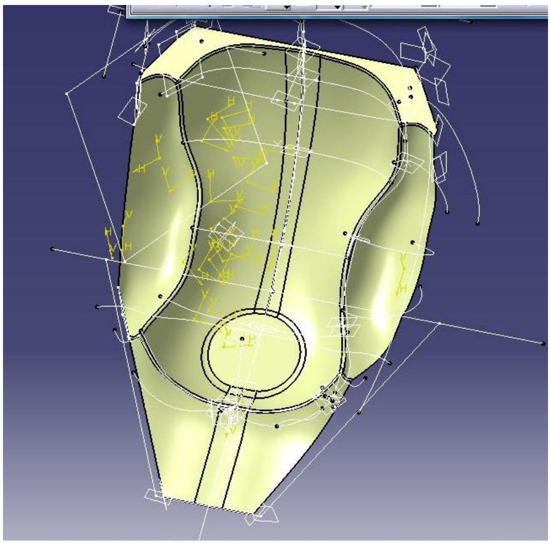


Figure 3.13: Seat model after creating the top and bottom surfaces

- <u>CAD template checking:</u>

After that operation, with the seat model in CATIA almost finished, it was the right moment to check if the template for the Formula Student template test fit into the car with the seat inside.

In order to do it, a template model was created in CATIA with the right dimensions defined in the Formula Student rules and it was put into the assembly file with the frame and the seat checking that there were interferences between the template and the seat.

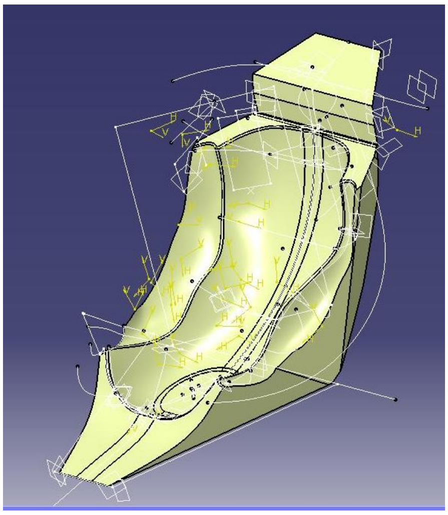
As a consequence, the template will not fit into the cockpit without removing the seat so it was clear that it will be needed to design and manufacture the firewall and seat in two different peaces.

- <u>Last modifications:</u>

After checking that the firewall should be designed and manufactured independently, the seat design is almost finished, but before sending the file to the milling machine in order to manufacture the milling model of the seat it is needed to close the surface. For this reason, the planes of the frame are used to close the sides and the bottom part.

The seat CAD design would finish closing the back of it. In order to simplify the future firewall design, the back zone to close the seat will be already designed as a part of the firewall.

This means that the firewall will have the same shape than the back of the seat CAD model and milling model. Moreover, designing this part at that moment, allows to follow the shape of the seat perfectly, making easier the task of fitting and supporting the seat over the firewall.



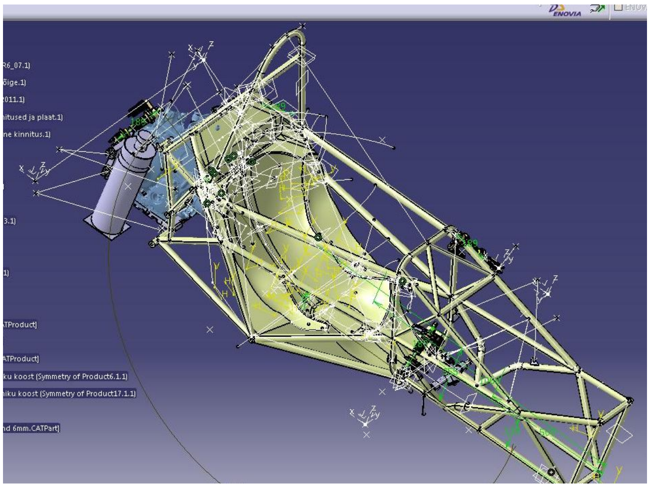


Figure 3.14: Seat model ready for integrated the milling machine

Figure 3.15: Assembly file with the seat and firewall

4. Firewall

4.1. Goals

There are two main goals for the firewall:

- First of all, it should isolate the driver from the engine to protect him from an excess of temperature and avoiding him to touch any hot part.
- Secondly, after deciding that it will be designed and manufactured separately from the seat, it is clear that the firewall needs to fit with the seat perfectly and be strong enough because has to work supporting the seat.

At the same time it is also wanted to make the firewall as simple as it is possible in order to put it inside the car and take it out easily.

4.2. Options and solutions

Before starting the firewall design there was different options about how to do it related to its structure, geometry and material selection.

- <u>Independence from the seat:</u>

The first decision, as it was said before, was design it separately from the seat after checking that it was not possible to make them together, because during the seat design it was checked using the assembly file in CATIA V5 that the template didn't fit into the cockpit with the seat inside.

- <u>Structure:</u>

Secondly, it was decided to try to make the firewall in one piece in order to make it stronger. Anyway, if it would be necessary to be able to put it into the car and take it out easily, the firewall could be finally manufactured in different parts, with one central piece and some extra small pieces, but always trying to make it as simple as possible.

- <u>Material selection:</u>

Finally, related to the material selection to manufacture the firewall, carbon fiber was chosen. The reasons to select it are pretty similar to the seat material selection. Despite the fact that it would have been possible to use some material cheaper and easier to manufacture the firewall, the quality of the product and the achievement of the project goals are the most important.

That is why carbon fiber was selected, because it has the right properties to construct it easily and isolate the cockpit from the engine correctly. Moreover using carbon fiber the firewall will be strong enough to support the seat.

- <u>Insulation material:</u>

However, it is not enough with the carbon fiber firewall to battle the excessive heat that could penetrate into the driver compartment. For this reason, in order to achieve a better thermal insulation, the back of the firewall will be covered with another insulation material after being manufactured.

The insulation material that will be used to cover the back of the seat is a composed of resin-bonded silica blanketing insulation sandwiched between a mylar facing on one side and a foil facing on the other. The highly-reflective mylar reflects heat away from surfaces, while the foil side is orientated away from the heat source to conduct any penetrating heat across its surface [7].

4.3. CAD Design

The firewall design starts using the back part of the seat CAD model created previously to close it before be sent to the milling machine. Then it is only needed to create different surfaces to close perfectly the space between the engine room and the seat.

In order to draw and create the surfaces needed to finish the CAD model, different planes are created using the references of the frame model in the assembly file. Then, the surfaces are drawn and created with the Fill tool within the Generative Shape Design CATIA environment. Then the surfaces are cut properly to join between them and get a firewall with the desire geometry and characteristics.

As it is said before, the firewall function is to separate the cockpit from the engine for driver’s security, working as thermal insulator and at the same time as seat support. Consequently, it is indispensable to check the assembly after every change on the firewall model to ensure that it goes as close as possible to the frame and it fits perfectly with the seat.

Finally, after finishing the design, it is much better if the firewall model is closed like the seat model before sending it to the milling machine.

As it will be explained in the next chapter, was necessary to make some little modifications in the shape of the firewall CAD model due to a change in the seat position that was decided after checking the milling model of the seat.

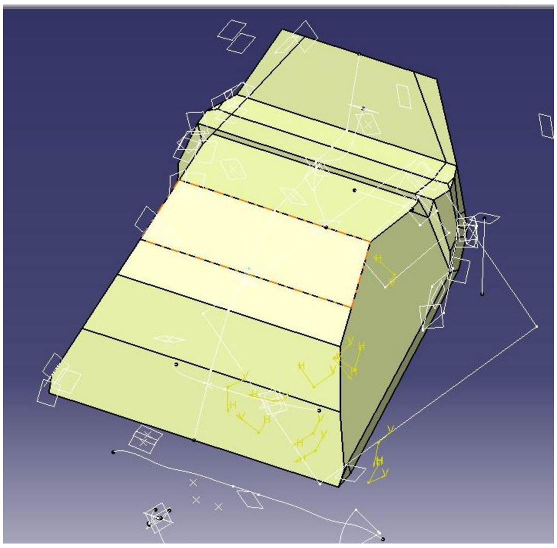


Figure 4.1: Firewall model ready for the milling machine

5. Manufacturing process

5.1. Milling models

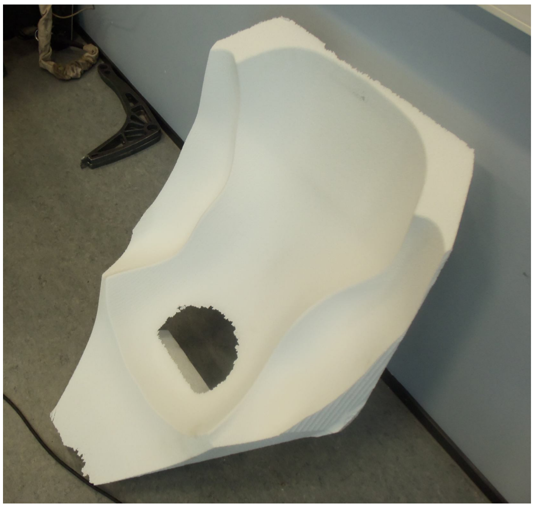
The milling models are indispensable to check if the CAD models are well designed. Moreover, the moulds will be obtained from the milling models after some operations that are needed.

For the purpose of obtaining these models a 5D CNC milling machine was used. Thank you to its computer numerical control and 5D mobility, the machine can reproduce exactly and automatically the information given by the CAD models.

In the case of the seat milling model, it is indispensable to decide if the model needs some modifications related to two basic points. First of all, it allows to test if the seat is enough comfortable for the drivers and provides a good support. Secondly, the milling model can be putted into the real frame (which is already manufactured) to see if it fits well and if it is necessary to change the position.

Before doing these verifications, the milling model needs to be reinforced, otherwise it would be broken if one driver seats down due to the fact that it is made of polystyrene. In order to make the model stronger, a metallic sheet is bent to get the same shape than the seat. Then, it is placed on the back of the seat to support it. Furthermore, the model is completely covered with adhesive tape.

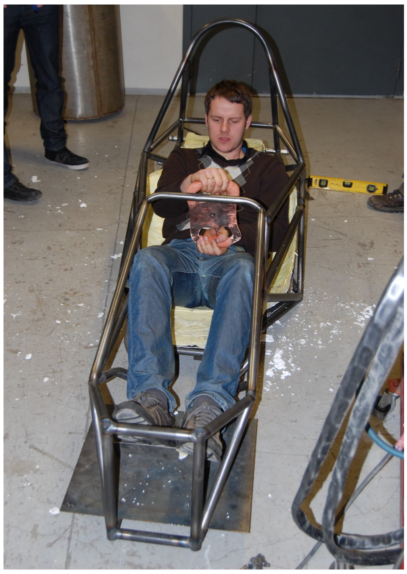
After the last operations the milling model of the seat was ready to be checked by the drivers. Firstly, to have a first idea about the result of the seat design, it is checked into the wooden frame. Later, when the real frame is manufactured the seat is put inside and after doing the necessary verifications some decisions about how to improve the seat are made.



Picture 5.1: Seat milling model

Picture 5.2: Milling model ready to be tested

In spite of the fact that is very difficult to obtain a seat with good characteristics for such a different range of driver's height, after testing the model it was shown that the seat had very good shape and characteristics to reach the goals of the project.



Picture 5.3: Milling model verification in the wooden frame

Picture 5.4: Milling model verification in the real frame

Only two modifications were decided:

- The modification of the bottom of the seat, putting more material to avoid the possibility of slide down during the driving.
- Position change of the seat, now a little bit more vertical to accomplish the minimal angle required for the seat belt in the FS rules. Furthermore, with the new position there is more space for the fuel delivery system.

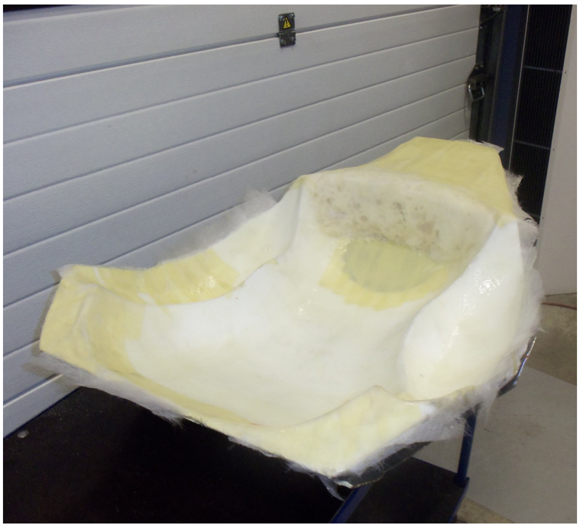
In order to achieve the aim of the first modification it is needed to change the model. At the beginning was tried to put some foam (polyurethane) at the bottom of the seat and then make the surface smoother manually using a knife and glass paper.

During the process, the drivers were checking the seat until it was good enough to reach the goal of avoiding the driver to slide down.

Picture 5.5: Milling model checking during the addition of extra foam

Later, the milling model was covered with fibers and epoxy to reinforce it and make it stronger and finally it was sent to the bodyshop in order to paint it, with a special paint based on polyester, and be able to get the mould after that.

Pictures 5.6 and 5.7: Milling model with extra foam being covered with epoxy



Picture 5.8: Milling model with extra foam and finally reinforced with epoxy

At firs it was seemed to be a good solution, but the bodyshop was not able to have the model ready to make the mould because the added surface was not smooth and strong enough.

For this reason it was necessary to change the CAD model according to the milling seat modified manually and then get a new milling model. This process was very quickly, because it was only needed to do some measurements in the milling model and then create the added material in the CAD model.

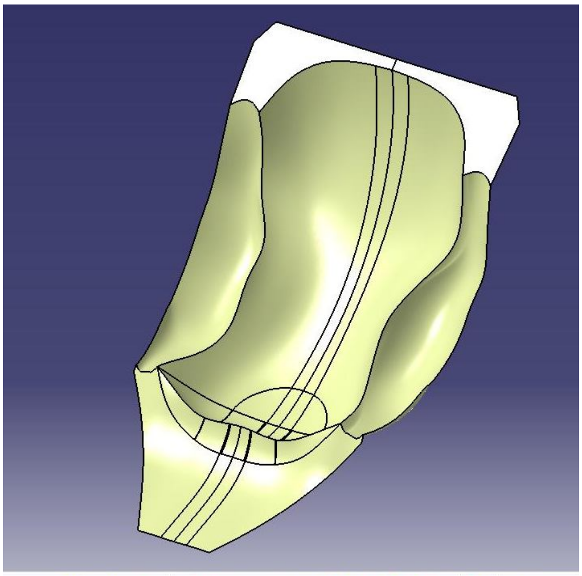


Figure 5.9: Final seat CAD model with the modification for the new milling model

After that, like it was done before with the first milling model, the new one was covered with epoxy and sent directly to the bodyshop in order to paint it and make it smoother to be able to obtain the final mould. I was possible to sent it to the bodyshop without doing any test due to the fact that only this bottom part was added, so it was clear that the new milling model would fit into the frame like the previous one.

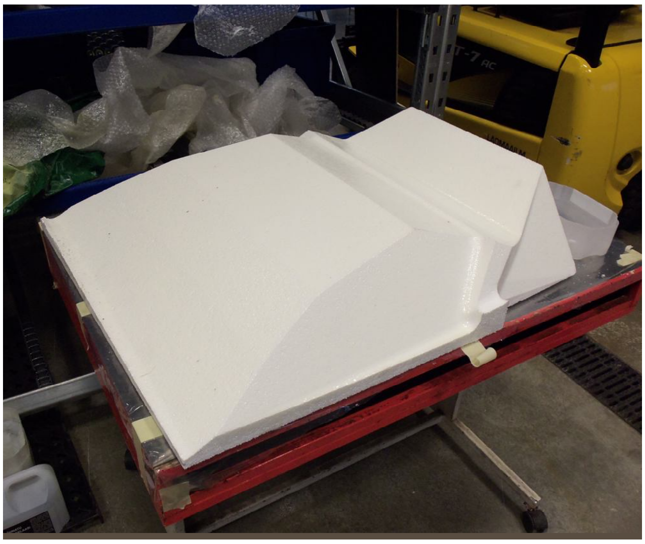
Moreover, the modified part of the CAD model was created according to the added foam put in the first milling model as a copy of it. Then it was guaranteed that the new milling model would have the desired characteristics.

Picture 5.10: New seat milling model being covered with epoxy

About the second goal, the change of position of the seat, it was only needed to change the position of the seat in the assembly file and, consequently, make some little modifications in the CAD model of the firewall before ordering the milling model of it to bodyshop.

After these modifications in the shape of the firewall CAD model, the milling model of it was ordered and obtained.

Then was checked that the milling model had been manufactured with the right dimensions and, in the same way than the seat milling model, it was covered with epoxy and fibers before being sent to the bodyshop to paint and get it smoother in order to have it ready to obtain the final mould to manufacture the firewall.



Picture 5.11: Firewall milling model ready to be sent to the bodyshop

5.2. Moulds, seat and firewall manufacturing

After being painted by the bodyshop, the milling models of the seat and firewall are sent to the mould manufacturer. The process to obtain the moulds is the last one before manufacturing the real seat and firewall.

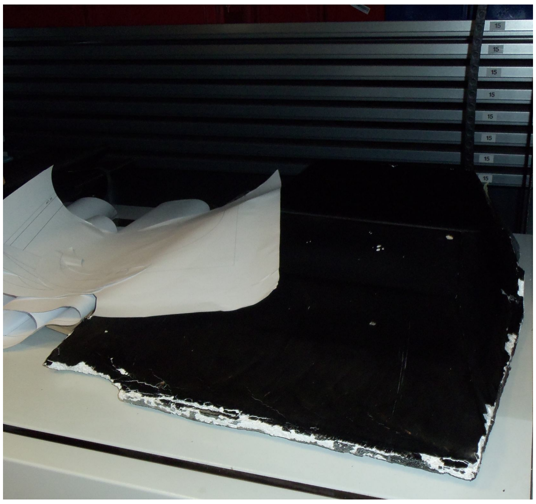
The obtaining process of the moulds is exactly the same for the seat and firewall. First of all, the milling models are sent to the mould manufacturer and there are finished a little bit more and then some layers of wax are applied over the milling models.

After that, the milling models are covered with gel coat in order to fill the pores around the surface. Finally, between 4 and 6 layers of fiber glass and polyester are applied alternatively. The fiber glass and the polyester are applied in this way in order to avoid excessive toughness and internal forces that could break the piece that is wanted to manufacture through the mould.

Pictures 5.12 and 5.13: Seat mould

When the moulds are finished is time to manufacture the real seat and firewall. For that purpose, as it was decided before starting the designing process, carbon fiber was used to manufacture both of them. Consequently, the process for the seat and the firewall are the same: Carbon fiber is put into the mould and epoxy is applied until the piece becomes hard and achieves the shape of the mould. Finally the piece is extracted. In order to make the extraction easier and avoid damaging the piece, mould release agents are applied into the moulds before putting the carbon fiber.

Due to the last modifications that were needed in the seat milling model, the first of the two pieces that were manufactured is the firewall.



Picture 5.14: Firewall manufactured over the mould

After the firewall was manufactured, it was tried to put it into the frame, checking that the firewall will need to be cut a little bit to be able to put and take it out of the cockpit easily.

For that purpose, after making the requirement measurements, a piece of cardboard was cut with the right dimensions in order to get a guide to cut the firewall correctly. Finally, the cardboard piece is fixed to the firewall in the correct position and then, using a disc cutter the firewall is cut following the cardboard.

When the firewall was cut, it was tried to put it into the frame again. With the last modification the firewall fit well into the frame and it was really easy to put it inside. However, there were some small zones that the firewall didn't reach to isolate completely the driver from the engine.

As a consequence it would be needed to put some small pieces to complete the firewall and isolate the cockpit from the engine. Anyway, the firewall was really compact and it fit perfectly in the correct position like in the CAD model.

Finally it was decided to test the car with the firewall at this stage and delay the construction and application of the final solution to cover the small areas that the firewall doesn't cover until having success in the car tests.

In order to have the firewall ready for the test, it is only needed to cover the back of it with the insulation material detailed in the chapter 4.2 (Firewall/Options and solutions). The insulation material was cut with the same dimensions as the firewall and then fixed to it.

Picture 5.15: Front of the firewall

Picture 5.16: Back of the firewall with the insulation material

After the firewall was ready for the car tests, the final seat was manufactured. In the same way as the firewall, after being obtained, the seat was put into the frame to see if represents exactly the CAD and milling model having the correct dimensions and shape and fitting into the cockpit.

When the seat was inside the frame it was checked that it fits perfectly into the cockpit and the shape of the seat was the adequate, being and exactly reproduction of the CAD and milling model.

Finally, with the seat in the correct position it was checked where the seatbelts has to pass through the seat, and four holes are made for that purpose.

Pictures 5.17 and 5.18: Seat manufactured

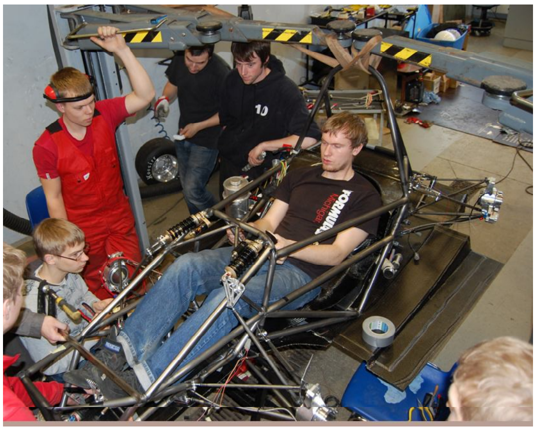
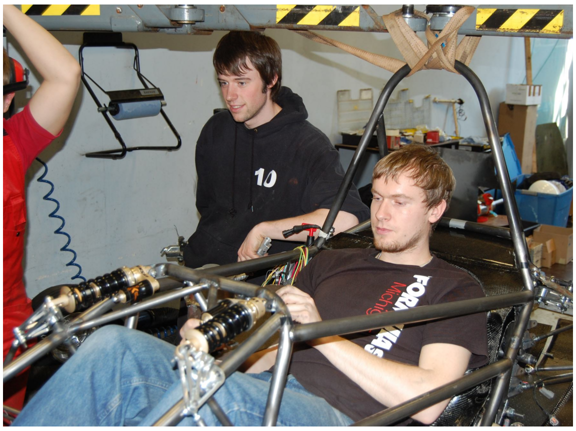
5.3. Seat and firewall during the car assembly and tests

At this stage of the process, when the seat, firewall and almost all the components of the car are already manufactured, it was time to start the car assembly for the first tests.

During this first assembly process, the firewall and the seat were needed to be into the cockpit at some moments, in order to check if there was enough space for the fuel delivery system and the rest of components and also see if the drivers feel good seating down on it with all the elements in the frame.

During the assembly of the car, it checked was all the components fit into the car with the seat and firewall inside. It was also checked that the seat achieved all the goals in terms of comfort and support for the driver.

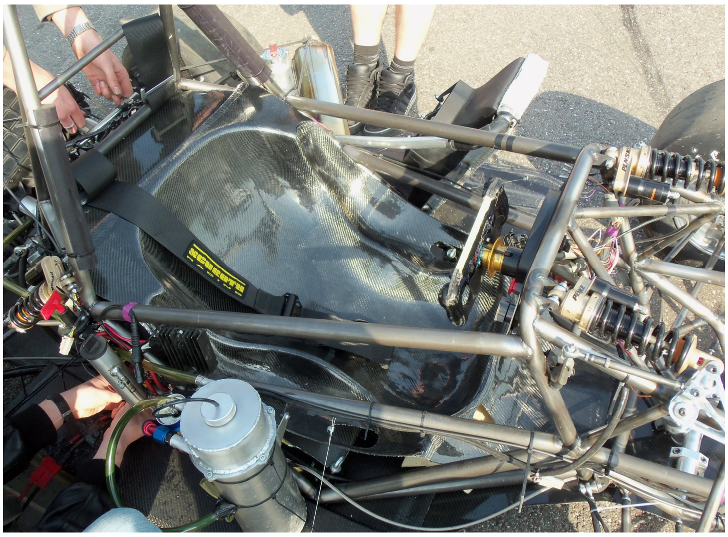
The only bad point, was the fact that the seat was quite flexible, so it was decided to wait until the car test, and then see if it should be solved and how would be possible to do it.

Pictures 5.19 and 5.20: Driver checking the seat during the assembly process

After the assembly was finished, the car, without the bodywork yet, was ready for the first tests. These tests took place in the Rapla kart circuit. During the first test, there was no chance to check the seat with the car running due to some problems with the engine.

When the engine problems were fixed, the team went to Rapla again to test the car and then was possible to check the seat with the car running lap after lap during 5 hours approximately. In this test it was confirmed that the seat achieved the main goals of the project with a low driver's centre of gravity and excellent support for the driver. However it was also confirmed that the seat was a little bit flexible. For this reason, it was decided to try to reduce this flexibility with the car bodywork and the extra pieces for the firewall.



Picture 5.21: Seat and firewall ready for the car test

Pictures 5.22 and 5.23: Drivers testing the car in Rapla

5.4. Last adjustments

After testing the car and checking that the seat and firewall had reached the main goals of the project, it was time to find a solution in order to cover the small zones that the firewall was not able to reach to isolate completely the driver from the engine.

The wanted solution needs to reach two basic points:

- It needs to be as simple as possible.
- It will be necessary to be able to remove the firewall easily and as fast as possible.

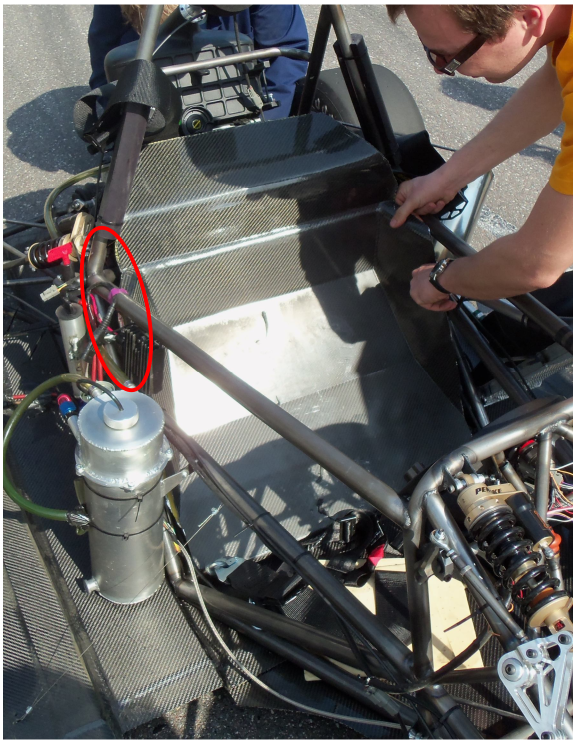
Finally, it was decided to complete the firewall with some sheets made of carbon fiber again. These sheets will be attached to the frame with screws. It will not be needed to remove these sheets from the car, so they can be attached strongly with as many screws as it will be necessary. Then, the firewall (as a central piece) should fit with the sheets and it will be fixed to them with screws too.

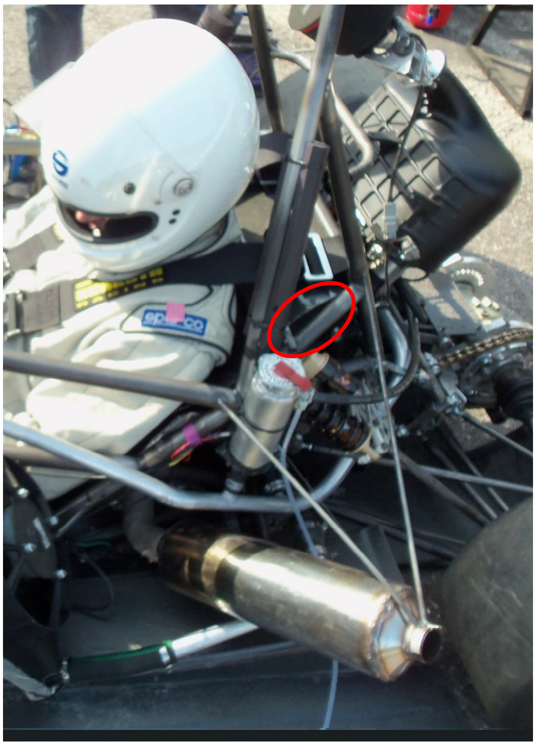
The number of screws to attach the firewall to the sheets needs to be enough for fix it correctly, being able to resist the heat and fire in case of ignition of the fuel tank. However, at the same time it is good to have as less screws as possible in order to take the firewall out easily. Consequently, the number of screws to attach the firewall to the sheets needs to be a balance between these two concepts.

Despite the fact that it would have been better to get the firewall in one piece, at the end, this solution will works good and it is really cheap and simple, so with it the firewall reaches the goals of the project.

Moreover, with the firewall completed and the bodywork put on the car, the seat will have better support and the flexibility of it will be reduced solving this little problem.

In the next pictures one can see highlighted with red circles some of the small zones that should be covered with the carbon fiber sheets.





Pictures 5.24 and 5.25: Zones to be covered by the carbon fiber sheets

6. Manufacturing cost summary

In the manufacturing cost report of the seat and firewall (Appendix II) it was taken into account the cost of the materials, the tools and the processes.

The manufacturing cost summary is the next:

- Seat:

Materials:	
- Carbon fiber:	122,40 $
- Fabric:	0,19 $
Processes:	
- Manufacturing process:	42,27 $
- Cutting operations:	14,00 $
Tools:	
- Composite tool:	2,82 $
SEAT TOTAL:	**181,66 $**

- Firewall:

Materials:	
- Carbon fiber:	52,00 $
- Polyethylene:	0,05 $
- Polyurethane:	1,40 $
- Heat Barrier:	20,00 $

Processes:

- Manufacturing process:	20,10 $
- Cutting operations:	20,3 $
- Heat barrier attachment (tape):	1,60 $

Tools:

- Composite tool:	1,41 $

FIREWALL TOTAL:	**116,86 $**

TOTAL SEAT + FIREWALL: 298,52 $

7. Conclusions and results

In general this master’s thesis, Firewall and driver’s seat for Formula Student race car FEST11, has reached all the goals that were wanted to achieve at the beginning.

About the seat, after being manufactured and tested, it was shown that it has the required characteristics and represents an improvement in comparison to the FEST10 seat. So, it is concluded that:

- The designing and manufacturing process of the seat was the adequate to reach the best quality optimizing the resources and costs.

- The combination of the foam seat, the scanned model, the CAD design, the milling model and the collaboration of the drivers are indispensable to assure that the seat has the needed characteristics before manufacturing the final seat.

- Despite the difficulties to design a good seat for drivers with big differences in terms on height and weight, the final seat reaches the goals of the project, being comfortable, providing a good support during the driving and achieving low driver’s centre of gravity.

Related to the firewall, it also reaches the goals of the project:

- It has the right shape to work supporting the seat correctly.

- The firewall (including the small sheets added at the end) isolates completely the driver from the engine.

- The firewall is strong enough and its structure is simple, being able to put it into the car and take it out easily.

Despite the fact that the goals of the project are reached, there are some aspects that could be improved if in the future it is decided to redesign the seat and firewall for a future car after the FEST11:

- It would be a good improvement to be able to manufacture the seat and firewall in one piece because it would be needed to get only one milling model and one mould. Furthermore, making them in one piece, flexibility problems will be avoided. However, is more important to obtain a good seat design than being able to manufacture it together with the firewall.

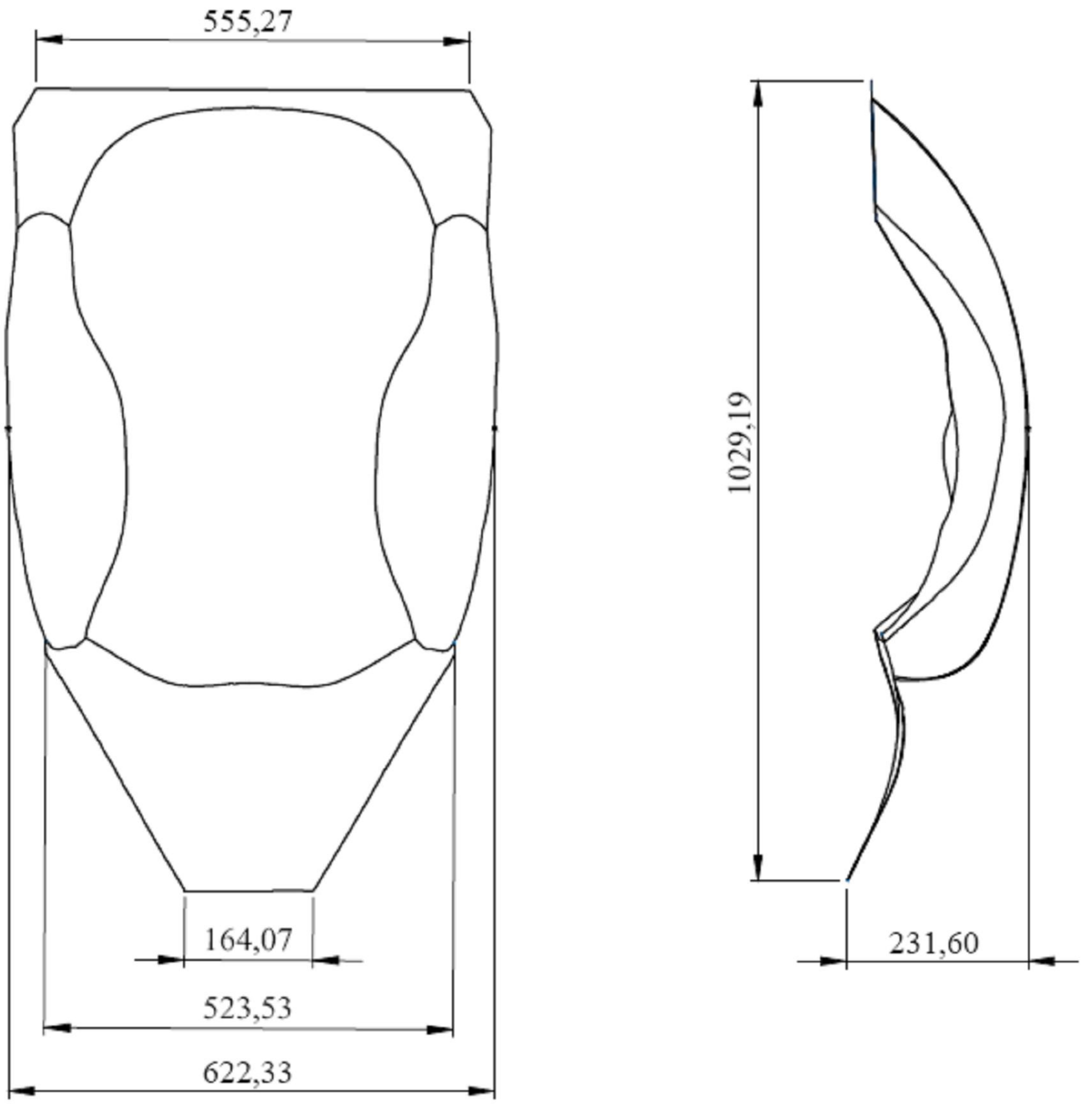
- It would be also desired trying to get the firewall in one piece, not needing the addition of the small carbon fiber sheets.

8. References

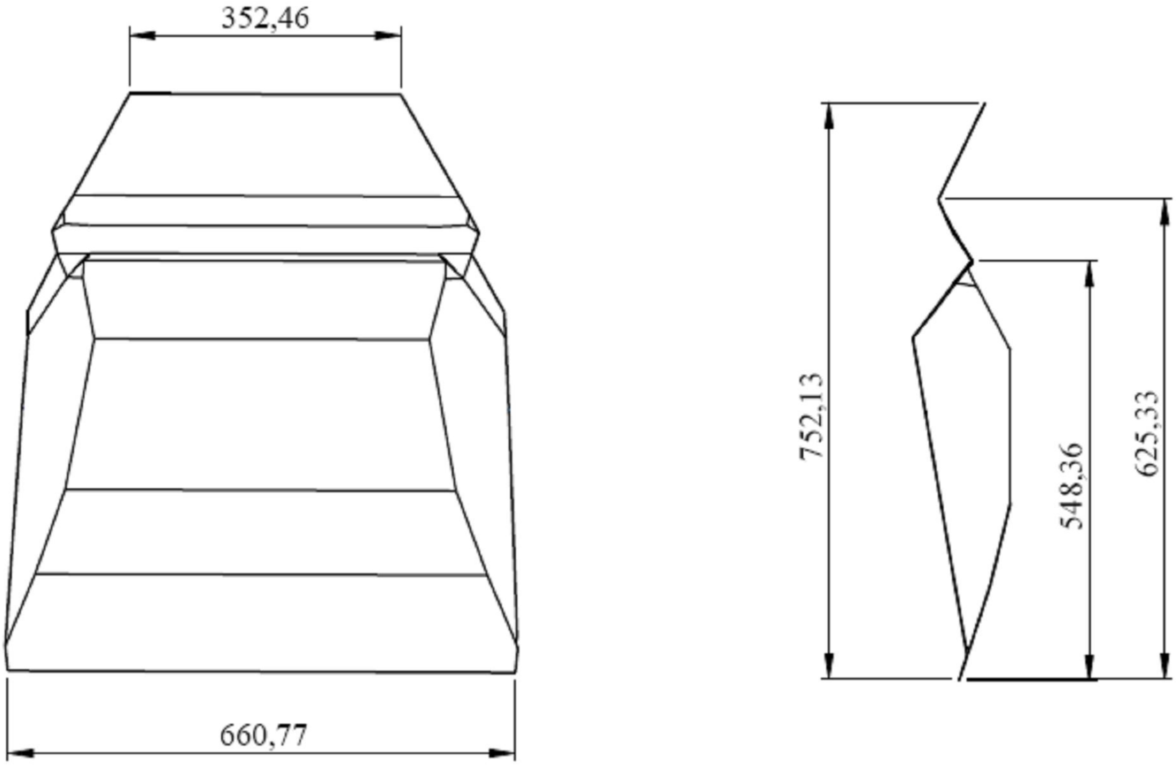
1. Society of Automotive Engineers. *2011 FSAE Rules*, USA; 2010.
2. Stauber R, Vollrath L, *Plastics in Automotive Engineering*. Munich, Germany; 2007.
3. Miravete de Marco A, Larrodé Pellicer E, Castejón Herrer L. *Materiales Compuestos Tomos I y II.* Zaragoza, Spain; 2000.
4. Zhao Z, Gou J. *Improved fire retardancy of thermoset composites with carbon nanofibers.* Science and Technology of Advanced Materials; 2009. 10 015005.
5. Apro K. *Secrets of 5-Axis Machining*. New York, USA; 2008.
6. Del Rio Cidoncha MG, Martínez Lomas ME, Martínez Palacios J, Pérez Díaz S. *El Libro de Catia V5*. Madrid, Spain; 2007.
7. Thermo-Tec Automotive Products, *Cool-It Mat product website*, 2011, URL: http://www.thermotec.com/products/14100-cool-it-mat.html (Accessed April 2011).
8. FS Team Tallinn, *FS Team Tallinn website;* 2011. URL: http://www.formulastudent.ee/en (Accessed May 2011).
9. Sengupta S, *Polyester Resin Vs. Epoxy Resin;* 2011. URL: http://www.buzzle.com/articles/polyester-resin-vs-epoxy-resin.html (Accessed April 2011).
10. Recaro Automotive, *Recaro Automotive Motorsport seats website;* 2011. URL: http://www.recaro-automotive.com/en/product-areas/motorsport.html (Accessed February 2011).

APPENDIX I: GENERAL DIMENSIONS

I.I. Seat



I.II. Firewall



APPENDIX II: MANUFACTURING COST REPORT. EXCEL TABLES.

II.I. Seat

ItemOrder	Material	Use	UnitCost	Size1	Unit1	Quantity	Sub Total
1	Carbon Fiber, 1 Ply	Seat	$ 200,00	0,153	kg	4	$ 122,40
2	Fabric	Seat	$ 2,50	0,075	m^2	1	$ 0,19
						Sub Total	**$ 122,59**

ItemOrder	Process	Use	UnitCost	Unit	Quantity	Multiplier	Mult. Val.	Sub Total
1	Lamination, Manual	Composite Fabric	$ 35,00	m^2	0,845		1	$ 29,58
2	Resin application, Manual	Composite Fabric	$ 5,00	m^2	0,845		1	$ 4,23
3	Cure, Room Temperature	Composite	$ 10,00	m^2	0,845		1	$ 8,45
4	Non-metallic cutting >76,2 mm	Holes for Seat belts	$ 1,40	cut	4	Composite	2	$ 11,20
5	Non-metallic cutting >76,2 mm	Seat	$ 1,40	cut	1	Composite	2	$ 2,80
6	Brush Apply	Apply glue	$ 0,02	cm^2	0,353		1	$ 0,01
							Sub Total	**$ 56,26**

ItemOrder	Tooling	Use	UnitCost	Unit	Quantity	FracIncld	Sub Total
1	Composite Tool	Seat	$ 10.000,00	m^2	0,845	1	$ 2,82
						Sub Total	**$ 2,82**

Part Cost	**$ 181,66**

II.II. Firewall

ItemOrder	Material	Use	UnitCost	Size1	Unit1	Quantity	Sub Total
1	Carbon Fiber, 1 Ply	Firewall	$ 200,0	0,065	kg	4	$ 52,00
2	Plastic, Polyethelene	Infusion Molding	$ 3,3	0,016	kg	1	$ 0,05
3	Hose, Polyurethane	Infusion Molding	$ 0,7	2,000	m	1	$ 1,40
4	Heat Barrier	Firewall, gas tank	$ 50,00	0,400	m^2	1	$ 20,00
							$ -
						Sub Total	**$ 73,45**

ItemOrder	Process	Use	UnitCost	Unit	Quantity	Multiplier	Mult. Val.	Sub Total
1	Lamination, Manual	Composite Fabric	$ 35,00	m^2	0,423		1	$ 14,81
2	Resin application, Infusion Molding	Composite Fabric	$ 2,50	m^2	0,423		1	$ 1,06
3	Cure, Room Temperature	Composite	$ 10,00	m^2	0,423		1	$ 4,23
4	Non-metallic cutting > 76,2 mm	Composite	$ 1,40	cm	3	Composite	2	$ 8,40
5	Non-metallic cutting > 76,2 mm	Firewall	$ 1,40	cm	3	Composite	2	$ 8,40
6	Drilled holes < 25,4 mm dia.	Composite	$ 0,35	hole	10		1	$ 3,50
7	Tape	Firewall, heat barrier	$ 0,80	m	2			$ 1,60
							Sub Total	**$ 41,99**

ItemOrder	Tooling	Use	UnitCost	Unit	Quantity	PVF	FracIncld	Sub Total
1	Composite Tool	Firewall	$ 10.000	m^2	0,423	3000	1	$ 1,41
							Sub Total	**$ 1,41**

Part Cost	**$ 116,86**