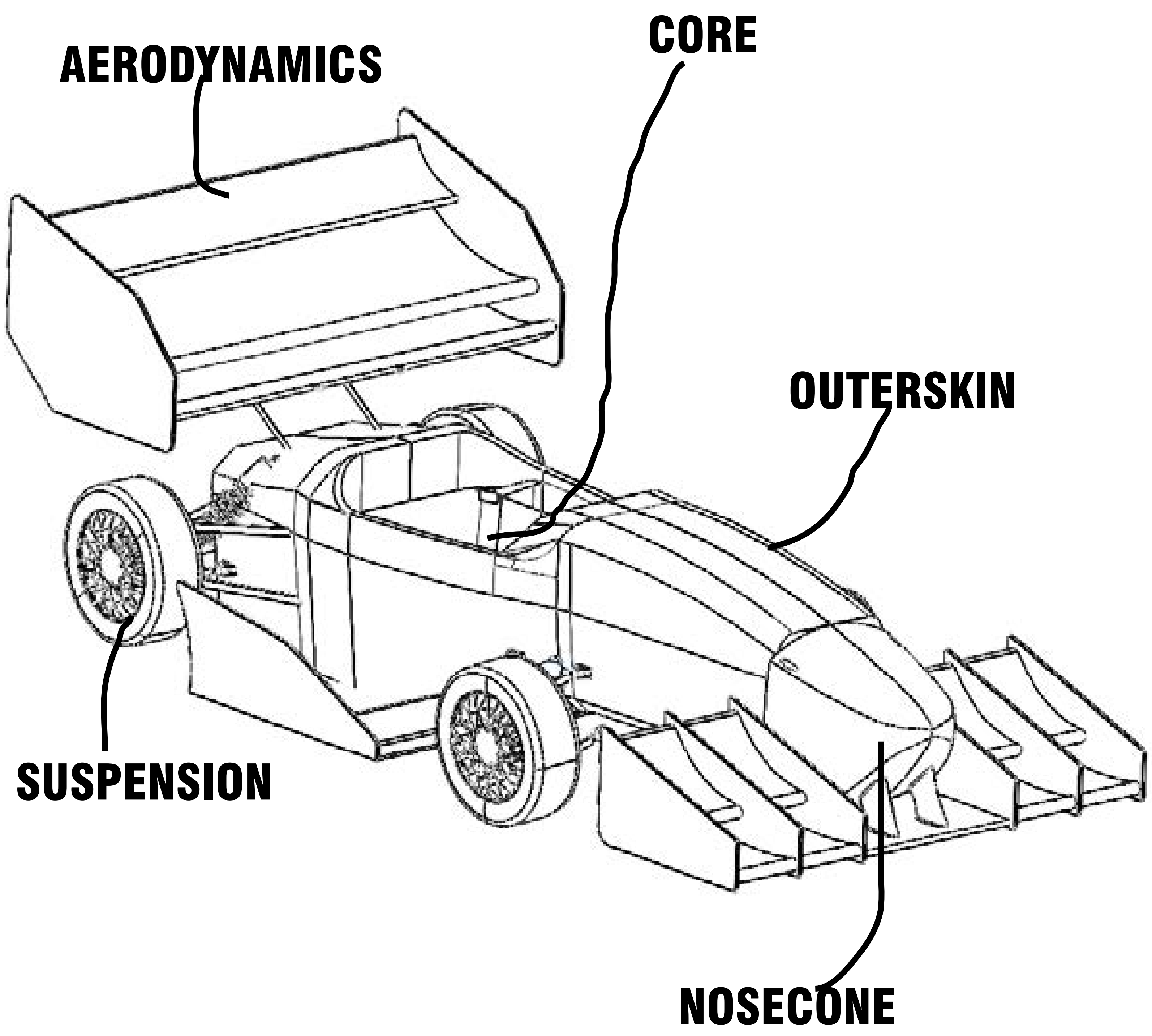
MONOCOQUE

Clara Ghattas MEng FYP
Project Summary

OVERVIEW



Benefits

WEIGHT SAVINGS

UGR's car weight without the driver is currently at 235kgs, compared to Revolve's 159kgs. The bulk of that weight is chassis difference.

ADDED STIFFNESS

SSF designs tend to be stiffer yes, however they add stiffness with no benefit. A monocoque will lower the overall stiffness, but be lighter so it levels out, and the layups can be explicitly designed to provide the right stiffness for the car, without excess stiffness and therefore weight.

SLEEKER DESIGN

The freedom to design without solid limitiations as in a SSF, as all attachments have to be through the nodes, whereas the monocoque attachments can be wherever you plan for them with an insert.

ADDED KNOWLEDGE

CFRP manufacturing is new for the university engineering teams, and adding that experience to the knowledge base will only be a benefit.

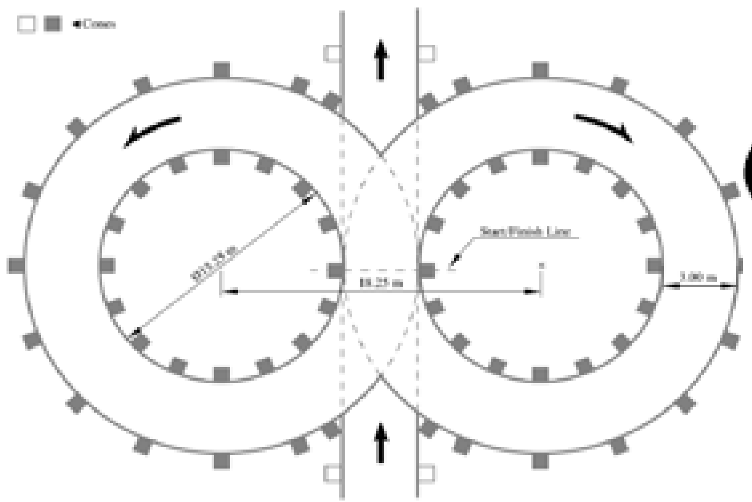
THE OPPORTUNITY

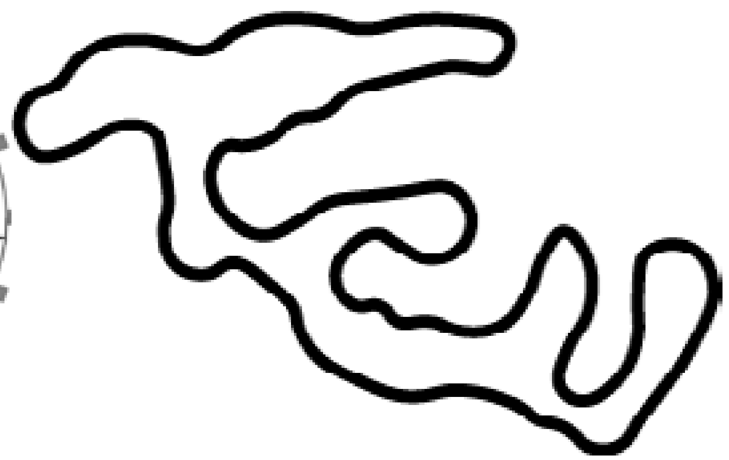
“I SAW DEATH COMING”
- Romain Grosjean

Those were the words uttered by Romain Grosjean after coming face to face with death in what was one of the worst crashes Formula 1 had ever seen. Despite being engulfed by violent flames at the edge of the circuit during the Bahrain GP in 2020, Grosjean rose like a phoenix out of the flames and ashes. The reason for his survival? The carbon fiber reinforced polymer (CFRP) monocoque chassis and halo that surrounded him.

Formula Student

Formula Student is, as the name suggests, the student version of F1. While it does not quite have 1.5 billion viewers that F1 has, FS accommodates aspiring engineers from over 20 countries and more than 600 universities. It is the biggest engineering competition out there for students, and one of the best ways to gain experience of working in engineering before having obtained a degree.





The current UGRacing chassis is a super heavy steel space frame. To remain competitve, UGRacing must advance like their peers into using a carbon fiber chassis. This upcoming year their chassis will be a hybrid carbon fiber monocoque with a steel space frame rear, to minimise weight but also to minimise the cost.

In future, UGRacing will move onto a full monocoque, to increase perfomance and chance of winning.

1% Decrease in Mass = 0.2% decrease in laptime

With the average steel space frame weighing around 50kgs and the average monocoque weighing around 20kgs, this could mean a decrease of 12% of the lap time.

This is a MASSIVE gain for any team, especially when UGRacing are already a competitive team within the UK.

The benefits of moving from a steel space frame to a monocoque are undeniable. With a 12% decrease in lap time, you are looking winning the competition not just placing in the top 5.

Project Goals

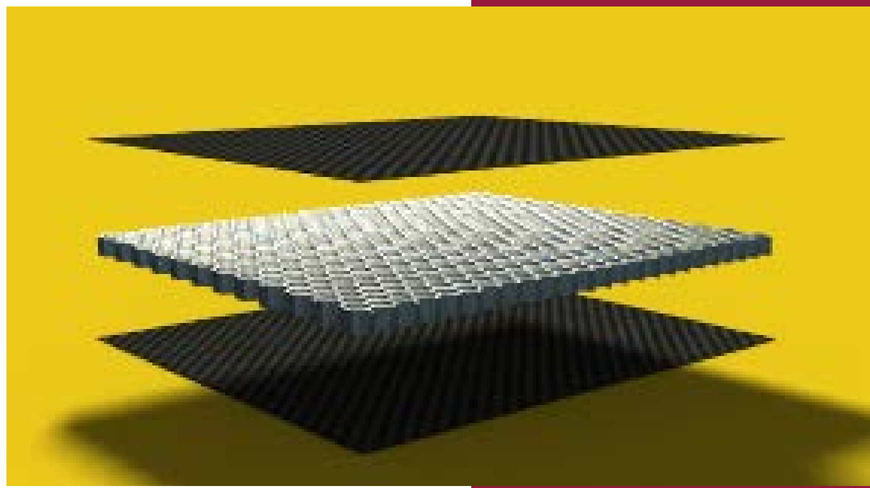
There are currently no other Scottish formula student teams that make a CFRP monocoque. To take on this challenge, would continue to push Glasgow over the edge in terms of competitiveness in the UK, and also maintaining their number 1 spot in Scotland.

The aim is to provide a feasible design and how the different areas of monocoque design work together to make the part that holds together the rest of the car.

The aim by the end of the project is to manufacture and make a small scale prototype to show the manufacturing process.

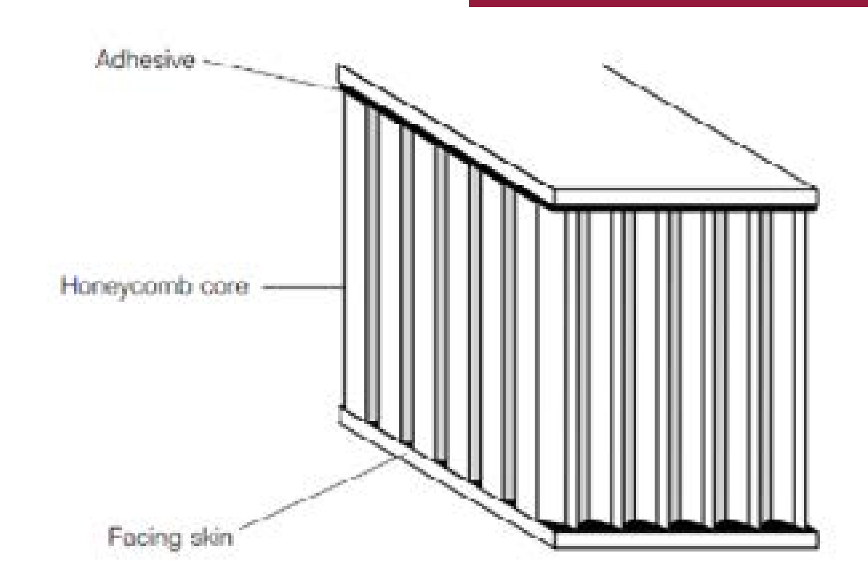
CARBON FIBER REINFORCED POLYMERS

Carbon fiber reinforced polymers are the most common fibers that are used in aerospace and motorsports. They are known for their super strength to weight ratio, and have improved the performance and efficiency of many aerodyanamic products over the years.



CFRP's fall under the polymer matrix composites (PMC) category. This is the most common category of composites, especially for use in the F1 and FS industries. The PMC's use a polymer based matrix such as resin or epoxy and fibers such as carbon, glass and aramid as the reinforcement.

Both the matrix and the reinforcement do not show particularly desirable properties on their own, but joined together they create exceptional results. Without the matrix, the fiber is only effective along its length, like the fibers in a rope. With the matrix, the load that is applied to the composite is spread between the individual fibers, and so the matrix also acts as a protective barrier from damage.



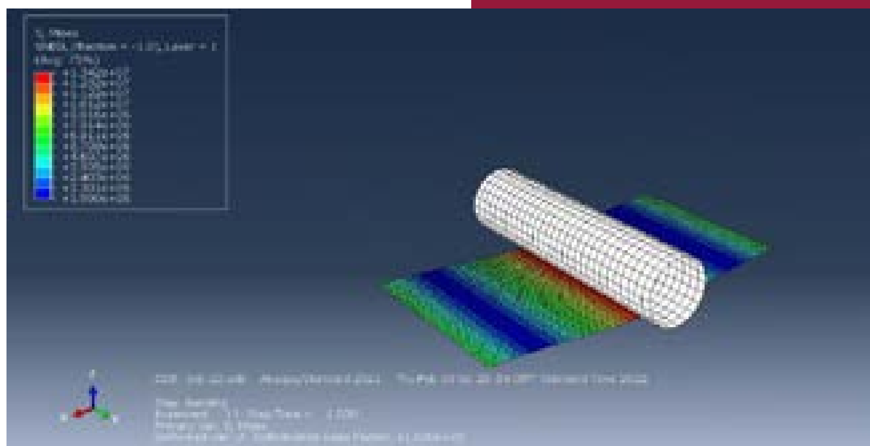
The main modes of failure in CFRP's are:

Maximum Stress Criterion

Maximum Strain Criterion

Tsai-Wu Criterion

Hashin Criterion



RESEARCH

Vehicle Dynamics

Vehicle Dynamics describes the characteristic behaviours in a vehicle when responding to an environment change. As the tyre is the only point of contact a race car has on the track, it is important to understand how the rest of the connected sprung and unsprung mass reacts to these changes.

Suspension

In a vehicle, the suspension exists to help with the vehicle handling, and improve the quality of the ride. Similar to how in composite layup design, the weight and stiffness are often at odds with each other, having to compromise one for the other, it is the same for suspension handling and quality. The suspension helps the driver concentrate the grip to specific tyres by controlling how the weight shifts while performing specific tasks. When a driver accelerates the weight shifts to the rear, and the opposite is true for breaking.

The suspension if soft will result in a higher body roll due to it compressing more, and a smoother ride, and if hard will result in a stiffer body, but a rough ride. When designing for a chassis, roll is the most important to account for. The torsional stiffness of a chassis should be approximately 4x the roll stiffness set by vehicle dynamics to be able to work the best with the suspension.

Torsional Stiffness

The Torsional Stiffness determines the roll angles of the front and rear axles and how close they get in parameters during cornering. The parameters that affect the torsional stiffness are:

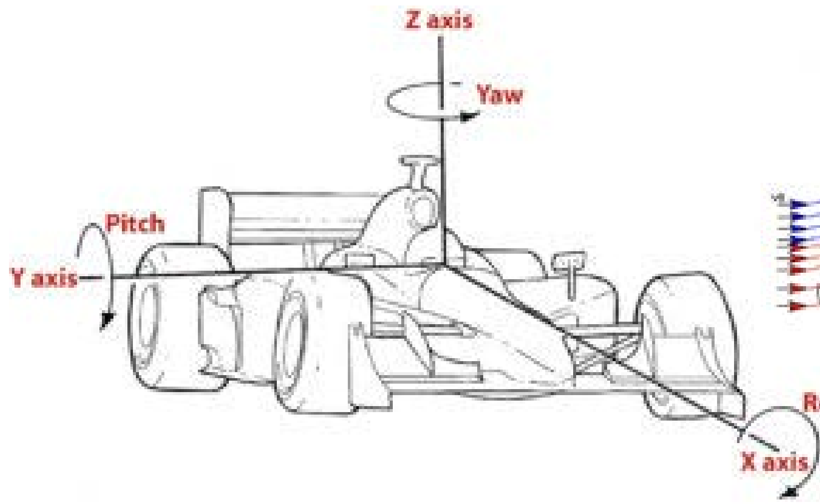
- The roll stiffness
- Static weight distribution of sprung mass
- The roll centre axis
- Weight distribution of unsprung masses
- Aerodynamic forces

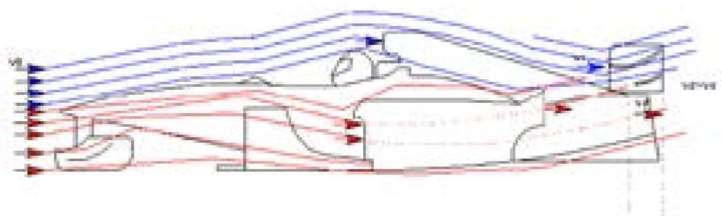
Vehicle Dynamics

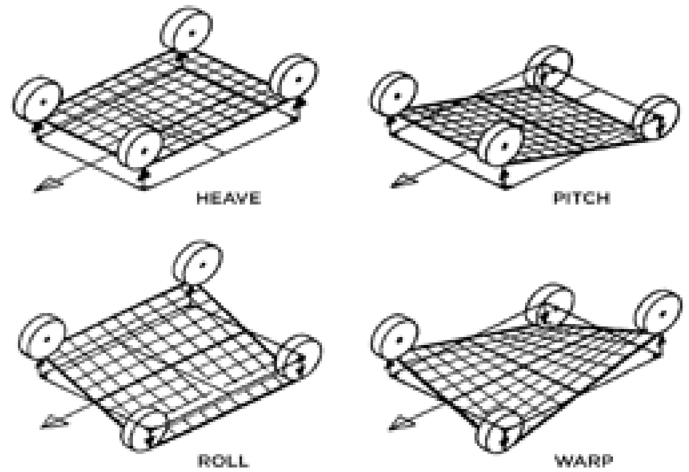
Inserts are what connect the suspension, main hoop, and anything else that needs attached, to the monocoque.

The attachment points and inserts have a lot of forces going through those points in the monocoque so there is a lot of engineering required in the dimensioning to make sure the inserts do not fail. It has happened before that an insert was under-dimensioned and a part got ripped out of the monocoque while in use. The inserts are a massive safety component so they are designed with a error margin in place.

Insert theory can be found in the European Space Agency handbook for insert design.





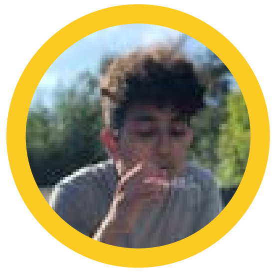


CONCEPT DEVELOPMENT

Rules

For every competiton, and even for Formula 1, there are a set of rules that the car has to be compliant with. The cars at competitons go through intense scrutineering and any car that doesn't pass just one stage does not get to compete.
The rules are the bread and butter of what teams design. Throughout the year teams can send in something called FAQ's to the judges, which are clarifications on specific rules.

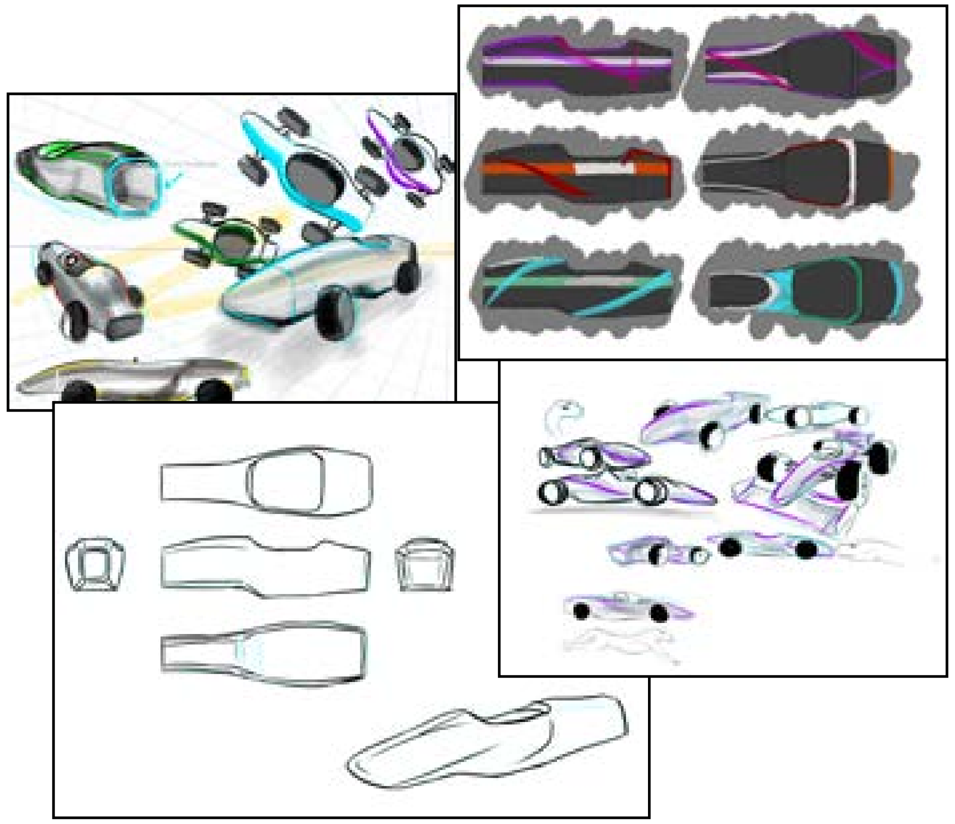
User Insight



Testing the design with users of different sizes to get their experience and adapt the model based on their feedback.
This along with the driver dimensions provided me with an accurate representation of key user stakeholders, to be able to iterate designs.

I also got some expert feedback from former collegues at Revolve who are now working in relevant industry such as Formula 1.

2D Exploration



2D sketches let me discover geometry and shapes without getting too stuck into the rules and what was and was not allowed. It opened the door up to more variety, and also the chance to design with biomimicry in mind.

It also formed the foundation for the first steps of aesthetic design for the end of the project with the final prototype.

2D exploration is quick and easy and does not take any effort.

This also helps me to see what all the options in front of me are

3D Exploration

3D modelling on SolidWorks and with small prototypes allowed me to visualise concepts to users and to myself without having to spend money and effort on physically making something large and having it be wrong.

My brain thinks in CAD modelling so this stage for me was the most fruitful, and I was able to see the issues with the templates and fix them before making final moulds.

PRODUCT DESIGN SPECIFICATION

Function
- To keep the driver safe
- To keep the other parts contained within the chassis

Performance
- Less than 20kg without main hoop
- Torsionally stiffer than 3000 N/Degree
- Get CG as low as possible.
- Have a weight distribution of 50-52% to the rear with the driver
- Not have more than 10% deviation between the model and reality

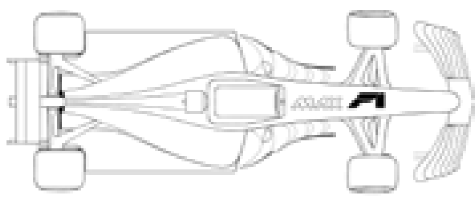
Ergonomics
- Build the drivers environment around the driver

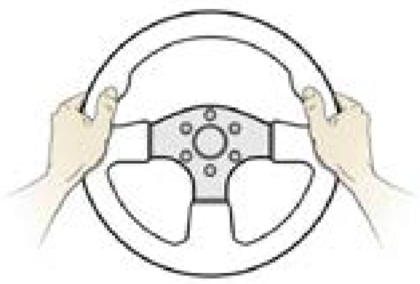
Aesthetics
- High quality surface after manufacturing without post processing.
- Plan for paint only on the surfaces where manufacturing surface wasn't the best.

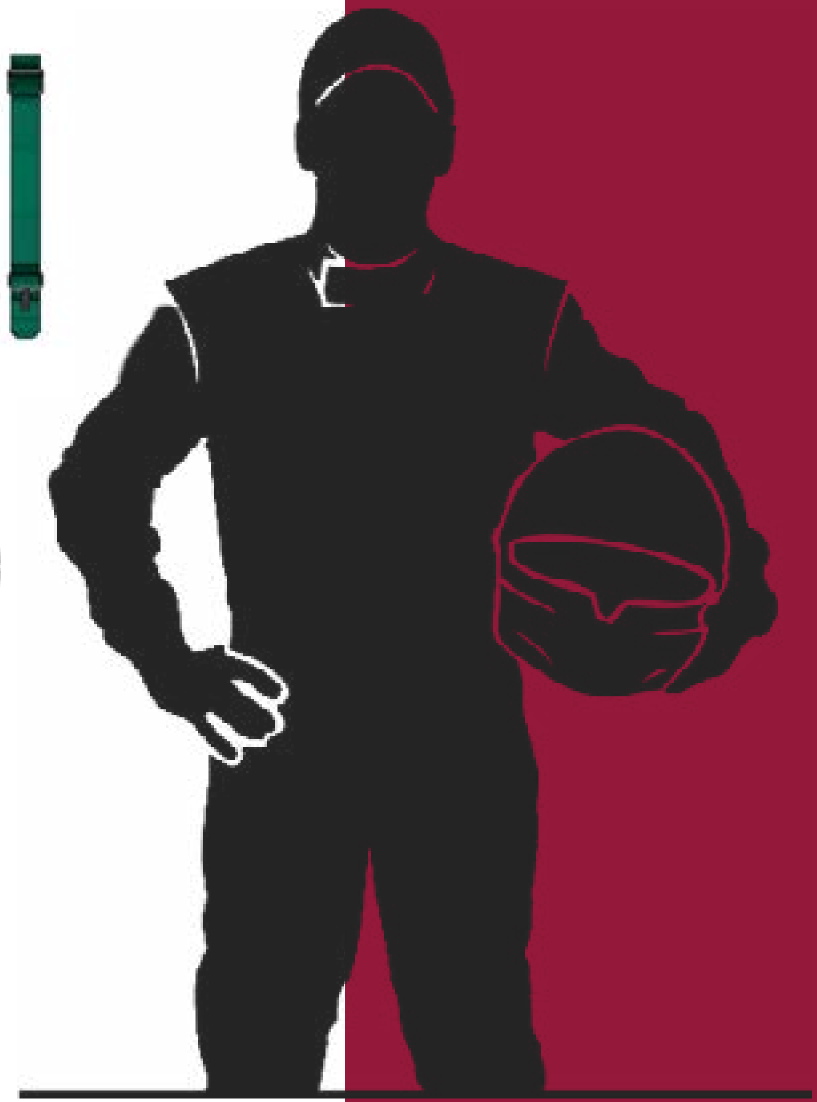
Manufacturing
- Keep manufacturing under a month for full scale team
- Break down and simplify the manufacturing process

Safety
- Strong enough to not break under suspension loads
- Firewall to separate driver from battery and combustable electronics
- Ensure manufacturing is safe

USER INTERACTIONS







The Drivers

The drivers interact with the car only through the cockpit. As a designer i have to ensure that the cockpit area is comfortable enough for the entire range of movement that they do, especially as the high G's make the experience uncomfortable already.

Things like ensuring the belts are hitting the drivers at a comfortable but safe angle fall within the scope of this project as it is related to the SES.

The Manufacturers

The other user for the monocoque is the people manufacturing. They arguably interact more than the drivers do. The manufacturers need a car that is easy enough to make.

The user experience of that usually parts that are hard to make, especially as a new member or group in the team. For that reason, the tooling has been changed into a 4 piece tooling instead of the standard 2 piece tooling, as one of the biggest issues is demoulding at the end of the process.

MATERIALS

Layups

The layups in a formula student race car have a direct effect on the overall performance. They are what define the torisonal stiffness, and the weight. Every panel on the car is defined by the rules as well.

The panels are shown below from the rules, with the baseline tube that the panels need to be made from.

When making a CFRP monocoque, there is a Structural equivalency spreadsheet (SES) that needs to be filled in to prove equivalency to those baseline tubes.

Fiber Selection

The clear winner from the matrix is DT120
Torsional stiffness of the same layup on same CAD but with two different materials:

These two fibers are produced with a DT120 matrix.

T800 : 2063 N/Degree

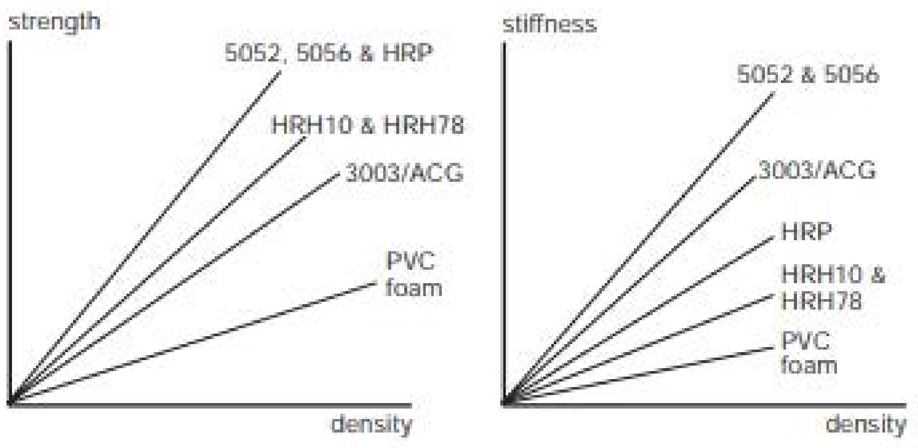
M46J : 2653 N/Degree

The winner between the two fibers is M46J. By using M46J, the overall stiffness of a SES panel will increase by ~40%. The difference in E-modulus is 29 Gpa with 66 Gpa for T800 and 95 GPa for M46J

Core Selection

To maximise performance and weight savings, different cores should be used for different areas depending on the SES requirements.

Strength and Stiffness of different cores



To improve shear test results, a higher density ALHC core could be used, for example a 98 density honeycomb instead of a 71 density one.

Using 98 density core in places like the FBH, ACPR and SHB where the SES demands are a lot more than everywhere else, will massively overshoot the UTS results compared to what is needed.
Changing the density in the SES gets better results for those areas.

Using something like ALHC 51 and IGF foam core for those unregulated areas will also decrease the weight. For areas that are complex and hard to make with honeycomb but are regulared, RIST 110 foam core can be used instead of honeycomb. It is denser than 98 honeycomb so it passes in the SES but it also adds weight, so should only be used sparingly.

DT120

M46J

Structure	thickness outer skin [mm]	outer skin layup	core material and thickness	inner skin layup	thickness inner skin [mm]
MHBT	1.48	45/0/UD0/0/UD0/0/UD0/45/	ALHC 71 20 mm	/0/UD0/UD0/UD0/45	0.79
FHBF	1.48	45/0/UD0/0/UD0/0/UD0/45/	ALHC 71 20 mm	/0/UD0/UD0/UD0/45	0.79
FBH	2.94	UD/0/45/0/45/	ALHC 98 20 mm	/45/0/45/UD/0/45/UD/0	1.47
FBHS	1.03	0/45/UD0/45/0/	ALHC 71 30 mm	/45/0	0.46
SIS vertical	1.03	0/45/UD0/45/0/	ALHC 71 30 mm	/45/0	0.46
SIS horizontal	0.46	0/0/	ALHC 71 20 mm	/0/0	0.46
ACPS	1.26	0/45/0/UD0/45/0/	ALHC 71 30 mm	/45/UD0/0/0	0.8
MHBS	1.26	0/45/0/UD0/45/0/	ALHC 71 30 mm	/45/UD0/0/0	0.8
SHB	1.61	0/0/0/0/0/0/0/	ALHC 98 20 mm	/0/0/0	0.69
SIS hor. 2	1.61	0/0/0/0/0/0/0/	ALHC 71 10 mm	/0/0/0/0/0/0/0	1.61
FHBR	0.45	45/UD0/UD0/	ALHC 71 20 mm	/45/UD0/UD0	0.45
TSPS	2.3	0/0/0/0/0/0/0/0/0/0/	ALHC 71 30 mm	/0/0/0/0/0/0/0	1.61
ACPR	2.3	0/0/0/0/0/0/0/0/0/0/	ALHC 71 30 mm	/0/0/0/0/0/0/0	1.61

MANUFACTURING

The Plug

The plug is the male mould that the female tooling is made from. It is the exact dimension and geometry of the outer surface of the monocoque. The plug is sanded, coated, and polished before production. It can be made from many materials, like MDF, aluminium, PU.

The plug surface needs to be the best quality, as the quality transfers to the outerskin of the monocoque, so care is taken with post processing. It is sometimes beneficial to have the outer most part of the plug as a good quality material, but fill the center of it with a not as good material, to save money and keep the quality.

The plug is 5 axis milled by external companies. In my case this company is CA Models.

The Tooling

The tooling is then layed up on the plug. It is a good idea to have the tooling be a material that reacts similarly to the material that will be used for the monocoque, as the tooling material if different, will react differently to heating, and could deform the monocoque.

For this reason, aluminium tooling is not recommended as it has a much higher rate of thermal expansion than carbon fiber, at six times higher. Tooling fiber like the Toray HX43 fiber should be used for the best results. 3K tooling

monocoque fiber, than the 12K tooling fiber, so this should be the first layer.

Before fiber is layed on the plug, it needs to be sealed and released so that all the micro scratches and disparities are sealed up for a smoother surface, and released so that the monocoque fiber does not bond to the tooling.

The Monocoque

The monocoque is layed up and put into an autoclave or oven after bagging in the following order:

Outerskin

Inserts

Core

Innerskin

Joint