
KEPLER
RACING
DESIGN & ENGINEERING PORTFOLIO

CONSTRAINTS AND CONCEPT

Analysing

Before designing the car, it is important to get familiar with the constraints applied by the Technical Regulations. All of the regulations have to be met in order not to obtain penalty points, which could be the difference between winning or loosing.

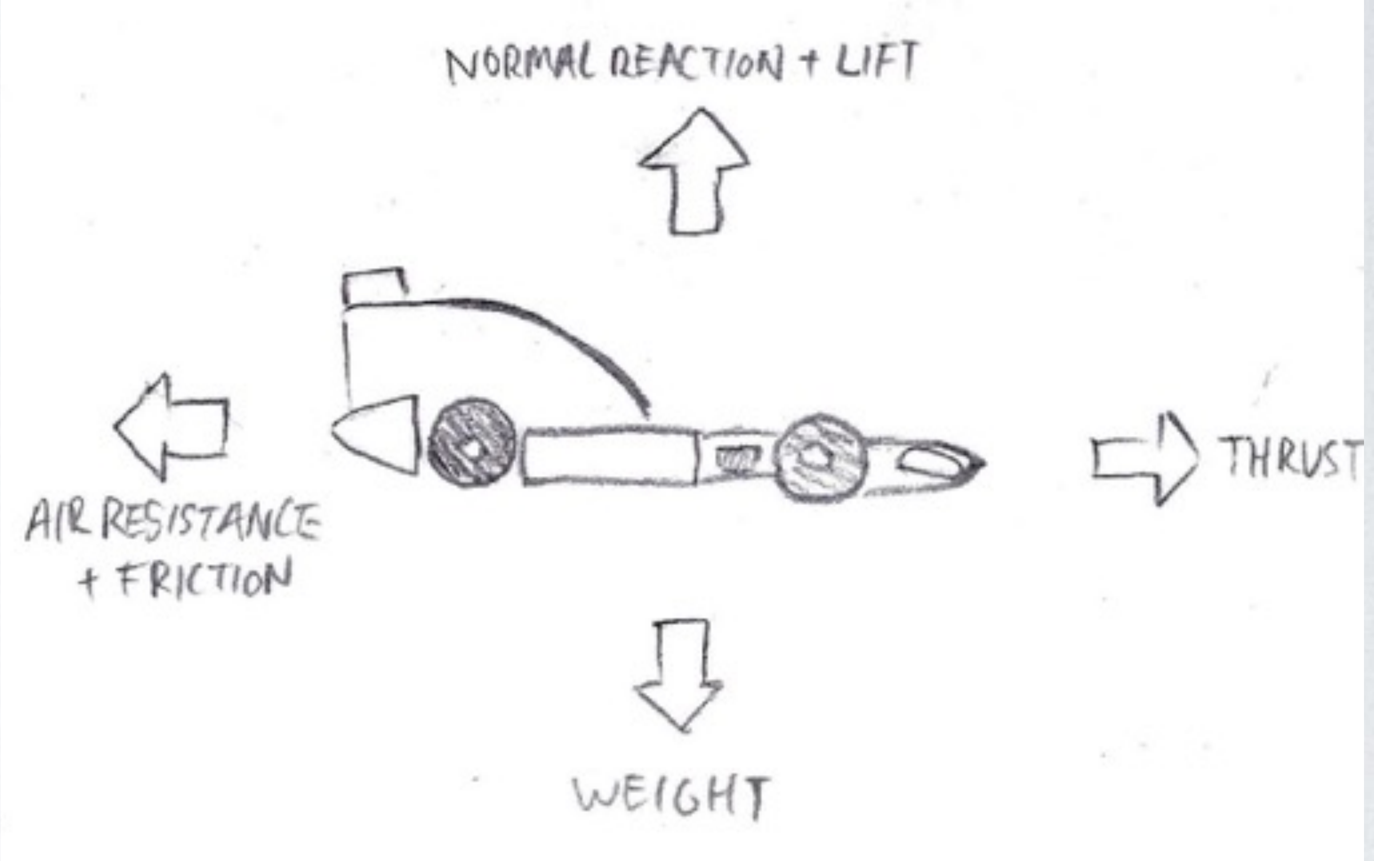
Important Constraints

Car length being between 170-210 mm,
Car width being at max. 85mm,
Total weight (without the CO_2 gas cylinder) being min. 55.0g,
Track clearance being min. 2mm,
Exclusion zones within a volume of 15mm immediately rear of either front wheel,
Wheel diameter being between 26-34mm,
Wheel width being between 15-19mm,
Regulations for the front and rear wings,
Regulations for the CO2 chamber.

Analysing the Task

The next step involved analysing the details associated with the manufacture of the car. They should be consistent with the Technical Regulations and the performance needs to be maximised as much as possible.

These problems included:
Looking at forces exerting on the car
How different forces can be optimised and how they affect the performance of the car
Testing and looking for optimal solutions



Concept Behind the Design

We focused on 6 different forces exerting on a car:
Weight
Thrust
Normal Reaction
Friction
Air Resistance
Rolling Resistance
The different forces that will act on the car during the race. The forces are resolved into horizontal and vertical forces. The diagram above is a diagram showing the forces

ANALYSING THE FORCES

Weight

The weight of the car is dependent on the density of the materials used and the amount of volume they take up. As not many factors affect the mass and the whole body has to be made from balsa wood, this is the force that cannot be massively manipulated.

However, the mass should be kept at a minimum to provide maximum acceleration ($a = F \div m$) at the beginning of the race.

Thrust

The thrust is created by the high pressurised gas escaping from the CO2 canister. The thrust is the effect of Newton's Third Law. The magnitude of this force will be the same for all of the teams.

Normal Reaction

The reaction force determines the magnitude of friction. The reaction force is variable and will change in a way in which there will be no overall vertical force acting on the car. At the beginning of the race it will be equivalent to the weight of the car, but once the car is moving and a lift force is created, the reaction force will gradually decrease.

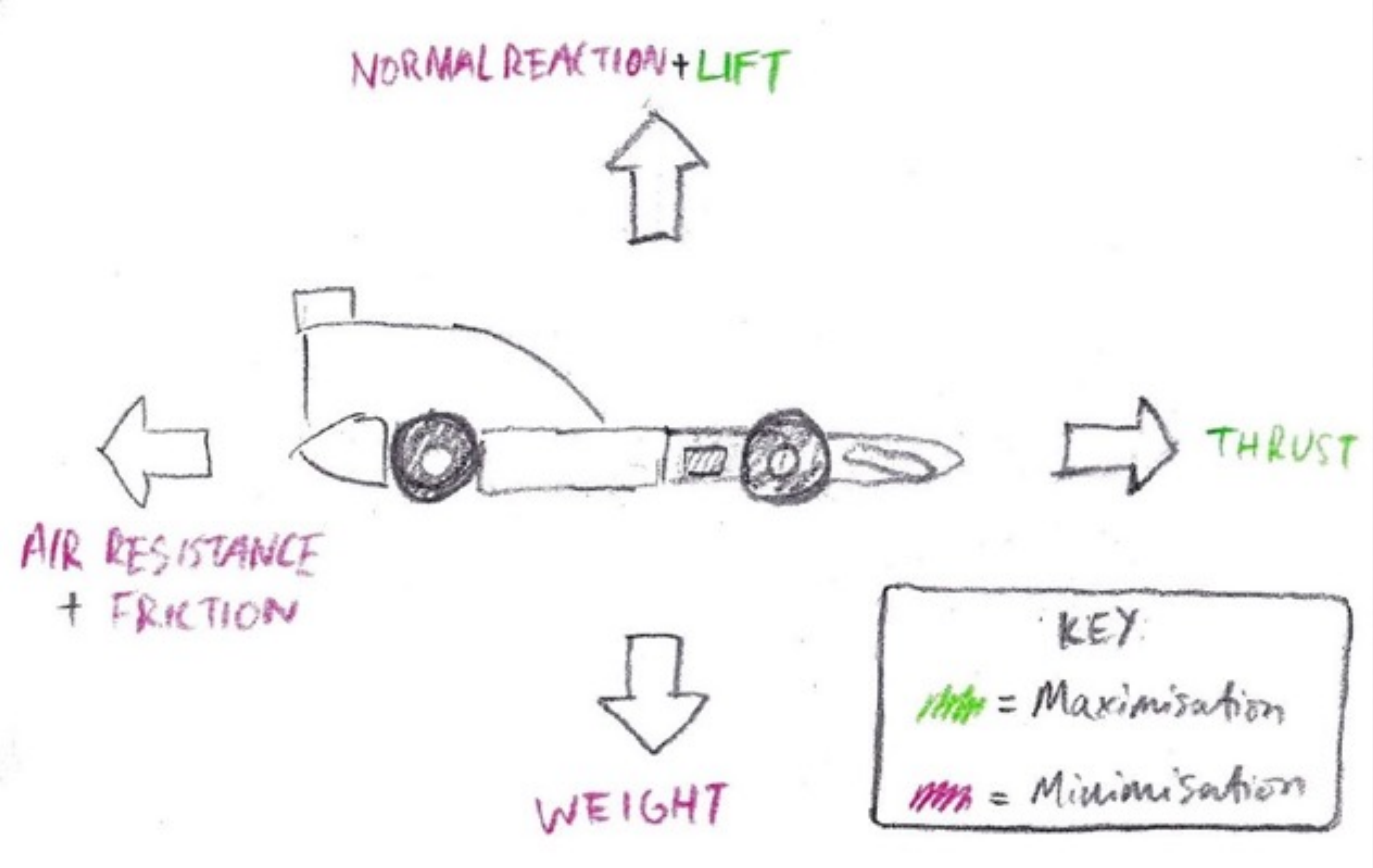
Friction

Friction is dependent on the reaction force, surface area and the coefficient of friction between the wheels and the track surface. As the wheels have to be free to rotate, the friction has to as small as possible.

However, when the speed is fast, the car would be lift up and stay away from the track surface. Therefore, no friction is generated. However, we also do not want the car to fly so there has to be a compromise.

Air Resistance

The air resistance is dependent on many factors (angle of attack of the airflow, surface area, difference of pressures created, the shape of the components of the car). This is the force that can be easily manipulated. It is crucial to get the design of the front of the car right. The air needs to flow smoothly around the car and turbulence has to be eliminated or minimised.



Optimisation of Forces

The mass of the car needs to be minimised to reduce the reaction force. A smaller mass will also mean greater acceleration at the beginning of the race.

The horizontal component of the air resistance has to be reduced to minimum.

The lift has to be increased to reduce the reaction force.

The friction has to be reduced to minimum.

The rolling resistance has to be kept at minimum.

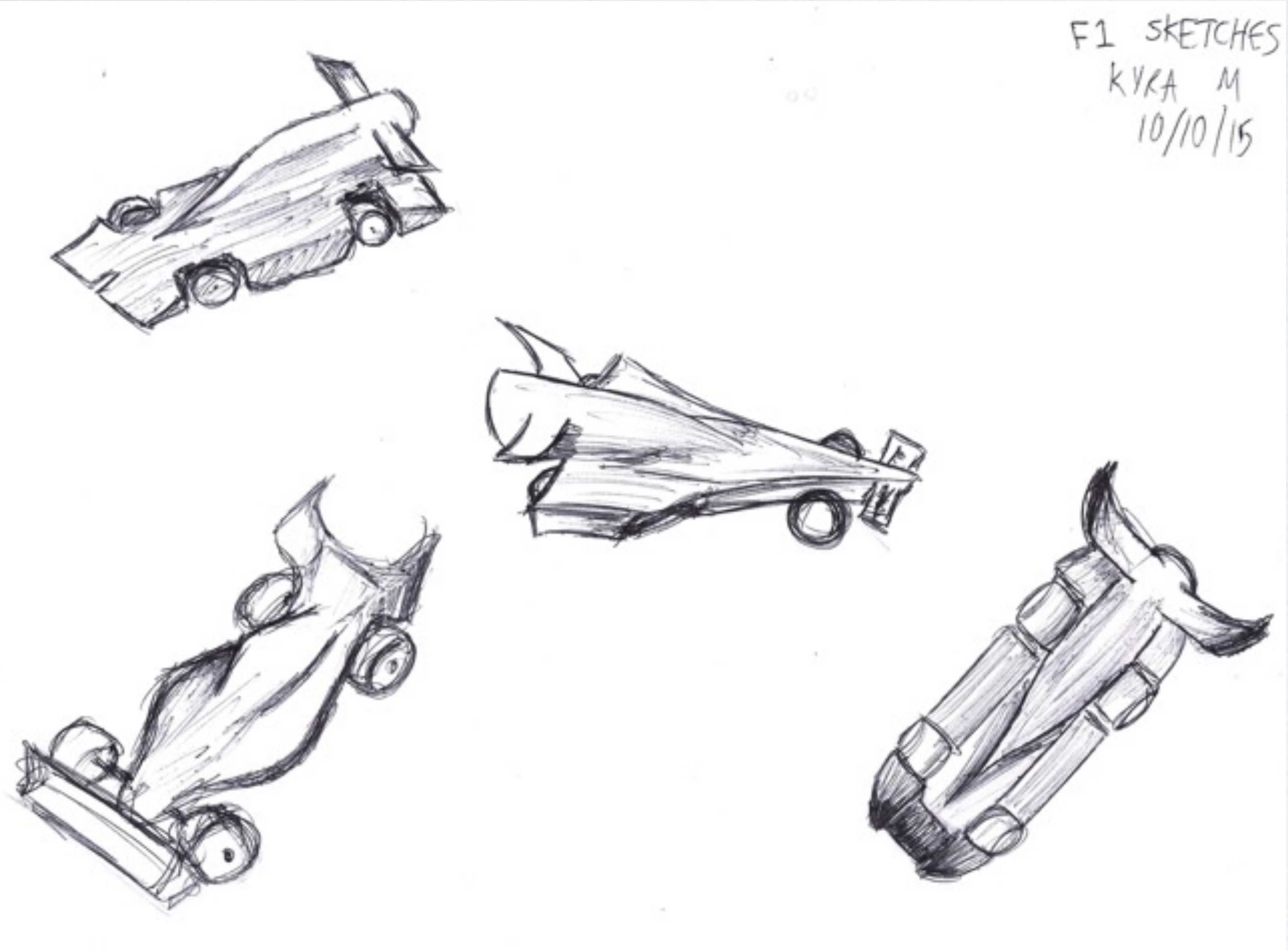
REACTION FORCE = WEIGHT - LIFT

FRICTION = REACTION FORCE x COEFFICIENT OF FRICTION

HORIZONTAL FORCE = THRUST - DRAG & FRICTION

RESULTANT HORIZONTAL FORCE = MASS OF THE CAR x ACCELERATION

DESIGN IDEAS AND ANALYSIS



We started by sketching a variety of ideas that first sprung to mind when thinking of race cars We looked at images of existing Formula 1 cars to understand features that are present. The aerodynamic design contained two main concerns: the creation of downforce, to keep the car down; and minimising the drag that gets caused by turbulence and acts to slow the car down. It had to be streamlined so that airflow was directed behind car, preventing creation of vortices

3D Modelling
After finalising our design, we modelled it with clay. This was a good way to visualise the car design in 3D space before deciding that this was the design we would use then design in the CAD software.

Design Ideas

Front wings direct airflow towards the bottom of the front wheels, so that the rolling of the front wheels is accelerated.
Thick rear wings generates a great deal of lift force at the back.

Making Decisions

As a team we decided, that changes will only be introduced if:
They are fully compliant with the regulations, as penalties will overweigh the benefits
Enough design analysis and testing was carried out
The change will improve the performance of the car
The change introduced will not affect the car's durability and will not make it prone to breakdowns

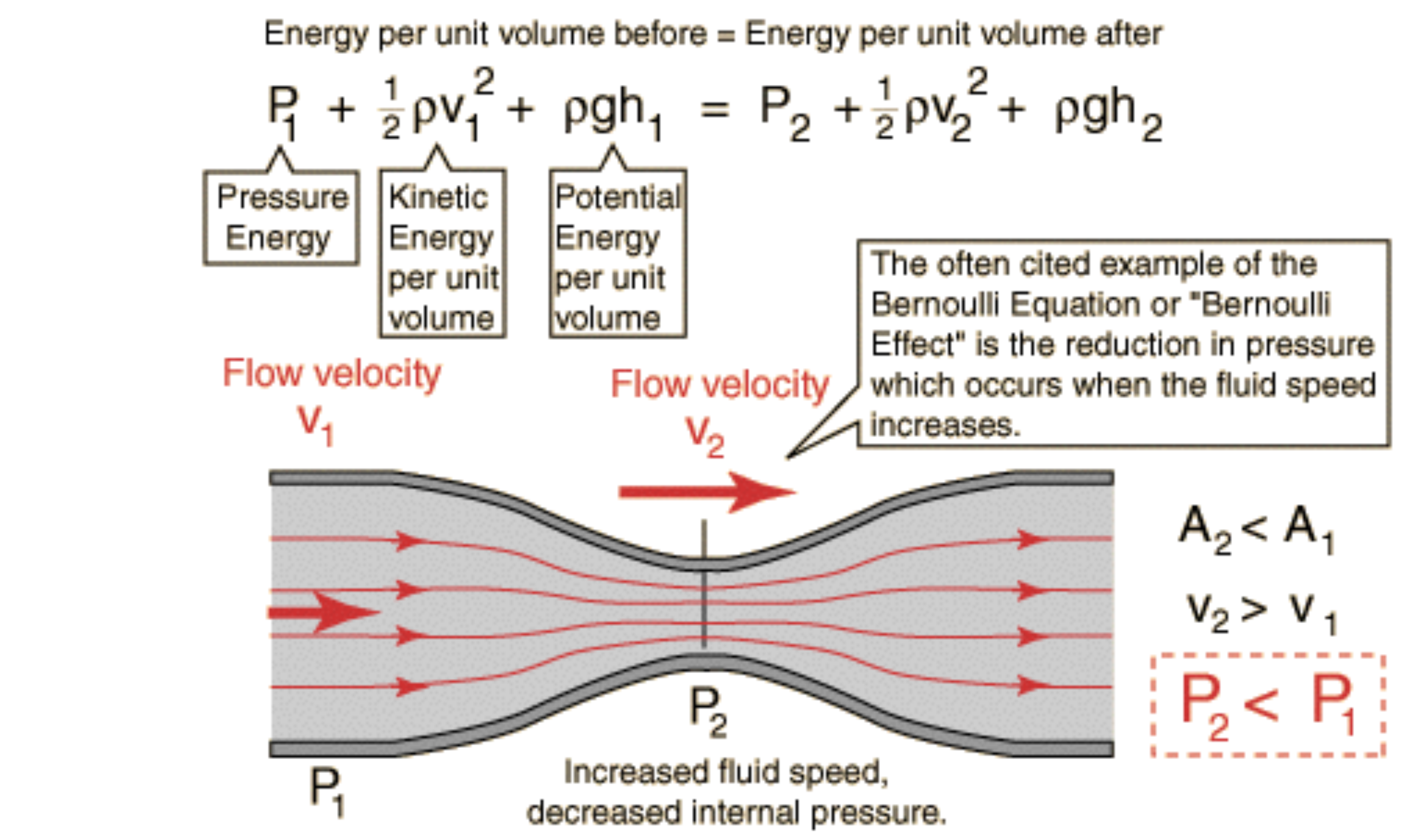
RESEARCH FOR DESIGN

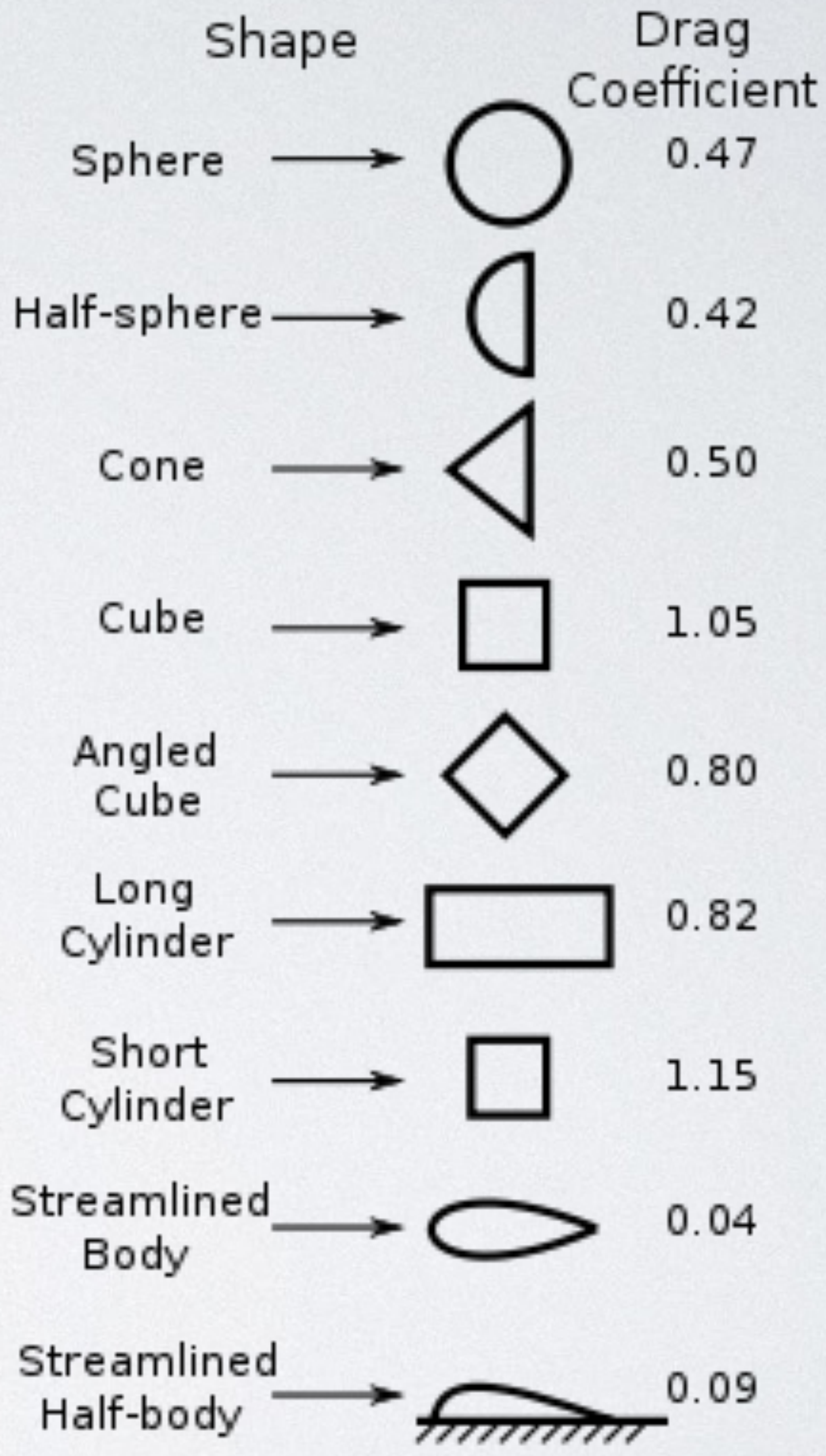
Shapes with the Smallest Drag Coefficient

Before re-designing the underside and the CO2 gas chamber car, research was undertaken into different car components. As part of this task, we looked into the shapes with the smallest drag coefficient, but also had a look at the different three dimensional shapes and their volume to surface area ratios.

This was very important before designing the body of the car. These results gave us an insight into how some of the car components should look like, such as the front of the CO2 gas chamber.

The analysis of the volume to surface area ratio was very helpful when designing the underside of the car. To create the maximum lift force, as much air as possible had to be pressurised underneath the car to create a substantial difference of pressures and therefore a substantial lift force. It was important to achieve this with the smallest amount of surface to reduce the drag acting on the car. From our research, we could conclude that a sphere has the best ratio; but on its own, it is not very practical and had to be joined with other shapes to create the most optimal solution.





Measured Drag Coefficients

RESEARCH FOR DESIGN

Downforce

Aim:

To help the cars keep traction by pushing the tiers into the track.
This helps with maintaining grip and speed in a corner , this also helps during acceleration however not in terms of reaching a higher top speed, so an aim for the best balance between top speed and acceleration is required to have the greatest average speed throughout a course.

How is it implemented?

Wings act in a similar way to the tail wing of an aircraft by producing negative lift, the angle means that air flows at two different speeds at either side of the component used to produce the negative lift by creating a disparity in pressure effectively utilising the Bernoulli effect (http://hyperphysics.phy-astr.gsu.edu/hbase/pber.html).
This does however, rely on the airflow being laminar and that any turbulent or chaotic flow is at a minimum. Which is why it is modelled taking Poiseuille's law into account as that takes the loss of energy due to friction into consideration, However it is apparent that a balance needs to be struck in terms of the smoothness of the material/ paint as too little friction would result in very little effect, whereas paint or coating which is too rough would result in too much turbulent flow creating more drag. This works with wings as the asymmetric shape from a side on perspective causes the pressure at the bottom to be lower (for a downforce configuration) resulting in the wing pushing down in the direction of lower pressure to attempt to balance out the pressure.
In racing cars the entire chassis is often designed around this with the front and rear wings being the most visible closely followed by diffusers which help to prevent a low pressure balloon forming at the back.
A major issue when designing these components is stability, if the design is too unstable the chassis may wobble which makes turning harder to control but also makes acceleration harder to control.
The front wings create significant downforce as the flow over it is perfectly linear, as a result the quality of airflow to other sections of the car is not as great. As a result of this one of the roles of the front wing in producing downforce is to also help maintain laminar flow above and under the car until it reaches the rear wing,as turbulent flow is inefficient at producing downforce.
As a result the rear wing has to deal with the most turbulent airflow.
The diffuser, doesn't produce downforce towards the rear of the car, but downforce spanning the length of the car, the aim is to diffuse high velocity air flow underneath the car towards the rear to make air flow similar to that under ambient pressure, It does this by allowing as much air to exit the underbelly of the car as possible allowing air at faster velocities to flow under. This effectively creates a Venturi tube.
Exhaust can also be used for this, however it is harder to apply this to our scenario.
To maintain stability it is preferable to have balanced downforce.

RESEARCH FOR MANUFACTURE & TESTING

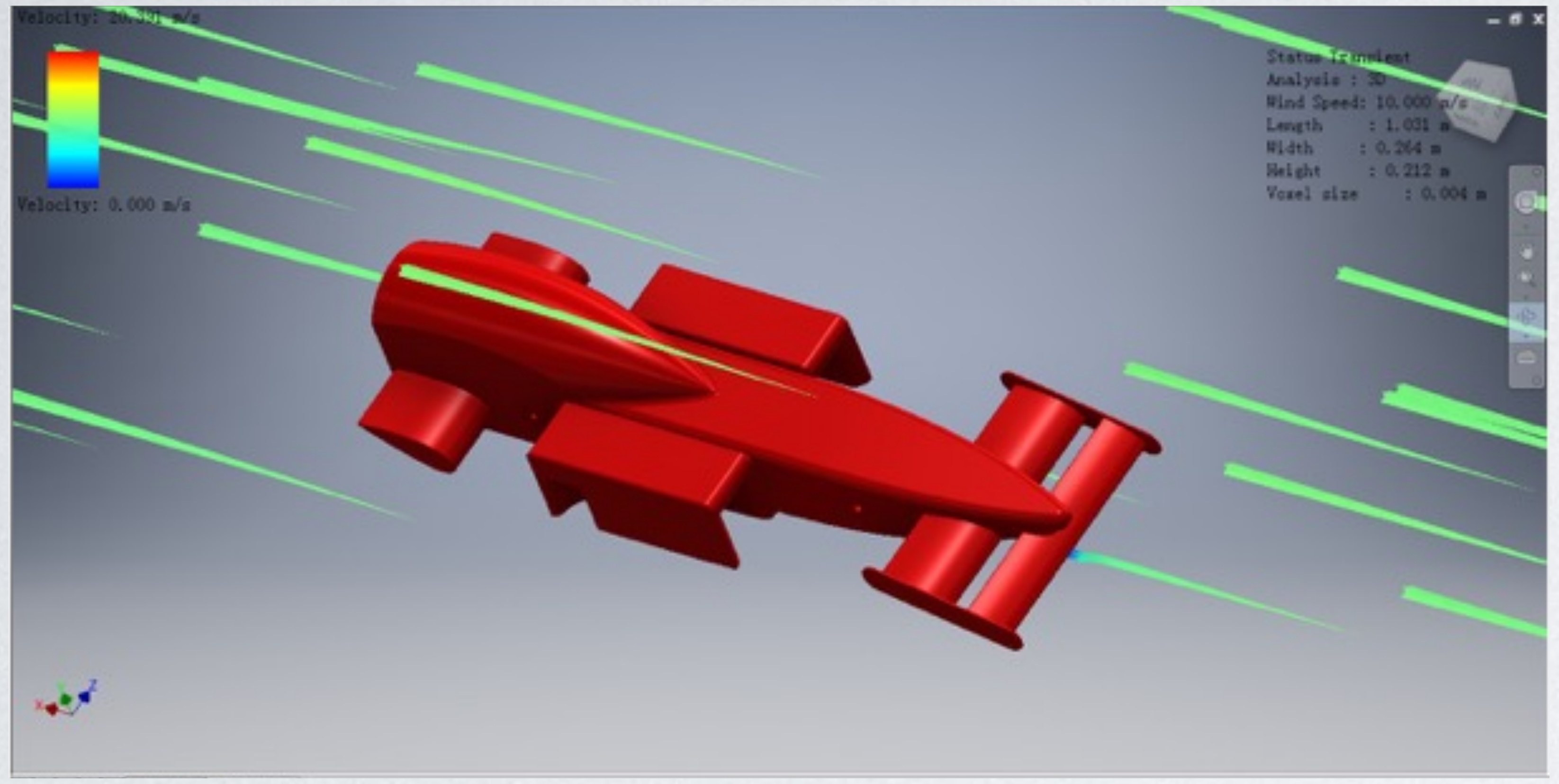
Paintwork in F1 cars

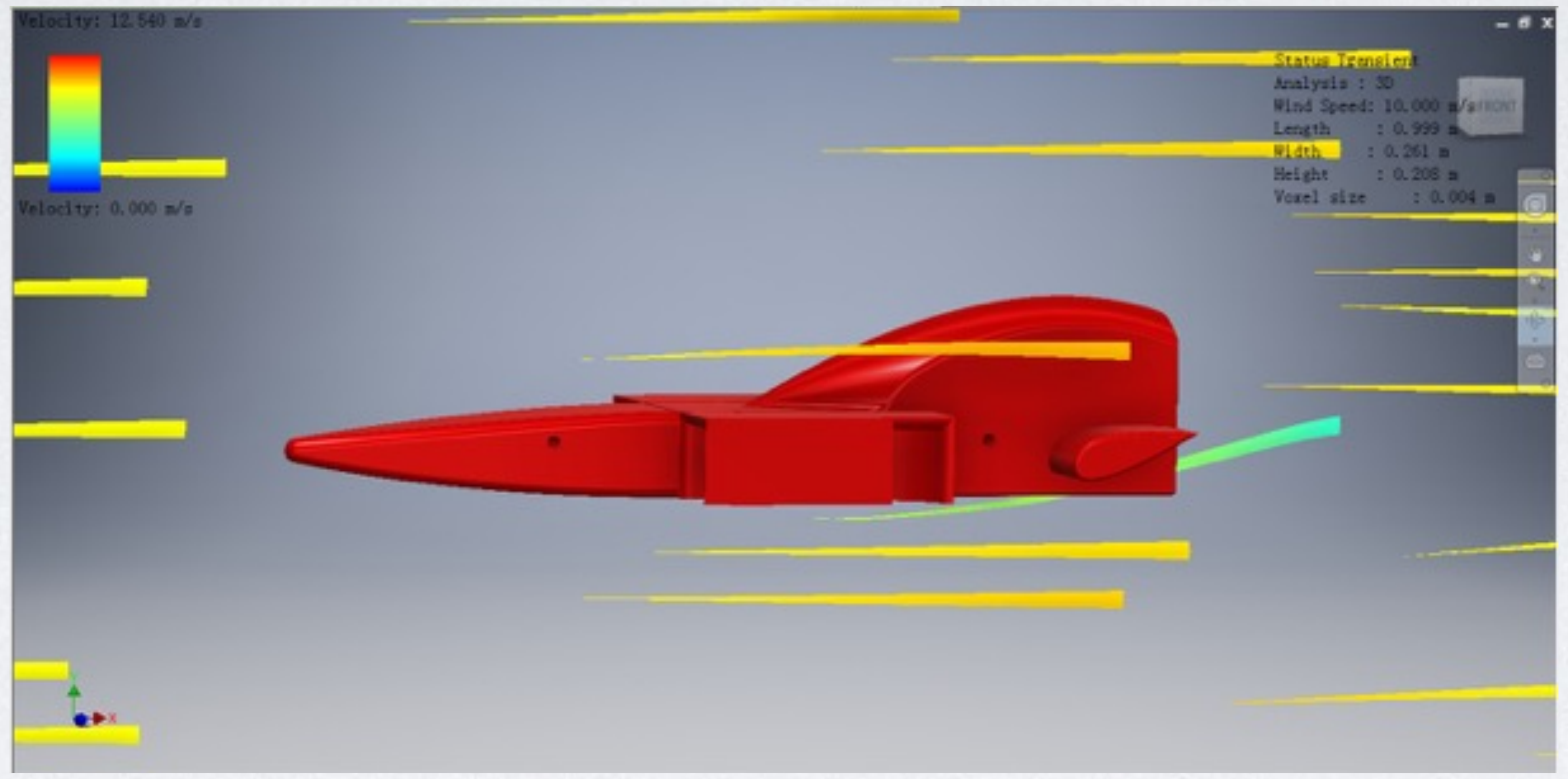
Paints developed for Formula 1 cars are specially designed to cover carbon fibre. It must be light and have good coverage to reduce the number of layers needed, overall minimising their weight. Using black paint means that less layers will be needed to cover black carbon fibre as opposed to using white paint. Painting a F1 car black only needs a base layer and top coat where as a painting it white would require about 3-4 layers and a top coat. This means using approximately 4 kilograms of paint. Using black would save about 30% of paint. Although the cars have a minimum weight, reducing the weight of the paint will mean that the extra weight could be taken up by something else which is perhaps harder to shave weight off. Since our car will be much smaller than real F1 cars the drop in weight will only be marginal so we should look at other qualities of the type of paint we decide to use such as its aerodynamics and resistance to heat. Also if we are short of time we may consider using paint which is fast drying.

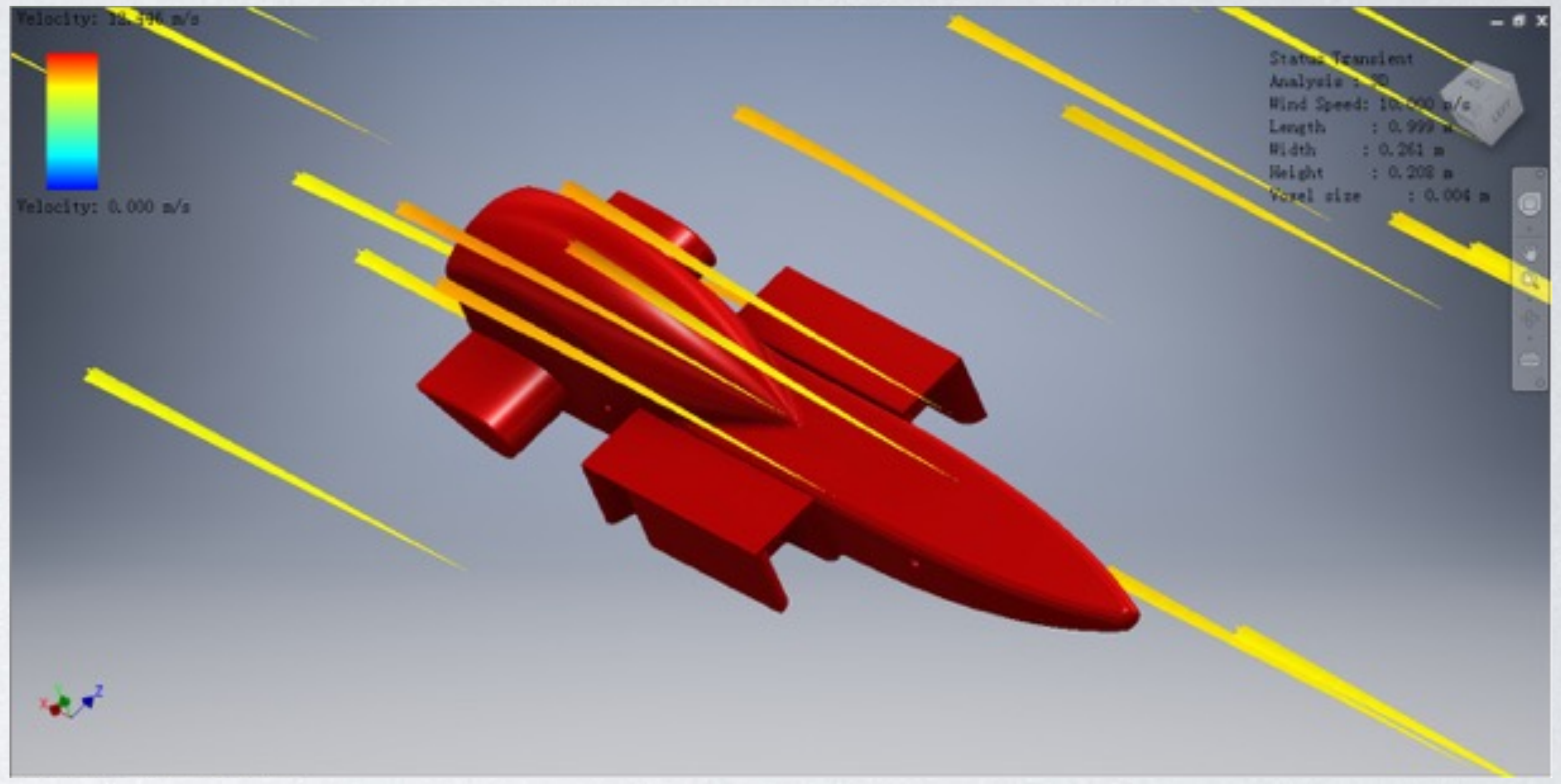
Testing the aerodynamic efficiency of the car

Air flow visualisation paint or flo-vis paint is a special type of paint which is aero-sensitive and it is used to test aerodynamic efficiency of a car's front wing, rear wings, or diffusers. it takes the place of sensors as they itself would have an effect on the aerodynamics of the car.

COMPUTER AIDED DESIGN ANALYSIS







These are screen prints of the program we used to set up our model.
We used AutoCAD to design our car. It was important to run wind tunnel simulation so we could see how effectively our model would run when against force, allowing us to see the main areas creating drag and where the air would flow when we actually go to race our car.

Once we had a design for our car, we met with three engineering students from UCL who gave advice with regard to our design. Main changes involved creating more down force and lift and ensuring the body was more continuous. We also raised the back wings slightly and brought the weight closer to the requirement of 55g. All of these changes were implemented in final design and manufactured product.

MANUFACTURING OF THE CAR

In our school, we had access to both a laser cutter and a router, which cuts out only 2D objects. By exploring these different machinery, we came to a conclusion that we needed a much more precise and accurate CNC router. So the racing cars were printed out thanks to Denford Ltd. Although this process was very expensive and used up most of our financial resources, we were very delighted with their services.

Laser Cutter

The laser cutter available at our school could only cut 2D shapes otherwise it would have been a cheap and efficient way of printing our cars.

Router

The router at school did the same jobs as the laser cutter, but could do it with denser materials. Also it was very imprecise and would not get the right amount of detail on the design. Therefore, we had to look for external manufacturing sites, such as Denford.

3D Printer

For the manufacturing of the wings we to turned to Denford Ltd.

Problems Encountered during Manufacturing

We had many failed attempts in organising a meeting early on with our assigned undergraduates at UCL. When a meeting had finally been organised it was quite late on in the project which gave us very little time to respond to their feedback. We also had difficulties with the manufacturing of the cars. We almost had no car to race with.

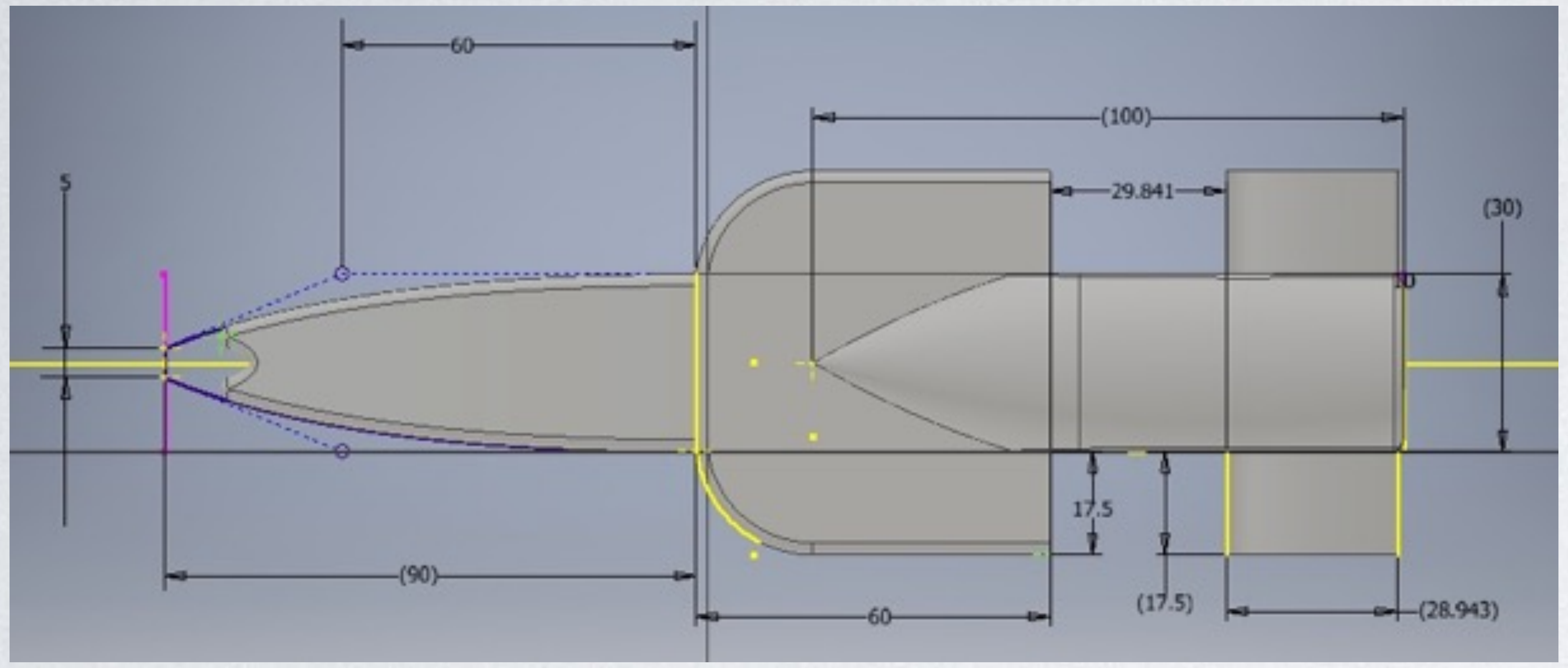
Finishing Problems

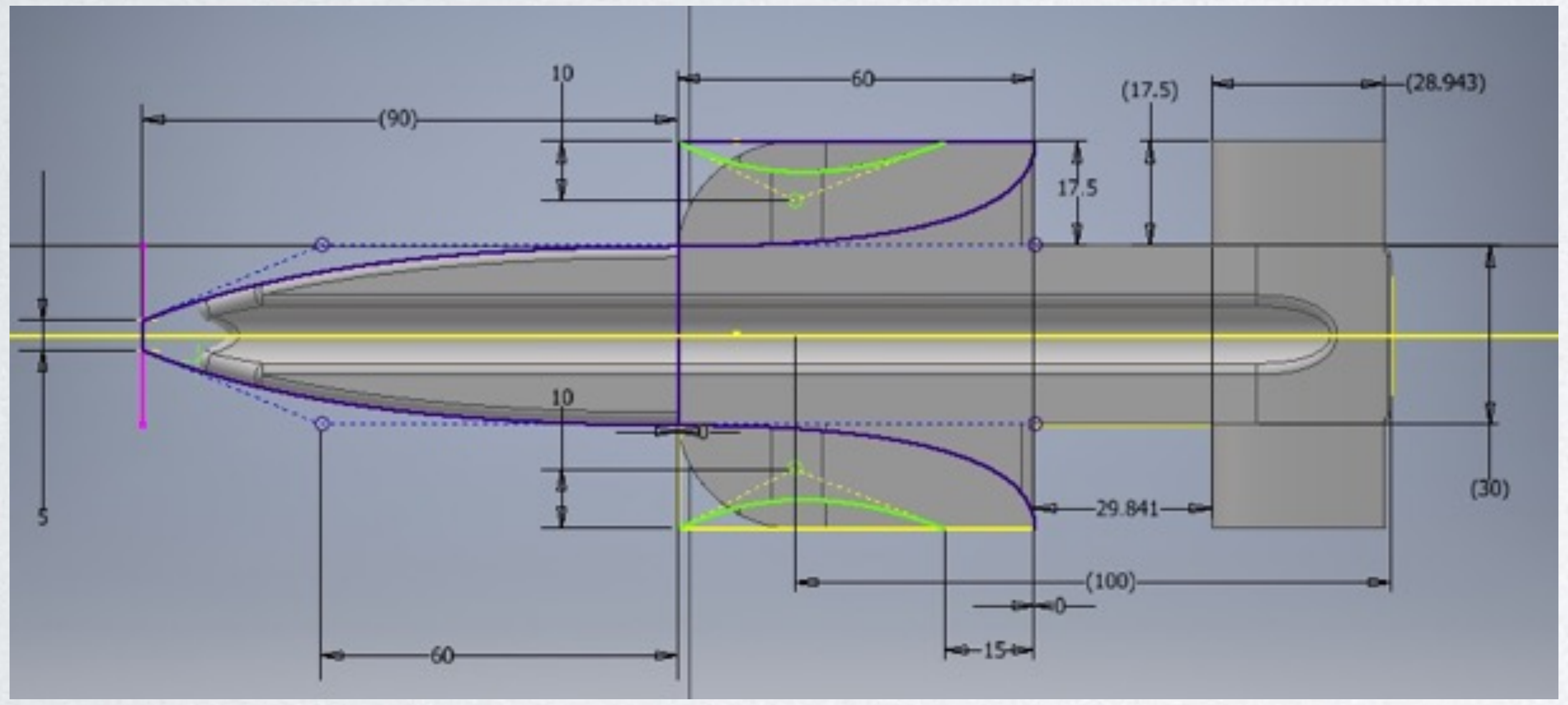
Although, the CNC router can cut out very precisely, we had to hand finish the car and shape some of the car parts individually as the CNC router could not reach them. This involved sticking the bits on with epoxy resin, sanding down the car and painting and varnishing.

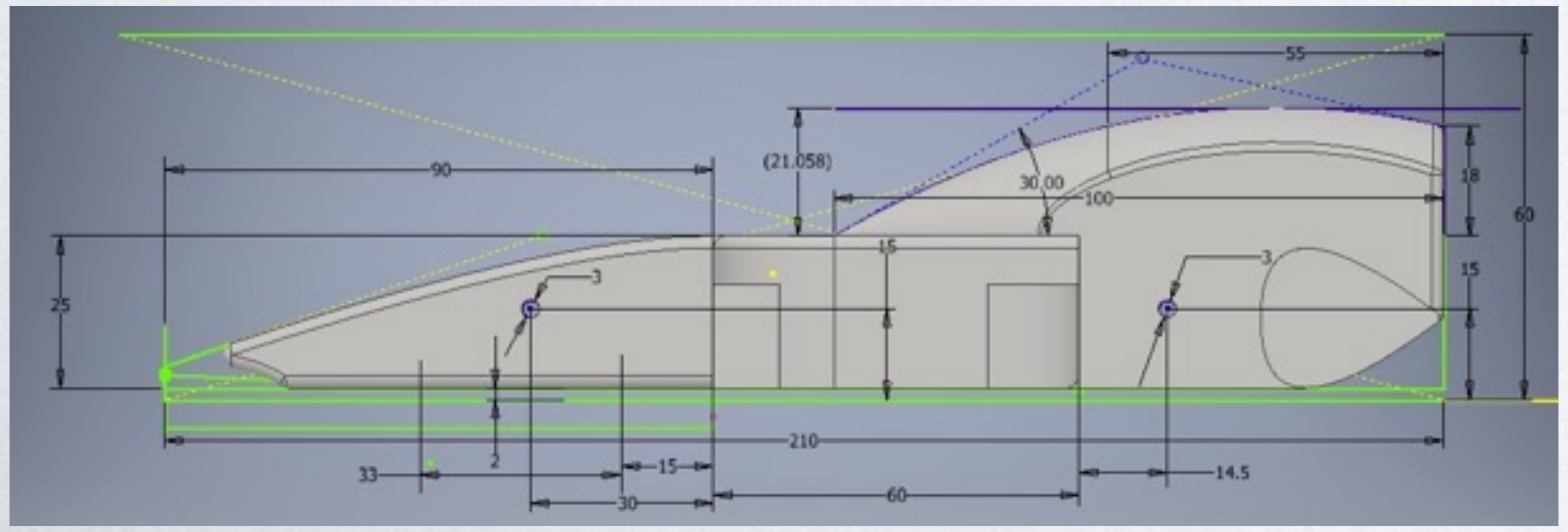
Manufacturing Details

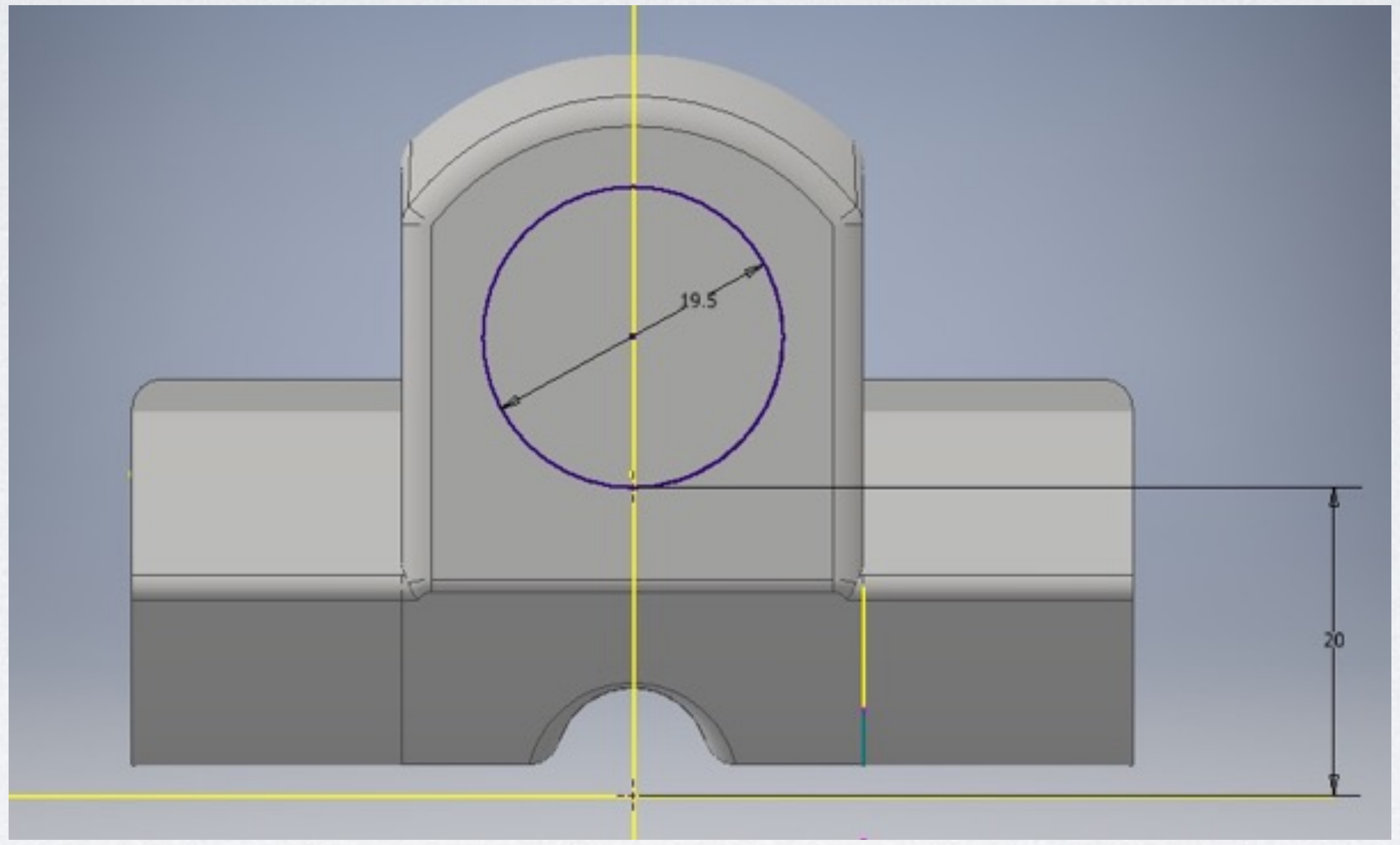
The whole body of the car was made out of balsa wood and the wings were printed using a 3D printer. This was all done by Denford Ltd. We decided to make the wings out of ABS due to its lightweight and strength. It can also be easily glued onto the balsa wood.

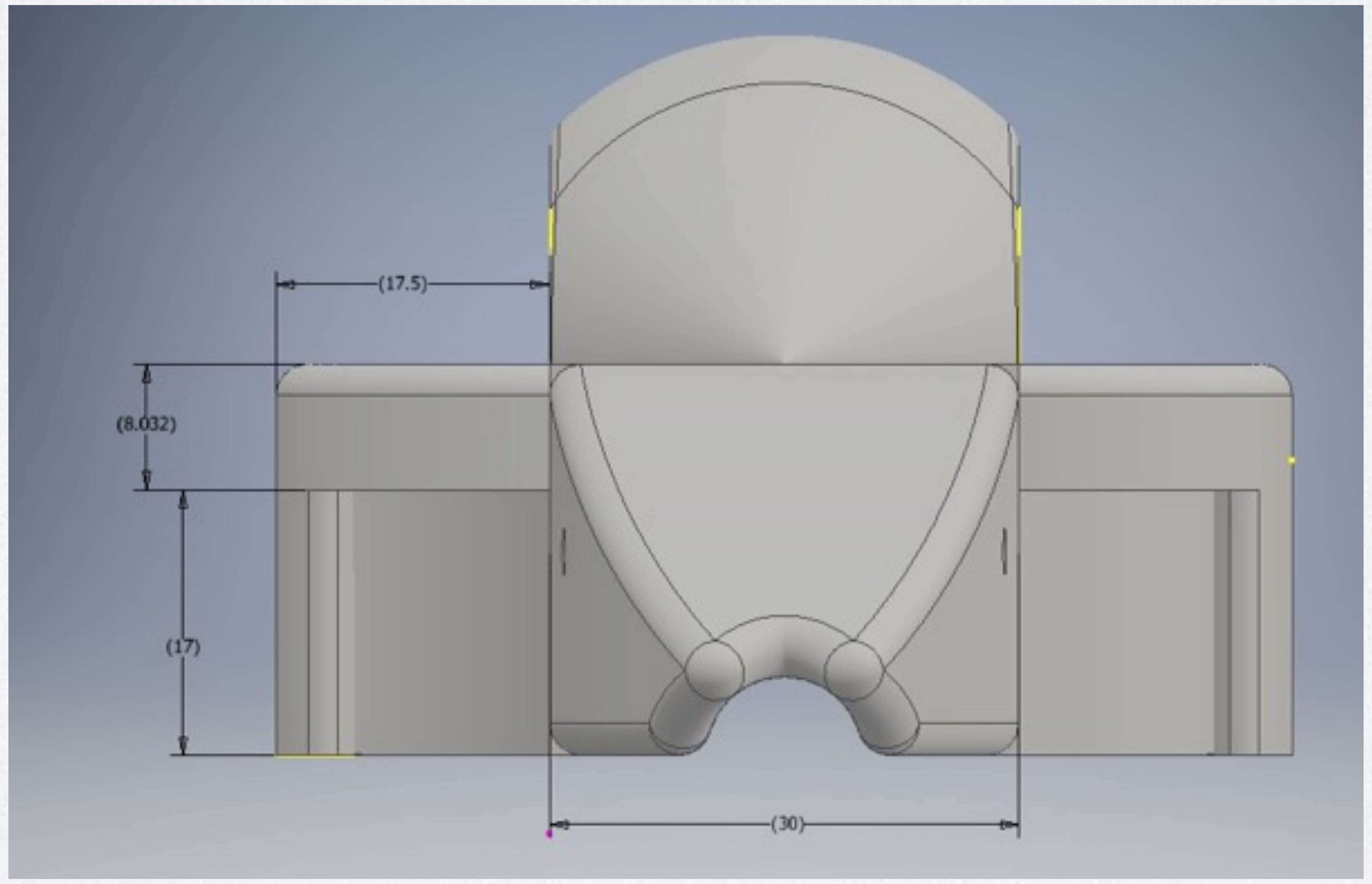
MANUFACTURING AND ASSEMBLY

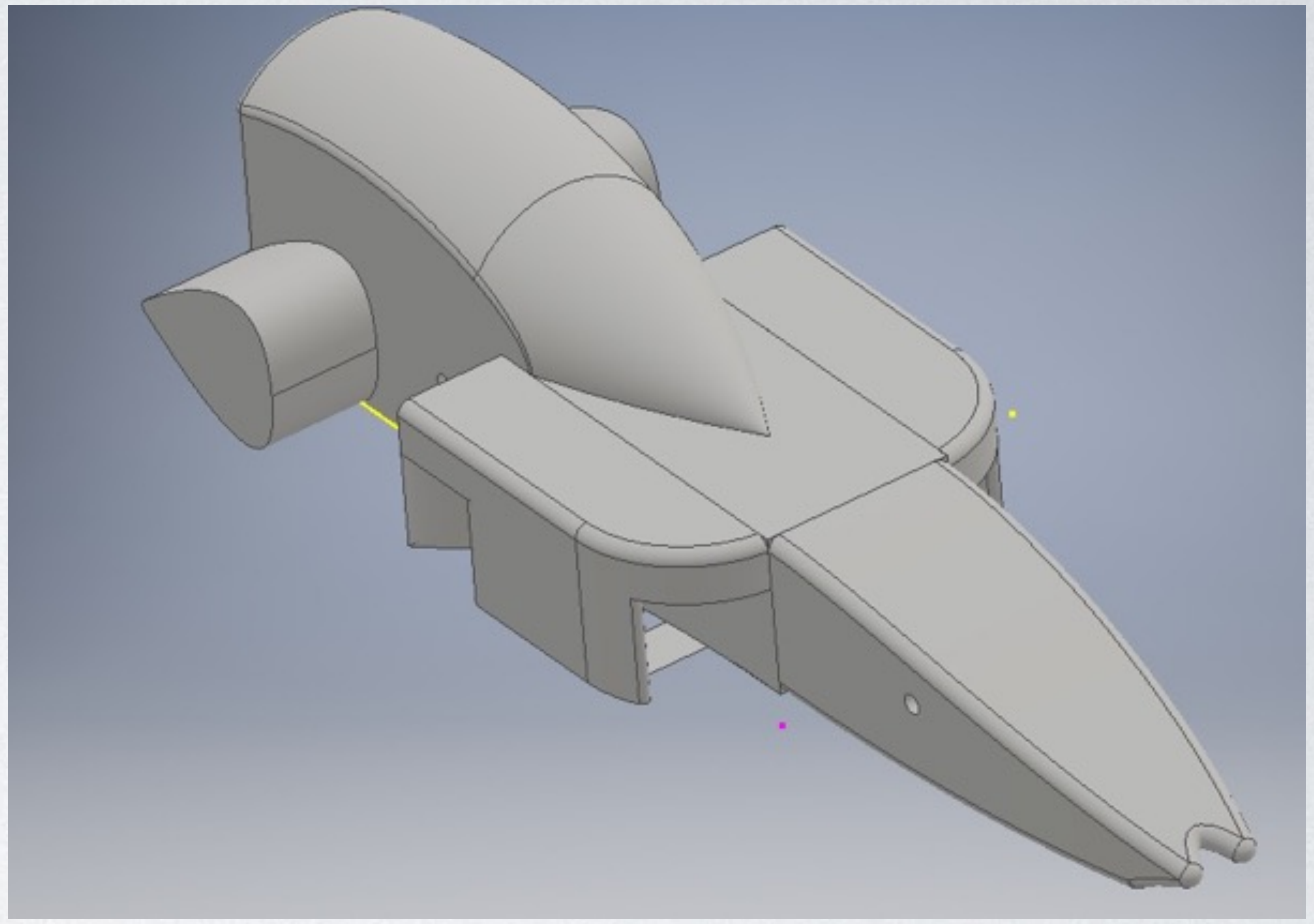












Review on Manufacture

The manufacture of the car happened very late which left us very little time to test the car in the real world. Ideally it should have been manufactured before the holidays so we could test it as soon as we came back but this did not happen.