Applied Research

Aerodynamic Forces

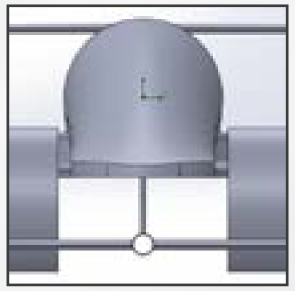
Our car is influenced by many forces throughout the race. These forces occur at different race stages and how we influence these forces will determine the performance of our car.

Drag

Aerodynamic drag is the force which simply opposes motion of our car through the air. We identified three main types of drag that influence our car: form drag, skin friction drag, and interference drag.

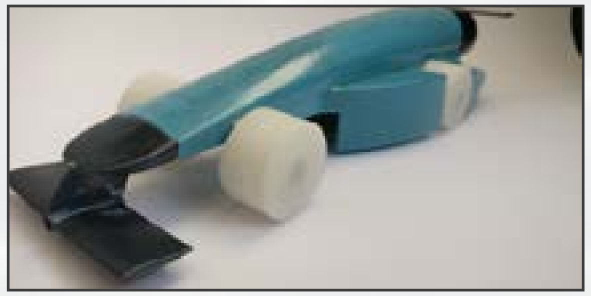
Form Drag

Form Drag is influenced by the general shape of our car. Air separates at the front of our car and comes together at the rear. We concluded that the best way to combat form drag was to reduce the frontal surface area of our car as much as possible.



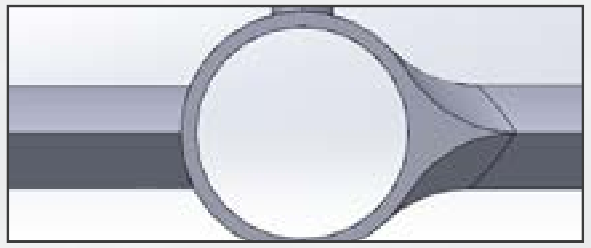
Skin Friction Drag

Skin friction drag is caused by air coming in contact with the car. The finish of the surface which the air is passing over is the determining factor of this type of drag. By ensuring a smooth, polished finish on our car, we can greatly reduce skin friction drag.



Interference Drag

This drag forms where two perpendicular bodies intersect (i.e. at a wing). The air compresses at this point and the most effective way to combat this is to install wing fillets.

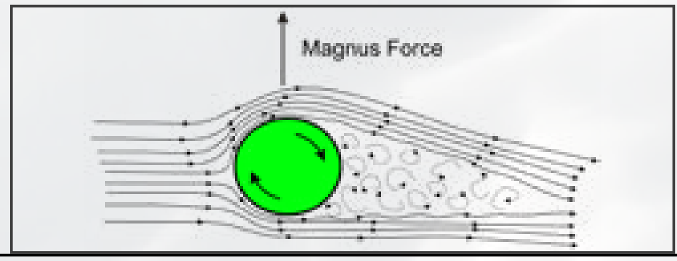


Thrust

Thrust comes from the gas canister at the start of the race and our car relies on this initial acceleration to propel it down the track. Each car uses identical gas canisters, therefore, the way we can improve thrust is an effective LERS device.

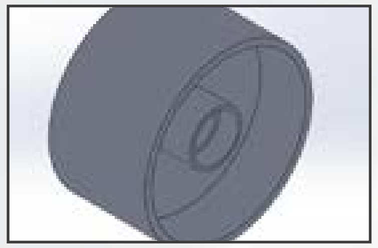
Magnus Effect

The Magnus effect is the force exerted on a rapidly spinning cylinder or sphere moving through air. The four wheels of our car rotating in a forward direction creates what is known as top-spin. This essentially sucks the car onto the track, as a result of downforce. To reduce the magnus effect, the surface of our wheel would have to be as smooth as possible.



Moment of Inertia

A heavier wheel will require a greater force to turn it; this is known as the moment of inertia. We concluded that our wheels should be designed and manufactured to be as light as possible. Making our wheels hollow and allowing only the rolling surface to turn is the most effective way to do this.



Bearing Research

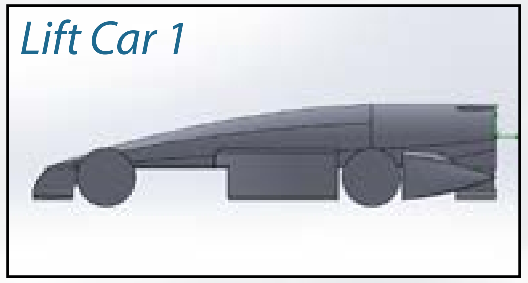
When choosing our bearings, we looked for two main characteristics. We wanted as little "play" on the bearing as possible and also as frictionless as possible. We found that ceramic plastic was the best type of material for a reduced friction bearing and also an ABEC rating of 5+ to determine how much "play" there was in the bearing.

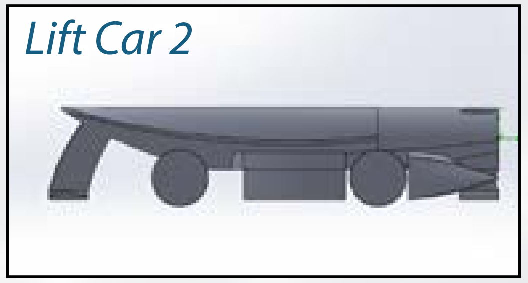
degree of precision (- to +)

ABEC
ABEC 1
ABEC 3
ABEC 5
ABEC 7
ABEC 9

Lift

Lift is the force which acts perpendicular to the airstream. We wanted to figure out from research whether our car would use lift. We conducted a study into how lift affected our car. We used high speed cameras and two different cars of varying lift values. We concluded from this test that our car lifts slightly at the start of the race with initial acceleration and then its effects are not noticeable after this stage. We decided to not utilise the effects of lifting our car during a race as it doesn't impact our car for the whole race unlike aerodynamic drag.





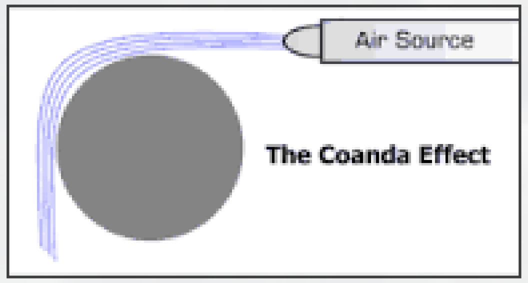
Downforce

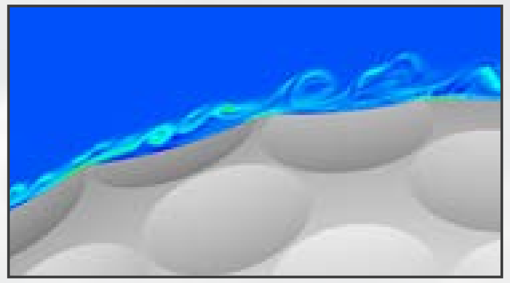
Formula 1 cars rely on downforce to keep them on the track. It is essential for cornering yet significantly impacts drag as can be seen in DRS zones. We concluded that downforce is not required since the tether line secures it to the track. Our lift research yields concern at reducing drag and have as little forces acting perpendicular to the airstream as possible.

Coanda Effect

The coanda effect is the phenomena in which a jet flow attaches itself to a nearby surface and remains attached even when the surface curves away from the initial jet direction.

Dimples on a golf ball create a thin turbulent boundary layer of air that clings to the ball's surface. This allows the smoothly flowing air to follow the ball's surface a little farther around the back side of the ball, thereby decreasing the size of the wake at the rear of the car. A dimpled ball thus has about half the drag of a smooth ball. We can apply this effect throughout our car and we have elaborated further on this effect on the next page.





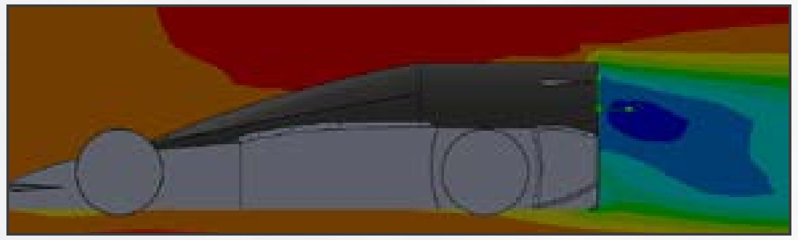
Design Concepts

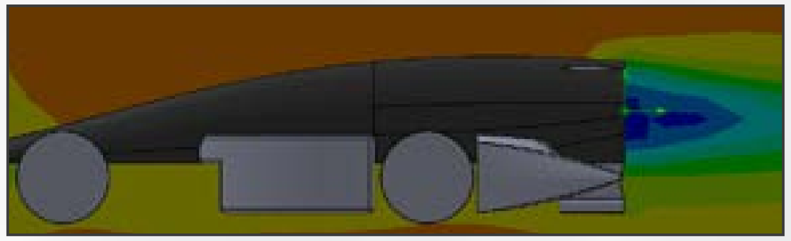
Technically Inspired Ideas

The cornerstone to getting the most out of design concepts was having substantial research to develop our concepts around. The design team held meetings to brainstorm various concepts for the car and individual components. Our main focus when developing our ideas was to ensure that every design improved the car's aeroydnamics. Below is a summary of our key design concepts that we developed from research.

Streamlined Chassis

Wake drag is one of the main forces which slows down our car. Air that separates at the front of our car tries to move to its similar position at the rear of the car. However, if a body is not streamlined, the air tends to form turbulence at the rear and this occurrence is known as wake drag. The air is essentially trying to fill a vacuum at the rear of the car and this vacuum is what slows the car down. This led to our streamlined chassis concept which lasts the entire length of the car.

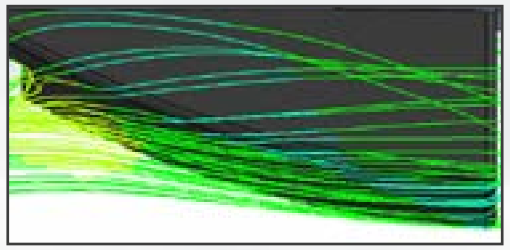




Coanda Effect Applications

Side Pod

The "coanda effect" is one of the main principles in aerodynamics that Formula 1 teams use for their side pods. It is a phenomenon in which an airstream attaches itself to a surface and remains attached even when the surface cuts away. Our design concept used a simple application of the "coanda effect" to divert air around the side of the rear wheel.

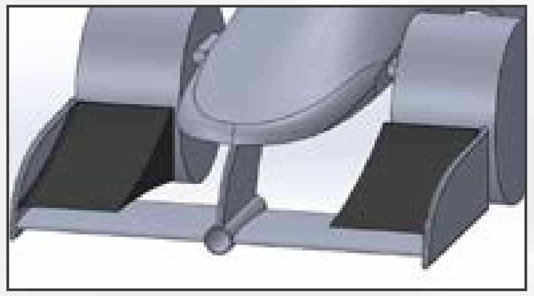


Rear Pod

The "coanda effect" uses the effect of rough and smooth surface finishing to bend air around faces. Having a car with a smooth finish may reduce skin friction drag but, more turbulence forms at the wake. Our design concept utilises a rough finishing on the rear pod's ends, and a textbook streamline model to eliminate wake drag.

Magnus Effect Front Wing

With the tether line securing our car to the track, our car doesn't have to create downforce to keep it on the track. The magnus effect occurs when air is deflected by a spinning cylinder i.e. our front wheels. Since the air moving under the car is faster than the air moving above the car, downforce is created. Our concept sends air over the wheel in order to minimise the magnus effect to prevent as much forces acting on the wheel as possible.

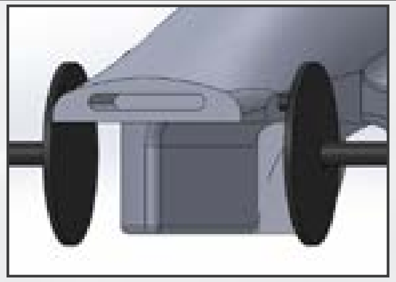


Rear Wing Endplates

We attached endplates onto the end of the rear wing. These are aerodynamic devices which prevent the mixing of high and low pressure bands. When pressure bands mix, they create vortices which lead to an increase in drag via a suction effect. Endplates combat the effect of vortices and thus improve the wing's performance.

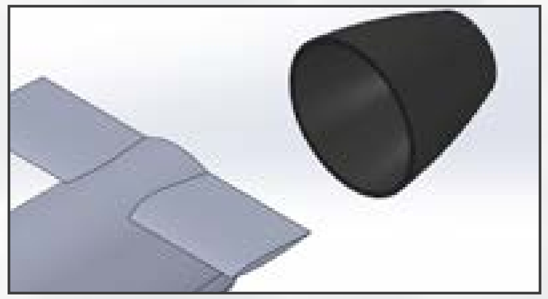
Mounting Plate Axle

With the new raised chassis concept, we had to reimagine our axle. We came up with the idea of having the axle suspended off a mounting plate which is secured into the car. This gave freedom in our design process regarding our chassis.



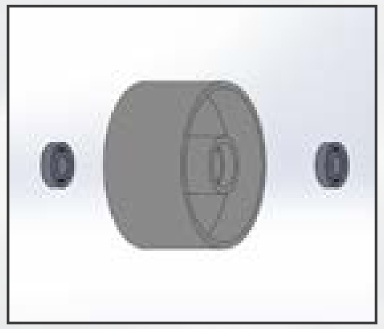
Parabolic LERS (Launch Energy Recovery System)

When introduced to the concept of using a LERS, we establish what we wanted our LERS to achieve. We set a clear goal that our device would reflect as much air as possible in order to achieve the most thrust. Our initial concept was a parabolic LERS which derived from our research on parabola. Our findings showed that any air coming from the focal point of the curve (i.e. the canister) will reflect off the parabola horizontally in the direction of the car. This in turn provides more thrust. This parabola would have to be developed by changing the focal point of the curve.



Dual Bearing System

One of the main points we took from our National's car evaluation was that there was too much play in on the wheel. This is mainly caused by play in the bearing which causes the wheel to "shake" as it travels down the track. Our concept for this was a dual bearing wheel which added stability to the wheel.



Concept Evaluation

The process of coming up with design concepts essentially meant using our knowledge of aerodynamics, which we had established from research, and applying it to usable design concepts. What we wanted to improve in this process was the way we used our research findings to develop new concepts. We did this through finding applications of research in real life objects, i.e. how an airplane generates lift, or how Formula 1 cars use the coanda effect. The idea of applying research to develop ideas is a skill utilised by engineers every day. Once we adopted this approach, we found that developing concepts was more straightforward.

3D Modelling

Manufacturing Considerations

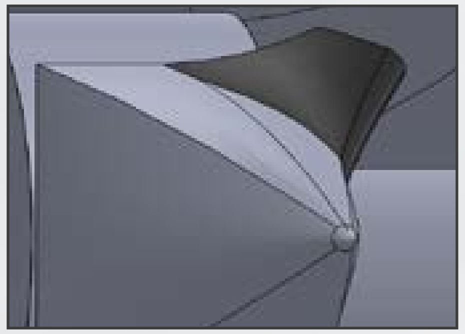
In order to ensure that our design was manufactured to as designed in the CAD model, we arranged a meeting with our manufacturing partner, Takumi Engineering. At this meeting, we scrutinised our design under the CAM platform and highlighted areas that needed to be altered to achieve a high quality model. We then improved on the following aspects of our car design and construction.

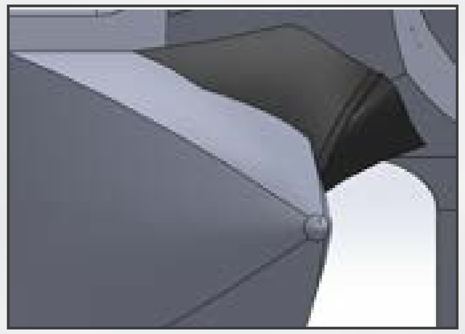
Concave Fillets

Since the machine used a ball nosed cutter, a 3mm concave fillet had to be implemented at any perpendicular intersection to keep the model accurate to the result.

Rear Pod Tendon

Another key area that had to be altered was the tendon which connects our rear pod to the chassis. When designed, the tendon did consider the accessibility of the cutter and, in order to be manufactured, a flat attachment had to be developed.





Block Dimension Considerations

After designing our Nationals car, we considered the dimensions of the block. To do this, we went through the Technical Regulations and identified any regulation that needed to be taken into account. After studying the block and the regulations, we made revision to the following:

- T3.4 - Total Width (Stated 85mm --- Revised 65mm)
- T5.1 - Diameter (Stated 19.5mm --- Revised 19mm)

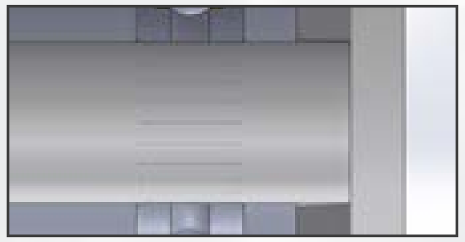
Paint Thickness

The thickness of the paint was also considered. This shortcoming was identified during our National Final's car evaluation, when we discovered we lost marks on a regulation due to the thickness of our paint. Some of the main considerations we took into account were:

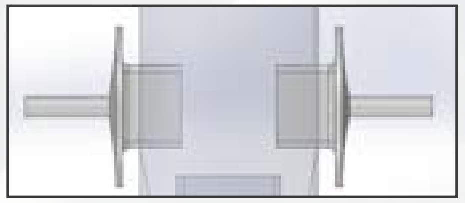
- T3.6 - Track Clearance
- T5.5 - Finishing of Chamber Surronds
- T10.11.1/2 - Front and Rear Wing Thickness

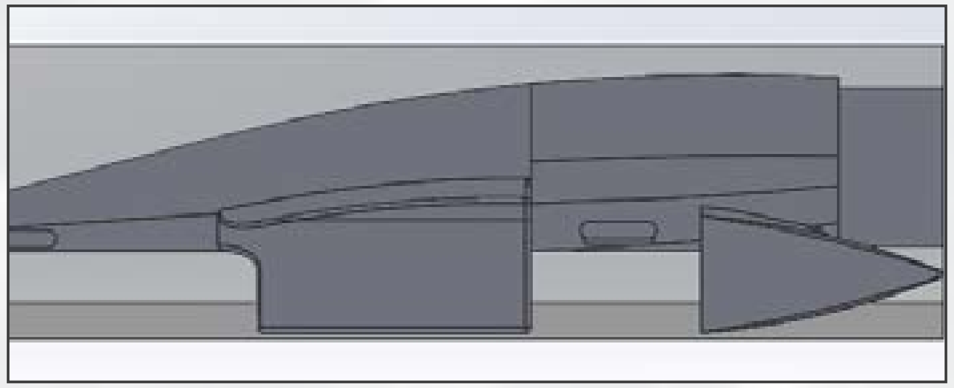
Wheel-Fitting Considerations

As our wheel system was designed in three separate sections that slot together, tolerances had to be considered. We applied a tolerance of 0.02 mm to the design to ensure each section slotted together easily.



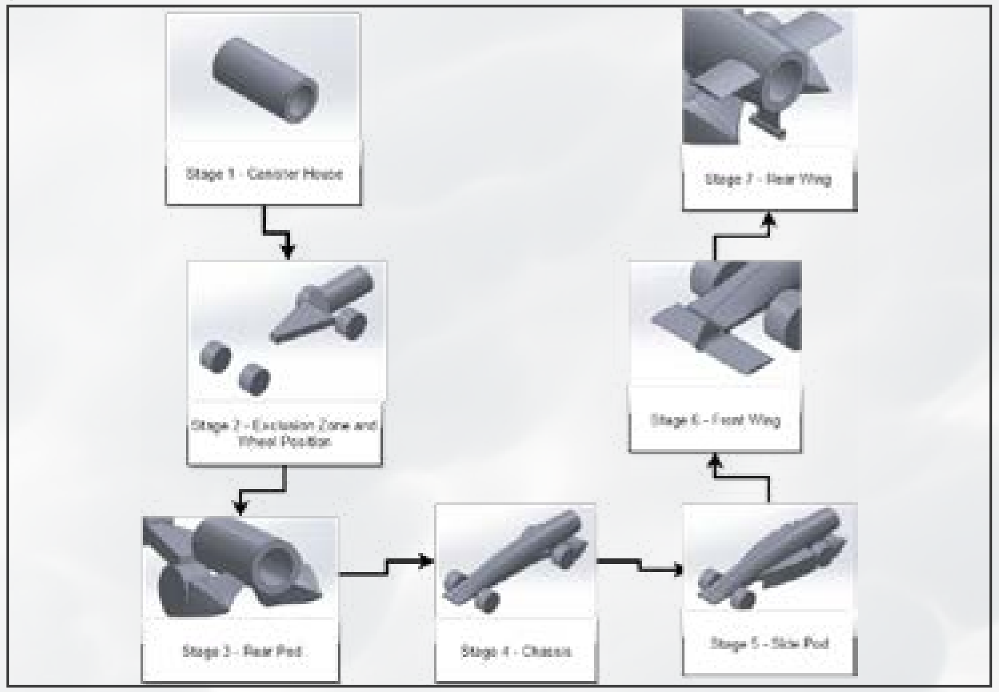
Another issue, was the alignment of the wheels. We designed the connecting tendon to slot into the body of the car as far as possible, to aid in strength and accuracy.





3D Modelling Process

We identified problems during our Nationals car design process evaluation. In order to improve the quality of our CAD models and the depth of our design developments, we implemented a unique "CAD process" that each car went though. Below is a flowchart outlining this process.



Modelling Process Evaluation

When we began the modelling process in October 2015, we had never used Solidworks or CAD software before. Through expert collaborations and hundreds of hours of practice, we have acquired the skills of taking an idea and converting a 3D model which we can then manufacture.

This modelling process quickly exposed shortcomings. Evidently, imperfections in the conversions were confirmed when we built a new part from an existing part of the model, and when we wanted to change or alter the existing part. To solve this, we built parts on 2D planes rather than from exisitng parts on the model. This action improved the accuracy of our CAD models.

We also improved our modelling process through ongoing evaluation with a review of removing inefficiencies. We noticed that our chassis was the most difficult part to edit during modelling. To solve this problem, we modelled our chassis to stage 6 of our process. At this stage, all features could be independently modelled and improved including our chassis, which improved the efficiency and the accuracy of our models.

Computer Aided Analysis

Computational Fluid Dynamics (CFD)

Testing Strategy

In order to develop our car with accuracy, we utilised advanced and relevant CFD analysis. To maintain relevance in the testing, we set out a testing strategy which proved very useful. The strategy was to use CFD to make refinements and improvements on the car and ultimately use track testing as a decider on the usage of a design. This balance between physical and virtual testing allowed our results to be accurate and relevant.

Software

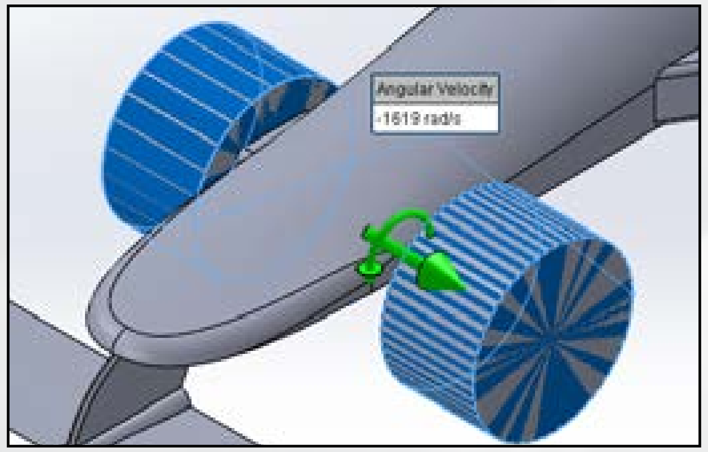
Each design concept went through a rigorous stage of development where over 30 individual test results were used to improve a concept. Therefore, when choosing what software we were to use for our CFD testing, a number of factors were considered. These were:

- Array of resultant features
- Software Accuracy
- Calculation Run Time

After much deliberation, we decided on using Solidworks Flow Simulation for its advanced input data features and its short calculation run time.

Wheel Rotation

One of the reasons why our CFD analysis was so advanced was that we created an environment that was as close to a physical test as possible. Utilising non-merging bodies, we were able to have our car's wheels spin which improved the accuracy of our drag results by a discrepancy of 0.1N in some cases. We calculated the wheel speed as 1619 rad/s for a wheel of 13mm radius to complete a 20m track in 0.950 seconds.



To calculate wheel speed (rad/s)

$Track\ Length = 20,000mm$

$Wheel\ Circumference \approx 81.68mm$

$(Wheel\ Radius = 13mm)$

$(Circumference = 2\pi r)$

$Time = 0.95\ seconds$

$\frac{20,000}{81.68} = 244.86\ wheel\ revolutions$

$\frac{[illegible]}{0.95} = 257.75\ rev/s \rightarrow 15,464.84rpm$

$15,464.84rpm = 1619\ rad/s$

Flow Trajectory Lines

Solidworks Flow Simulation allowed for an array of results to be documented and analysed. We wanted to use CFD to its full potential and we wanted our results to reflect how advanced our CFD tests were. Below is a summation of our CFD result features. These include: Force Tests, Pressure Counters, Velocity Cut Plots and Flow Trajectory Lines.

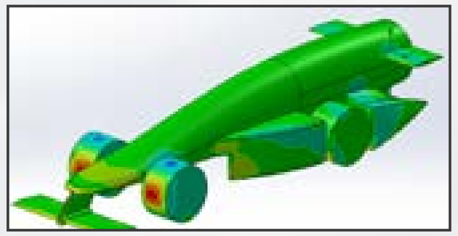
Force Tests

The decider on whether to use a refinement was the results from force tests. We tested for drag, lift and sideforce.

Name	Progress	Averaged Value
Drag	Achieved (IT = 232)	0.214532 N
Lift	38%	0.0501734 N
Sideforce	67%	-0.00243151 N

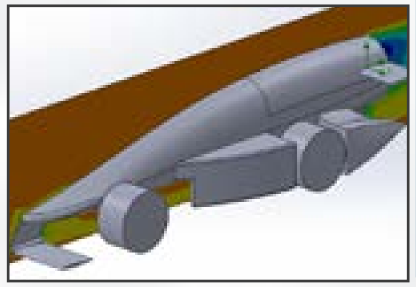
Pressure Contours

In order to pinpoint regions where the large volumes of air was striking our car, we used pressure contours and isolines.



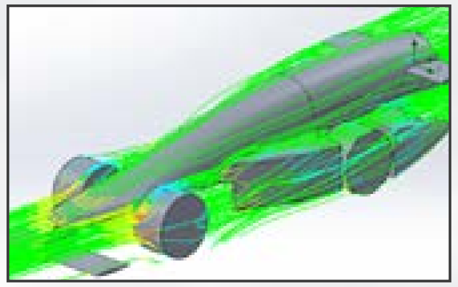
Velocity Cut Plots

Velocity cut plots are a key indicator of where drag occured. We took two primary cut plots of the car when analysing the chassis and the wheel line.



Flow Trajectory Lines

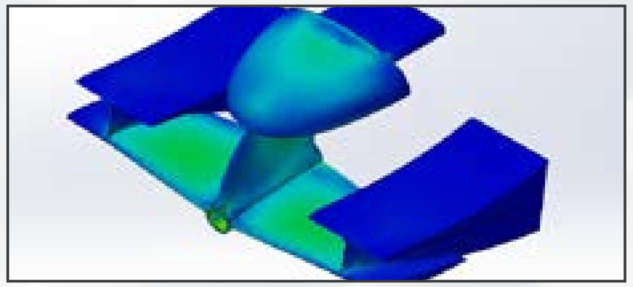
By using flow trajectory lines, we can see where areas of turbulence form. We then can use modelling techniques to eliminate turbulence.



Finite Element Analysis (FEA)

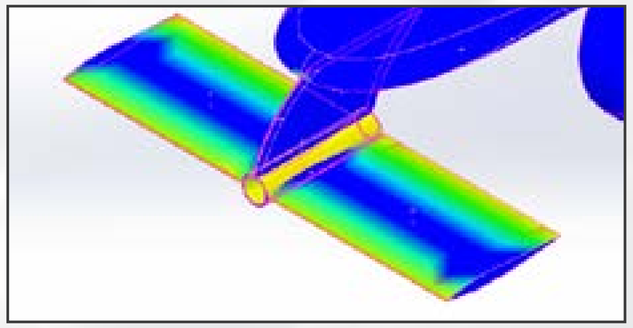
Force Test

Our front wing is designed to be sleek and aerodynamic with minimal wall thickness. We applied a force of 20N to our car's front wing which we calculated via (F = m x a) to simulate the car's deceleration. We noticed displacement and large stress impacting the part. Therefore we concluded that the best way to decelerate our car was to use a raised system and decelerate the chassis which is stronger than the wing.



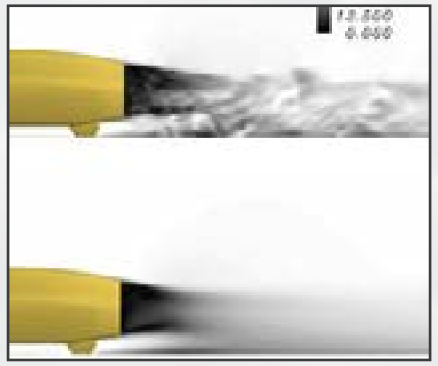
Wall Thickness Test

As well as the declaration of our car being an issue, the strength of some of the parts of our car was something we wanted to look at. We ran a wall thickness test using FEA to see where pressure was building up at certain parts of the car which were less than 1mm.
From this test we found that the tether guide was very weak. At any point where a vertical and a horizontal body meet, a stress point forms. This stress point was identified at our front wing and we solved the problem by thickening the part.



Computer Aided Analysis Evalutation

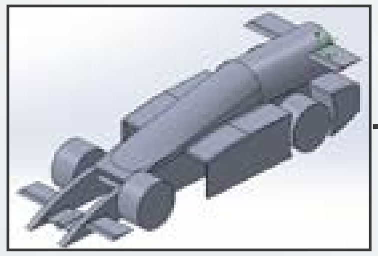
We identified the problem of accuracy in the early stages of our CFD analysis. We were concerned with the strength of our solver and wanted to run more powerful analysis to improve our car. We collaborated with EDS.ie, a design and simulation company that uses very powerful CFD solvers. We were able to run our model through their software and we observed turbulent areas in the wake of our car which we would not have seen elsewhere. This improved the virtual analysis we conducted on our car.



Car Development

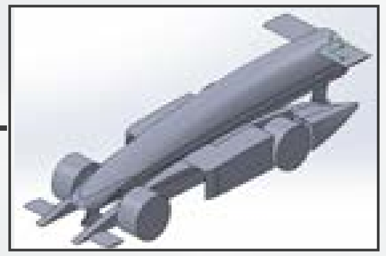
Base-Concept Development

After we had conducted our research, created our design concepts, modelled our designs and analysed them, our car was ready to be built. In order to easily edit and develop our car, we set out by building a base car, which we could then use to implement our design concepts and developments on. Below is the development of our base model.



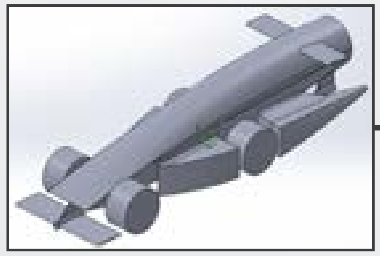
Blue Lightning (NATS)

Drag = 0.292N



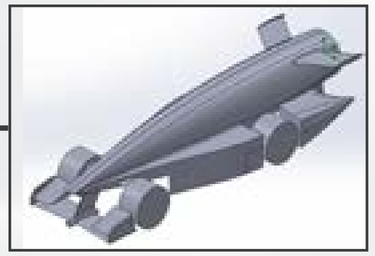
Blue Lightning 2.0

Drag = 0.279N



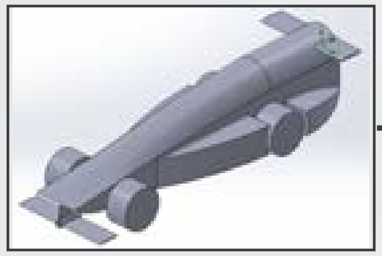
HR - 16P

Drag = 0.266N



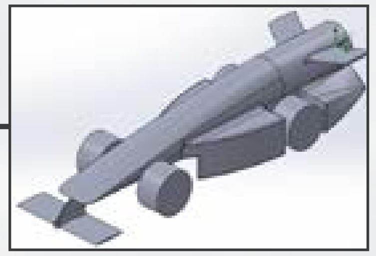
The Monarch

Drag = 0.257N



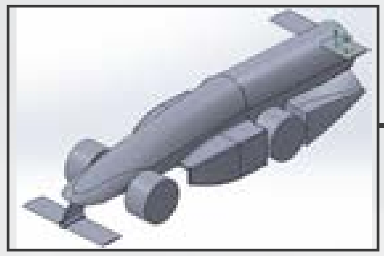
HR - Patron

Drag = 0.245N



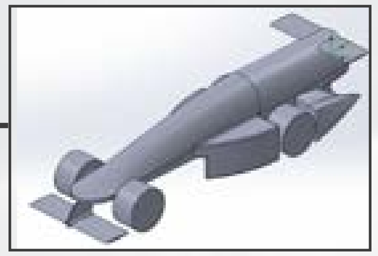
LH.2 Lone Ranger

Drag = 0.241N



HR - KoK

Drag = 0.239



HR - MkV

Drag = 0.234N

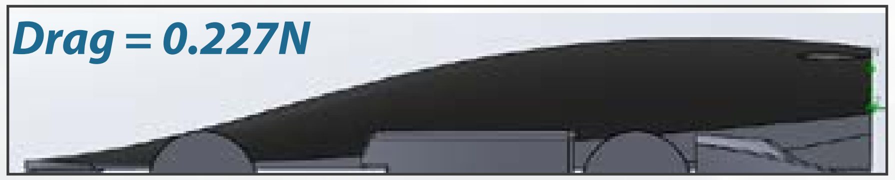
Chassis Development

We wanted to develop a streamlined chassis in order to perfect our car's aerodynamics. We did this by taking variables which we could change and examined wake drag as an indicator of how efficient our design was. These variables being:

- General Curvature
- Nose Aerodynamics

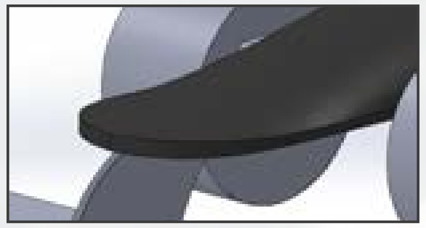
We found from our results that the best curvature was one that mimicked a logarithmic curve i.e. starting with a small gradient, and gradually increasing.

Drag = 0.231N

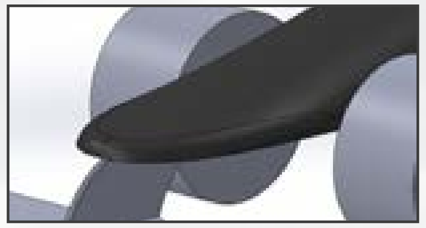


Drag = 0.227N

We then developed the nose of our chassis. We found that air wasn't fully integrated at the nose so to combat this, we developed the car to resemble a teardrop where air could easily flow onto the chassis.



Drag = 0.227N



Drag = 0.223N

Side Pod Development

Forces which act upon our wheels are one of the key causes of a reduction of speed in our car. Side pods in Formula 1 cars are designed to cool the engine so we had to re-imagine their purpose for our car. We set out to use the side pods of our car to minimise drag at the rear wheels of our car. We tested the following air diversion designs which used the coanda effect as the main principle.

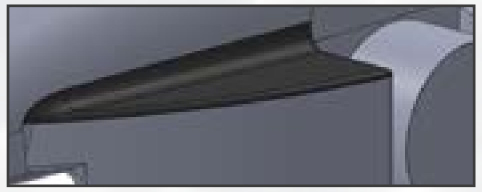
Drag = 0.223N

Drag = 0.219N

Drag = 0.216N

Drag = 0.214N

We then wanted to improve upon this design so we developed the top surface of our side pod to have a slight gradient. This designed further improved the air diversion around our rear wheel.



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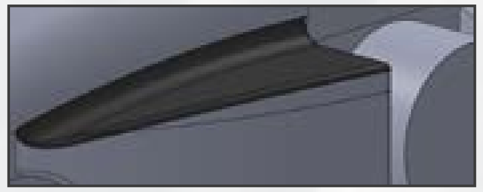


Drag = 0.208N

Design Process Evaluation

When developing our car, we followed what's known as the "scientific method". We began with a concept derived from research, we then modelled and tested this concept, and finally developed it based on test results. This method allowed us to constantly improve our design. We noticed that our process of identifying developable areas was not defined. For example, when developing our chassis, what we had to establish exactly what we could develop. To improve this, we added a stage in our design process known as "development concepts".

Development Concepts

Development concepts occurred before 3D modelling. For each individual concept we had, we outlined the set of variables we could change in the design. For each of these headings, different values and conditions were outlined. For fillet size for example, we tested 1mm, 2mm and 3mm fillets on our side pods. Each value and condition was modelled and tested individually. What this improvement essentially allowed us to do during our design process was to get the best out of every design concept; re-imagining what it means for a design to be "developed".

Coanda Effect Side Pod

- General curvature of side pod
- Height above ground
- Overall length of side pod
- Side pod - chassis integration
- Fillet Size

CAM and CNC

Manufacturing Overview

Our goal in the manufacturing process was to manufacture our car designed in our CAD model. We identified that there are two steps in the CNC process: programming the machine and operating the machine.

CAM - Software

We used a software called SolidCAM to program our Computer Aided Manufacturing. SolidCAM is a complex, industry standard software which gives extremely accurate results. It is available as an add-in for our CAD program Solidworks. It is also the software used by our manufacturing partner, Takumi Precision Engineering, who increased our knowledge and understanding of the software

Programming

SolidCAM was used to program our CAM. This means converting the CAD model into a format that the machine can understand to manufacture the car. Programming the CNC machine is the most time-consuming part of computer-aided manufacturing and involves a number of steps.

1. MAC

The first step was to set the MAC. This means telling the machine which way the car is facing. We set our first MAC setting (MAC 1) with the car being upside down. We then have to set the position within the MAC. This is setting the position of the spindle. We had a total of 5 MAC positions.

2. Operation

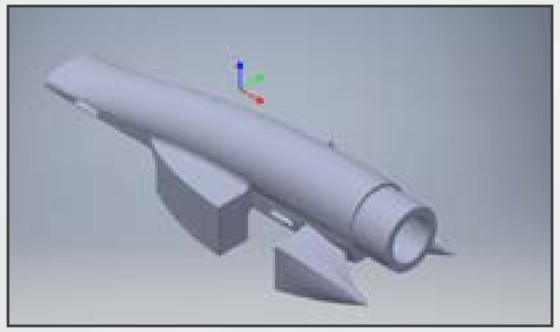
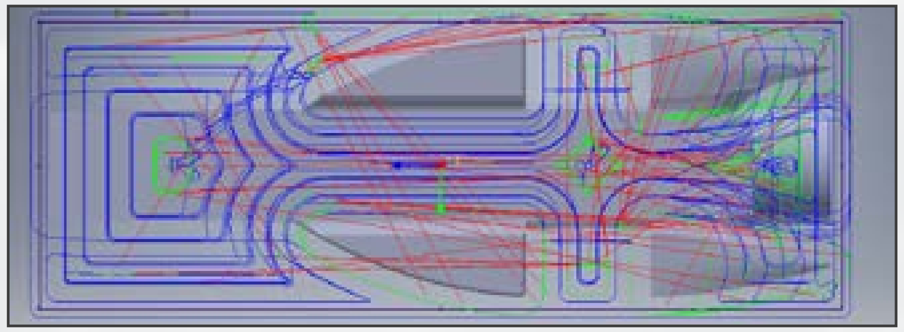
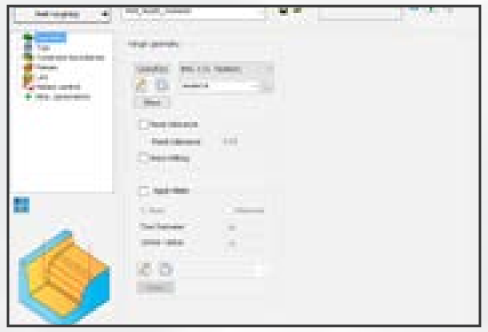
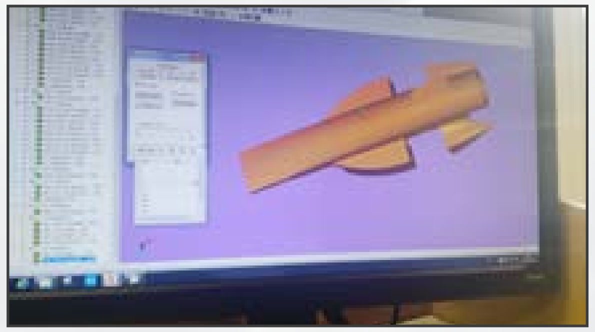
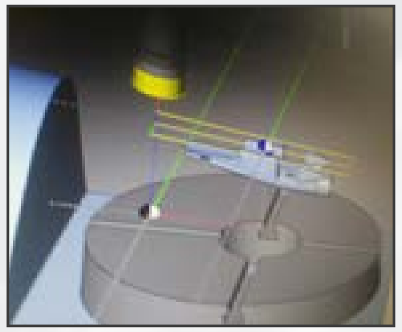
The next step was to set a milling operation. This is the method the machine follows to machine our car. Our first operation was a High Speed Roughing operation. This means that the machine will quickly rough out the face that we had selected. This is fast but leaves a very bad finish. We then use a High Speed Surface (HSS) operation which finishes the area to perfection. To achieve a flawless finish on the sloped surfaces of our car, we used a contour operation. This is an application that is used on machines with five or more axes. Instead of stepping down in fine-grained increments to approximate a surface, the workpiece is rotated to make the cutting surfaces of the tool tangent to the ideal part features. This produces an excellent surface finish with high dimensional accuracy.

3. Parameters

While selecting the operation, parameters have to be set to tell the operation exactly what to do. This is where the majority of CAM programming takes place. Some of the parameters include tool, tool size, spindle speed, boundaries, upper level, lower level, depth, and more.

4. Simulator

SolidCAM has a built in simulator, which allows us to see exactly where errors are occurring. We ran the simulator after each operation and corrected our model accordingly.

CNC Milling Machine

Our collaboration with Takumi precision engineering gave us access to 5 axis, computer numerical control, milling machines (CNC).

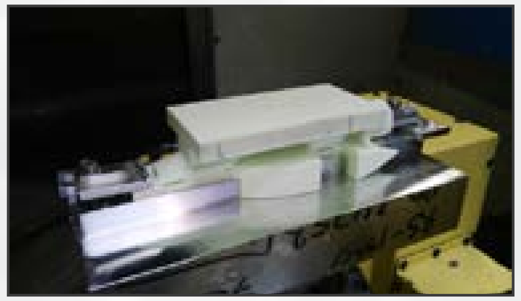
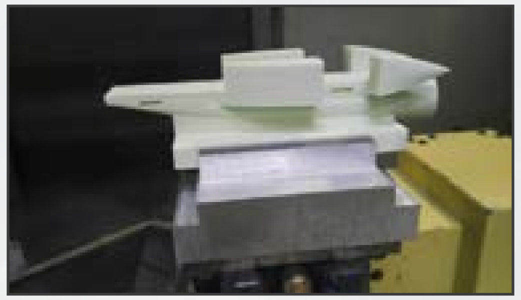
We used a "Mori Seiki" milling machine which is a high precision 5-axis machine with a tolerance of 0.001 mm. 5-axis means that the cutter moves along the X, Y, and Z axis while the mounting plate can also tilt and twist. Using a 5-axis CNC machine eliminates many problems and has an overall better finish than a 3-axis machine.

CNC Jigs

The vice on the CNC machine was not sufficient to clamp our stock material, so we manufactured our own vices out of aluminium.

We made two jigs. The first held the stock material on the bottom and sides of the car would be machined in this position. In our CAM model we set this as MAC 1.

Our second jig held the car in the upright position, to allow the car to be machined from the top. We called this MAC 2 in our CAM model.

Machining process

Once the CAM program is complete, the first step is to set a reference point on the stock material. This is done to ensure the stock material in the CAM model is exactly the same as the actual material, and to make sure the machine works in the right area. This is often the most important part of computer aided manufacturing. We then let the program run, and watched the car being machined. We could adjust the feed and speed rates on the machine by 50% each way to make sure everything ran smoothly, ie. we slowed the program at critical areas.

3D Printing

Manufacturing Outsourcing

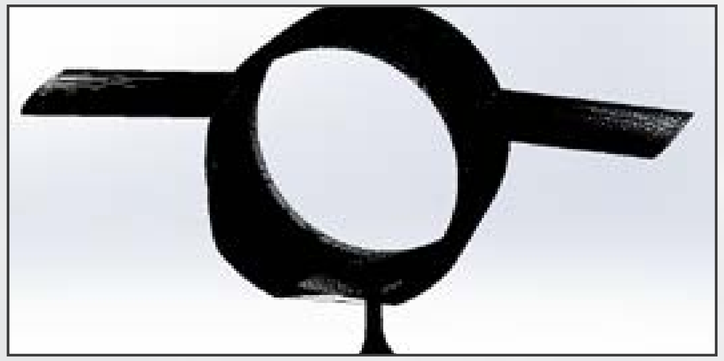
Our school has very limited resources in terms of precision manufacturing equipment. We purchased a Vertex filament 3D printer which we used to 3D print test parts. However, the finish was rough in places due to support structures and after testing we found it caused a lot of skin friction drag. We therefore needed to outsource and collaborate with a company to obtain high quality parts. We partnered with Athlone Institue of Technology and Laser Prototypes Europe (LPE), who use Stereolithography (SLA) machinery with a tolerance of 0.001mm on their parts. Outsourcing was justified as we gained a flawless finish, and our parts were a great deal more frictionless compared to our Vertex printer. We also partnered with APT who gave us the use of their percision microscope and art stone base balance.

Component Manufacture

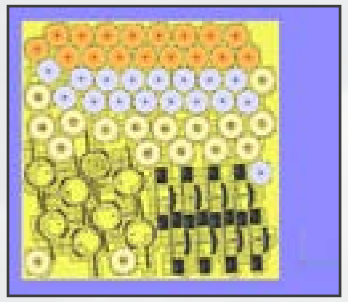
There were a number of processes and stages involved in manufacturing our components to ensure a high quality output.

Stage 1 - Preparing the file

The SLA machine must be able to read the part in a format it understands. This was done by saving the file as an STL extension. We could then adjust the density to ensure the highest quality finish before proceeding to manufacture on the SLA printer.



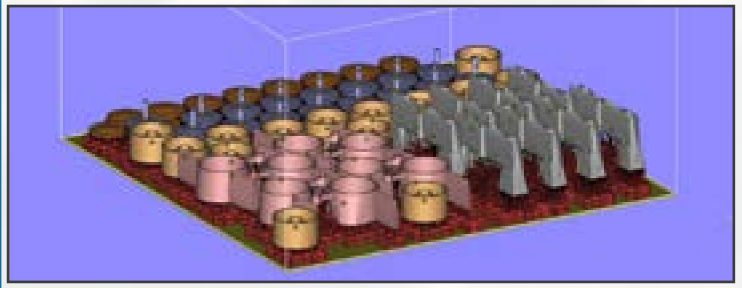
We then imported the file to the SLA computer. Here we could set various parameters such as speed infill density and support structures. We arranged our parts on one platform so they could be manufactured in one run



Stage 2 - SLA Processing

Our parts were manufactured using an iPro 8000 SLA machine, with a part tolerance of 1 micron (0.001 mm) and minimum wall thickness of 0.5mm. We used a material known as Accura Xtreme for our 3D printing which mimics the properties of ABS with a higher strength to weight ratio.

SLA is quite different to a filament 3D printer. A special resin in liquid form is used, and is contained in a container. A laser beam is then fired into the resin to solidify the material. The build platform, or container, then moves down a tiny amount, 0.001 mm in our case to form the next layer. This process is repeated until the part is formed.



Car Weight

Aerodynamics is commonly thought of as the single most important aspect of building a fast car. However through our testing, we found that aerodynamics doesn't play a huge part in the speed of the car if the car is overweight. We wanted to manufacture our car to be as light as possible. Regulation T2.8.2 states that there is a tolerance of 0.5 grams when measuring the weight of the car. However ,T2.8.4 states that the electronic balance used is calibrated to +/- 0.1 gram. Based on this, we decided to manufacture our car to the exact weight of 54.6 grams.

Weight Measurement

As we are taking such a risk with the weight of our car, we want to make sure that it is exactly what we want. While painting the car, we weighed our car on an electronic balance which we obtained from our school's science department. This was to give us an estimate of our total weight. Our collaboration with Athlone Institute of Technology gave us access to a state of the art stone base balance. This was accurate up to 0.0001 g and ensured a high quality result.

Stage 3 - Post Processing

After the parts had been manufactured, they went through post processing. The parts were sanded down firstly using high grit sandpaper. This removed any processing errors and prepared the parts for bead blasting. Finally, our parts were bead blasted using aluminium oxide. This was done using a Guyson bead blaster and it gave our parts a smooth and, more importantly, consistent finish.

Manufacturing Evaluation

Our main goal in manufacturing was to make the car exact to the CAD deisgn. We also wanted to be able to completely manufacture our car from scratch by ourselves. We feel that our regular two-hour trips to Limerick Institute of Technology and Takumi Precision Engineering were of great benefit to us and taught us exactly that. We manufactured our car as designed in our CAD model through a in-depth understanding of using SolidCAM, CNC machinery and percision SLA 3D printers

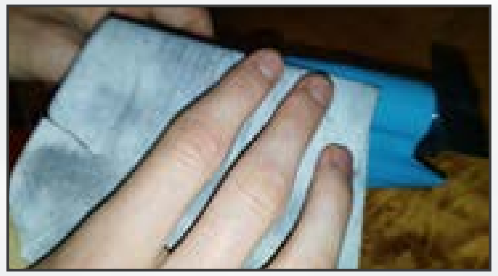
Finishing and Assembly

Finishing and Assembly Process

Our finishing process is as follows: Sanding, Priming, Painting, Lacquering, and Polishing. It was important to wear a face mask and gloves during the finishing process, as fumes from paint can be poisonous and harmful to the skin. Painting was done in a well-ventilated, open area.

Sanding

When the car came out of the CNC machine, we sanded the material. This removed the minimal scalloping marks that were remaining, and ensured an overall smooth chassis. We used high grit files and sandpaper to make the body as smooth as possible.



Priming

A primer was used to ensure that the colour of the paint was true to what we wanted. It also helps the paint stick better to the model. Multiple coats were applied.

Painting

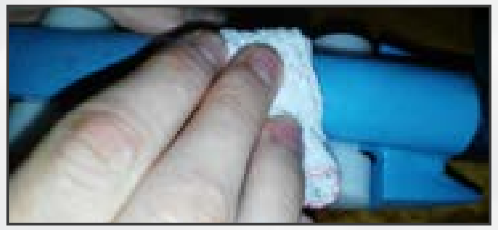
We used spray paint, intended for use on cars to add colour to our car. This was used for the base layer, while acrylic paint was used for painting a racing stripe. Multiple coats were applied to the model, applying a very light coat each time.

Lacquering

The lacquer was applied on top of our paint. It gives a shine to the car, and also seals it, making it smooth and preventing any moisture from being absorbed, which can add weight to the car. One coat of lacquer was applied per day, allowing time to dry, as wet lacquer is roughly twice as heavy as dry lacquer. The car was weighed continuously during this process.

Polishing

We polished our car using car polish to ensure a smooth finish on the car. This improves speed, as there is less skin-friction drag present. We wanted our car to stand out and shine during race day and polishing it helped us achieve this.

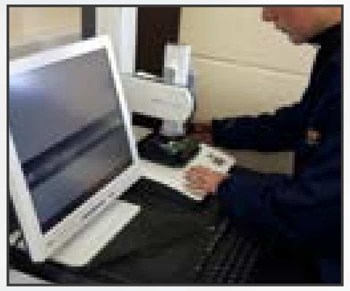


Quality Assurance

Quality assurance processes and checks were implemented to ensure our car was manufactured at a high quality so that the car fully conformed to regulation.

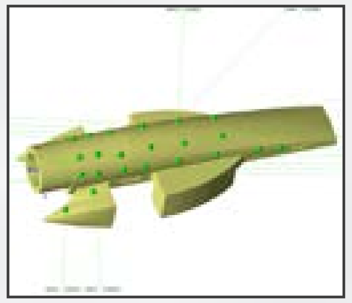
Precision microscope

Our collaboration with Athlone Institute of Technology gave us access to a super high precision digital microscope. This was used to check that our car was within every regulation.



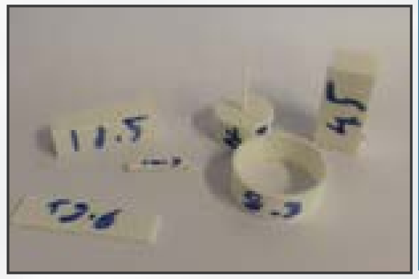
Coordinate Measuring Machine (CMM)

Takumi Precision Engineering gave us access to the use of a co-ordinate measuring machine. This is used to make sure our final model of the car is exactly the same as our CAD design. Our car was measured both before and after paint was applied, to ensure the model was within tolerance.



Regulation Jigs

For certain regulations of the car that involved a whole body and not a point, i.e. distance from the track, using precision measuring equipment wasn't adequate. We therefore manufactured a set of regulation jigs which we could use to test the following regulations (T3.6, T4.5, T8.2, T8.3, T8.4, T11.5).



Finishing Time Plan

Not enough time was left between coats of lacquer for our Nationals car. This resulted in bubbles forming, and an overall poor finish of the car. We decided to implement a timing plan which allowed an adequate amount of time between each coat of lacquer which gave a higher quality finish.

Assembly

The wings of the car were assembled before the lacquering process. This ensures a seal was formed between the wings and the body of the car. Our bearings were applied using minimal amounts of glue. For our test parts, we made sure our design had a slightly greater tolerance, to allow for ease of installing and removing the parts.

Wheel Alignment

Making sure that all four wheels are exactly aligned is crucial to ensure a fast car. We made an alignment jig to make sure that our wheels are aligned straight. The car was placed on the jig while the glue was drying. This dramatically improved the alignment.

Workplace Safety

We had little experience with manufacturing machinery and taking adequate safety precautions was very important. When using the CNC machine, we made sure to wear appropriate safety gear, such as ear, eye and hand protection. Finishing our car required an appropriate environment to work in. Paint fume poisoning was the most obvious risk so we did all of our painting outside, or in a well ventilated area. We also wore a face mask when painting our car.

Evaluation

When assembly was complete we were left with a flawless result. The area of sealing our car was explored. However, we found that brushing a sealant onto our car left a rougher finish and thus was marginally slower in our track tests. We opted to manufacture our car without a sealer.

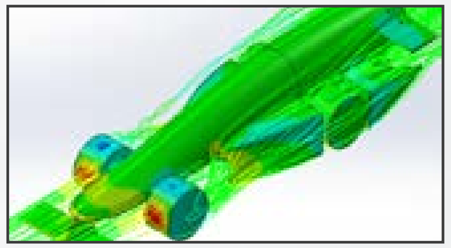
The finishing process was constantly evaluated to see how it could be improved. We found during finishing that our test cars that the parts weren't fully secure in the car. We improved upon this by assembling the wings of our car and then lacquering our car. This essentially sealed the wings into the car body itself.

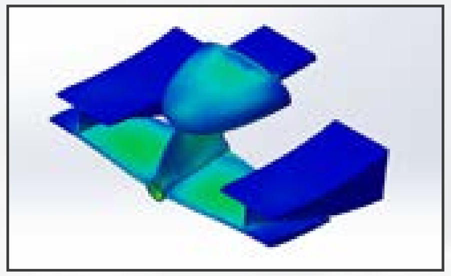
Testing

Testing Strategy
Purposeful testing was the cornerstone of our car's improvements. We set out a testing strategy that each design concept adhered to. Every design concept went through virtual and physical testing to ensure we maximised a design's potential. Developments were made from results from both virtual and physical testing.

Virtual Testing
We used FEA and CFD to get a simulated performance of our car. We used CFD to identify where large amounts of pressure built up, where turbulent air formed, where air flowed at its fastest and slowest, and ultimately the measure of the forces acting on our car.

The main purpose of any FEA test we conducted was to improve the strength of our car. FEA told us, where parts were weak at stress points, what parts would warp when affected by a given force and what parts are at risk of breaking under pressure. We constantly wanted to back up our virtual test findings with physical testing and it was this balance of virtual and physical testing that lead to developments in our car.



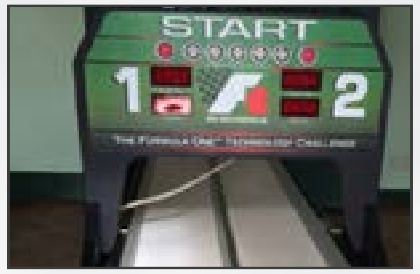


Track Testing
Track testing was our main form of physical testing. We used it to determine the performance for a given design concept and the overall aerodynamics of the car itself. We created a set method and list of conditions that must be met to ensure accuracy when testing.

- Gas canister of 28g (+/- 0.8g, 10%)
- Control room temperature of 20C
- Air Humidity of 40-50%

Every car component was tested 4 times (number of races) and the average time was taken as the concept result.

Video Analysis
Video analysis is a type of testing that coincided with the physical track testing. We used high-speed cameras and thermal imaging to find areas of friction and to note various variables such as when the wheels start turning, and how well the LERS works.



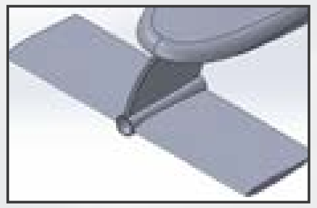
Wind Tunnel
We used wind tunnels to identify areas of turbulence which existed around our car and to calculate the lift (in newtons) of our car. This ultimately allowed us to back up our CFD results via physical testing and make developments.

In the beginning we were very limited on resources so we designed our own wind tunnel. We placed a candle in front of our car and observed the trail of smoke around the car. We used a high speed camera so we could identify areas of turbulence.

However, through our collaboration with AIT, we had access to a state-of-the-art professional wind tunnel. With this we used a force balance to measure the lift and down forces that were acting on the car.

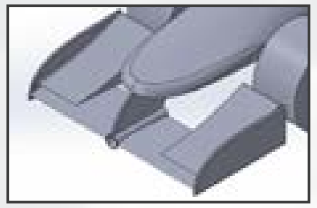
Front and Rear Wing
With access to a filament 3D printer, we able to test multiple concepts both virtually and physically. We tested 10-15 concepts of both front and rear wings and took the top 4 of each type to manufacture and test. We used wind tunnel testing to back up our CFD results and develop the wing further if needed. When selecting our front and rear wing, we looked at two main attributes: track performance and wheel durability. We therefore chose our wing based upon results from track testing and FEA analysis. The results of these tests can be summarised below.

Front Wing A



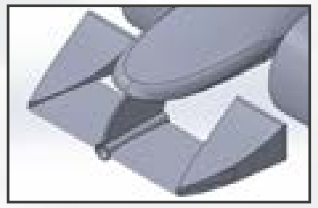
Time = 1.256s

Front Wing B



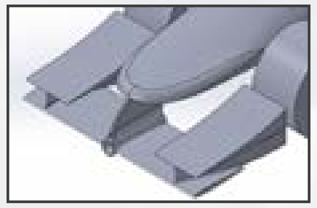
Time = 1.179s

Front Wing C



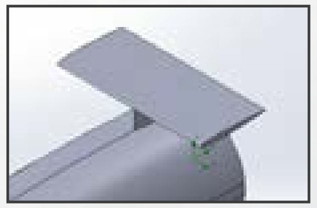
Time = 1.134s

Front Wing D



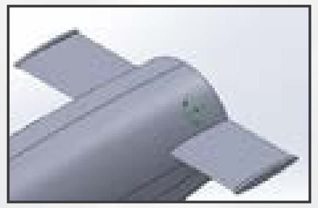
Time = 1.105s

Rear Wing A



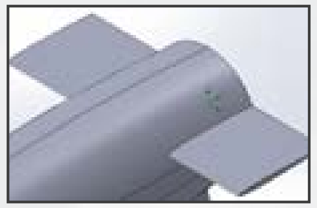
Time = 1.105s

Rear Wing B



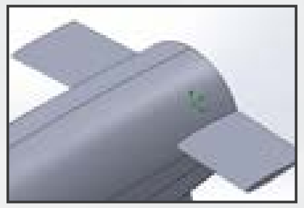
Time = 1.098s

Rear Wing C



Time = 1.077s

Rear Wing D



Time = 1.064s

LERS
To test the effectivness of our LERS we used track testing accompanied with video analysis. We tested various shaped LERS and how well they deflected the canister air.

Bearings
To test the bearings, we put different sets of bearings in one wheel of the car. We then placed the car on a piece of cardboard next to a protractor. We tilted the cardboard and noted at what angle the car began to move, i.e what force is needed to move the car. From our tests we concluded that silicon nitride ceramic bearings were the most frictionless.

Steel - ABEC 1
Angle = 3 degrees

Ceramic - ABEC 5
Angle = 0.4 degrees

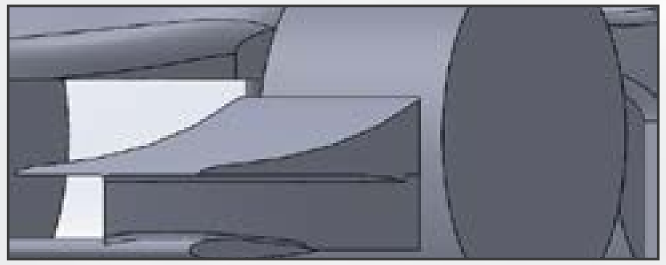
Final Development & Design Evaluation

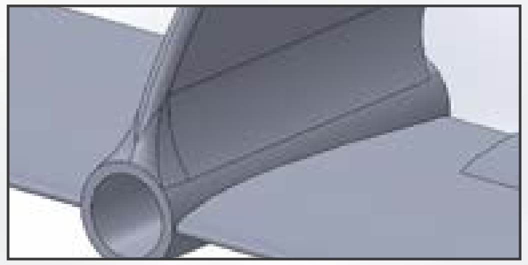
Car Developments
After we had completed both our virtual and physical testing on all components of the car, we were able to make final developments to the car. These developments were solely based on research and test findings alone.

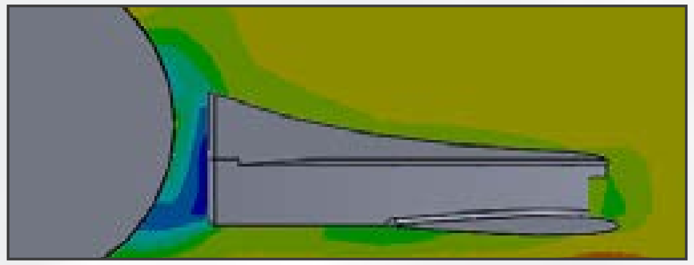
Front Wing Development
From our wind tunnel tests, we noticed a large amount of turbulence occurred in the wake of the front wheel. We developed our front wing to send a larger volume of air over the wheel as opposed to under the wheel to reduce air turbulence.

We identified that the joint between our tether guide tendon and our tether line guide was under a lot of pressure. We therefore added 5mm fillets to improve the strength of this part.

To further develop our design, we wanted to ensure the air at the front of the car didn't slow down due to form drag. We used CFD results from our velocity cut plots to improve the general slope of our front wing to maximise the wing's performance.

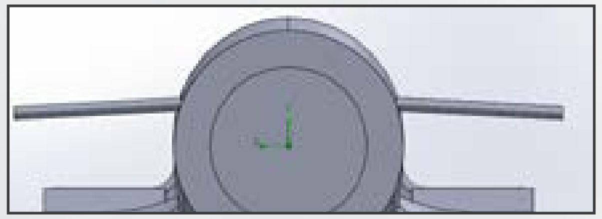




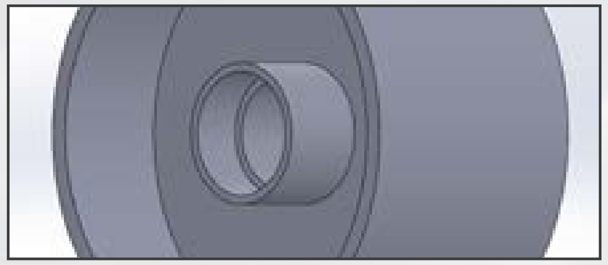


Car Weight Development
One area with which we wanted to improve our car was how the weight was distrubuted. At first, our prototype was over 15g under the minimum weight which lead to problems in finishing the car. We therefore made our 3D printed parts more dense by using Xtreme and configuring the .stl file to print at a higher density.

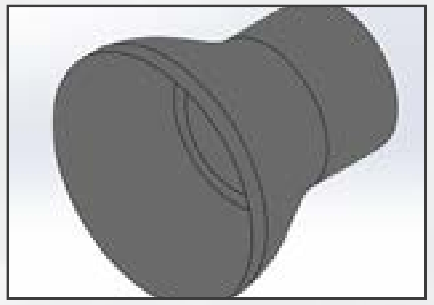
Rear Wing Development
From our CFD results, we found that a wing at an anhedral angle of 3 degrees performed the best. We backed this design development up with research on the dihedral effect of wings.

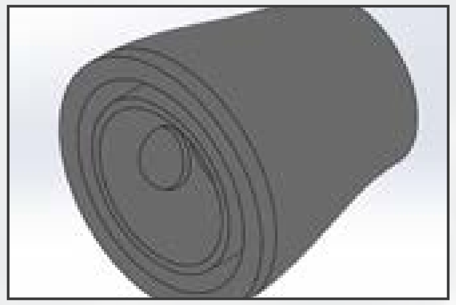


Wheel System Development
To find the ideal wheel design, we wanted to develop a wheel body that had a strong inner spoke system. We used FEA to simulate the force our wheel was under during the race and develop an inner wall which would support the wheel throughout the race.

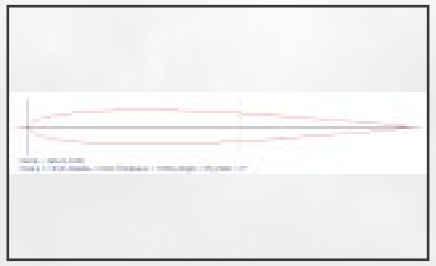


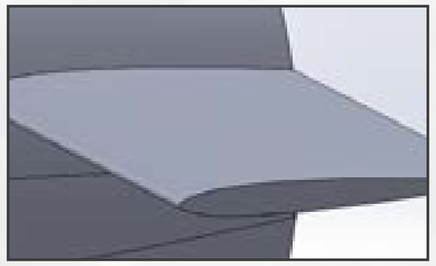
LERS Development
To develop our LERS design further, we used video analysis to analyse how our LERS deflected the air from the canister. From our video analysis, we found that a LERS which enclosed our car, but didn't touch our car, performed the best as it captured the most air.





Airfoil Development
We wanted to maximise the potential of our wings when designing. To do so, we collaborated with DesignFoil who use airfoil plotting software. We used a NACA 0006 wing which had an extremley low base drag coefficient. We inputted our chord length and thickness to the software and were able to model the perfect aerodynamic wing which created the lowest drag possible.

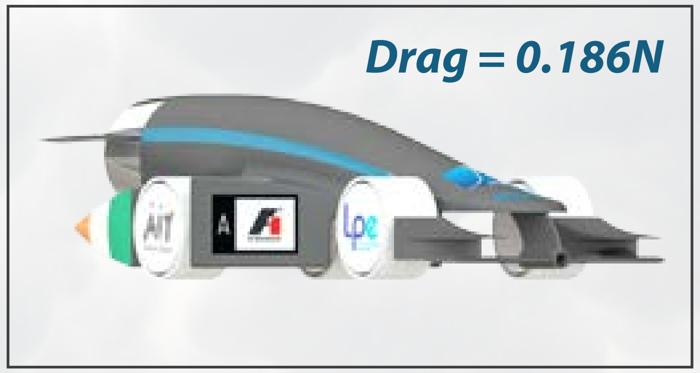




Design Process Evaluation
Our final car is the product of hundreds of hours of designing, testing, developing, and evaluation. We developed an aerodynamic base model and improved each individual area of the car using a comprehensive design process. This design process was developed from the scientific method. We essentially took a design based on research, analysed and tested it, and then developed this design. We evaluated this method and improved our final design process. Our elaborate system uses two stages of development. The first stage of development is based on virtual analysis alone and the second stage of development is based off test results. This balance of virtual and physical testing allowed for improved developments. It also allowed us to constantly test our car in the instance of a physical test malfunctioning.

The difference in our World Final's car and our National Finals car is phenomenal. Our chassis is longer and uses a developed teardrop design to improve overall aerodynamics. We utilised the coanda effect in our side and rear pods to reduce all drag present about our rear wheels. We also developed a multifunctional front wing which diverts as much air as possible away from the front wheel in an elaborate design. We maximised the potential of our rear wing design by using an NACA 0006 wing. As well as our car being designed to perfection, we manufactured our car to perfection. Our car was designed and manufactured to rigid specifications.

National Finals Car



World Finals Car