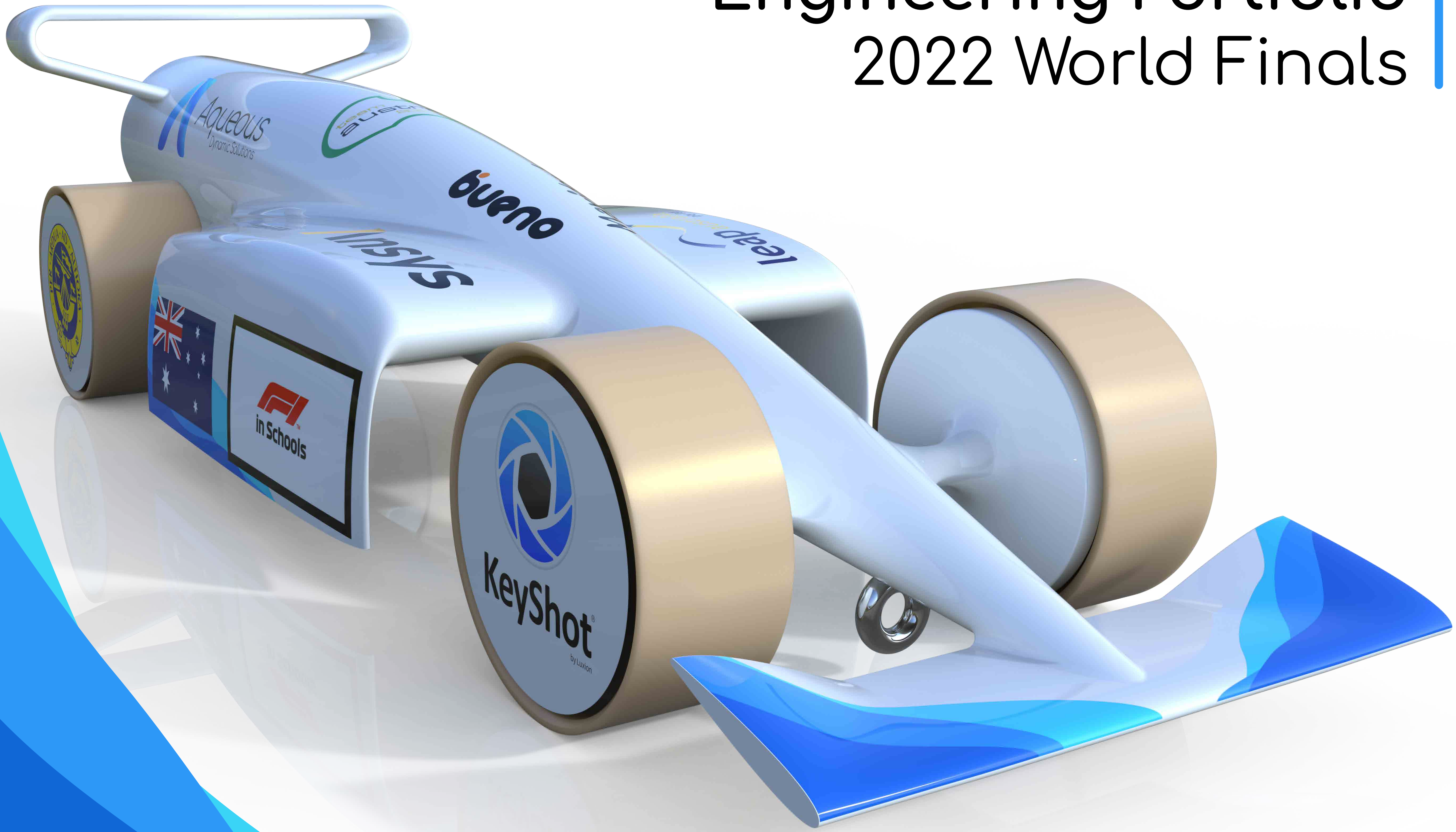
Engineering Portfolio
2022 World Finals



Aqueous
Dynamic Solutions

RE-ENGINEERING AUSTRALIA FOUNDATION
leap australia pty ltd
Ansys
bueno
LEK
Maxident
OBJECTIVE 3D DIRECT MANUFACTURING
KLAUSEN
morgans
CAPRAL ALUMINIUM
goodcitizens®
KeyShot

Research & Development

Research & Development Cycle

1 - Requirements Analysis & Research

Understand R&D factors and requirements of an F1 in Schools car. Use the strengths and weaknesses of previous cars to formulate plans compliant with the goals of the team. Undertake comprehensive research on key design features and principles, then produce research reports on how this applies to components.

2 - Planning

Validate ideas with the engineering team and produce projected budgets and flowcharts to confirm practicality.

3 - Parameters Testing

Where possible, use various forms of testing to collate data about pivotal factors on a car's time (e.g. finding the optimal wheelbase with a physical testing rig). Collate this data in a document, building requirements for all CAD models.

4 - CAD & Scrutineering

Make CAD models for all concepts (individual components and assembly) then verify their compliance with the technical regulations and predicted manufacturability.

5 - Validation, Virtual Testing & Documentation

Use physical testing to validate the virtual testing processes. Test car in virtual testing (CFD, FEA, etc.) and collate all quantitative data in a testing document. Collate qualitative data (e.g. airflow trace/pressure diagrams) in a folder for later reference. This should follow the planned 3 stages; design philosophy, ideas and refinement to reach the ultimate design freeze.

6 - Analysis & Implementation

Based on the data, plan for further changes to CAD. Design and test wheel system to chassis design and optimal centre of mass.

7 - External Design Review

Review design validity with external sources; mentors, supporters, etc. and manufacture cars to shine a light on any issues e.g. problems with manufacturability or structural issues.

Process Evaluation

This allowed for iterative/incremental comparison and refinement in measured stages. When progressing through design development a defined R&D process was aligned to certain deadlines outlined in our project management portfolio.

Previous Design Analysis & Comparison

PerPetrol PNR 5.1.5

PNR 5.1.5, Perpetrol's National finals car, had a Grand Prix time of 7.897 s and a fastest lap of 1.259 seconds. It violated one critical regulation due to a manufacturing defect, yet the car was compliant with the regs thanks to tolerances in CAD. The cars' average mass was 50.37 grams. In development class, Perpetrol focused on aerodynamics, reducing their drag to the value of 0.22694 newtons. Perpetrol's most significant aero innovation was their method of legally milling top-down while still being compliant with the development class technical specifications, opening them up to the avenue of an enclosed central channel. An improvement to PNR 5.1.5 would be the consideration of non-aero factors e.g. COM.

Aeolus Mercury 3.2

Aeolus Racing's National finals car was Mercury 3.2, with a Grand Prix time of 7.827 seconds and a fastest lap of 1.265 seconds. No critical regulations were violated, with a 69/80 compliance score caused by a manufacturing error. The cars' average mass was 50.76 grams. In development class, Aeolus Racing's design philosophy focused on testing multiple design ideas (less so on refinement), utilising physical testing to develop innovations. The car's drag force, under equal CFD conditions, was 0.372 N. Mercury 3.2 focused on stability rather than aerodynamics, achieving this with a long wheelbase of 134 mm. Improvement for this car would be the manufacturability and depth of understanding surrounding the factors influencing the car's performance (e.g. centre of mass and wheel system).

Photonic Racing PDCN 32.0

Our Brand Coordinator was previously the Design Engineer for Photonic at the National finals, and had a cumulative Grand Prix time of 8.460 seconds and a fastest lap of 1.288 seconds. The final two cars had an average mass of 51.72 grams. Under professional class regulations, Photonic's design philosophy explored innovation and iterative aerodynamic improvement (similar to PerPetrol). The car's drag force, under equal CFD conditions, was 0.152N. PDCN 32.0 had many drastic innovations, finding many loopholes in the Australian Technical Specifications. The first was ALES (Aerodynamic and Launch Enhancement System), a rear wing support system, which was a 3D printed attachment on the rear of the CO2 chamber. Its purpose was to decrease wake off the car's trailing edge, recovering lost energy from the canister at launch. Photonic purposefully broke a non-critical regulation, extending the sidepod front as an attachment to their front wheel tether guide and wheel support system, drastically decreasing drag.

Figure 1 - A set of renders of final car designs from our previous teams. (source: PerPetrol, Aeolus, Photonic)

Evaluation

Feedback given to all of the previous cars was the consideration of non-aerodynamic factors. This focus and comparison of different design avenues was a point of difference when optimising our car. After evaluating the importance of different factors, we were able to draw from previous research, particularly the reduction of aerodynamic forces. Continuing from three teams with successful aero-centric cars, we opted for 'mechanical' research, initiating new testing on manufacturability, stability, the centre of mass and the centre of thrust. Firstly, these factors were found to be most influential on speed and secondly, effective design solutions could be created from previous aerodynamics testing, limiting the digital analysis to a combination between these and our mechanical parameters.

Research & Development

Research

Pressure drag

Drag is an aerodynamic effect that opposes our car's motion. There are two primary components of drag, pressure drag and skin friction drag. Pressure drag is an effect created when there is high pressure at the front of an object and low pressure at the rear. As an object moves through a fluid medium, fast moving air accumulates at the front of the object creating high pressure, whilst low pressure accumulates at the rear of the object. This variation in pressure provides resistance to the object's motion slowing it down. A design challenge for a car is to minimise drag. Minimising drag will minimise the resistance of the car as it races. We can not entirely eliminate pressure drag. However, we can reduce it through the design of the car. Minimising the frontal area minimises the amount of high pressure at the front of the car. The shape of the car can also be designed to minimise the collection of low pressure air at the rear of the car.

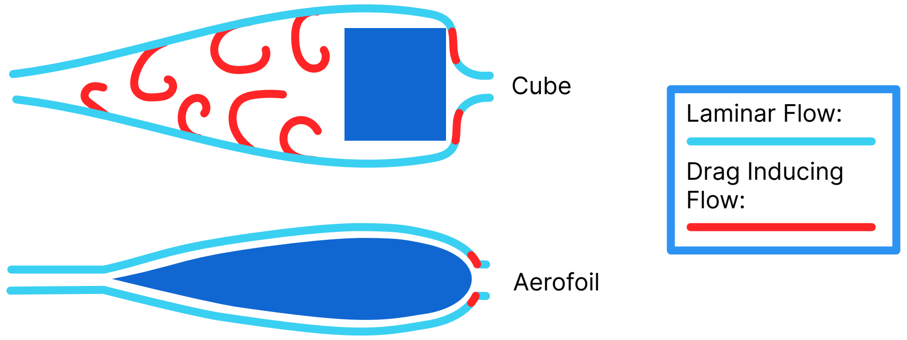


Figure 2 - An illustration of pressure drag (source: team files)

Downforce and Lift

Downforce and lift are vertical forces that act on an object as it passes through a fluid medium. Downforce is the force that pushes down on the object and lift is the force that pulls up on the object. Much like drag, an imbalance in pressure across the car creates this aerodynamic effect. In our car's design, we wanted lift and downforce to be as minimal as possible. Having neutral downforce would minimise friction on areas of the car such as the wheels and tether line guides. However, it is also important to have some level of downforce as this will improve the stability of our car.

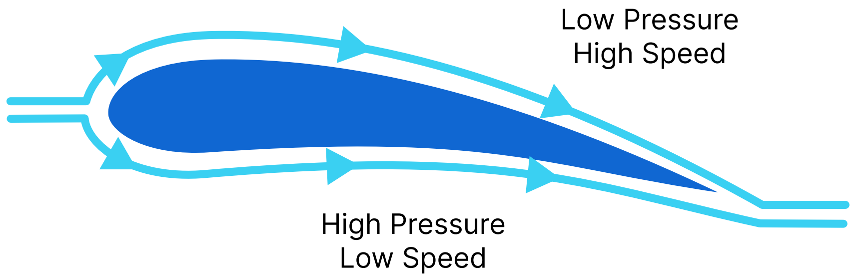


Figure 3 - An illustration of lift (source: team files)

Thrust Efficiency & Stability

Our research indicates the F1 in Schools canister will produce at most 18 N of thrust. In a utopia, all of this would be converted to motion pushing the car forward. To allow for this possibility, the Centre of Mass (COM) of the car would have to be directly in front of the Centre of Thrust (COT).

Due to regulatory limitations, the COM will always be lower than the COT, this induces a pitch moment around the COM that forces the nose cone downwards. Some of the thrust force is transferred into a moment, the resultant thrust force which pushes the car forward will be less, and the car's thrust will be less efficient. The efficiency of the thrust conversion to forwarding motion largely impacts speed, seeing as any drag or rolling resistance forces will usually be less than 2% of the maximum thrust force.

We can only maximise thrust efficiency by manipulating the COM and resultantly reducing the pitch moment. The pitch moment's impacts on stability must also be considered. There are many uncontrollable factors,e.g. launch and track surface anomalies, that affect the stability of the car throughout its race. Observing an F1 in Schools car race can reveal these variables, usually indicated by an indirect racing line and a loss in acceleration and general forward motion.

The manipulation of controlled downforce can reduce this issue, although too much downforce applies unnecessary pressure on the wheels. Development of the COM and downforce (only relevant in the first 0.4-0.5 seconds of the race) can help improve stability and thrust efficiency.

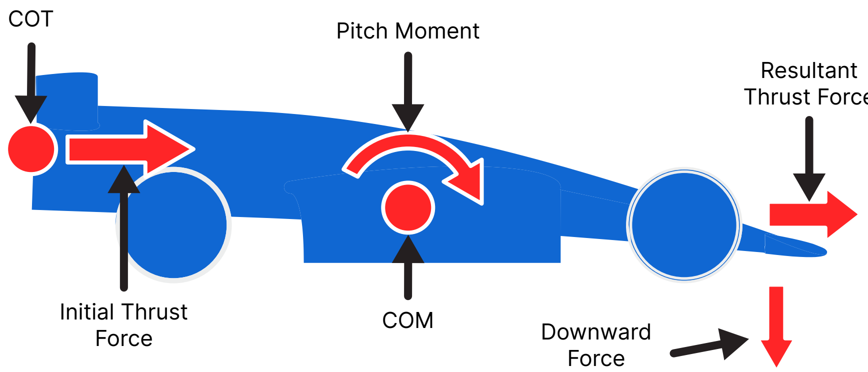


Figure 4 - An illustration of COM/COT effects (source: team files)

Skin Friction Drag

Skin friction drag is resistance created as air particles slide across an object's surface and become turbulent as they meet small inconsistencies in the surface finish. The smoother an object's surface the less skin friction drag is created. Knowing this information we made sure to prioritise a well manufactured car with incredible surface finish, that not only looks good but races well.

R&D Factors

Aerodynamics

How reduction to drag, lift and lateral forces influences speed. Improvements to aerodynamics can come from understanding a model's solution fields, produced with digital simulation (CFD) and physical testing (wind tunnel).

Stability

How the mass of the car is distributed across its contact points and around its centre of mass affect its balance and ability absorb the effects of turning moments, especially those created during the launch.

Manufacturing Quality

How the quality of the car's surface finish creates skin induced drag and affects the overall aerodynamic package along with the velocity profile. Additionally how a slightly asymmetric vehicle across its longitudinal axis, due to manufacturing errors, will decrease performance.

Friction

How friction across all contact surfaces reduces rotational velocity and in turn how that affects the overall car performance. This includes both the interaction between the wheels and the track, the bearings and even the tether line and tether guides.

Objectives

Our approach to designing our cars was to consider every aspect of it, leaving no stone unturned. We considered all avenues to solve design solutions, considering the small scale of individual components, but more importantly, the entire philosophy of designing a car, understanding the effect that every factor had on speed.

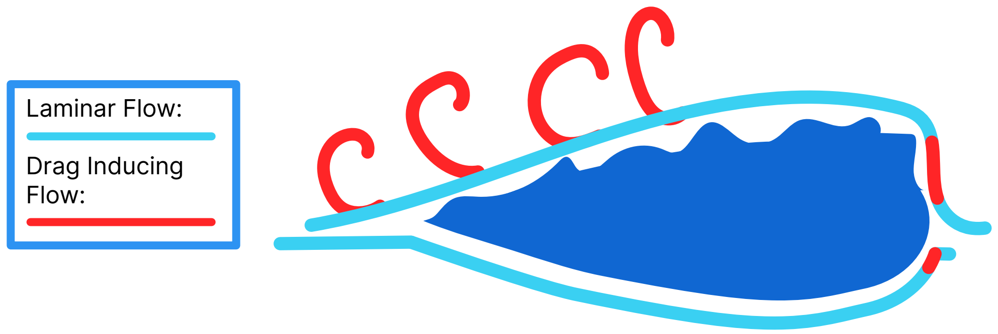


Figure 5 - An illustration of skin friction drag (source: team files)

Testing

Virtual Testing

CFD Overview

Our CFD (computational fluid dynamics) software ANSYS (provided by our sponsor, Leap Australia) had two forms of flow simulation, GPU and CPU. GPU was the fastest process, taking up to 5 minutes per simulation. CPU was far longer, often taking close to an hour. Both offered similar visualisation tools of factors such as pressure and airflow traces. We tested various designs from our respective National Finals teams, of which we iteratively developed. Analysing the similarities of physical testing data to the two different forms of CFD it was found that CPU was far more accurate, leading us to apply this process for design decisions. Data produced by CFD is quantitative, in the form of drag, lift and lateral forces and qualitative, in the form of solution fields. The aim was to most accurately replicate the situation of the car when racing in reality. As we couldn't simulate the car moving forward across a stationary plane, we instead simulated the wheels rotating at 1500 rad/s. Due to the Magnus effect, wheel spin has significant impacts on downstream aerodynamics, supported by our comparative testing of CFD setups. During our tests, we used an air velocity of 20 m/s, allowing for simpler calculations.

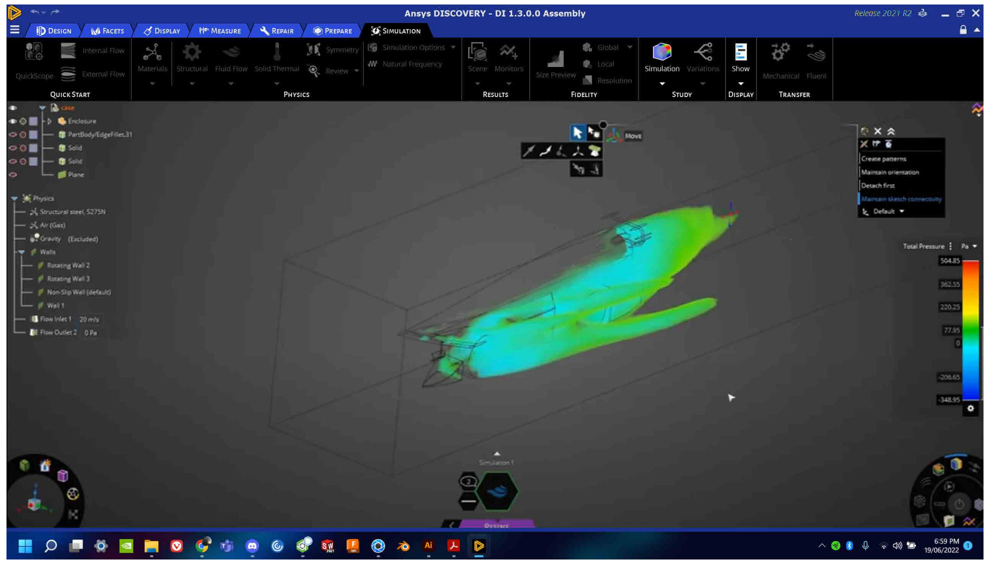


Figure 6 - A screenshot of one of our Ansys CFD simulations (source: team files)

FEA Overview

Our finite element analysis (FEA) software was ANSYS, provided by Leap Australia, allowing us to analyse a model's strength. This allowed us to isolate points of weakness and strengthen them. FEA testing occurred in two ways, testing the car's assembly to interpret weakness in joints, and testing individual components to interpret weakness on a smaller scale. Most data produced by FEA was qualitative, where we varied the stress applied to a digital model and interpreted the solution fields.

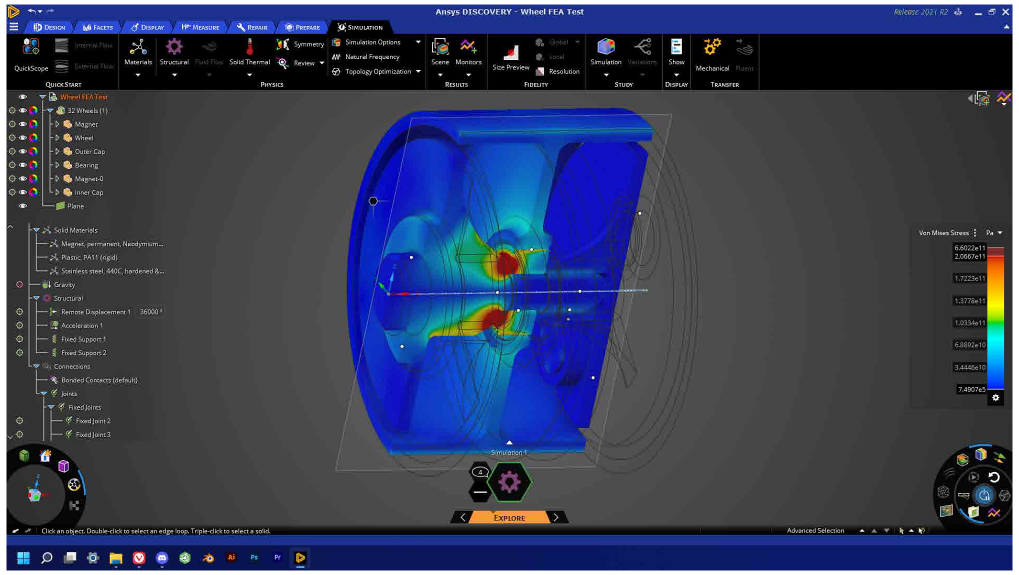


Figure 7 - A screenshot of a structural simulation of our wheels (source: team files)

Physical Testing

Wheelbase

The wheelbase (distance between the centrelines of the axles) of the car is vital to improve the stability of the car. To optimise the wheelbase, we used a wheelbase testing rig. This rig was a 3d printed car, which made use of slots to move a consistent wheel system from a range of 150 mm to 100 mm wheelbases (10mm increments). When completing this testing, it was important to keep the conditions as similar as possible to the race. For this reason, the car had a mass of 50 g. The total car length was also 209 mm, as well as a consistent lateral distance between wheels.

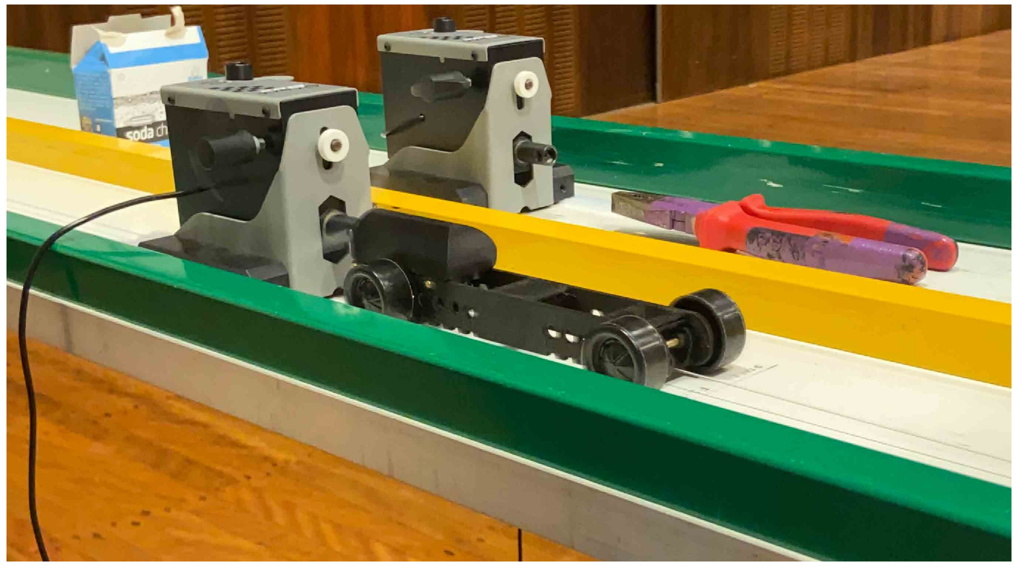


Figure 8 - Our wheelbase testing rig on track (source: team files)

Method

Once the testing rig had been assembled, testing was completed by changing the position of the wheels from slots 1-6, for both the back and front wheels. The times were then recorded by the regular timing gates. This was repeated 10 times per wheelbase in order to decrease the impact of puncture variation. The wheel system was replaced after each wheelbase variation, to increase accuracy.

Results

After completing testing, we found that a 130mm wheelbase (position B3F6) was the most effective, recording an average of 1.707 seconds.

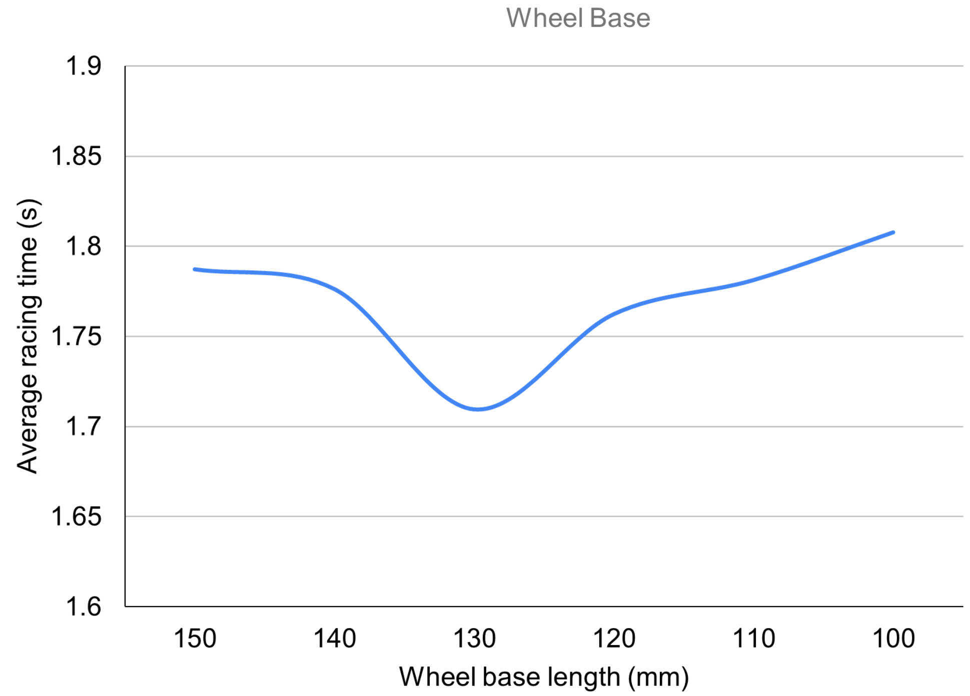


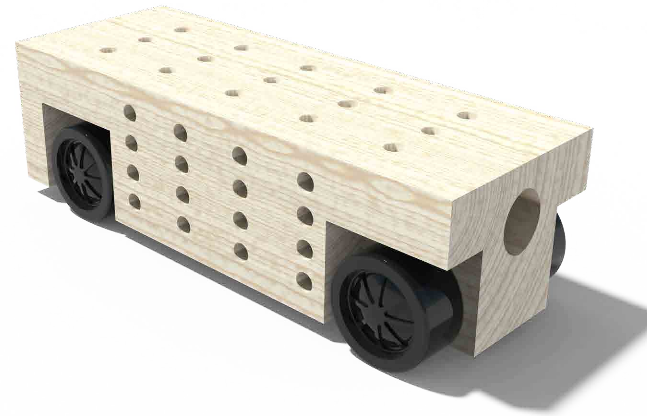
Figure 9 - A graph detailing the trend from our wheelbase testing (source: team files)

Centre of Mass

The centre of mass affects car stability greatly. On launch, the car will be pushed forward in the direction of its centre of thrust but will pivot around the centre of mass. The Centre of mass can be manipulated with variance to the positioning and size of components as well as the density of materials used. Our testing rig was made from a balsa block, where holes were drilled in an array. 3D printed caps locked onto the end of each, housing a drill bit that was moved to manipulate weight. A development class wheel system was used, as it could be controlled between tests. To most closely replicate a race, our optimal wheelbase of B3F6 was used and the rig's total length was 209 mm. Unfortunately, the mass could not be controlled at 50 g due to the density of balsa as a material, but the mass was equal for every test.

Testing

Figure 10 - Our centre of mass testing rig (source: team files)



Method

Once the testing rig had been assembled, testing was completed by changing the position of the drill bit between the rig's holes. The times were then recorded by the regular timing gates. This was repeated 5 times per COM in order to decrease the impact of puncture variation. The wheel system was replaced after each variation had been tested.

Results

Our data reflected the optimal centre of mass was approximately from the leading edge of the car, in line with the COT, with an average lap time of 1.681 seconds.

Canister Angle

The canister angle at launch (specifically, the chamber) alters the centre of thrust directly, as there is only one point generating force. Manipulating the centre of thrust in regards to the car's centre of mass (COM) affects its tipping point. Our testing rig had 7 different options for variation, one at each increment above and below a neutral chamber. These fell within regulation T5.4 outlining an allowance for 3 degrees above and below. Similarly to the wheelbase rig, this model was 3D printed to replicate a real race.

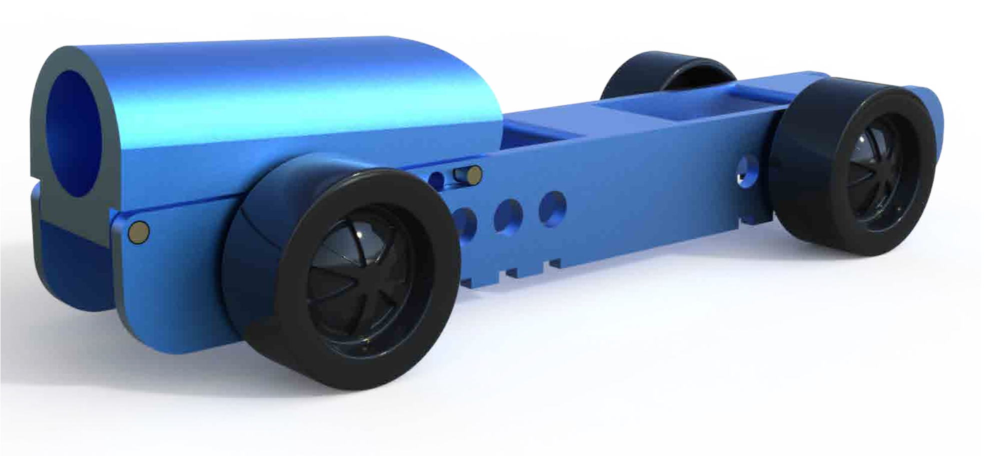


Figure 11 - A render of our canister angle testing rig (source: team files)

Method

Once the testing rig was assembled, testing was conducted by changing the separately printed canister chamber's angle, with the times recorded by the timing gates. This was repeated 10 times per angle to decrease the puncture variation's impacts. Wheel systems were replaced after each variation was tested.

Results

Data showed a 2-degree angle downwards was the most efficient, recording an average lap time of 1.664 seconds.

Bearing Testing

We aimed to find the optimal bearing type for our wheel system, comparing hybrid ceramic and stainless steel. Minimising friction in our wheel system is vital to the car's performance. Full ceramic bearings were considered. But later ruled out for strength and cost issues.

Method

Bearings were fitted to a jig, spun using a dremel at 12,000 rpm and left to spin after 10 seconds. The time taken for the bearing to stop was recorded. This was repeated 5 times for both bearings.

Results

Hybrid ceramic bearings were more efficient, with an average spin time of 20.5 compared to 11.9 seconds with the stainless steel bearings.

Figure 12 - Our hybrid ceramic bearings (left) and steel bearings (right) (source: team files)

Design Philosophy Comparison

Many different factors affect the car's performance, the main 'mutually exclusive' distinction being aerodynamic and non-aerodynamic optimisation. The former made us of mass amounts of iterative CFD to minimise aerodynamic forces (drag, lift and lateral force). The latter values optimising the wheelbase, centre of mass, manufacturability and wheel system. Both of these were considered when making design adjustments, but it was important to understand which had a greater influence on a car's performance. To understand which approach was better, we produced two cars, one with the intent to minimise aerodynamic forces and the other designed directly to the parameters set by our previous physical testing results and to the highest ease of manufacturing.

Method

Once the first car (aerodynamic focus) was manufactured, it was tested 15 times, times being recorded after each test. This process was repeated with the second car (mechanical focus).

Results

Our testing reflected the mechanically focussed car performed better than the aerodynamics focussed car. The two had average lap times of 1.238 and 1.364 respectively.

Aerodynamic Focused Philosophy

Non-Aerodynamic Philosophy

3D Modeling

Process Overview

We split our car design process into four main stages. The first was design concepts, where we reflected upon previous findings. The second was design philosophy analysis, where we compared broad concepts which would influence the design (e.g. consideration and weighting of different factors on design decisions). The third was design ideas, where we iteratively tested design concepts for individual components and parts (e.g. sidepod, rear pod, front wing). In this stage we tested concepts, moving backward on the car (testing front wing before sidepod variations) this was because we had to control the downstream impacts of design features. The last stage was refinement, where we made small adjustments. In this stage, minor changes to reduce aerodynamic forces were made using variable based CAD. Changes were also made to improve manufacturability concerns in this stage.

CAD Software Evaluation

We deliberated between a variety of CAD software options. These included Autodesk Inventor, Onshape, Catia, and Solidworks. After testing these options, we found the design capabilities and usability of all these software were comparable. Collaboration was the unique factor in choosing Onshape. As a collaboration team, comprising three primary engineers, the most influential factor affecting the quality of our product was the efficiency, as we could iteratively design and test prototypes from separate devices. By having an online collaborative CAD program, we could organise and collaboratively work on the same model, removing the need to share files.

CAD Organisation

All models for the Aqueous car design development were on one single document, separated into part studios and assemblies in branches of folders. The first was the design stage, the second the component being varied, and the last the variation number. The naming convention consistently used throughout the design development followed this, an example being DI 1.2.3.4.

Compliance and Planning Sketches

We created a base sketch on all planes for each design. These sketches defined key dimensions which referred to each regulation, allowing us to effectively integrate tolerances. A base, or planning sketch, ensured a car model's compliance, as most geometry was created from shapes and visual indicators. Shapes of specifications, like key exclusion zones, were outlined on these sketches, to have a visual indication of its compliance with these specific regulations. By continuously developing one prototype, we could alter these shapes' measurements or positioning, altering the geometry in a manner which was controlled, thus remaining within the technical regulations' bounds.

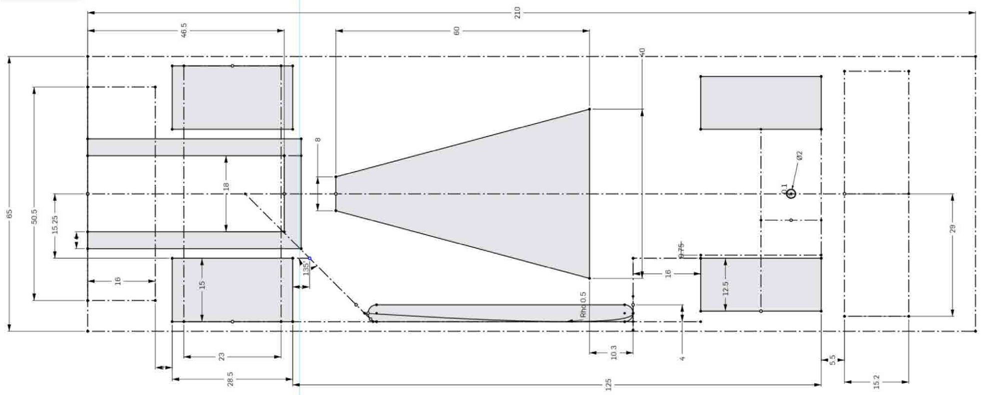


Figure 13 - Top car planning sketch (source: team files)

Modelling Techniques

Loft & Sweep

Lofts and sweeps permitted us to make complex and controlled geometries within our CAD design process. To optimise the car under aerodynamic and manufacturing considerations, curved components following a path were necessary. An example of this was the design of the sidepod, which connected two faces with a guide rail. These rails also allowed us to house important regulations, in particular the virtual cargo.

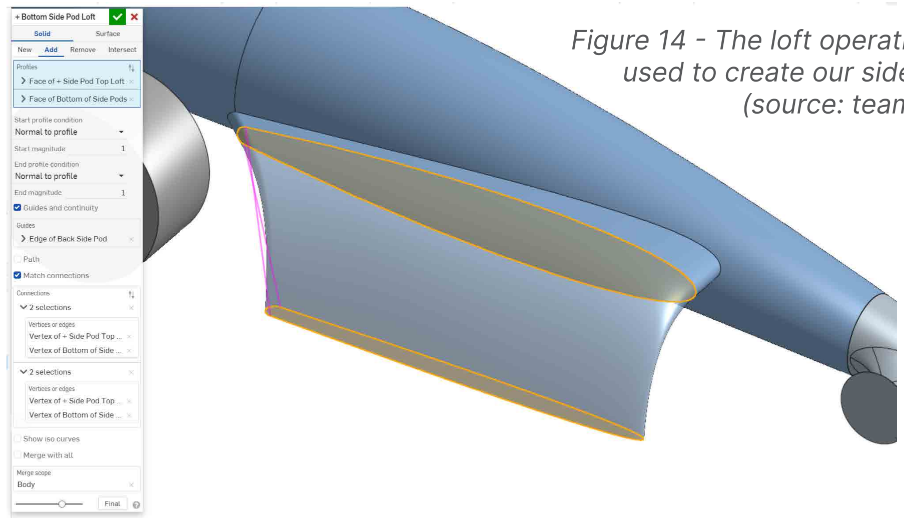


Figure 14 - The loft operation we used to create our side pods (source: team files)

Sweeps start at a single face and extend across a path. These were useful when we needed to create complex forms while maintaining a certain thickness. For example, the shape of our front wings was made with a sweep as it controlled its thickness and chord length across the curved span in order to ensure compliance with article T9.5.

Generative Design & Topological Optimisation

Generative Design and Topological Optimisation surround a similar purpose. They both produce a geometry with minimal mass for a given maximum stress to withstand.

Accounting for our design philosophy, Topological Optimisation and Generative design wasn't necessary on external components, meaning mass reduction processes were necessary only in the wheel hub development, as it was important to maintain low rotational mass. We experimented with these processes in components, such as the front wing support structure, to manipulate the COM, but aerodynamic impacts to lap time outweighed any benefit to the COM.

Variable Based CAD

Variable Based CAD is a feature of Onshape used predominantly in our refinement stage of development. It allowed us to isolate dimensions on sketches and parts and alter them seamlessly, without delving into sketches to change the model. Before modelling the car, we created a list of all possible variables associated with the design, both regulatory and non-regulatory, and then implemented these into sketches. By adjusting these variables, we could test the impact of these small alterations and make changes to comply with regulations without affecting the operations of the CAD. This also allowed us to easily add, update, and manage manufacturing tolerances as we progressed with our materials manufacturing testing and processes.

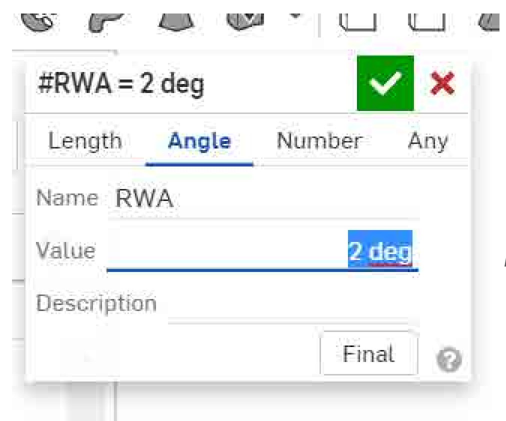


Figure 15 - (left) An excerpt from our variables list (source: team files)

Figure 16 - (right) An example variable parameter, Rear Wing Angle: RWA (source: team files)

Manufacturing Considerations

The manufacturing consideration in our 3D modelling process focussed on the following areas: the ease and quality of manufacturing, compliance with the technical specifications, consideration of the manufacturing process and material limitations. To account for the quality and ease of manufacture, we created assembly jigs and used female and male joins in the intersection between parts. When considering our car's compliance, we identified and applied minimum tolerances based on each part's manufacturing process. Foam parts had a larger tolerance of 1 mm to account for sanding and finishing a soft material, plus a fillet radius to account for the nature of the milling process. Our SLS Nylon and SLA PEEK parts had lower tolerances of 0.5 and 0.25 mm respectively, as these additive processes are more accurate and require much less finishing.

Design

Generative Design & Topological Optimisation

We attempted to manufacture a few different wheel models applying either Topological Optimisation or Generative Design, finding that the finishing processes required on an SLA or SLS wheel hub could not be applied to this wheel model. This led us to the decision that a simpler geometry was required to accommodate our manufacturing constraints.

Wheel Structure

When we entered our wheel development process we understood there is some room for variation in the wheel structure. We outlined the key objective to be a low friction wheel with minimal rotational mass. It also needed to comply with our parameters surrounding strength and COM and have a high level of manufacturability.

We produced two key design solutions, both with areas for variation e.g. number of bearings, internal geometry, weight saving measures etc.
The first of these solutions was one developed by one of our predecessors, Photonic, with success. It involved three key parts, a wheel hub that joined the bearing to an outer rim, an internal wheel cap connecting an axle to the car body and an outer cap that locked onto this axle. The team also produced a magnetic component to the outer wheel cap to improve ease and quality of alignment, but further evaluation for worlds found it more harmful than beneficial (COM and COT). The model has a low rotational mass, with a strong composition yet difficult assembly process.

The second design solution is one explored by another one of our predecessors, Paradoxum. It involves just two interlocking parts, connecting an outer wheel hub to bearings at the outer and innermost widths. The wheel hub acts as the outer face, joining to an axle. This wheel system is more manufacturable and cheaper to produce, yet has a higher rotational mass. It also doesn't have the freedom to alter internal geometry (mass saving) as the bearing connection isn't enclosed.

This led us to continue wheel development with design solution 1, of course, adapting it to connect with our final car chassis.

Bearing Configuration

With the significant value to our car's COM, we looked for ways to move the COM further forward on the car. One way we did this was by housing two bearings in each front wheel compared to one in each rear wheel. With a COT angled down toward the nose cone, we also understood an increase in stability in our front wheels would be beneficial to imbalance at launch.

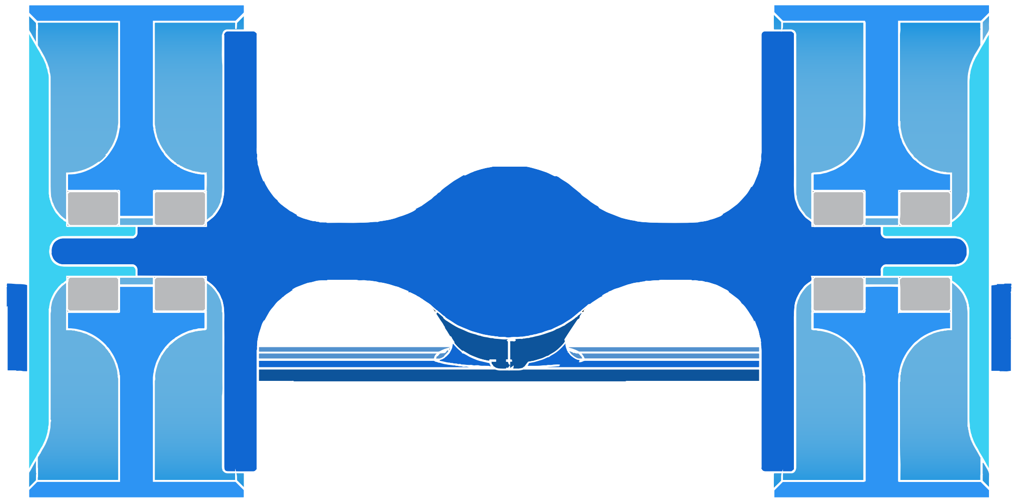


Figure 17 - A cross section of our front wheel system (source: team files)

Honeycomb Model

Biomimicry is the form of bioinspired design which we used, applying the functions of forms in nature. Alternatives that were less effective in an F1 in Schools project were biomorphism and bioutilisation. For example, the kingfisher dives into water at high speeds, its beak penetrating the water's surface with little splash and resistance - thus proving its efficiency in both aerodynamics and hydrodynamics. This form has been applied in the shinkansen - a Japanese bullet train with the capability of travelling at 320 km/h. Said design change reduced air resistance by 30% and increased speed by 10% (according to GTAC). To minimise rotational mass in our wheel hubs we applied the strength to weight ratios of the honeycomb structure found in beehives. This consists of hexagonally tessellated circles.

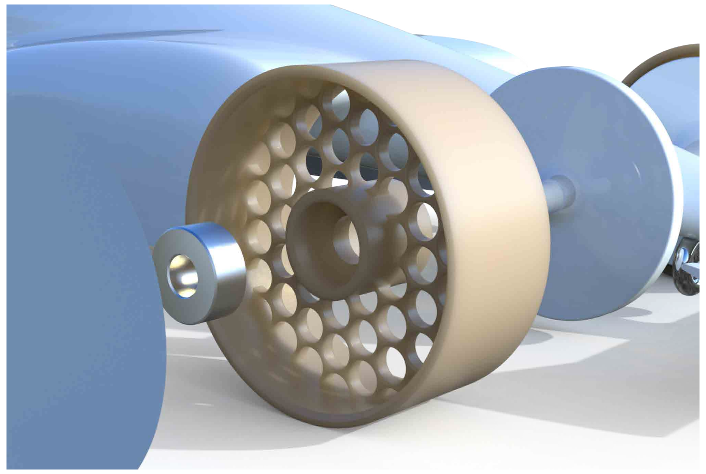


Figure 18 - A render of our honeycomb wheel (source: team files)

Materials & Manufacturing

SLA

SLA (stereolithography) is a form of 3D printing which uses a controlled moving laser to precisely cure a liquid resin in layers. This solidifies it into the desired shape, with the capability and accuracy to make complex geometries. SLA required very specialised and expensive materials and equipment to operate.

SLS

SLS (selective laser sintering) is a form of 3D printing which also uses a controlled moving laser, this time fusing powder into the required geometry. This process allows for the production of complex and strong parts. SLS required specific machinery to operate.

FDM

FDM (Fused Deposition Modelling) is a form of 3D printing where a nozzle extrudes thermoplastics. This nozzle is heated and melts the filament, then layers it onto a bed, cooling into the final model. FDM can be cheaply operated to produce large quantities of parts relatively quickly.

Milling & Turning

A CNC (Computer Numerical Control) machine uses a drill bit, following a pre-identified path it removes material to produce the desired shape. A lathe removes material by rotating material around a stationary cutting tool. It produces objects with very good concentricity and symmetry. Both machining methods can produce a component of almost any material with even density. Often to achieve the desired surface finish and accuracy these machines are expensive to obtain, maintain and operate.

Manufacturing Options Evaluation

To assess our manufacturing options, we identified factors that must be considered: material mechanical properties, surface finish, accuracy, availability (logistically, financially, and time), and geometric constraints.

We compared all materials available to us, namely Nylon, PEEK, Aluminium, Carbon Fibre, Acetal and Teflon. Analysing a range of their mechanical properties, we found PEEK to be the optimal material. This was because PEEK had a low density, can be accurately manufactured and had an equally low value for static friction (equal with aluminium and acetal). We also researched to find it had little environmental offset.

Machining processes produced the best surface finish, symmetry, accuracy and concentricity. However, there are inherent geometric limitations to machining, in addition to its high expense. We also considered SLS as this has the desired mechanical properties, but lacks surface finish and the desired resolution. Aqueous's partnership with Maxident provided access to SLA printers, able to produce geometries of thicknesses as low as 0.25 mm thick with similar accuracy to machining. The process of curing a liquid resin gives us more freedom with the wheel structures available to us, and thus we decided to use PEEK SLA, with a honeycomb structure.

Car Development

Overview

When considering the individual design development of our cars' major components all major design decisions were made in the Philosophy and Ideation stages of our development process. In design philosophy, we tested combinations of different component models with different aerodynamic approaches. We then verified all choices with various tests. In the design ideation phase, we concluded that mass, stability and manufacturability had a greater effect on our cars' performance than aerodynamics. With this knowledge, we designed the next models of the car with those variables as a priority over aerodynamics. We then finally utilised a refinement state which ensured full regulatory compliance and performance optimisation.

Front Wing Development

The front wing is the forward most component of the car, so this is where we started our development process. Across the four design philosophies, the two which were continued displayed differing trends toward the most effective approach to the aerodynamic and mechanical issues T9.5.1 and T9.6 introduces. The purpose of the front wing is to divert airflow from the leading edge of the front wheel and minimise high pressure at the front of the car.

For the first design philosophy (completely closed underside channel) the most effective design was a stacked and ramped front wing system. Compared to the average drag force for this collection testing reflected a 0.051 newtons reduction. For the second design philosophy (completely open/no underside channel) the most effective design was found to be a neutral airfoil connecting to the nose cone, at each edge a swooping piece of support material joined a floating ramp which was also classified as a support structure. This design had a 0.048 newtons reduction in drag from the average for its collection.

From our initial design philosophy testing concluded a stacked front wing design was the most aerodynamically efficient option, we decided to move towards a philosophy that was the optimal pathway for mass, stability and manufacturability. However, we still applied the learnings gathered about aerodynamics to the design.

When analysing the CFD solution fields, we found that an increasing ramp wing system was necessary to prevent turbulent flow. When opting for a more simple front wing design that prioritised manufacturability and COM, we achieved this by employing a neutral aerofoil that sweeps upwards towards the outer edges.

Figure 19 - A render of our stacked front wing concept (source: team files)

Rear Pod Development

The rear pod is the body directly behind the rear wheel. Its purpose is to handle wake and prevent a vortex/any turbulent flow off the car's trailing edge, in addition to impacts on the car's aerodynamics and stability.

Across testing all philosophies, it was identified that an efficient rear pod began with the rear wheel's width to a smaller trailing edge. Analysis of solution fields indicated the pod coming to a point is only effective when the curve is gradual, meaning the rear pod would have to be over 35 mm in length. Our physical testing instilled a parameter that the optimal wheelbase is 130 mm, leaving far less space for a rear pod. All testing under these conditions indicated a rear pod makes little to no difference considering aerodynamic factors, thus eliminating its need.

Side Pod Development

The sidepod is the joining component between the front and rear wheels, with the purpose of housing the virtual cargo, maintaining the attachment of airflow in the exclusion zone behind the front wheels and diverting air from the leading edge of the rear wheels and exclusion zone in front of the rear wheel.

For the first design philosophy, we found the most effective design solution to be a square sidepod connecting the width of the front wheel to the intersection between the width of the rear and the exclusion zone in front of the rear wheel. Regarding the second design avenue we found the most efficient sidepod solution to be a single airfoil lofted around the outline of the wheels.

As per the open channelled design, we further developed an aerofoil side pod. We found the curved but neutral shape of the airfoil maintained airflow attachment, the low surface area decreased drag and the side face effectively managed turbulent flow leading to the intersection with the exclusion zone in front of the rear wheel. In these ways, it was lighter and more cohesive.

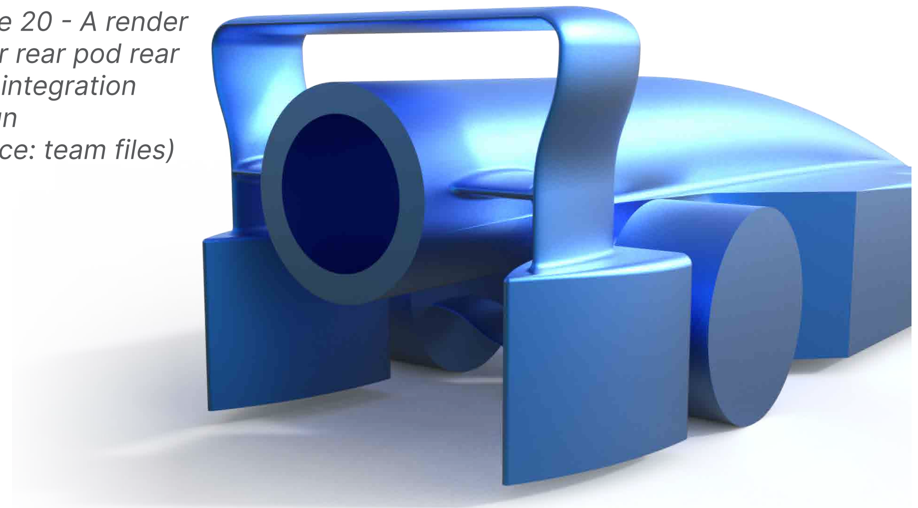
Rear Wing Development

As per the regulations, the rear wing is required to be a single, unbroken span. A legal rear wing must exist a minimum of five mm above the canister chamber without violating a clear airspace. For iterations that had large back pods, predominantly focussed around closed and hybrid channel models, we found that the most efficient method of joining this airfoil span was to connect it to or suspend the rear pods. This model decreased the average drag force by 0.007 newtons.

For open channel iterations, the most effective design deemed viable was a triangular join to the channel wall, decreasing drag by 0.006 newtons. The most effective system tested was a curved rear wing span which swept at a constant 6 mm airspace around the chamber then joining at a lower point. Under heavy consideration, while this did reduce average drag by 0.01 newtons we did not continue developing this concept due to regulatory and manufacturing factors.

In rear wing development, the team manipulated the angle of the airfoil, accounting for our solution fields, we concluded a neutral wing would be most efficient. We found any benefit this produced was negligible and less significant than stability lost by decreasing the wheelbase.

Figure 20 - A render of our rear pod rear wing integration design (source: team files)



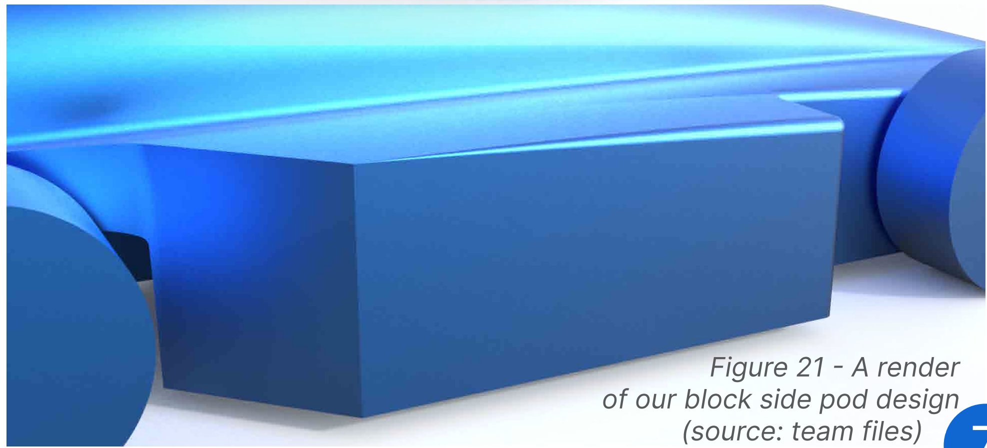


Figure 21 - A render of our block side pod design (source: team files)

Car Development

Progression

Development Evaluation

Throughout the development process of our car, the development process itself underwent significant changes. Initially, we started our development process completely centred around CFD. This was due to restrictions created by COVID-19 pandemic. Then once the restrictions eased we reevaluated our development process of the car so far.

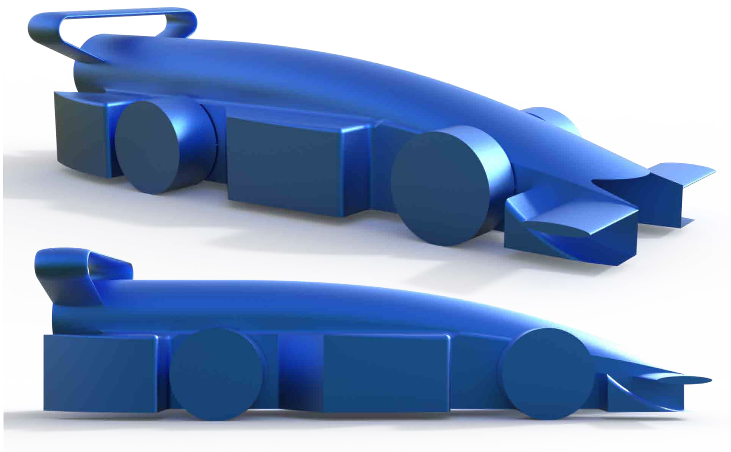
Figure 22 - Below is a snapshot-based overview of our car development progression (source: team files)

Through this evaluation, we decided to complete physical testing, and the results demonstrate that mass, stability and manufacturability would have a much greater effect on our cars' success than aerodynamics.

With our design process reformed we continued the development of our car centred around these variables. Whilst we acknowledge that the development of cars was not as efficient as possible and we should have begun with physical testing, it is critical to understand that starting with a CFD-orientated development first, was better than not starting at all. However, there were negative implications to beginning the development process with CFD.

It meant significant amounts of data were generated that did not directly go towards the design of the car. Nevertheless, this data was not completely useless and informed us on how aerodynamic principles translated into practical applications. Ways of improvement for our development process would be beginning with physical testing. This would provide us with strict constraints on our car's design. Then once we had gathered all necessary information from physical testing we could pursue the optimisation of the cars' aerodynamics, whilst remaining within the constraints set from the physical tests. The development process we undertook was tailored to our circumstances and the unpredictable nature of the COVID-19 pandemic.

Design 1 - DI 1.1.3.0



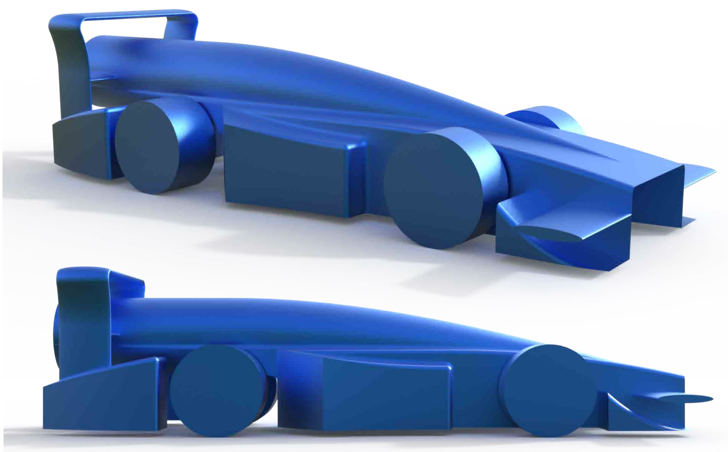
Drag: 0.266 N Lift:-0.013 N (@ 20 m/s)

DI (Design Ideation) 1.1.3.0 is the product of our testing of a closed channel car. The car body is produced with a face-to-face loft, connecting with a shortened nose cone. The front pods direct airflow over the front wheels, stacked with an airfoil to comply with regulations.

To maintain the attachment of airflow a square sidepod connects the two exclusion zones where turbulent flow is present. To maintain this attachment and reduce wake behind the car the rear pods reduce to a thin trailing edge. The rear wing is simple, joining a straight airfoil span in a triangular formation.

Overall this car effectively considers aero factors in a closed channel design but doesn't take other design avenues nor other R&D factors into account.

Design 2 - DI 1.3.2.1



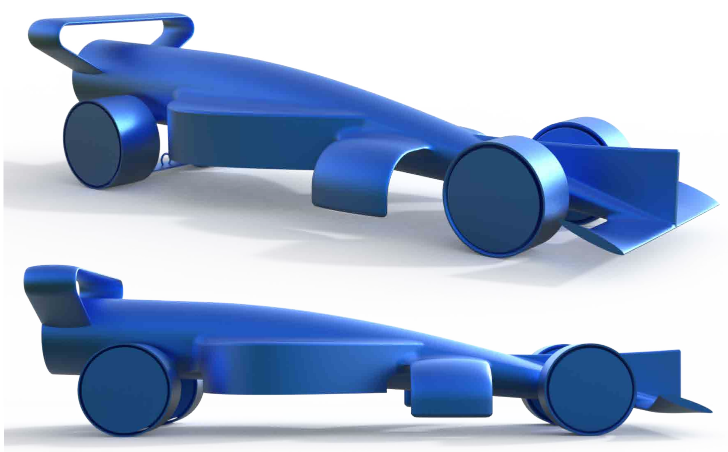
Drag: 0.228 N Lift:0.062 N (@ 20 m/s)

DI 1.3.2.1 is a continuation of DI 1.1.3.0 with a hybrid channel (enclosed until end of sidepods) and further development of the sidepod, rear pod and rear wings. It was identified that a pointed loft is optimal with a hybrid channel.

Focussed on drag reduction, the hybrid channel model involved shifting the rear wheels further in, so that their outer edge lines up with the front wheel. This influenced our sidepod design, using a concave curve on the top and side planes to more effectively maintain airflow attachment. Without a channel wall at the car's rear, we joined our rear pods to the wing support structure.

Overall this car further improved aerodynamics but harmed the COM (e.g. heavy 3D printed rear pods) and subsequent thrust efficiency. It was also theorised to be difficult to manufacture.

Design 3 - DR 1.0.0.0



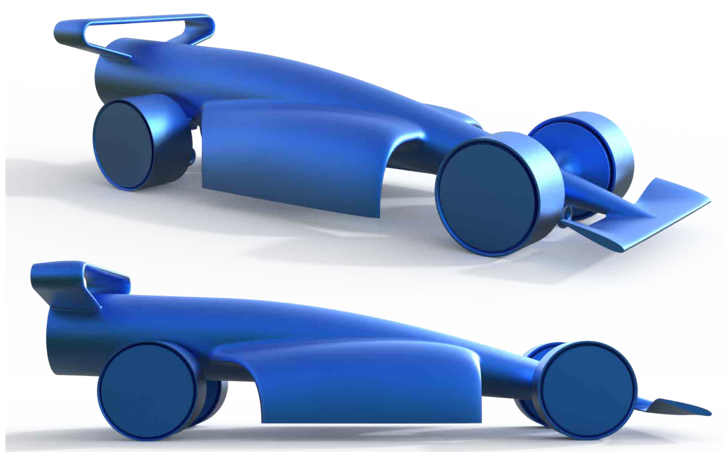
Drag: 0.271 N Lift:-0.058 N (@ 20 m/s)

DR (Design Refinement) 1.0.0.0 is the first design applying all of our physical testing sourced parameters. It uses a mostly neutral front wing to improve the ease of manufacturing. To comply with our required COM we implemented a barge board system behind the front wheel exclusion zone and a different side pod model.

To comply with COM and wheelbase requirements we removed our rear pods, our testing indicating they are harmful under these conditions. We also implemented an addition to the nose cone briefly tested by our predecessors Aeolus Racing and Thrust Vector, theoretically breaking the light gate sooner than without.

Overall, this design successfully applies our physical testing parameters but required further refinement and manufacturing considerations.

Design 4 - Neptune IX



Drag: 0.243 N Lift:-0.037 N (@ 20 m/s)

Neptune IX is our final car, applying findings revealed throughout our research, testing and development processes. It continues the COM, wheelbase and thrust efficiency considerations of DR 1.0.0.0 but further refines its aerodynamics and manufacturability. The front wing system is slightly altered to deflect more airflow over the front wheel. Our side pods are adapted to a single airfoil lofted to maximise the attachment of airflow. The mass distribution of this loft allows it to comply with COM requirements. This sidepod improves manufacturability, reducing risk of damage due to CNC vibrations. Consistent r1.5 fillets are added on every edge to consider CNC limitations. Variable based CAD is also applied to minimise drag on a smaller scale.

Overall, this car successfully fulfils our design aim.

Manufacturing

CAM & CNC

Milling

Choice of Equipment

Originally to mill our cars we used our school's mill, the IMPACT! CNC Storm. This mill's turnaround was fast, but it had a very low tolerance (±0.5mm), due to the misalignment when changing the angle of the cut. To improve, we looked into other solutions. We made custom parts to improve the origin setting of the router, and tried different jigs to maintain the block position.

These still didn't provide the accuracy necessary for the design. We then tested REA's Denford Router 2600 Pro, which was extremely accurate (±0.05mm), this was largely due to the router having a rotary fixture, allowing for precise alignment of the block. We found that the higher level of accuracy was worth the increased milling time.

Use of Milling

The g-codes for milling was made on VR CNC Milling 5. This program is designed for the Denford machine, easing resolution and path adjustments. The path along the block was 45°. This increased complex curve accuracy and sped up milling times. The car was attached to the block with 2 arms, in easily removable and sandable spots.

A 6mm Ball drill bit was used for both the roughing cut and the fine cut. The 6mm bit was chosen due to little resolution being lost compared to a smaller drill bit and the time saved by using the larger bit. Our car design allowed for only a top and bottom cut to be needed, halving the machining time.

Figure 23 - One of our test cuts for our car (source: team files)

3D Printing

Selective Laser Sintering

Our team already had experience with both FDM (Fused Deposition Modelling) and SLS (Selective Laser Sintering) printing. SLS printing was selected for the creation of the final parts; wheel support system, rear wing and front wing. The SLS printing utilised the material nylon. Nylon is an incredibly strong material but is also lightweight. Utilising nylon as a material reduced the bulk weight of 3D printed parts.

SLS can create extremely accurate parts due to its strictly industrial use. This gave us the freedom to design surfaces at any angle or curve without the need for support material, reducing sanding time and increasing the accuracy of parts and creating a relatively good finish quality. SLS inherently has better bonding compared to other printing processes, such as FDM, due to each layer being melted in place together, increasing strength. Due to the SLS printing process, our parts were slightly porous. This was an advantageous property as it made it easier to paint.

However, the SLS printing process does not initially create a great surface finish. Thus some sanding was necessary before painting. SLS is an extremely expensive and high end printing process, leading to neither school having direct access to it. Thankfully we were able to outsource our production to Objective 3D, this gave us access to industrial printers, allowing the SLS parts to be thin, complex and overall well made.

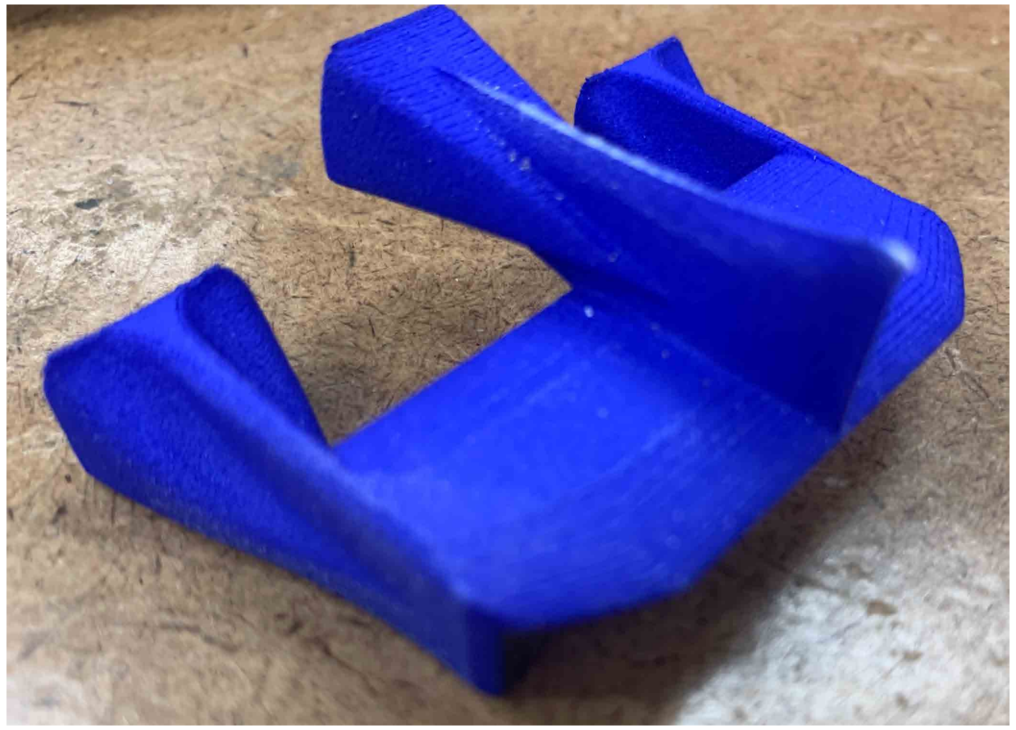


Figure 24 - A test SLS front wing component (source: team files)

Finishing

Painting

To smooth out the imperfections left by the mill and give the car a hard shell, many coats of spray paint were used to fill in the cavities and created a resistant and smooth shell. We used 2X Flat White Primer, to create a smooth surface because it could be applied in thick coats and could be sanded down easily and effectively. The primer was applied 10 times to the body, as an undercoat and twice to the SLS parts, due to them having fewer defects and their ease of sanding. White Knight SQUIRTS Gloss White Paint and Prime, were used to give the car a glossy and tough finish, as this paint was less powdery than the primer and harder when dried. Two coats were applied to both the body and the SLS parts. A gloss coat, of White Knight SQUIRTS Gloss Clear, was applied after the waterslide decals, once the car was fully assembled. This helps bond the decals in place and prevent movement.

Figure 25 - Bill, our manufacturing engineer, painting our cars (source: team files)

Sanding

Sanding was extensive and time consuming. It was important to take caution when sanding to prevent the over-sanding of regions, revealing foam. To assist with making sure the critical areas on the car (connection points) stayed in the correct dimension the team used Sanding Jigs. The Sanding Jigs are simplified parts that were temporarily glued into place allowing for sanding to consider where the SLS parts are attached. These jigs streamlined sand requiring less care to obtain the required results. The Nose Sanding Jig was used to sand down the connection arm (from milling) whilst keeping the curve of the body. The sanding grits were slowly increased from 240 grit to 1500 from coat to coat to allow for the higher grits to do their job. No sanding was done on the final 3 coats (gloss coats) to prevent the scratching from sanding from being visible.

Process

Assembly

Assembly was the final stage of our manufacturing process so it was critical that it went well. The assembly process started in the CAD. All joining points between 3D printed parts and foam parts had indents. These indents guided the 3D printed parts into their exact positions, this ruled out any significant opportunity for human error when gluing parts onto the cars and kept the parts in position throughout the gluing.

The second stage of assembly utilised jigs. We designed jigs to aid in the assembly of the SLS printed parts to the foam body. The jigs held the SLS printed parts and the body in place as the glue dried. This in combination with the indents meant the parts would be glued precisely, leaving little room for error.

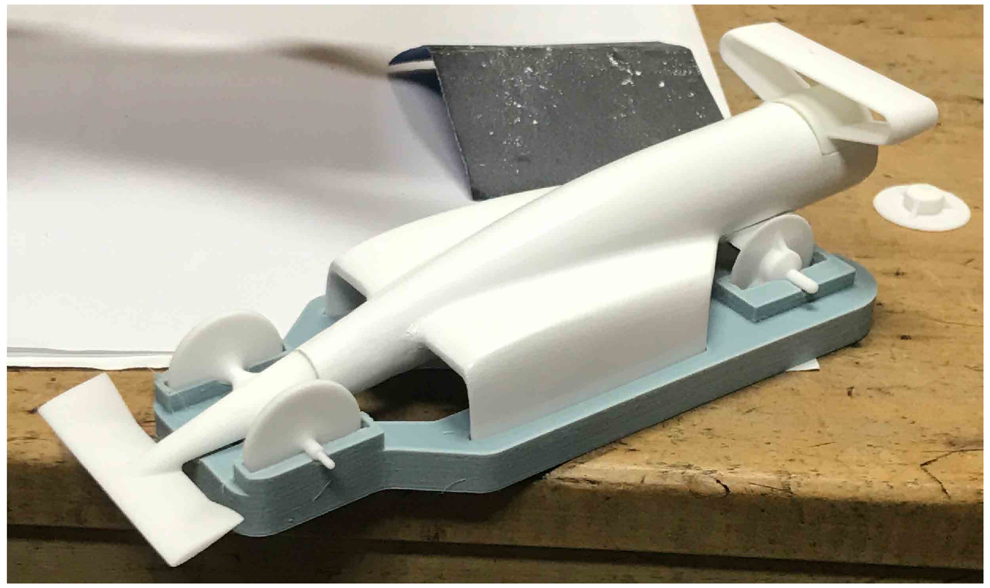


Figure 26 - Our car placed into our assembly jig system (source: team files)

We then placed the water slide decals on the car. We utilised water slide decals as they are incredibly thin, roughly micrometre thick, allowing them to curve and surfaces and have little effect on the cars' surface finish. We dunked the decals in warm water, slid them off their paper using tweezers and applied them to their appropriate positions using renders as a reference.

Now it was time for the wheels. We designed the wheels with a press fit so that the bearings would slot into place without requiring glue. This was possible thanks to the accuracy of SLA printing. The only parts in the wheels requiring glue were the front wheel caps. We designed the wheels to utilise as little glue as possible to minimise the risk of glueing bearings. Then a fully assembled racing car was born.

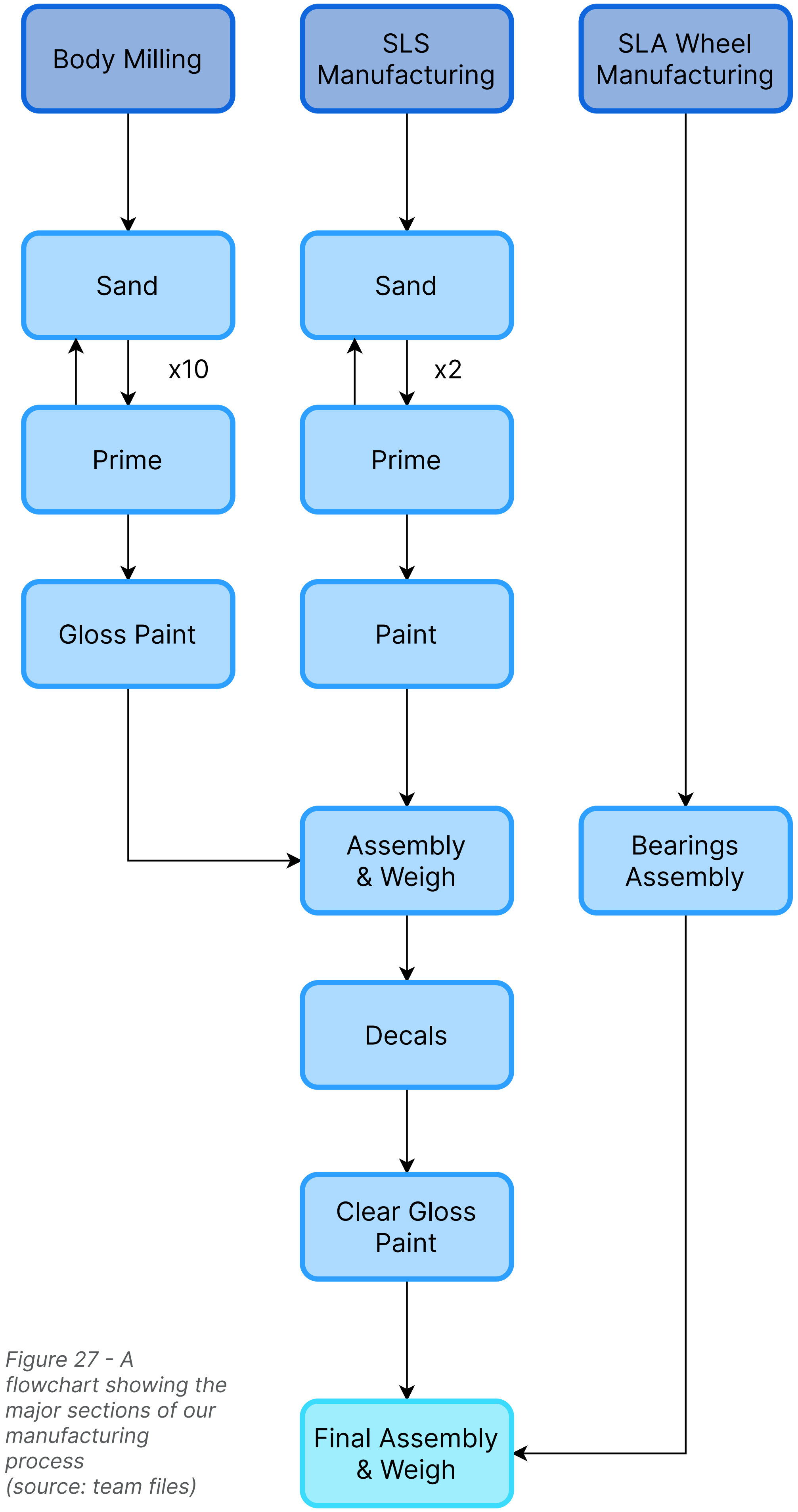


Figure 27 - A flowchart showing the major sections of our manufacturing process (source: team files)

Manufacturing Evaluation

The manufacturing process that we undertook was shaped by our previous experiences, it was refined from previous competitions and adapted to the new materials and processes we used. To fabricate the parts of our car we outsourced it to other companies, due to their extensive experience with their machines, hence they had increased accuracy and time efficiency. These parts arrived soon after we ordered them.

Allowing the finishing to start early, some parts were prioritised over others which ended up as a detriment because the SLS parts were all but forgotten about. This meant that there was a disparity between the finishes on the body and SLS parts which were undesirable. Fortunately, that means the body's finishing was really good, as our finishing process worked very well, for the body, which was designed to be sanded with long flowing curves and with few tight corners.

Another effective manufacturing process was the final attachment of SLS parts to the body. This process was effective at aligning the wheels, although it meant that many parts looked skewed. The gaps were filled with glue to smoothen the joint, this was again an effective method although it looked awful. With the hard and patient work that was put in we were able to produce four spectacular cars.

Category	Risk	Control Measures	Likelihood	Consequence	Residual risk level	Residual risk	Accept reject
People Safety	Inhaling particulates and aerosols	Wearing a mask when spraying or sanding. Using dust extraction.	Unlikely	Minor	6	Insignificant	Accept
	Getting spray paint on hands	Wearing gloves and using sticks/rods when painting all objects to distance body parts	Very unlikely	Minor	6	Insignificant	Accept
	Injuries to person/s in workshop or at home	Following the schools risk management at home as well at school	Unlikely	Moderate	5	Low	Accept
Assembly	Inaccurate gluing of wheel system	Use of assembly jig for wheel alignment, and incidents for princely cured areas	Unlikely	Moderate	5	Low	Accept
Car Safety	Over sanding while sanding	Using sanding jigs on critical areas and sanding little in risky areas	Unlikely	Moderate	4	Medium	Accept
	Damage to car during transportation	The use of custom plastic boxes made to size with padding inside. Caution when handling package, ie, placing it in an	Very Unlikely	Major	5	Low	Accept

Figure 28 - An excerpt from our manufacturing risk assessment (source: team files)