PHOTONIC

ENGINEERING PORTFOLIO
NSW STATE FINALS

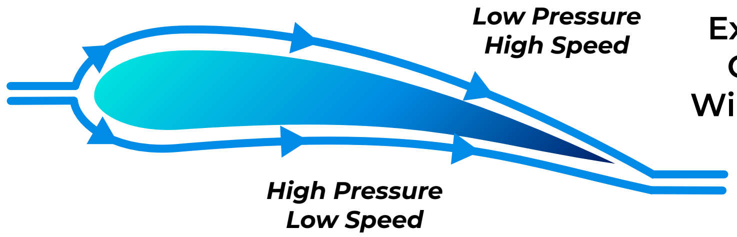
PREPARATION

Research

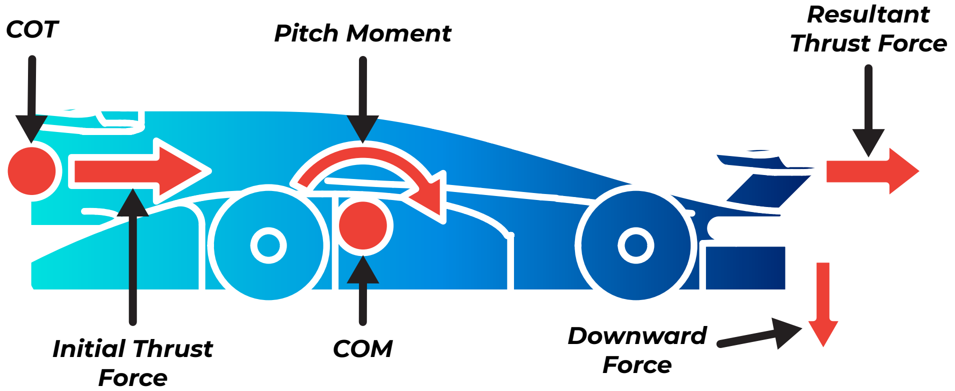
Before designing and testing our car, we investigated all the main factors that will affect our race time, including lift/downforce, drag, wheel stability, etc. We researched and analysed each one of these factors in great detail to determine how we could use them to our advantage.

Lift & Downforce

Each F1 in Schools car has either lift or downforce, which is a vertical force that either pushes the car upwards or downwards. Two factors influence this, the air pressure around the car, and the relative height of the Centre Of Thrust (COT) compared to the Centre Of Mass (COM). The primary method we can use to manipulate lift or downforce is the aerodynamics of our car, via Bernoulli's Principle. If there is low pressure above aerodynamic surfaces and high pressure below, lift will be created. If there is high pressure above and low pressure below, downforce will be created. The positioning of the COM relative to the COT, as of a result of regulation T10.4, will always cause a moment, or pitch force, around the COM that will press the front of the car downwards. This force does help to stabilise the car at the beginning of the race, however, it is most beneficial to have the COM close to the same height from the track surface as the COT. This is to maximise thrust efficiency by minimising how much thrust force is converted into moment forces.



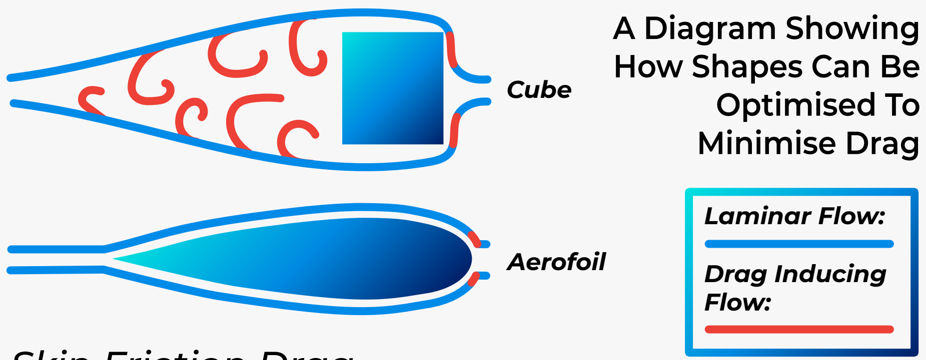
Example Lift Generating Wing Surface



COM/COT Force Diagram

Pressure Drag

As our car races down the track, it disturbs the air around it and can create areas of high or low pressure, depending on where it displaces air. This will cause pressure variations around the car, slowing it down. Any moving entity in a fluid will have two main areas of pressure drag. High pressure will be at the front of the entity as a result of the fluid having to be forced around the entity. Low pressure will be at the rear of the entity as the fluid returns to its orginal position (i.e. a 'wake'), and will cause undesirable turbulance. These effects cannot be eliminated, but our car is designed to mitigate them where possible. This is done mainly by minimising frontal area, and by maximising delivery of air to the rear of the car. Our underbody airflow channel is the most prominent feature that is designed based on this.



A Diagram Showing How Shapes Can Be Optimised To Minimise Drag

Skin Friction Drag

Skin friction drag is created as a fluid travels over a surface, and becomes turbulent as it encounters small inconsistencies in the surface finish, i.e. how rough the surface is. The most effective method of reducing skin friction drag is to ensure that the surfaces of the car are painted well and are extremely smooth, and the overall minimisation of frontal area.

Wheel Stability & Alignment

Through the design and development of our wheels for the Western Sydney Regional Final, we discovered that having excellent wheel stability and alignment is critical to reducing our race time. The key isssues that could be present in a wheel system are wheels that do not remain straight throughout the race, therefore increasing resistance, and the pairs of front and rear wheel not being concentric. For the state finals, we completly redesigned our wheel system to ensure that it could easily and accurately be aligned during assembly, and that it was as stable as possible.

Car Design Requirements

Based on the research we conducted we drafted a list of design requirements that a successful car must fulfill. These reflected what we learnt during our research, and experience from past competitions.

Minimal Frontal Area

Minimising frontal area is the only way to reduce pressure drag originating from high pressure zones where air is forced around a leading edge of a car. This is critical to lowering the car's overall drag.

Minimal Surface Area

Minimising surface area is crucial to minimising the car's skin friction drag, and also in turn lowers the car's mass.

Laminar Aerodynamics

The promotion of laminar flow around the car is integral to maximising aerodynamic effciency. Any turbulance created will slow down air, form unwanted pressure zones, and increase drag. Minimising turbulant flow will allow the air to flow around the car undisturbed and quickly return to its original state, reducing the wake.

High Thrust Efficiency

The position of the COM relative to the COT has a significant effect on our race time. Ensuring that the COM is as high as possible within regulations will minimise how much of the forward force of thrust is converted into pitch moments.

Fully Legal, With Tolerances

The car must be fully legal such that there are no time penalties, and minimal points are deducted from our overall score.

DESIGN IDEAS

Design Ideas

Throughout our design process, we have created and analysed a variety of of innovative design ideas, each aimed at imporiving a certain aspect of our car's performance. Even though not all of these are implemented in our final design, the concepts and analysis behind each still had a positive impact on the creation, analysis, and refinement of our final design.

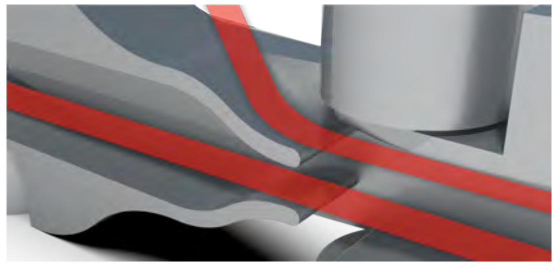
Wall Inlets

PDCR 4.1 - 4.2

Throughout our CFD process, we have noticed that pockets of turbulent air were getting trapped behind the front wheel due to low pressure in the exclusion zone. To combat this, we decided to test 'air inlets' both in front of and behind the wheel, that help fill the low pressure area.

Drag: +0.027N

Lift: -0.172N



The wall inlets are fairly successful in removing turbulent air from the exclusion zone, though this does create an increase in both drag and lift. As a result, we did not pursue this, and focused more on refining our nosecone design.

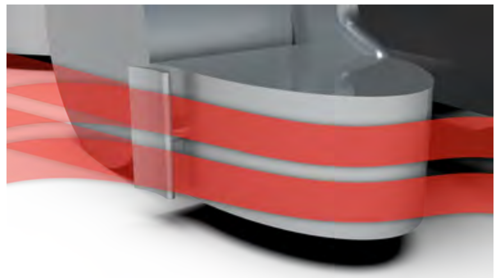
Aerodynamic Manipulators

PDCR 11.0 - 11.7

To improve airflow around our car, we introduced the concept of 'aero manipulators', small design features specifically targeted at areas of low pressure or turbulent air. We tested various versions, such as vortex generators & plates to manipulate the air around the car.

Drag: All increased

Lift: Varying



Though none of our aerodynamic manipulators had a positive effect on our car, we have still gained experience about various aerodynamic factors and what designs work.

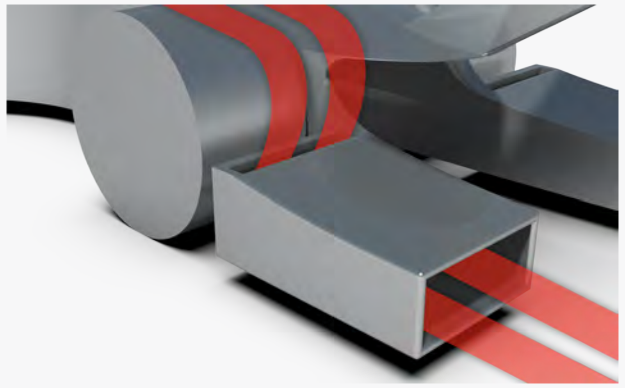
Pressure Reduction Wings

PDCR 5.1

During the research stage of the design process, we came across the McLaren Elva, a high performance sportscar that utilses an innovative aerodynamic system that directs incoming air at the front of the car up and backwards as such that it produces a low pressure zone over the occupants of the car, ie. a virtual windscreen. We designed a similar system that would reduce the high pressure area on our front wheels, caused by the high frontal area.

Drag: +0.032N

Lift: +0.028N



Though this concept did actually decrease the high pressure zone on our front wheels significantly, it increases drag in other ways, so we decided not to implement this idea.

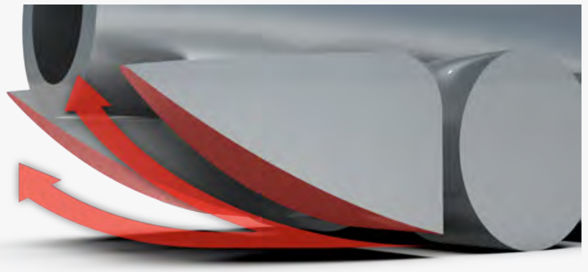
Downforce Inducing Rear Pods

PDCR 6.2

To further increase stability underneath the centre of thrust, we decided to utilise our rear pods to create a low pressure zone underneath the cylinder chamber, producing downforce, 'pulling' the car onto the track, and helping to stabilise the car during launch.

Drag: +0.025N

Lift: -0.06N



Though this concept does promote downforce below the centre of thrust, which will stabilise the car during launch, this may increase rolling resistance. The small reduction in lift is not worth the increase in drag, so we did not pursue this.

Note: Each of the quoted drag and lift values represent the change in drag force at 20ms^{-1}, relative to control design in its given major iteration.

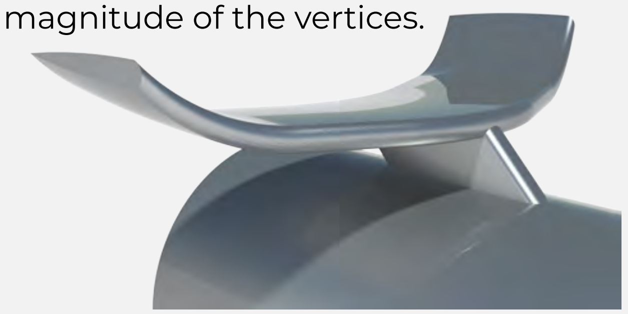
Curved Wingtips

PDCR 9.3

We noticed during our CFD testing that our wings, even though they have a neutral aerofoil profile, still have a pressure difference above and below the wing surfaces. This will create vortices that disrupt laminar airflow around the car. To minimise the generation of these vortices, we implemented curved wingtipes to our front wing surfaces to make the mixing of the different air pressure areas more gradual, reducing the magnitude of the vertices.

Drag: -0.035N

Lift: +0.072N



The implementation of this has minimal impact on other design features of the car, and the manufacturing on the car, whilst improving performance, so we did implement this.

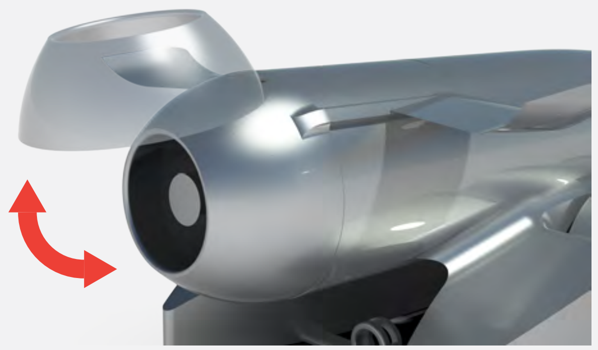
LEDC System

PDCS 16.1

We created a Launch Energy Deflection Cap (LEDC) System that is designed to both reduce the wake of the car, and to provide more efficient use of thrust during launch. This is a fully legal system that uses a cap that is attatched to the Rear Wing Support System that opens and closes over the cylinder chamber to allow for the placement of the gas canister. The cap is shaped to taper the end of the cylinder chamber, reducing the wake to almost zero, and the cap fits over the launch system and deflects excess gas back towards the direction of thrust.

Drag: -0.023N

Lift: -0.018N



Due to the complexity of the hinge/clip functionality, and a COVID-19 outbreak at our school, the development of this system was only completed in part, so we did not implement this into our State Finals design. However, if we proceed to the National Finals, we will implement this into our design.

INNOVATION

Innovative Design Features

Thanks to our extensive research and preparation, and comprehensive testing and analysis, we have managed to implement numerous innovations into our design and manufacturing processes that have proved to be beneficial to our car.

As shown in our design ideas page, we developed and tested many innovative ideas, many more that feature on this page, and this is because we see no value in innovation purely for the sake of innovation. Our aim is to produce the fastest car, and we found that, through our testing, often a more simple aerodynamic philosophy is more effective.

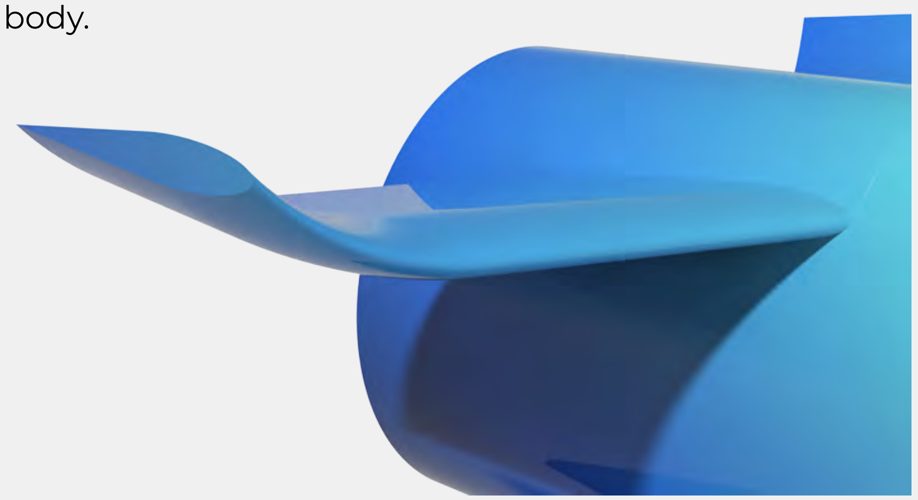
Wheel System

A critical element of our car's performance is the design and manufacturing quality of our wheels. We have designed our wheel system to be easily assembled, by minimising the number of parts, and by removing the need for glue, as all parts friction-lock together. This allows for quick and easy assembly and repairs and ensures that all assembly is perfectly accurate and concentric, a must for high-performance wheels with low rolling resistance. Our wheel design features a unique dual bearing system, unlike most teams that opt for a single bearing. Having two bearings increases our wheel stability significantly, and because of our very small, lightweight, and extremely low resistance hybrid-ceramic bearings, the difference in mass and resistance is negligable.

An expoded render of our wheel support system

Wing Tips

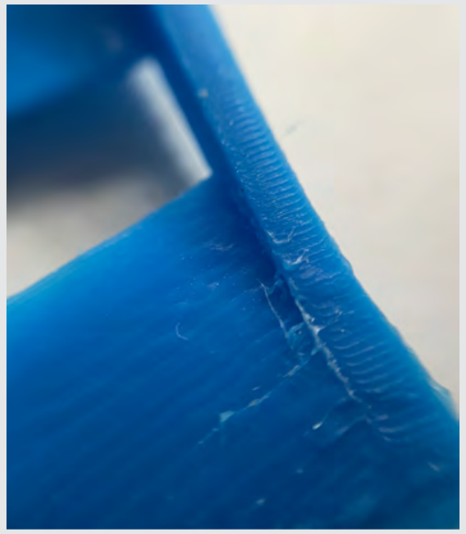
Another innovation we have considered and implemented in our design is our curved wingtips. During our CFD testing, we noticed that flat wings were resulting in turbulent air spiralling off the wingtips. These vortices are formed when the pressure difference between either side of the wing meets at the tip, causing it to mix in a vortex, and spiral off. Turbulent vortices create high amounts of drag when flowing next to the surface of the car, and eliminating these was critical to our design. To further reduce the effect of vortices on the car, we raised our front wing surfaces, such that any resulting vortices are created further away from the car body.



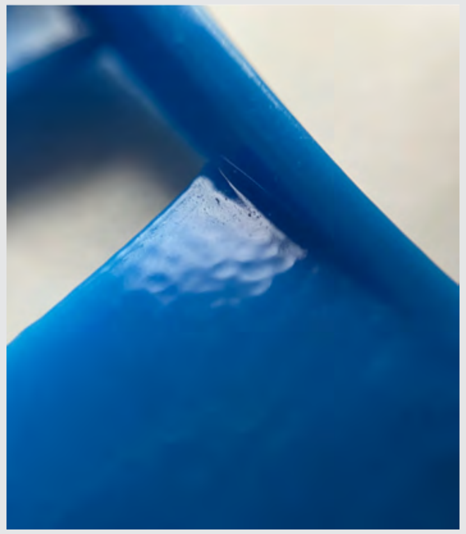
A render of our rear wing with curved wingtips

Polysmooth

The surface finish of our car is crucial to reducing drag, as an uneven surface will create a layer of turbulent air next to our car, increasing skin friction, and slowing our car down. We chose to 3D print all our wings, wing support, and wheel support structures out of Polymaker PolySmooth PVB, which has very similar mechanical properties to the easy to print and reasonably strong PLA. However, the PolySmooth PVB acts is a solute when mixed with Isopropyl Alcohol (IPA). Because of this, once the desired part is printed as if it were PLA, it can be placed inside a machine that vaporises IPA, and dissolves the surface of the part. This removes all layer lines produced by 3D printing, which significantly improves surface finish, and also increases the strength of the part once dry. This process is very quick, it takes up to half an hour, and much more effective than any other smoothing process, such as sanding.



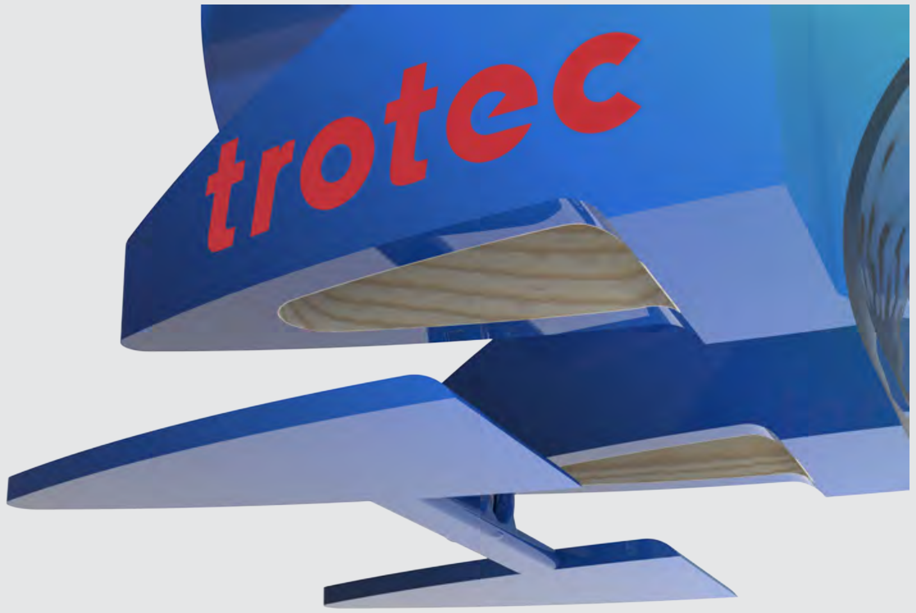
A close up photograph of a newly 3D printed part with 0.05 mm layer height.



A close up photograph of the same part after the polysmoothing process, with no sanding at all.

Hollow Rear Pods

Mass is a critical factor in determining how fast a car is, so making the car as light as possible is crucial to achieving the minimum mass.
Because of this, we decided to hollow out our rear pods to save mass of our balsa block, but we found that the air would get trapped in the area inside the rear pods.
To combat this, we integrated a cover for the hollow rear pods into our tether line guide support system,. This will significantly improve how the air leaves the back of the car, which is crucial to minimising the car's wake, whilst still maintaining a low mass.



A render of our rear pod cover

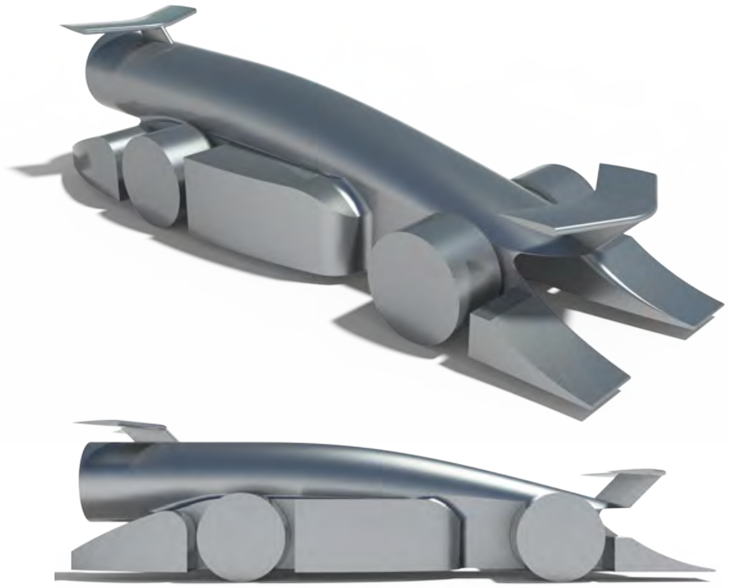
DESIGN REFINEMENT

Design Development & Refinement Process

Our design development process consisted of two main stages. The first stage was to test every possible design idea, from front and rear wings to side pods and airflow channels. This was from PDCR1.0 through to PDCR10.3. From PDCR11.0 onwards was our second stage, where we took the most effective combination of features and refined them, through further testing, to produce our final design. Each major design version had up to 20 subversions. Below is just 4 key design versions, out of a total of 78 different designs. All drag and lift values are measured at $20ms^{-1}$.

PDCR 1.0

This was our first design as Photonic Racing. It incorporates features of cars from our previous three teams, such as elongated rear pods, an underbody airflow channel, wedge style front wings, and a face-to-face type loft for the cylinder chamber leading edge (alternative to a face-to-point).



Drag: 0.317 N
N/A

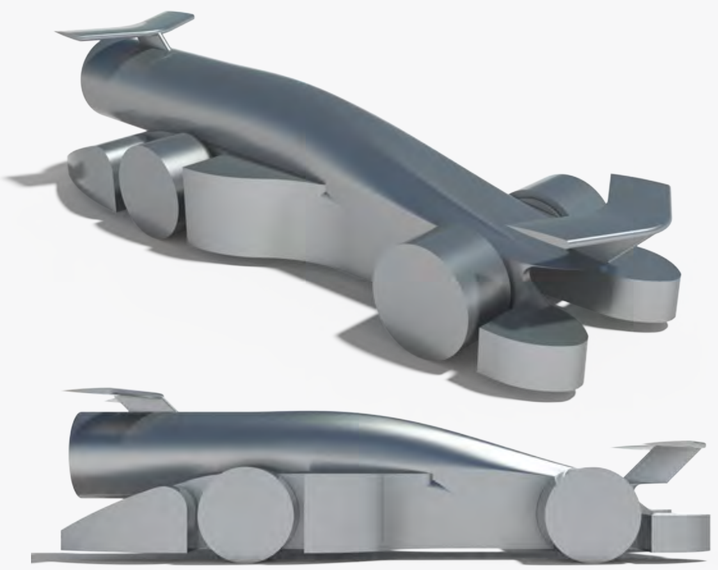
Lift: - 0.221 N
N/A

Evaluation

This design is a good starting point for our design process. Many of the design features are sound, but this is very rough and unrefined. The overall car 'system' lacks cohesion, so none of the aerodynamic features, however good individually, interact well. The design has a very large volume, and minimal manufacturing tolerances.

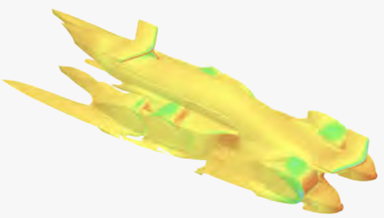
PDCR 5.4

This prototype has significantly less drag than our initial prototype, having reduced drag by nearly 25%. It features convex front wheel deflectors that reduce frontal area infront of the wheel, updated sidepods that more effectively promote laminar airflow around the rear wheels, and a new body, utilising a similar but refined face-to-face loft.



Drag: 0.236 N
- 0.081 N

Lift: - 0.040 N
+ 0.185 N

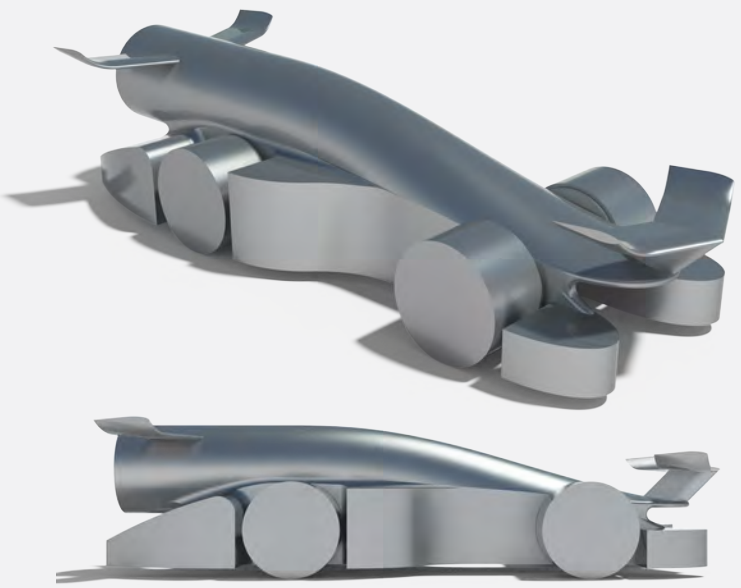


Evaluation

This is a good design, and is beginning to take shape, leading to our final design. Many of the final features of the design have been implemented, such as the swept back wings, convex front wheel deflectors. Many of the features have yet to be refined, and most of the manufacturing tolerancing has yet to be added.

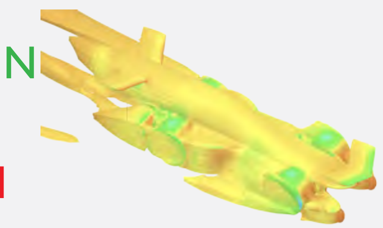
PDCR 10.0

This design is very similar to our final design, with only minor changes to each feature, and the sidepod design. All manufacturing tolerances have been added, and the whole CAD geometry has been redesigned from the ground up for simplified and more editable geometry. This design also incorporates virtual cargo.



Drag: 0.228N
- 0.008 N

Lift: - 0.155 N
- 0.115 N

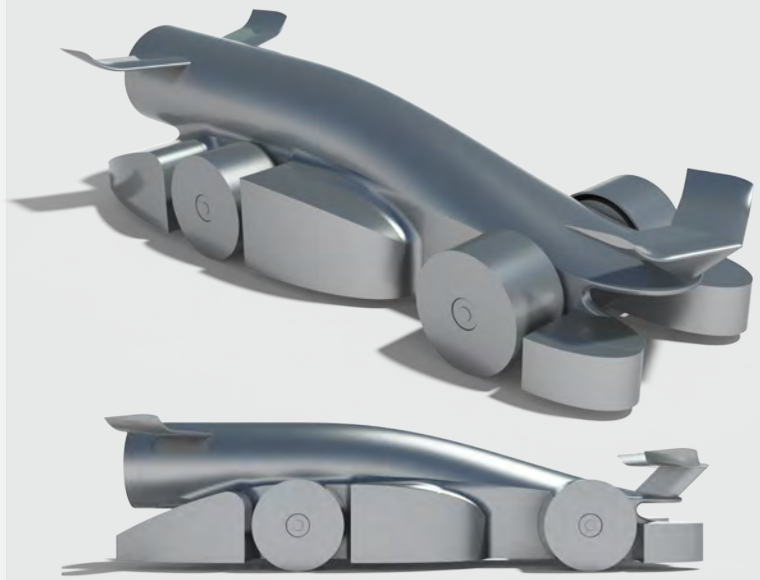


Evaluation

This design is very close to completion. However, it is very simple, and we have yet to implement and test a variety of innovative features. Otherwise, this design only requires minor refinement, and the design of how each part interfaces with other parts.

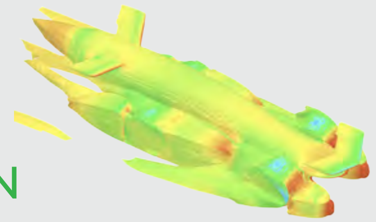
PDCS 16.0

PDCS 16.0 is our final version, and the car design we will be racing. It features all parts refined with full manufacturing tolerances, ready to be manufactured. It also features hollowed out rear pods to reduce weight, and implements our final sidepod design and wheel design, as well as other new features.



Drag: 0.206N
-0.022 N

Lift: - 0.146 N
- 0.009 N



Evaluation

Throughout our extensive design process and numerous revisions, we have managed to reduce drag by nearly 40%, and generate lift to reduce the effects of rolling resistance. We have utilised various aerodynamic principles, and designed various features to use them to our benefit.

TESTING & ANALYSIS

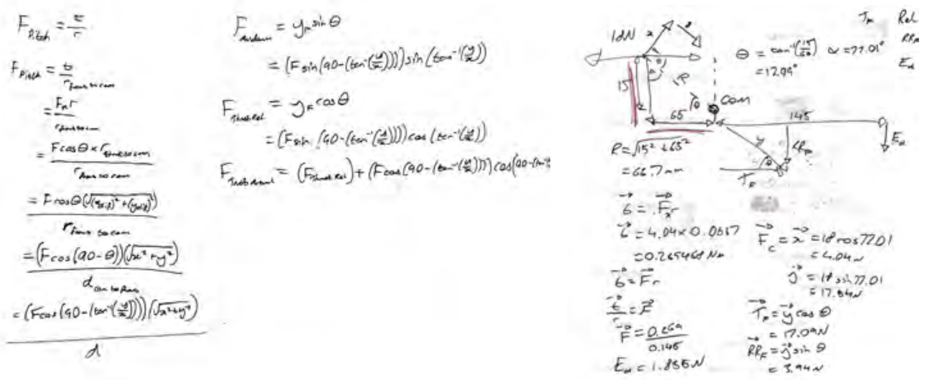
Simscale

A key process in the design of our car was the use of Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) to analyse various aspects of our car design so we could refine and improve. For our virtual testing, we used Simscale, an online, cloud-based program. Simscale is industry-standard software that gave us extremely accurate results, for both quantitative and qualitative analysis. We were sponsored with unlimited core hours, allowing us to test our car extensively, and we were mentored by Jousef Murad, who taught us how to use Simscale to maximise the accuracy and reliability of our data. Because Simscale is cloud based, it allows all team members access, wherever and whenever needed, maximising our efficiency.

SIMSCALE

Theoretical Times Formula

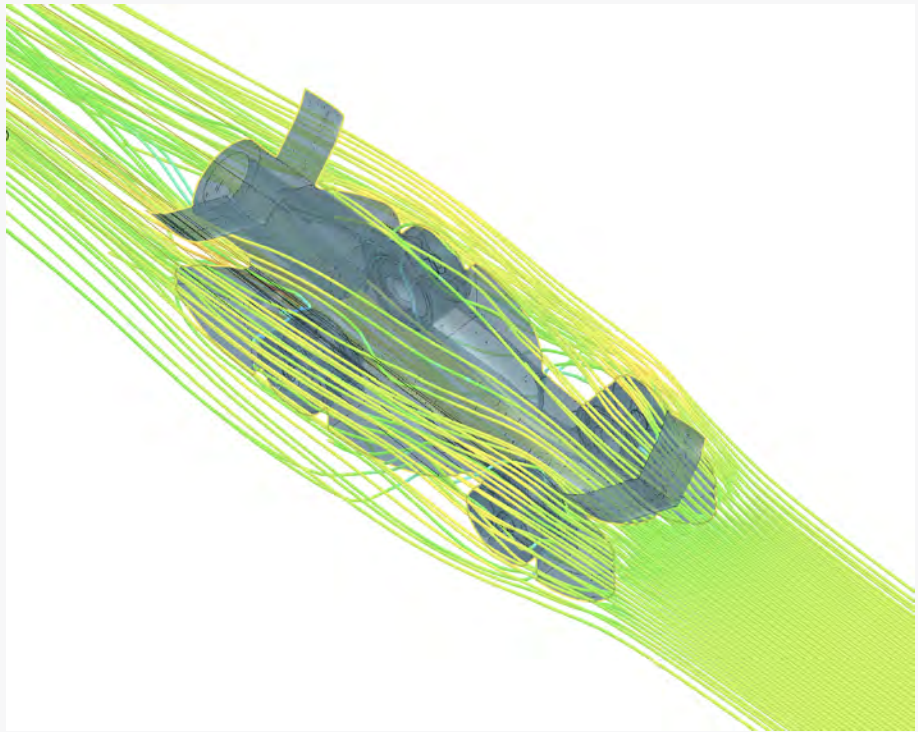
To assess the overall effectiveness of each of our prototypes, and how they would perform on-track, we have created a mathematical formula (see below) that predicts the race times of each design. We have incorporated drag forces, lift forces, thrust forces, centre of mass, rolling resistance and weight, to as accurately as possible represent the effectiveness of each car. We have created a document in excel to quickly make these calculations, and allowing us to put in stats for each design model, and instantly receive a predicted race time. As well as using this formula to compare prototypes, we could also experiment with the values for each field, to determine how much it impacted the final race time.



CFD

We used Computational Fluid Dynamics extensively in the testing and refinement of our car. Every single design version and sub-version was tested in CFD to determine the drag and lift of the design (measured at 20 ms^{-1}). Simscale was easy to use and gave accurate results. Every time we tested a design, we kept the bounding box, mesh, windspeed and track parameters identical, to ensure valid results. Being able to test the forces acting upon the car allowed us to identify areas of weakness that we could improve, helping us reduce the drag by 40 percent from our initial prototype to final car.

Using CFD also allowed us to visualise many different aerodynamic factors of the car's performance, most importantly airflow and air pressure. Being able to simulate this allowed us to gain important insights into not just how good our designs were, but how the aerodynamics worked, and areas where we could improve. Each time we tested a version, we simulated the airflow over the car to see where airflow was turbulent, and where airspeeds were faster or slower. We also looked at cutting planes and isovolumes to see the air pressure around the car, which was critical in allowing us to minimise low and high pressure zones, especially at the front and rear of the car.

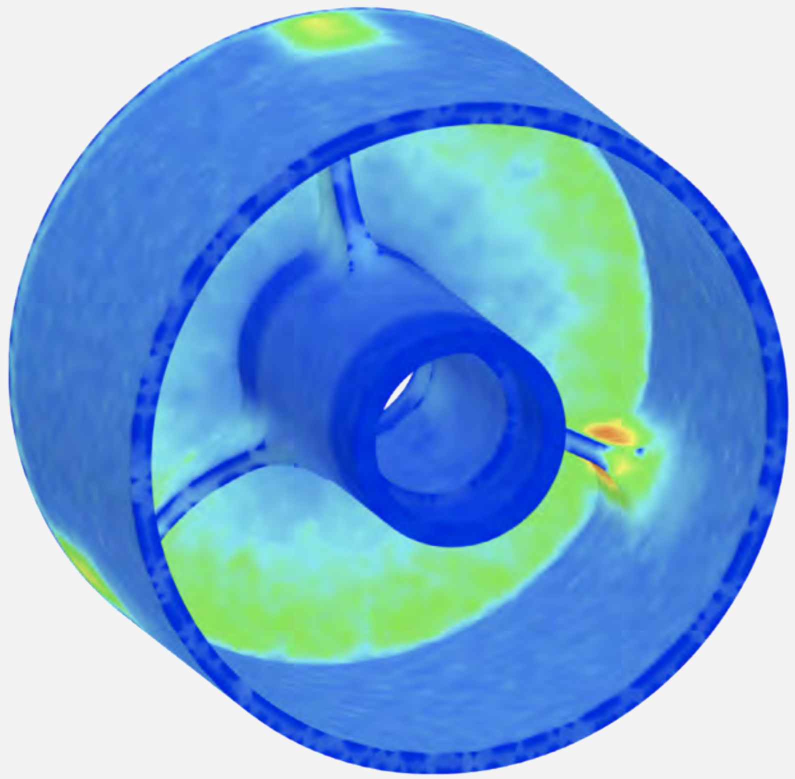


Above: A CFD particle trace image, showing how air flows over our car

FEA

Finite Element Analysis was another critical part of our testing, as it allowed us to test the strength of our car during the race, and in the deceleration phase. With the high speeds our car will undergo, it is subjected to strong forces, making weak areas susceptible to breakage. We used FEA to identify these places of weakness, and strengthen them, and identify redundant material that we could remove, whilst maintaining strength. Every time we made a major design change to our car, we tested it using FEA, to ensure that it was strong enough to withstand the forces subjected. We also tested each component individually, and each connection point, to mitigate the risk of breakages in racing.

FEA was especially critical in ensuring a high strength-to-weight ratio for our wheel design. We tested and refined our wheels extensively, as they are the parts of the car subjected to the most stress, spinning at 20,000RPM, they have to be as light as possible, to reduce rotational inertia. We managed to optimise the strength of our wheels, and after testing various designs, found that a 5-spoke design with thin spokes but thicker, filleted connections provided enough stability to withstand the stress, while remaining extremely light.

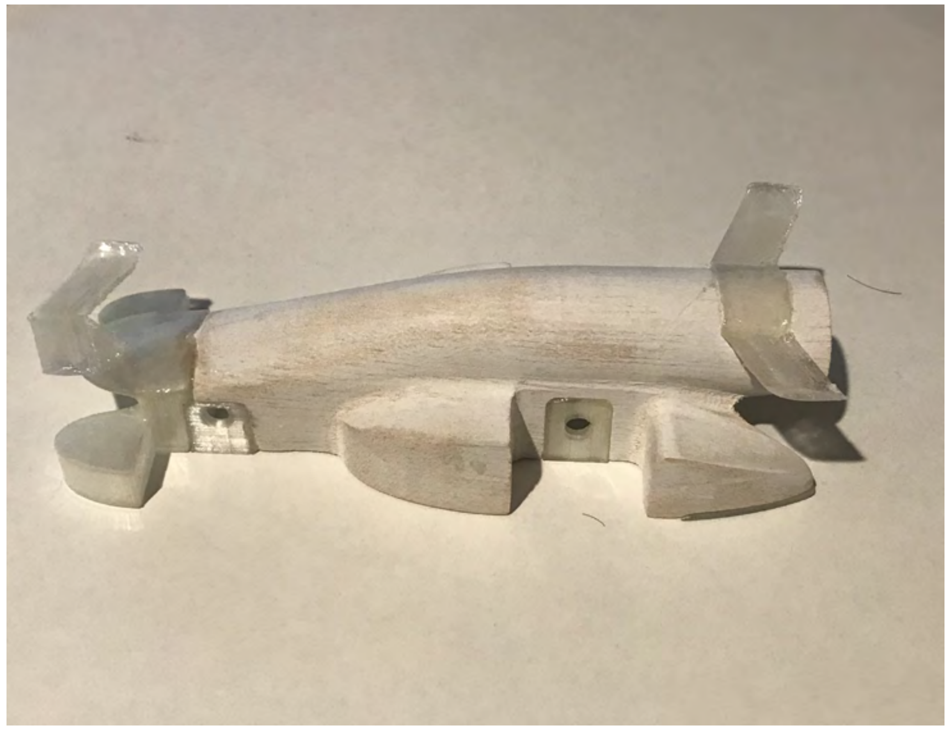


Above: An image from one of our FEA tests, visualising the stress on our wheel.

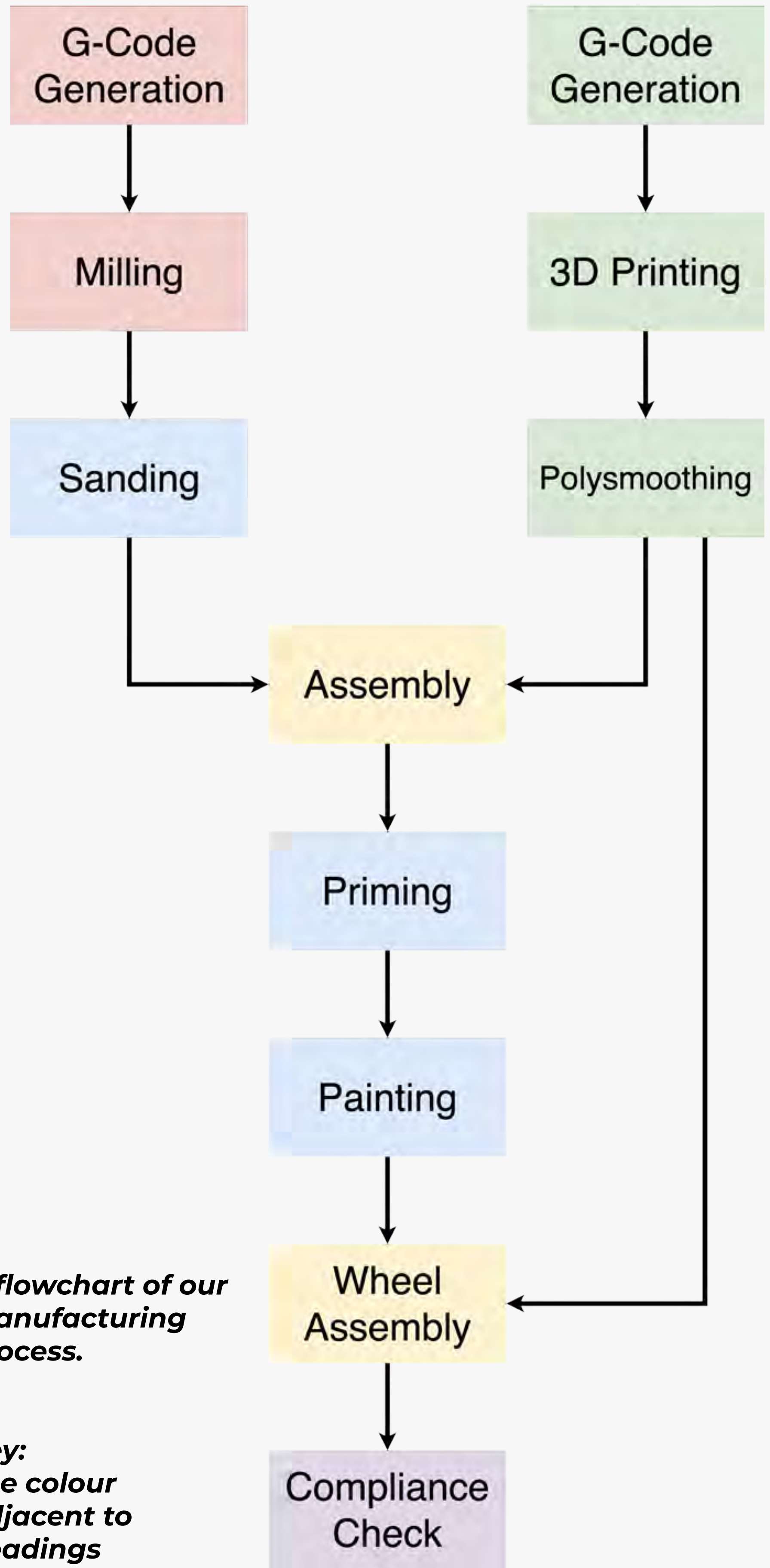
MANUFACTURING

Manufacturing Overview

We have utilised a number of innovative processes and technologies in our manufacturing and assembly process. We began our manufacturing by researching and educating ourselves on various manufacturing techniques, and the requirements for our car, and decided what we would utilise to reduce weight, improve accuracy, and strengthen our car as much as possible. During our preparation, we also talked with our mentors, including Michael Laws from Teaching Tech. Michael has been involved in the manufacturing industry for many years, and has immense knowledge and experience with various technologies and machinery, and how we should utilise them. He introduced us to the concepts of Polysmoothing, Thermoforming plastics, and recycled plastic parts. We have been in regular contact with Timack Engineering, and they have helped us refine our wheel concepts to improve the strength and manufacturability, and in choosing the right material for our needs. Our manufacturing process has been extensively planned, and executed to produce a car of the highest possible quality.



Above: An image of our car during preparation for painting.



A flowchart of our manufacturing process.

Key: See colour adjacent to headings

Milling

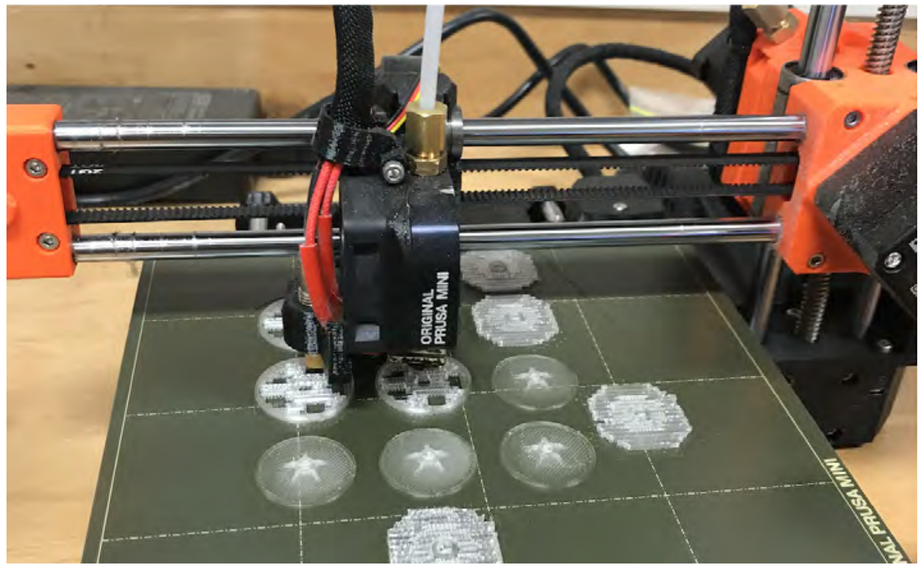
The milling of the car is one of the most important stages of the manufacturing process, since it lays the foundation for the rest of the manufacturing, and the calibration of the equipment must be done to precision, often by eye. For this reason, we conducted many test cuts before milling our final car. First, we converted the CAD drawings into G-Code for our IMPACT! CNC router to interpret. We chose to use Fusion 360 for our software, as it is free, easy-to-use and compatible with our router, with the correct post processor. We set a feed rate of 2500mm / minute, a two-way parallel cutting strategy, a stepover of 0.3mm for high accuracy, and no roughing, as we believed this extra milling time was not worth the minimal improved accuracy. After we had completed the G-code, we mounted our custom made, 3d printed jigs, made specifically for an F1 in Schools balsa block into the CNC with high precision. We designed these ourselves, not only for our own team, but also for our whole school. Once mounted, we used a “zeroing jig” which helped us align the zero point at the appropriate location. We decided to use the standard 6 mm ball nose endmill for Development Class teams, to mill our car because our school has three Development Class teams all needing to cut their cars at the same time, and this made the whole process more efficient. We repeated this process four times, for top, bottom, left and right cuts, changing our jigs to other jigs which fit the car at a different angle.

Above: An image of our car being milled

MANUFACTURING

3D Printing

To produce all our components, besides the car body, we decided to use 3D printing, a form of additive manufacturing. This method of manufacturing is cheap, accurate, and reliable, and can be used with a variety of different materials and configurations. After testing 6 different materials for price, strength, accuracy, reliability and surface finish, we decided that PolySmooth PVB (see page 3) plastic was the most suited to our needs. We printed our parts on a Prusa Mini printer, and set the extrusion thickness to ultrafine (0.05 mm), and the infill to 5%. This gave us a light, accurate yet strong enough print, suiting our requirements. The surface finish of our front wings is critical to the performance of our car, as any imperfections can cause pockets of turbulent air that spiral along the car, increasing drag greatly. To achieve an immaculate finish and increased strength, we have utilised Polysmoothing, a process that involves spraying a fine Isopropyl Alcohol mist over our parts, which lightly dissolves the surface layer. This is then left to dry and reforms as a perfectly smooth part. We have also utilised 3D printing to create our assembly jig, allowing us to position parts perfectly accurately before attaching them to the body. After contacting many companies to manufacture our wheels, we could not ourtsource our wheel manufacturing to a CNC lathe company. This meant that we decided to 3D print and polysmooth our wheels as well instead of using the desired PEEK plastic.



Our wheels being 3D printed.

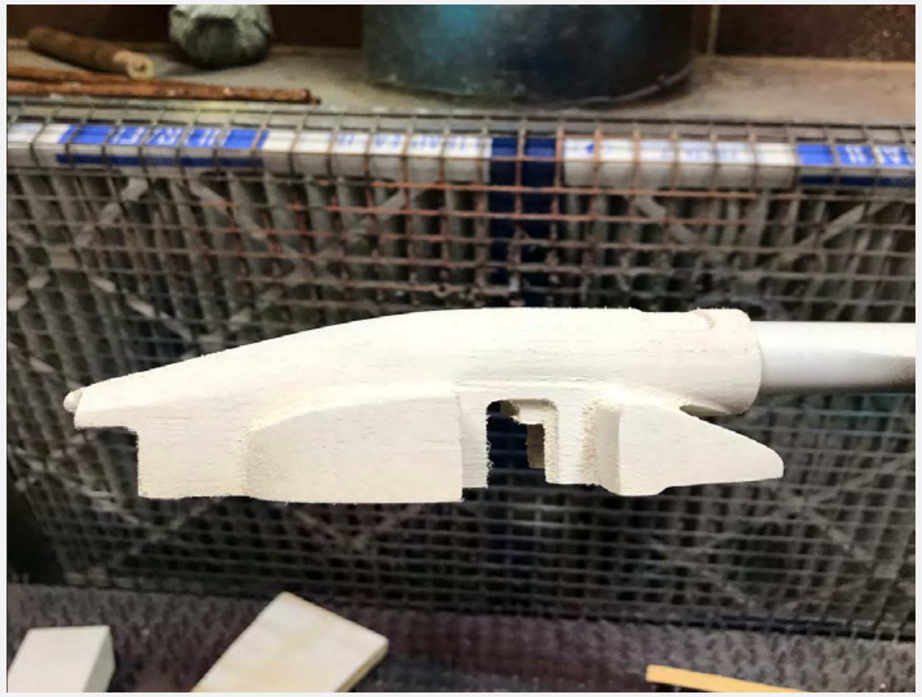
Assembly

The assembly of our car is another critical component of it's performance on the track. We have designed and created a custom jig that allows us to place each part of the car, then glue it together with perfect accuracy. We used epoxy glue, as it is extremely strong, sets quickly and retains strength for a long time. We have designed our wheels and wheel support system to lock together with no glueing required. This allows for quick, replaceable and perfectly accurate assembly. Once the cars are complete, it is important that we ensure no regulations are broken, as this can cost points and time. For our quality control processes, we have allowed at least 1 mm for each regulation in our CAD model. We have also created a regulations jig, that allows us to check each regulation simultaneously by placing our car into the jig. If the car doesn't fit in any area, we know the regulation is broken. In addition to this, we have designed a series of regulation compliance tools that have been laser cut to ensure perfect accuracy. These allow us to check each regulation individually, and to see how close to legal each dimension is. Once the main body of the cars are assembled, they are ready to be finished. After the finishing, our wheels are then attached to the wheel support system.

Our car, during the gluing process, placed in our mounting jig.

Finishing

To achieve a perfect skin finish to our cars, we have implemented a precise finishing process. First, our balsa body was sanded down, then spray wood primer was added. Then we repeated this process 3 times, each with more and more fine sandpaper until a smooth finish is achieved. We then added wood putty to fill any areas that did not adhere to regulations, and sanded this further. Once our car was assembled, we primed and sanded further, to ensure there were no gaps between parts, and that all parts created a smooth, cohesive skin. To paint our cars, we have collaborated with Angela Harris, from Blue Mountains Refined Finishes and Custom Shutters, a professional painter and finisher. We first painted a coat of white paint, then used tape to cover all areas but our blue gradient design. We then carefully coated the area with dark blue, then used our lighter blue to build up the gradient. Once the paint was complete, we added a coat of metallic paint that accentuates our colours and gives the livery a shiny look. To add our sponsors logos, we have used waterslide decals, which are extremely thin, yet remain bright and accurate to our render. Once all decals were applied, and the wheels are attached, our cars were ready to race!



Our car body after the first coat of primer.

PHYSICAL TESTING

Physical Testing Overview

Though theoretical CAD analysis is extremely helpful, and has a number of useful applications, it can never account for all variables in a car's performance. We have conducted physical testing throughout our design refinement process to allow us to see the performance of a physical model in real life. There are a number of types of physical testing we have utilised, such as strength testing, wind tunnel testing, and track testing, which involves racing cars down an actual track. For each major prototype change, or whenever we felt we needed to visualise a specific aspect of the car in real life, we would mill or print a whole car or single part, and test it as required. This allowed us to integrate physical testing data into our refinement process, and helped us to see where designs needed to be improved, and how our manufacturing process can be compared to our CAD models. Physical testing was an integral element of our car design process, and helped us enormously with both design, and manufacturing.

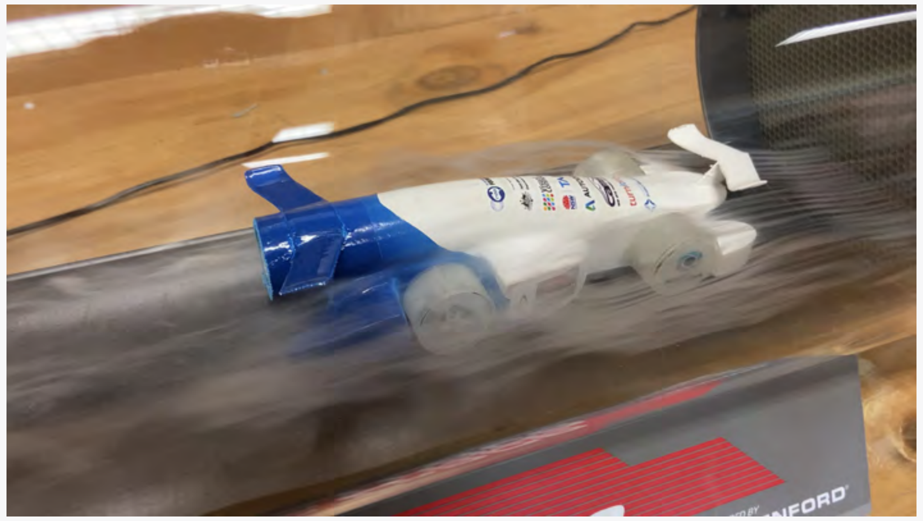
Plastic Strength Testing

Prior to 3D printing our parts, we conducted testing of 6 different types of filaments. We printed front wings for each, then analysed the strength, flexibility, cost, weight, accuracy, surface finish and print time (see below). To test the strength of each part we created our own mechanism, which, with a weight, drops the part down onto a mat, to mimic the deceleration process into the towels. We found that Polysmoothed PVB (PLA) best suited our needs, as it is strong enough, cheap and easily

Material	Mass	Surface Finish Rank	Warping	Accuracy Tolerance
PLA	4.97 G	3rd	None	0.1-0.2 MM
Tough Resin	7.16 G	1st	Noticeable	0.2-0.3 MM
Polycarbonate	4.61 G	2nd	Minimal	0.1-0.4 MM
ASA	4.58 G	4th	None	0.2-0.4 MM
Nylon	4.41 G	6th	Excessive	0.1-1 MM
Pegasus PP	2.76 G	5th	None	0-0.4 MM

Wind Tunnel Testing

We have used our school's high-quality Air Trace Visualisation System wind tunnel to see how airflow acts over our car in real life. First, we conducted some baseline, or control tests with previous F1 in Schools cars. This allowed us to see what was normal for an F1S car, and how fluids behave. We also could see pockets of turbulent airflow, usually off the rear of cars, and in the exclusion zones. This showed us what we could focus on in our designs to improve our car's aerodynamics. For some of our main versions we designed, we milled a half-and-half car, with one side as the old design, and one as the new design. This allowed us to put the model into the wind tunnel, and visualise not just the airflow over our most recent model, but also how we have improved, and where we still needed to improve. During our testing, in addition to pockets of turbulent air (mentioned previously), we noticed that our concave front air deflectors (i.e. the 'wedge' design), diverting air over the front wing were not acting as intended, and airflow was slowing down significantly, after 'hitting' the front wheel, contributing to a high pressure area in front of the car. To improve this, we designed our new front air deflectors, which divert air around the sides of the wheel, and let air flow, unimpeded over the front wheels. This not only reduced drag (CFD testing), but was clearly more efficient when seen in the wind tunnel.

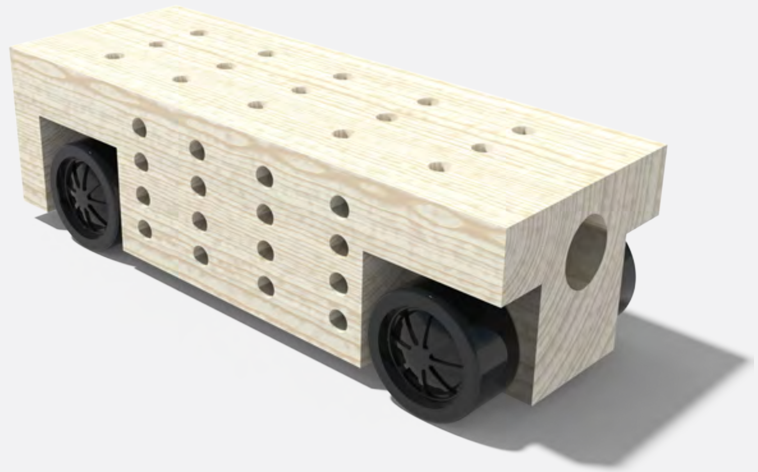


A photograph of our car during a wind tunnel test.

Track Testing

Though our school does not own an F1 in Schools track system, we had planned on milling various prototype cars, and gathering race data during a testing day at Western Sydney Uni (who own an F1 in Schools track). We had planned to test a variety of physical elements to the car, such as centre of mass relative to centre of thrust, wheelbase length, height of canister, angle of canister, and number of bearings used in the wheels. We have designed prototype cars for each of these concepts, so we can easily adjust a single element, and run as many test runs required to gain accurate and valid data. For centre of mass, we have designed a block in which large screws are placed to adjust the CoM forward, back, up or down (left and right are irrelevant, as cars are symmetrical). To test canister height and angle, we have designed a car with a custom 3D-printed canister hole, with adjustable height and angle, so various combinations can be tested. To test the wheelbase and bearings, we have designed a model that has many different axle holes in which to position the wheels, and wheel stubs that can fit up to 3 bearings. We also understand that each canister puncture can vary enormously, so to gain valid results, we planned to run each test at least 5 times. We have also researched the concept of the standard deviation model, and can plot times for every run, and see and eliminate outliers from our data, ensuring all results are completely fair. Unfortunately, our track testing day was cancelled due to a COVID-19 outbreak at our school in the leadup to the competition.

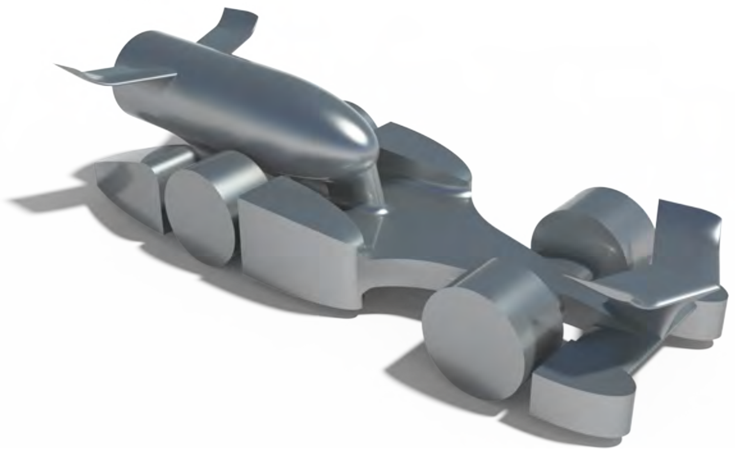
A render of our COM physical testing model.



EVALUATION

Research Evaluation

Our research and preparation process, before beginning to design our car was the first stage in our engineering process. We researched all forces that would act upon, and affect our car, including aerodynamic principles, thrust forces, rotational forces, and surface finishes. This research was extensive, and ensured that all team members could understand what was required of our car design to improve it in various ways. During this period, we also contacted mentors to assist us in our learning, such as Michael Laws and Jousef Murad, who taught us about manufacturing processes and computational data, respectively. We also conducted research into our manufacturing processes, and how we could manufacture our parts, as well as the requirements for each part. This allowed us to view a range of material and machinery options for various parts, and evaluate the effectiveness of each one in helping us create a lightweight, accurate and strong car. We decided to utilise Polysmoothed PVB for our printed parts, and to use an extensive sanding and priming process, in which we use wood putty, spray primer, various grits of sandpaper, and a glossy finish of paint to allow as smooth a finish as possible. Our research phase was extremely valuable to the development of our car, and our learning, and we believe the research we conducted allowed us to design and manufacture a fast F1 in Schools car. In preparation for the National Finals, we would have more time to work, allowing us to research more in-depth into these topics and processes, and refine and build on the knowledge we have gained.



A potential innovative design philosophy that we plan to develop further if we progress to the national finals, further research, testing, and analysis.

Design Process Evaluation

The design of our car is a critical element in it's race performance, and as such, we spent a lot of time and effort in our design process, to perfect our final car. We decided to use a structured testing process, testing individual elements against a control version, then combining these into various versions, from which we refined further. We believe that this process has worked extremely well, as we learnt what design elements work, could experiment and adjust extensively, and we have tested every single element of our car's performance, ensuring we are extremely confident in the design of our car. This process was based around our CFD testing, conducted using Simscale, but in the prototype testing and refinement phase, we integrated physical testing analysis from our wind tunnel, to improve specific areas of airflow. We also used a similar process for the design of our wheels. We first designed initial prototypes, each utilising a different concept, such as independent wheels, wheels joined by an axle, magnetic technology and integrated hubcaps. We analysed their weight, strength, cost and effectiveness, then selected the best prototype for our needs. We then refined it using FEA data, adjusting the design to minimize weight and maximise strength. In future, we will spend even more time developing our wheel design, as it is a critical component of the car, and look into some more innovative concepts for our wheel design and manufacturing. Overall, we believe our structured design process for both the car design and our wheels was extremely effective, and allowed us to conduct in-depth testing into all design elements, and integrate data from physical and CAD-based testing. If we progress to the National Finals, we will further refine our current design, and test a variety of new design ideas. We will also fully develop our LEDC system (see page 2, Innovation), which unfortunatly could not be realised due to time constraints.

Manufacturing Evaluation

The manufacturing of our car is the most important stage in ensuring our car is as fast as possible, so we tried to perfect the manufacturing of our cars. We conducted research into many innovative concepts, some of which we have used to manufacture our car, some of which we would love to look into further and work with in the future. The milling of our cars worked extremely well, and the custom jigs we designed worked perfectly to keep the block still and accurately positioned. Our 3D printed parts also worked well, and Polysmoothing was extremely successful. Our assembly jig also worked extremely well, and reduced assembly times and inacuraccies immensely, though we would have liked to have spent more time on puttying our final model to fill in minor gaps between parts. We spent extensive time on our finishing process, and this has been justified, as our livery and surface finish are extremely high-quality. We conducted research into materials for wheels, such as nylon, acrylic, teflon, PTFE or PEEK, and planned to lathe our wheel parts on a high-quality machine. Unfortunately this plan did not materialise, as companies were busy and did not reply, could not manufacture our wheels, or had too short a timeframe. Our backup plan was to utilise 3D printing to create our wheels, as this is easy and quick, and can be calibrated to maximum accuracy for our wheels, ensuring concentricity. In future, we would line up the manufacturing of our wheels far earlier, to ensure that we can create the best wheels possible. Our manufacturing process has been a success, and in future we would love to continue to innovate and excel.

PHOTONIC

TESTING DATA

Photonic Design Process Chart

Iteration	Design Feature	Design Requirements	Regulations	Sub-Iteration	Design Features	Drag	Lift	Feature Evaluation	Overall Evaluation
PDCR 1	Main body loft shape	1. Minimise frontal area 2. Promote laminar air over and around canister 3. Minimise low pressure zone at rear	All	PDCR 1.0	Convex loft, flat	0.317	-0.221	Manufacturable, legal, low drag Will be considered for prototypes	All body lofts are good options and will be considered for prototype testing. All further feature testing will be completed using PDCR 1.2, as it was narrowly the best.
				PDCR 1.1	Pointed loft	0.297	-0.266	Manufacturable, legal, low drag Will be considered for prototypes	
				PDCR 1.2	Concave to convex loft, flat	0.271	-0.005	Manufacturable, legal, low drag Will be considered for prototypes	
PDCR 2	Sidepod length in side view	1. Promote laminar flow around and over rear wheels 2. Optimise airflow angle for sidepods	T 4 all T 7.9	PDCR 2.0	Long sidepods	0.269	-0.002	Manufacturable, legal, high drag Not considered for prototypes	A short to medium length sidepod reduces drag, medium length sidepods will be used for further testing. Refinement and optimisation to be tested on prototypes.
				PDCR 2.1	Medium length sidepods	0.25	-0.097	Manufacturable, legal, low drag Will be considered for prototypes	
				PDCR 2.2	Short sidepods	0.266	-0.021	Manufacturable, legal, low drag Will be considered for prototypes	
PDCR 3	Sidepod shape in top view	1. Promote laminar flow around and over rear wheels 2. Minimal weight	T 4 all T 7.9	PDCR 3.0	Concave sidepod, tangent to edge of wheel	0.254	-0.108	Manufacturable, legal, high drag May be considered for prototypes	Both PDCR 3.0 and PDCR 3.2 are very similar, both sidepod features will be considered for future prototypes.
				PDCR 3.1	Convex sidepod, flush with car body	0.309	0.025	Manufacturable, legal, high drag Not considered for prototypes	
				PDCR 3.2	Convex to concave sidepod, incorporating both aspects	0.253	-0.008	Manufacturable, legal, low drag Will be considered for prototypes	
PDCR 4	Wall features behind front wheels	1. Minimise low pressure zone behind sidepods 2. Minimise turbulent air behind sidepods 3. Maintain underbody air pressure	T 3.9.2 T 4.4 T 4.6 T 7.9 T 8.1	PDCR 4.0	No gaps in wall	0.251	-0.006	Manufacturable, legal, low drag Will be considered for prototypes	PDCR 3.0 is clearly the best design option for wall features, closed walls will be used in future prototypes, except in special circumstances.
				PDCR 4.1	Wall direction adjusted to provide air outlet to LPZ	0.278	-0.178	Weak design, legal, high drag Not considered for prototypes	
				PDCR 4.2	Wall gaps added to provide air inlet to underbody	0.282	-0.152	Weak design, legal, high drag Not considered for prototypes	
PDCR 5	Front wing styles	1. Promote laminar flow over and around rear wheels 2. Minimise weight	T 3.2 T 5 all T 6 all T 7.5 T 7.8 T 7.9	PDCR 5.0	Concave wings, 'scooping' air over wheels	0.247	-0.002	Manufacturable, legal, med drag May be considered for prototypes	A variety of different front wing options have low drag, and will be considered for prototypes. PDCR 5.4 will be used in testing, and refined/merged with PDCR 5.3 for prototypes.
				PDCR 5.1	Air compression boxes, releasing air upward	0.279	-0.03	Manufacturable, legal, high drag Not considered for prototypes	
				PDCR 5.2	Convex front wings, breaking airflow	0.241	-0.038	Manufacturable, legal, low drag Will be considered for prototypes	
				PDCR 5.3	Convex front wings, also directing air around wheels	0.25	0.052	Manufacturable, legal, high drag May be considered for prototypes	
				PDCR 5.4	Convex front wings, only directing air around wheels	0.236	0.04	Manufacturable, legal, low drag Will be considered for prototypes	
				PDCR 5.5	Thin aerofoil wing, breaking air before wheels	0.248	-0.08	Weak design, legal, med drag Not considered for prototypes	
				PDCR 5.6	Raised front wing, no effect on wheels	0.279	0.158	Manufacturable, legal, high drag Not considered for prototypes	
PDCR 6	Back pod styles	1. Fill the low pressure zone behind wheels 2. Minimise air turbulence at rear of car 3. Minimise weight	T 7.9	PDCR 6.0	Loft tangent to wheel, to a vertical line	0.236	0.075	Manufacturable, legal, low drag Will be considered for prototypes	PDCR 6.0 and 6.1 are very similar styles, loft to a line back pods will be used in future prototypes. Angle and tangency optimisation testing to occur.
				PDCR 6.1	Similar to PDCR 6.1, with a longer line	0.249	0.242	Manufacturable, legal, low drag Will be considered for prototypes	
				PDCR 6.2	Loft upward from bottom of wheels, flat top	0.261	0.145	Manufacturable, legal, high drag Not considered for prototypes	
				PDCR 6.3	Loft to a line, flat top	0.284	0.424	Manufacturable, legal, high drag Not considered for prototypes	
				PDCR 6.4	No back pods	0.272	0.273	Manufacturable, legal, high drag Not considered for prototypes	
PDCR 7	Back pod lengths in side view	1. Fill the low pressure zone behind wheels 2. Minimise air turbulence at rear of car 3. Minimise weight	T 7.9	PDCR 7.0	Medium length backpods	0.238	0.085	Manufacturable, legal, low drag Will be considered for prototypes	Medium length backpods achieve minimum drag, will be used for future testing and prototypes.
				PDCR 7.1	Short length backpods	0.264	0.294	Manufacturable, legal, high drag Not considered for prototypes	
				PDCR 7.2	Long length backpods	0.34	-0.073	Manufacturable, legal, high drag Not considered for prototypes	

Above: The testing spreadsheet we used to record data for our prototype design development

Note: data only shown up to iteration 7, data from then onward could not fit on page.