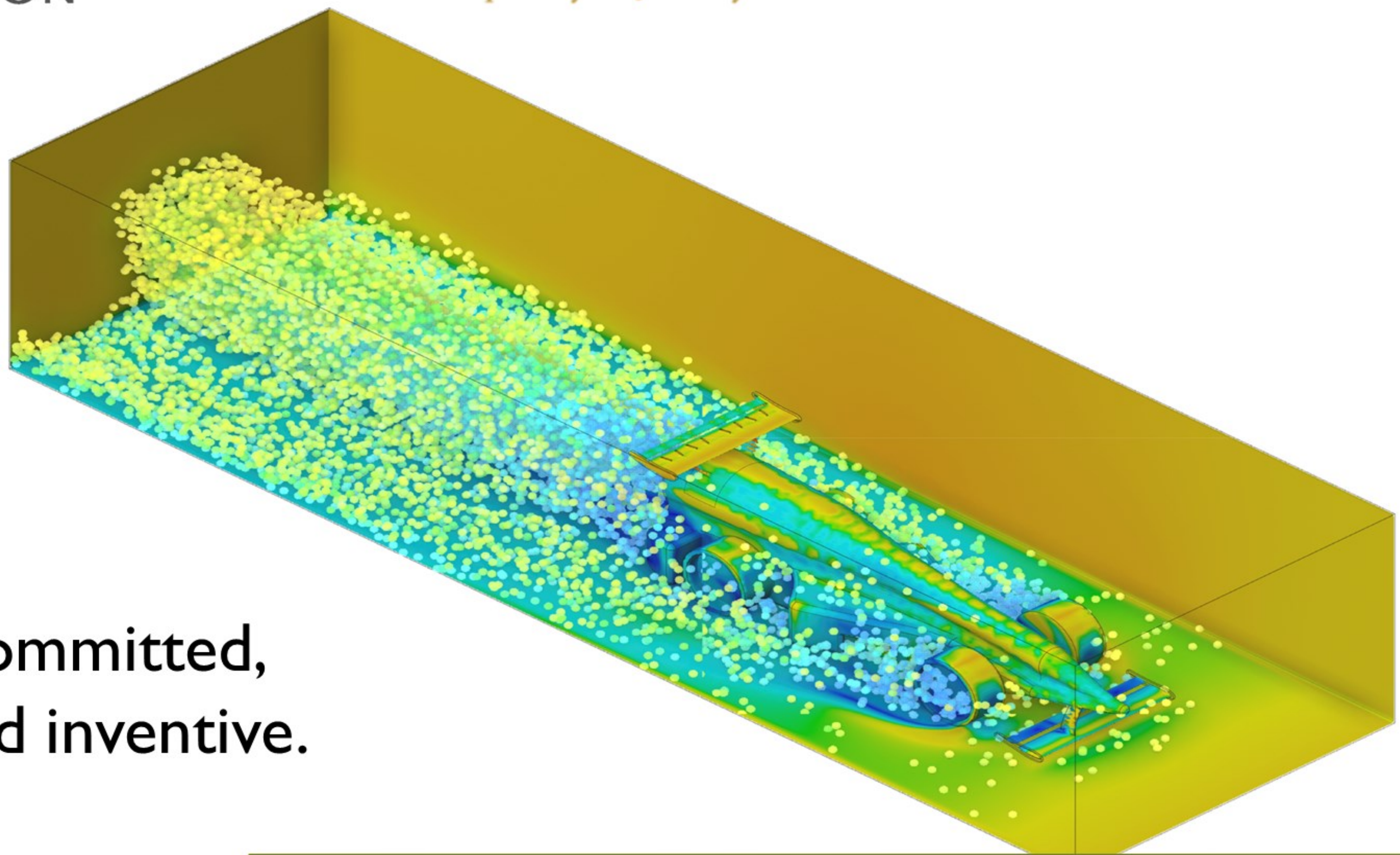
KPH CONSTRUCTION

HOLBEIN Carpentry & Joinery Ltd

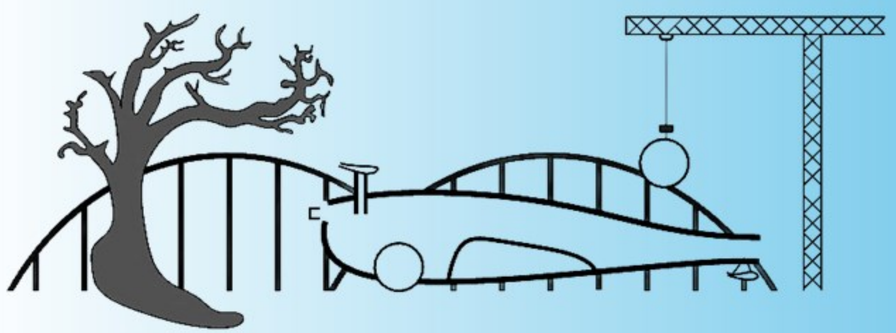
MHL



Passionate, committed, innovative and inventive.

Engineering Portfolio

KPH Construction Racing



Introduction

As a team of three students, we had our work cut out entering into this project. Emmet Glynn Johnston the Design and Manufacturing Engineer for Team KPH Construction Racing, in Pobailscoil Inbhear Scéine, has a passion for engineering and science. He loves to understand how things work and learn more about the world around us. Under the guidance of Team Manager Conor Casey, Emmet has created this document over the last couple of weeks as we come to the end of this project. We hope it gives a quality synopsis of the work that has been put in over the past 5 months since we started at the end of November.

Emmet has come to learn so many new skills that otherwise, he would have not invested the time into learning, meaning he has most certainly benefited from participating in this competition. It has been a huge amount of work, developing his knowledge to the level he has obtained today and he is really looking forward to being able to bring this knowledge forward into next year's competition and other areas in his future career and life.

Conor had a wealth of knowledge in the area of applied mathematics, which he used to assist the team in conducting computational fluid dynamics (CFD) simulations and analysis. This eased some of the workload on Emmet as the task of CAD modelling and CFD simulations could be carried out simultaneously.

Software Used

Our initial intentions were to start our design using Fusion 360 and then migrate over to our schools professional SolidWorks package which would include integrated CFD software. Once schools closed, it became obvious that this would not be possible so this resulted in us continuing to use Fusion 360 since we already had it downloaded. This posed a challenge as Emmet's laptop did not meet the necessary specifications to run Fusion 360. Fortunately Fusion 360's cloud based storage meant that most progress was recoverable in the event of a program crash.

We decided on using Discovery Live for our aerodynamic analysis. We used a Google Clouds virtual machine to run this software as Emmet's laptop was not up to the task. Setting up the simulation scenarios was difficult, due to a slow frame rate as a result of poor WiFi speed, but once the simulation was started, it proved to be a very quick and effective way of completing this computationally taxing task.

For the formation of this document, Microsoft Publisher was used to create a well laid out document that was easy to navigate.

Limitations and Challenges of Remote Working

Asher	Conor
To discuss the features of the car that would allow for effective placement of decals and colour schemes which would enhance the team branding and sponsorship return on investment. To give pictures that could be used for the team social media page To decide on effective colour schemes for the car.	To avail of Conor's knowledge in the field of fluid dynamics from his knowledge of applied mathematics and previous projects. To ensure that Emmet was meeting the deadlines outlined by Conor, as the Team Manager. To resolve any issues Emmet was having with his tasks. To discuss and agree on a budget for any supplies Emmet needed for manufacturing the car.

Remote working reduced our ability to collaborate with teachers and other professionals in this area. We only had email as a form of communication between vital contacts in the competition, such as Mr. Healy our leading teacher, and Mr. Corcoran the school metalwork and engineering teacher. This proved challenging when it came to discussing the capabilities of the machinery we had to work with and formulating schedules and plans. Emmet didn't have access to the engineering room until after the Easter break, which only left him with 5 days to manufacture the car's axle set up. This limited our ability to create the best system possible, which was unfortunate but we had to accept the circumstances which the Pandemic has left us in.

On the other hand, having online classes resulted in an increased amount of time which we had to work on the project, as there was often 10 to 20 minutes between classes, and some free periods. Emmet always maintained contact with Conor and Asher through twice weekly team meetings and DM chats using MS Teams.

Time Management

Good time management is absolutely key to the success of any task, big or small. It allows you to work efficiently and reach your full potential, without investing any more hours into the task than you should have to. Conor, the Team Manager was responsible for creating a schedule of deadlines, for Emmet, the Design and Manufacturing Engineer. By keeping to this time schedule, it allowed the team to see visible progress as various milestones were reached, while also allowing the time necessary to prepare for various school tests and assessments.

Our Time Management process involved:

Identify a clear objective
Realise the desired outcome
Break the job down into smaller tasks.
Work on each task with complete dedication, while sticking to the order outlined in our plan
Identify and execute the next important action.

We created a timeline to suit the original competition schedule, but as this changed, our timeline evolved to maximise the time we had to invest into advancing our project further. We benefited from the additional time we had to design and create our car. Here are a few key deadlines we aimed to reach.

- Design Concepts to be finalised by **24th January**
- Initial CAD designs to be finished by **21st February**
- Main Body to be finalised by **5th March**
- All components to be ordered by **28th March**
- Nose cone, wings and additional 3D printed components to be completed by **12th April** ready to be finished and painted.

Researched Concepts

Major concepts

No concept or knowledge is too basic to bother learning. Going into this project with very little experience in the area of fluid mechanics meant that a huge amount of research had to be conducted. We focused on learning the basis of knowledge that is required before trying to understand more complex concepts. Here are a few of the definitions we formed for some key terminology found in fluid dynamics.

- **Drag:** A force that acts on and opposes a bodies motion.
- **Laminar Flow:** When air flows in smooth layers and little mixing between these layers occur.
- **Turbulent Flow:** When air flows in a chaotic manner and no layers can be distinctly identified.
- **Viscosity:** Quantifies how resistance a fluid is to deformation, or more commonly, flow.
- **Vortices:** Spirals of air that flow around an axis. They can be used to manipulate the way in which air grips a body.
- **Aerofoil:** A highly aerodynamic shape that is used as the basis of the shape of wings.
- **Wings:** Used to manipulate the way air flows to create lift or downforce. Wings can also be used to direct air flow around an object such as wheels or onto side pods to help maintain laminar flow around the body.
- **Boundary Layer:** An area of air surrounding a solid body that remains attached and will distort other airflow around that body.
- **Angle of Attack:** The angle at which air flows into a body, which can be used to change the way in which air is directed behind the body.

Parasitic Drag

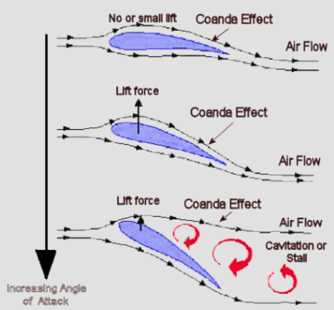
Drag that acts on a body moving through a fluid that in no way aids or benefits the motion of that body through downforce or lift is called parasitic drag. Parasitic drag comprises of form drag and skin friction.

Skin Friction: Skin friction arises due to the friction between the fluid and the skin of the body in contact. It is directly proportional to the surface area of the body and will increase as the body's velocity increases. This can be combatted by creating a smooth surface finish using abrasives and paints and ensuring that the main body is designed to minimise its surface area.

Form Drag: As the name implies, this type of drag is induced by the shape of the body moving through the fluid. This can be combatted by streamlining the shape of the body. This will also promote laminar flow. Turbulent flow as a result of form drag will have a direct effect on skin friction, as more air will be coming into contact with the surface of the body.

The Coanda Effect

A phenomenon where air will flow over a body and still stay attached to the surface even when the surface curves away. This effect is the basis for the working of a wing. A wing will create a force opposite to the direction that its trailing edge points so long as the trailing edge is reasonably sharp. An aircraft has flaps on its wing to allow it to generate more lift when it is slowing down for landing, without stalling. A plane will always need to generate a certain amount of lift to fly, regardless of its speed. A wing at a higher speed will generate more lift than the same wing at a slower speed so this means that we will have to find a perfect balance in the shape of our wing and the direction its trailing edge points in to ensure that airflow remains attached to it's surface and produces the sufficient amount of downforce.



Inertia

Inertia is explained as the resistance a body has to any change in it's velocity. Momentum is a common way of describing inertia as any body that is in motion needs a force acting on it in order for the body to come to a stop.

Similarly, the **moment of inertia** describes the amount of force needed to set a body in motion. It will be vital that the moment of inertia is as low as possible. We can do this by reducing parasitic drag and rolling resistance.

Drag Force Analysis

The **drag coefficient** is a mathematical formula which quantifies drag on a body relevant to its frontal area, regardless of it's size. In spite of initially thinking this could be a useful figure to acquire for our models, we realised it could actually mislead us into thinking one car was more aerodynamically efficient than the other, due to one car having a greater frontal area. To add to the inaccuracies of the drag coefficient, obtaining the frontal area of our models proved to be rather difficult, even after seeking the knowledge of experienced users of Fusion 360.

A more accurate analysis of our various concept cars' aerodynamic efficiency was to obtain a drag force value. This allowed us to fairly compare every design. All cars would be powered by the same CO_2 cartridge regardless of variations in size, so the drag force value would be ideal in this scenario for allowing us to deduct.

Lift / Downforce Analysis

Discovery Live gave us a Z force vector component value for our car which we will be referring to in this document. Of course, we know that one newton is equivalent to about 100 grams of mass on earth, so with the weight of the car being estimated at just over 50 grams, we aimed to have a Z force value of under 0.3 Newtons.

Reynolds Number

Reynolds number can be used to predict flow patterns in fluid dynamics. Flow at lower figures is dominated by laminar flow and at higher figures, it is mainly turbulent. Laminar flow generates less drag force through skin friction so it was important to create smooth surfaces that would reduce turbulent air flow. We predicted that in order to correctly simulate the viscous forces of laminar air flow on our car, the Reynolds number would have to be under 4000 to enter the transitional flow stage of a mixture of turbulent and laminar air, and under 2000 to be perfectly laminar. This was accounted for in our CFD testing.

Design Development Overview

Design Development

As we had little knowledge of CAD software and how to use it, Emmet initially started by following tutorials online for simple and basic projects, that outlined the features of Fusion 360. Our concept models for our Project Proposal were very basic and more of a method for ideating and practicing the CAD skills that would prove vital for the success of the project.

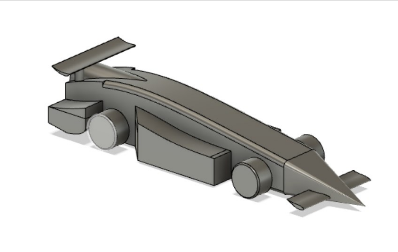
The stages of our design process were as follows

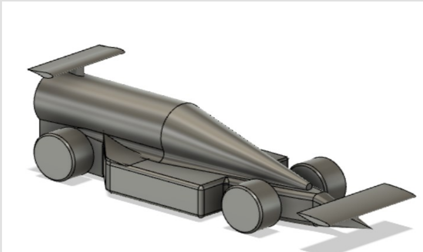
1. Research
2. Ideate: Creating rough drawings together on whiteboards with markers.
3. Draw up designs in CAD, based on our sketches.
4. Test the design using CFD software and running CAM simulations.
5. Manufacture prototype components using a 3D printer, finish and assemble.
6. Test the assembled 3d printed car in our homemade wind tunnel.
7. Manufacture the final car.

White Board Sketches

As a team we held brainstorming sessions where we exchanged ideas and broke them down to the strengths, weaknesses and potential for improvement by drawing rough sketches. We used Autodesk Sketchbook to form our ideas, which allowed us to save our drawings.

We brought these ideas to life in Fusion 360. We came up with two concepts, of which we eventually went on to combine to create the design we have submitted to race. These initial CAD drawings not only helped us to create a vision for our final car design, but they were also excellent practice for Emmet to help him to improve his CAD skills in the early stages of the competition.





Budget

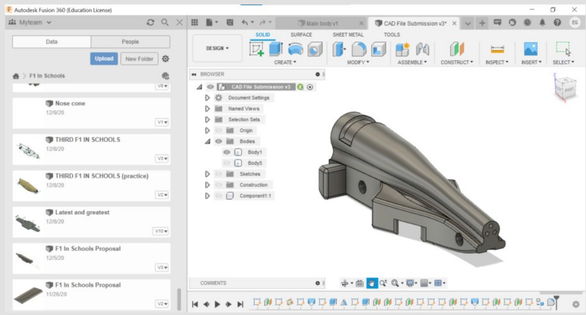
Of course the most limiting factor in the design process of our car's components was the budget we had to work with. We were very fortunate to receive sponsorship from three sponsors, but of course funds had to be distributed throughout all aspects of the project. As the Design and Manufacturing Engineer, made an estimated budget using prices from websites online to decide on how much funding would be allocated to the engineering side of the project.

Applications of Research

We attempted to incorporate every researched concepts into our designs over the course of the project. As mentioned before, we kept our research to the basic principles of aerodynamics at this early stage in the competition. This allowed us to work to a higher level of accuracy as we were using knowledge that we could properly grasp rather than depending on our own interpretations of more complicated concepts that could not be effectively utilised in our design.

Challenges Overcome

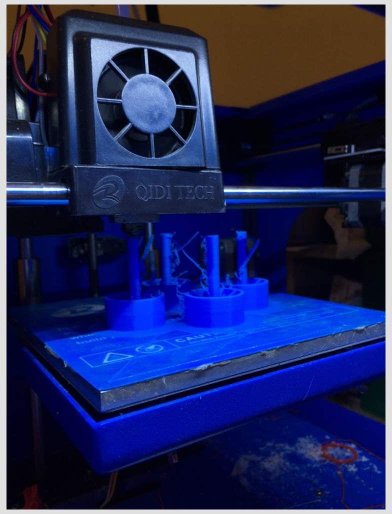
The most significant challenge that had to be overcome on the engineering side of the project was of course learning how to use CAD modelling software. Watching tutorials online and reading forums for advice was the main source of outside help for our project. Unfortunately with the lockdowns we faced, we did not have the help of our DCG teacher to assist with teaching the use of CAD software. On the other hand though, we are proud and relieved that we managed to learn all of this on our own without the direct assistance of others. Independence is central to any project work and this is a prime example of using initiative.



Another issue of course was the amount of time we had to invest into this project. We often found ourselves working for three or four hours per night on the project, and regularly even more. Now that we have spent so much time acquiring many new design skills, we feel many of the initial, seeming laborious tasks could have been executed much faster if we had these skills from the beginning.

Prototyping and Design Analysis

Prototype testing was a major part of our project. This allowed us to test numerous physical aspects of our designs such as strength, airflow in our wind tunnel and printability. Having constant access to 3D printers was key to successful and meaningful prototype testing. We used our 3D printers to test wing designs and their support structure, as well as the tether lines since these would come under significant external forces through the race. We did this by attaching weights to our wings and tether line guides and the breaking force necessary was analysed and used to further develop the design.



Evaluation

With no practice races to be had in the regional finals and little prior knowledge, a lot has been achieved in a relatively short space of time. We felt that by designing one main body we, could localise our efforts to the particular area of designing the wings.

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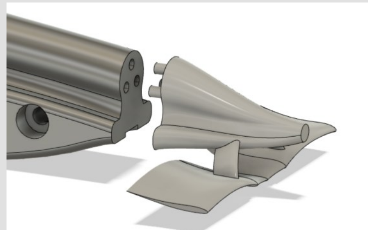
Main Body Design Development

Applications of Research

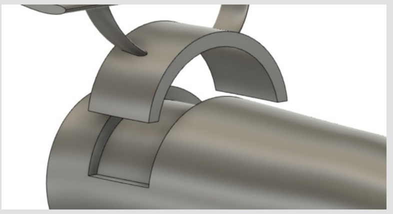
In order to achieve laminar flow, the main body needed to have a sleek shape and smooth finish. Turbulence could occur as a result of insufficient mating of parts such as the nose cone and the rear wing so to combat this, we would have to redraw these mounting faces, based on a canvas captured from the final manufactured main body to ensure a smooth continuous transition between the highly accurate 3D printed parts and the less so, CNC machined F1 model block. This page will cover some of the numerous design features we included to promote laminar flow.

Nose Cone Mounting System

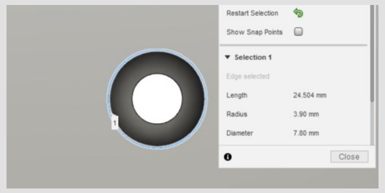


With no actual knowledge of the physical properties of the foam Modelblock, we had to devise a system that would allow for the nose cone to be properly aligned and mounted onto the main body of the car. It was decided that a dowel joint would be ideal, as it was not complicated and could be easily machined into the model block. After printing a few test nose cones, it was noticed that easiest way to implement this joint system was to put the holes into the main body and to put the dowels onto the 3d printed nose cone. This allowed for the cleanest surface finish throughout the joint as the dowels could be lightly sanded to provide a nice tight fit, and the holes in the modelblock were predicted to have a high quality machine finish from the drill bit or endmill.

Rear Wing Mounting System



As the rear wing had to be one solid body, we had to mount it above the main body. We utilised a 'loft cut' operation to remove a section of material just in front of the end of the car, that was then lofted back over as a new body that could be 3d printed. This gave us **three flat surfaces** that would be make for easy and accurate mounting of the rear wing.

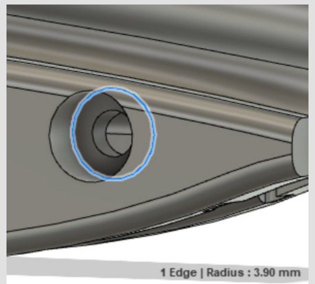


We had looked into the idea of using a small key way for better alignment and to reduce the size of the overall chamber safety zone, but came to the conclusion that this would be unsuitable as it would eat into a tiny amount of the chamber safety zone that would violate the technical regulations and the machinability could have been an issue. We definitely had to make the main body slightly bulkier to incorporate this system, but believed the advantages of having a secure and tight mounting system outweighed the drawbacks.

Bearing Mounting System

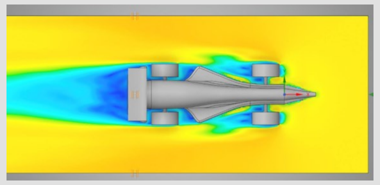
7.8mm diameter holes were incorporated into the side of the main body that would allow for a 'press fit' bearing assembly. The internal axle casing was a 4mm diameter hole that would allow the 3mm axle to rotate freely. More is outlined on the 'Wheel and Axle Assembly' page.

Side and Back Pods



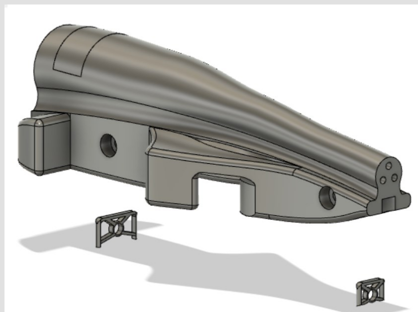
Our side pods were designed to direct air around the rear wheels. By following the shape of the virtual cargo, we found we could incorporate a reasonably large sized duct on the underside of the car. This shape proved to be quite efficient in our CFD testing as well.

On the top of the side pods, we introduced a gradual curvature upwards from front to back to attempt to push the airflow over the rear wheels. We had some trouble with a minute surface that we did not initially see until a final review of our CAD model and drawings. We hoped this would not interfere with the machining of the car, but were glad to see it had no affect on our 3D printed prototype cars.



We followed the side pods with back pods behind the rear wheels that promoted the streamlined wake left behind the car as pictured. They were designed to taper back to promote a streamlined wake behind the car.

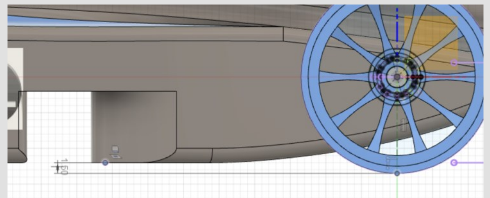
Tether Line Guide



We designed our tether line guide so that it could sit into the main body by means of two slots machined into the front and rear of the car. The tether line guide could simply slot in allowing for us to continue to develop our wing design after the submission of our CAD file for the free manufacturing service, without having to worry about not being able to adjust the height of the tether line guide holes.

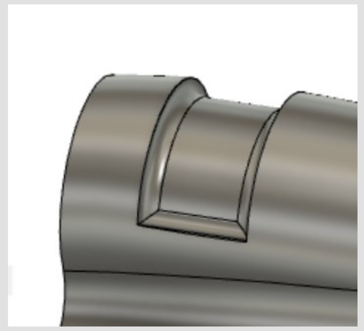
Having practical and simple mounting systems for the wings and other components of our cars allowed us to continue working on our 3D printed components after we submitted our main body to avail of the free manufacturing service.

Ground Clearance



For the purposes of attempting to induce what is known as the 'Ground effect' we attempted to keep the track clearance of the car to as minimum a dimension as possible. The ground effect is caused as a result of low pressure beneath the car that sucks the car down onto the ground. This reduces the dependence on the downforce generated from the wings. We believed that it was worth sacrificing the additional frontal area, for the downforce generated by the low ground clearance.

CNC Manufacturing Considerations and Machinability



While we did not conduct the machining of the car ourselves due to a lack of the correct CNC machine to conduct the process, we ensured we had a proper understanding of how the process would work before we sent our CAD file off to be manufactured. We used knowledge found in the technical data sheet to create an approximation of the physical properties of the Modelblock which would help us to incorporate machinable design features. Examples of this are found in our tether line guide and nose cone mounting system, where we ensured that cuts were made into the material rather than depending on features such as dowels to be cut out. Having a car with good structural integrity was vital in this competition and we were pleased when our car's main body arrived to find that these careful design considerations had resulted in a strong main body.

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Wheels and Axle Design Development

Bearings

Arguably, bearings are the most critical part of the car, as these will allow for the free rotation of the axles, reducing the friction between the track and the wheels. In addition they can also be the most expensive of component. We felt it would be worth getting the best bearings we could possibly source and we ended up purchasing 693 full ceramic 3x8x3 single groove ball bearings. We purchased 8 of these to allow for replacements and test assemblies of 3d printed models.

For testing purposes, it proved very useful to create mock bearings with our 3D printer to reduce the need for handling bearings.

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Eight ball bearings were purchased, so it is likely that we will incorporate bearings into each of the wheels as well, as reserves should the primary bearings fail. From the technical data sheet supplied, we found that these bearings are rated to turn at up to 4200 rpm, so when we realised that potentially the wheels of our car could rotate at up to 13500 rpm, the need for additional bearings was really recognised. This of course will depend on there still being eight functioning bearings by the deadline for the postage of our car.

Axle Material

Two low cost axle materials were purchased.

3mm carbon fibre rod: Very light weighing in at only grams. It is very easily sanded which allows for convenient friction fits of the bearings. It is not very stiff but has very good resistance to fracture and over a short span of about 60mm, we believed it would be ideal for the purpose of axles in our car.

3 millimetre grade 5 titanium: This material was found to be slightly over it's advertised dimension. This meant we would not be able to use it.

Bushings vs Friction Fit and Adhesives

When it came to designing a good axle set up, we were unsure whether it would be necessary to use bushings to restrain the axles from side to side movement, or would careful and specific sanding of our axle shafts, and adhesives be enough to prevent the axles from breaking loose. There was no practical and truly accurate way to simulate the sort of forces the axles would come under during a race, so this was a particularly challenging decision, as the entire project was quite literally riding on it!

Here are some of the factors we considered when deciding on this matter:

- **By using bushings:**
  - The force on the bearings will increase thus increasing the moment of inertia.
  - The axle will be more rigid, and less likely to break loose.
  - The carbon fibre axles are strengthened.
  - The overall weight of the car will increase.
  - Additional components to manufacture, and the dimensions could be too small to successfully machine a number of accurate parts.
- **By not using bushings:**
  - The overall weight will reduce, lowering the moment of inertia and promoting a faster car.
  - Less potential for unwanted friction, should the bushings misalign.
  - More potential for the axle to slip out of their friction fits.
  - More dependence on adhesives and bearing retainers to successfully manufacture a solid and secure axle setup.

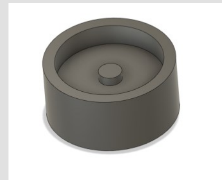
The Bearing Dilemma

Two methods of bearing mounting were investigated as part of our research into the axle set up of our car. One method was to have a static axle and place the bearings inside of the wheel and the other was to place the bearings inside the car and have a solid axle which wheels could then be glued onto. We decided that due to a lack of a CNC lathe, it made more sense to mount the bearings in the car, as it would have been difficult to bore out an 8mm press fit bearing receiver into the wheels accurately across four wheels, plus spares.

Wheels

Of course, our primary concern in designing a wheel was to keep friction between the car and the track to a minimum. We did this by keeping the track contact width to just over the minimum dimensions outlined in the technical regulations and choosing hard wearing plastics to come into contact with the track. The roundness of the wheel was another vital feature and we had to ensure that the weight was as low as possible. We didn't want to overestimate the forces that would be exerted on the wheels of the car as the payload is quite insignificant when the strength of hardwearing plastics such as Delrin is accounted for. We explored a number of concepts and below is a list of the most significant ideas we came across.

Acetal Delrin wheel: This design was going to require material to be removed around the axis of the wheel to bring the weight down to decrease the point of inertia. The idea would require us to outsource external manufacturing as our school engineering workshop is not equipped with the tooling necessary to execute this idea well.



We reconned this would have to be done with either a CNC lathe or mill, a lathe with a small boring tool, or a milling machine with a small rotary table. It would provide a very strong and round wheel, that would be well balanced.

3D Printed Wheel: An entirely 3D printed wheel could be used instead of turning one on a lathe. We would incorporate wheel spokes to reduce weight while maintaining sufficient strength. There would be the obvious limiting factor in this method, that is the resolution of our 3D printers. The perfect circular shape of a wheel is critical in reducing drag through friction and allowing the bearings to work as intended. As a result, we further developed this idea by incorporating the use of lathe finishing the surface of the wheel, by 3d printing a hub onto the wheel that we could grip in the jaws of a lathe chuck to sand to a perfectly round finish.

3D printed wheel rim and Delrin tyre: This would involve 3D printing a wheel rim, similar to the wheel design described above and press fitting a tyre, machined on a lathe from acetal Delrin, around the rim. This would incorporate the roundness of lathe turned plastic and the technical geometry that 3D printing allows us to produce to create a balance of lightness, roundness and strength. This concept could encounter problems to do with the balance of the wheel, and could result in wheel wobble.

Conclusion: We believe that the idea of 3D printing a wheel rim and fitting an acetal Delrin tyre over would be best as it would probably be the most accurate manufacturing process. The reason why we cannot specify in this document which design we would use is because Emmet did not have access to the schools engineering shop until after the Easter holidays, which of course coincides with the week of the submission for this document. Regardless of this fact, we will be certain to use the idea that combines the greatest functionality and machinability.

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Nose Cone and Front and Rear Wing Design Development

Wing features

Vortex generators: We attempted to incorporate VGs into our wing foils to help to generate a strong stream of air behind the front wing that would divert the turbulent air from around the wheels away from the car. While vortex generators can generate drag, their benefits can be difficult to identify in CFD.

End plates: We believed it would be beneficial to use end plates as they would contribute to the separation of the fast moving air over the wings and the slower moving air just beside each end of the wings which would promote more uniform air flow.

Maximising support structures: The various structures we designed which would firmly hold our wings could be used as means of stabilising the cars direction in the forward motion. They could also be used to direct airflow around other components of the car.

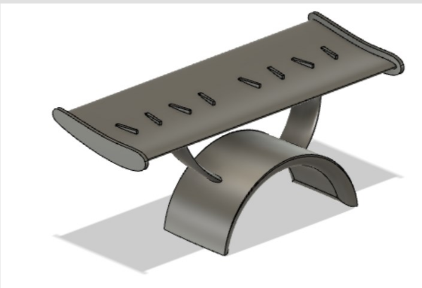
Initial Considerations

Front wing: The front wing could be used to **direct air flow** over the front wheels, as well as to generate downforce at the front of the car. It also has a massive bearing on the airflow over the rest of the car.

Rear wing: The rear wing must have a very precise amount of downforce, as it acts like a lever on the rest of the car. Too much downforce generated by the rear wing could cause the front of the car to lift off the ground due to a lever effect over the centre of mass of the car, which due to the CO2 charge, was quite far back.. Vortex generators could help to bring the wake of the car together which will improve its aerodynamic performance.

Mounting Systems

As aforementioned, we had incorporated a dowel joint system into our nose cone to allow for the easy exchange of spare nose cones after races, should it encounter any damage. Initially it was thought that the holes for the dowel joints would print better in the nose cone, but when we realised that the Model Block was not actually balsa wood, but rather a high density foam, the dowels had to be redesigned into the nose cone as we were unsure whether the foam would possess the necessary properties to have 2mm dowels machined into it. It was found that a small amount of glue helped the wing to stay firmly in place.

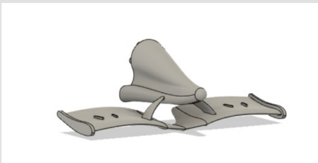


The rear wing would not have any flat surface to mount onto due to its mounting system being machined with a 2mm ball nose cutter, so it was deemed that it would be sufficiently strong to have 4 surfaces in contact between the main body and the wing.

Front Wing Concepts

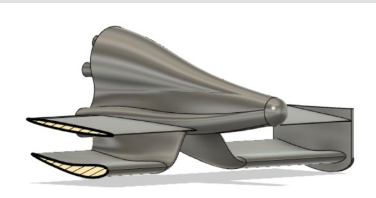
One: This design incorporates a thin airfoil that provides lots of downforce and attempts to direct air over the wheels. The curvature promotes airflow around the car as well as over. The design technically uses two separate wings and is joined in the middle to provide integral support. The support structures are also designed to direct air onto the side pods and to generate a small amount of down force.

We further advanced this design by adding vortex generators and end plates. This wing proved to generate quite a lot of drag in our CFD analysis, but we were unsure whether the positive effects on the airflow would outweigh the drawbacks on its drag force.



Two: In design concept two, we explored the use of one single foil. This allowed us to reduce the frontal area of the car as the length of the wing could be reduced to the minimum dimension of fifty millimetres. We had concerns over whether the effects of the stream of air being forced up onto the nose cone and main body of the car would cause drag or even lift, so we combatted this by reducing the aggressiveness of the angle of attack. The end plates were intended to direct airflow away from the body of the car, by curving outwards. This increased the span of the trailing edge. We encountered issues around the 5 millimetres of clear air space around the wing.

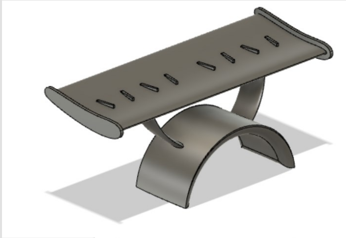
Three: Design concept three looks into using two wing foils. One wing was designed solely for the purpose of generating downforce while the other foil was used to direct airflow over the front wheels and onto the side pods. We found this very difficult to creatively model as we had to ensure there was 5mm of clear airflow over and beneath the bottom wing. While a legal design was created, we were unsure of how effective it would be but we still considered it for our CFD testing.



Four: Our final design concept looked at two completely separate wings with a continuous profile rather than separate support structures. This design proved to be very rigid, but had the disadvantage of increasing the frontal area of the car even further due to the 25 millimetre minimum span of each wing. The separate wings would definitely not interfere with the tether line which was a big advantage when compared to our other designs.

Rear Wing Design Features

We didn't see the need to explore as many design concepts with our rear wing as we did with our front wings, as we felt we had to prioritise reducing this wing to it's minimum dimensions. We explored the use of end plates and vortex generators to try and streamline the wake behind the car. It was not realised until after the car had been manufactured that the ball



Reflection

Once we designed an effective rear wing, we spent much time exploring numerous concepts for our front wing design as proven by our four primary designs outlined here. We had to take into account our 3D printers resolution when designing our foils and support structures in order to ensure good printability.

The wings were most certainly the hardest component to design and manufacture. We found the technical regulations limited our ability to be creative with the wing design. Due to the 15mm height limit of where the wing could be positioned, we could not utilise any sort of effective aerodynamic features that would direct air around and over the front wheels.

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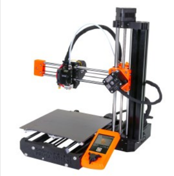
3D Printing and Wind Tunnel Testing

3D Printing Facilities

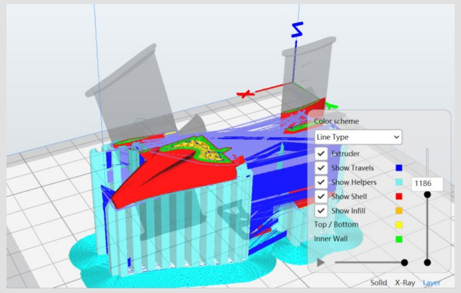


We had access to 3 entry level fused filament fabrication printers (FFF) — an Ender 3, a Prusa Mini and a Qidi Tech One 2. All of these printers were basic hobbyist machines and not necessarily of the highest quality, but with circumstances inflicted by the pandemic, it was not going to be practical to have parts printed externally. We chose not to avail of the free manufacturing service, as believed there was little point in losing out on an additional month of design time. As aforementioned, our CAD and CFD skills were an ever evolving asset, so every additional moment we had to design components allowed us to create more technical and advanced models.

3D Printing Filament Choice

We purchased PLA and ABS filament, but in the end, decided to only use PLA as it was much easier to get good printing results with our lack of enclosed printing environments. PLA proved to be a strong and versatile material; we rarely had warped or deformed results when using it. It was also a cheap and widely available filament so we were happy to designate it as our primary 3D printing plastic.

Slicer Utilities



When preparing stl files to be printed in the various slicers we used, we ensured that our parameters were set for high quality prints. Through trial and error, we improved our 3D prints by adjusting the orientation of parts, the line thickness, the location of supports and many more variables that could be adjusted in the slicer.

Infill

Infill was mostly kept to around 20 to 30 % as this seemed to provide a good balance between reasonable print times, decent component strength and weight reduction. We had no prior experience of using 3D printers so there was a lot of trial and error involved in getting the infill right.

Supports

Removing support material on minute components near integral parts such as wing support structures was a tricky process. With printing times for wings being at 6 to 8 hours, it was worth taking the time to delicately remove the supports as it was so easy to ruin an entire piece. Cleaning the support structures from the finished prints was mostly done using abrasive paper. A Dremel die grinder with a brush wheel was also tried, but often generated too much heat and could melt the prints.

Additional Components

Tether line guides were another crucial component that had to be carefully designed and tested. It was absolutely vital that we carried out numerous stress tests of each tether line guide we 3D printed, as this was a major point for the technical regulations

.

Prototype Components: We printed numerous main bodies so that we could continue to test fit our components whilst waiting for the actual main body to be machined. Various bushings and mock bearnigs were printed so that we did not have to spend time or money on actual components for test fitting. Lathe work is time consuming, whereas 3d printing is an automated process

.

Wind Tunnel

Introduction: Our intentions of our wind tunnel testing were to create an environment in which prototype cars could be placed to analyse physical visual representations of the airflow. Wind tunnels can cost hundreds of thousands, or even millions to buy, meaning regardless of how much we spent, we probably would not be able to produce a very effective version. As a result, it was decided to keep spending to a minimum on this area of the project.

Safety: This involved working around steel so composite toe capped shoes were used to prevent injuries to feet. When preparing steel and welding, an extraction system was used to remove fumes from the work area. When weather allowed, all of this work was conducted outdoors. Ear defenders were used around loud machinery, welding shields with a shade 11 darkness factor were worn while being exposed to the harmful UV light omitted from arcs and gloves prevented arc burn and general burns. Gloves were not worn around any rotary tools such as grinders and drills to prevent loose clothing being grabbed and as a result, injuries.

Construction: We used mainly recycled materials such as old menu boards or offcuts of Perspex sheets from previous projects. A Perspex box was assembled using 6mm angle steel at the 4 corners of the base to provide a solid structure. A bead of silicon was placed at each corner to ensure that the air in the test chamber could not leak out, possibly causing misinterpretations of the airflow over the car. An old extractor hood from a previous project was used as the contraction tube. It was most certainly quite short and wide for the job, but it was better than nothing. This was used to accelerate the wind speed.

To produce smoke, rolled up cardboard was lit and a compressor was used to blow air through the middle to produce plumes of smoke.

Testing: We didn't have access to an anemometer so we could not accurately record the wind speed, however we tried to record airflow using basic slow motion video recording on a smart phone, but unfortunately it was so faint that it was impossible to make out on a screen. We could recognise smoke entering and exiting the ducts which was a positive. We would most certainly look to improve upon our wind tunnel design in the future, by adding flow straighteners, and adding a door to our test chamber.

Conclusions

Overall we feel we did very well with regards to our 3D printing and wind tunnel testing in our project. Our wind tunnel provided us with physical representations of our car's aerodynamic performance, but it was a worthwhile project that adds merit to our project.

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CFD Analysis

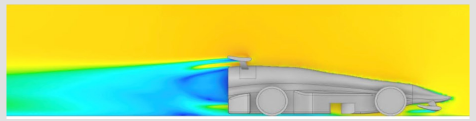
Design Concept 1

Description: In design concept 1, we tested a car that had our third front wing design concept with VGs, end plates and a curved style foil, that technically comprised of two separate wing plates. We used our most developed rear wing design with VGs and end plates for this scenario.

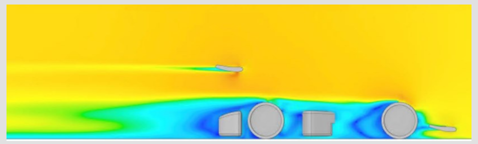
Fx: -0.278 N

Fz: 0.248 N

Velocity Plane



We saw that the vortex generators on the rear wings worked to narrow the wake of the car. There was also an area of low velocity beneath the front wing.

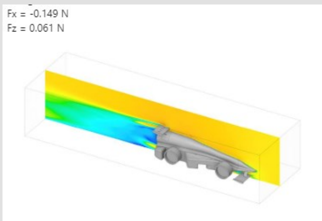


The front wing clearly causes an area of lower velocity behind the front wheel thus indicating less drag force coming against the bulky wheel.

Verdict: This design appears to be our most promising combination. The drag force appears to be the lowest out of all the cars we tested.

Design Concept 2

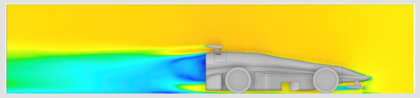
Description: In design concept 2, we tested a car with the same rear wing but our second front wing design. Due to the five millimetres of clear air rule, we realised that the wheels had to increase by 3mm in diameter, which we believe had an enormous effect on the drag force. Our initial test appeared to be our most promising (Drag force: 0.149 N), until we discover the legal issue.



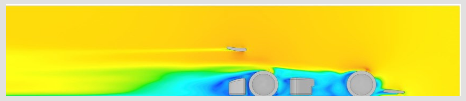
Fx: -0.329 N

Fz: 0.255 N

Velocity Plane:



We can see that airflow velocity directly behind the front wing is quite low, indicating a bad wing design, and the ground clearance is causing a lot of air to travel beneath the car.



Airflow over the wheels is disrupted, and far from smooth.

Verdict: Ineffective design as the drag force is too high and mainly parasitic drag, as the downforce is quite low.

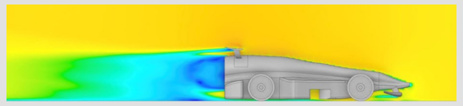
Design Concept 3

Description: In design concept 3, we tested wings without end plates or vortex generators to find out if these features added value to our designs. This meant we tested our first front wing design concept without

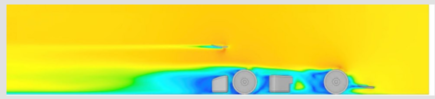
Fx: -0.296

Fz: 0.256

Velocity Plane:



We believe the wake behind this car is more dispersed, in particular behind the CO_2 cartridge chamber.



It appears that the airflow over the wheels is not as smooth as what is seen in our first design concept. This is most evident just behind the front wheel.

Verdict: We are glad to see in all aspects, our vortex generators improve the performance of our car. Our first design concepts drag force and vertical force is lower and the airflow seems more desirable too. We can confirm this design concept will most certainly not be pursued further.

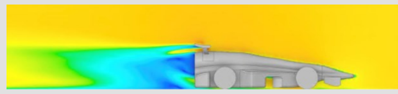
Design Concept 4

Description: In design concept 4, we used our dual foil wing design (concept 3) and our rear wing with VGs and end plates. This design was expected to generate more downforce.

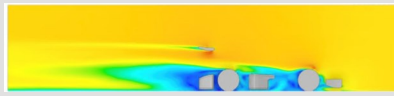
Fx: -0.284

Fz 0.181

Velocity Plane:



This wing has no effect over the centre of the car, due to it's two foil design.



We can see that in spite of generating a lot of drag, there is little benefit over the side pods and wheels. The airflow is rather chaotic indicating turbulence and the wake is quite dispersed.

Verdict

Due to the difficulties in printing this wing, and the surprisingly negative effects on the airflow over the wheels, this design would not be of use,

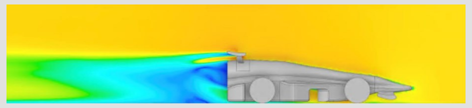
Design Concept 5

Description: In design concept 5, we looked at using our separate wings outlined in front wing design concept 4 along with our rear wing with VGs and end plates..

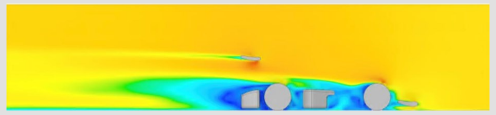
Fx: -0.283

Fz 0.176

Velocity Plane:



We cannot deduce much from the centreline plane, as the front wing has no effect over the centreline since it is in two parts. This has an effect beneath the car.



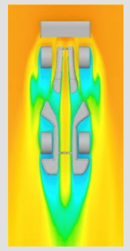
Over the wheels, we can see very disrupted air flow. This could be as a result of no vortex generators. The airflow beneath the front wing is slower compared to our other design.

Verdict

This wing generates the most downforce. The drag force is quite low relative to our other designs, but we feel that it generates too much downforce, generating unnecessary induced drag.

Other Design Features

Main Duct



It is believed this is rather promising as there is an area of low pressure beneath the car, indicating that our ground effect inducing design may potentially work. The ports behind the front wheels are working as intended as they are not allowing too much air into the duct which could potentially escape beneath the car and cause lift.

CFD Analysis Evaluation

With limited prior knowledge of fluid dynamics and CFD software, we believe we did a fairly good job at using this tool to our advantage. We were a little disappointed to see the drag force figures being quite high but we feel we know where we could potentially improve the wing design in the future.

Final Assembly

Safety Precautions

Particulate matter and vapour inhalation: Abrasives used for hand finishing parts such as 3D prints and the Official Model Block foam, produce minute dust particles that could be hazardous to our health, so Emmet utilised a 3M 6000 series half mask and P3 particulate filters that were certain to reduce the inhalation of dust to negligible amounts.

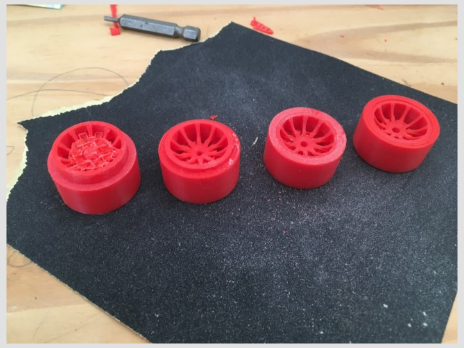
Gloves were worn when spray painting and aerosols were applied outside for ventilation.

Careful Considerations

We had limited supplies of key components such as bearings and our main body. We could not risk damaging these components for example by getting debris inside the ceramic races, or scratching the surface of the main body. We implemented precautionary measures such as wearing gloves when handling these components, and working over countertops and trays.

Surface prep

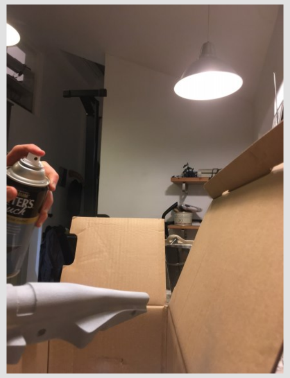
We experimented with sanding the modelblock but felt it was unnecessary, as we risked causing irregularities on each side which could imbalance the performance of the car. We opted for just using primers and paint instead to improve the surface finish. We were impressed with the quality left by the CNC router anyway so were confident in this decision.



For the 3D components, it was vital that we properly sanded everything prior to painting. This removed any supports or strands of filament that remained after the printing process. We would have preferred to use an SLA printer to print our parts as we believe this would leave a better finish but sanding was the best we could do with the facilities we had.

Colour Scheme and Application of Decals

Before painting our car, we were able to test our paints on another piece of the official F1 Modelblock we had acquired. In our painting tests, we found that the paint added a lot of unnecessary mass to the car that we could not afford to have. We found that this could be combatted by spraying in very light mists.



A grey aerosol spray on primer was used initially to help the paint adhere to the modelblock. This provided a good base colour for the rest of the car, filled many of the porous holes in high density foam and assured us that the gloss, grey spray paint would leave an aesthetically pleasing finish. We followed the grey base colour layer with some patterns that we sprayed on using a hand cut stencil to enhance the visual appearance. This final coat was the lightest possible mist of blue spray paint. It was vital that we ensured that the final coat would not add unwanted thickness to the main body.

To try to reduce the thickness of the decals, we stuck the decals on, once our primer was applied. We then covered the decals with masking tape, and applied the final coat so the paint and the decals married up nicely. In our testing we found that the decals would not adhere well to the foam, whereas the primer removed the layer of dust and porous surface which would ruin the effectiveness of the glue on the back of the decals.

For our nose cone and our rear wing, we intentionally printed using PLA "Sky Blue" filament to reduce the need for excessive amounts of paint. We found that a light coat of paint would help to fill the irregularities in the surface of our budget 3D printer manufactured components.

To finish, components were sprayed with a clear coat lacquer to try and get as smooth a surface finish as possible. This should promote laminar flow and reduce skin friction.

Assembly Process

- The axle shafts were cut to size using a Dremel die grinder with an abrasive cut off wheel. These were sanded down in very specific places to allow the bearings to slide into the correct place. We marked the positions where the bearing would sit with a marker and ensure that part of the shaft was not sanded.
- The lathe finished wheels were to be manufactured using one of two methods:
  1. Acetl Delrin is bored to a 24 millimetre diameter hole and turned down to a 28 millimetre diameter. This iss slotted over the 3d printed rim.
  2. The entire wheel is 3D printed and then put on the lathe to be finished with abrasive paper to ensure a round finish.

- The wheels are then slotted onto the axle shaft, whether we use bearings inside the wheels or not is still to be decided.
- One bearing had to be fitted onto one side of the axle shafts. Some bearing retainer adhesive was used to try and ensure a secure fit, while ensuring that none got inside the races as this would have catastrophic effects.
- The other bearings were pushed onto the axle from the other side.
- Masking tape protecting the mating surfaces of the wings and tether lines was removed. These components were pushed into place, using a suitable adhesive.

Evaluation

We feel we have outlined a clear assembly process that will be implemented to ensure that a high quality finish of our car is achieved. Much research has gone into our car design, and to not finish it to a high standard would result in a significant amount of lost productivity. All things need to come to a proper conclusion, and the completion of our car is no exception to this.

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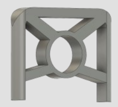
Final Car Design Overview and Project Conclusions

Rear wing: Vortex generators streamline airflow behind the car and end plates promote laminar flow over the wing. Printed out of PLA, it simply glues onto the car with a large mating surface.

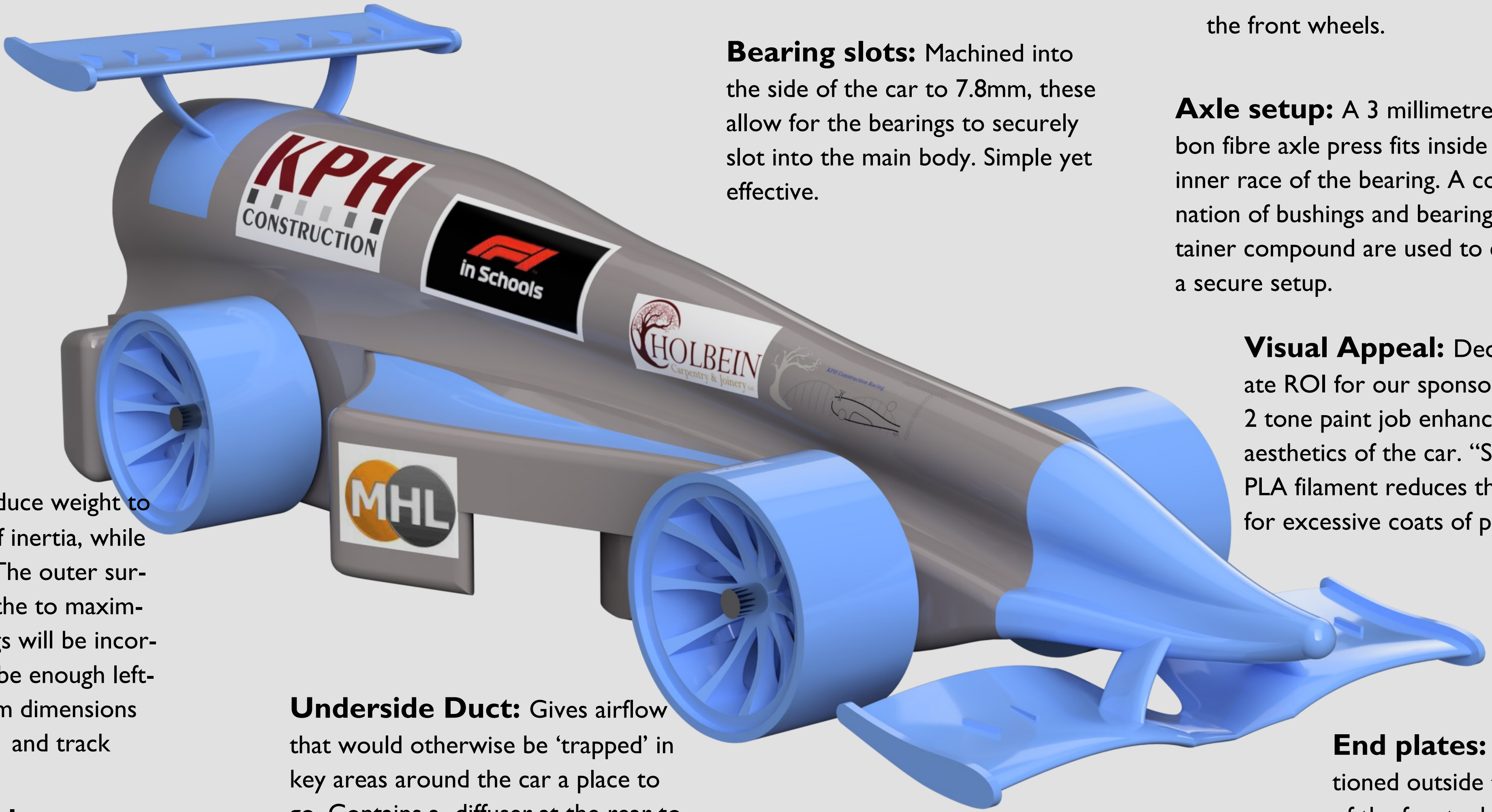
Main body: Designed to incorporate minimum ground clearance to promote the 'ground effect' allowing for smooth airflow and additional downforce. Designed with very universal mounting systems for other components, we could confidently submit our CAD file for the free manufacturing service, with the ability to continue design development on 3D printed components.

Tether line guides: Slides up underneath the car into slots, and held in with adhesives. Tested to support a minimum of 300 grams.



Front wing shape: Technically being two 25 millimetre foils, and joined in the middle by a strengthening support structure, it allows for the tether line to enter into the guid with plenty of room all around. The curvature attempts to direct airflow around and over the front wheels.

Rear Pods: To try and reduce turbulence behind the car, tapering side pods are used to direct airflow into a streamlined wake.. Flat at the bottom to prevent air from escaping the duct which could generate catastrophic lift.



Bearing slots: Machined into the side of the car to 7.8mm, these allow for the bearings to securely slot into the main body. Simple yet effective.

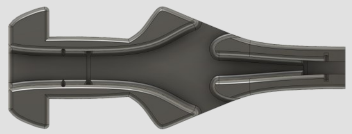
Axle setup: A 3 millimetre carbon fibre axle press fits inside the inner race of the bearing. A combination of bushings and bearing retainer compound are used to create a secure setup.

Visual Appeal: Decals create ROI for our sponsors, and a 2 tone paint job enhances the aesthetics of the car. "Sky Blue" PLA filament reduces the need for excessive coats of paint.

Wheels: Spokes reduce weight to reduce the moment of inertia, while maintaining strength, The outer surface is finished on a lathe to maximise roundness. Bearings will be incorporated should there be enough leftover. Kept to minimum dimensions to reduce frontal area and track surface friction

Side Pods: Designed to take airflow over the top of the rear wheels and direct around the sides onto the rear pods. Smooth, gradually curved surfaces promote laminar flow.

Underside Duct: Gives airflow that would otherwise be 'trapped' in key areas around the car a place to go. Contains a diffuser at the rear to reduce air pressure. A well though out entry width should prevent excessively high pressure beneath the car.



End plates: Positioned outside the width of the front wheels.

Front wing vortex generators: Attempt to force turbulent air generated by the wheels away from the car by generating aerodynamically beneficial vortices.

Design Overview

This project has been a thoroughly brilliant experience. It has provided us with an enormous challenge, but has given us the motivation to learn so many new skills that we can bring forward with us in life. Without a doubt, at times it has been a difficult task, but we feel we have overcome so many challenges independently at this point that it has boosted our confidence going into other tasks that initially seem near impossible!

Aside from this, to return to the design of our car, we feel that we have maximised our knowledge and skills to produce our very best work. All design features were researched thoroughly and numerous concepts were explored before implementing our best design created. We have covered numerous aspects of design, from practical features such as interchangeable components to the aesthetically pleasing look of our car.

We can already see potential design concepts that we could explore in the future, but for the time being we are really looking forward to seeing how our car fairs in its very first race in a few weeks time.

Portfolio Overview

We hope that our portfolio has given a deep insight into our project, and more importantly was engaging. Much thought went into the layout of this document which has hopefully proved to be easy for you the reader to navigate.