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CARBON FIBER REINFORCED COMPOSITE SUSPENSIONS FOR A SOLAR VEHICLE.

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Contents

1 *State of art*

1.1 Introduction

The potential of solar energy is more appealing than the one of fossil fuels, isn't it?
What proposals will we make for the future?
We could change the mobilities and try to develop a low emission technology?
I think so, and there are a lot of people that work with this goal!
Now it's time to take a step back and start from the beginning.
One of the most recent topics is the reduction of pollution, indeed day by day the number of low pollution car increases.

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Toyota Prius-the most famous hybrid car

We know many different technologies, each of which has positive and negative characteristics, that could reduce the pollution and improve our life.
The fact that, due to these technologies, everyone could make the difference in reducing the amount of air contamination is amazing.

There are a lot of harmful behaviors to the environment, 90% of which concerns our life, from transportation to communication.

If we want to preserve our world, we must work hard to reduce the pollution and take actions in the automotive and transport fields.

The most famous low emissions technologies in the automotive filed are hybrid cars, electric cars but there's another technology not so famous worldwide which can become our future key technology: the solar power.

When we talk about a full electric car or a mild hybrid car, we have to consider a lot of advantages and some disadvantages.

If we think about a car produced with this technology we must consider that initially it's necessary to invest more money than a "normal" car, but then it is cheaper to use because the price of electricity is lower than the price of gas and also because we have some reliefs about tax or insurance.

However it's time to speak about the most interesting advantages of an electric car: the performance.

Rimac Concept One

The performance of an electric motor on speed up moments is much better than the one of a combustion engine, because the torque is almost vertical on the diagram and this property signifies that the car increases its speed quickly.

One of the best examples is Rimac Concept One, this car accelerates from 0-97 Km/h in 2.5 seconds and the top speed is limited at 340 Km/h.

Obviously, our solar car is not optimized for this performance, but I mentioned Rimac to show the potential of this technology.

The electric power has some disadvantages too, one of which is the autonomy, and the example is the Fischer Karma.

Fischer Karma-the first full-electric supercar

This car was the first full electric supercar but its autonomy was limited at 80 Km, luckily we have solved this problem with the help of technology and the clearly example is Tesla that built a real electric car in less than 20 years.

Tesla Model X

1.2 <u>Onda Solare Team</u>

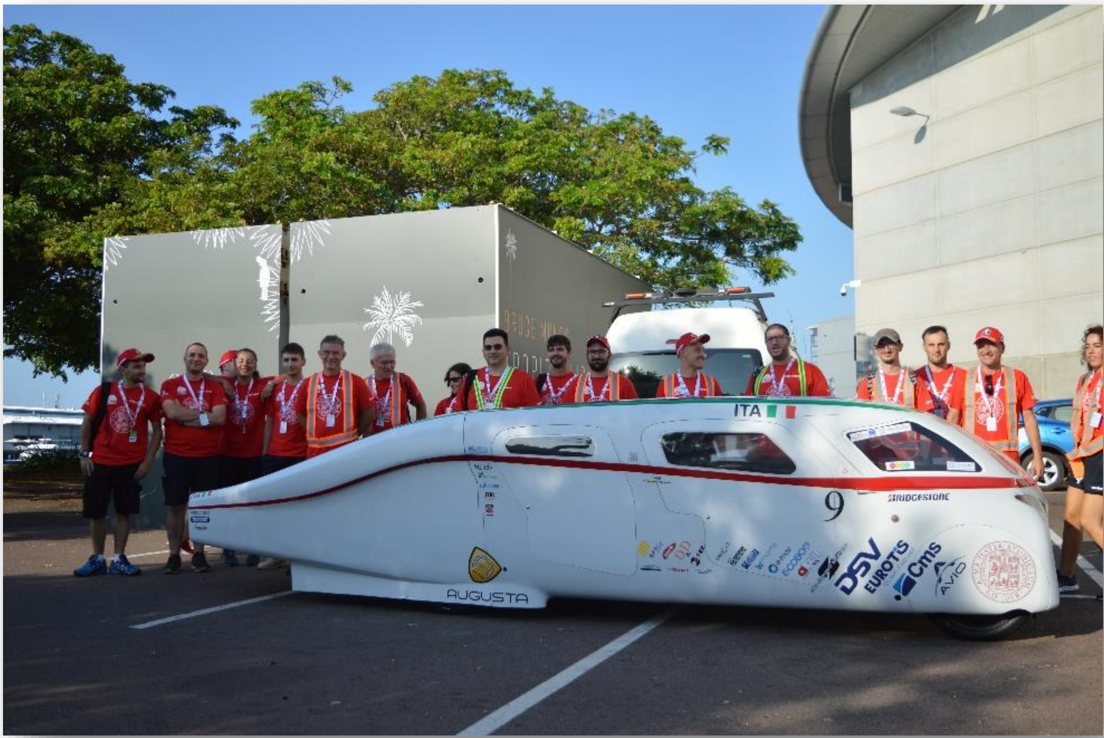
A solar car is a normal car, or better, it is an electric car, with a heavy battery pack that is like a tank where we can store the electricity power that we will use at the most appropriated time, for ex. when it's rainy or when the road conditions are hard.

This battery is filled by means of the sun that it is caught with the solar panel and very often with kers that is the kinetic energy recovery system, a technology which allows to receive the kinetic energy during the braking phase.

The best feature about the solar car is that when it is sunny day, we can move around without pollute because we can exclusively use the solar energy to power the car's motors.

Now it's time to speak about our university solar car team, Onda Solare.

They started this project like a game, in the far 2004, in a little work close Bologna, in Castel San Pietro, thanks to some artisans who created an E-bike that took part in the World solar challenge, the most famous race in the world for electrical vehicles.



Emilia 4LT at the BWSC2019

The team was born with less than 10 members, all of whom were artisans, but now the team counts 60 people working every week to build and improve the car. The majority of those people are volunteers and during the week they do a different jobs.

In this close-knit group there are 3 different positions:

First of all there are the engineers, they have the task of projecting the car in every single aspect, not only from an electrical point of view, but also from a mechanical one.

This project is a very useful training ground for them because they have the possibility to work together with high level people who work in this field every day; Furthermore this project is useful for the purposes of finding a job at the end of university, because if you can establish a good relationship with the highly qualified members of the group you may have more opportunities to show your talent and your potential.

The second category are the artisans, they were the founders of this group and now they carry on playing an important role, because they know every trick to fix up problems during the race or during the building of the car.

The last category is composed of people who have the power of administration of the association and they are the base because there are rules to be respected in order to work legally.

This project was fantastic, creating a team means development human values other than engineering aspects.

Cooperating in a hard moment during the race makes you learn to compare your opinions and ideas with the ones of other members of the team.

Another amazing aspect is the possibility to travel around the world, because you have the opportunity to meet a lot of people together with their different engineering philosophies and cultures.

It means that you have the chance to open your mind towards new ways of thinking and I believe that this feature is even more important than university skills.

At last but not less important there is the knowledge that you get from just one race: you are absorbed in a very competitive and fast reality and if you want to keep up you have to give your best and never give up.

Obviously, it is very difficult because you live one week in a tend without comfort, with 4/5 hours of sleep per night, in an inhospitable climate, always very hot and with high humidity.

Furthermore, you also have to keep attention on dangerous animals, like snakes; However these difficulties are totally paid back because it is an unforgettable experience.

But now it’s time to comeback to our team.

BWSC2019

We were saying that, Day by day, year by year this heterogeneous group realized 4 solar cars, so we arrive at the highest performance car Emilia 4LT.

Emilia 4 won the American solar challenge in 2018 and this year Onda Solare, with Emilia 4LT taken part of world solar challenge in Australia with a very big team composed by 24 people in assignment in Australia and almost 60 people that worked in Italy to realize this flagship of Italian's technology.

These two races are the most important in the world, there are a lot of teams from all over the world and from the most famous and illustrious university.

Every aspects of these races have only one goal, the sustainability and the development of new technologies to help and save the environment to improve our life.

These races are the most prestigious for these cars and our Italian team was the only one between famous universities from all over the world.

We raced on iconic and historic roads for example on the Oregon Trail in the USA, the most famous emigrant trail, that finds the route of National Trail System that celebrates the 50° anniversary whereas in Australia we crossed the desert on the Stuart Highway, the only road that runs from north to south and which is very important for the commerce of coal.

These races are composed of two parts.

The first one is on the track, during this first part the team has to fix the potential problems of the car and it has to create the best balance for the race in order to have the maximum efficiency without forgetting the target speed that it has to respect to compete in the race.

The work of organization is to control that the car is safe to run on a legal road and that it respects all the rules of the street code, but also that it can withstand accidents, without harming the driver and the passengers on board.

This first part is very difficult to pass: the organization has to be meticulous in controlling every aspects of the car, so not only the mechanical parts but also the electronical parts; infact the most dangerous component is absolutely the battery pack that, in case of issue or crash, could be a hazard due to acids, or worse, it could prime a fire.

At the end of this first demanding part, the race joins the more dynamic and interesting section that is on track.

This section is important because it permits to admire the dynamic potential of the car with a brake test, a slalom and at the end a fast lap on the track, that is necessary to qualify for the race.

When this part is done it’s time to move on to a legal road to do a real race.

This kind of races have a peculiarity: They cover a very long distance throughout the state, for ex in USA where we moved from Nebraska to Oregon or in Australia where we started from Darwin to Adelaide for a distance that it is around 3000 kilometers.

When the teams are in the street, they take to move within convoy to preserve the security of the solar car, and they have to respect some procedures in case of overtake and when they want to change lane.

This phase is very emotional because everyone knows that something could wrong but no one knows when and what and at the end you stay with this incredible agitation for 3000 kilometers.

First stage BWSC 2019

Another intriguing aspect is that at the end of the day for the most part of the nights you're going to sleep at the roadside, with an incredible view of the stars if you are in a wild zone in the nothingness; otherwise, in case you sleep in a more populated zone, you can meet a lot of pleasant people intrigued by the car, prepared to help you if you need it.

1.3 Solar Car Design

For the time being we talked about the race and the organization but now it's time to speck about how to create a solar car; we can try to do a panoramic about all the mechanical and electrical parts.

The cars that take part in this race are prototypes and they are studied end developed by students who work together with the company of the automotive and aerospace fields.

First of all, we have to describe the technology that stays in the background of a solar car.

It is necessary to know that the base of a solar car it is an electric car and for this kind of competitions it's necessary to decide how big it is our battery because it will influence the weight of the car and its autonomy, the race strategy and the balance; it's important to find the best compromise between this aspects.

If we want to talk about our team, we cannot reveal the real facts because they are covered by professional secret, but we can say that it was projected and realized in university by our students and engineers and that its patent is held by one of our teachers.

This was the first necessary thing to know.

The second important thing to know is the panel.

The panel's job is to store up the energy that comes from the sun and has been converted into electricity.

It is shaped with a carbon fiber mold that is necessary to decide the localization and the form of the panel, inside the mold there are the cells, on the automotive universe there are some different types of cells that influence the panel's performance.

We spoke about the large use of carbon fiber, what is the motivation behind this choice?

The answer is easier than what people think.

We use carbon fiber because it is a composite material with the peculiarity to have a very high resistance, but a very low weight.

Monolithic materials cannot always satisfy the demands of today's advanced technologies.

Only by combining several materials at a different length scales, as nature does, the requested performances can be met, and this performance requests are requested on the solar car's field, because we are talking about the maximum level of technology development.

As it is possible to see in the Ashby diagram, the carbon stays in the middle of the x-axis, but it is on the top of y-axis and this position describes a very good mechanical performance and also a low weight, that is necessary on the automotive field.

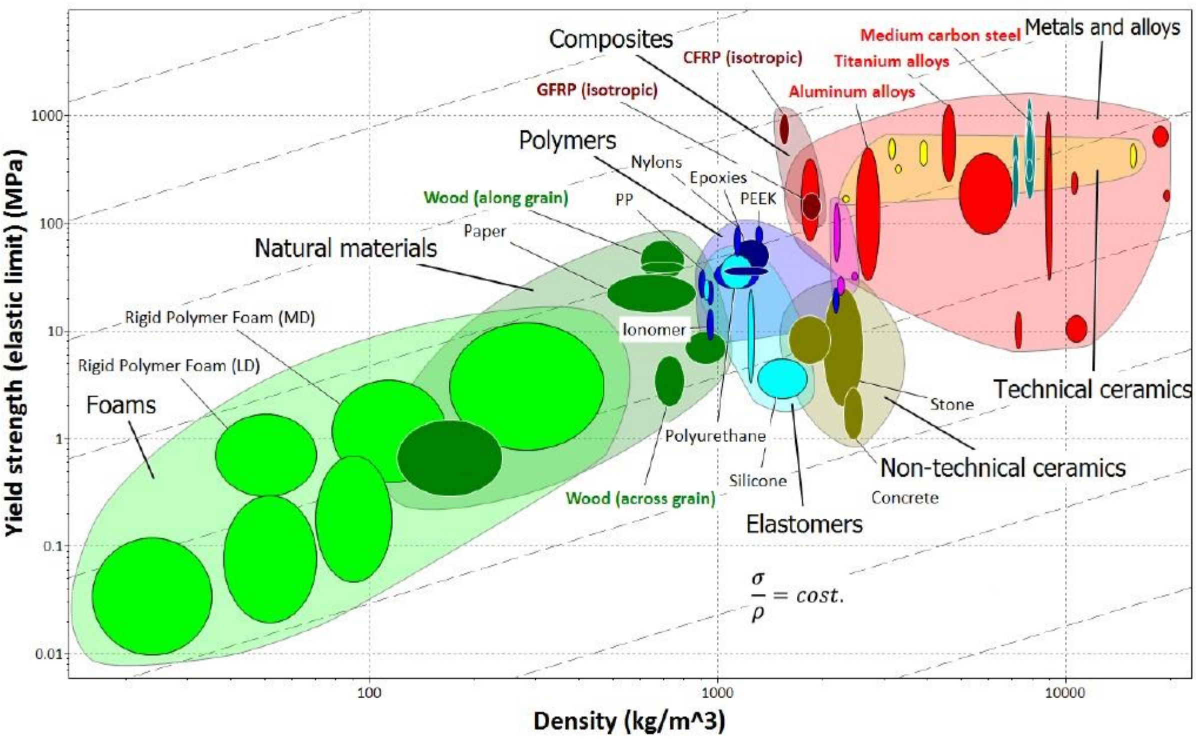


Fig 1-3 Ashby diagram Yield strength vs Density

In the Ashby diagram of Fig 1-3 the yield strength is on one axis and the density of common engineering materials on the other one and the dotted parallel guidelines link materials that have same specific strength (along the grain), comparable to the medium strength of aluminum alloys or medium carbon steels.

Values of specific modulus, strength and toughness are given in table 1-1 for common fiber reinforced plastic and bulk metals. The reported strength refers to yield strength for metals and compression to failure along fiber direction for FRP (the hardest in-plane load condition for composite laminates).

Material	Density (kg/m^3)	Young modulus (GPa)	Tensile strength (MPa)	KIC (MPa* m0.5)	Specific modulus (GPa/ (kg/m3))	Specific strength ((MPa/ (kg/m3))	Specific KIC (MPa *m0.5/ (kg/m3))
Steel (40 NiCrMo 6)	7800	205	1100	100	0.026	0.14	0.013
Aluminum (7075-T6)	2600	72	500	30	0.028	0.19	0.012
Titanium (T6-Al-4V)	4400	120	900	70	0.027	0.20	0.016
Epoxy	1200	4	80	1.5	0.003	0.07	0.001
Glass fiber (E-glass)	2500	72	3500		0.029	1.40	
UD glass/epoxy	1800	42	900	10	0.023	0.50	0.006
Cross-ply glass/epoxy	1800	20	550	10	0.011	0.31	0.006
Aramid fiber (Kevlar 49)	1500	130	3800		0.087	2.53	
UD aramid/epoxy	1400	75	350	10	0.054	0.25	0.006
Cross-ply aramid/epoxy	1400	31	250	10	0.022	0.18	0.006
Graphite fiber (PAN)	1800	230	3400		0.128	1.89	
UD graphite/epoxy	1600	140	1600	10	0.088	1.00	0.006
Cross-ply graph/epoxy	1600	75	800	10	0.047	0.50	0.006

Table 1-1 Specific modulus strength and toughness for common fibre reinforced composite and bulk metals

A visual representation of the listed features is given in the graph specific strength vs specific modulus of Fig 1-4. Glass, Kevlar and carbon fibers have specific modulus and strength that is an order of magnitude higher than metals 4. The major reason of their high strength is their thin diameter (e.g. 7 µm for carbon fibres). Thinner is the diameter and lower are the chance of an inherent flaw in the material and therefor higher is the strength, which is sensitive to flaws. Note how also in this case the structural dimension plays a major role on the strength of the material. However, fibres are not able to carry compression or bend loads by themselves, while a bulk version of them would be less strength and too fragile. For this reason, fibres are embedded in a polymeric matrix such as epoxy, which allows to transmit the load between them.

As a consequence, the resulting elastic modulus and strength of the UD composite, along fibre direction, are roughly a weighted average (on volume) of its constituents. These properties are then halved when equal amount of fibers are disposed at right angle to each other (cross-ply), in order to have a laminate with equal strength in both principal directions. Looking at the table, a structure in CFRP that has to carry loads on different direction can weight up to half on the metal equivalent one.

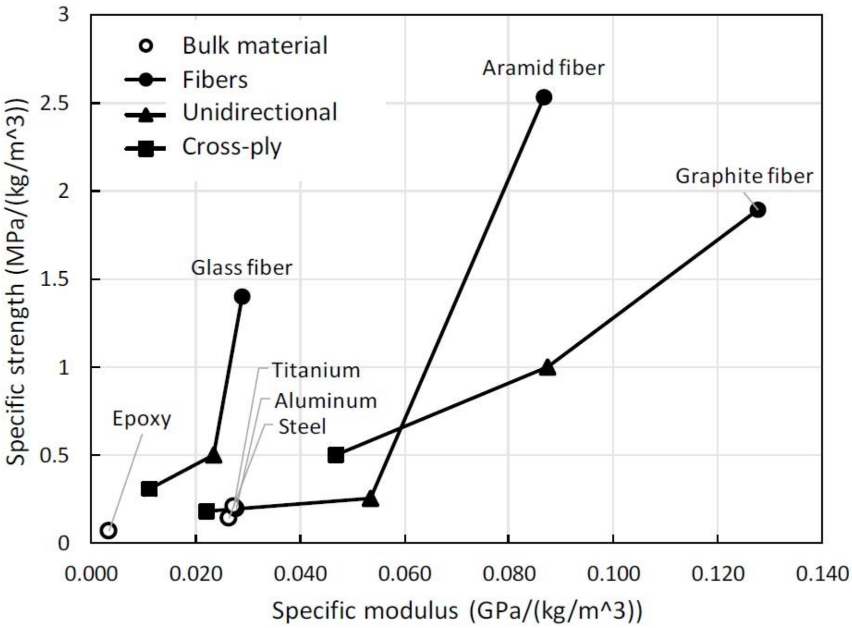


Fig 1-4 Specific Strength vs specific modulus for common FRP laminates and bulk metals.

2 *Thesis*

2.1 Component Presentation

Now we will talk about a very important component that takes advantage of this technology. We used the carbon fiber for the 90% of our car and the suspension system is included in this percentage.

In particular we will describe the suspension arm, because it is planed with an innovative philosophy and technology, infact we usually use a triangle system with a tubular technology, but in this case we decided to use a carbon fiber box that is very difficult to prevent the material performance, but at the same time it is the lightest.

This particular has the task of link the wheel with the car and it is subjected to 3 different forces: the longitudinal, the transversal and the torsional ones.

It takes a maximum stress during the corners or when the car takes a bump on the street.

The assemblies in which it takes part are different between front and rear wheels because in the front it links the arm wheel, that it is connected with the wheel, and the car, but the assembly is very tricky because it depends on the steering wheel.

On the rear assembly there are different problems because the wheel includes the motor that generates a torque and it has effects on the suspension arm.

2.2 Latest Version (Usa)

Firstly we made it in aluminum and we used it in the American solar challenge where we took the first win of Emilia 4.

Than we decided to change the suspension in order to decrease the weight and because the carbon is more exotic and performant even if also the aluminum one worked well, and it was a good compromise between weight and mechanical strength.

We planned it with the participation of Marco Scalorbi who follows the organization of the majority of the components.

He works a lot with Solid Works, and he planned this component in its first step, the metal one.

From this first plan we developed the upgraded version that is the highest evolution step in carbon fiber for the race in Australia this year.

We used to make this a new version of vacuum bag that is composed by a few steps.

First step: we start from the prepreg, which is organized in a roll conserved at very low temperature (-18°C) so that the resin conserves the peculiar structure.

Second step: now we have to clear the mold (ex-acetone) and decide the final dimension of our object, then we check that the carbon fiber receives a uniform pressure inside the mold.

Third step: we put on one or more released application, approximately in 15 minutes between the previous one to avoid that the resin goes out of the specimen due to the autoclave's pressure.

Fourth step: Now we can start with the lamination phase which is composed by the overlapping of many sheets. In according with the project, in regard with the composite materials, the orientation and organization of the sheet is very important, because it permits to modify the strength and in general the mechanical feature.

Last step: when the lamination in finished, we complete our project with the curing.

We have to apply a particular temperatures way with ramps of increase and decrease that allow the catalyzation by the resin that gives the final mechanical features to the laminated.

Now we have described the steps to build a new carbon fiber piece, but to apply this process we have to make a vacuum bag.

It is a very important and tricky process because we have to create a bag that permeated the vacuum during the process into the autoclave and at the same time permeated the insert of the component and the come out of the air.

2.3 Finite Element Software, Ansys

That's right, now we know the physical process but to decide the organization and orientation of the fibers we have to do an optimization about the structure with Ansys Workbench.

Ansys is a very useful program to create and optimize any particulars in composite material, infact we used it to create our suspension.

It works with overlapping flats and it uses the nodes technology to create the mesh, so you can decide to use triangles or quadrilaterals.

This decision influences the response of the structure about the forces and at the same time it is important to understand that if you use all over the quadrilateral the mesh is more heavy and it could be a problem because you need more potential devices to do a simulation; However we will explain Ansys' features in the next several sections.

3 Planning and structural evaluation

3.1 Introduction, component operation and different technologies

Now it is time to explain how our component works.

We have to do a step back and we need to remember what the principal function of the arms in a car is.

The arms in a car have the function of linking the wheels with the chassis and they cover a primary rule about the stability of the car, its driving delight and resistance of the car.

The arms are very stressed during the corners, in this case the forces increase with the corner speed end the weight of the car.

An other critical moment for the arms is when the car takes a bump, because it withstands a peck of forces and if the material is too hard or not elastic enough it could break.

We told that because when we projected the arms for Emilia 4, before everything else the most important goal was to find a balance between the maximum resistance and the minimum weight and this was the reason why we decided to use composite materials even if they are more difficult to project and produce.

When we talk about composite materials, we have to think about a material that has an average performance between the performance of the materials that composed its structure.

On our specific case the carbon fiber it's like a sandwich composed by some layer and resin, it's very important to have a perfect contact between the layers to avoid the mutual slip during the moment of maximum stress.

It is possible to adapt the proprieties of the carbon fiber to our necessity varying the fiber orientation, infact there are two principle kinds of fiber: the mono-directional and the bi-directional, the main difference between those two fibers is the direction of the maximum resistance.

The mono-directional has an highest level of resistance, but just in one direction with an angle of zero degree respect the vertical line; On the other hand of the bi-directional one has not an high resistance but it could stand in the way of two directions, with an angle of zero and 90° degree respect the vertical line.

At the bottom of the composite materials there is the mold, which divides the composite materials in some categories, anyway, the biggest number of them are polymeric because they guarantee a low density but increase the performance with the temperature.

The mold has the function of including the support and guaranteeing the cohesion of the composite material and, at the same time, it has to guarantee that the support's particles have a correct dispersion without segregation.

In the case of carbon fiber the resin has the job to hold the fiber in position and maintain the handmade form.

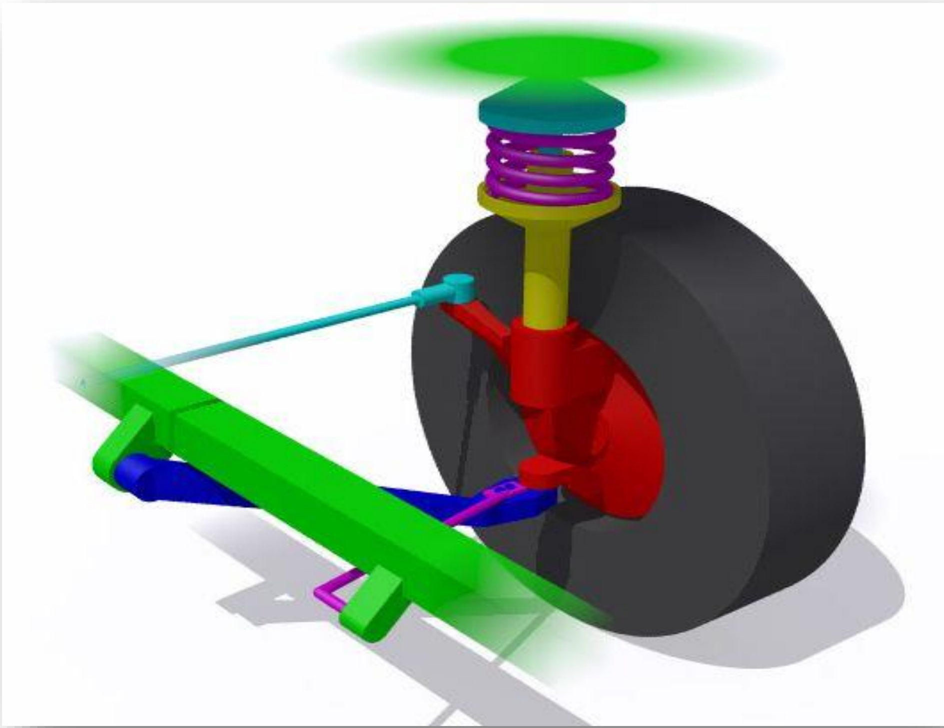
We have told that our component has an active contribute on the car during the travel.

It links the wheel with the chassis, and it works with the leaf spring on the bumps.

Its tasks aren't easy because it is subjected to variable and intense forces in particular in the corner's moment.

We used to link our wheel a system that is similar to the A-ARM system, but what is the A-ARM?

The A-ARM is a suspension linkage formed in the shape of an "A" or "V" found commonly on the front suspension.



A-Arm system

The sides of the two legs of the A-ARM are attached to the wheel assembly.

In this way, the wheel can freely move up and down.

Sometimes there is an upper A-ARM, a lower A-ARM, or both upper and lower A-ARMS.

The inboard (chassis) end of a control arm is attached by a single pivot, usually a rubber bushing. It can thus control the position of the outboard end in only a single degree of freedom, maintaining the radial distance from the inboard mount. Although not deliberately free to move, the single bushing does not control the arm from moving back and forth; this motion is constrained by a separate link or radius rod.

A control arm may be used to carry the suspension load and transmit them to the spring or shock absorber.

Torsion bar suspension commonly does this, with the outboard end of the torsion bar attached to the inboard bearing of the control arm.

We decide to use the CFRP technology because we need to have a very lightness and heavy-duty component that looks about the racing performance.

3.2 CFRP use for light and resistant components and carbon fibre features

When we talk about CFRP we are talking about the Carbon Fibre Reinforced Polymer Composites (CFRP) which are lightweighted, strong materials used in the manufacturing of numerous products used in our daily life. It is a term used to describe a fibre-reinforced composite material that uses carbon fibre as the primary structural component.

In general, CFRP composites use thermosetting resins such as epoxy, polyester, or vinyl ester. Although thermoplastic resins are used in CFRP Composites, "Carbon Fibre Reinforced Thermoplastic Composites" they often go by their own acronym, CFRTP composites.

Not only are carbon fibre composites lighter weight, but CFRP composites are much stronger and stiffer per unit of weight. This is true when comparing carbon fibre composites to glass fibre.

The binding polymer is often a thermoset resin such as epoxy, but other thermoset or thermoplastic polymers, such as polyester, vinyl ester, or nylon, are sometimes used. The composite material may contain aramid (e.g. Kevlar, Twaron), ultra-high-molecular-weight polyethylene (UHMWPE), aluminium, or glass fibers in addition to carbon fibers.

The properties of the final CFRP product can also be affected by the type of additives introduced to the binding matrix (resin). The most common additive is silica, but other additives such as rubber and carbon nanotubes can be used. The material is also referred to as graphite-reinforced polymer or graphite fibre-reinforced polymer.

Of course, there are many variables that could change this comparison.

The grade and quality of materials can be different, and with composites, the manufacturing process, fibre architecture, and the quality need to be taken into account.

Of course, there are many variables that could change this comparison.

CFRPs are composite materials. In this case the composite consists of two parts: a matrix and a reinforcement. In CFRP the reinforcement is carbon fibre, which provides the strength. The matrix is usually a polymer resin, such as epoxy, to bind the reinforcements together. Because CFRP consists of two distinct elements, the material properties depend on these two elements.

Reinforcement gives CFRP its strength and rigidity, measured by stress and elastic modulus respectively. Unlike isotropic materials like steel and aluminium, CFRP has directional strength properties. The properties of CFRP depend on the layouts of the carbon fibre and the proportion of the carbon fibers relative to the polymer. The two different equations governing the net elastic modulus of composite materials using the properties of the carbon fibers and the polymer matrix can also be applied to carbon fibre reinforced plastics.

The following equation:

$$E_c = V_m E_m + V_f E_f$$

Is valid for composite materials with the fibers oriented in the direction of the applied load.

Ec is the total composite modules, Vm and Vf are the volume fractions of the matrix and fibre respectively in the composite, and Em and Ef are the elastic moduli of the matrix and fibers respectively.

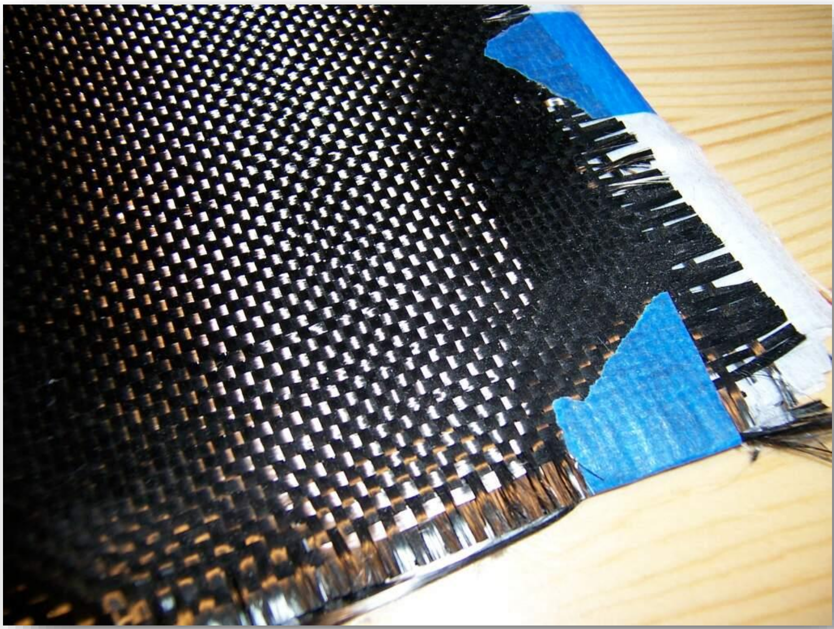
The other extreme case of the elastic modulus of the composite with the fibers oriented transverse to the applied load can be found using the following equation:

$$E_c = \left(\frac{V_m}{E_m} + \frac{V_f}{E_f} \right)^{-1}$$

The facture toughness of carbon fibre reinforced plastics is governed by the following mechanisms: 1) debonding between the carbon fibre and polymer matrix, 2) fibre pull-out, and 3) delamination between the CFRP sheets. Typical epoxy based CFRPs exhibit virtually no plasticity, with less than 0.5% strain to failure. Although CFRPs with epoxy have high strength and elastic modulus, the brittle fracture mechanics present unique challenges to engineers in failure detection since failure occurs catastrophically. As such, recent efforts to toughen CFRPs include modifying the existing epoxy material and finding alternative polymer matrix. One such material with high promise is PEEK, which exhibits an order of magnitude greater toughness with similar elastic modulus and tensile strength. However, PEEK is much more difficult to process and more expensive.

Despite its high initial strength-to-weight ratio, a design limitation of CFRP is its lack of a definable fatigue limit. This means, theoretically, that stress cycle failure cannot be ruled out. While steel and many other structural metals and alloys do have estimable fatigue or endurance limits, the complex failure modes of composites mean that the fatigue failure properties of CFRP are difficult to predict and design against. As a result, when using CFRP for critical cyclic-loading applications, engineers may need to design in considerable strength safety margins to provide suitable component reliability over its service life.

Environmental effects such as temperature and humidity can have profound effects on the polymer-based composites, including most CFRPs. While CFRPs demonstrate excellent corrosion resistance, the effect of moisture at wide ranges of temperatures can lead to degradation of the mechanical properties of CFRPs, particularly at the matrix-fibre interface. While the carbon fibers themselves are not affected by the moisture diffusing into the material, the moisture plasticizes the polymer matrix. The epoxy matrix used for engine fan blades is designed to be impervious against jet fuel, lubrication, and rainwater, and external paint on the composites parts is applied to minimize damage from ultraviolet light.



Carbon fibre layer

We used just two types of carbon fibre, Twill300 and Twill800, they have a different response about loaded and different reaction regarding force direction and in particular the biggest difference is the tensile strength.

We use T300 for the supports, crossbeams and pivots whereas we use T800 for the body suspensions. Both of them have a particular orientation because it influences the surface strength.

T800-Twill

T800 - TWILL > Constants

Density	1.8e-006 kg mm^-3

TABLE 60
T800 - TWILL > Orthotropic Elasticity

Temperature C	Young's Modulus X direction MPa	Young's Modulus Y direction MPa	Young's Modulus Z direction MPa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY MPa	Shear Modulus YZ MPa	Shear Modulus XZ MPa
	71500	71500	7600	6.e-002	0.3	0.3	4300	2800	2800

TABLE 61
T800 - TWILL > Orthotropic Strain Limits

Temperature C	Tensile X direction	Tensile Y direction	Tensile Z direction	Compressive X direction	Compressive Y direction	Compressive Z direction	Shear XY	Shear YZ	Shear XZ
	1.12e-002	1.12e-002	8.e-003	-9.1e-003	-9.1e-003	-1.2e-002	2.2e-002	1.9e-002	1.9e-002

TABLE 62
T800 - TWILL > Orthotropic Stress Limits

Temperature C	Tensile X direction MPa	Tensile Y direction MPa	Tensile Z direction MPa	Compressive X direction MPa	Compressive Y direction MPa	Compressive Z direction MPa	Shear XY MPa	Shear YZ MPa	Shear XZ MPa
	1150	1150	50	-620	-620	-170	85	67	67

Data Sheet T800-Twill

T300-Twill

T300 - TWILL > Constants

Density	1.8e-006 kg mm^-3

TABLE 66
T300 - TWILL > Orthotropic Elasticity

Temperature C	Young's Modulus X direction MPa	Young's Modulus Y direction MPa	Young's Modulus Z direction MPa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY MPa	Shear Modulus YZ MPa	Shear Modulus XZ MPa
	64500	64500	6900	6.e-002	0.3	0.3	3200	2700	2700

TABLE 67
T300 - TWILL > Orthotropic Strain Limits

Temperature C	Tensile X direction	Tensile Y direction	Tensile Z direction	Compressive X direction	Compressive Y direction	Compressive Z direction	Shear XY	Shear YZ	Shear XZ
	1.26e-002	1.26e-002	8.e-003	-1.02e-002	-1.02e-002	-1.2e-002	2.2e-002	1.9e-002	1.9e-002

TABLE 68
T300 - TWILL > Orthotropic Stress Limits

Temperature C	Tensile X direction MPa	Tensile Y direction MPa	Tensile Z direction MPa	Compressive X direction MPa	Compressive Y direction MPa	Compressive Z direction MPa	Shear XY MPa	Shear YZ MPa	Shear XZ MPa
	630	630	50	-450	-450	-170	65	63	63

Data Sheet T300-Twill

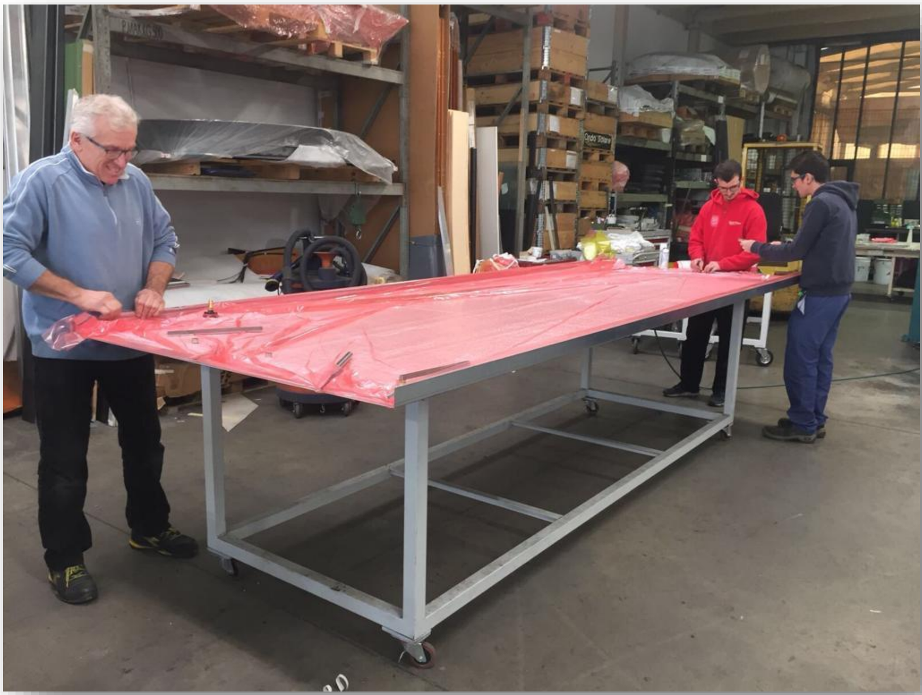
3.3 Building technology

MANUFACTURE

The primary element of CFRP is a carbon filament; this is produced from a precursor polymer such as polyacrylonitrile (PAN), rayon, or petroleum pitch. For synthetic polymers such as PAN or rayon, the precursor is first spun into filament yarns, using chemical and mechanical processes to initially align the polymer chains in a way to enhance the final physical properties of the completed carbon fibre. Precursor compositions and mechanical processes used during spinning filament yarns may vary among manufacturers. After drawing or spinning, the polymer filament yarns are then heated to drive off non-carbon atoms (carbonization), producing the final carbon fibre. The carbon fibers filament yarns may be further treated to improve handling qualities, then wound on to bobbins. From these fibers, a unidirectional sheet is created. These sheets are layered onto each other in a quasi-isotropic layup, e.g. 0°, +60°, or −60° relative to each other.

From the elementary fibre, a bidirectional woven sheet can be created, i.e. a twill with a 2/2 weave. The process by which most CFRPs are made varies, depending on the piece being created, the finish (outside gloss) required, and how many of the piece will be produced. In addition, the choice of matrix can have a profound effect on the properties of the finished composite.

Many CFRP parts are created with a single layer of carbon fabric that is backed with fiberglass. A tool called a chopper gun is used to quickly create these composite parts. Once a thin shell is created out of carbon fibre, the chopper gun cuts rolls of fiberglass into short lengths and sprays resin at the same time, so that the fiberglass and resin are mixed on the spot. The resin is either external mix, wherein the hardener and resin are sprayed separately, or internal mixed, which requires cleaning after every use. Manufacturing methods may include the following.



MOLDING:

One method of producing CFRP parts is by layering sheets of carbon fibre cloth into a mould in the shape of the final product. The alignment and weave of the cloth fibers is chosen to optimize the strength and stiffness properties of the resulting material. The mould is then filled with epoxy and is heated or air-cured. The resulting part is very corrosion-resistant, stiff, and strong for its weight. Parts used in less critical areas are manufactured by draping cloth over a mould, with epoxy either preimpregnated into the fibers (also known as pre-preg) or "painted" over it. High-performance parts using single moulds are often vacuum-bagged and/or autoclave-cured, because even small air bubbles in the material will reduce strength. An alternative to the autoclave method is to use internal pressure via inflatable air bladders or EPS foam inside the non-cured laid-up carbon fibre.

Molding

VACUUM BAGGING:

For simple pieces of which relatively few copies are needed (1–2 per day), a vacuum bag can be used. A fiberglass, carbon fibre, or aluminium mould is polished and waxed, and has a release agent applied before the fabric and resin are applied, and the vacuum is pulled and set aside to allow the piece to cure (harden). There are three ways to apply the resin to the fabric in a vacuum mould.

The first method is manual and called a wet layup, where the two-part resin is mixed and applied before being laid in the mould and placed in the bag. The other one is done by infusion, where the dry fabric and mould are placed inside the bag while the vacuum pulls the resin through a small tube into the bag, then through a tube with holes or something similar to evenly spread the resin throughout the fabric. Wire loom works perfectly for a tube that requires holes inside the bag. Both of these methods of applying resin require hand work to spread the resin evenly for a glossy finish with very small pin-holes.

A third method of constructing composite materials is known as a dry layup. Here, the carbon fibre material is already impregnated with resin (pre-preg) and is applied to the mould in a similar fashion to adhesive film. The assembly is then placed in a vacuum to cure. The dry layup method has the least amount of resin waste and can achieve lighter constructions than wet layup. Also, because larger amounts of resin are more difficult to bleed out with wet layup methods, pre-preg parts generally have fewer pinholes. Pinhole elimination with minimal resin amounts generally require the use of autoclave pressures to purge the residual gases out.

Vacuum Bagging

Autoclave

3.4 Vehicle dynamic and forces

1b - BENDING (CORNER ON 4 WHEELS)

Mf_max = k * Fv * (μ_t * r + ET) =	**1424**	**[N*m]**	% di carico (da prova EECE 324)	0.75	0.5
			Mf_max_% [Nm]	**1067.687**	711.7912
k = safety factor:	2.0	[-]		carico selezionato	
Fv = wheel static load (vertical load):	2412	[N]		da cui derica un CS pari a:	
For TÜV: Fv = 650[kg]				[(1+0,405)*2]*0,75 = 2.1	
In our case: Fv = (((m*g)/2)*% ant + ((m*g)/2)*%post*0.405)					
> we have supposed to transer all the load transversally					
> we are on four wheels					

2a - TORSION (TÜV E/ECE)

Mt = k * Fv * r =	**673**	**[N*m]**
k = safety factor:	1.0	[-]
Fv = wheel static load (vertical load):	2412	[N]

2b - TORSION (BRAKE)

It's possible to assume two different condition:

Brake test 1 (on 4 wheels)		
Fv = ((m*g)/2*% ant + (m*g)/2*%post*0.405)	2412	[N]
Fl = longitudinal load (Fv * μ_l):	2653	[N]
Mt = Torque (Fl * r * k):	**740**	**[Nm]**
Brake test 2 (on 2 wheels)		
Fv = ((*m* **g*)*% ant + (*m* **g*)*%post*0.405)	4824	[N]
Fl = longitudinal load (Fv * μ_l):	5306	[N]
Mt = Torque (Fl * r * k):	**1481**	**[Nm]**

3 - COMBINED (BENDING + TORSION)

Mf_combined = k * Fv * (μ_c * r + ET) =	**2438**	**[N*m]**
Fl_combined = Fv * μ_c	3608	[N]
Mt_combined = Fl_combined * r * k	**2013**	**[Nm]**

> we have supposed to be on only 2 wheels; it's an unusual but probable case

4 - ROLLING LOAD (STATIC) - BY TÜV

Si fissano le superfici di contatto canali/pneumatico e si applica un carico verticale al centro della flangia pari a:

S = safety factor per la presente prova:	2.5	[-]
Fv = carico statico di ruota (carico verticale):	2412	[N]
Carico per Rolling Test (da TÜV):	**6030**	**[N]**

5 - CRASH TEST 5g

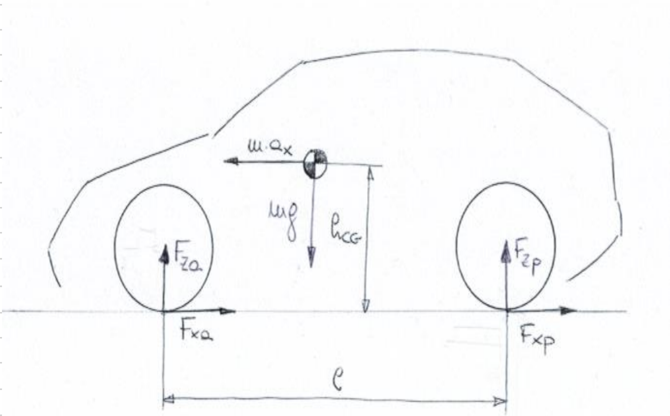
Si fissano le superfici di contatto canali/pneumatico e si applica un'accelerazione verticale (in un sistema di coordinate al centro della flangia) pari a 5g (circa 50000 [mm/s^2]).

6 - CRASH TEST - BY TÜV

Calcolo del carico statico di impatto:

D = 0.6*Fv/g + 1800 [N] =	**2095.05**	**[N]**
dove:		
Fv = carico statico di ruota (carico verticale):	4824	[N]

INPUT			
MASSE (Ipotizzata al 09/2016)			Note
Massa Veicolo:	400.0	[kg]	
Massa occupanti:	320.0	[kg]	
Massa totale "*m*":	720.0	[kg]	
VEICOLO			
Velocità massima	90	[km/h]	
Velocità massima	25	[m/s]	
Passo (l)	2770	[m]	
Semipasso a1	1385	[m]	x
Semipasso a2	1385	[m]	x
Quota baricentro hCG	0.5	[m]	x
PNEUMATICI (Da Datasheet Michelin)			
Diametro	279	[mm]	
Raggio di contatto r	139.5	[mm]	
Coefficiente aderenza	0.8	[-]	Ipotizzato
CALCOLO REQUISITI REGOLAMENTO			
Spazio massimo di arresto	57.6	[m]	
Decelerazione teorica minima	5.425347	[m/s^2]	
Massima decellerazione tecnicamente realizzabile	7.848	[m/s^2]	
CALCOLO RIPARTIZIONE DI CARICO			
Statico - Assale anteriore (Fza)	3531.6	[N]	
	50	[%]	
Statico - Assale posteriore (Fzp)	3531.6	[N]	
	50	[%]	
Trasferimento di carico ΔZ	0.705099	[N]	
Dinamico - Assale Anteriore (Fza)	3532.305	[N]	
Dinamico - Assale Posteriore (Fzp)	3530.895	[N]	
CALCOLO CONDIZIONI LIMITE			
Distacco del posteriore (Ribaltamento)	27173.7	[m/s^2]	
Forza limite aderenza anteriore (Fxa)	2826.096	[N]	
Forza limite aderenza posteriore (Fxp)	2824.464	[N]	
Coppia Frenante massima - Assale anteriore	394.2404	[Nm]	
Coppia Frenante massima - Assale posteriore	394.0127	[Nm]	



We told that the car is submitted by a lot of forces, in particular during the corners and during brake or speed up moments, but it is necessary to tell the input value that takes part at the evaluation.

A lateral tire force originates at the "centre" of the tire contact with the road, lies in the horizontal road plane and is perpendicular to the direction in which the wheel is headed if no inclination or camber exists.

The term side force is frequently used as interchangeable with lateral force but is better reserved for situations involving the complete vehicle.

A vehicle turns because of the applied lateral tire forces.

When we talk about the wheel there are so many variables that influence the performance.

First of all, the diameter.

The diameter is important, a large diameter wheels traverse bumps better than small diameter wheels, but a large diameter however increases car weight and also requires a large reduction ratio between motor and drive wheel, possibly making the design and construction of the transmission more difficult.

To reduce the friction, we can use ball bearings, but it would be possible that the ball bearings takes the form of permanent deformation of the balls and the result of this damage is that the bearing then runs rough with significantly increased friction.

Be especially careful to lubricate bearings with light oil.

Now after this first introduction about the wheels we talk about the forces.

We told that the wheel is submitted by a lot of forces and we took this forces by virtual simulation and real simulation on the previews cars.

On this excel script we analyse some different situation, in particular the most important was the corner with two and four wheels and the brake.

We use for the bending a formula where appears a safe factor: the wheel static load that is divided between front and rear and we have supposed to transfer all the load transversally:

$$\mathbf{Mf\_max = k * Fv * (\mu t * r + ET)}$$

We evaluate the torsion during the brake moment with a formula that consider longitudinal load, the safety factor and the overall diameter:

$$\mathbf{Mt = Torque\ (Fl * r * k)}$$

All in all, we evaluate together this situation and we have supposed to be on only two wheels, it’s unusual but a probable case.

$$\mathbf{Mf\_combined = k * Fv * (\mu c * r + ET)}$$

$$Fl\_combined = Fv * \mu c$$

$$Mt\_combined = Fl\_combined * r * k$$

At the end, we can said that we made this valuation to know the dynamic performance and the forces that submit our car.

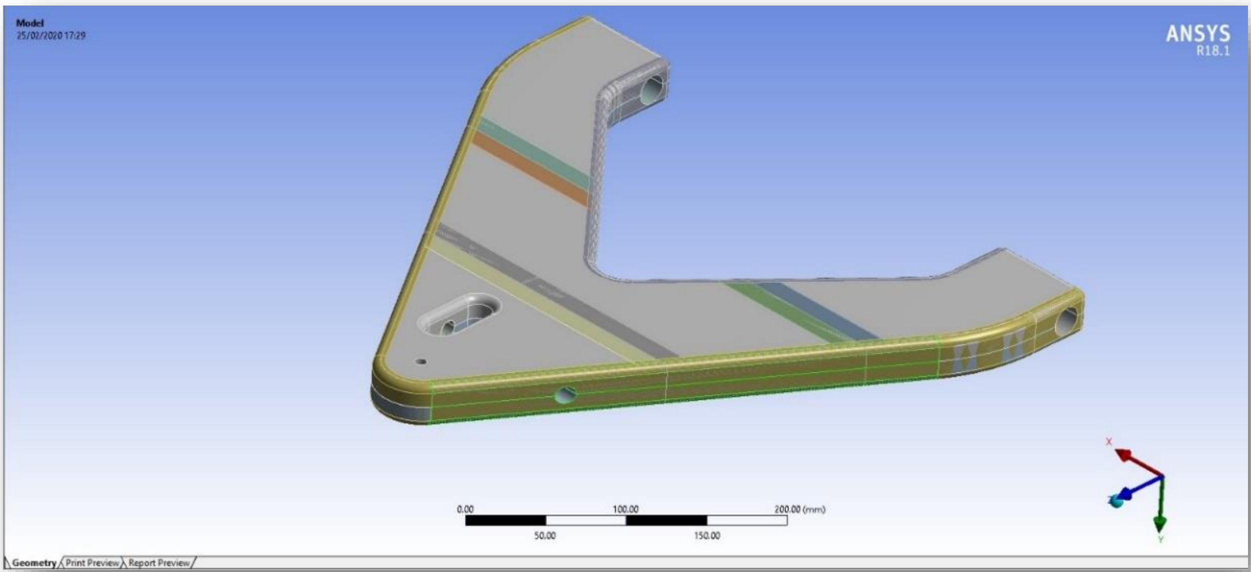
4 *Design development*

4.1 Geometry development with CAD

We use for the development of our component two tips of cad:

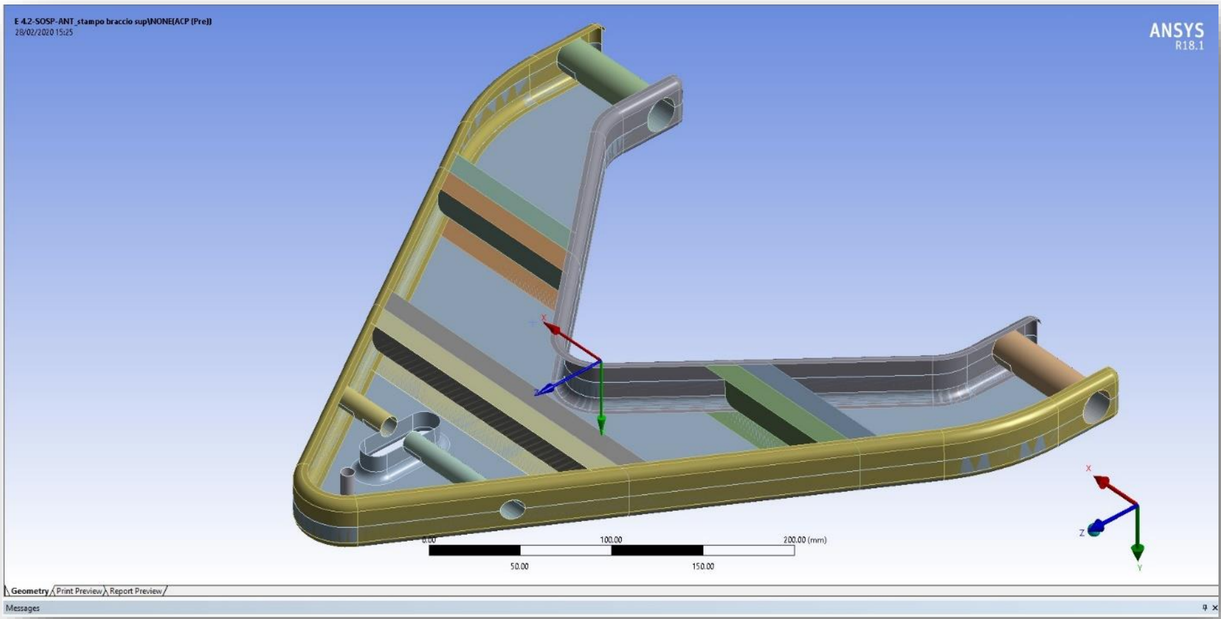
Solidwork and Ansys Workbanch.

The first one has been used to make the drawing of the suspension by Marco Scalorbi that Developed the first metal upgrade that has become the base for the carbon fibre's evolution.



Front suspension-Ansys source

As it is possible to see we used a design to combine hight performance with less weight infact with this semi-triangular form we are able to assign the load along the merge of the body suspension and this feature increases the resistance, but unfortunately isn't enough to bear the forces and we added some supports how it is possible to see in the next picture.



Reinforced front suspension

We added some transversal supports to balance the torsion of the component, because it is a three-dimensional component and it means that you must control not only the vertical and diagonal curve but also the torsion, and it is a very hard work for the engineering. Infact you have one more degree of freedom and the component is less rigid then a traditional suspension like Macpherson strut or usually A-Arm or multi-link suspension but at the same time it gives more motivation to the developer.

4.2 Basic operating procedures in Ansys

We spoke about a multiple use of CAD, but we didn’t speak about how it works.

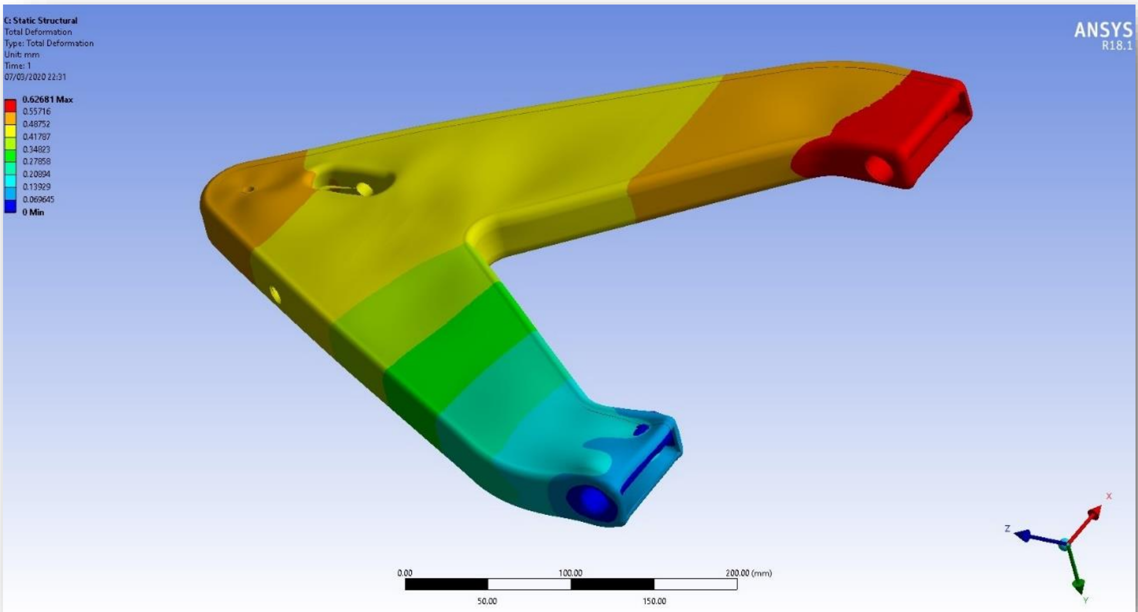
First of all, a CAD, in particular Ansys, is an analysis software which enables you to solve complex structural engineering problems and make better, faster design decisions. With the finite element analysis (FEA) solvers available in the suite, you can customize and automate solutions for your structural mechanics problems and parameterize them to analyse multiple design scenarios.

The finite element method (FEM) is the most widely used method for solving problems of engineering and mathematical models.

The FEM is a particular numerical method for solving partial differential equations in two or three space variables.

The FEM subdivides a large system into smaller, simpler parts that are called finite elements. This is achieved by a particular space discretisation in the space dimensions, which is implemented by the construction of a mesh of the object: the numerical domain for the solution, which has a finite number of points. The finite element method formulation of a boundary value problem finally results in a system of algebraic equations.

Differential equations can not only describe processes of nature, but also physical phenomena encountered in engineering mechanics. These partial differential equations (PDEs) are complicated equations that need to be solved in order to compute relevant quantities of a structure (like stresses, strains, etc.) in order to estimate a certain behaviour of the investigated component under a given load. It is important to know that FEA only gives an approximate solution of the problem and is a numerical approach to get the real result of these partial differential equations. Simplified, FEA is a numerical method used for the prediction of how a part or assembly behaves under given conditions. It is used as the basis for modern simulation software and helps engineers to find weak spots, areas of tension, etc. in their designs. The results of a simulation based on the FEA method are usually depicted via a colour scale that shows for example the pressure distribution over the object.



Result of a simulation based on the FEA method

4.3 Ansys design explanation

We talked about how Ansys works and now it's time to explain how we used Ansys.

At the beginning we took the first step of the project on Solidworks and we made some adjustments to have the necessary features to do the upgrade to the carbon fibre technology.

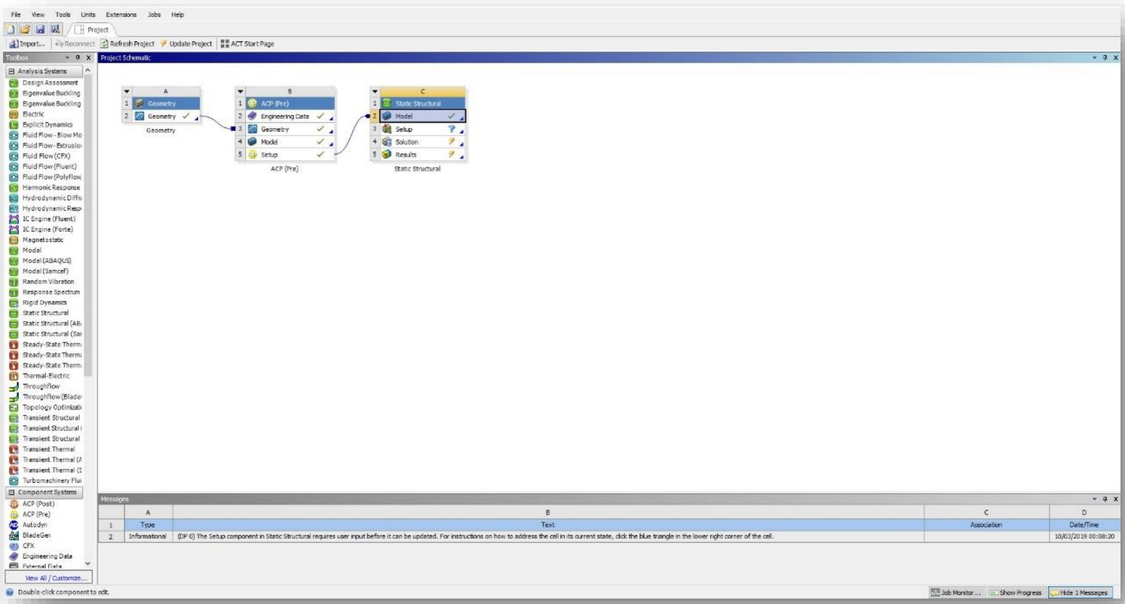
Now, it is time to upload the Solidworks design on Ansys.

We used the static structural division that is the division that calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads.

A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads.

Static analysis is used to determine the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects.

Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time.



Screenshot of Static structural division

As it is possible to see on the screen, Ansys Structural includes a lot of different function that you can use, step by step, to create your model like the real component that you need to test.

We import the geometry with the box A "Geometry".

In this box we can fix the little blemish for example the merge or the surface that not combined exactly. It is very important to fix this problem because this structure is the base when you have to work on the next step to create your simulation and if you make a little mistake now it would be very difficult to fix in a second moment.

Now we are ready to link the box A with the box B.

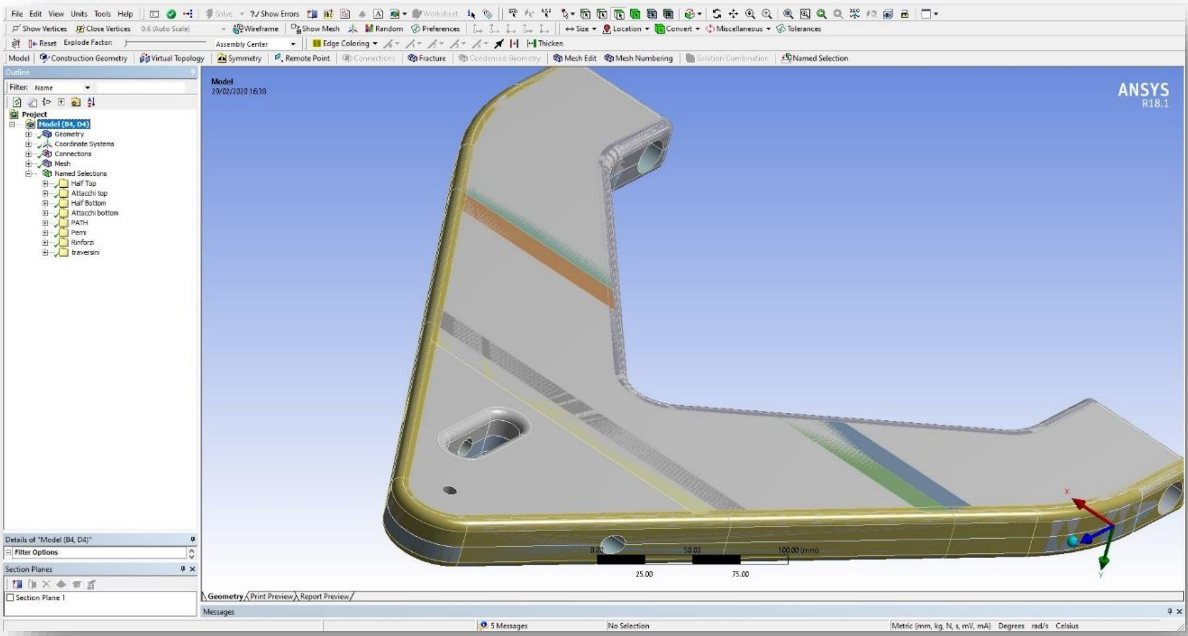
In this box we put inside the tool ACP.

This tool is divided in 2 parts:

ACP(Pre) and ACP(Post) and inside this, there is Static Structural.

The ACP (PrepPost) is a dedicated tool for composite layup modelling and failure analysis. You can generate layered composite models for implicit and explicit structural and thermal, as well as fluids, simulations. ACP provides efficient layup and solid element modelling capabilities.

In the ACP (Pre) we import the geometry with a link in "Geometry", and after deciding some external aspects in Engineering Data, like materials(we used only TWILL-T300/T800) or temperature and so we are ready to create a Model.

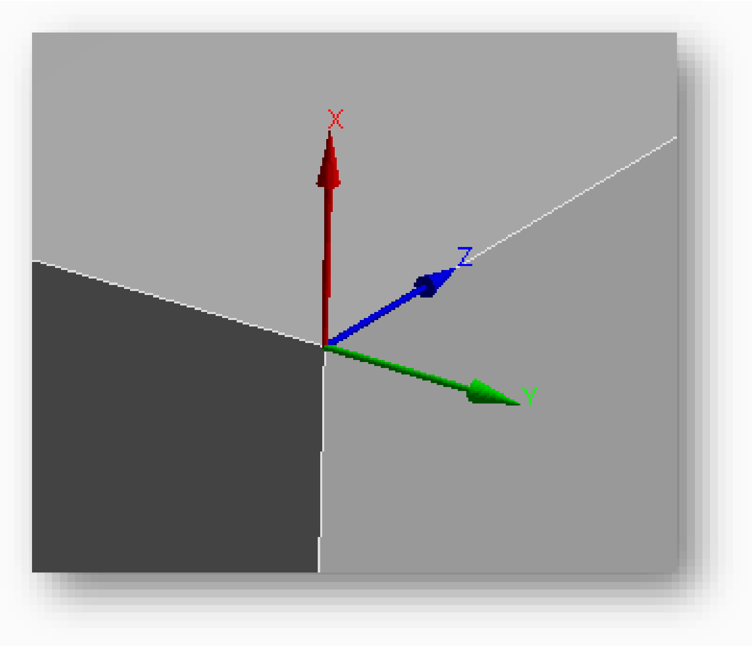


Model Screen shot

In the Model Tool we can import the geometry and after that we can insert the coordinate systems, the connections and then we are ready for the mesh.

Coordinate systems are one of those things that are fundamental to Finite Element Analysis.

Ansys cares a lot about coordinate systems because they allow the program to solve in a standard, global, Cartesian system while allowing loads, constraints, material directions, layer information, beam sections, joints, result values, and a whole slew of other important aspects of the model to be specified in unique coordinate systems.



Coordinate System

Connections are important because they are necessary to connect different layers and edges and to have just one piece that reacts to the forces.

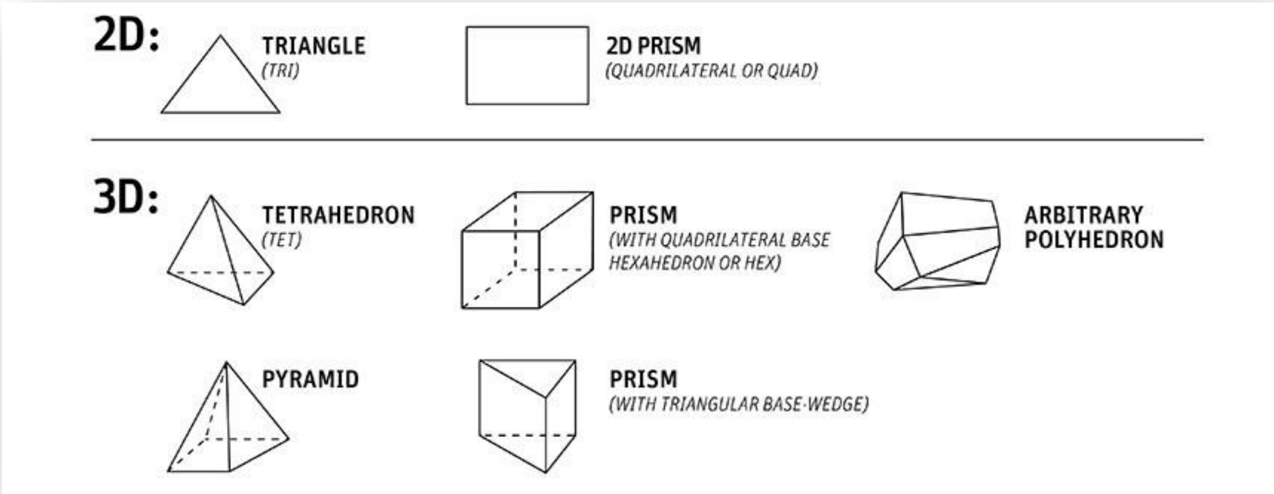
Now it is time to make the mesh.

Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh influences the accuracy, convergence and speed of the simulation.

Ansys provides general purpose, high-performance, automated, intelligent meshing software which produces the most appropriate mesh for accurate, efficient multiphysics solutions.

Methods available cover the meshing spectrum of high-order to linear elements and fast tetrahedral and polyhedral to high-quality hexahedral and Mosaic.

You must be careful in particular on the edge, the most critical part of the component, infact the program have to cover edges or corner (that have an angle) with tetrahedral and/or polyhedral and it is impossible if you stay in a normal mathematical field.



Common Type of Meshing

All in all, it is the round of Named Selections.

Named Selections are interesting because you can create some different groups of elements that you can recall in the next tools, for example when you want to create a particular fibre orientation or get in line the layers and then it is difficult to make a good choice because you have to imagine what you have to need in the future.

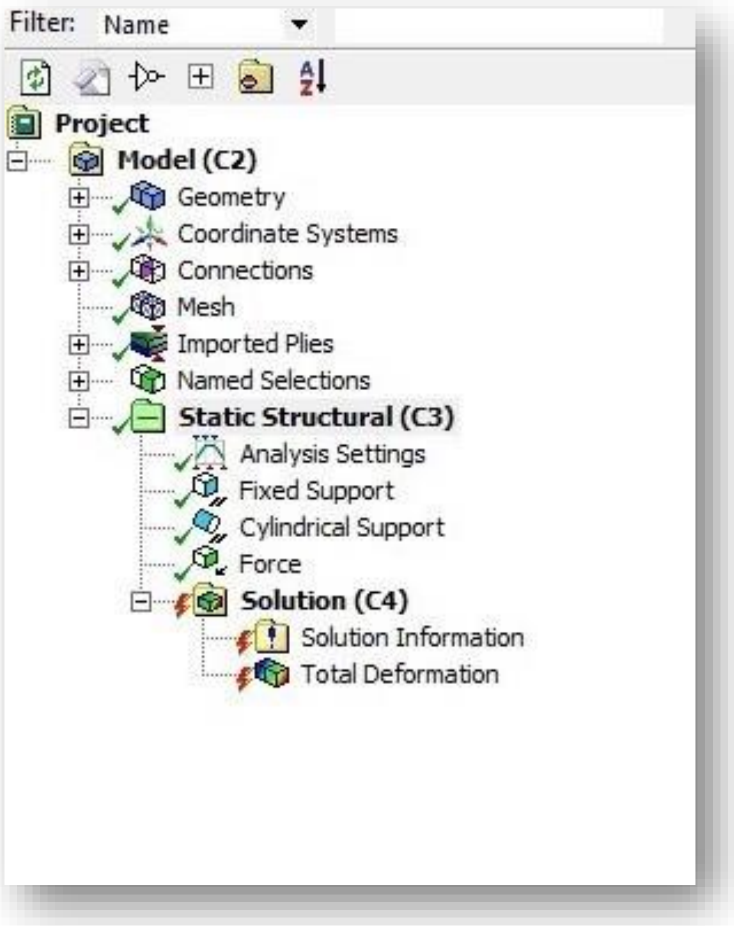
Now it is time to compile our model the bottom “setup”.

That’s right, the second box is Finished.

It’s time to talk about the static structural.

We arrive at the static structural with the link from setup that comes in model.

We don’t repeat the functions and features of “Model” and we talk about Setup, Solution and Results.



Static Structural screen

In this phase we can decide where we want to apply the forces or fix strategies points to reproduce the reality. This is a very important step because if you fix a wrong point or edge or if you apply forces in different points than reality you will have a wrong answer from your component and maybe you won't analysed or won't find the most critical parts.

We used a support to fix our component when it takes the forces.

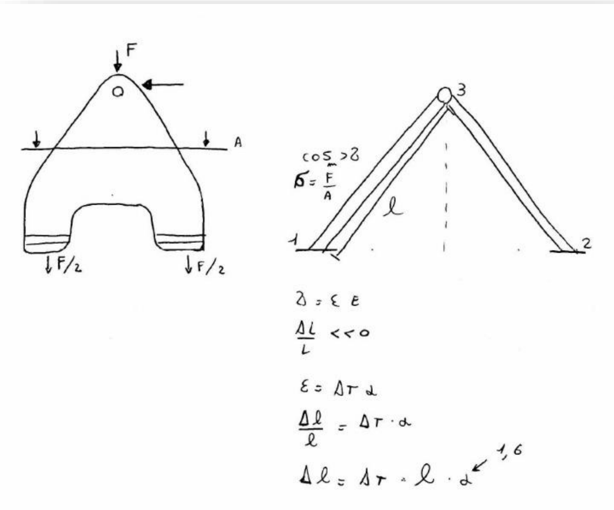
We fixed radial translation using a constraint on cylindrical support, it is important to imagine what are the constraints on the real component to simulate the contortion direction.

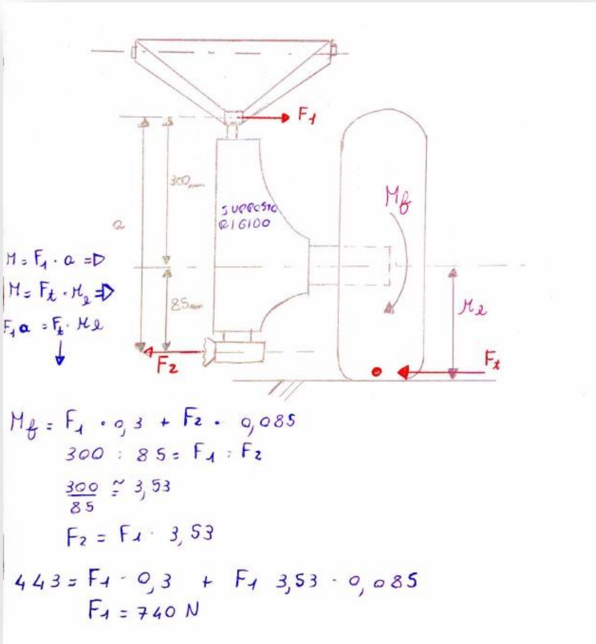
We fixed axial translation of both of cylindrical supports because on the car they are attached to the chassis and they can't move perpendicularly to the car, but suspension's front is able to move up and down on the bumps.

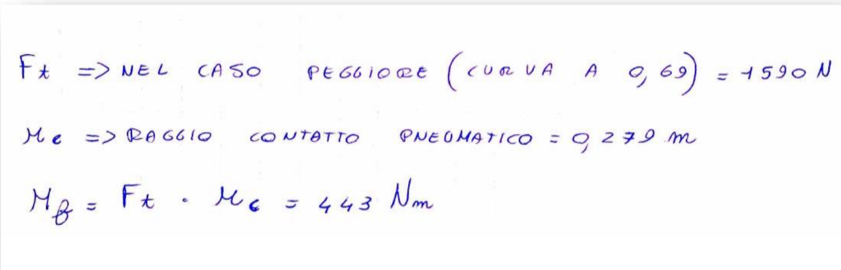
TABLE 54
Model (C2) > Static Structural (C3) > Loads

Object Name	*Cylindrical Support*	*Displacement*	*Cylindrical Support 2*	*Force*
State	Fully Defined			
Scope				
Scoping Method	Geometry Selection			
Geometry	1 Face	1 Edge	1 Face	
Definition				
Type	Cylindrical Support	Displacement	Cylindrical Support	Force
Radial	Fixed		Fixed	
Axial	Free		Free	
Tangential	Fixed		Free	
Suppressed	No			
Define By		Components		Components
Coordinate System		Global Coordinate System		Global Coordinate System
X Component		0. mm (ramped)		-1590. N (ramped)
Y Component		Free		0. N (ramped)
Z Component		Free		0. N (ramped)

As it is possible to see on the table, we put the lateral force in the front of suspension, and we estimate its intensity in 1500N, with the following equations.





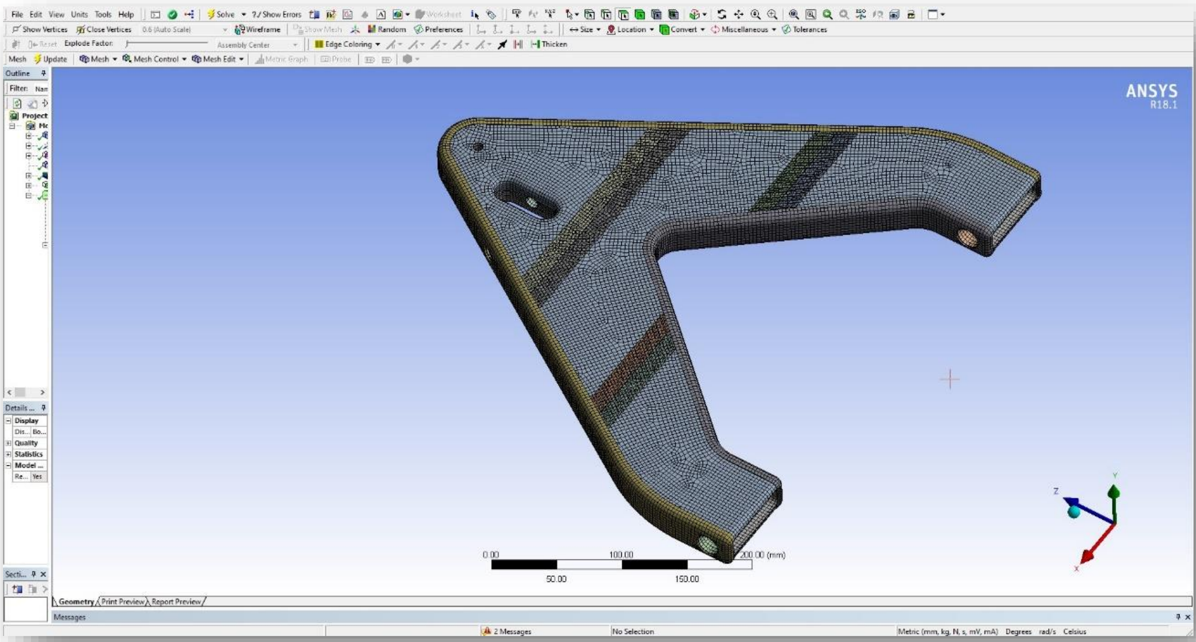


We take the value of wheel and support directly on the car, because we use the geometry of the old suspension also for the new ones.

The base of the facts used on the preview equations it is the outcome of experimental values that derive of tires and car data sheet.

This moment is very important also for finding mesh error.

Infact, when ansys develops the result it uses the mesh, if the mesh is not good there is a possibility that the component will be more resistant or fragile and that the results aren't truth.

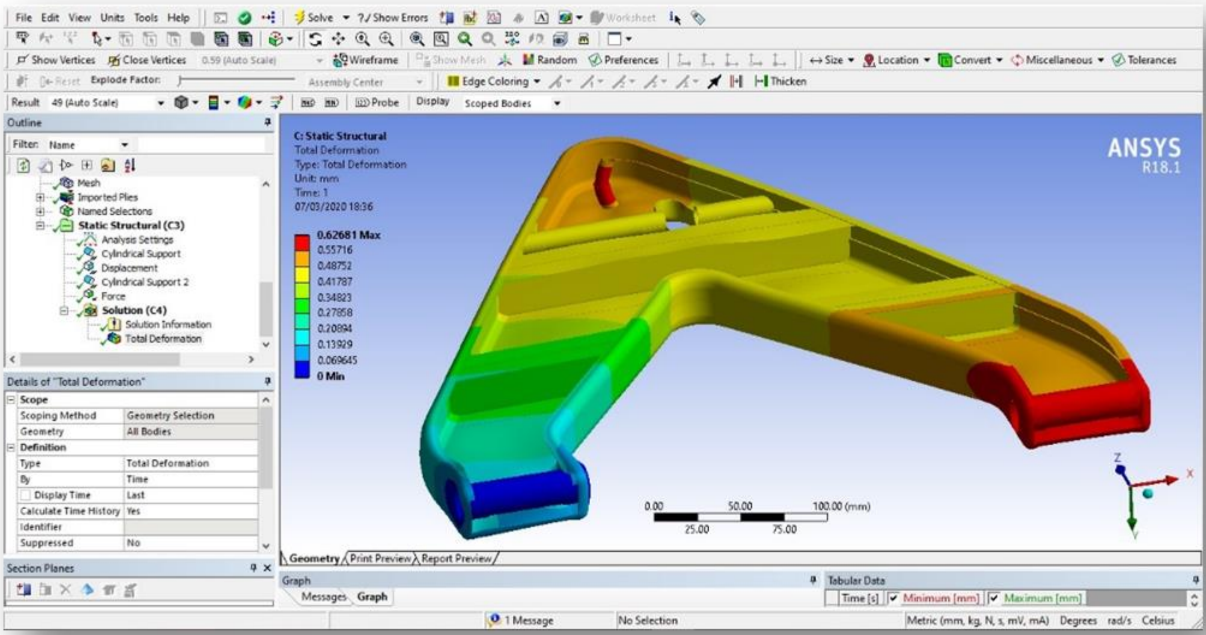


Mesh example

Well done, now we can see the results, that are described with different colours in connection to the forces and deformations. It is one of the most characteristic appearance of the mesh simulator in general.

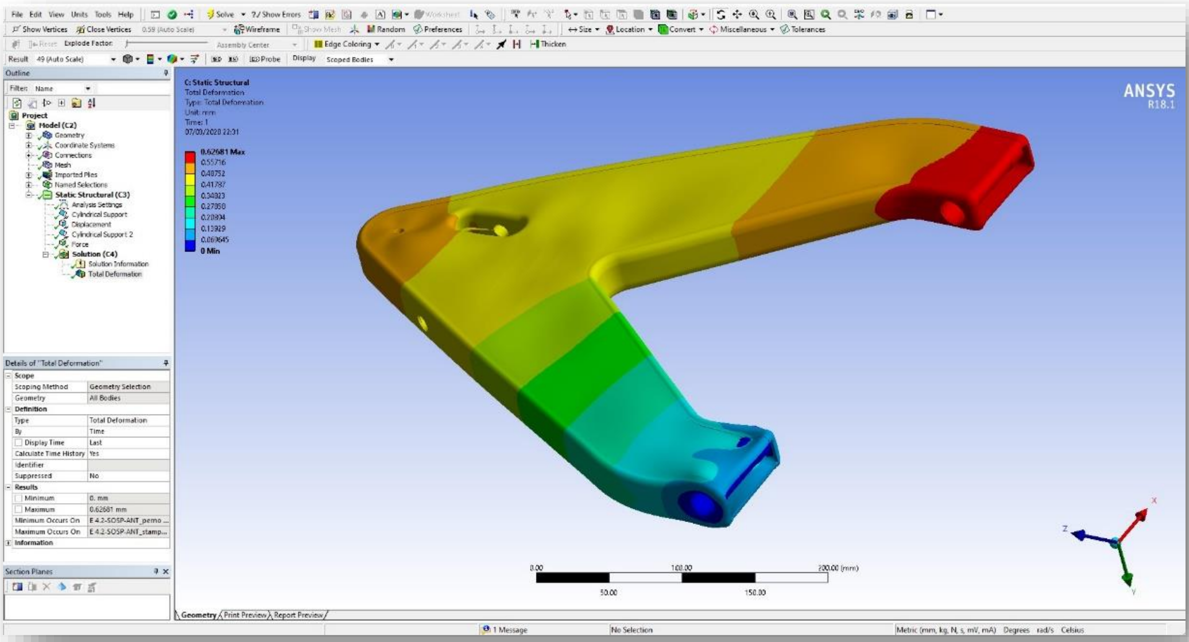
Now we link the Static Structural with ACP(Post) or rather we link Engineering Data, Geometry and Model from ACP (Pre) to ACP (Post) and Solution with Result.

In "Result" we can see the critical aspects and we take stock of the component, where we have to increase the resistance or where it is oversized. It is the most important moment because you can understand if the component it is strong enough but it is difficult to evaluate this, because you need to have a very powerful computer that is able to do the calculus and especially you have to do all preview steps corrected. At the end of the simulation we realized that the component, even on the worst condition, is able to resist at the forces and don't have an overstate deformation. We can see on the screen with red colour the maximum disfiguration that is in order of 0.63mm.



Ansys simulation

We keep attention when we analysed the result at the hollows on the top and bottom surfaces and in our case, along the junction because it is the most fragile part of our suspension and obviously where it is easier to have a creep.



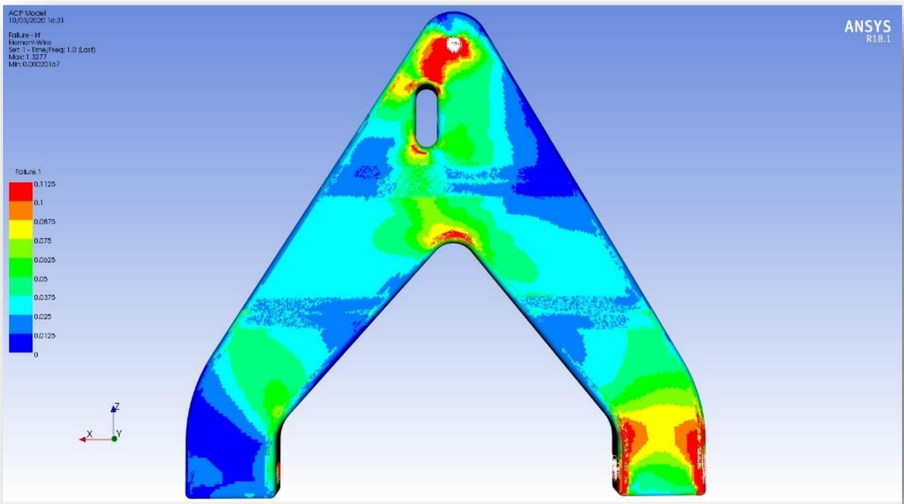
Ansys simulation

The numerical results of our test are in the following table:

TABLE 57
Model (C2) > Static Structural (C3) > Solution (C4) > Results

Object Name	*Total Deformation*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	0. mm
Maximum	0.62681 mm
Minimum Occurs On	E 4.2-SOSP-ANT_perno posteriore 2\NONE(ACP (Pre))
Maximum Occurs On	E 4.2-SOSP-ANT_stampo braccio sup\NONE(ACP (Pre))
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Solution

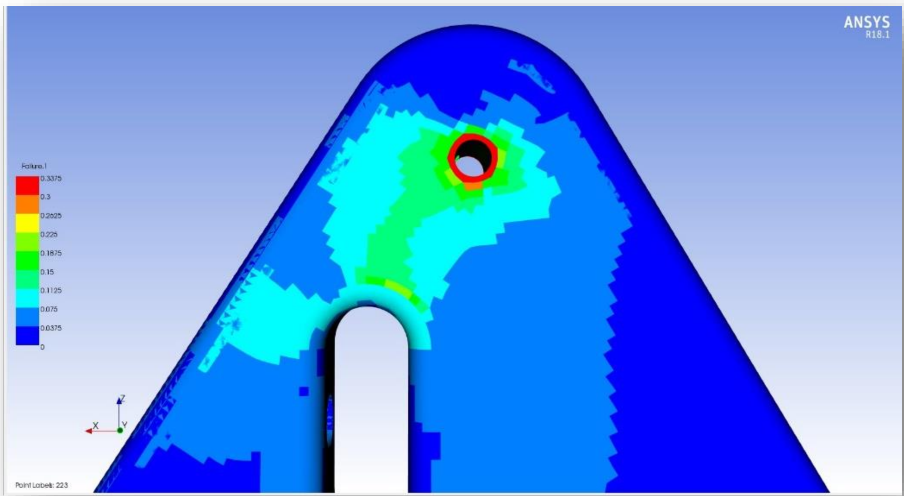


All in all, in ACP (Post) we can evaluate the margin to failure with reserve factor.

The critical values of reserve factors lie between zero and one, whereas the non-critical values range from one to infinity. Whether the results are shown in numeric form or as contour plots, the non-critical values tend to be emphasized in comparison to critical values. Therefore, the inverse reserve factor IRF is often preferred in practical use:

IRF=1/RF

The non-critical values of IRF range from zero to one and the critical values from that point on. The IRF range is associated with different colours.



IRF Particular

5 *Production*

5.1 Production and carbon fibre lay-up

We did the carbon fibre lamination in a depot near Bologna.

The first step is to take the mould and put it inside the resin and attempt some hours, because it's necessary that the resin dries off.

After that you can take the carbon fibre and put them inside the mould.

It is very important that the carbon it's not too cold, because you need to activate the resin and it is necessary that the carbon sheet is big enough to cover all the mould.

After that it's time to put other resin with a brush over the carbon fibre and make more layer.

SUPERFICI	POSIZIONE	N° LAYERS	SPESSORE (mm)	CARBONIO	SPESSORE TOTALE (mm)
Body Sospension					1.75
All surfaces	Top	1	0.25	Tw-T800	0.25
All surfaces	Bottom	1	0.25	Tw-T800	0.25
Bordo Verticale	/	3	0.25	Tw-T800	0.75
All surfaces	Top	1	0.25	Tw-T800	0.25
All surfaces	Bottom	1	0.25	Tw-T800	0.25
Pivot					0.46
All surfaces	/	2	0.23	Tw-T300	0.46
Crossbeam					0.46
All surfaces	/	2	0.23	Tw-T300	0.46
Support					1.38
Verticale	/	2	0.23	Tw-T300	0.46
Verticale + Raccordo	/	2	0.23	Tw-T300	0.46
All surfaces	/	2	0.23	Tw-T300	0.46

Now we can put the components inside the sack and put them in the autoclave for some hours.

It is necessary that the bag it's perfect, without dumps because it must be watertight. Now, if we have made a good job, we should have a perfect carbon fibre suspension.

6 *Conclusion*

6.1 Advantages and comparison between new and old suspension

We spent a lot of time and a lot of words to describe the component but now it's time to explain what are the difference from the old ones. The biggest difference is the weight, we have a racing car and anyone knows that is necessary to have the lightest car possible, in particular if you take part in a solar race where the goal is the efficiency.

Aluminium Suspension

The second reason of the carbon fibre is the engineering evolution, infact we want to have not only the faster car, we want the best and more exotic car and if you want to follow this objective you need to take some risks and try to use new technology with all parts as much as possible. In the end we are in love with the carbon fibre, if a team has table and bench in carbon fibre it's a normal consecution that they have a carbon fibre suspension.

Front Suspension Bottom

Front Suspension Top

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In the end I would like to say that these people are extremely important but you need to find motivation inside your soul every morning to finish your own journey.

I want to close this work with two basic phrases that describe this travel.

-VOLARE BASSO PER VEDERE PIU' LONTANO

-SE DEVI CORRERE BEH, ALLORA VAI DA SOLO, MA SE VUOI VIAGGIARE ALLORA FALLO IN COMPAGNIA

THANKS, GRAZIE!

Marco Pintossi, 2020