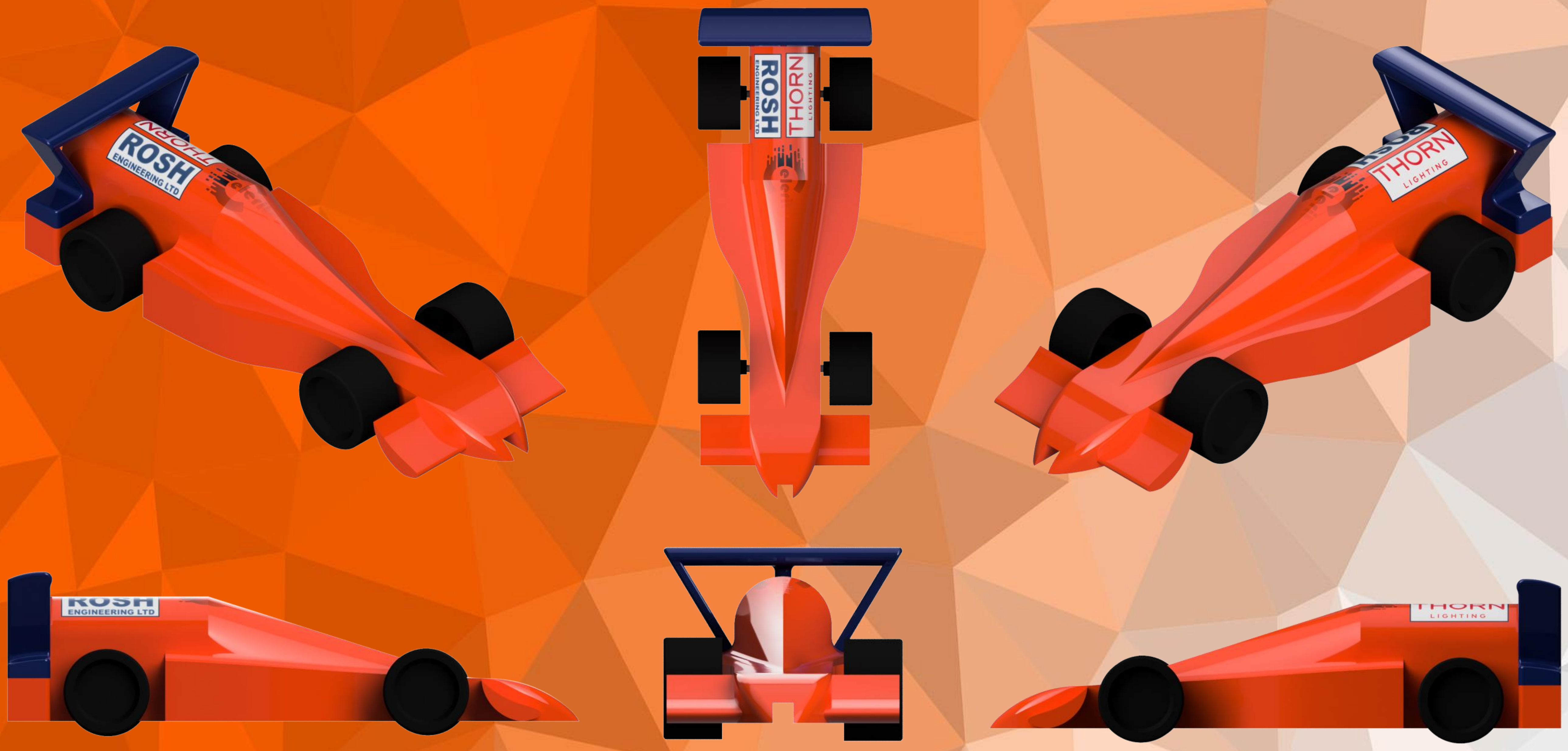
Design and Engineering Portfolio

Celerity

St Cuthbert's Catholic High School

F1 in schools



F1 in Schools National Finals: Leeds University

Research

Physics and Aerodynamics

The most important factor to consider while creating our car is aerodynamics. This is because every car is given the same force of propulsion where the only difference between the races are the designs of the cars.

- Excessive lift or downforce should be avoided. This is in relation to Bernoulli's principle which states that a speed of a fluid, air in this case determines the force of pressure that a fluid can exert. This creates unnecessary forces on the car down into the track, wasting energy that could be used to push the car forwards.
- Laminar flow is the process where fluid particles In this case air, follows a smooth, parallel path in layers where each layer flows smoothly past each other without conflict. If air around out car is not in laminar flow, the fluid particles will cause friction and slow down our car. We can maximise laminar flow by smoothing surfaces and removing areas that might cause air to be in conflict.
- Drag, or air resistance is the force where oncoming air creates friction with a moving object, like our car, which causes the car to decelerate. This type of drag is often referred to as skin friction as it occur when a fluid, in this case air particles, rubs against the surface of an object. Therefore, we should prevent drag as much as possible, this can be done by smoothing down edges and sides as well as making the car as small as possible and when skin friction can't be eliminated it is beneficial to align its direction with the rear end of the car to prevent it from creating any turbulence which would further hinder our cars race performance.

Drag

Drag can also be represented as a coefficient, which is the drag force divided by the product of velocity, pressure and frontal area. This value can be found by using a digital software or a wind tunnel. Ideally, our design should have a low drag coefficient whilst still being light so that friction doesn't negate all benefits of low drag.

$$c_d = \frac{2F_d}{\rho u^2 A}$$

- We looked into the shapes and race times of past teams' cars and found that a slim, curved shaped cars had the best times. We decided to incorporate this into our design and attempt to make our wings into aero foils as they were subject to the least air resistance.
- The 4th shape shown (in the righthand picture) is essentially a flat-bottomed aero foil which is aerodynamic due to its rounded leading edge and its sharp shaped trailing edge. This allows air particles to enter a state of laminar flow and easily pass over and around the wings and body of our car. We also tested out a cambered aero foil but later found that it would create excessive lift at the speed that our car was travelling which would risk increasing the time taken for our car to complete the race.

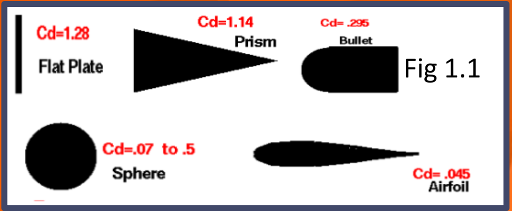


Fig 1.1

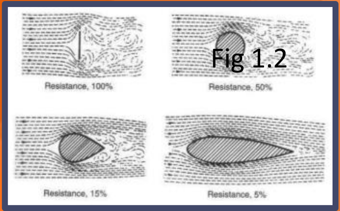


Fig 1.2

- The term flow detachment refers to when air cannot flow into certain pockets behind the car, creating drag and slowing down the car overall. This means when designing the car theses pockets should be considered and reduced as much as possible.

In the regional final, we were forced to use PLA to 3D print the front and back wings, as it was the only material that the 3D printer, we had access to that could print and with our past budget we were not able to afford the price to outsource the printing to outside companies.
Now that our budget and scope has increased, we can now consider this option.

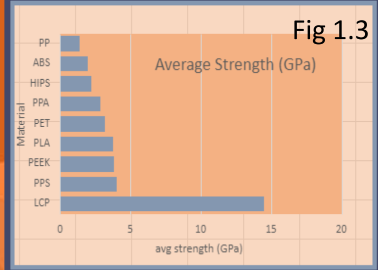


Fig 1.3

We researched several different 3D printing materials and compiled their average strengths from several sources. PLA is comfortably in the top few strongest materials, but the material that was far above in strength than any other material was Liquid Crystal Polymer (LCP). At a cold temperature, it acts like a crystal and becomes liquid at high temperatures, making it possible to print. Sadly, this printing method is not available to us, and outsourcing this step would be far too expensive to be viable.

According to Newton's 2nd law of motion, the force is equal to mass × acceleration. As the amount of force put into the system is always equal, decreasing the mass will increase the amount of acceleration. Therefore, the mass must be kept as close to 60g as possible while not falling under the minimum. A difference of 10 grams could mean the difference between first place and a mid-leaderboard place.

The importance of a lightweight, smooth, fluid design was further emphasised by our research into past competitors. We looked into 4 main teams from the 2022 Development class races at the national finals. The two fastest cars of the 4 that we sampled were NEBULON RACING's car and CELERITY's car (although both were beaten by a single team that we could not find data on and hence omitted). These cars weight in at 60.5 grams and 60 grams respectively and it was evident that their weight made a difference as the two other teams that we sampled, SUPERARE and VORTEX RACING, had drastically different car weights: with SUPERARE's car weighing in at 67.1grams (higher than it should be for the sake of efficiency) and VORTEX RACING's car weighing in at 59.9 grams which is 0.1grams under the legal limit (meaning that it breached technical regulations and would have weight added during the race to ensure that it did not have a fair advantage thus hindering its performance). This further supported our initial hypothesis that the car should be as light as legally possible to minimise the harmful forces exerted on it.

DEVELOPMENT CLASS	CAR	REACTION	SPLIT	TRACK	FINISH	CRUISE
LANE 1: SUPERARE	B	0.198	0.507	1.469	1.667	12.1 m/s
LANE 2: CELERITY	B	0.176	0.508	1.413	1.589	13.0 m/s
DEVELOPMENT CLASS	**CAR**	**REACTION**	**SPLIT**	**TRACK**	**FINISH**	**CRUISE**
LANE 1: NEBULON RACING	A	0.230	0.498	1.424	1.654	12.1 m/s
LANE 2: VORTEX RACING	A	0.243	0.530	1.455	1.698	12.0 m/s

Fig 1.3

Ongoing Evaluation

The research done for the national finals were much more in depth than regional finals. Now we understand the intricacies of all the factors that determine the speed of our cars. All of these factors may not feature in our design, but their considerations helped the project as a whole.

Polyurethane is the material provided by official F1 in schools providers such as DENFORD. It is an ideal material as it not only is it easily shaped and perfect for CNC and CAM processing but the polyurethane block that we use is also devoid of any traces of chlorofluorocarbons. The polyurethane block that we will use has a density of 0.163g/cm3 which makes it robust and strong, perfect for an F1 in Schools car subject to high levels of stress. The importance of sustainability is also not to be understated and the polyurethane block has been shown to be biodegradable which lessens its environmental impact. Some more of its physical properties are listed below and are sourced from the DENFORD website on the F1 in school regulation blocks that they produce.

Design Process

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Main body


Fig 2.1

Design
The side of the body for our regionals design was made to push air off of the wheels, however air still became turbulent when interacting with the back wheels (Fig 4.1) and thus had to be redesigned

Manufacturing
On the front are holes for front wing alignment and a cutout at the back for the back wing; however, the front holes were too difficult to align properly and meant the front wing was difficult to manufacture, furthermore inaccuracies in machining meant the back wing and cut out could not mesh properly


Fig 2.2

Design
The body was designed to be wider to ensure that less turbulent air flow was created by the rear wheels. However, at the back of the car there as a lot of detachment (Fig 4.2), partially because of the area behind the back wheels being angled up.

Manufacturing
The cutout and front holes were removed on this design for reasons previously stated.
Also, the car was slightly too wide, by ~1mm, meaning it could not be manufactured properly and broke regulations


Fig 2.3

Design
There is a lot more material on the sides of the body as an attempt to keep the flow of air laminar while traveling over the back wheels. The body is also angled down so that air goes over the wheels rather than against them and then behind the back wheels is also designed to accommodate the back wing design.

Manufacturing
The body had to be sanded down so it could properly accommodate with the back wing. When it was manufactured, we realised it was a bit heavier than previous designs because of added material however we found that it performed better than previous designs because of its aerodynamics.

Evolution of the car

Front wing

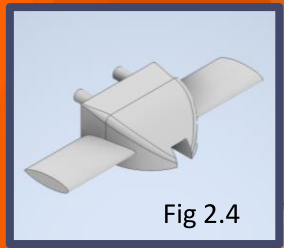
Fig 2.4

Design
A simple wing design that could be attached to the front of the car. We later found that the front wheels caused turbulence (Fig 4.1) and air would need to be sent over the front wheels.

Manufacture
The alignment rods were too difficult to manufacture and caused too many problems


Fig 2.5

Design
Designed to push air over front wheels, which we found to be quite effective in maintaining laminar flow over the wheels and body

Manufacture
Removed the the alignment rods for previously stated reasons.


Fig 2.6

Design
Slight evolution of the previous wing with a lower gradient and slightly longer to reduce downforce created by redirecting air upwards.

Sketch for Fig 2.3, 2.6 and 2.9

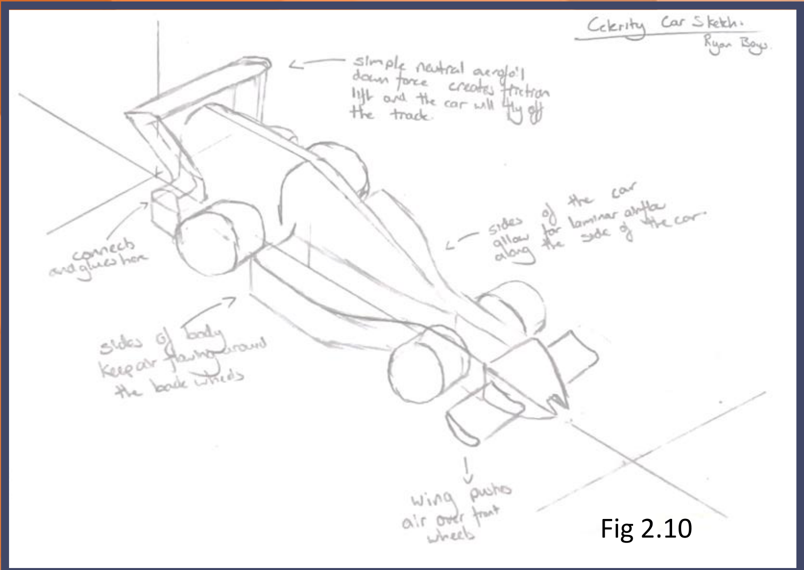

Fig 2.10

Back wing

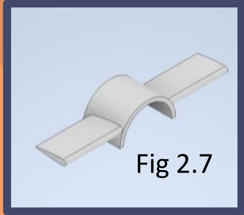
Fig 2.7

Design
A simple design primarily meant to have a limited impact on aerodynamics. We later found that it broke regulations as the cut in compromised the C02 cartridge chamber was compromised because of the cut in.

Manufacturing
Because of the cut in design there had to be small margins of error in machining so was extremely hard to manufacture.

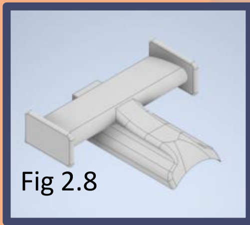
Fig 2.8

Design
A neutral wing that would sit on top of the cartridge chamber. It was design to allow air to flow over it, however we found it to find turbulent airflow. (Fig 4.1)

Manufacturing
The wing was intended to be simple to glue on, however it was difficult to glue straight, and was often lopsided. The design would therefore have to change so that it could be properly manufactured.


Fig 2.9

Design
Similar neutral wing but designed to have less of an aerodynamic impact as before.

Manufacturing
The wing was intended to be easier to fit than the previous design, but still required a bit of sanding

Ongoing Evaluation
Our car for the regional finals got a time of 1.572s (not including reaction time). This will have to be a lot better if we want a chance at winning nationals. Therefore, we built on top of our regionals car and refined the design to be even better. Than it was before.

Manufacturing Process

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Now that the design process is finished, the manufacturing process can begin.

The use of CAM (Computer Aided Manufacturing) software and machinery was essential in the manufacturing process, allowing us to create a far more precise car than hand tools.
To enable the use of the CAM machine, a 3d model of our design must be made on CAD (Computer Aided Design) software like Autodesk Inventor, which we used.
The model then went through a CNC (Computerised Numerical Control) process where the model was translated to CNC manufacturing code (also known as G code) that a CAM machine can interpret, coordinating the machine into moulding the block of polyurethane foam into the main body of our car.

Using a CAM process of manufacturing has many obvious advantages to hand tools, most significant of all, safety. These machines use a far more controlled and contained method of manufacturing compared to other tools with the added advantage of not needing human involvement. We also ensured that no students would be allowed to be close to the machine when it is enabled, unless accompanied by another member of staff.

The main body was cut out of a F1 In Schools supplied block of Polyurethane foam. It is the ideal material for CAM processing because of its ease of shaping, the block also has a density of 0.16g/cm^3 which is light but still strong, able to withstand high levels of stress, perfect for the purpose of making an F1 in schools model car.

An additional bonus to the material is the lack of stratosphere depleting CFC, common in foam materials, as well as being shown to be biodegradable, both lessening the material's environmental impact. According to the material fact sheets of the block given by DENFORD, all of its strengths are in the millions of pascals, which is strong enough for this F1 in schools setting.

The method shown on the left was applied to the Inventor model of the car, and after the CAM machine has finished processing the block of foam into the beginnings of the main body, the rest of the manufacturing process can begin. 1


Fig 3.1

Using a band saw, **remove the support material** in the front of the car. This support is there so the CAM machine does not have to cut through unnecessary material while also giving material for the machine to clamp onto the block 2


Fig 3.2

With a pillar drill, use the ø3,0mm head to **drill out the placement for our axles**, then a ø6,0mm head for **axle brushes**. We ensured that the drill holes are accurately placed by using both a water level to keep the car's orientation constant and marking the points of drilling before starting the step. 3


Fig 3.3

3D print the front and back wings with PLA. The main advantage of 3D printing is the ease of access. At school, this method is the only one we could access unless outsourced. If this option was possible, a method like Selective Laser Sintering (SLS) would be far more precise than regular 3D printing, improving the quality of the print greatly. However, the printer prints in layers from the base up. This means the texture of the print are layers of cylinders, which would have to be sanded out carefully to create a smooth surface.

- Each set of 3 front and back wings were printed separately to minimise waste of material in the event of a failure, which happened once.
- The material shown in orange is support material to hold up the wing during the print and was snapped off.
- The residue visible on the picture of the 3D printer is glue to give the base of the print a surface to grip to.

4

Polish the main body and wings to have a more even coat of paint, improving aerodynamics. On the main body, the polishing was limited to the site of the band saw because the CAM machine result was already adequately smooth, only sandpaper was applied. On the wings, sandpaper was applied dry to remove impurities from the 3D printing process, and then wet to achieve a smooth finish. 5

Apply the first 3 layers of spray paint on each part of the car separately, with time in between to dry. The colour of spray paint was less saturated than the scheme shown in the render of the car. After all, 3 layers were applied, we measured the masses of every part of the car combined, the result was that the car would already be at ~67 grams, so it was decided that a layer of lacquer would not be added, the reasoning was the additional mass would slow the car more than improved aerodynamics. 6

Superglue together the wings to the main body. Dry sanding was applied to the surface where glue between the wing and body was applied to remove the layer of unnecessary spray paint and scratch up the surface for a more effective bond. 7

Cut down the length of the wheel axle from 70mm to 55mm, a little wider than the main body, with a hacksaw. As shown in our air visualisations, this step is shown to improve aerodynamics, with the addition of reducing the car's weight. 8

Apply a final layer of spray paint, this time a blue accent that gives a gradient from orange to blue, serving a decorative purpose. 9

Complete the assembly by placing the wheels and axles in their correct location. Make sure that they are centred with the car. 10


Fig 3.7

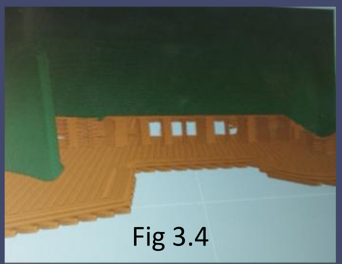
Fig 3.4

Fig 3.5

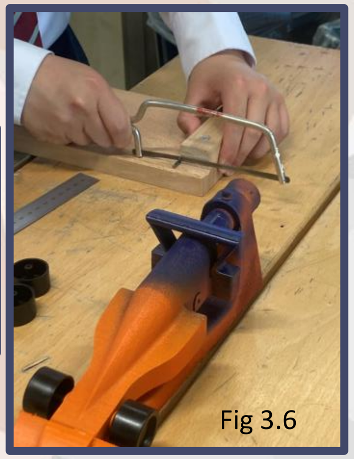
Fig 3.6

Ongoing Evaluation

The manufacturing process was generally favourable, but some weaknesses of the design process were brought to light. We should have made calculations to determine the mass of the car before production since the density of the block is known. There were some slight misalignments and mismeasurements, for example, inaccurate drilling made the car steer a little, one of the axles were cut to around 54.5mm, a little short.

Testing

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Stress analysis

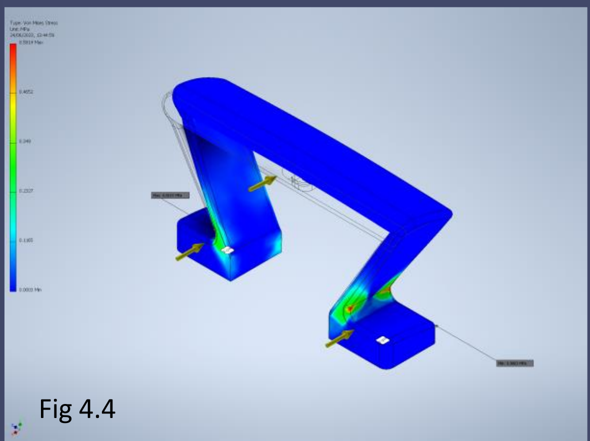

Fig 4.4

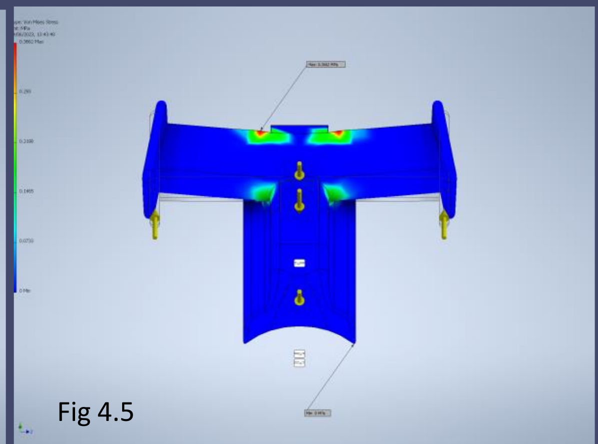

Fig 4.5

The stress analysis for the two new back wing designs showed that the PLA plastic we were using to 3D print the wings with was more than suitable for its desired application. The analysis shows that with a force of 10N, the wings would experience a maximum stress of 0.6Mpa (Fig 4.4) and 0.3 Mpa (Fig 4.5), and a maximum displacement of less than 0.2mm. The stress values are well within PLA's capability meaning it was suitable for the wing manufacturing.

Air Visualisations

After finishing the design and manufacturing of our car models we wanted to ensure that they met the standards that we initially expected based on our designs and based on our predictions based on our understanding of the physics related to stress on our car.
We were unable to get access to aerodynamic simulation software or get a hold of Newcastle University to use their testing facilities. Therefore, we decided to use an AirTrace visualistaion kit to visualise the airflow over the cars.

Fig 4.1

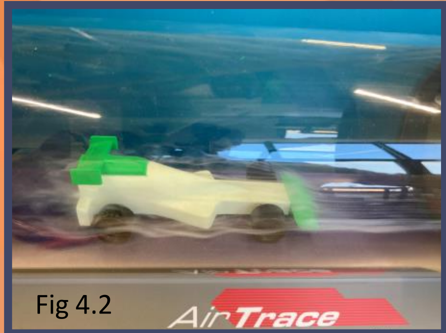

Fig 4.2

Fig 4.3

There is a lot of turbulent airflow around the wheels, as the front wing does little to control airflow, as it soon has to go over the wheels, which creates a lot of turbulent flow. We therefore decided to change the design of the front wing (Fig. 2.5) so that air would go over the front wheels and maintain

The new wing design is shown to be quite effective, however the sides of the body redirect the flow of air quite a lot, which will slow the car as it travels through the air.

As we can see the airflow is a lot more streamlined and there is little turbulence except for the detachment behind the car. Notably we also decided to sand off the support between the wing and chamber as it created turbulent flow while not providing much in the way of an actual support for the wing.

On the track

Fig 4.6

We used our half-scale F1 in schools track for practical testing of our car designs in a realistic scenario.
Unpainted, our regionals car got a time of 0.568s.
Our second design unpainted got a time of 0.543s.
Our final design fully painted got a time of 0.542s.
Note: paint weighs about 10g once finished, so the minor time difference would be greater if we decided to use our second design and fully painted it.

Testing Evaluation

Overall, our testing was a lot more rigorous than in regionals, with the use of stress analysis which helped influence the design of the wing, and the air visualisations to show what needed to be improved in each design. We conclude that the car is perfectly fit to be taken onto the grand race track, guaranteeing that wings will not break, regulations are followed, aerodynamics are sufficient and is proven by our simulation races.

Fig 2.

Scrutineering

During the process of designing the car on Autodesk Inventor, the regulations were put into careful consideration. The car is designed so that there would be 0 violations of technical regulations. This was then also verified by hand by measurements on the finished car. To accommodate the regulations, the aerodynamics of the car were compromised, which we concluded was beneficial to our point tally.

Final Evaluation

This project as a whole has brought many valuable lessons in STEM fields. Our knowledge of physics, materials, software like Autodesk Inventor, the process of CAM, machining tools, testing methods etc. has increased greatly. However, there were still many things we could improve on, as laid out in our previous ongoing evaluations. For example, the mass of the car was 7 grams above the minimum, impeding our car from preforming to its full potential. The knowledge we have gained provides a great opportunity for careers in the future, with employers being able to see our efforts in this competition and proving our knowledge against other competitors is above them. This competition experience have improved us as a person. It has improved our communication, cooperation, teamwork skills.

May we carry these lessons, possibly in a future professional class competition, into the future and our careers.

Engineering Drawings

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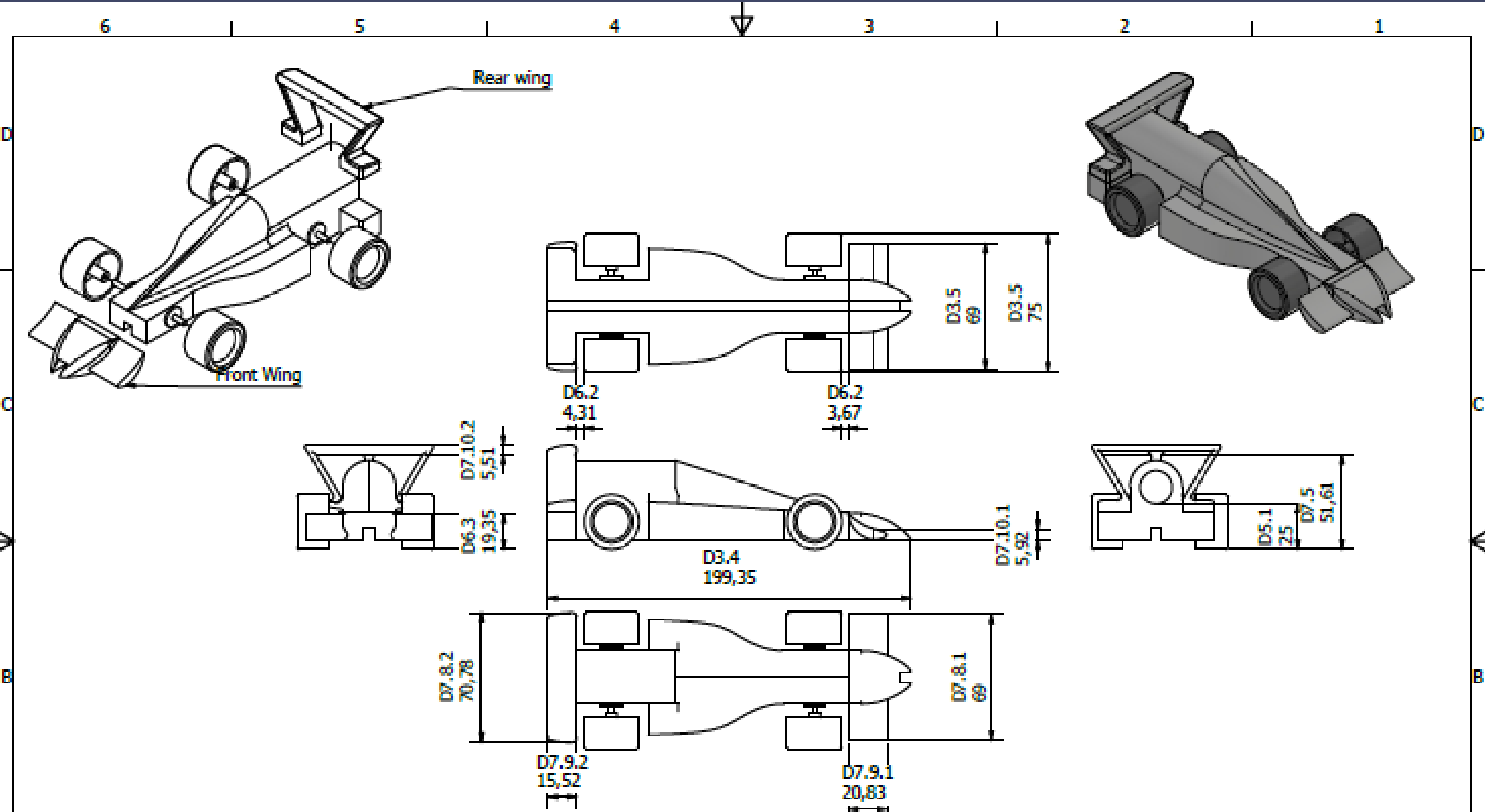

PARTS LIST

ITEM	QTY	PART NUMBER	MATERIAL
1	1	Car 3 back wing	PLA Plastic
2	1	Car 3 main body	Polyurethane
3	1	Car 3 front wing	PLA Plastic
4	2	own_axle	Mild Steel
5	4	F1 Wheel	Acetal Resin, Black
6	4	F1 Axle Bush 1	Polypropylene

DESIGNED BY	CHECKED BY	APPROVED BY	DATE	DATE
4715xx178				16/06/2023

	ISSUE	SHEET
Assembly CAR 1 drawing		1 / 1