Briefing

The Aim of this project is to design a frame and a cover for a prototype Formula Student car. Following the championship rules, all the parameters that influence on the design will be controlled trying to get the lighter, toughness and economic car design, but keeping an eye on the execution time. It is necessary to know when it is possible to validate the design of a frame. Then it is very interesting to know the criteria that the car designers use on different competitions, like the GT World Championship.

Knowing the aim to achieve, choosing a suitable design tool is very important. The tool chosen will be the Finite Elements Theory. At the same time we have to keep on mind all the building processes of the frame while designing the frame.

Currently there is no a specific rules or regulations for a tubular frame design. While for the building construction we can find a lot of regulations, designing the frame that we are studying there is only specific competitions that give preliminary ways of design, just to guarantee minimums of safety. In our case we will follow the FORMULA SAE rules.

Index

Contents

Index Figures, Equations and tables

1. Introduction

When I started my Erasmus semester on the Dublin Institute of Technology I got the chance to design a frame and a body for a formula student. Then a lot of doubts appeared. The first doubt was witch design tool I will use. The tool chosen and used for the entire project designing was Solid Works. SolidWorks is a 3D technical CAD (computer-aided design) program that runs on Microsoft Windows and is being developed by Dassault Systemes Solidworks Corp. SolidWorks is currently used by over 1.3 million engineers and designers at more than 130,000 companies worldwide. It is a really powerful design tool. Getting use to it needed a lot of hours but using it is so simple and intuitive.

The design process was marked on a module given on the DIT and it is the first pass to the Formula Student DIT Team. This institute has participated on the competition several times and currently one team is building a car for the next year competition. The Formula Student Competition is a very important event. It has a lot of knowledge and learning regarding. It is a very good chance to investigate and optimize design, build processes and so on. It gives to the students a very good opportunity to not only design and permits to connect the University with corporations, workshops and companies. This is the first pass to the total integration of the student to the working life.

The balance that I take from the time I have been studying on Dublin and the contents of my studies and the project is so positive. First I have learned to use Solid Works. And I have learned the steps to design a Formula Student car and all the regulations and problems to solve, from people of the DIT team that they have been working on a real car.

2. Formula Student Competition

2.1- Description of the Formula Student Competition

Formula Student is the biggest and best of its kind in Europe. Run by the Institution of Mechanical Engineers (IMechE), in partnership with various well known companies in the industry, it promotes careers and excellence in engineering, by challenging university students to design, build, develop, market and compete as a team with a small single seater racing car.

It provides the students with a real-life exercise in design and manufacture and the business elements of automotive engineering. It teaches them all about team working, under pressure and to tight timescales. It demands total commitment, lots of late nights, and many frustrations and challenges along the way, but the net result is the development of highly talented young engineers.

Formula Student attracts entries from universities all over the World, from the UK, mainland Europe and from the Americas, Asia and Australasia. For the universities, Formula Student represents a valuable project that blends academic work and learning with the development of practical engineering skills. They are increasingly using it to attract school leavers to their degree programmes, and to forge closer links with local industry.

The automotive and motorsport industries in particular, and many other high technology engineering companies, know just how important the continuing supply of high quality engineers is to their success. For them, involvement in Formula Student helps them maintain and develop that supply. At a time when many university engineering courses have difficulty filling their places, Formula Student uses the excitement and appeal of motorsport to open young minds to the world of possibilities that a career in engineering involves, and gives them a wealth of real experience to prepare them for success in that career.

For the purpose of the competition, the students are to assume that a manufacturing firm has engaged them to produce a prototype car for evaluation. The intended sales market is the non professional weekend autocross or sprint racer. Therefore, the car must have very high performance in terms of its acceleration, braking, and handling qualities. The car must be low in cost, easy to maintain, and reliable. In addition, the car's marketability is enhanced by other factors such as aesthetics, comfort and use of common parts. The challenge to the team is to design and fabricate a prototype car that best meets these objectives. Each design is compared and judged with other competing designs to determine the best overall car.

2.2- Championship Structure

The main aim is to choose the best car during the championship, being evaluated in static and dynamic trials by automobile professionals. The type of the car that competes are formula type with naked wheels. Are around 3 metres long and they are propelled by almost 610 cc. engines, able to give 70 CV power. For that, the design safety rules are very strict (Formula SAE).

2.3- Static Trials

At the static trials are evaluated technical aspects of the car. There are three trials, first one regards to the design, second asses the cost of the project and the third is just to present the vehicle. The tests are aimed at establishing a dialogue between the team and the judges that evaluate the trials.

Technical Inspection	No points
Cost Analyses	100 points
Business Presentation	75 points
Design	150 points
TOTAL	**325 POINTS**

Table 1. Static Trials Marks

Cost Analyses.

It's needed to present a report where will be detailed all the vehicle building costs in a limited series production. This report has to include all the building processes and commercial components justification.

Business Presentation.

For that trial it's needed to take a Commercial Representation role. It's needed to sell our product to a fake car manufacturer. Then it's addressed issues related to commercialization and standardization of components. A deep knowing of the destiny market of our product will help.

Design.

In the design trial it's evaluated the solutions taken by the makers and designers of the vehicle, that will be judged by an expert team of judges. It's needed to bring a report for give authenticity and validate the design.

2.4- Dynamic Trials

The dynamic tests have the aim to check the vehicle's performance. It's necessary to pass some technical trials of the vehicle, like acceleration test, braking tests, noise check and rollover behaviour. The marks of the trials are expressed on the next table.

Acceleration	75 points
Skid Pad	50 points
Autocross	150 points
Fuel economy	50 points
Endurance	350 points
TOTAL	**675 POINTS**

Table 2. Dynamic Trials Marks

Acceleration.

In this trial it's measured the acceleration of the single-seater in a 75 meters straight road. In the test is evaluated the engine performance and the capacity of the suspension to give the maximum grip. There is a equation that determines the marks:

$$Acceleration\ score = 71{,}5\ x\ \frac{{}^{5{,}8}/_{Tyour} - 1}{{}^{5{,}8}/_{Tmin} - 1} + 3{,}5$$

Equation 1

Where *Tyour* is the team time in seconds and *Tmin* is the minimum between all the contestants respectively. This nomenclature is used in the other trials equations, also. The marks can't be negatives.

Skid-Pad (or 8 trial).

In this trial is checked the line that the vehicle can develop on closed turns. The car has to draw circles on clockwise and anticlockwise. In the trial is checked the suspension performance and the capacity to support lateral accelerations (g forces). The two circles that form the eight are limited by cones and have 9.25 meters of interior diameter and 15.25 of external diameter. The centres are at 18.25 meters of distance. The equation that determines the marks is:

$$Skidpad\ score = 47{,}5\ x\ \frac{\left({}^{6{,}184}/_{Tyour}\right)^2 - 1}{\left({}^{6{,}184}/_{Tmin}\right)^2 - 1} + 2{,}5$$

Equation 2

Autocross (Sprint)

In the autocross trial is checked the manoeuvrability of the vehicle. The vehicle has to accelerate on a straight road, making him brake and take a turn on an 800 meters circuit. The circuit will be composed by cone slaloms, straight roads, 180 turns and quick turns.

The equation that determines the marks of this trial is:

$$Autocross\ score = 142{,}5\ x\ \frac{{}^{Tmax}/_{Tyour} - 1}{{}^{Tmax}/_{Tmin} - 1} + 7{,}5$$

Equation 3

Tmax is equal to 125% of Tmin.

Endurance

In the endurance trial is checked the reliability of the vehicle and it's consume. In the test would be checked between 5 and 7 vehicles at the same time. For avoid accidents and impacts the circuit has specific zones to overtake other cars. The test is developed over 22 km and is obligate to switch the pilot at half of the way.

The equation that determines the marks of this trial is:

$$Endurance\ score = 300\ x\ \frac{{}^{Tmax}/_{Tyour} - 1}{{}^{Tmax}/_{Tmin} - 1} +\ 50$$

Equation 4

Tmax is 1.333 times *Tmin*. In case of *Tyour* is greater than *Tmax*, the marks will be zero.

$$Fuel\ economy\ score = 50\ x\ \frac{{}^{Vmax}/_{Vyour} - 1}{{}^{Vmax}/_{Vmin} - 1}$$

Equation 5

Vyour and *Vmin* are the consume of the team and the minimum, respectively. *Vmax* is 5.72 litres. The teams which consume more than *Vmax* or 1.333 times *Vmin*, will have zero marks.

3. Frame Design

3.1- Frame design criteria

A frame of a car can be defined like a structure that has the finality to connect in a rigid way the front suspension with the rear one and at the same time brings anchorage points for the different parts of the vehicle. Its finality is also protecting the driver in case of impacts or rollovers.

The design of a frame is a commitment between rigidity, weight and volume, without forgetting the final economic cost. Have to be considered the static resistance and the fatigue, the loads limits on the unions, the building and the assembly. In this project only takes into account the static stresses and the impacts, leaving for a higher level of complexity the fatigue calculations.

Rigidity criteria.

We must differentiate between bending stiffness and torsional stiffness. The first refers to the deformation of the frame under the weight of the different elements. Not a problem while designing the chassis. The second refers to the frame deformation when is under an asymmetric load, such as when one wheel goes through a hole.

An effective strategy to achieve a higher stiffness is to triangulate. Through what is called bracers is possible to achieve that a great part of the bending moment that has to be absorbed by the knots of the frame, become supported by the bar like a axial load. Several studies show that the deformation due to axial forces is much smaller than due to bending moments and torsion. That is why it is better to load the bars with axial efforts than with bending moments or torsion moments. Regard with the axial effort type, is better the compression efforts than the traction efforts to avoid buckling problems.

In the frame design, regarding to stiffness, there are some aspects to take in count

- Items that are not part of the structure that give stiffness to the frame.
- The anchor points that support large loads must be triangulated, like the suspension attachments.
- Although is interesting to the frame to allow deformation due to a impact, the part that protects the legs has to be totally rigid.

Mass distribution criteria.

- Is interesting to maintain the rigidity of the frame, trying to get the overall weight of the frame lower as possible to take advantage of the engine power.
- Regard to the suspension studies, is convenient to keep the center of gravity as low as possible.

Space criteria

- Leave space for the engine and its components (exhaust, air intake…) and the transmission (chain and differential).
- The frame needs to allow the entry on the cockpit of a 95th percentile male with a helmet.
- The size of the pedals, the angle and length of the legs and feet determine the length of the pilot's compartment (cockpit).
- In the formula student competition is very important evacuate capacity of the pilot from the car, has to be lower than 5 seconds).

Cost criteria

- The selection of the bars has not to be very varied in terms of diameter and thickness
- Will be bending the low number of bars and trying to bend only bars of one determinate diameter.
- Minimum number of joints.

3.2- Description of the overall design process.

The concept is to design a tubular frame and a cover for it, following all the design rules described on the 2011 FORMULA SAE RULES. This document talks about all the rules to follow at the time of making the design of the frame with the aim of guarantee a minimums of safety to the driver.

The process of the design will start with a line sketch of the future structure of pipes. After that the pipes will be created, and a list of all the cuttings of the structural pipes. As said before, the design will follow all the SAE RULES, for the type of structure, protections for the driver, minimum sizes of cockpit, size of pipes depending on the part of the frame they are, etc…

These rules, named the Percy rule, and the templates rules, will be described later, demonstrating that our frame design accomplish with all. Basically the rules are about the relation between the driver and the size of the frame and the cockpit, and will assure that the driver will be safe in case of impact or roll over.

3.3- General structural requirements

Basically the frame of the vehicle has to include two antiroll over arcs reinforced by bracers, a frontal panel that at the same time has to be useful to support the front bulkhead and lateral impact structure.

The vehicle must be open-wheeled and open cockpit (formula style body) with four wheels, not on a straight line. There must be no openings through the bodywork into the driver compartment from the front of the vehicle back to the roll bar main hoop or firewall other than required from the cockpit opening. Minimal opening around the front suspension components are allowed. The wheelbase must be at least 1525 mm. The smaller track of the vehicle must be no less than 75% of the larger track. All items on the inspection from must be clearly visible to the technical inspectors.

3.3-1. Materials Requirements

There are some options for choosing the material that will take part of the frame, as steel, mild or alloy (minimum 0,1% carbon). There are special rules for using aluminium, and monocoque chassis. We are going to use steel round pipe. There are some properties that we have to follow to choose our steel, and may not be lower than the following:

- Young's Modulus (E) = 200 Gpa
- Yield Strength (Sy) = 305 Mpa
- Ultimate Strength (Su) = 365 Mpa

One important point to take on count will be the rule that indicates where welded tubing reinforcements are required (inserts for bolt holes or material to support suspension cut-outs). The tubing must retain the baseline cold role strength while using the welded strength for the additional reinforcement material.

3.3-2. Pipe sizing

Our frame will be formed by round pipes. Then we are going to follow only the round piping structure rules, ignoring the rules for monocoque chassis. About the size and the thickness of the pipes that take part of the frame, the next table is extracted from the SAE rules and describes all the minimum sizing of the pipes.

ITEM or APPLICATION	OUTSIDE *DIMENSION* X WALL THICKNESS
Main & Front Hoops, Shoulder Harness Mounting Bar	Round 1.0 inch (25.4 mm) x 0.095 inch (2.4 mm) or Round 25.0 mm x 2.50 mm metric
Side Impact Structure, Front Bulkhead, Roll Hoop Bracing, Driver's Restraint Harness Attachment (except as noted above)	Round 1.0 inch (25.4 mm) x 0.065 inch (1.65 mm) or Round 25.0 mm x 1.75 mm metric or Round 25.4 mm x 1.60 mm metric or Square 1.00 inch x 1.00 inch x 0.049 inch or Square 25.0 mm x 25.0 mm x 1.25 mm metric or Square 26.0 mm x 26.0 mm x 1.2 mm metric
Front Bulkhead Support, Main Hoop Bracing Supports	Round 1.0 inch (25.4 mm) x 0.049 inch (1.25 mm) or Round 25.0 mm x 1.5 mm metric or Round 26.0 mm x 1.2 mm metric

Table 3. Minimum pipe sizing

3.3-3. Rules to follow

For designing the cockpit, there are rules to follow as the TEMPLATES RULE and the PERCY RULE, which talks about the volume of a regular driver will have while driving. These rules will be checked with some volume balls that simulate a driver, and some templates that have to fit in the frame. These rules will be described and proved in the next points of this chapter.

Side impact members

There are other rules that we have to follow to have a correct design. One of them talks about the position of the side impact members (Figure 1), that will take the driver safe in case of side impact. This rule talks about the position of the side impact pipe, from the floor.

This rule says that the side impact structure for frame cars must be compromised of at least three tubular members locates on each side of the driver while seated in normal driving position.

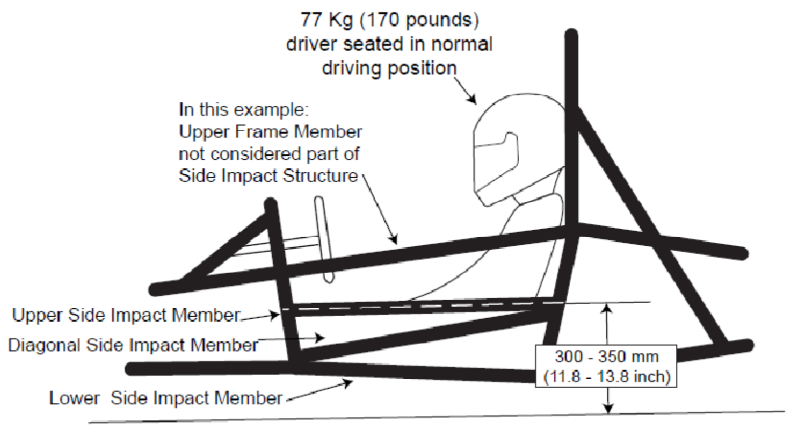


Figure 1. Side impact member position

Hoop Bracers

Other important rule to follow is one that talks about the main Hoop braces. This rules says that the main hoop braces must be attached as near as possible to the top of the Main Hoop but no more than 160 mm below the top-most surface of the Main Hoop. The angled formed must be at least thirty degrees.

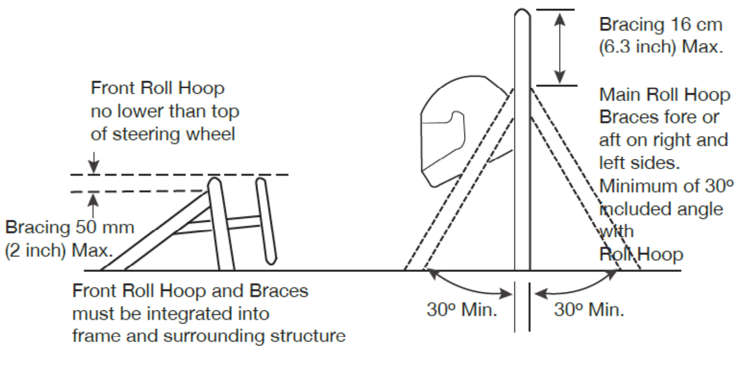


Figure 2. Required bracing position

Driver's position

Regards to the position of the driver in the cockpit, and the minimum distance between his helmet and the protecting structures, there are a important rule, named the HELMET CLEARANCE RULE. This rule will assure that the driver head and hands, will not contact the ground in any rollover attitude. The frame will include both a Main Hoop and a Front Hoop. The helmet of the driver (based in a 95th percentile male) must:

- Be a minimum of 50.8 mm from the straight line drawn from the top of the main hoop to the top of the front hoop.
- Be a minimum of 50.8 mm. from the straight line drawn from the top of the main hoop to the lower end of the main hoop bracing.
- Be no further rewards than the rear surface of the main hoop if the main hoop bracing extends forwards.

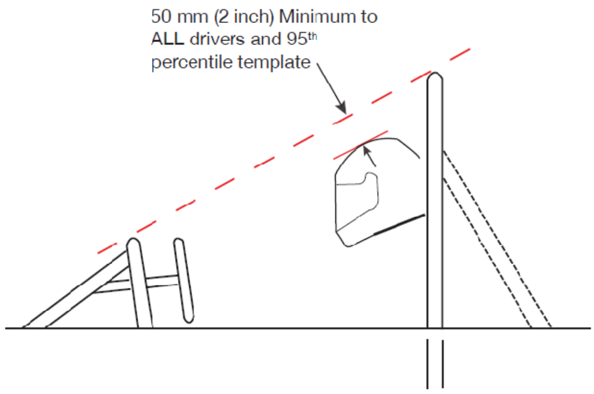


Figure 3. Driver's head safe position 1

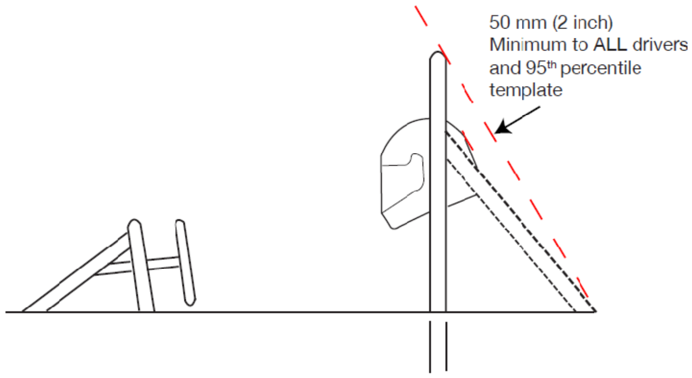


Figure 4. Driver's head safe position 2

Belt and shoulder harness

Another important rule talks about the position of the belt and the shoulder harness. Regards to the lap belt, it must pass around the pelvic area below the anterior superior Iliac Spines (the hip bones). Within upright driving position in side view, the lap belt must be at an angle of between forty-five degrees and sixty five degrees to the horizontal. The centre line of the lap belt at the seat bottom should be between 0-76 mm forward of the seat bottom junction.

Regards to the shoulder harness, must be mounted behind the driver to structure. It cannot be mounted to the Main Roll Hoop Bracing or attendant structure without additional bracing to prevent loads being transferred into the main roll Hoop Bracing. The shoulder harness mounting points must be between 178 mm and 229 mm apart.

3.4- Alternative solutions

There is more than one solution to give a structure to the frame that we are designing. The competition regulations it is not very restrictive and permits to the designer freedom to design.

3.4-1. Principal structure

There are three different choices basically. The first is to make a roll bar type structure with steel tubes. This is the choice chosen, and then we are going to explain it later. The second is to make the same kind of roll bar structure but with aluminium pipes and the third will be the composites utilization for making a mono hull.

Aluminium roll bar choice

It will be a excellent choose for making the vehicle frame: the low density of the aluminium regarding the Iron's make this choice very attractive. But if we analyse and take count with some factors like the welding cost and difficulty, the cost of the thermal treatments that we have to do in the frame if we make it on aluminium, and the cost of the raw material (aluminium is more expensive than iron), make us to deny this option.

Carbon fibber hull choice

This choice is so practical, because if we make the hull on carbon fibber, it makes the function of frame and body, has a totally flexible design, allows more space to put the different elements of the vehicle, and the weight is reduced. But there are some aspects that make us to deny this option. One is the elevated cost of the material, and the other is the elevated cost of the building process. We need to build a mould in a special material called LAB900 and put the carbon fibber on determinate conditions of temperature and pressure. There are few workshops that offer this process and its cost it's so elevated.

3.4-2. Rear structure

The regulation gives us total freedom at the time of designing the rear structure. There are two main options to make it, tubular structure of pipes or box type structure. We have chosen the first one that basically consists on continue the main structure to the rear part of the vehicle getting a pipes framework. This is a economic choice and this will be the quicker way to make it.

Other options will be to make a sand mould and cast the rear part like a metal box, giving us freedom to the shape and a reduced weight, but we deny this option because its cost is elevated. Other option will be to make a frame of mild aluminium, but the cost its again making us to deny this option.

3.4-3. Impact attenuator

The aim at the time of designing the impact attenuator it's clear: maximize the energy absorption having the lower weight possible. There are not a lot of materials that accomplish with these characteristics, for that we don't have a high range of choices. One economic valid option it's to build it with empty conserve cans grouped by plans and glued with resins, but we have reject this option because the calculus of the energy absorption becomes imprecise.

Finally we have chosen a material that the mechanical properties and its behaviour are well know, honeycomb shape aluminium panel.

4. Chosen solution: detailed description

In this section it will be explained in a general way, the characteristics of the chosen solution.

4.1- Overall frame sizing

The next figure (fig.1) shows the overall dimensions of the designed frame in millimetres.

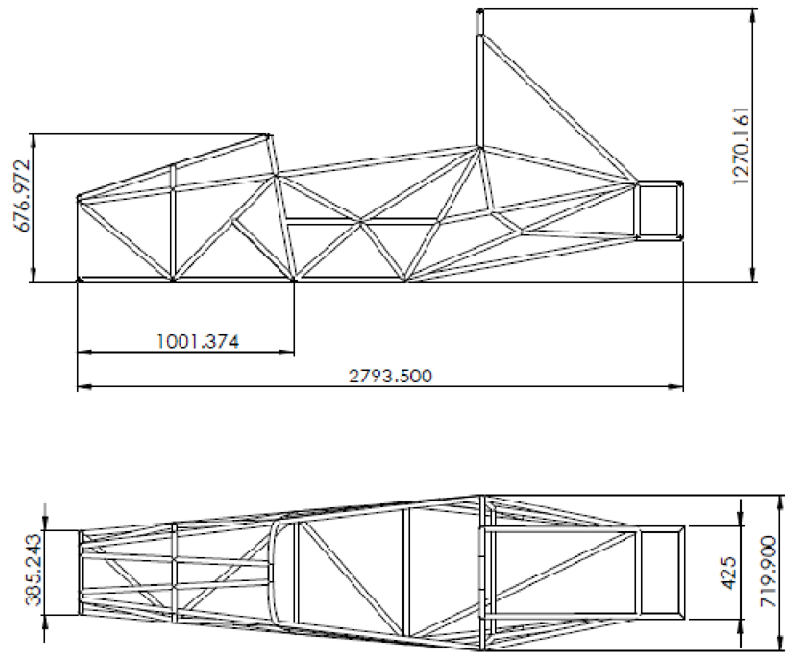


Figure 5. Overall frame dimensions (mm.)

Specifications	
Structure	Round pipe tubular frame
Material	AISI634 pipes 25x2.5, 25x 1.75 and 25x1.5
Joint method	MIG welding
Chassis weight	44.3 kg
Impact zone materials	Hexagonal honey comb structure
Impact zone length	187 mm.
Dissipated energy by impact device	8137 J

4.2- Materials Used

There are some options for choosing the material that will take part of the frame, as steel, mild or alloy (minimum 0,1% carbon). There are special rules for using aluminium, and monocoque chassis. We are going to use steel round pipe. There are some properties that we have to follow to choose our steel, and may not be lower than the following:

- Young's Modulus (E) = 200 Gpa
- Yield Strength (Sy) = 305 Mpa
- Ultimate Strength (Su) = 365 Mpa

There are a plenty of types and choices about stainless steel but we have reduced the list to two four to our needing:

- **AISI 301** - highly ductile, for formed products. Also hardens rapidly during mechanical working. Good weldability. Better wear resistance and fatigue strength than 304.
- **AISI 304** - the most common grade; the classic 18/8 stainless steel. Outside of the US it is commonly known as "A2", in accordance with ISO 3506 (not to be confused with A2 tool steel).
- **AISI 634** – Also called S355. This is a not expensive but tough Precipitation-Hardening Nonstandard grade *Stainless Steel*. It is commonly called AISI Type 634 Chromium steel. It is used to structure building.
- **AISI 4130** - Widely used in oil patch applications. It is extensively used in tubular form for downhole tools. AISI 4130 has improved weldability but not that good hardenability in comparison to 4140. The depth to which the alloy will harden must always be taken into account when using this alloy. The alloy is hardened and tempered.

The properties and the composition of these materials are on the next table:

PROPERTIES	AISI301	AISI304	AISI634	AISI4130	UNITS
Density	8	8	7.7	7.85	g/cc
Poisson's Ratio	0.27-0.30	0.29	0.29	0.29	N/A
Elastic Modulus	193	193-200	200	205	Gpa
Tensile Strength	515	505	1520	670	Mpa
Yield Strength	205	215	1286	435	Mpa
Elongation at break	40	50	8	25.5	%
Hardness	78	70	-	92	HRB

ELEMENT	AISI301	AISI304	AISI634	AISI4130
C	0.15	0.08	0.10 – 0.15	0.28 – 0.33
Mn	2.00	2.00	0.5 – 1.25	0.40 – 0.60
Si	1.00	1.00	0.5	0.15 – 0.30
Cr	16.0 – 18.0	18.0 – 20.0	15.0 – 16.0	0.80 – 1.10
Ni	6.0 – 8.0	8.0 – 10.5	4.0 – 5.0	-
P	0.045	0.045	0.04	0.035
S	0.03	0.03	0.03	0.04
Mo	-	-	2.5 – 3.25	0.15 – 0.25

Table 4. Properties and composition of alloy steels

The material chosen will be **AISI 634** due to its good weldability, is not a very expensive material and have a very good commercial availability. The AISI 634 Stainless steel, accomplish with all the SAE regulation demanded parameters.

One important point to take on count will be the rule that indicates where welded tubing reinforcements are required (inserts for bolt holes or material to support suspension cut-outs). The tubing must retain the baseline cold role strength while using the welded strength for the additional reinforcement material.

4.3- Cut list

The next table is automatically created by SOLID WORKS software and list all the sizes and diameter that we need to build the frame. It will be very useful for the building of the car and will be used for the workshop personal to cut all the pipes that take part of the frame.

TEM NO.	QTY.	DESCRIPTION	LENGTH
1	2	PIPE 25 X 3.2	0.66
2	2	PIPE 25 X 3.2	0.51
3	2	PIPE 25 X 3.2	1.09
4	2	PIPE 25 X 3.2	0.18
5	1	PIPE 25 X 3.2	0.15
6	1	PIPE 25 X 3.2	0.5
7	1	PIPE 25 X 3.2	0.08
8	1	PIPE 25 X 3.2	0.5
9	1	PIPE 25 X 3.2	0.49
10	1	PIPE 25 X 3.2	0.49
11	1	PIPE 25 X 3.2	0.77
12	1	PIPE 25 X 3.2	0.38
13	1	PIPE 25 X 3.2	0.39
14	1	PIPE 25 X 3.2	0.38
15	1	PIPE 25 X 3.2	0.06
16	1	PIPE 25 X 3.2	0.17
17	1	PIPE 25 X 3.2	0.05
18	1	PIPE 25 X 3.2	0.43
19	1	PIPE 25 X 3.2	0.43
20	1	PIPE 25 X 3.2	0.17
21	1	PIPE 25 X 3.2	0.13
22	1	PIPE 25 X 3.2	0.17
23	1	PIPE 25 X 3.2	0.44
24	1	PIPE 25 X 3.2	0.92
25	1	PIPE 25 X 3.2	0.92
26	2	PIPE 25 X 3.2	0.42
27	1	PIPE 25 X 3.2	0.44
28	2	PIPE 25 X 3.2	0.43
29	1	PIPE 25 X 3.2	0.44
30	1	PIPE 25 X 3.2	0.57
31	1	PIPE 25 X 3.2	0.4
32	1	PIPE 25 X 3.2	0.63
33	1	PIPE 25 X 3.2	0.63
34	1	PIPE 25 X 3.2	0.57
35	1	PIPE 25 X 3.2	0.34
36	1	PIPE 25 X 3.2	0.59
37	1	PIPE 25 X 3.2	0.4
38	1	PIPE 25 X 3.2	0.74
39	1	PIPE 25 X 3.2	0.54
40	2	PIPE 25 X 3.2	0.54
41	1	PIPE 25 X 3.2	0.71
43	1	PIPE 25 X 3.2	0.72
44	1	PIPE 25 X 3.2	0.41
44	1	PIPE 25 X 3.2	0.34
46	1	PIPE 25 X 3.2	0.95
47	1	PIPE 25 X 3.2	0.95
48	1	PIPE 25 X 3.2	0.45
49	1	PIPE 25 X 3.2	0.45
49	1	PIPE 25 X 3.2	0.65
51	1	PIPE 25 X 3.2	0.65
52	2	PIPE 25 X 3.2	0.21
53	2	PIPE 25 X 3.2	0.43
54	1	PIPE 25 X 3.2	0.21
55	1	PIPE 25 X 3.2	0.21
56	1	PIPE 25 X 3.2	0.4
57	1	PIPE 25 X 3.2	0.4
58	1	PIPE 25 X 3.2	0.25
59	1	PIPE 25 X 3.2	0.25
60	1	PIPE 25 X 3.2	1.15
61	1	PIPE 25 X 3.2	0.93
62	1	PIPE 25 X 3.2	0.33
62	1	PIPE 25 X 3.2	0.62
64	1	PIPE 25 X 3.2	0.69
65	1	PIPE 25 X 3.2	1.15
66	1	PIPE 25 X 3.2	0.94
66	1	PIPE 25 X 3.2	0.72
67	1	PIPE 25 X 3.2	0.41
68	1	PIPE 25 X 3.2	0.69
69	1	PIPE 25 X 3.2	0.54
70	2	PIPE 25 X 3.2	0.17
71	1	PIPE 25 X 3.2	0.54
72	2	PIPE 25 X 3.2	1
73	1	PIPE 25 X 3.2	0.25
74	1	PIPE 25 X 3.2	0.25
75	1	PIPE 25 X 3.2	1.19
76	1	PIPE 25 X 3.2	0.5
77	1	PIPE 25 X 3.2	0.75
78	1	PIPE 25 X 3.2	0.74
79	1	PIPE 25 X 3.2	0.71
80	1	PIPE 25 X 3.2	0.5

Table 5. Pipes cut list

There is also a balloons drawing, that describes the position of all the pipes listed on the cut list, to make building and welding easier. The appendix part of this project will include a bigger and clear drawing of the Balloon scheme for welding parts, and the table of cuts.

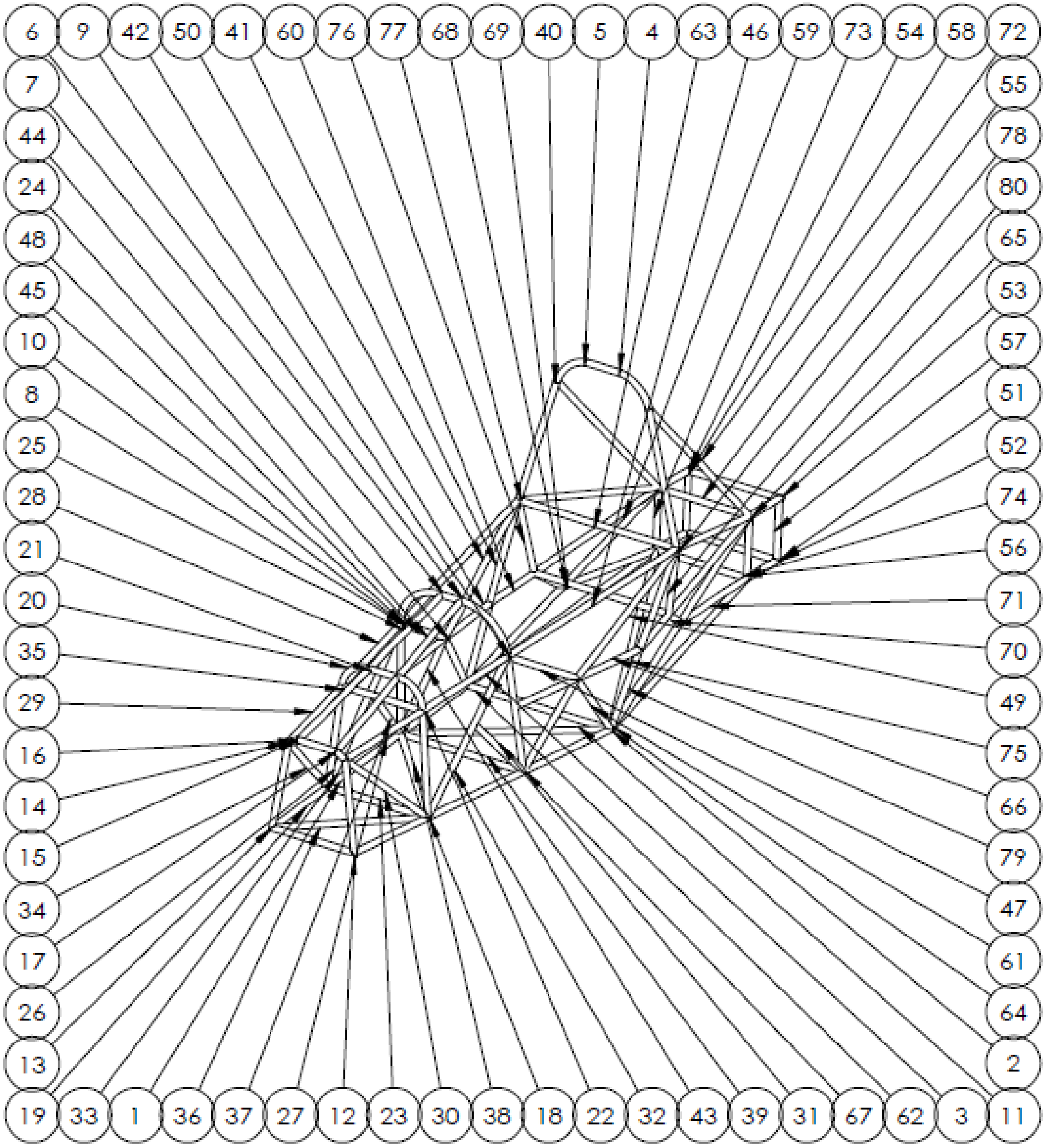


Figure 6. Balloon scheme of cut list

4.4- Demonstrate compliance with the Percy rule

There is a very important rule that regards of the size of the driver and his relation with the sizes of the cockpit, trying to help to resize the cockpit and assuring safety for the driver. The rule is based in a template that reflexes the average size of the driver who will drive the formula student. That template is based in the next dimensions:

95th Percentile Male Template Dimensions

A two dimensional template used to represent the 95th percentile male is made to the following dimensions:

- A circle of diameter 200 mm (7.87 inch) will represent the hips and buttocks.
- A circle of diameter 200 mm (7.87 inch) will represent the shoulder/cervical region.
- A circle of diameter 300 mm (11.81 inch) will represent the head (with helmet).
- A straight line measuring 490 mm (19.29 inch) will connect the centers of the two 200 mm circles.
- A straight line measuring 280 mm (11.02 inch) will connect the centers of the upper 200 mm circle and the 300 mm head circle.

Table 6. 95% Male template dimensions

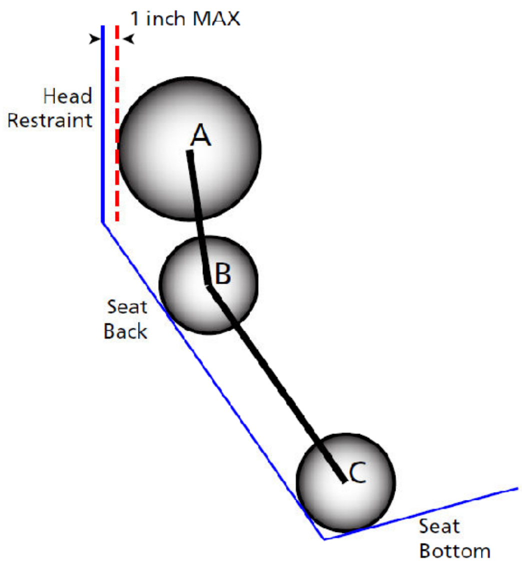


Figure 7. Male template scheme

This template has to be positioned as follows. The seat will be adjusted to the rearmost position. The bottom 200 mm. circle will be placed at the junction of the seat back and the seat bottom, tangential to both. The middle 200 mm circle will be positioned no more than 25.4 mm away from the head restraint.

This is the drawing that demonstrates that the Percy template fits in our designed frame, and there is a minimum of 50.8 mm from the straight line drawn from the top of the main hoop to the top of the front hoop. And also demonstrate that there be a minimum of 50.8 mm. from the straight line drawn from the top of the main hoop to the lower end of the main hoop bracing.

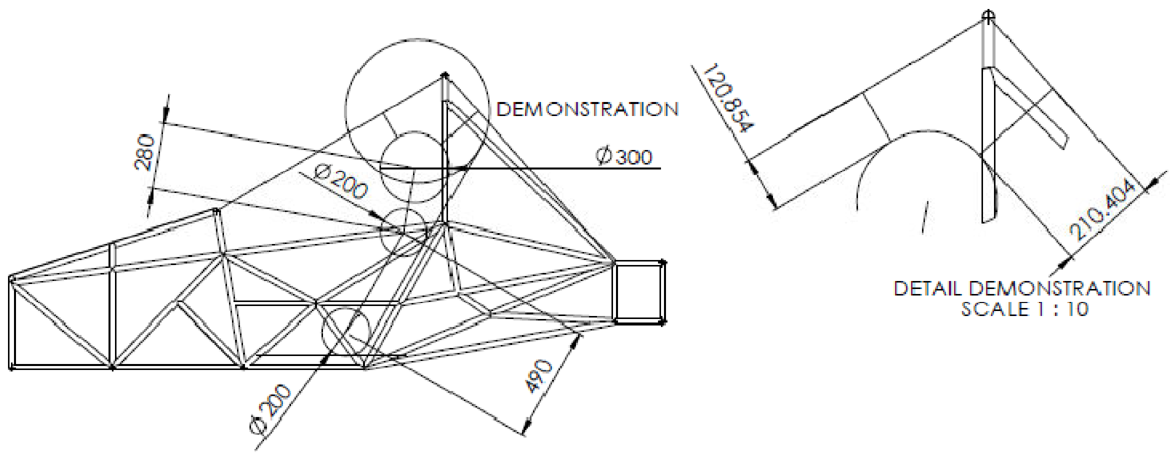


Figure 8.Demonstrate compliance with Percy rules

4.5- Demonstrate compliance with cockpit rule

To assure the correct sizing of the cockpit, there is a rule that gives the minimum sizing of the cockpit, In order to ensure that the opening giving access to the cockpit is of adequate size. The template that follows this text 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. No fore and aft translation of the template will be permitted during insertion.

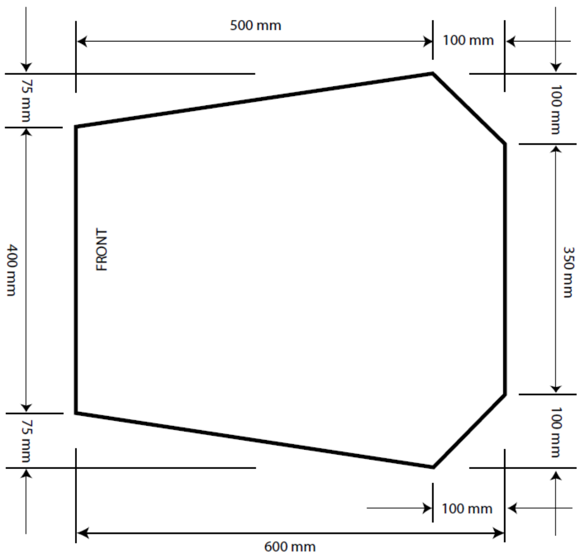


Figure 9. Cockpit template sizes

And the next figure shows how our frame accomplishes this rule, allowing enough space for the template.

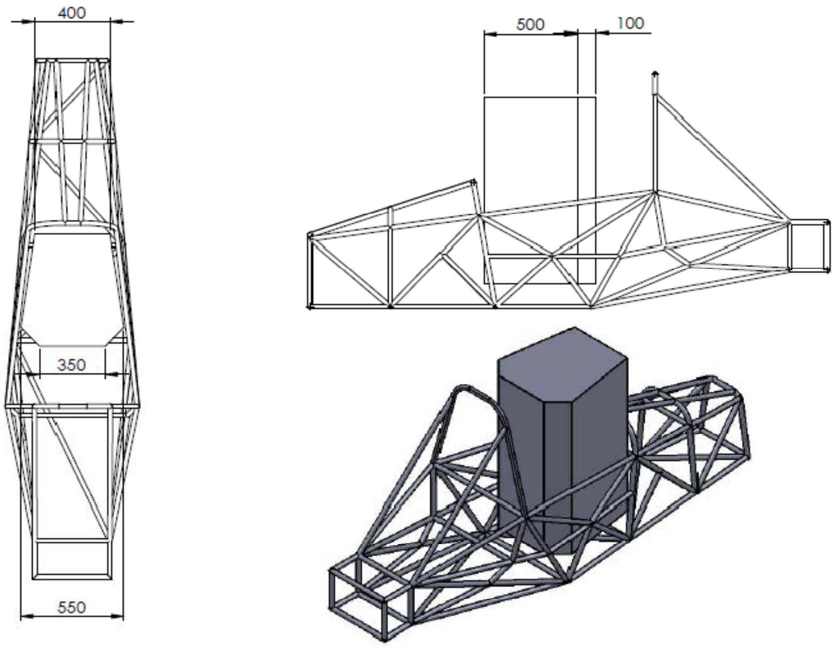


Figure 10. Demonstrate compliance with cockpit template rule

The next template has to pass horizontally through the cockpit to a point 100 mm rearwards of the face of the rearmost pedal when in the inoperative position, must be maintained over its entire length. If the pedals are adjustable, they will be put in their most forward position.

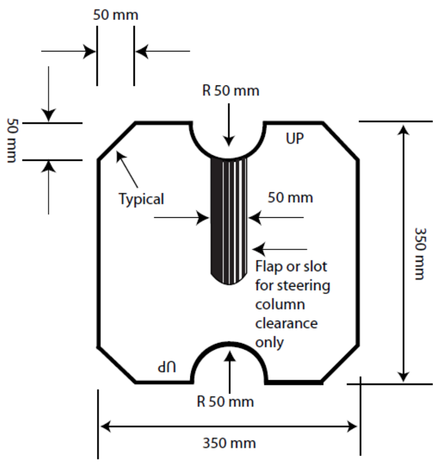


Figure 11. Legs template sizes

The template with maximum thickness of 7 mm, will be held vertically and inserted into the cockpit opening rearward of the FRONT ROLL HOOP, as close to the FRONT ROLL HOOP as the car's design will allow. This rule has to finality to assure enough space for the driver's leg, and allows enough distance between the driver legs and the frame, to avoid contact in case of impact.

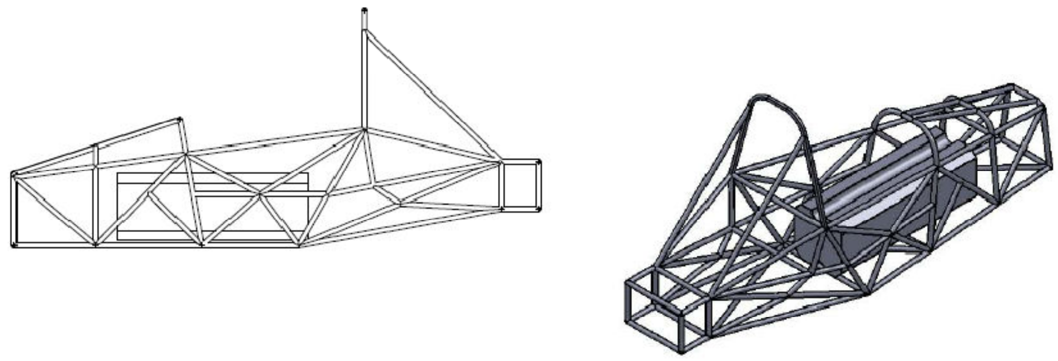


Figure 12. Demonstrate compliance with legs template rule

The way of design of the frame has started trying to accomplish with all the design rules. These rules are so important because they will mean the safety factor for the driver in case of impact. In the next chapter we are going to demonstrate that our frame accomplishes all the FEA analysis that simulate deformation and stresses in case of impact and in the normal working order of the car.

5. FEA analyses of frame

5.1- Torsion rigidity of frame

One of the most important FEA analyses of the frame will be the Torsion Rigidity analysis. That is because with this analysis, we are going to check the rigidity of the frame in all the cases that the car is running, breaking, turning and dumping. All this dynamic actions will provoke serious torsion stresses on the frame. For that, making a correct analysis of the deformation and torsion stresses on the frame is very important.

5.1-1. Method of loading for torsion rigidity

To do the FEA analysis of Torsion Rigidity, we have to create a structure that will simulate the wishbones of the suspension, just in the line where the front axe will be. This structure will be finish on the point where the front wheels will be. That's because we want to simulate the efforts that the road make on the wheels. This effort will be traduced on torsion efforts on the frame. In one of that point we will apply a load of **169.7 N**, normal to the bottom plane of the car. In the other point we are going to apply the same load, with the same direction, but in the opposite way, creating the torsion effort.

The frame will be fixed selecting the eight joints at the rear of the frame where the suspension would mount. The maximum allowable deflection will be of 25 mm, and failure must not occur anywhere in structure.

5.1-2. Results report and conclusions

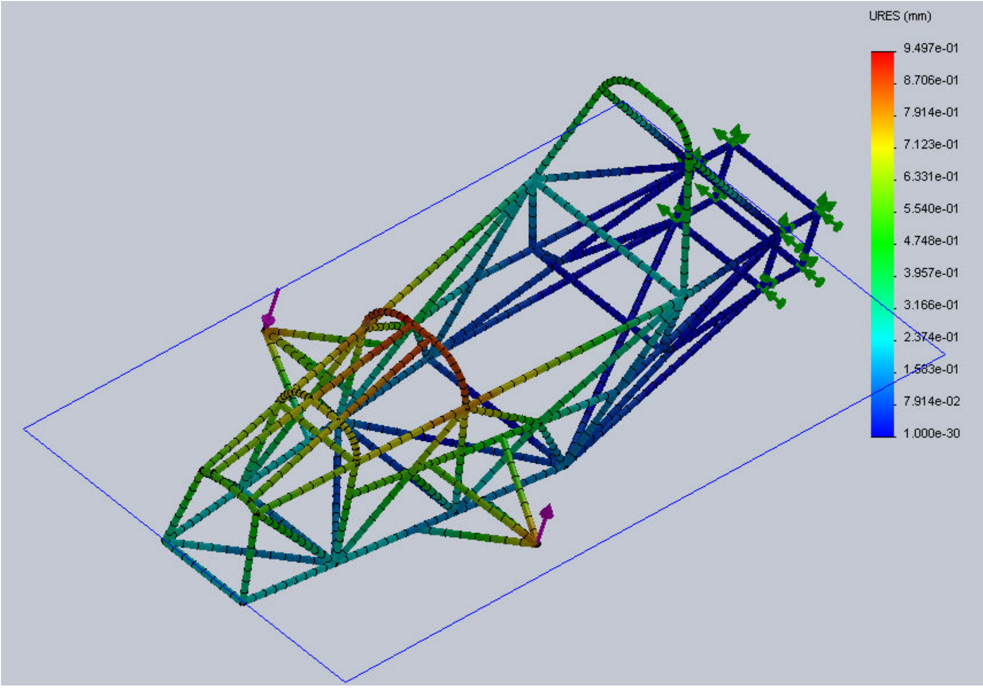


Figure 13. Deformation torsion displacement (mm.)

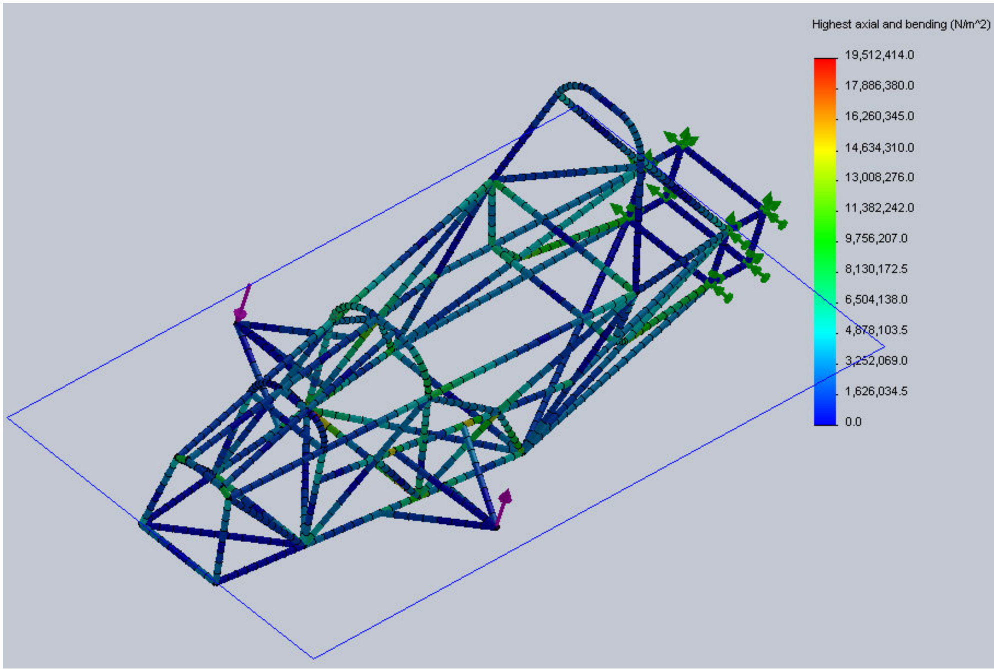


Figure 14. Torsion stress (N/m^2)

As we can see on the displacement plot, the maximum displacement in any components of the frame, under a torsion effort will be about 1 millimetre. That is totally acceptable. As we see on the stress plot, the maximum stress will be totally under the material resistance. That is possible by a correct design of the central part of the frame. One of the important factors is that the car is not very heavy at all, minimizing the efforts. Other factor is that the suspension will absorb the great part of the impacts produced by bumps on the road. That provokes that the load that we use to make the test is reduced.

5.2- FEA on main roll hoop

5.2-1. Method of loading on main roll hoop

To do the FEA analysis of the main roll hoop, we are going to applicate the following loads:

Load Applied: Fx = 6.0 kN, Fy = 5.0 kN, Fz = -9.0 kN

The point of application of these loads will be the Top of Main Roll Hoop. The frame will be fixed displacement but not rotation of the bottom nodes of both sides of the front and main roll hoops.

The maximum allowable deflection will be of 25 mm, and failure must not occur anywhere in structure.

5.2-2. Results report and conclusions

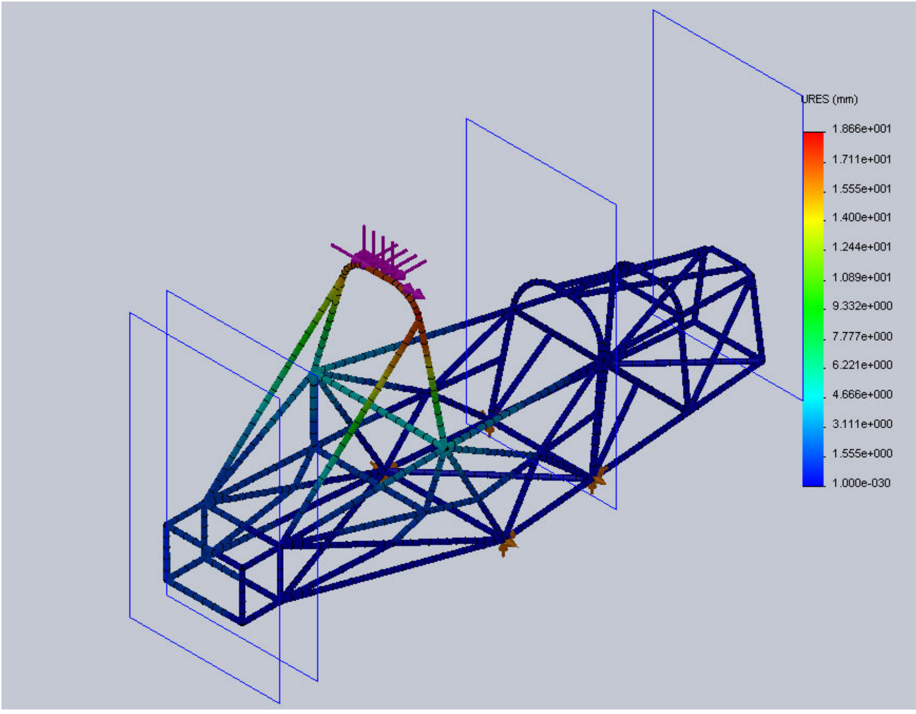


Figure 15. Main roll displacement (mm.)

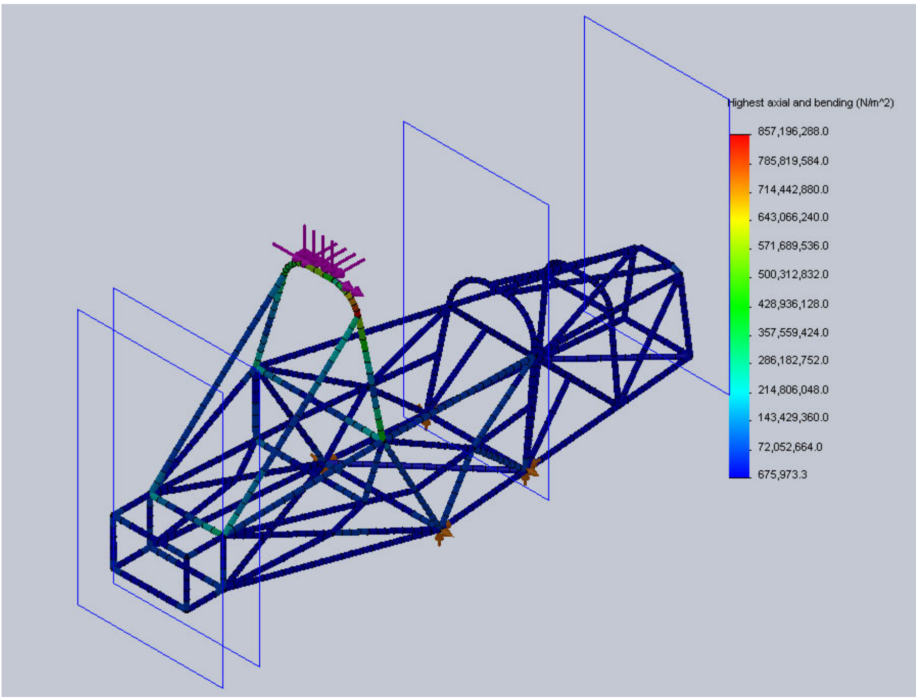


Figure 16. Main roll stress (N/m^2)

As we can see on the first picture above, the maximum displacement on the main roll hoop, after the application of the forces described, and fixing the frame correctly is 18 mm. Then we accomplish the 25 mm maximum displacement rule. As we show in the second picture that follows, failing it's not occurring in any part of the frame. That has been got thanks to a correct designing of the shape of the main roll hoop, and through the help of the bracing, that has been studied the position and the points of anchorage with the main frame.

5.3- FEA on front roll hoop

5.3-1. Method of loading front roll hoop

To do the FEA analysis of the front roll hoop, we are going to apply the following loads:

Load Applied: Fx = 6.0 kN, Fy = 5.0 kN, Fz = -9.0 kN

The point of application of these loads will be the Top of Front Roll Hoop. The frame will be fixed displacement but not rotation of the bottom nodes of both sides of the front and main roll hoops. The maximum allowable deflection will be of 25 mm, and failure must not occur anywhere in structure.

5.3-2. Results report and conclusions

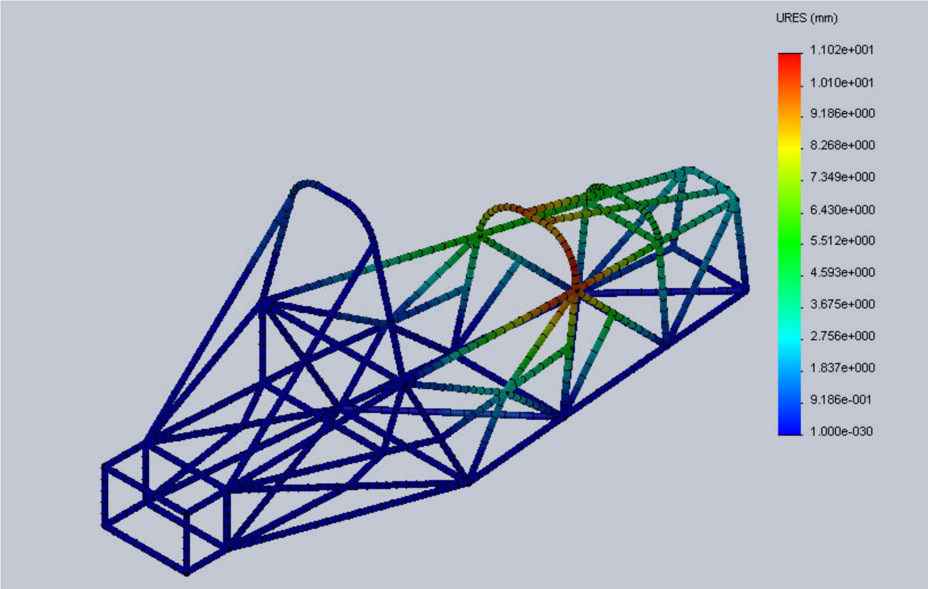


Figure 17. Front roll displacement (mm.)

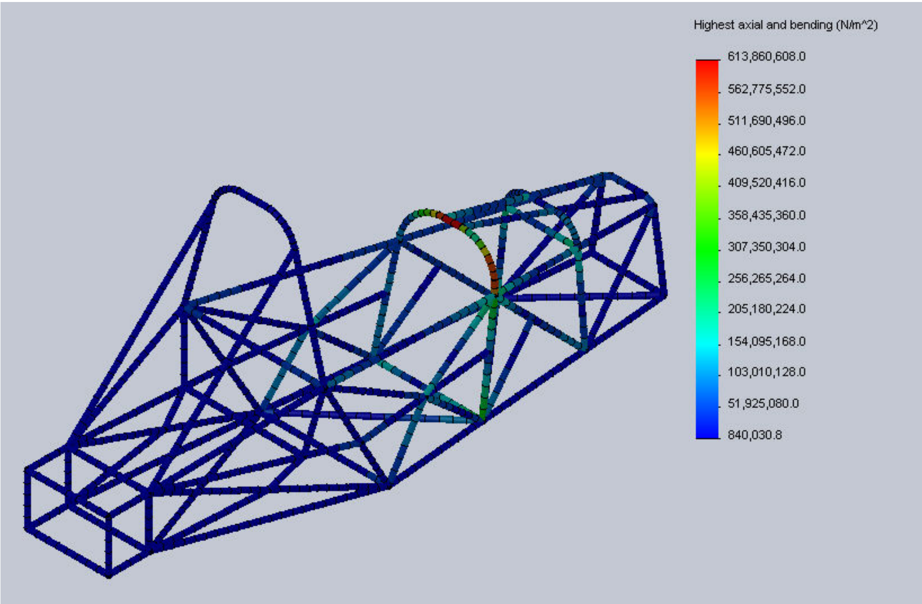


Figure 18. Front roll stress (N/m^2)

As we can see on the first picture above, the maximum displacement on the front roll hoop, after the application of the forces described, and fixing the frame correctly is 11 mm. Then we accomplish the 25 mm maximum displacement rule. As we show in the second picture that follows, failing it's not occurring in any part of the frame.

We have less than a half of the maximum displacement allowed. This indicates that we can use lighter pipes for this part of the structure, reducing the overall mass of the frame. We don't make this change because we are using the minimum size of pipes allowed by the SAE rules. This low result of the displacement shows that the front roll hoop is correctly designed. It will be because it has two bracings between the front roll hoop and the front bulkhead, giving a lot of rigidity to the whole front part of the car.

5.4- FEA on the front bulkhead

5.4-1. Method of loading front bulkhead

To do the FEA analysis of the front Bulkhead, we are going to apply the following loads:

Load Applied: Fx = -150 kN, Fy = 0 kN, Fz = 0 kN

The point of application of these loads will be the actual attachment points between the impact attenuator and the front bulkhead. The frame will be fixed displacement but not rotation of the bottom nodes of both sides of the main roll hoop and both locations where the main hoop and shoulder harness tube connect. The maximum allowable deflection will be of 25 mm, and failure must not occur anywhere in structure.

5.4-2. Results report and conclusions

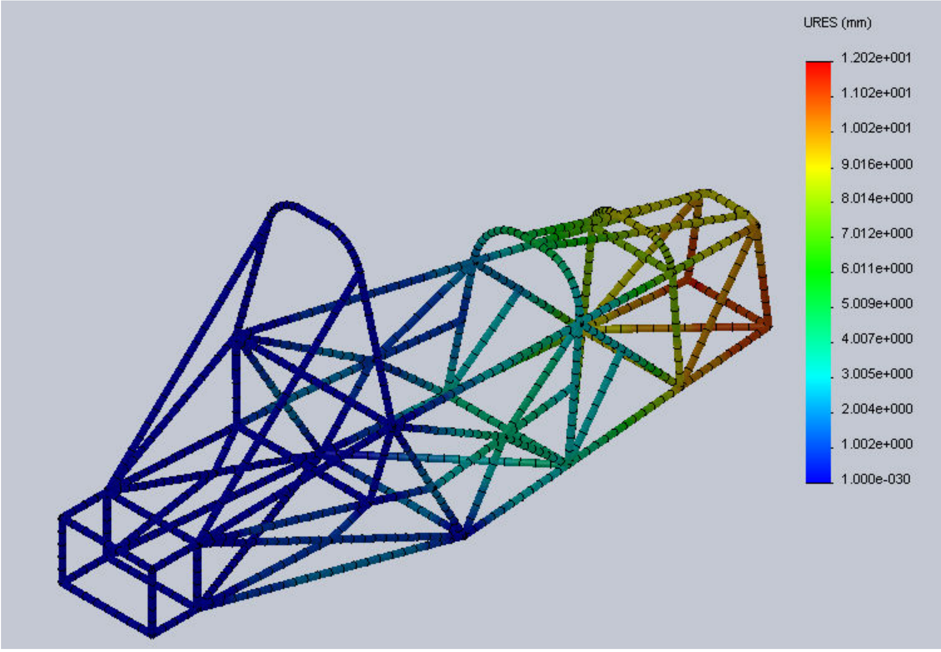


Figure 19. Front bulkhead displacement (mm.)

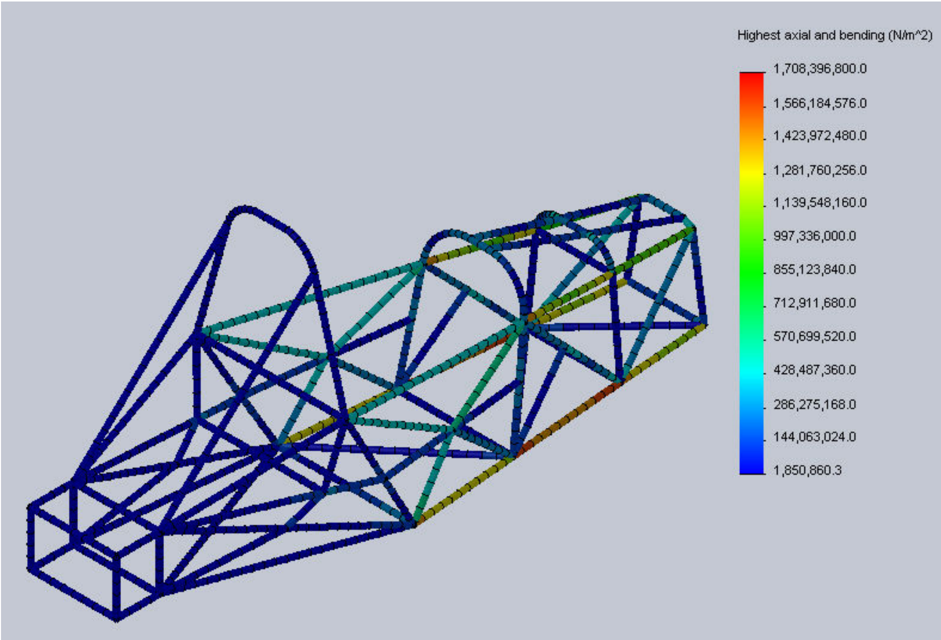


Figure 20. Front bulkhead stress (N/m^2)

The force applied on the front bulkhead, on the direction of the z axis is pretty big, because is simulating a front impact. Then we need a very thought structure for resist this kind of impact. As we can see, the result of the test is that the maximum displacement under these conditions is 12 mm, which is totally inside of the limits of the rule (25 mm of maximum displacement). This result will be done because the triangulations of the bracers of the frame are in correct position, giving a high rigidity to the frame.

5.5- Overall conclusions from FEA and recommended design improvements

The conclusion that we can get of this FEA analysis is that the frame piping is correctly dimensioned for the weight of the car. That will be because the pipe size that de SAE rules suggest is optimum. Other factor is that the triangulation of the beams of the car is so well done. If we were in the need of making a frame for a heavier car, maybe it will be better to improve the material and think about making the frame of a lighter material like aluminium. In that case the pipes will be wider, but reducing the weight of the car. Anyway if we would make a real frame, we would run real tests with the finished model, because in the FEA analysis the welding is idealized. Maybe in a real frame we will have problems with the welding, and its quality would be an important factor to consider.

5.6- Impact attenuator

The regulations of the competition oblige us to give a front impact attenuator able to support a 7 m/s impact against a rigid barrier, without exceed a average des acceleration of 20G.

To design the impact attenuator is chosen like base material a honeycomb shape aluminium panel. That it is chosen due to its lightness and it lineally deformation. Its base characteristics are:

$$Y=1{,}711\text{MPa}; \quad \rho = 82{,}6 kg/m^3$$

5.6-1. Impact attenuator calculus

Due to know the needed length from the bloc to deform giving a deceleration lower than 20G, it's done an equivalency between the Kinetic Energy that the car have before the impact, and the energy absorbed by the impact attenuator. Then:

$$E_{cin} = E_{abs}$$
$$\frac{1}{2} m \cdot v^2 = F \cdot d$$

Equation 6

Where d is the deformation length. Knowing that F=m*a, we can substitute and found and expression for d:

$$d = \frac{1}{2}\frac{v^2}{a} = \frac{1}{2}\frac{7^2}{20 \cdot 9{,}81} = 0{,}1249m$$

Equation 7

At the same time it's needed to know the bloc surface needed to absorb all that energy. Knowing that $E_{abs} = S*Y*d$, where S is the section and Y is the material resistance, we make an equivalency again between energies:

$$E_{cin} = E_{abs}$$
$$\frac{1}{2} m \cdot v^2 = S \cdot Y \cdot d$$
$$S = \frac{\frac{1}{2} m \cdot v^2}{Y \cdot d} = \frac{\frac{1}{2} 300 \cdot 7^2}{1711000 \cdot 0{,}1249} = 0{,}0344 m^2$$

Equation 8

This is the minimum section to absorb the impact energy.

Through multiple essays its well know that the on the first instant of the impact is produced a peek of acceleration that we can't ignore (that depends directly to the front area shape). Trying to minimize this effect, the shape of the bloc will be done giving a frontal section that increases area on the deformation direction.

Following the regulations, that oblige us to have almost a 100x200mm section 150mm from the rear part of the impact attenuator, the next shape is decided with the 'ho' and 'l' parameters:

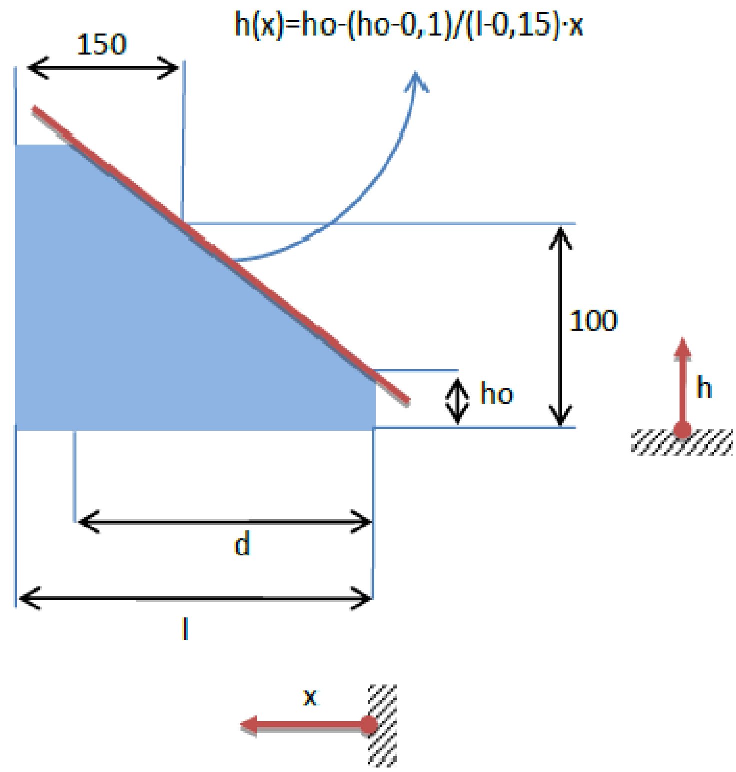


Figure 21. Attenuator shape parameters

On the absorbed energy calculus, is include the front surface (that depends on h) across of x axis.

$$E_{abs} = Y \cdot \int_0^d S(x) \cdot dx = Y \cdot \int_0^d 0{,}3 \cdot h(x) \cdot dx$$

$$E_{abs} = Y \cdot 0{,}3 \cdot \int_0^d \left(ho - \frac{ho - 0{,}1}{l - 0{,}15} \cdot x \right) \cdot dx = Y \cdot 0{,}3 \cdot \left(ho \cdot d - \frac{1}{2} \frac{ho - 0{,}1}{l - 0{,}15} d^2 \right)$$

Equation 9

Parameters are given to 'ho' and 'l' until the absorbed energy value arrives to a maxim (always considering acceptable dimension to the bloc). For values of:

Ho=0,06m

l=0,187m (considering that the aluminium honeycomb collapses at 80% of deformation)

$$\boxed{E_{abs} = 8136{,}478J}$$

It is checked that the dissipated energy is higher than the Kinetic Energy from the vehicle (Kinetic energy = 7350J).

Bloc mass:

$$Volume = \int_0^d S(x) \cdot dx + 0{,}3 \cdot h(d) \cdot (l - d) = 0{,}3 \cdot \left(\int_0^d h(x) \cdot dx + h(d) \cdot (l - d) \right)$$

Equation 10

$$Volume = 0{,}008m^3 \; ; \quad Mass = Volume \cdot \rho = 0{,}008 \cdot 82{,}6 = 0{,}693kg$$

5.6-2. Impact attenuator attachment to the frame

The impact attenuator will be attached to the front bulkhead of the frame to accomplish with its aim, to absorb all the energy of an eventual front impact. The impact attenuator will be fixed by fitted staples, but without using any kind of welding, just to reduce the process time and cost.

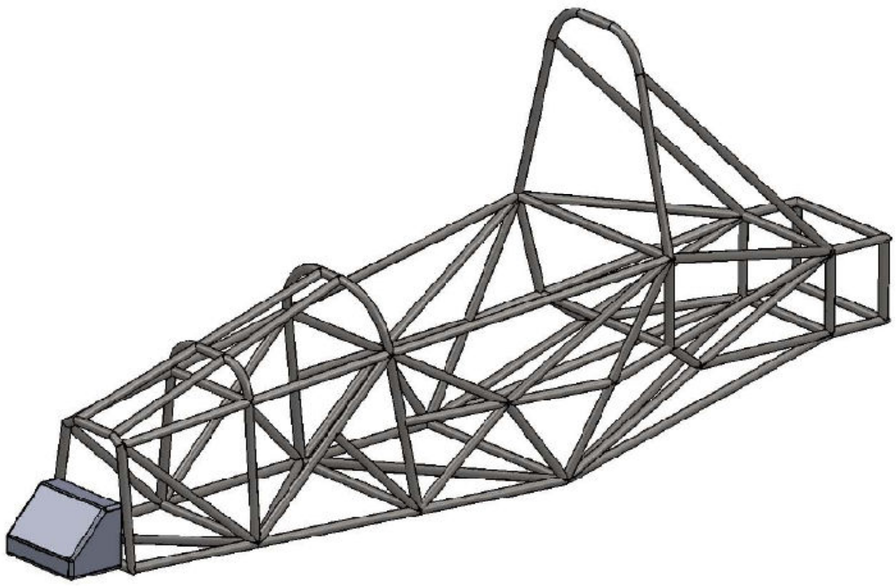


Figure 22. Impact attenuator assembly to the frame

6. Body design

6.1- Description of unique body design

Designing the body of our car will be a very important task. The role of the body on our car will be as important as the frame. That's because is not only to make the car attractive, also reduces the air friction in a great part. For that we need to make a body as more aerodynamic as possible. The body will be done on Fiberglas, as the main material, because is a light and strong composite, and will deform properly in case of impact, absorbing the impact energy. The body will be making in a single piece, reducing the possible air friction and turbulence that would be create in the joints. Also we have to consider letting two air inlets, one on each side of the body, just to keep the engine refrigerated.

As we are going to expose later, for our car will be not necessary to include aerodynamic wings to the body, due to the low speed that this kind of cars run.

6.2- Design process

The process followed to design the shape of the body is just to make an offset of the external shape of the frame, and try to round all the corners to soft arcs. We have to take count that the fibreglass material that will conform the body will have 3 mm. of thickness. We will start making an offset of 5 millimetres from the shape of the front bulkhead, the front roll, and followed this shape along the car, creating a loft surface between all the offsets created trying to get a soft shape just to improve aerodynamics. We are going to include two air inlets to help to the engine refrigeration.

One important part of the body is the nose of the car. It will follow the shape of the body from the front bulkhead to the very first part of the body, but always trying to keep the impact attenuator inside its volume. Because the nose will be build with fibreglass, it will deform in the right way just helping the impact attenuator to absorb de energy created by an eventual front impact. It has to be noticed that the frame will have some gaps and opening for the attachment of the front suspension that not are represented here because they don't take part of this project.

6.3- Body rendering

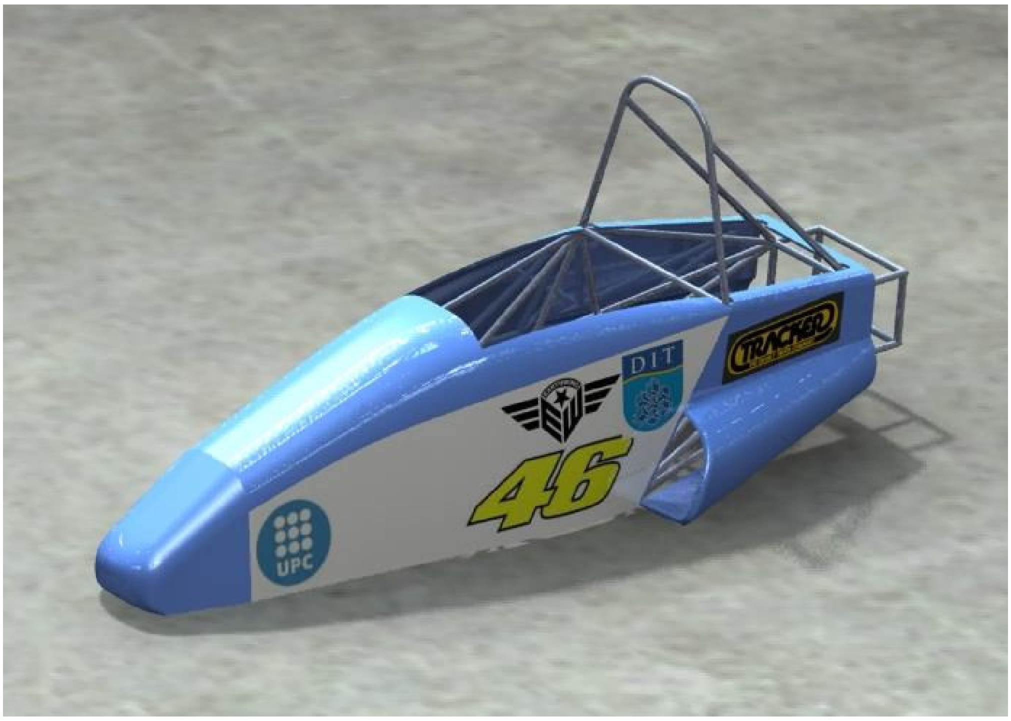


Figure 23. Rendering of the body and frame

6.4- Assembly and disassembly of body to frame and methods of attachment

The design of the body will be aimed also to get a easy assembly and disassembly to the frame, just to reduce this process time in a eventual competition or demonstration. The weight of the body will be reduced also to make the lift easier and reduce the force needed. A composite material like the fibreglass used here, is the best option due to its rigidity and lightness.

The assembly of the body and the frame will be done in three steps. First step will be putting the body and the frame close. In the second step, we will lift the body until it's in the front top of the frame. The third step will be lowering the body until touching the frame and put them together.

At the first step we will have the body and the frame presented at the same level.

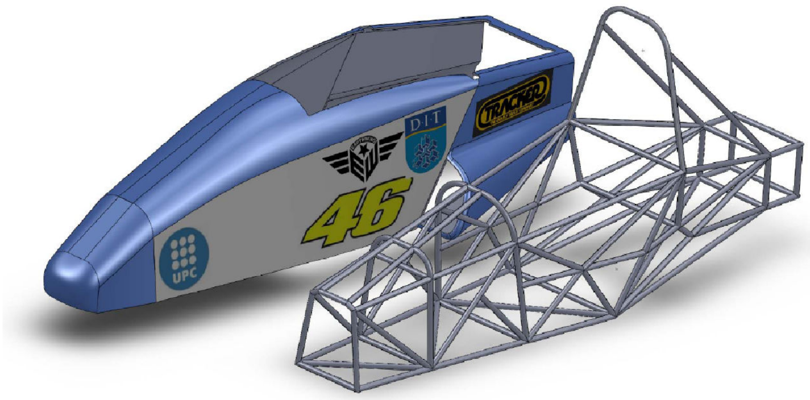


Figure 24. Assembly step 1

In the second step we are going to lift the body upside the main roll hoop, trying to introduce it by the cockpits gap like the figure shows.

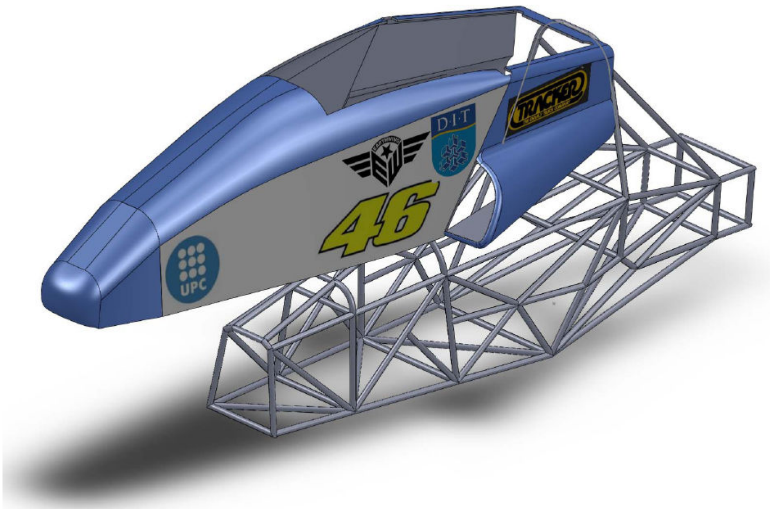


Figure 25. Assembly step 2

The third step will be just to low the body until touching the frame, just trying to get the plugs of the fasteners on the shape of the frame.

Figure 26. Assembly step 3

The method of attachment of the frame with the body will be trough automotive fasteners. These fasteners will be have one part strapped to the frame by staples (female part), and with a screw will fix the body to the frame. We are not going to weld nothing to the frame because it will make the mounting more slow and expensive.

The fasteners will be distribute along the points of contact between the frame and the body, and will be located in points easy to achieve. The material of the fasteners will be alloy steel to provide good welding with the frame. The material of the screw will be INOX STEEL.

6.5- Body decals

We are going to apply some images to the body (decals) simulating the possible sponsors or college name, that will demand to recognise them. These decals will be put on the body after finished and will be adhesive stickers, printed on a vinyl. We will put there a number simulating the car will be competing in a race.

6.6- Aerodynamic analyses of the body

Doing the aerodynamic test to the body is a hard task, which has made easily thanks to the modern computer software like Solid Works Flow Test. We have used this software to done it. We are going to apply a source of wind on the front and set a velocity for it. The software will show us the path of the air. We will look to find two goals: Drag and Lift.

The software will give us these two values in a numeric table and a graphic. We are going to explain this two factors and how they influence on the behaviour of the car on track.

Drag

In fluid dynamics, drag (sometimes called air resistance or fluid resistance) refers to forces that oppose the relative motion of an object through a fluid (a liquid or gas). Drag forces act in a direction opposite to the oncoming flow velocity. Unlike other resistive forces such as dry friction, which is nearly independent of velocity, drag forces depend on velocity. For a solid object moving through a fluid, the drag is the component of the net aerodynamic or hydrodynamic force acting opposite to the direction of the movement.

Our aim at the time of designing the body it’s to keep this value as low as possible, because a high level of drag will be traduced in a loss of engine power to counteract the drag force, and a high level of air friction noise and vibrations.

Lift

A fluid flowing past the surface of a body exerts a surface force on it. Lift is defined to be the component of this force that is perpendicular to the oncoming flow direction. It contrasts with the drag force, which is defined to be the component of the surface force parallel to the flow direction.

If the fluid is air, the force is called an aerodynamic force. An airfoil is a streamlined shape that is capable of generating significantly more lift than drag. Aerodynamic lift is commonly associated with the wing of a fixed-wing aircraft, although lift is also generated by wings on auto racing cars. While the common meaning of the word "lift" assumes that lift opposes gravity, lift in its specialized technical sense obviously can be in any direction with respect to gravity, since it is defined with respect to the direction of flow, rather than to the direction of gravity. On the wing of a racing car. In this last case, the term down force is often used. Lift may also be horizontal, for instance on a sail on a sailboat.

On our case we have to pay attention to this value and we need to get it as negative, as a down force. It will improve the grip of the car at the time of turning, avoiding drift and making the drive more efficient. In contrast, too much down force will increase the force that the car make to the ground, increasing the wheels wear away, and reducing the speed and increasing the power needed to move the car.

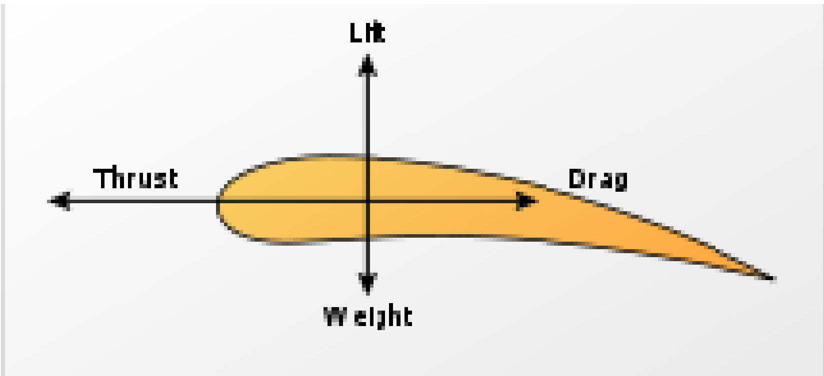


Figure 27. Forces taking part on aerodynamics

6.6-1. Aerodynamic model

To do the aerodynamic tests to the body, a aerodynamic model will be created. This model has the same external shape as our body with the same sizes, but trying to get the more accurate results, all the air entries will be closed. That is because our test will be only for the behaviour of the air and its trajectories on the external part. The next picture shows the aerodynamic model created to make the tests:

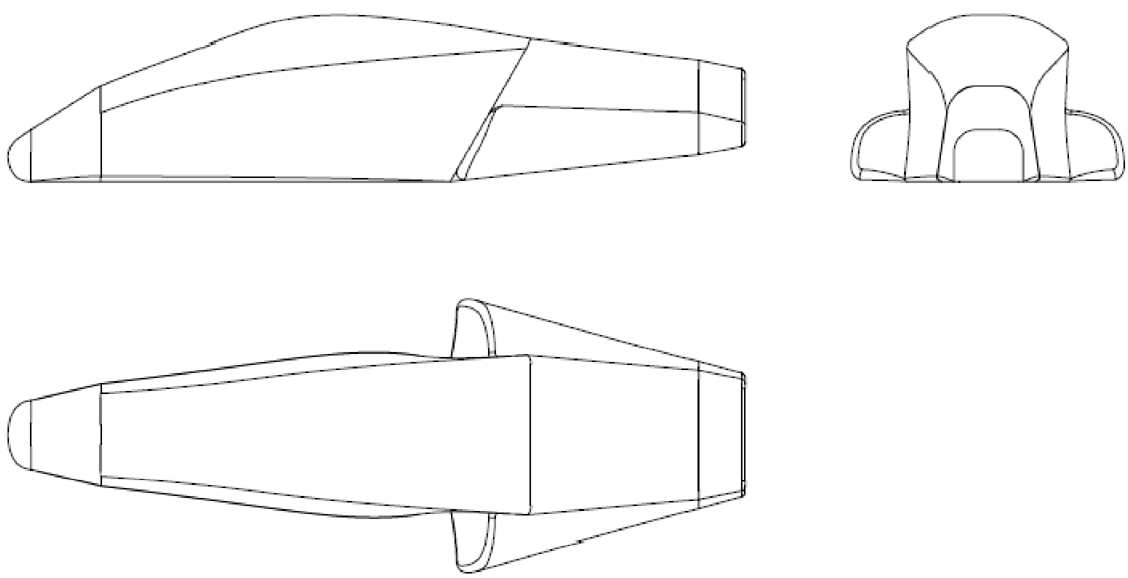


Figure 28. Aerodynamic model

6.6-2. Vehicle speed settings

The value of the car's speed for introduce into the test will be of 55 mph. This speed will be the normal speed for the car on the circuit and will be adequate to make the drag and lift tests. As said before this speed it is not higher enough as to justify placing aerodynamic wings to the body.

6.6-3. External body simulation of drag and lift

In the real world, the car would be moving through stationary air. In a wind tunnel, the car is stationary and the air is moving. The Flow Simulation example as a virtual wind tunnel, the car is stationary and the air is moving. That it is done through the software solid works. The next table shows the conditions settings for the tests:

Velocity	55 mph
Analysis type	External
Reference axis	Z
Default fluid	Air
Wall thermal condition	Adiabatic wall
Result resolution	4

Table 7. Condition settings for aerodynamic tests

The next step is to set the goals of our study, just to get the valid values. The global goals of the study will be the drag and the lift of the body, created for the pass of the air through the shape. The drag values will be on the z axis, positive and the lift on the y axis positive as well.

The next pictures will show us the air trajectories around the car and simulates a wind tunnel test. It indicates the air pressure across the shape of the model, and uses the colours to show the values, as indicated on the left scale. The minimum pressure will be the basic air pressure from the atmosphere (101202 Pa).

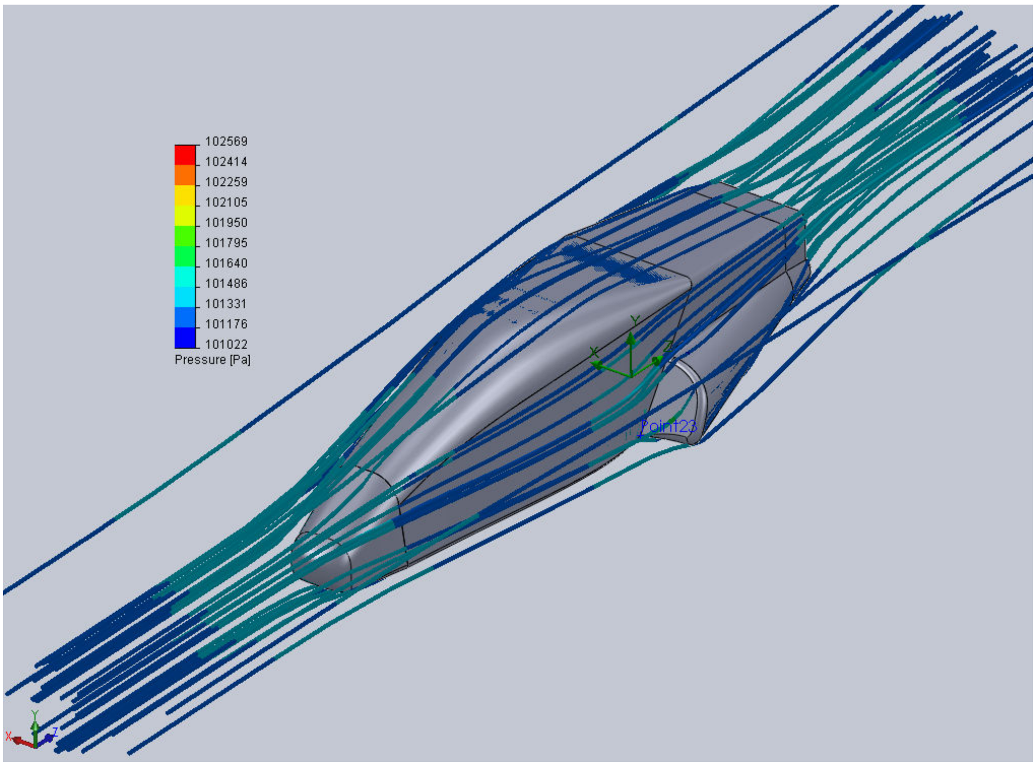


Figure 29. Air trajectories and values for pressure [Pa]

As we can see on the picture, the increment of the air pressure it is not very significant. That means that no high friction forces and no consequent air friction noise will be created by the pass of the air. As well we can see that the maximum air pressure along the shape of the car will be around 101331 Pa. That means an increment of only 200 Pa from the base air pressure.

The second picture (figure 29) shows a similar plot, but the values there are air velocity. The base air speed it is 55 mph, as we have set like the base speed of the car racing. The plot will show us the speed increment of the air passing through the body shape.

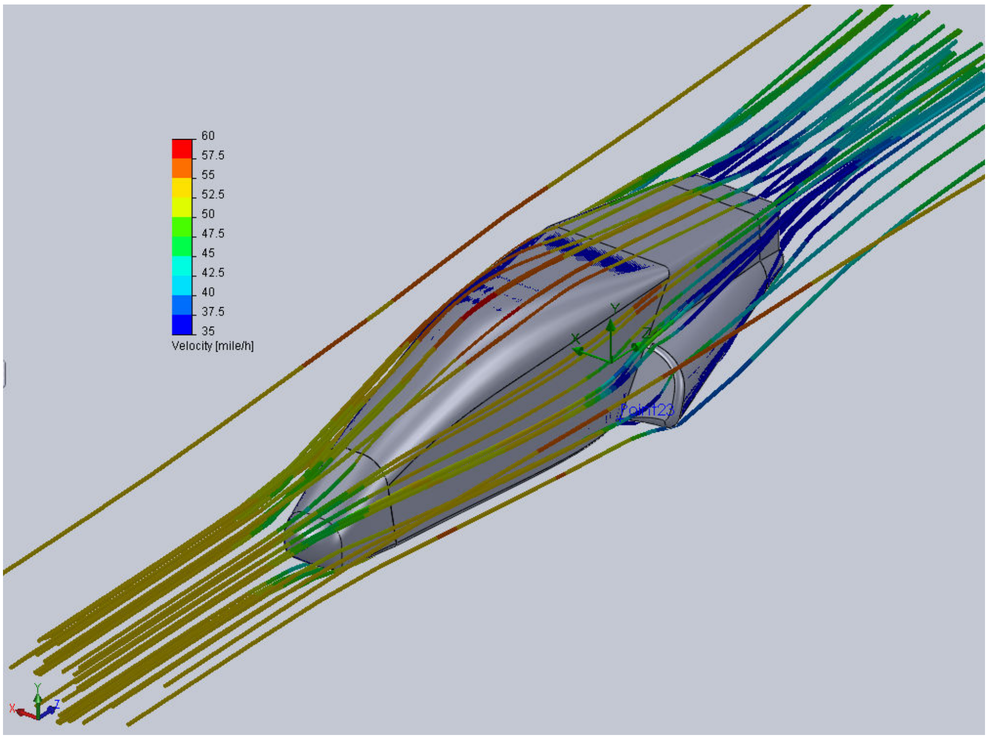


Figure 30. Air trajectories and values for speed [mph]

From the figure 29 we can take the conclusion that the shape of the body is aerodynamic acceptable. As we can see on the plot, the maximum velocity of the air it is around the 60 mph. That means only a 5 mph increment of the air speed. We can see as well that the increment a decrease of the speed air is totally progressive and there is no quick speed change. That means that the air turbulence there will be reduced. The increment of the air speed on the top of the model shows us that the lift force (in our case down force) it is significant. And the lost of velocity on the nose of the car show us that the drag force is reduced there. That is a very good sign.

The next table show us the values of the goals throught the iterations done by the software. As we can see the lift is negative, that means a down force, that give to our car extra grip. The second goal, the drag is positive, but as we can see the value is not very high. The values are gramforce.

Aerodynamic Tests

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Lift	[p]	-4476.222161	-4425.93808	-4507.569394	-4246.962143	100	Yes	260.6072508	362.3349054
Drag	[p]	5013.715363	5032.486803	5007.519201	5109.31532	100	Yes	101.7961188	394.3246777

Iterations: 44
Analysis interval: 21

Table 8. Aerodynamic tests values

The maximum values of the drag will be 5109.31 gram force. That means that we need an extra power of the engine of 50 Newton. That's totally acceptable. In the case of the lift the maximum will be the minimum, because the sign is negative. This value will be around 45 Newton. That force will help the tyres to grip on the road. Those values are totally on range and they are acceptable.

The next graphics shows the values of the table. We have the force for lift and drag respectively, on the y axis, and the iterations done by the software on the x axis.

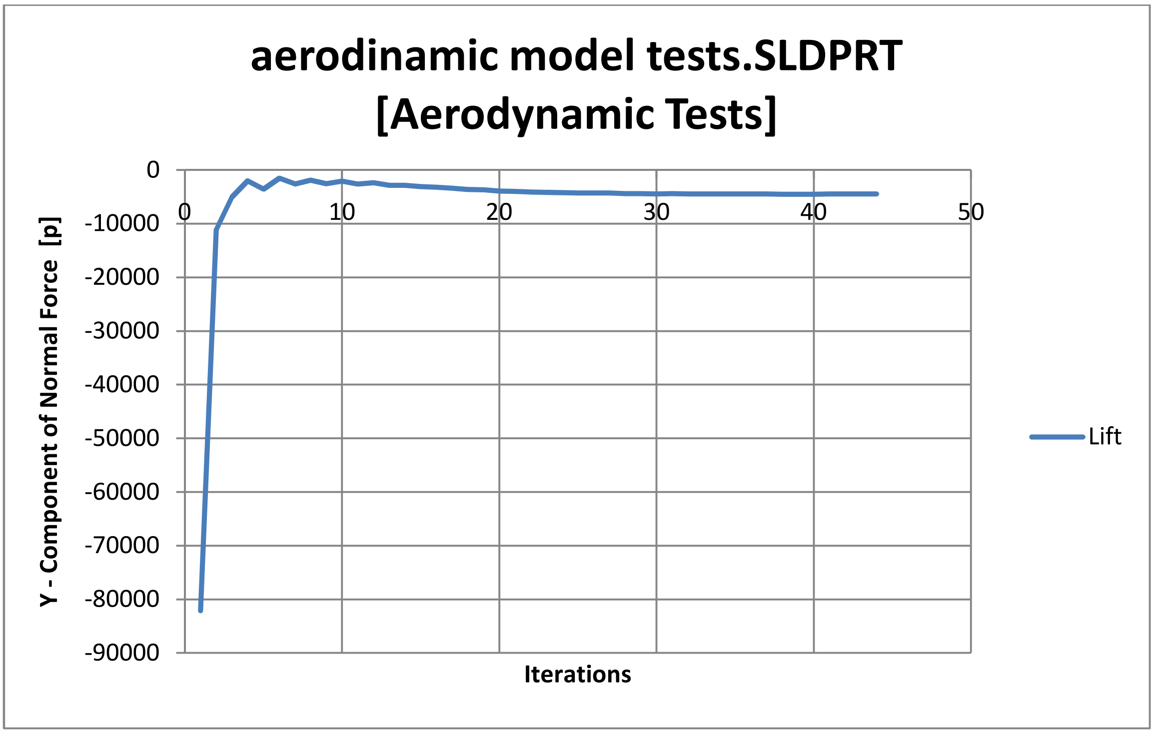


Table 9. Graphic results for lift

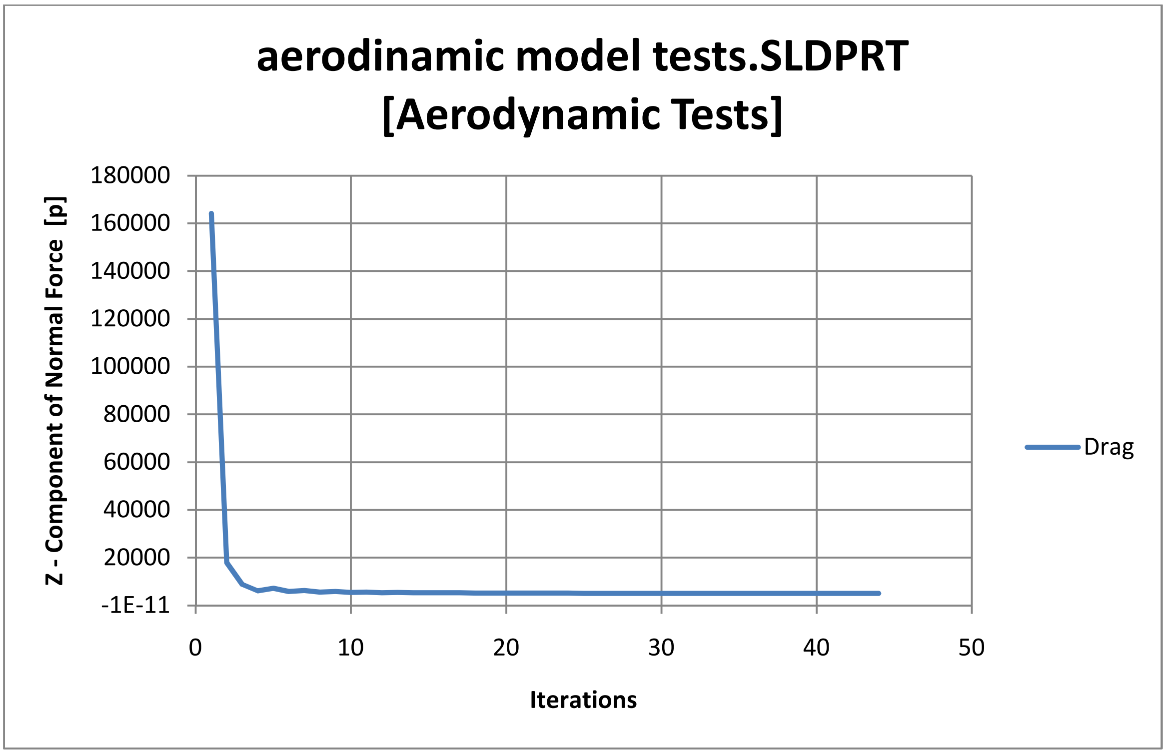


Table 10. Graphic results for Drag

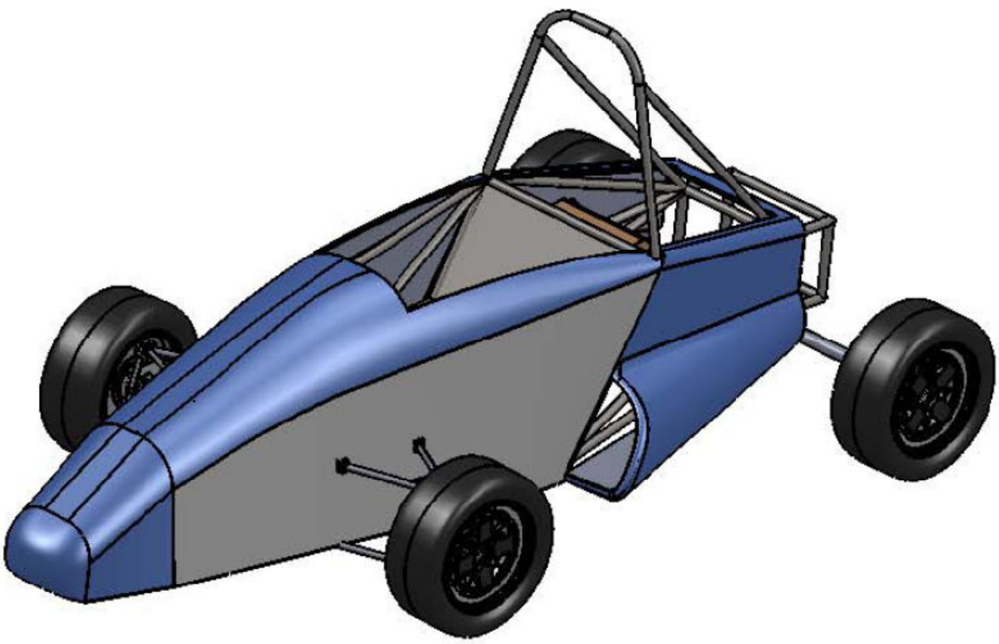
The conclusion that we get looking at the graphics are that the values are very stabile through the iterations. That is because the shape of the car is soft and we don't have subtle changes of shape. The aerodynamic of our body is acceptable.

6.6-4. Discussion of results and conclusion

The conclusion than we extract of these aerodynamic analyses is that the body seems to be correctly designed. I mean the values of drag and lift, they are low. That will be caused because the shape of the body is very progressive and there are no important brakes on its line. Also, the speed that this body will run is not very high because the formula student is not a high speed competition. If the speed were higher, we will think about some modifications like spoilers, air inlets, so on.

7. Frame and body design conclusions and recommendations for improvement

The design of the frame and the body for a vehicle FORMULA STUDENT is a though task. The design conditions are very concrete and bounded, and it's totally necessary the maximum optimization of costs and building processes. That is because it will be make on a university Workshop and its building will be done by students. I also believe that the design is quite successful and have the opportunity to design a vehicle with these characteristics is very important. The frame could be improved by optimizing the number of bars and tubes that are part of it and repeating over and over FEA Analyses. In this way could reduce the number of nerves and triangulations, thus reducing the weight of our vehicle. One of the main improvements to be made in such designs would be to build the frame in a material such as aluminium. It is much lighter and more malleable. The problem may be in the welds and the strength test. An attractive option is to perform the monocoque style frame. That will greatly facilitate the assembly and may even mean the cover save, which represents a major advance because it is difficult to build.



8. References

Engineering Properties of Steels, Philip D. Harvey, editor, American Society for Metals, Metals Park, OH, (1982).

Handbook of Stainless Steels, Donald Peckner and I. M. Bernstein, McGraw-Hill Book Company, New York, NY, (1977)

Metals Handbook, Howard E. Boyer and Timothy L. Gall, Eds., American Society for Metals, Materials Park, OH, 1985.

Metals Handbook, 10th ed., vol. 1, ASM International Handbook Committee., ASM International, Materials Park, OH, (1990)

The Race Car Chassis, Forbes Aird, Ed. HPBooks, Penguin Group, New York, NY, (1997)

Chassis engineering, Herb Adams, Ed. Berkley Publishing Books, Penguin group, New York, NY, (1993)