Fibonacci

DESIGN + ENGINEERING PORTFOLIO

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RESEARCH FINDINGS

These research ideas will be addressed throughout our development.

Figure 1A: Research findings- aerodynamic

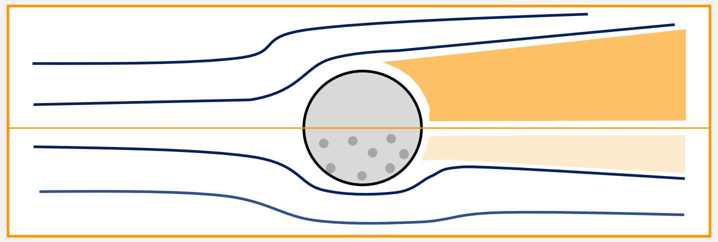
1 DRAG FORMULA

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

ρ = Density of Air
v = Speed of car
C_D = Drag Coefficient
A = Frontal Area

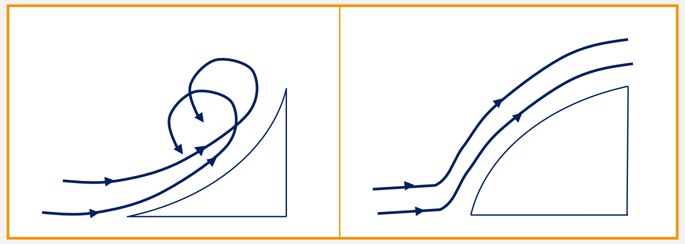
The drag equation shows the factors the total drag force is proportional to. Drag coefficient, C_D and frontal area, A are the two main variables we have control over with our car.
We took the **density of air,** ρ to be 1.28 kgm^{-3} however it varies based on the room **temperature.**

2 FLOW SEPERATION



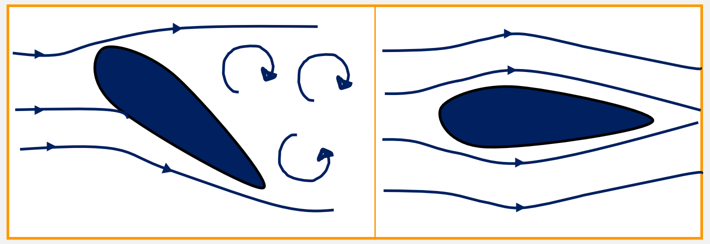
Dimples on a golf ball reduce flow separation by creating a **turbulent boundary layer** which keeps the air attached further around the curvature of the ball. Flow separation is when the air detaches from a surface into a wake, increasing drag.

3 COANDA EFFECT



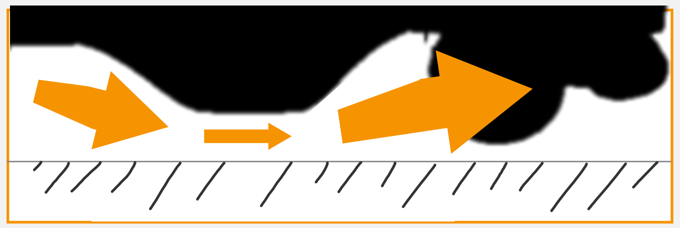
The Coanda effect theory states that because **air is viscous**, it follows a curved convex surface. However, with a concave surface it separates and forms eddies, increasing turbulence.

4 LIFT



For small angles an aerofoil generates lift roughly proportional to angle of attack. Stalling happens when the incline is too steep resulting in turbulence. The best **aerodynamic section** is an aerofoil with $0°$ angle of attack.

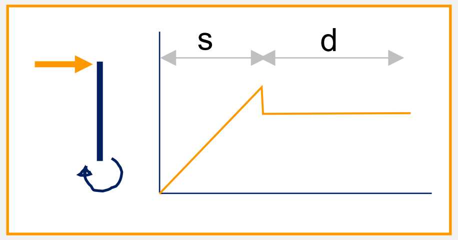
5 BERNOULLI PRINCIPLE



Bernoulli's principle states that a faster flowing fluid has lower pressure than slower flowing fluid. In practice this means when air is compressed through a narrower space, such as beneath an F1 in Schools car, the air flow is faster which reduces the pressure beneath the car. The difference in pressure creates **downforce.**

Figure 1B: Research findings- mechanical

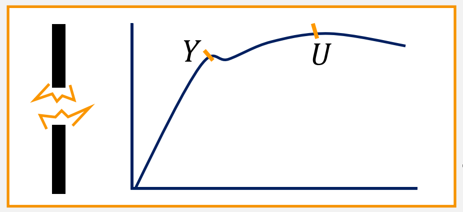
6 TORQUE



s = Static Torque
d = Dynamic Torque

Torque is the force that creates an angular acceleration of a mass. Within our bearings there is frictional torque which resists angular acceleration. Before motion there is static torque and once in motion the resistance is dynamic torque.

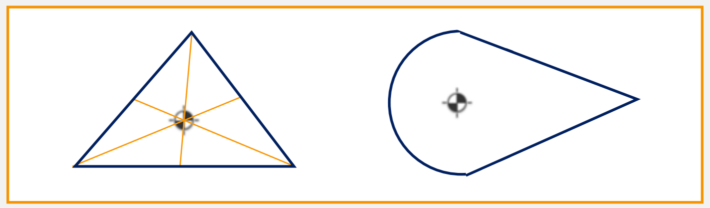
7 TENSILE STRENGTH



Y = Yield Strength
U = Ultimate Tensile Strength

As this graph shows, a material deforms in response to a tensile load. Beyond the yield point it permanently deforms as this is beyond the elastic limit. The ultimate tensile strength is the maximum stress it can withstand.

8 CENTRE OF MASS



Centre of mass is a hypothetical point where the object is balanced. Simple cross sections have formulas we can use to find the centre of mass theoretically. A force acting on an object away from this point creates a **moment.**

COMPUTER AIDED ANALYSIS SET UP

The following steps are carried out to run each CFD simulation:
-Import CAD design and **edit mesh** to make specific regions more detailed, focussing on complex geometry.
-Assign volume of wind tunnel to 'air'. Simulation is irrespective of car materials.
-**Boundary conditions**: air inlet velocity at 20ms^{-1}, outlet pressure at 0, remaining walls set to **'slip'**, body walls set to **'no slip'**
-Wheel rotation + CO_2 escaping implemented.

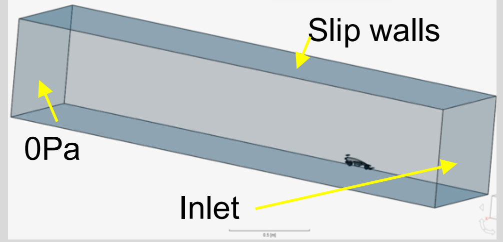


Figure 2: Boundary conditions

WHEEL ROTATION

The angular velocity of the wheels is calculated by **dividing the track length by the circumference** of the wheels to find the rotational speed in RPM and then multiplying that by 2π to find the **angular velocity** in radians per second.

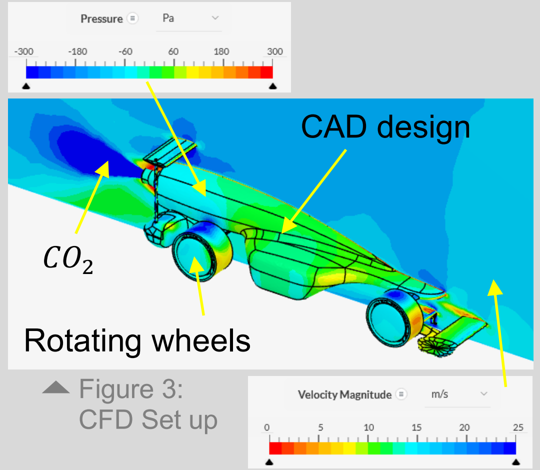


Figure 3: CFD Set up

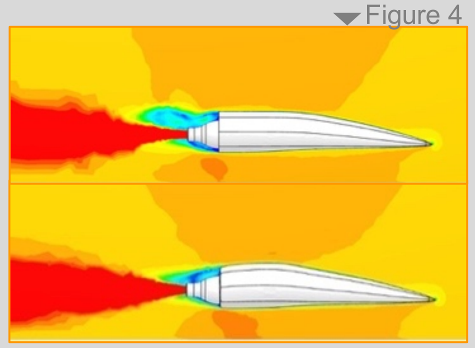
CO2 ESCAPING CANISTER

The escaping CO_2 **changes the airflow** at the rear significantly, so we modelled this in the simulation. As the pressure difference is so high when the canister is punctured, choked flow occurs giving a velocity of Mach 1 at 15C. Over time this decreases, so we modelled an average escape velocity of 150ms-1

CO2 CHAMBER DEVELOPMENT

The first application of Virtual Analysis was to alter the curve of the CO_2 chamber to utilise the **coanda effect** and reduce **flow seperation** at the rear of the car.

Figure 4



DESIGN CYCLE AIMS

We created clear **aims** to guide our purposeful car development. Within each segment of figure 5 are the ways we ensured that we achieved our design aims: Fast, strong, and legal.

Car Aims

Fast
Technically inspired ideas.
Purposeful testing.
Virtual Analysis integrated.
Ongoing idea evaluations.
Advanced use of 3D modelling techniques to implement ideas.
Relevant R&D throughout entire development cycle.

Strong
CAM/CNC techniques used.
Detail + develop all manufacturing stages.
Designed for manufacture.

Legal
Quality control checks.
Compliance tools.

Figure 5

3D MODELLING

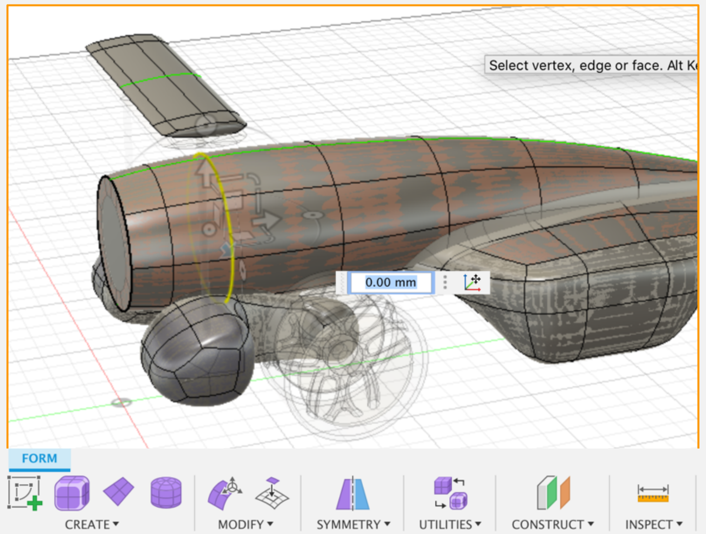
Advanced use of 3D Modelling techniques were used throughout the process of CAD modelling our car and parts. Here is a **timeline** to show our 3D Modelling process. Each step prepares our car for being CAM Manufactured with Fillets being **manufacturing considerations** for a **3mm CNC** end bit. Each part was checked with the measure and interference tool to ensure **highly detailed modelling.**

MEASURE TOOL

INTERFERENCE TOOL

FORM TOOL

Figure 6



We use the ‘Form’ workspace to model the majority of our F1 in Schools car. Fluency with these tools allow us to model any design concept with a high degree of freedom.

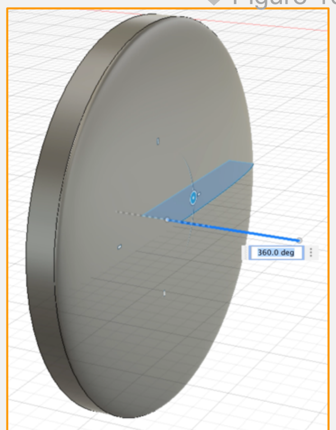
We begin with a flat plane form or a cylinder and use the ‘Edit Form’ tool to adjust and mould the form to our desired **highly detailed** shapes.

Within the ‘Form’ workspace additional tools such as ‘mirror’, ‘fill hole’ and ‘insert edge’ are used to achieve **highly detailed 3D models**.

The mirror tool creates a mirror line with an existing plane and any edits on one side of the model **automatically alter** on the mirrored side. ‘Fill hole’ closes gaps in the form achieving solid bodies while ‘Insert edge’ gives an extra edge to adjust giving more **precise 3D modelling**.

REVOLVE

Figure 10



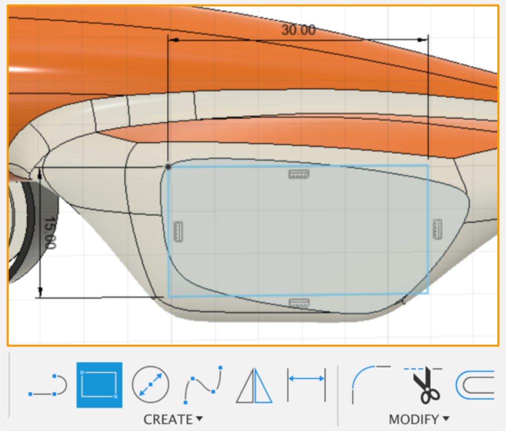
The ‘Revolve’ tool **rotates a cross section** made as a sketch around an axis. We used this tool to model our wheel system and hubs as we could alter the cross section sketch easily and Fusion 360 updated the final form along the timeline.

Figure 11: Autodesk Icons

SKETCH TOOL

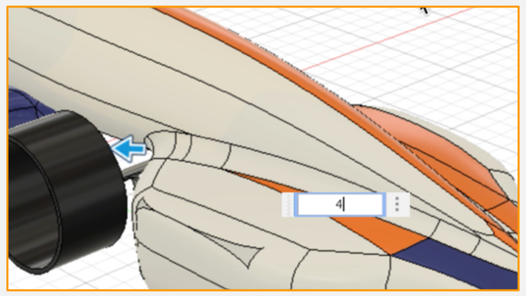
Using the sketch tool we can create the **initial** shape for all 3D Modelling commands (blue icons).
Within the sketch tool we can create ellipses, arcs, and any other **highly detailed** sections.

Figure 7



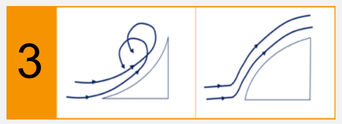
FILLET

Figure 8



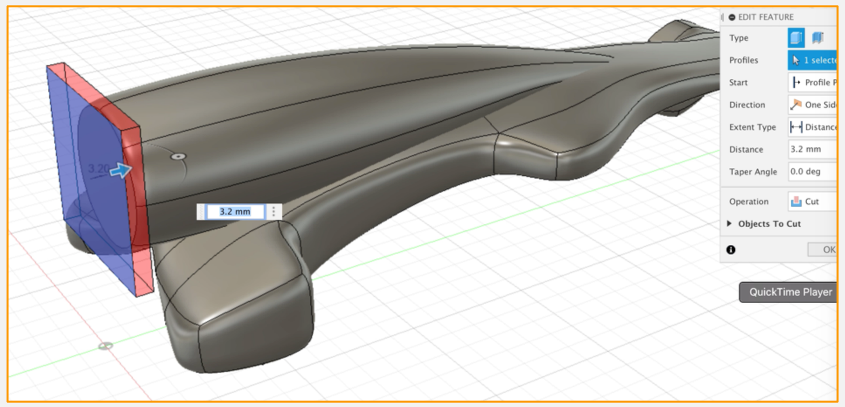
Fillets are added to accommodate a 3mm ball nose CNC mill bit. Without the fillet the CNC wouldn’t be able to reach all parts of the model.

‘Fillet’ creates a **concave/convex curve** in the seam between two bodies. We used this to curve sharp edges to improve the aerodynamics of our car.



EXTRUDE

Figure 9



‘Extrude’ makes a 2D sketch or profile into a **3D body.** Additionally it can subtract from an existing body. We used this tool to **subtract material** from our car such as the cut off at the back of our car.

MAIN BODY

The first modification to our Nationals car (fig 12) was to **sink the bottom** (fig 13). With the front sinking at a steeper angle and both sections behind the wheels and under the car having an incline. The idea was to **create downforce** and reduce turbulence going under the car.

Due to the regulation change for the minimum wheel diameter we had to **change the front wing** design.

Figure 12: Nationals Car

Figure 13

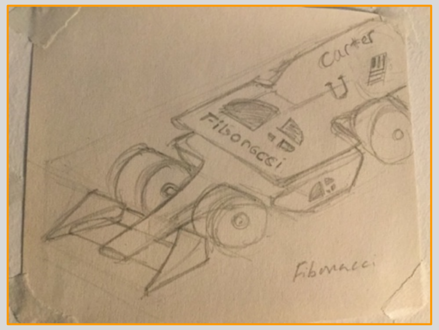


Figure 14

Concept (fig 14 and 15) aims to reduce frontal area.

1 $F_D = \frac{1}{2}\rho v^2 C_D A$ $A \downarrow$

Not designed for manufacture so developed to be made from a single piece of model block as a **manufacturing consideration.**

Figure 15

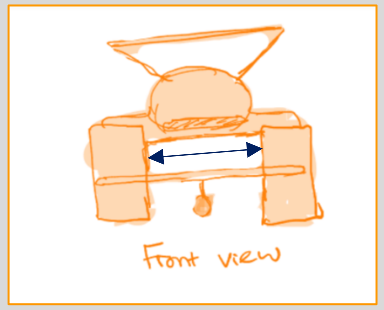
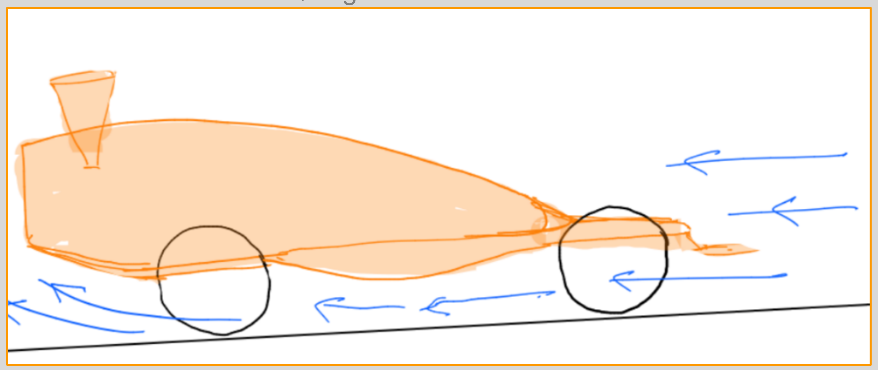
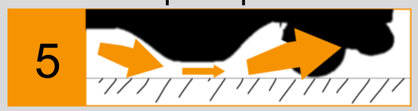


Figure 16



Increasing distance between wheels (fig 15) and raising CO_2 chamber utilises bernoulli’s principle.



Now more air passes beneath the car increasing downforce and stability.

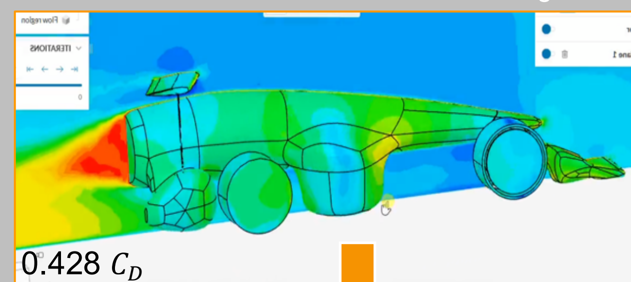
CO_2 CHAMBER DESIGN

The CO_2 Chamber housing was developed to the narrow seperated design through the CFD results.
By using **two separate forms** for the CO_2 housing and the main body, a streamlined more defined car could be designed.
In fig 18 there’s a **consistent pressure gradient** reducing the aerodynamic drag of the design. As coefficient in fig 18 is less than in fig 17 this main body has better aerodynamics.

$C_{D\ fig\ 17} < C_{D\ fig\ 18}$

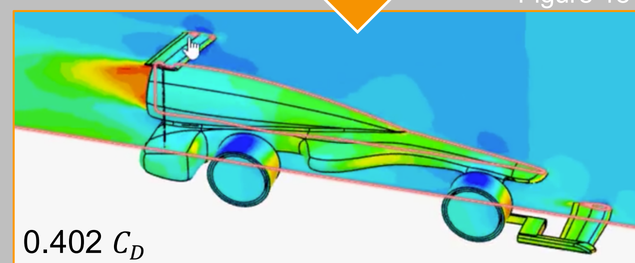
1 $F_D = \frac{1}{2}\rho v^2 C_D A$

Figure 17



0.428 C_D

Figure 18



0.402 C_D

DRAFT ANALYSIS

'Draft Analysis' colours the surface based on its **gradient**. As you can see in figure 19, the front of the CO_2 housing has purple areas right where the CFD shows low pressure indicating **turbulence**. We altered the shape to even up the colours and create a more **gradual convex shape**.

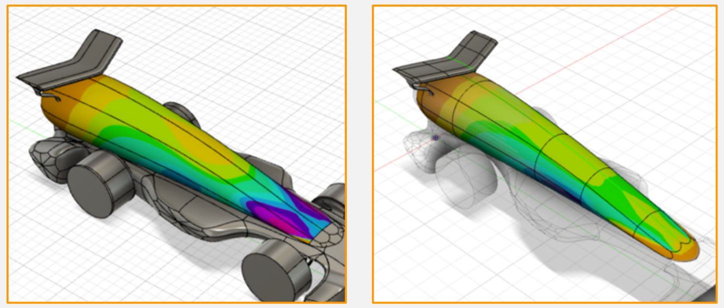


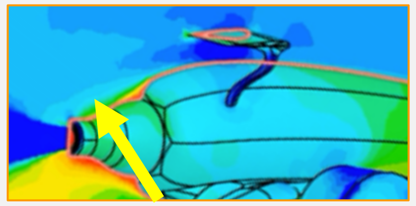
Figure 19: Draft Analysis

1 $F_D = \frac{1}{2}\rho v^2 C_D A$

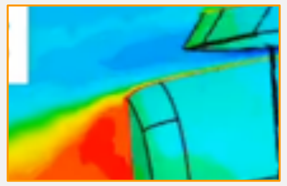
Draft Analysis tool **reduces the drag coefficient** as consistant curves disrupts airflow less. This creates more **laminar flow** along the main body and reduces turbulence.

CO2 CHAMBER CUT

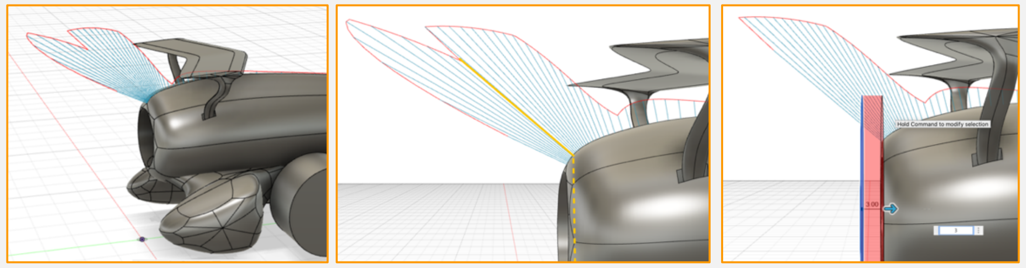
Figure 20: CO2 Chamber Cut Off



We used Fusion 360's 'Curvature Comb Analysis' where it projects data points along the top curved edge and shows any **drastic changes** in the gradient. This way we could clearly identify where the rear of the car tips off sharply and cut it off there. There's no use keeping the material here as its so steep that the **airflow separates before it.**

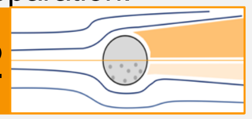


Here the air flow separates at the back of the car. Here we explored how **changing where the cut off was** at the back could **reduce the turbulence** from the flow separation.



Clear improvement with no more premature flow separation.

2



FRONT WING CFD DEVELOPMENT

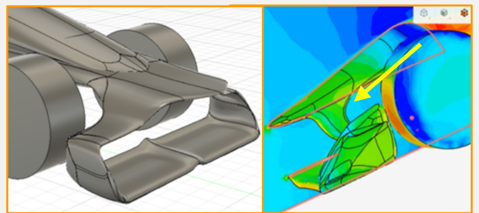


Figure 21

This design **distributes the pressure** well. However there's nothing diverting the air from hitting the front wheels, **creating turbulence** and resistance.

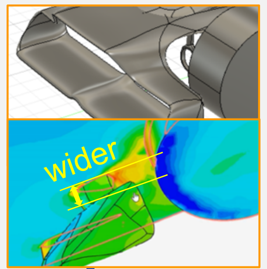


Figure 22

We tried making the top support wedge wider to **divert more air** from hitting the wheels. However it only adds more drag, with barely if any improvement to airflow.

A B C D E

By filling in the material we fixed the high pressure under the wing however the **air hitting the wheels** is **worse** and there is still lots of **drag from the supports**.

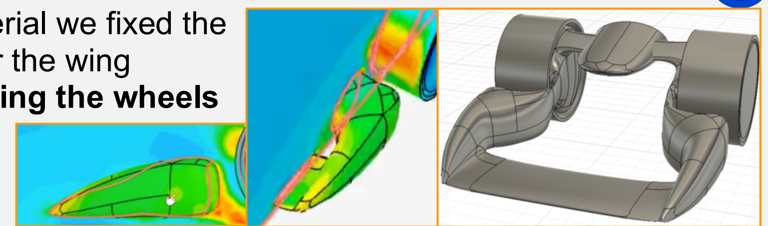
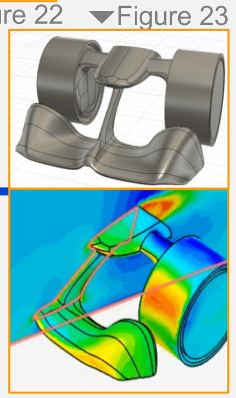


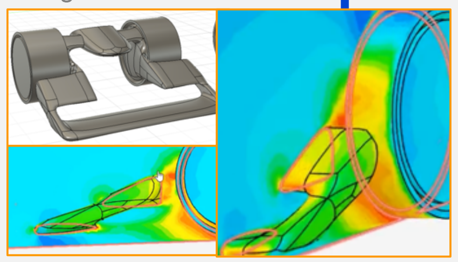
Figure 24

Figure 23



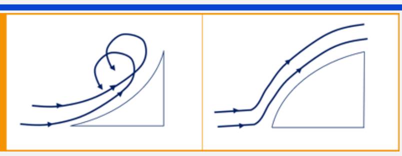
To direct the air from the front wheels we tried this wavy design. The pressure is **unevenly distributed** at the front and there is still lots of air hitting the wheels as well as turbulence under the wing in space.

Figure 25



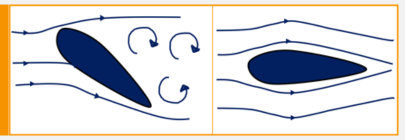
We took the clear airflow from A and the connection to the front wing from D to create this design which does **distribute pressure** well, however the wheels have a lot of air hitting them- a **persisting problem.**

3



Final wing directs air away from wheels with a **convex support**. Narrow design to allow for larger **wheel base**. Straight wing airfoil section to minimise drag and create **laminar air flow** down the car body.

4



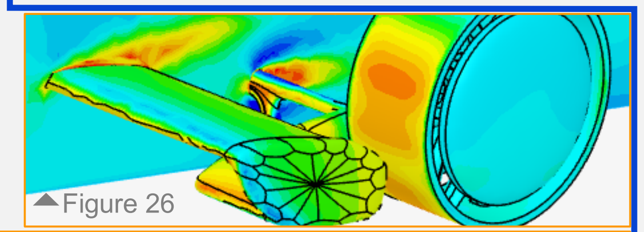
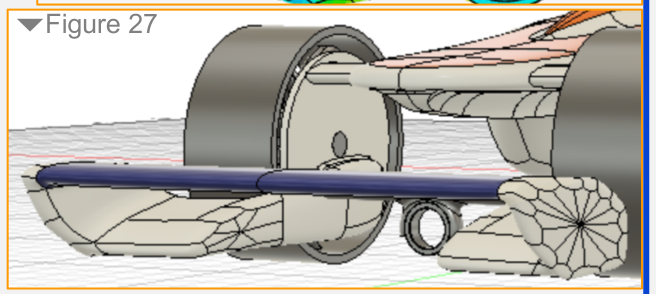


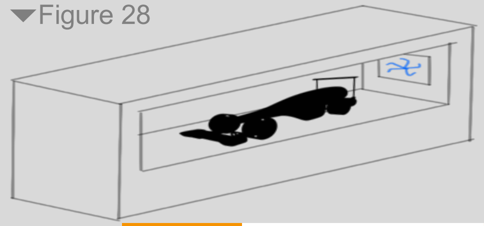
Figure 26

Figure 27



PHYSICAL TESTING- WIND TUNNEL

Figure 28



We learnt from engineers at Ford that they use a **10 to 1 rule** for the ratio of wind tunnel size to test model. This is due to **interference of the walls** of the wind tunnel to the airflow around the model.

For this reason we didn't base our design developments purely on the wind tunnel results.

We used our wind tunnel for **testing surface finishes** as this relies on air speed and not on **laminar flow.**

6

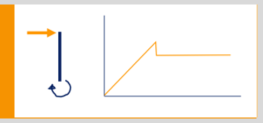
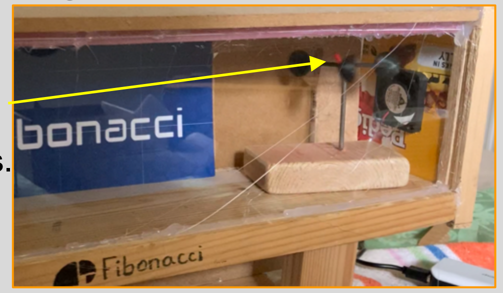


Figure 30



ANEMOMETER

To calculate the speed of airflow we designed and made an anemometer.
This improved the **quality of our results** by being able to **calibrate** the airflow first. It involved setting everything up without a model in the tunnel and counting the **number of revolutions** in 30 seconds.
This tells us the phase of the race the results we gather are representative of. For example at $20ms^{-1}$ we know this is the average coasting speed so a **good representation.**

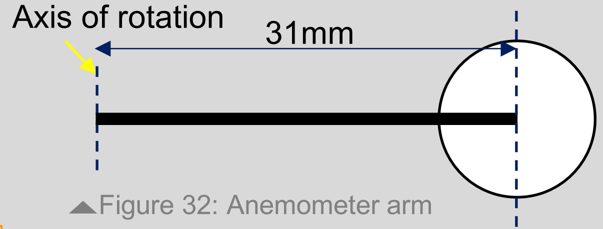


Figure 32: Anemometer arm

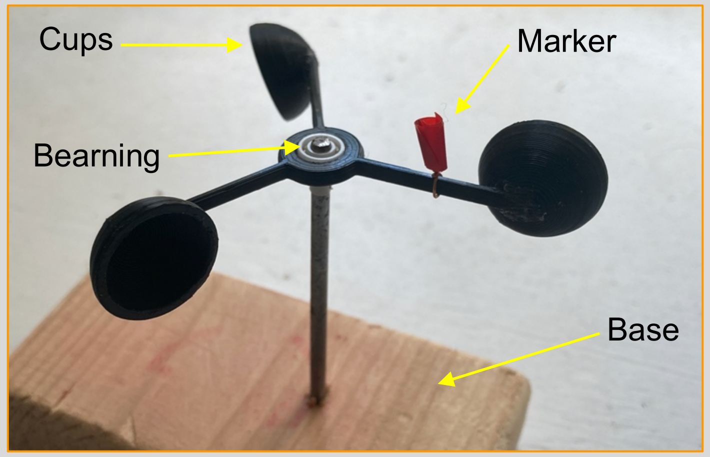


Figure 31

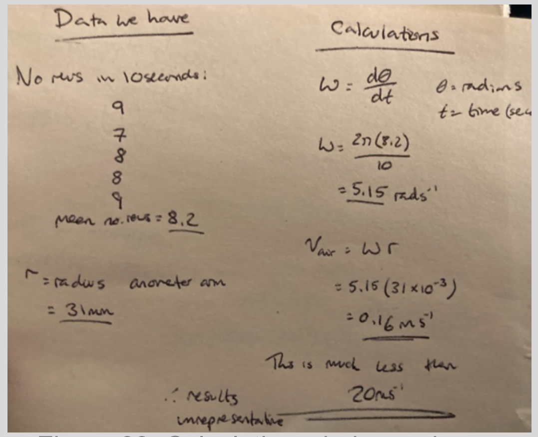
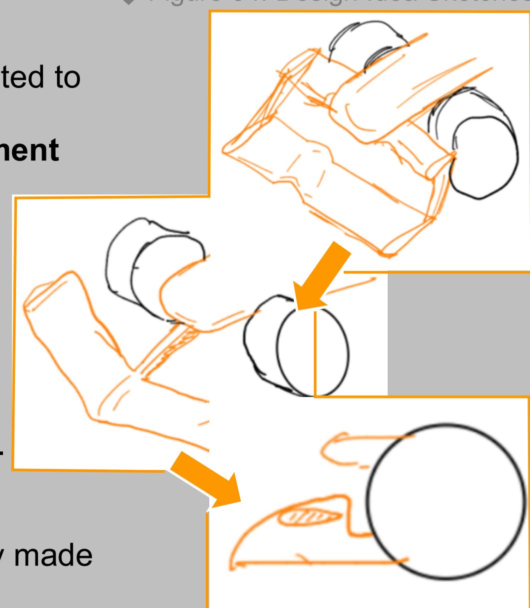


Figure 33: Calculating wind speed

DESIGN PROCESS EVALUATION- CAA

IDEA EVALUATION

Figure 34: Design Idea Sketches



- 'Draft Analysis' was easily and effectively implemented to develop the car main body.
- **Research implemented** in the **design & development cycle** to incorporate several research findings before arriving at the final front wing.
- **Virtual Analysis integrated** into the aerodynamic development of the main body and front wing.
- Anemometer used effectively to better interpret physical testing of main body aerodynamics.

IMPROVEMENT ACTIONS

- For precision of results, investing in a professionally made anemometer could be worth it.

REAR WING

From exploring rear wing designs, the supports holding up the wing created lots of drag. Our idea to minimise this was to have **thin pylons** to minimise the drag coefficient of the wing support as well as the frontal area of the car.

1 $F_D = \frac{1}{2}\rho v^2 C_D A$

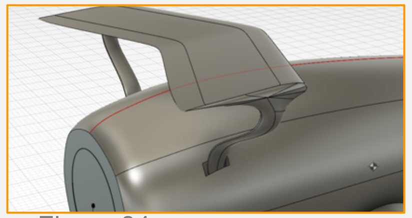


Figure 34

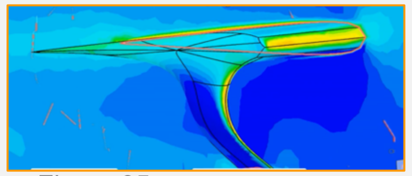


Figure 35

There is a darker **low pressure area** between the top surface of the car so to improve before manufacturing we're going to **increase the wing's height** above the car (greater than the minimum 5mm) to see if that improves airflow around the wing and fixes the low pressure region.

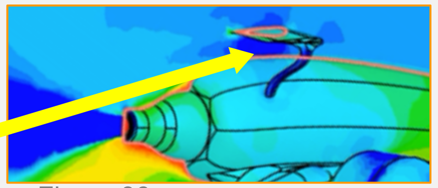


Figure 36

Figure 37

CFD RESULTS ON WING CHANGE

Figure 38: Rear Wing Before

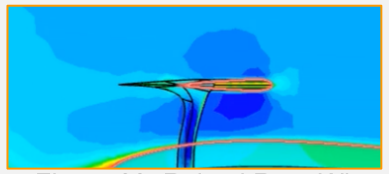


Figure 39: Raised Rear Wing

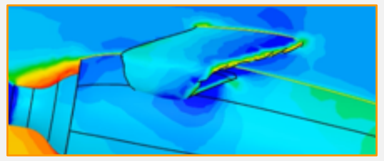


Figure 40: Wide Support

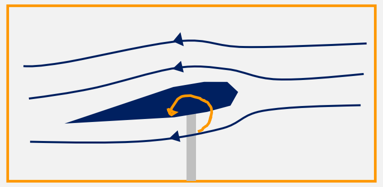


Figure 41: Wing Moment

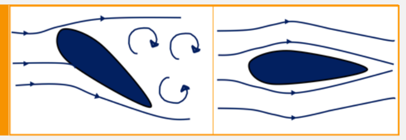
Raising the rear wing **has improved** the very high pressure region.

This could be due to the arrow shape as this pressure analysis is taken at the **peak of the wing**, next we'd like to test a straight wing for comparison.

Compared to a wide support, it's clear having a **thinner, less obtrusive support** is much better aerodynamically.

The support for the rear wing must be connected securely as any lift generated over the wing will create a turning moment on the joint between rod and wing.

4



ATTACHING REAR WING

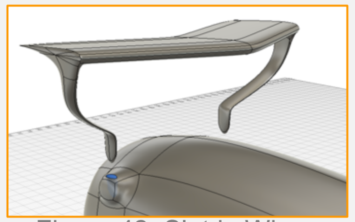


Figure 42: Slot in Wing

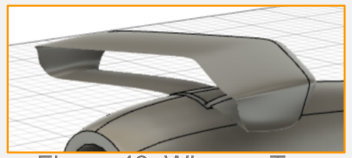


Figure 43: Wing on Top

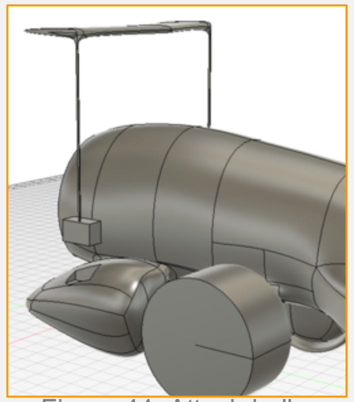


Figure 44: Attach bellow

By having extra material at the sides of the CO_2 housing, we can slot in the rear wing support. This is **structurally weak** and **creates drag** from the bulges.

Instead, by attaching the wing to the top of the car we have **more surface area** to work with but a break in the join would infringe safety regulations.

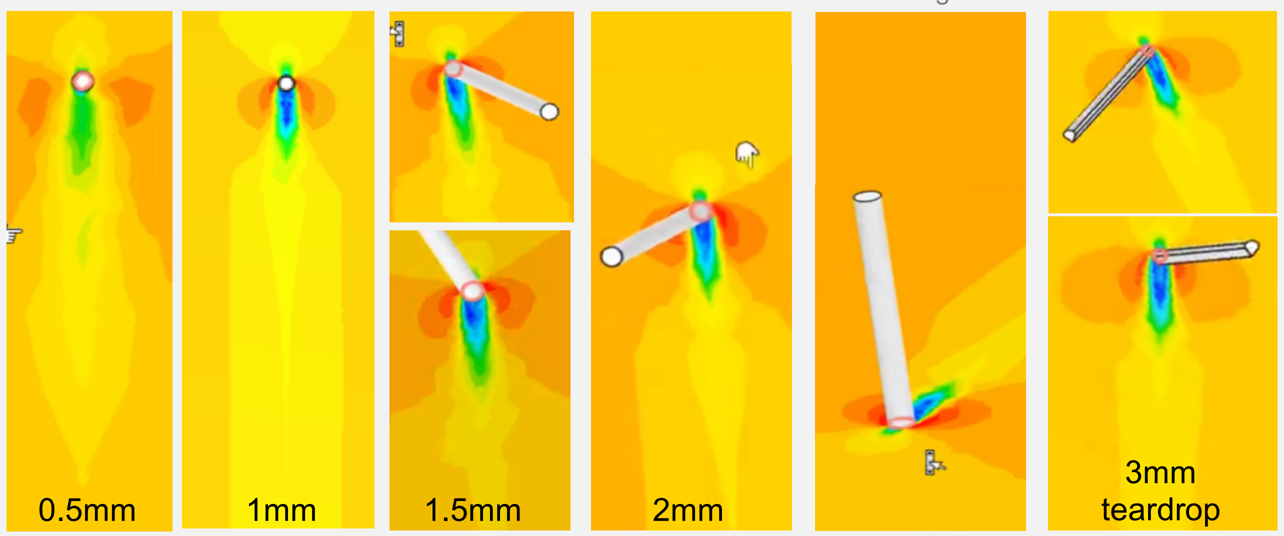
By attaching the rear wing supports to the pods behind the wheels we have more material to work with. This allows for a **securer fit**. The CO_2 chamber can now be made narrower, reducing the **frontal area** of the car and total drag produced from the wing and supports.

1 $F_D = \frac{1}{2}\rho v^2 C_D A$

ROD SUPPORT RADIUS

CFD shows the thinner the support rod, the less drag. We're aiming to hit the **goldilocks zone** between minimum diameter to reduce drag while being structurally strong enough for racing and sufficiently supporting the rear wing. Shaping the rod to an **aerofoil shape** does slightly improve it's aerodynamics.

Figure 45: Rod Diameter Effect



THEORY TESTING PITCHING MOMENT

Wheel base is a major decider in the **scope of exploration** we can do in the shape of our rear wing.

On page 2 we show our development of the front wing where we kept it as narrow as possible while making it aerodynamic and structurally strong.

By having a straight wing the **wheel base can be maximised.**

Figure 46

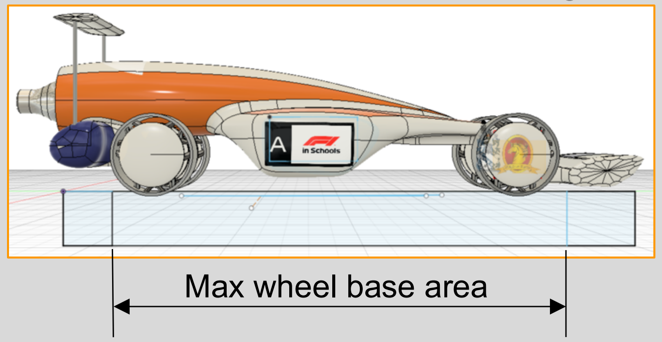


Figure 47: Centre of masses

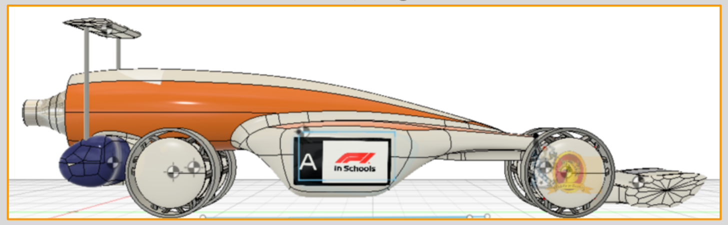
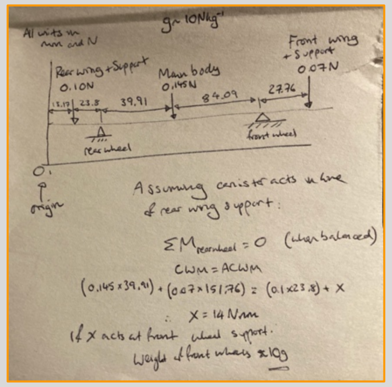


Figure 48: Centre of mass co-ordinates

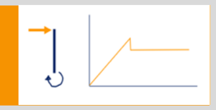
Figure 49: Centre of Mass calculations



$$\sum M = 0$$

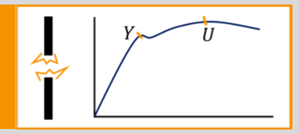
CWM=ACWM
Weight of each part creates a moment around the wheel support pivot.

6



When the CO_2 is released, **additional load** acts on the bearings and stress occurs in the contact area between the roller and the raceway. Deflection, caused by stress, creates an offset in the **rotating axis** creating a **resisting moment.**

7



By finding the centre of mass of each part we can calculate the system centre of mass which will be the **pivot** that the **impulse** from the CO_2 acts on.

We theoretically found the centre of mass of each component. By sketching a **free body diagram** with the weight of each component acting at its theoretical centre of mass we can calculate how to **balance our car.**

When 3d printing we should **increase rear wing and front wheel system density** to bring the cars centre of mass up and to prevent pivoting during the coasting phase of the race.

REAR WING R&D EVALUATION

IDEA EVALUATION

-Rod support for the rear wing **reduces turbulance** and comes as a natural progression.

-Centre of mass theory informed the infill we used for front and rear wings resulting in a **balanced final design.**

-Support developed from research results showing purposeful testing.

IMPROVEMENT ACTIONS

-For **efficiency** rod radius being CFD tested could be done after **stress testing** (see page 5) so only the diameters we have available are tested.

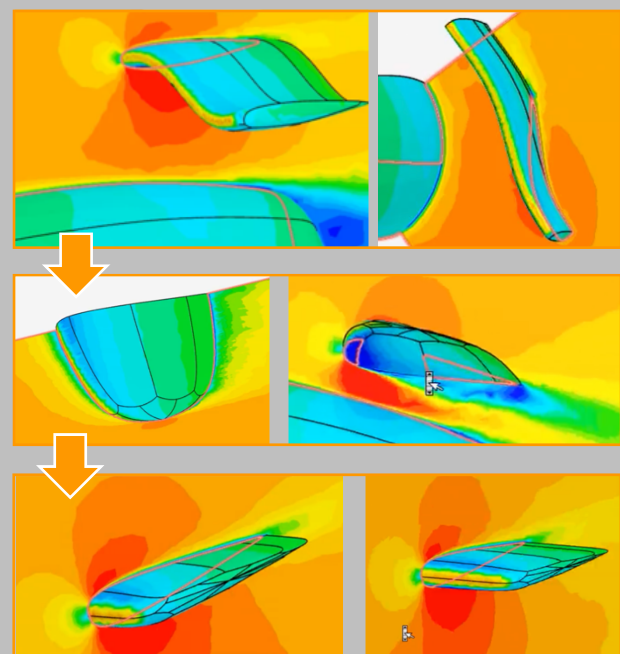
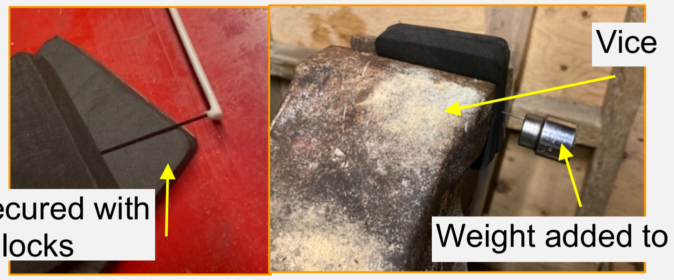


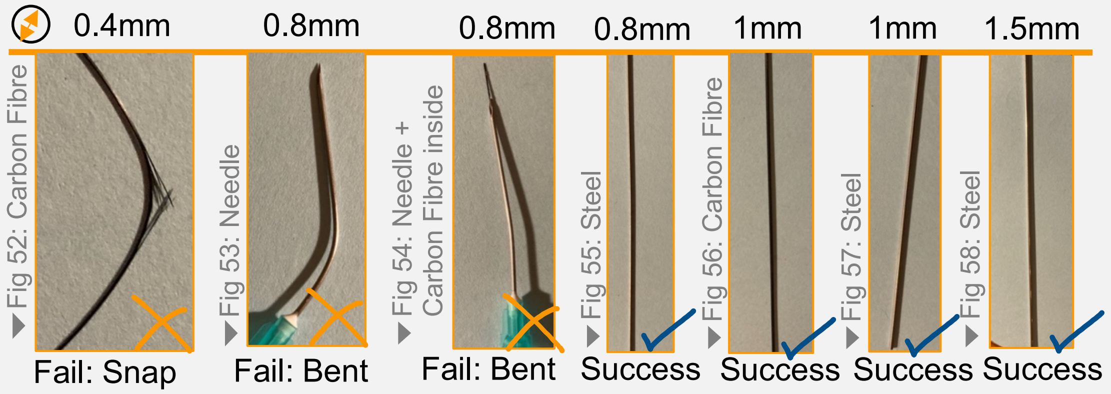
Figure 50: rear wing shape CFD

SUPPORT STRUCTURE MATERIALS

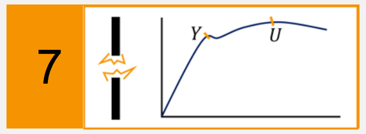
Aim: Find the material that allows us to have the minimum diameter of rear wing supports.
Method: Source a variety of potential rear wing supports, use vice and 0.5kg weight to test suitibility.
Expected outcome: Final rear wing support rod diameter and material determined.

Figure 51: Rod Test Method





Outcome:
0.8mm steel is the thinnest successful rod. It flexes but returns to straight when the weight is removed. In case the deceleration from the brushes bends the rod greater than it's **yield point** it will permanantly deform or break. We decided to use the **1mm carbon fibre** as it is lighter and also a success with less flex.



CONCEPT DEVELOPMENT- REAR WING SUPPORT

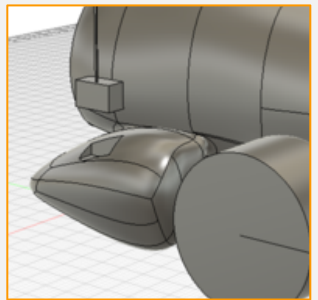


Figure 53

Initially we designed the support to have a 3D Printed base to the rod which fits into the rear pods made of model block.
To Improve:
-strength of support
-manufacture considerations

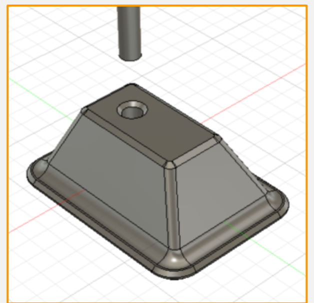


Figure 54

By **widening the base** of the support, strength is increased between the rod and 3D Printed base. Chamfers are added to the model block edges and the base.
To Improve:
-Use virtual analysis to consider aerodynamics
-Keep wide base up to rod so not fiddily.

A B

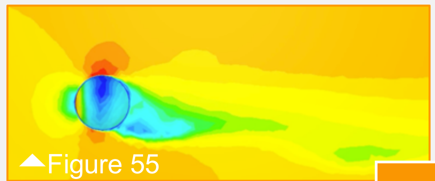


Figure 55

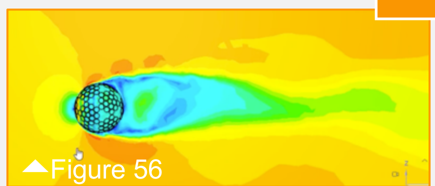


Figure 56

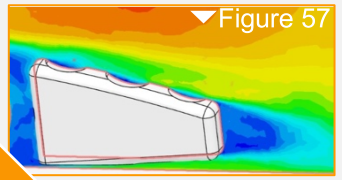


Figure 57

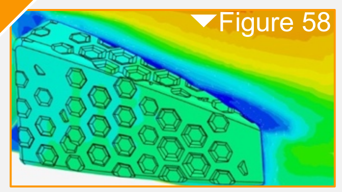
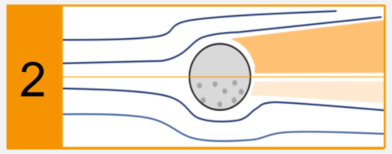


Figure 58

Similar to the dimples of a golf ball, this **reduced the wake** of the car. Virtual analysis shows the smaller dimples to be more effective on the rear support although harder to manufacture.



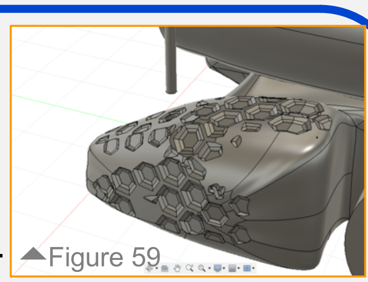


Figure 59

To improve:
-Replace model block rear pods as 3mm model block not strong enough.

C D

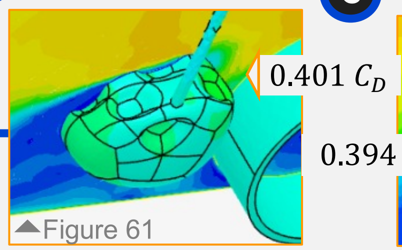


Figure 61

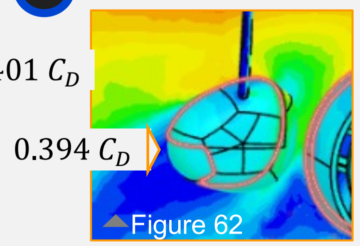


Figure 62

The dimples in the support create more turbulance as the **air interacts with the rod.** The increased drag coefficient means we've removed the dimples for the final design.

1 $$F_D = \frac{1}{2}\rho v^2 C_D A$$

By CAD designing the support with a separate 3D Printed part we can add **magnets.** This ensures no breakages as everything **separates** at the brushes. Strength increased as the plastic is stronger than model block.

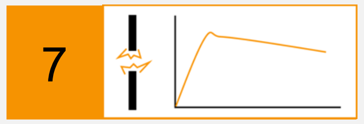
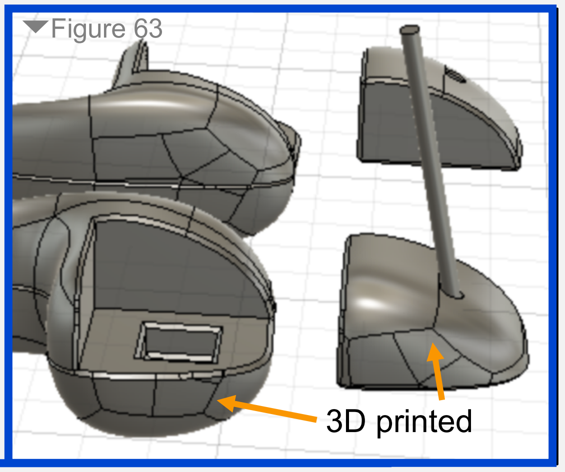


Figure 63


REAR WING SUPPORT MANUFACTURE

Before manufacure the rear wing support structure was split to reduce support material. Assembling reduced accuracy and quality of parts due to **misalignment** so we printed upside down with parts un-split.

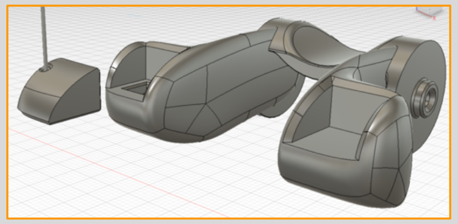


Figure 67: Rear wing support system before split.

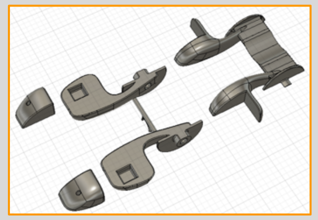


Figure 68: Rear wing support system split up.

0.4mm chamfers were added as this is the nozzle diameter. This **manufacture consideration** ensured clean edges that allow the parts to fit perfectly with the CNC machined main body.
Each part was made from PETG plastic with a 0.1mm layer height.

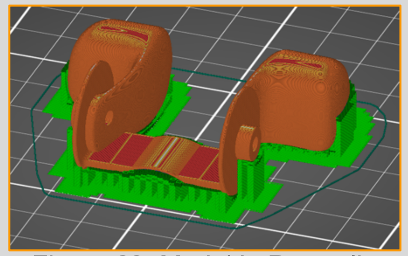


Figure 69: Model in Pursaslicer.

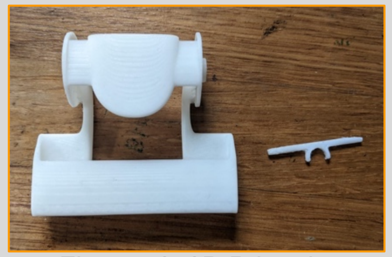


Figure 70: 3D Printed parts.

MAGNETIC SYSTEM DEVELOPMENT

Our aim is for the magnets to be strong enough to stay **engaged during racing** but to separate on impact after the finish line. To give a rough idea of magnet strength needed:
Impulse = mv-mu
=0.05(0)- 0.05(20)
= <u>1Ns</u>
Impulse=ft
time ≈ 0.05seconds
Force=1/0.05=<u>20Newtons</u>
So we're looking to achieve a pull force of just **under 2kg** so the wing separates just after the initial contact with the brushes.

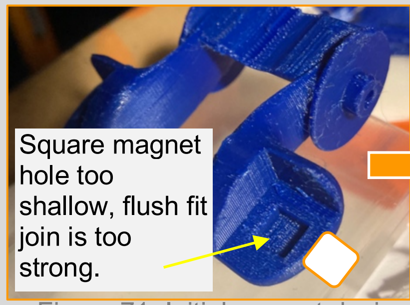


Figure 71: Initial support design


Figure 72: Final design


Figure 73: Magnet A

Pull Strength: 1.8kg
Fail: Too strong


Figure 74: Magnet's D

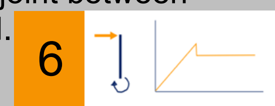
Pull Strength: 0.5kg
Success: Disengages after brushes

REAR WING EVALUATION

IDEA EVALUATION

-Strength testing eliminated rods that would likely fail during racing by applying a load to them.
-Rod connection to car developed to be **sufficiently strong.**
-Virtual testing improved aerodynamics of this concept making it a **worthwhile development** to our car.
-Magnets cleverly solve impulse issue with **rapid deceleration** when the car hits the brushes (fig 76).
-After test racing, support rods angled forwards to increase **horizontal component** of force going into disengaging magnet instead the exerting a torque on the joint between wing and rod, however the rod twists instead.

Figure 75: Brush height



IMPROVEMENT ACTIONS

-Each rod could have been tested through racing to give a more **accurate representation** of its ability to withstand force.

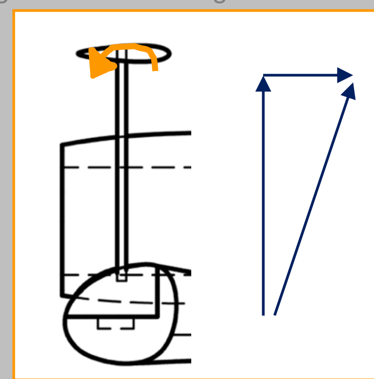


Figure 76: Moment on rear wing

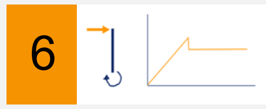
WHEEL PHYSICS RESEARCH

For the **general case** for wheels to decide whether to develop solid wheels or hollow rimmed wheels, we calculated the inertia.

We kept the units as mm as it was for comparitive results and as the wheel material would be the same for both, we kept density as "ρ".

Rimmed wheels of 1mm thickness have **less than half the Inertia** of solid wheels! This is due to the volume being being significantly less.

Because of this we **foccused on developing thin rimmed** wheels.



$\tau = I\alpha$

For a given Torque, τ we want to maximise the angular acceleration of our wheels, α so we need to **minimise the Inertia** of the wheels.

radius, r
inner radius, r_0
width, w
Volume, V
Density, ρ
Inertia, I

Solid

$V = \pi r^2 w$

$= 3.14 * 14^2 * 15$

$= \underline{9232mm^3}$

$m = \rho * V$

$m = \underline{9232\rho kg}$

$I = \frac{1}{2} mr^2$

$I = \frac{1}{2}(9232\rho)(14^2)$

$\underline{I = 904736\rho}$

Rimmed

$V = \pi w(r^2 - r_0^2)$

$V = 3.14 * 15(14^2 - 12^2)$

$\underline{V = 2449mm^2}$

$m = \rho * V$

$m = \underline{2449\rho kg}$

$I = mr^2$

$I = (2449\rho)13^2$

$\underline{I = 413881\rho}$

Half the Inertia!

WHEEL RESEARCH + DEVELOPMENT

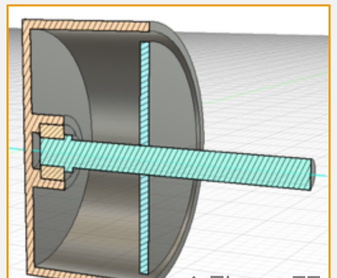


Figure 77

Initially we had the bearing **fitted to the wheel** with the axle inside and an inner wheel hub fixed to the axle. This was simple to manufacture and assemble with the axle **push fitting** into the bearing.


Figure 78


Figure 79

To improve:
-Too unstable (see fig 79), wheel wobbles lots.
-reduce inertia of rotating wheel, **hub connection inefficient.**
-Improve contact with axle and car.

A

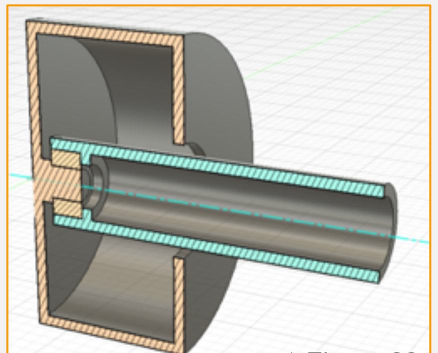


Figure 80

This is similar in all ways except the wheel spins on the **inner race** of the bearing. The idea being it has lower inertia as the inner ring of the bearing's spinning not the outer so the mass of the wheels **closer to the axle of rotation.**

Figure 81

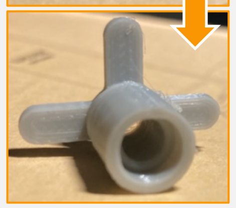



Figure 82

We designed a circular piece to hold the outer race of the bearing. However we were **unable to remove** the bearing. Instead we designed a T-Piece holder, using a hole at the back to allow the bearing to be removed.

To improve:
-Although rotational inertia is reduced, **stability is worse**. Main focus to develop is increasing wheel stability.

B

C

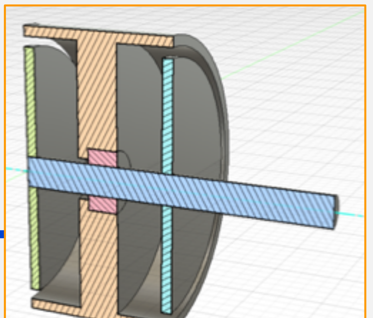


Figure 83

This design allows for **lower inertia** and the bearing is closer to the main body, increasing wheel stability.

CURVED HUBS

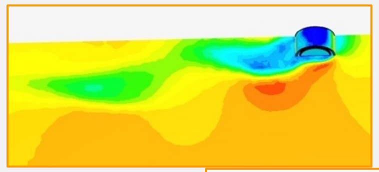
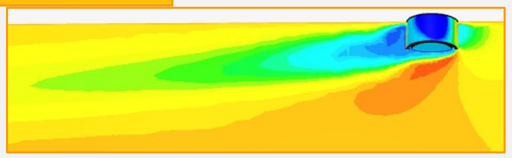


Figure 84 0.471 C_D

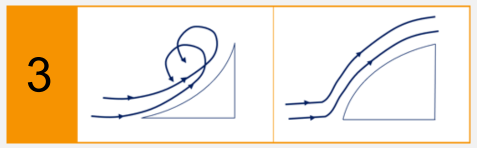
1 $F_D = \frac{1}{2}\rho v^2 C_D A$

Figure 85 0.431 C_D


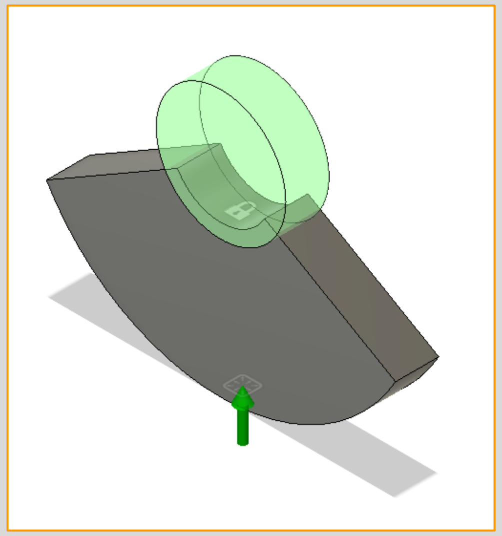
We included hubs to reduce **turbulence** inside the wheel. In this design the hubs are fixed which allows for a **convex surface** that keeps flow attached around the wheel. In the **horizontal plane** you can see the benefit of this.


Figure 86

Curved hubs improve the aerodynamics around the car.



GENERATIVE DESIGN

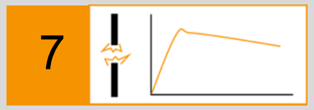
Figure 87: Set up of generative design


The wheel needs to be equally strong at any point on its surface, as it rotates whilst supporting the weight of the car.

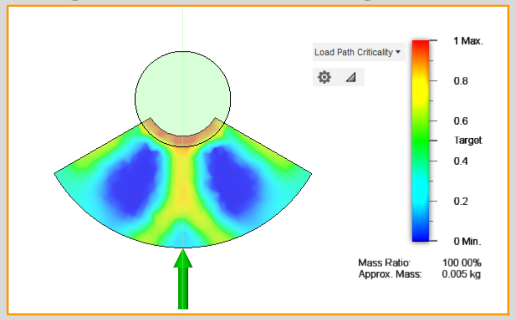
To use **shape optimization** a segment of the wheel is modelled, as Fusion 360 can't solve for a load at all points on the wheel simultaneously.

The area where the bearing is inserted is marked with a **preserve region** (green cylinder) to ensure that there is enough material to hold the bearing securely.

The face where the bearing is inserted is set as a **fixed constraint** (padlock symbol), as the wheel needs to be rigid about the bearing and not **deform under expected loads.**



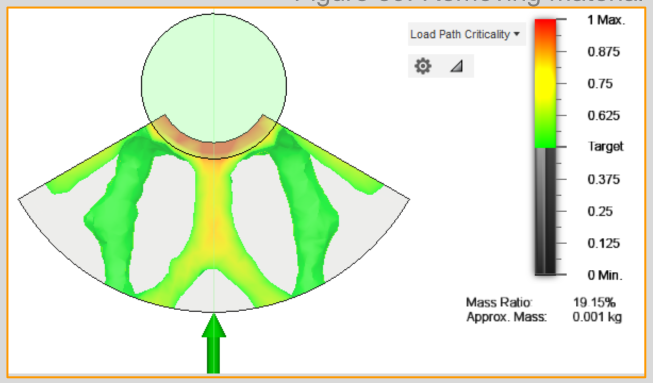
SIMULATION RESULTS

Figure 88: Generative design results


The results are shown as a mesh, coloured by how important each cell of material is to the **strength of the part**, the 'Load Path Criticality'.

A mesh is then exported for various levels of mass, and tested for strength in an **FEA simulation** to verify that they are sufficiently strong and won't deform.

FINAL WHEEL FROM RESULTS

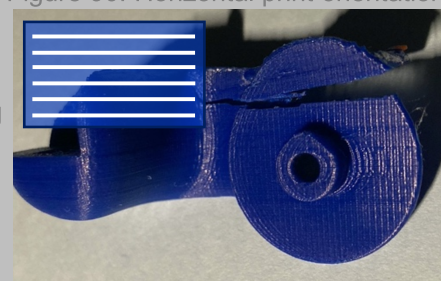
Figure 89: Removing material


Our final wheel was about **20% of the weight of a solid core wheel**, whilst maintaining sufficient strength to support our car as it races down the track

The mesh is then promoted to the design workspace and rotationally patterned, and then finished using solid workspace tools to create the final wheels ready for manufacture.

WHEEL SYSTEM EVALUATION

IDEA EVALUATION

Figure 90: Horizontal print orientation


-Designs developed in steps based on manufactured testing which resulted in a stable and **well manufactured** final design.
-Axle system developed based on **theoretical research** to reduce rotational inertia, this resulted in a faster final wheel design.
-Print **layer orientation** changed after printing as the support is too weak.

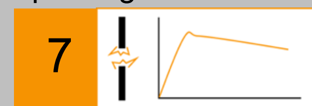
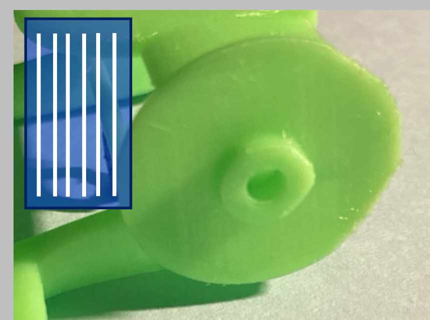


Figure 91: Vertically orientated


IMPROVEMENT ACTIONS

-Explore splitting the wheel 5 or 7 times to gain even lighter '**strength to weight' ratio** designs.
-Work with an industry partner to try simulating a wheel with a 3d printed makeup. How would the layer weaknesses alter the strongest design generated?

TETHER LINE GUIDE

Our **aims** for the tether guide set our target to work towards development.
We kept in mind the key purpose to the tether line guide: to keep the car **travelling straight** down the track. We have a range from 3mm inner diameter to 6mm inner diameter to consider how to best fulfil the tether guide aims.

We refer to these checkboxes to evaluate each design.

☐	STRONG	Won't break during racing or knockouts.
☐	AERODYNAMIC	Minimal aerodynamic disturbance.
☐	LOW FRICTION	Reduce friction between guide and tether.

DESIGN DEVELOPMENT

All designs are **evaluated** in relation to our tether guide aims. Either fulfilling the aim or not. Initially we 3D printed a tether guide to attach between the wheels. It was **designed for manufacture** by chamfering the edges and beveling the connections. The result is bulky as the walls need to be thick to be strong enough.

☑ ☐ ☐

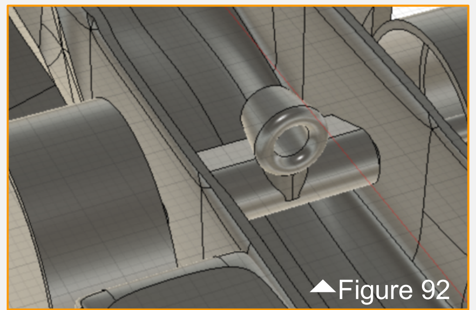


Figure 92

Figure 93

Things to improve:
-Material needs to change as 3d print **snags with guide**
-Simpler design with considerations of the rest of the car
-Explore wider inner diameter as currently at minimum with **lots or rubbing** with guide
-Better securing system to the car not requiring axles through the car.

A

Figure 94

Figure 95

☐ ☑ ☑

Instead we used a strip of carbon fibre that runs parallel to the track. Then a carbon fibre loop is **secured on top of the strip**. This fulfils the simplicity aspect and the carbon fibre loop doesn't **snag** as it's pre-manufactured with a smooth edge.
To improve:
-stronger connection to main body as model block snaps.

B

To improve strength we increased the **contact area** between the tether guide loop and the support. To strengthen the wheel system and prevent bowing we designed the tether guide support to go between the wheel supports.
The loop material we changed to **nylon** as it has the lowest **coefficient of friction** with the nylon tether guide.

☑ ☑ ☑

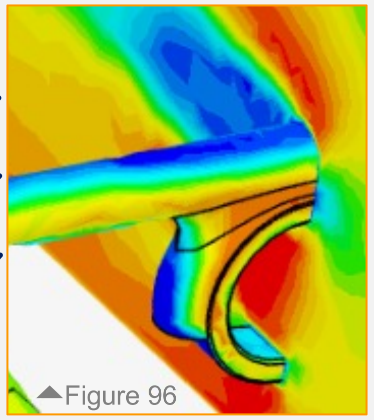
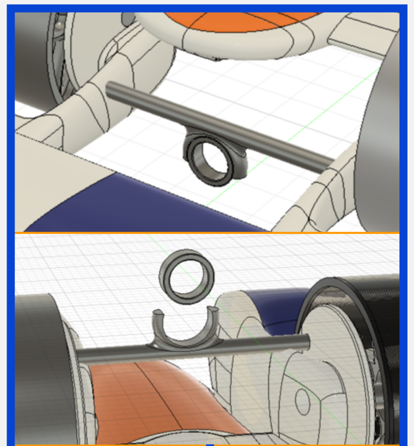


Figure 96

Figure 97

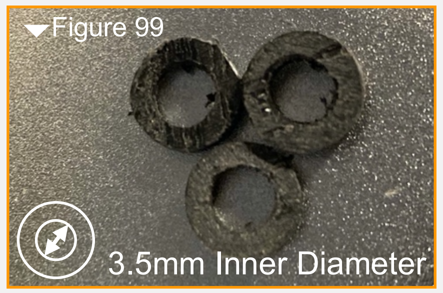
Figure 98: Final tether guides



C

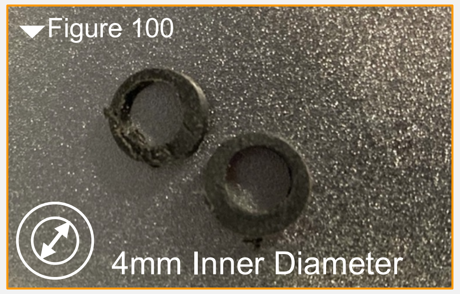
By varying the inner diameter from 3.5mm to 4mm to 4.5mm we can select the best quality guide loops. We chose the 4mm guides due to **even thickness** of nylon.

Figure 99



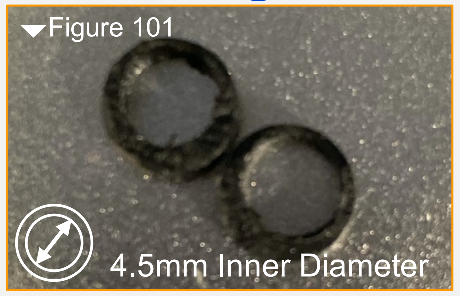
3.5mm Inner Diameter

Figure 100



4mm Inner Diameter

Figure 101



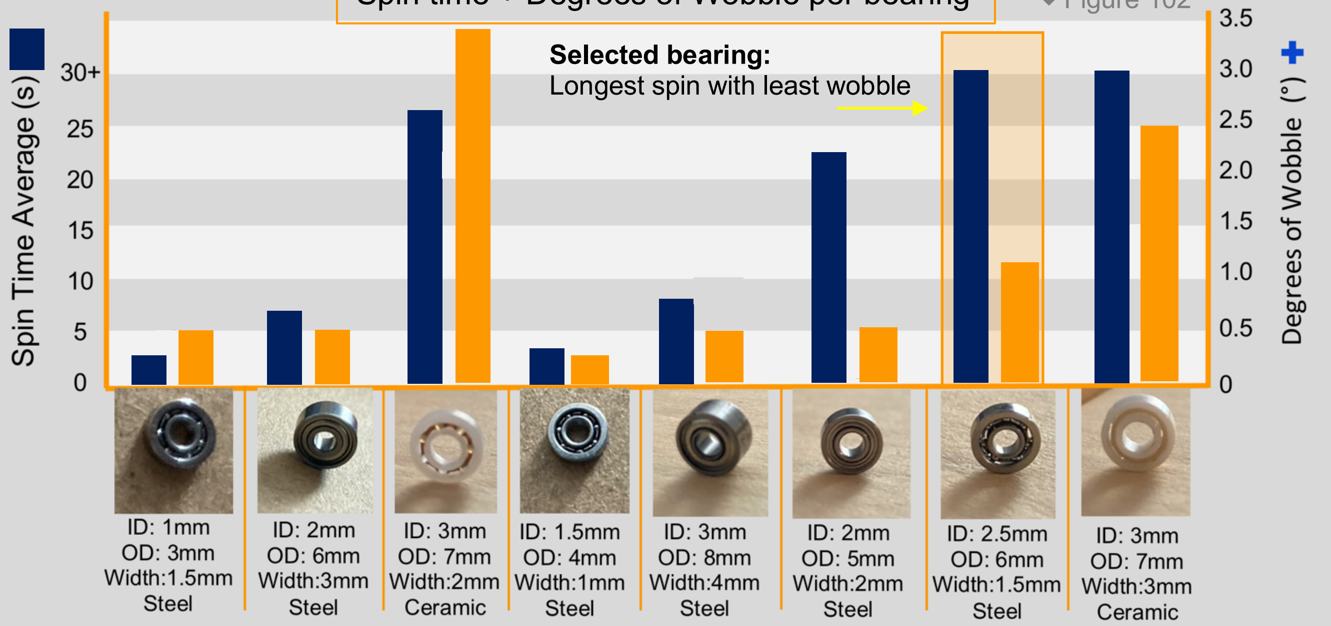
4.5mm Inner Diameter

BEARING TESTING

Aim: Determine the best bearings which have the least wobble and spin for the longest.

Spin time + Degrees of Wobble per bearing

Figure 102



SPIN TIME METHOD

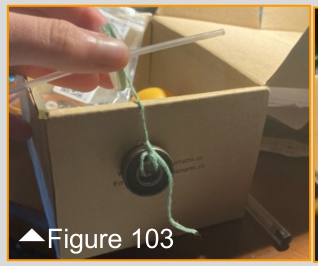


Figure 103

Figure 104

Spin time is **proportional to friction**. We machined disks with a groove for a string and weight to hang so we can exert an **equal torque** for each bearing and reliably find which bearings spin for longer and have less friction. Measurements were repeated 3 times and the average displayed on a graph.

WOBBLE METHOD

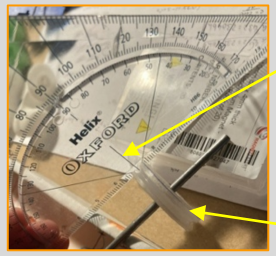


Figure 105

We aimed to reduce wobble in bearings as this would reduce **energy losses.** We measured it with a thin disk fitted onto each bearing. The angle of maximum tilt was measured with a protracter and recorded.

WHEEL SYSTEM EVALUATION

IDEA EVALUATION

-**Several technically inspired ideas** for wheel systems were developed to a successful final design.
-**Advanced use of 3D modelling** techniques + generative design used for **highly detailed** wheel systems modelled and manufactured to develop ideas.

IMPROVEMENT ACTIONS

-**Increase accuracy** of bearing wobble method. Protracter not easily set to 0 position so **reading uncertainty** of at least $\pm 1°$.
-**Axis for wobble** could be **reversed** as then the best bearing would have the tallest orange and blue bars.

VISCOUS FRICTION

Lubricant in the bearing **reduces wear** and deformation due to the parts rubbing against eachother, however the grease itself **resists the rotational motion.**
We removed this by **soaking** the bearings in Acetone as speed is our priority over durability.

Figure 106

SPIN TIME

Spin time average for the bearings goes from 34 seconds to 67 after soaking in Acetone.

MANUFACTURING GOALS

Clear manufacturing goals guide our **evaluations** of **machining processes** to ensure high quality manufacturing of our final car.
In addition to our manufacturing goals we evaluated each process in terms of sustainability. Focussing to reduce machining time and waste material as a result of manufacture.

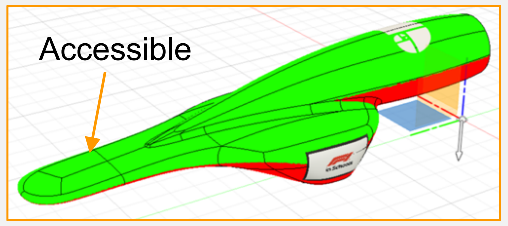
CONSIDERATE	**Manufacturing considerations** incorporated to design.
APPROPRIATE	Appropriate **machining techniques** + equipment used.
CONSISTENT	Manufacturing processes precise and **repeatable**.
ACCURATE	Manufacture CAD design to high degree of accuracy.

CNC CONSIDERATIONS

ACCESSIBILITY

CNC milling requires the model to be accessed from each plane it's milled in. The CNC machine we used was a **X axis CNC**. We **outsourced** as we don't have our own machine to use. For our final car we machined it to **±0.1mm to ±0.5mm accuracy.**

Figure 107



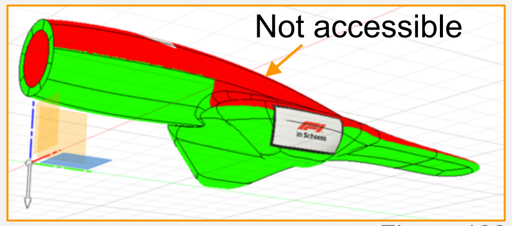
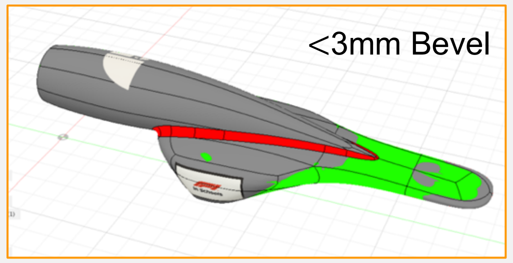


Figure 108

MINIMUM RADIUS

Before CNC manufacturing our main body we used Fusion 360's **accessibility testing** to make sure it was fully machinable. We added **bevels** on the edges so the CNC Machine could access all edges and points on the CAD model.

Figure 109



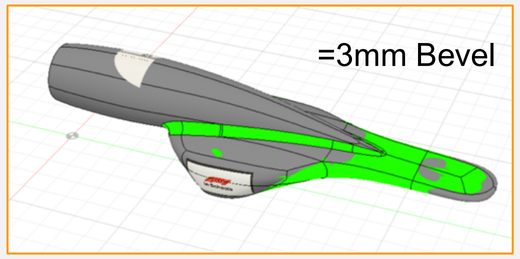


Figure 110

CNC SET UP + MACHINING

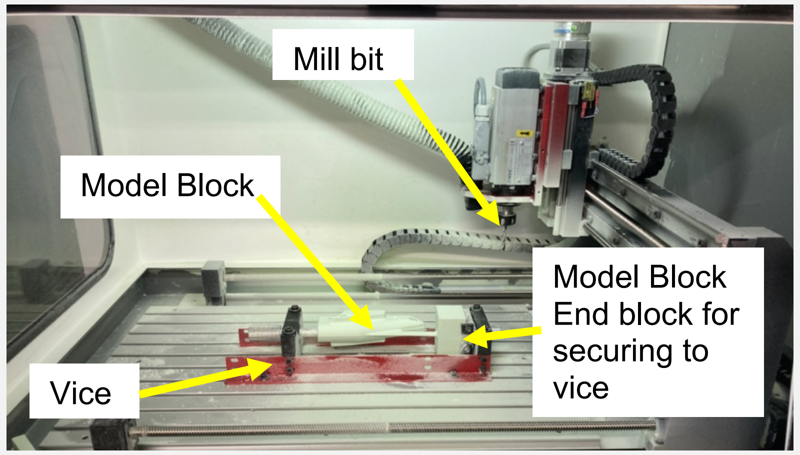


Figure 111: Denford 2600 PRO

CNC milling involves using a **rotating cutter** to slice away material from solid stock according to a **computer program**, and so is known as a **subtractive manufacturing method.**
The most common cutter type used in smaller mills are called endmills. These typically have 1-4 cutting edges known as flutes. The rpm of the motor that turns the cutter (the motor and cutter holding assembly is called the spindle) is **carefully controlled**, as well as the speed that the material is fed into the cutter, so that **consistent** amounts of material are cut by each flute.
The speed of the cutter can also affect the surface finish of the part and wear on the tool.

CNC MANUFACTURING STAGES

Figure 112: Manufacturing stages

Step 1: Prepare CAD for CNC

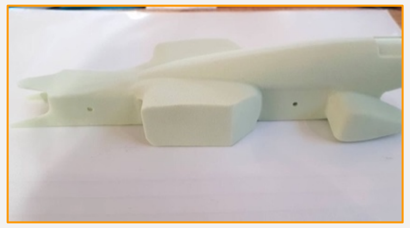
Additional parts removed, checks done.

Step 2: Set Toolpaths and CNC car

Set up machine and create toolpaths then CNC the car.

Step 3: Remove body from CNC

When finished remove main body from the machine.



Step 4: Remove supports + sand

Break off support structures and sand machining marks.

3D PRINTING OUTSOURCING

Before 3D printing, the design must be checked to ensure that it is completely solid and all parts are thick enough that the nozzle can extrude there- the standard **nozzle diameter is 0.4 mm**. 3D printed parts are **built up in layers** and develop a "grain", where the connections between layers are weaker than each individual layer.
Care must be taken to **orient the layers** correctly in locations where strength is needed.

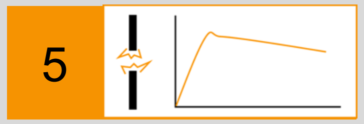


Figure 113

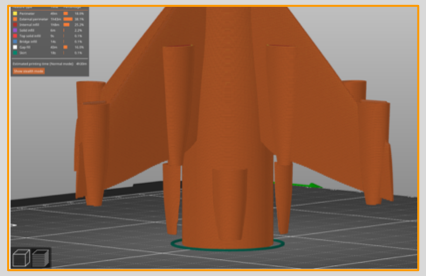
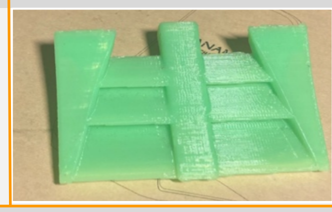
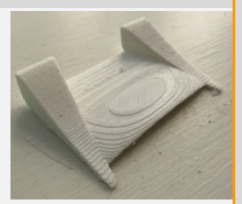


Figure 114: 3D Print materials

	FILAMENT MATERIAL		
	PLA	ABS	PETG
MACHINE USED	Prusa Mk3 PrusaSlicer software	Ultimaker 2 Ultimaker Cura	Ultimaker 2 Ultimaker Cura
STRENGTH (Ultimate Strength Mpa)	65 Mpa	40 Mpa	53 Mpa
FLEXIBILITY	None	Little bit of give. Impact resistant	Only when thin
SURFACE FINISH	Smooth	Requires sanding	Smooth
EASE TO REMOVE SUPPORTS	Difficult, leaves rough surface	Difficult, leaves rough surface	Easy break off, leaves smooth surface
COLOURS AVAILABLE	Clear, Green	Black, grey, white, blue	White, orange
PICTURE			

MANUFACTURING EVALUATION

IDEA EVALUATION

-We **outsourced** CNC machining to two suppliers: a local school and Nissan. This allowed for **quality control** checks to be made.
-Within each manufacturing stage we were **extensively involved** with our partners we outsourced to, so we learnt about the machines operations and **safety measures.**
-To evaluate the filament options for 3D printing, test parts were made **creating waste**. We are passing them on to future teams to use as a reference, so they **don't do the same.**

IMPROVEMENT ACTIONS

-Alter support structure locations to see where **pressure is best distributed** during manufacture.

Figure 115

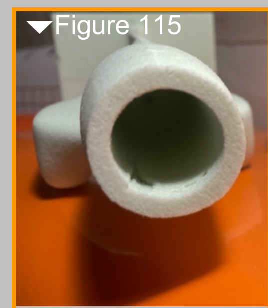
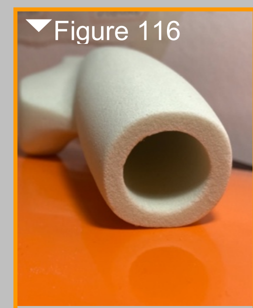


Figure 116



SCHOOL vs NISSAN

SURFACE FINISHING

We used a microscope to see the **details** of surface finishes.
Aim: To definitively be able to evaluate each method for surface finishing.
We monitored each finish development by checking it to our success criteria and using an **iterative approach** going forwards.

Quality goals:
A Completely coats foam
B Vibrant Strong colour
C Smooth surface
D Easy to apply
E Sharp edges

Method:
Use cut offs from Model block and treat each one as if coating the final car. Then observe under the microscope and evaluate, developing from results.


Figure 117: Microscope

Figure 118: Method

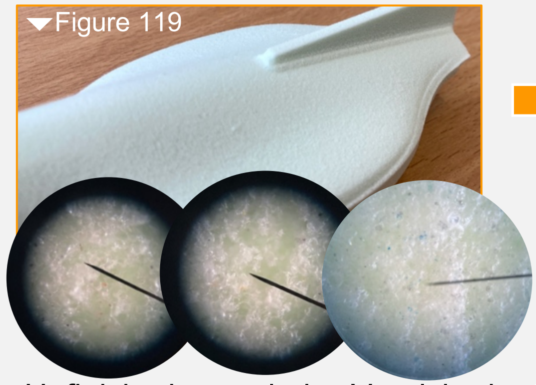

Figure 119

Unfinished model block sanded Varnished

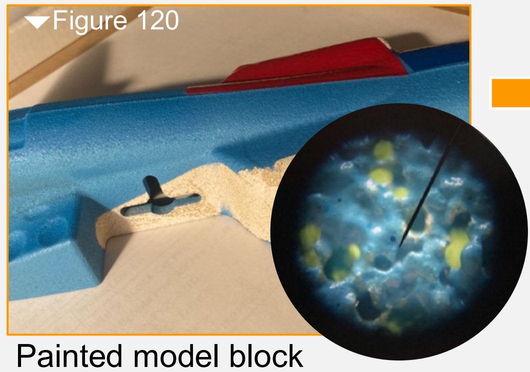
Figure 120

Painted model block

Figure 121

Vinyl wrap surface finish


Plastidip surface
Figure 122
Plastidip edge

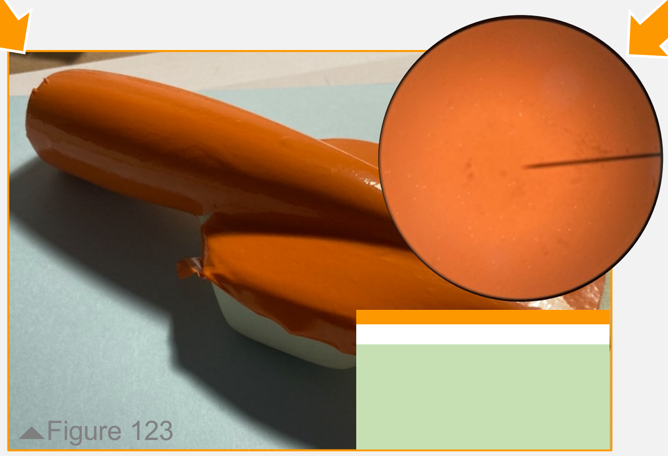


Figure 123

STAGES
1- lightly sand machine marks off model block
2- Spray Varnish on Plastidip 4 coats taking care to let fully dry
3- Glue wheel supports to main body
4- Apply vinyl wrap and cut edges
5- Attach decals to the car

Our final surface finish used the varnish to **seal the model block** then we applied heat transfer vinyl for colour and smoothness of the surface.

PLASTIC SURFACE FINISHING

For 3D Printing, we used a **small layer height** as the result is much **smoother and stronger.**
Our **process** for finishing was:
-Rough sanding to remove excess plastic
-Place tinfoil in Jar with acetone
-Leave to vapour finish, checking every 20 minutes
-Remove when 80% of desired smoothness
-Leave to solidify and set

Then for aesthetic and aerodynamic purposes we used vinylwrap to add detail and design to parts.

Figure 124: 3D printed surface finishing

VAPOUR FINISH

Before

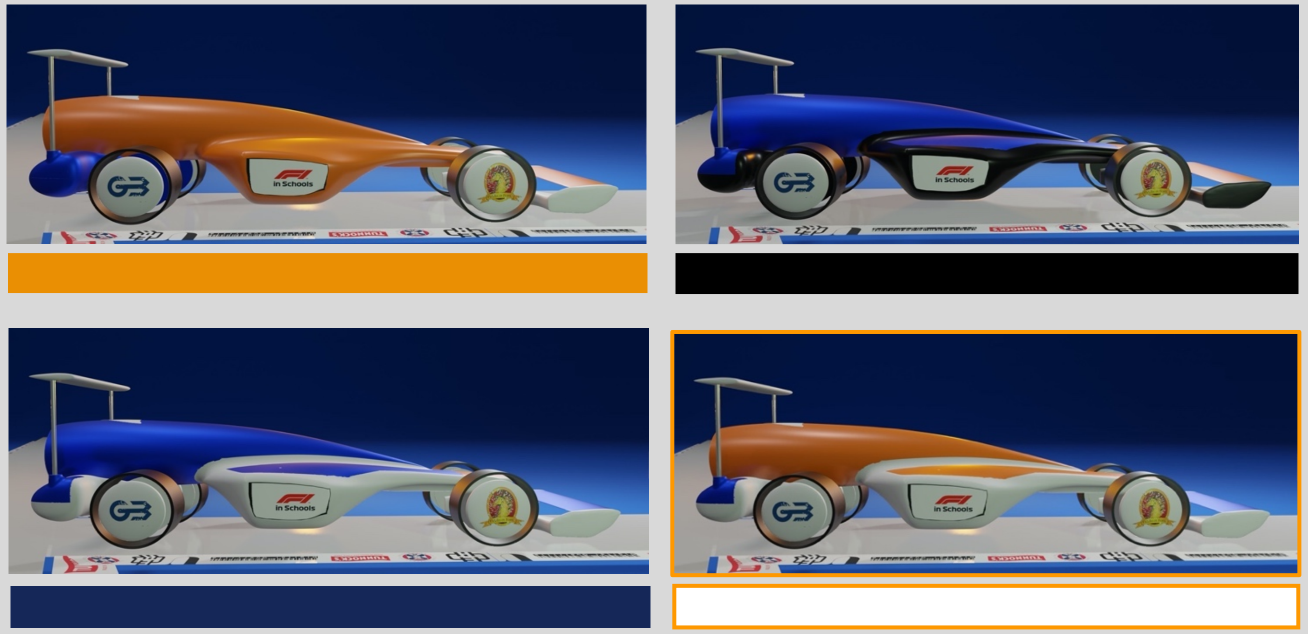
After

VINYL WRAP

-Requires curves, no right angles
-Convex shapes instead of concave
-simple parts best
-smooth aerodynamic final finish

WARNING!
Safety considerations made with handling Acetone:
-Gloves must be worn
-If any touches skin wash immediately
-Safety goggles in case of splashing
-Seal jar securely
-Keep away from sparks as highly flamable
-Leave to vapour finish parts outside with plenty of ventilation
-Store bottle at room temp

EXTERIOR DESIGN

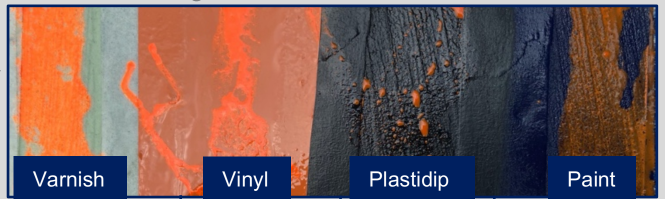
Figure 125: Rendered surface designs


We decided on the final colours for the exterior design after evaluating these four options.
Logo decals were outsourced and **industraly printed** and carefully transferred to the vinyl wrapped car components. This ensured a **clean cut, professional** final design.


Figure 126: Decals

WIND TUNNEL PHYSICAL TEST

We increased the supply voltage to the fan, using the anemometer (page 3) to set the air speed in the wind tunnel to roughly $20ms^{-1}$. Then we applied **luminescent oil** with a syringe to each surface finish method on a sample strip. By placing in the wind tunnel for 10 seconds then leaving to dry we can use the **traces** left to see the best surface finish method is the plastidip and vinyl.

Figure 127


Varnish	Vinyl	Plastidip	Paint
Lots of viscous drag. Bad final surface finish.	Smooth, with luminescent oil running off easily.	Best surface finish as low viscocity.	Worst surface finish as oil lingers across whole surface.

SURFACE FINISH EVALUATION

IDEA EVALUATION

-Using a microscope to look at surface finishes educated us on the **makeup of materials**, a major **learning experience** for the team.
-Surface finish methods were effectively removed from consideration for the final finishing processes due to test results with the microscope.

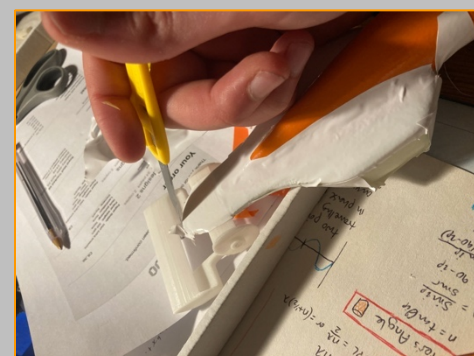


Figure 128: Cutting Vinyl

IMPROVEMENT ACTIONS

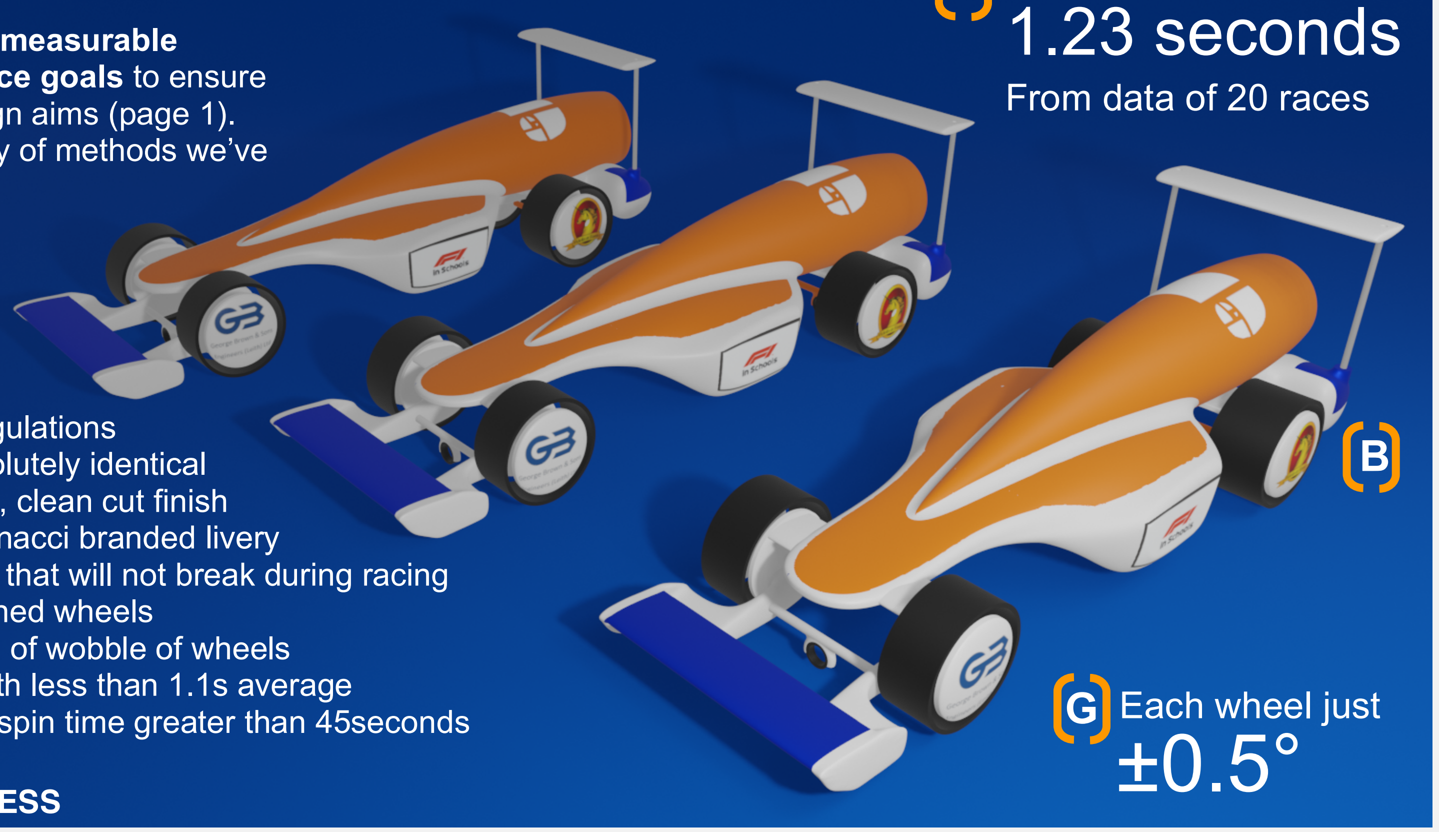
-Acetone finishing smoothed certain plastic parts but also **weakened the plastic** and added flex. Chemical research would allow us to explain this and find a way to smooth the parts without weakening.
- Outsourcing the vinyl wrapping could have improved the edges. To **improve adhesion** while the plastic cools a jig could have been made with the invert of the car.

Craft knives are extremely sharp.
Heat gun can burn.
Knife slips easily on vinyl.
Protective goggles must be worn.
Keep fingers away from heat.

QUALITY ASSURANCE

We made **clear, measurable quality assurance goals** to ensure we met our design aims (page 1). Through a variety of methods we've met each one.

Figure 129



(H) 95% Confidence Interval
1.23 seconds
From data of 20 races

(B)

(G) Each wheel just
±0.5°

Quality goals:
- A Meets all regulations
- B All cars absolutely identical
- C Professional, clean cut finish
- D Vibrant Fibonacci branded livery
- E Strong parts that will not break during racing
- F Straight aligned wheels
- G Less than 1° of wobble of wheels
- H Test race with less than 1.1s average
- I Each wheel spin time greater than 45seconds

= SUCCESSUL DESIGN PROCESS

TEST RACING CONFIRMS (E)

Figure 130

We have **purposefully tested** our fully assembled car on a track to ensure we can say with 100% confidence our car will not break during racing.
In addition to this we removed segments of the track to give **greater impact** with the brushes and our car withstands the impact.

LASER CUT TOOLS (A)

Quality assurance is important with pieces to make sure they work, laser measurements, calipers and find tolerances from machines and check compliance.
Laser cut tools to check and ensure regulations are met. This is a cost effective and sustainable method with high positive project impact as it ensures this **quality control** point is met.

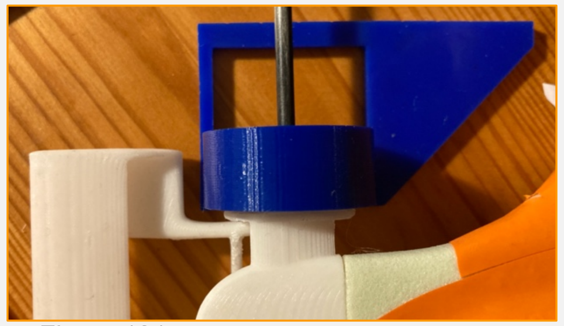


Figure 131

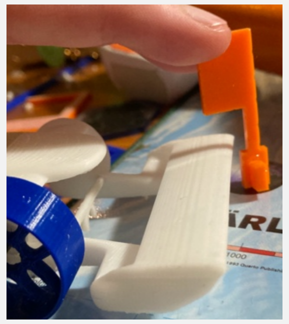


Figure 132

(I) Wheels spin for over 100 seconds!

Using the same method as on page 6, our wheels will spin for over a minute before they stop. This was achieved through evaluating a variety of bearings and using acetone to **remove viscous lubricants.**

Figure 133

WHEEL RIG (F)

From track testing it became clear how important **alignment** was by seeing how much our car wobbles down the track. We have developed a wheel system where the wheels don't share the same axle which means there's much more opportunity for **misalignment** and increasing wobble.
Here are the rigs we designed and made for attaching wheel supports to the car for a **perfectly aligned fit** everytime.

Figure 134

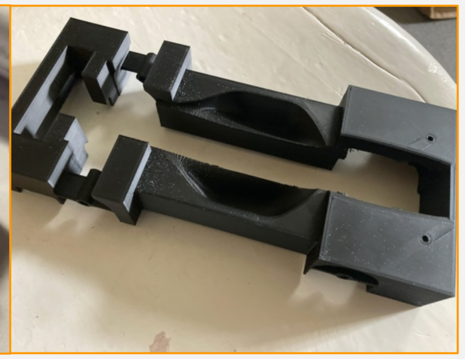


Figure 135

ASSEMBLY PROCESS

Once we have all our parts manufactured and individually finished.
We use a **rig to assemble all parts.**

1. Place model block from above.
2. Push wheel supports into snap fit from below.
3. Remove model block and add super glue to joints.
4. Place model block back and leave to dry with alignment rod in place.
5. Insert axles through guides.
6. Insert bearings, wheels and hubs to axles.
7. Super glue hub and back of axle to seal onto car.
8. Remove from jig and vinyl wrap over joints
9. Push fit rear wing support through holes in jig.
10. Super glue and magnetically attach rear wing.

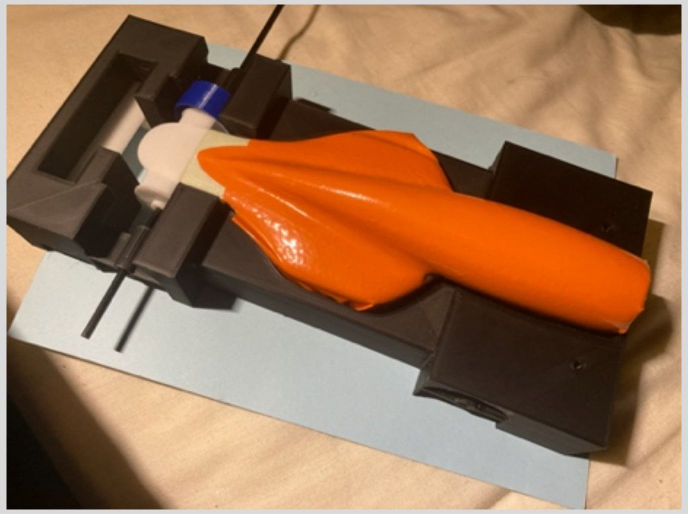


Figure 136: Midway through assembly model of our car

REGULATION CHECKS

To ensure our car met all the **regulations**, we created bodies in CAD. With the wheel safety zones we added 1mm on all sides to ensure if any manufacturing mistakes occurred or slips while assembling it would remain a fully legal car.
Together with our laser cut checking tools (see fig 134) this ensured we fixed any **possible infringements.**
To meet the decal regulation for clear visibility on the side pod with ±10° from the vertical plane, we had to alter the design, making it flatter to meet the regulation.

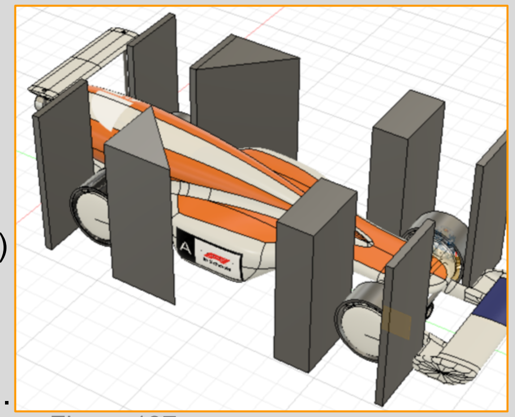


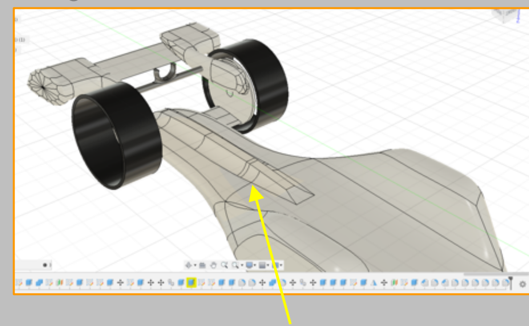
Figure 137

DESIGN PROCESS EVALUATION

IDEA EVALUATION

-Every part of our car has been developed through a **thorough design process** resulting in an excellent final product.
-**Virtual analysis** was integrated throughout achieving a highly aerodynamic car.
-**Manufacturing considerations** resulted in high quality parts and assembly processes.
-**Variety of testing methods** ensured we met our design aims of a fast, strong and legal car.

Figure 138

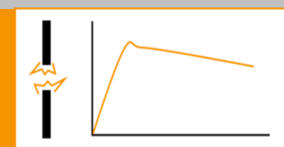


Ridge added for strength

IMPROVEMENT ACTIONS

-**Stress test** model block to definitively have a thickness limit. This could have **avoided** later design changes such as adding a **ridge to strengthen** our car and informed design developments.

5



FIBONACCI

3D MODELLING

SOFTWARE USED

Autodesk Fusion 360

CREATED BY

Mattie Ball Torokoff
Project Manager + Design Engineer

Kenneth McIver
Manufacturing Engineer

Amius Marshall-De'Ath
Graphic Designer

VIRTUAL ANALYSIS

SOFTWARE USED

Simscale
Autodesk Fusion 360

CREATED BY

Kenneth McIver
Manufacturing Engineer

MANUFACTURING

SOFTWARE USED

Prusaslicer
QuickCam Pro

CREATED BY

Kenneth McIver
Manufacturing Engineer

Miron Zadora
Hacklab Engineer- Outsourced Sponsor

Fibonacci

Did you notice our folio layout follows the fibonacci sequence?

DATA REFERENCES

Figure:	Source:
114	Simplify3d.com/support/materials-guide/properties-table/

Theory + concept understanding

Research No. :	Source:
1	SQA AH Engineering Syllabus
2	SQA AH Physics Syllabus
3	SQA AH Engineering Syllabus
4	"
5	"
6	SQA AH Mechanics Syllabus
7	SQA AH Engineering Syllabus
8	SQA AH Engineering Syllabus
1- Drag Equation	En.wikipedia.org/wiki/Drag_equation

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