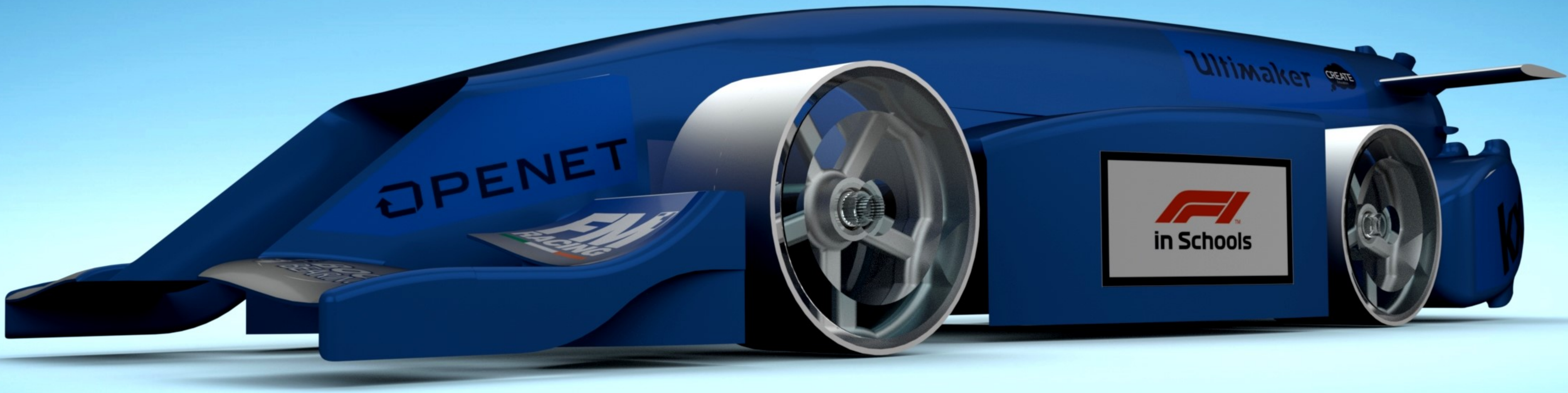
Ultimaker | kx | W DISPLAY | McKeon Bros. | OPENET | DHL EXPRESS | BOCA BEARING

NON-STOP *INNOVATION*



IRELAND'S BEST ENGINEERED CAR: *UPGRADED*

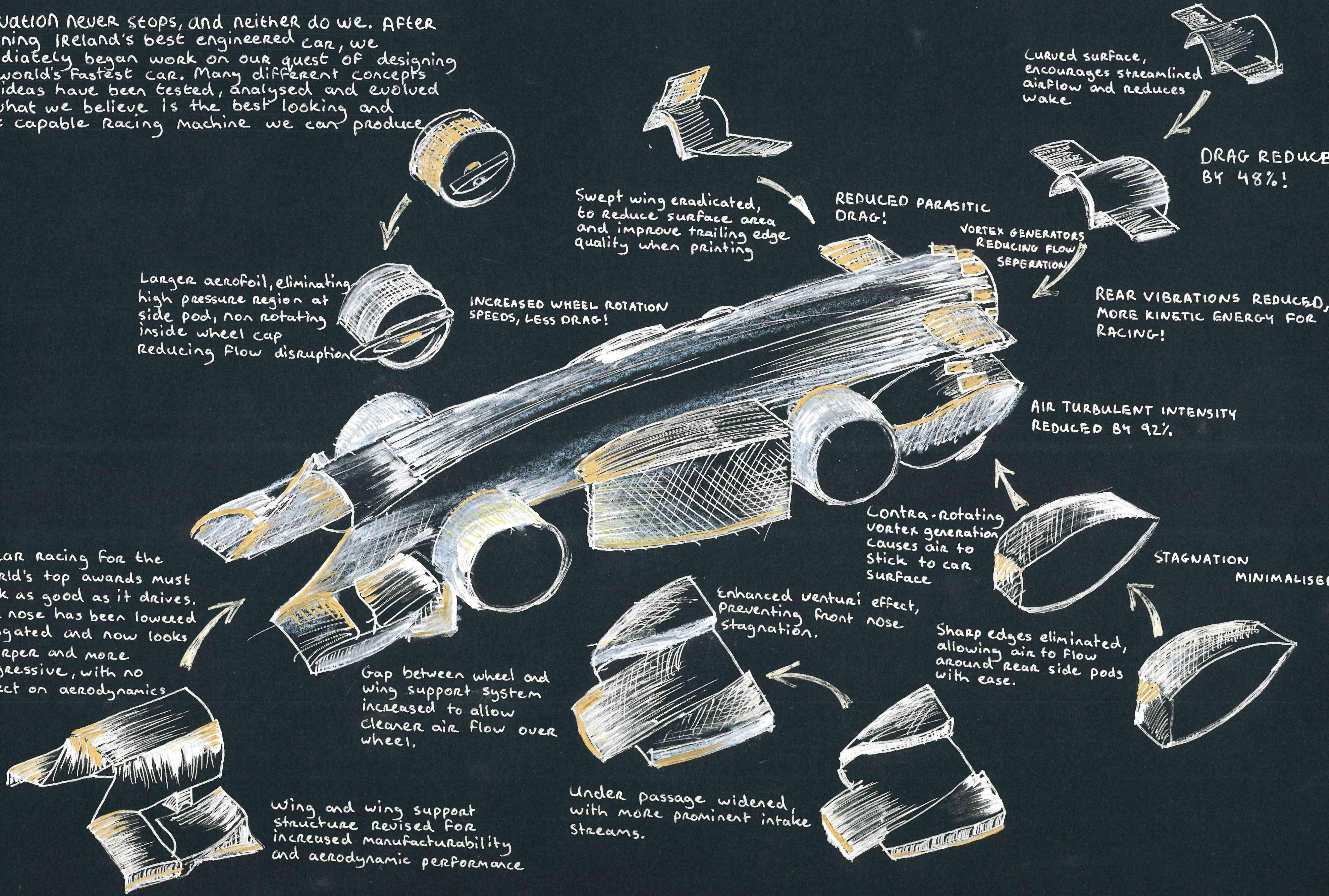
DESIGN & ENGINEERING

F1 in Schools

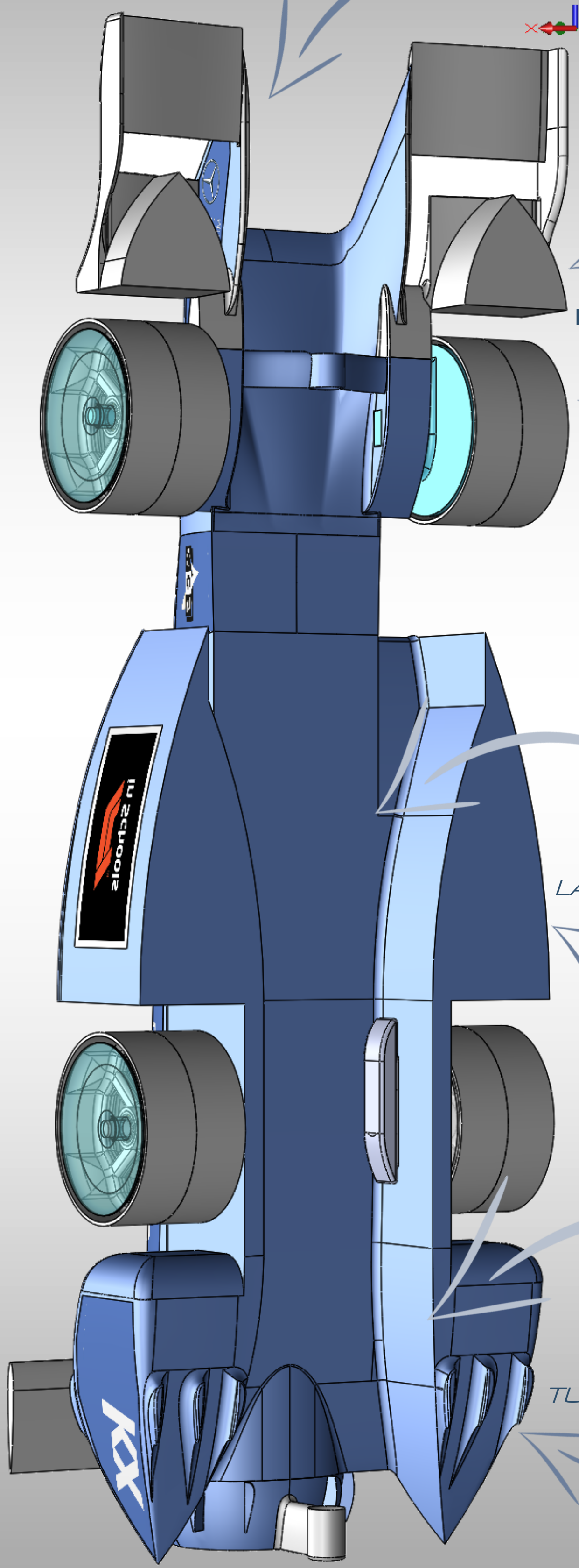
World Finals Singapore 2018

FM RACING

Innovation never stops, and neither do we. After designing Ireland's best engineered car, we immediately began work on our quest of designing the world's fastest car. Many different concepts and ideas have been tested, analysed and evolved to what we believe is the best looking and most capable racing machine we can produce



CAR DESIGN



MINIMISED *RESISTANCE*

The open-mouth design of the front of the car allows oncoming air to channel right underneath the car un-opposed, rather than being forced to flow above or around the car.

Air is pushed both above and around the front wheels.

MAXIMISED *ROTATION*

The wheels have the smallest dimensions allowed in the technical regulations. This enables them to create less drag, and spin faster as surface in contact with the track is closer to the axel

Air flowing within the underside of the car experiences the Venturi effect, moving at a higher speed and lower pressure.

GREATER *LAMINAR FLOW*

Air flowing outside the car sticks to the curvature of the side and rear side pods.

Air travelling outside and inside the car meet and mix with equal pressure and velocity. The interior and exterior surfaces of the rear side pods converge, leaving no wake or flow separation.

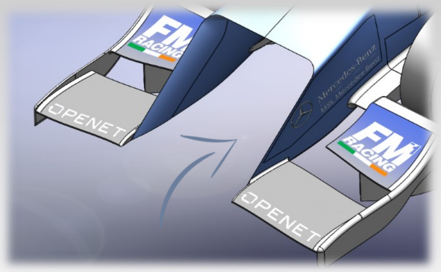
DIMINISHED *TURBULENT FLOW*

Vortex generators and rear diffuser reduce wake turbulence, by eliminating boundary layer and reducing flow separation

UNCOMPROMISED *SPEED*

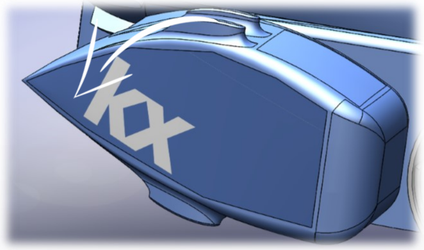
Biomimicry has been used by engineers for hundreds of years. Studying the aspects of nature and incorporating them into their own designs has helped designers create better, faster, stronger and more efficient machines. In the automotive and aerospace industry, aquatic and airborne animals are constantly analysed, as many of them hold the key to the greatest designs possible. We took a similar approach on designing our car.

MORE *CONTROL*



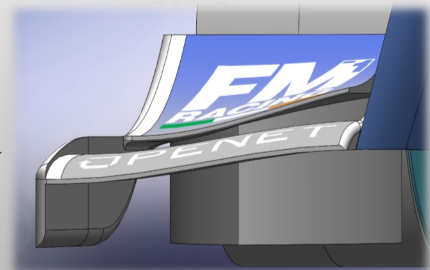
The Manta Ray is one of the most beautiful species to grace the ocean. When cruising through plankton biomasses, the Ray's cephalic fins unfurl, creating a region of low pressure in front of its mouth, channelling the surrounding water and food into its mouth, allowing it to eat more, with considerably less effort. The front of our car features a similar concept, inspired by the cephalic fins, guiding large volumes of air underneath the car

LESS *DISRPUTION*

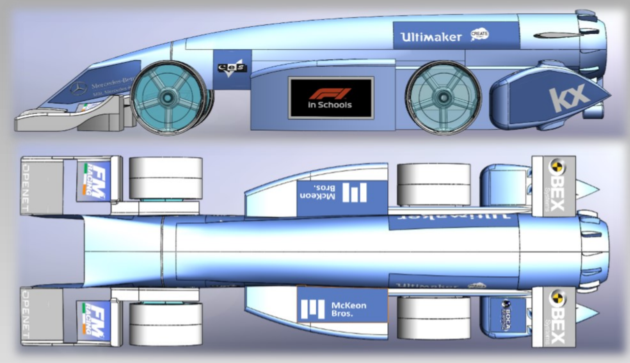


Our rear side pods are designed to channel incoming fluid above, below and at either side together, without leaving a wake. This shape was inspired by the tail of the Blue-Fin Tuna. This fish uses its streamlined teardrop shape to accelerate into the list of the world's fastest-swimming fish. Although not directly taken from this fish, our vortex generators stay true to this concept, allowing our car to effortlessly cut through the air, leaving as little a trace as possible, and as little drag as possible

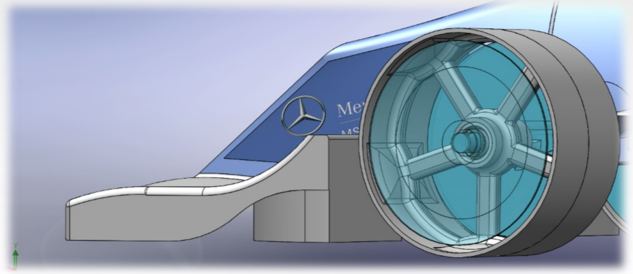
UNSTOPPABLE *PERFORMANCE*



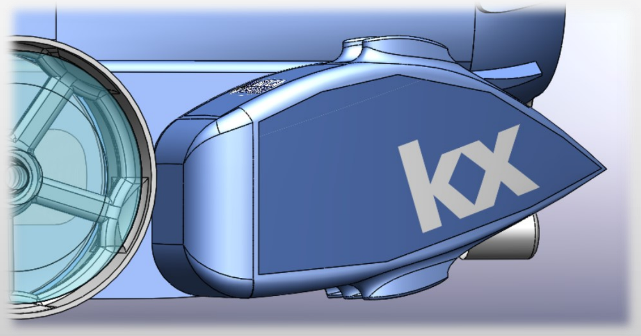
An albatross can travel ten thousand miles in a single flight, without exhausting itself of energy. Its wings have a very high aspect ratio, and a low thickness, enabling it to glide for huge distances without flapping. The car's front wings mimic this with the lowest legal thickness and chord, giving it a similar profile to the wing of an albatross. The curve of the albatross's wing was also added to the car's wing for aesthetic purposes



The car's body is designed to be completely curved and smooth, with no interruption, air can flow smoothly above and around all surfaces.



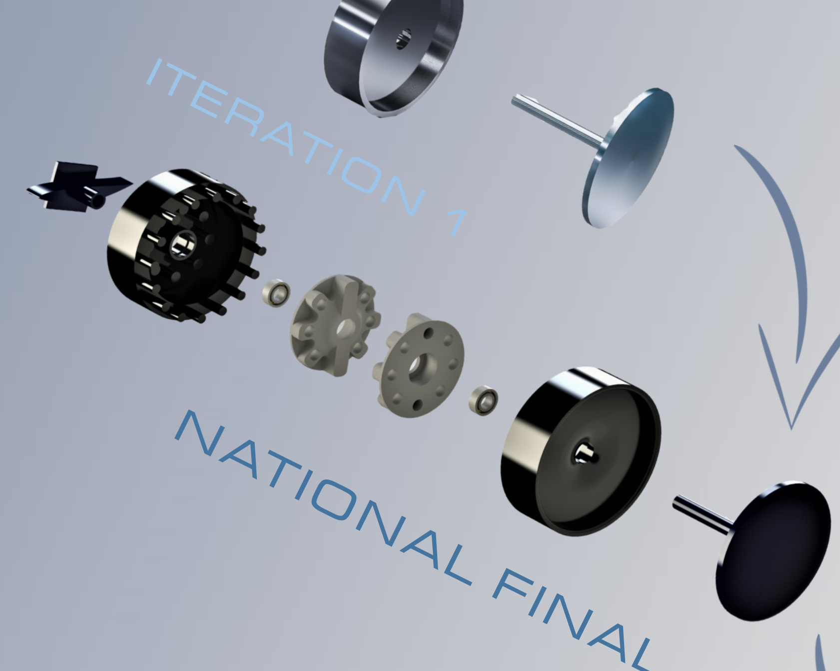
It was necessary for us to deflect the air travelling towards the front wheels over the wheel, eliminating a potential high pressure area. However, too much air can oppose the forward rotation of the wheel due to skin friction, reducing its axial velocity. For this reason, only air flowing above the front wing is deflected over the wheel, and air flowing beneath the wing is deflected around the wheel.



The rear side pod is not entirely sheltered by the wheel in front of it, as air sticks to the cylindrical surface of the wheel, flowing downwards and creating a high pressure, high drag region. For this reason, the front face of the rear side pod is significantly lowered, before rising again to meet higher velocity air flowing above the wheel, before converging with air flowing beneath the car. Large fillets on the face further help any air to flow around the structure, and not stagnate.

VEHICLE ASSEMBLY

We used Strengthened PLA with an internal honeycomb structure to provide our parts with the highest strength.



Our wheel system has evolved significantly in search of the most efficient configuration.

SEAMLESS *INTEGRATION*

The car's nose assembly is divided into three components: the nose cone, the wheel support carriage, and the nose connector. Each part plays a vital role in the car's performance. The three parts slide together perfectly like a jigsaw, without the use of an adhesive.

33% of the car body's weight consists of the coating and paint, creating a smooth finish, reducing drag

The front axel slots have a larger surface area than a traditional slot or rectangle, allowing for more grip on the parts.

Our World Finals car features 29 individual components, which has been reduced from 41 components for our National Final car. We reduced our amount of parts in order to produce a more reliable, simple racing machine, while retaining complete functionality. Adhesive is only used for joining 4 of the parts.

The rear tether guide has been integrated into the rear wing support module, making assembly much easier, and reducing drag and weight

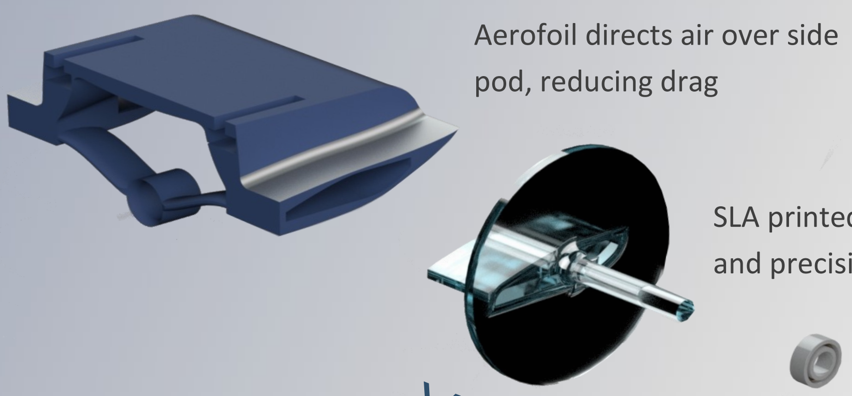
SIMPLICITY:

CHEAPER, STRONGER, FASTER

PMMA, the same material used in bullet-proof glass was used to manufacture our axels, providing strength and low weight.

COMPLETE *PRECISION*

Aerofoil directs air over side pod, reducing drag



SLA printed axels offer ultimate strength and precision.

Machined slots in the car body allow the wheel axel mounts to fit perfectly into the body, to support the wheel system with perfect alignment.

WORLD FINAL

Bearings mounted outside wheel, eliminates need of bearing lock plate.

Transition fit tolerances allow entire system to be assembled and disassembled with no adhesive.

Full ceramic bearings, for optimal rotation

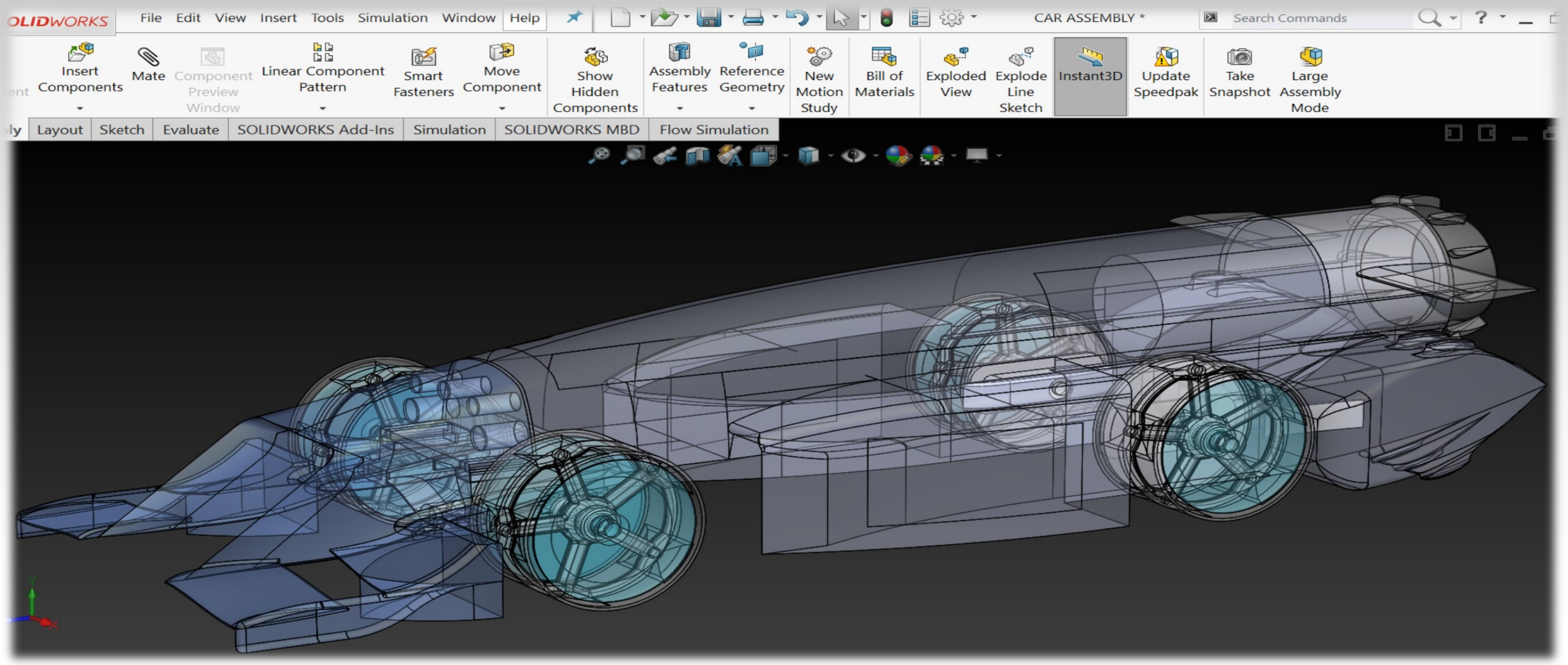
CONTINUOUS *DEVELOPMENT*

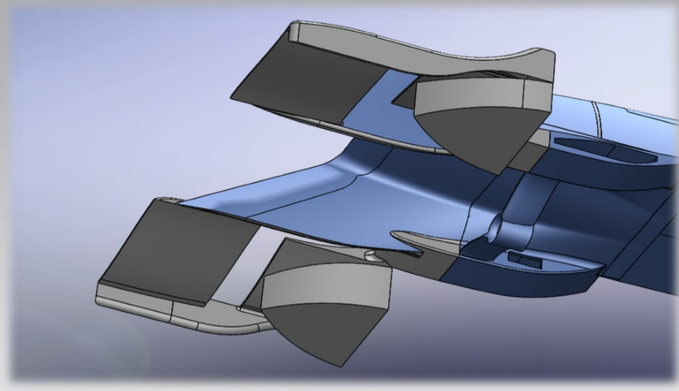
DESIGN EVALUATION

Research; develop. Analyse; improve. Study; enhance.

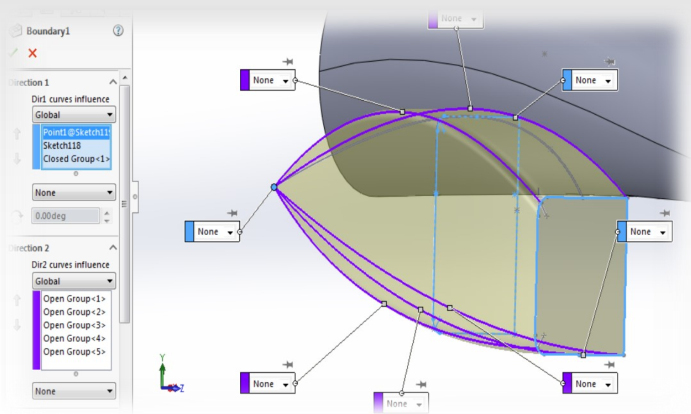
Our final car is the result of the continuous application of these verbs to our design process. Looking back to our first ever F1 in Schools Car to our 2018 World Finals Car shows the impact of a comprehensive design and R&D strategy. All F1 cars are prototypes none of them are perfect, but we firmly believe that this car is as any could be. However, this is not enough for us, If we continue racing in F1 in Schools, we will continue to develop, enhance and improve, to find every hundredth of a second possible.

All components of the car were modelled using SolidWorks at the facilities of our school's DCG room or at Dublin City University's CAD/CAM studio. SolidWorks was used due to our two engineers' experience using the software, and its array of advanced modelling features and its seamless integration with ANSYS, Alpha-CAM and SimScale, enabling the car to be transformed from sketches to a 3D model, and from there, a manufactured racing machine.

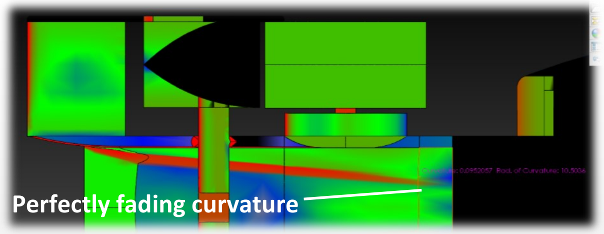




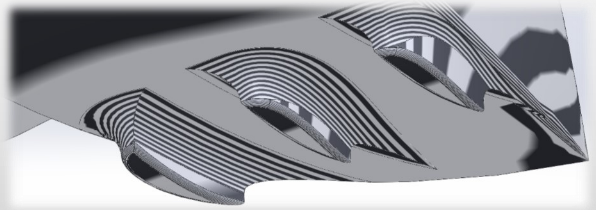
The nose, alongside most of the car was modelled using solid lofts and boundary fills. Solid geometry was preferred over surface geometry, as the aerodynamic cross sections of some of the parts cannot be defined with surfaces, even when they are thickened, for example, aerofoils and other flow structures. Using solid features, the exact desired shape of the car's components were achieved.



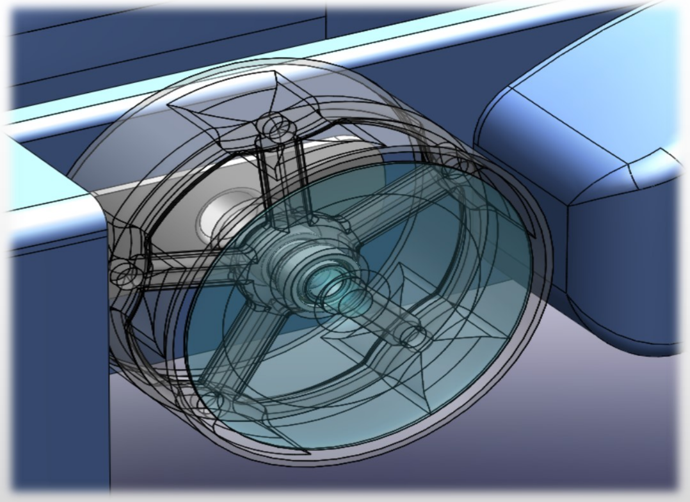
Four planar and four non-planar sketches were used to define the geometry of the rear side pods with a Boundary Fill. The rear pods play a critical role in the aerodynamic setup of the car, as they allow air flowing over the wheel to converge, reducing the car's Reynolds Number. This feature and many others included fillets, to help with the machining process



By pushing our CAD package's capabilities to the limit, we analysed the curvature and shape of our car. SolidWorks' post-model curvature highlighted all areas of curvature on the car, on a relevant scale, allowing us to analyse where the complex shape and curvature of the nose transitioned to the flat underside of the car, to see if we were happy with this surface.

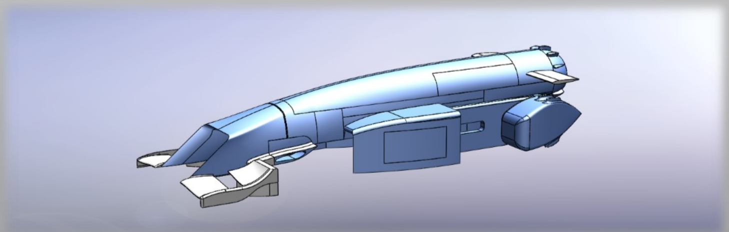


Zebra stripes were used to study how complex surfaces integrate to one another. The zebra pattern changes on every surface deviation, enabling the team to closely analyse areas of the car, such as the fillets on our vortex generators, which more clearly display how the surfaces flow, and if this shape will be manufacturable.

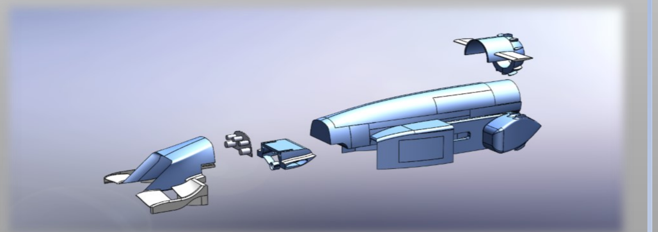


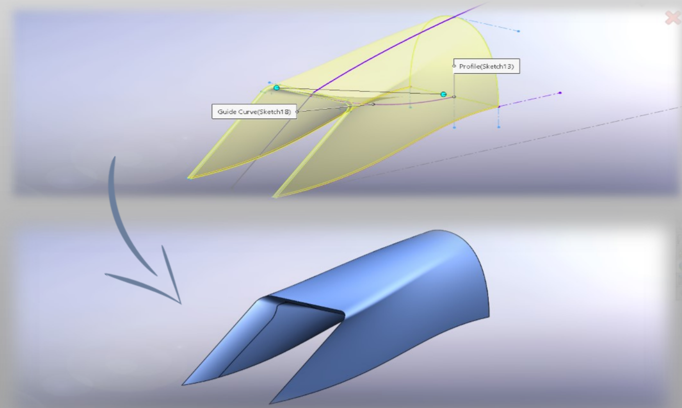
The full CAD assembly contains all 33 individual car components mated, a decrease from our National Finals car, which had 41 parts. We decreased the complexity of our car to reduce costs and manufacturing times, while improving performance. This assembly allowed us to visualize exactly how the parts interact with each other and allowed us to find any potential problems that may have arisen with the manufacturing or assembly processes. Shown here is the intricate internal assembly of the rear wheel.

The entire car, excluding the wheels was produced using the "bottom up" master assembly method. First, the entire car was modelled as one. Then, using the "split" and "combine" features, each individual component could be isolated and saved as a part for manufacturing. This method greatly reduced the time of the modelling. Each part was then reassembled, to study how they interact as separate mated components and to find any potential errors.



FIVE PARTS MODELLED IN THE SAME TIME AS ONE

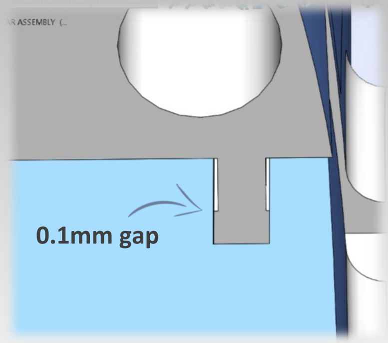


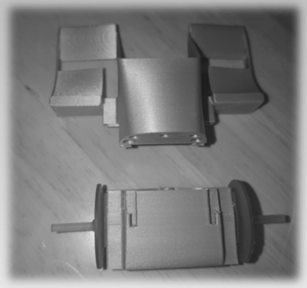


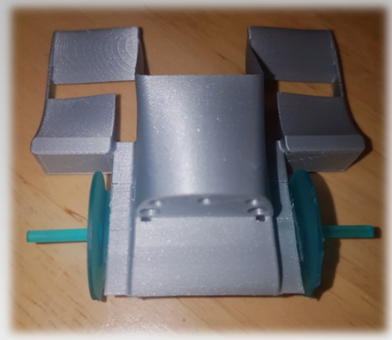
Using tools such as the adaptive "FilletExpert" solver on SolidWorks, we could transform some parts of the car, such as the open front nose loft from simple, dull faces and contrasting edges to clean, smooth, continuous and more streamlined curves. This was very beneficial to the shape, aerodynamics and aesthetics of our car.

CAD MANUFACTURING CONSIDERATIONS

When Modelling the car on SolidWorks, every feature was assessed to determine if it could be manufactured effectively, via both additive and subtractive manufacturing.

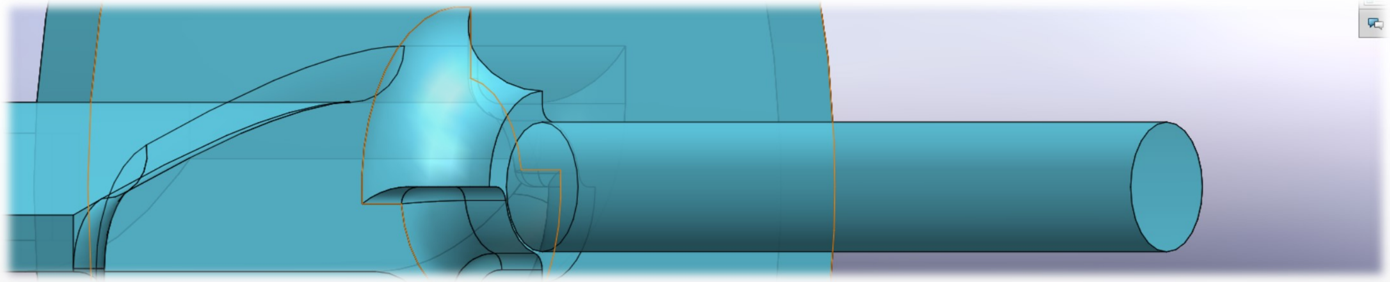




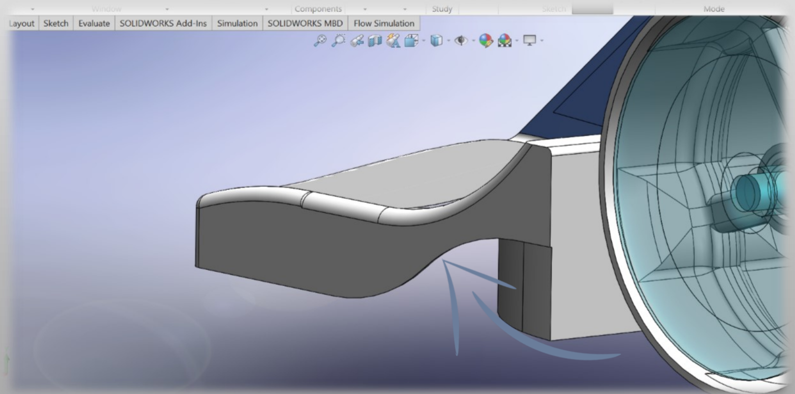


FULLY MODULAR, *TRANSITION FIT*

The car's design was intended to be fully modular, allowing all components to be changed, replaced or improved, with very little time or expense. This meant that all components must be fitted together with no glue. We concluded that a transition-fit tolerance would be the most effective at keeping the parts strongly mated together, with friction, but they could be removed with reasonable force, and without risk of damage. Any part that inserted to another had at least a 0.1mm gap, so that the tolerance zones partially overlapped, making sure that our accurately built parts fit together seamlessly.



The axels of our car have experienced the highest amount of change and improvement of any car component. Originally optimised for FFF 3D printing, the axel was long and thin, fitting our bearings, but extremely fragile, and not entirely accurate. To improve this, we decided to manufacture the axels with SLA tough resin, with properties similar to shatter-proof glass. We added short support columns to increase the strength of the axel further, while also locking the bearing in place, preventing the wheel from sliding or the bearing from falling out of place.



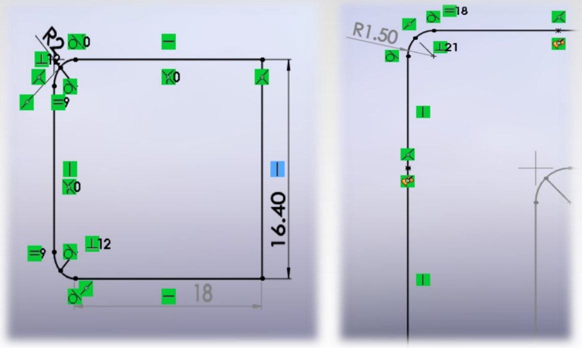
A large radius was added to the front wing support system. This was originally a vertical surface, which still allowed the air to flow around the wheel, however, when 3D printing, there was no surface underneath it for support material to build from. For this reason, the radius was cut into it, eliminating the overhang and the need for support when the nose is printed pointing upwards.

NO STONE *UNTURNED*

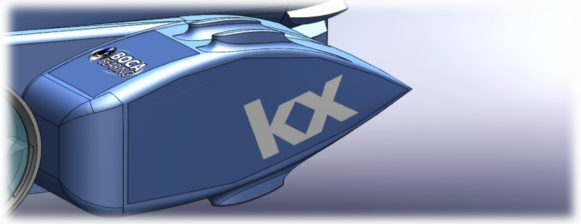
The rear side pod section is by far the most intricate part of the car to be manufactured by subtractive manufacturing.

The rear side pod features a multi-radius fillet, that was added to the sketch profiles rather than the finished 3D body itself. This enabled a much more consistent and controllable shape, which starts with a 2mm radius on each edge, before converging to a single point at the end of the car.

Our vortex generators on the top and bottom surfaces of the rear side pod have been designed to be 4mm apart, so that a 3mm cutting tool can comfortably fit through them. Each aerofoil has a 1.5mm radius, so that it perfectly blends into the parent surface while being cut, greatly improving the aero-efficiency and strength of each vortex generator.

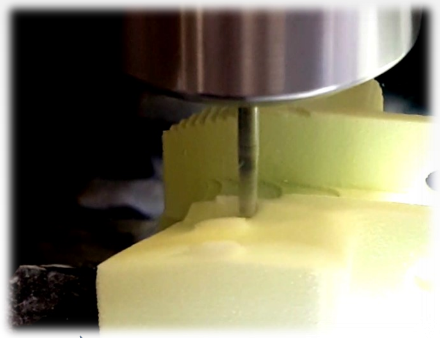


Varying fillet radii for profile sketches of the side pod

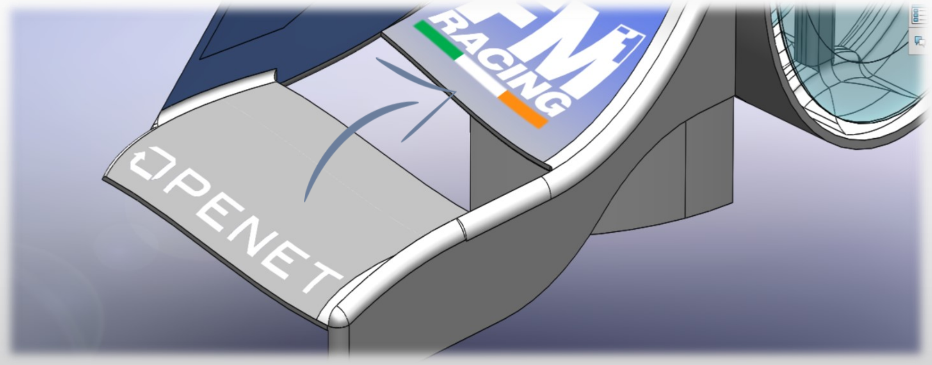


Completed model

GREATER *MANUFACTURING EFFIENCY AND QUALITY*



Finished Product



In theory, the leading edge of the fairing behind the front wing should be an edge, and not a face. However, a 0.25mm face was added, so that when printing, the 0.25 nozzle of the 3D printer will accurately construct this part, and not leave a gap, as the slicer will not programme anything less than the nozzle diameter to print.

CAD EVALUATION

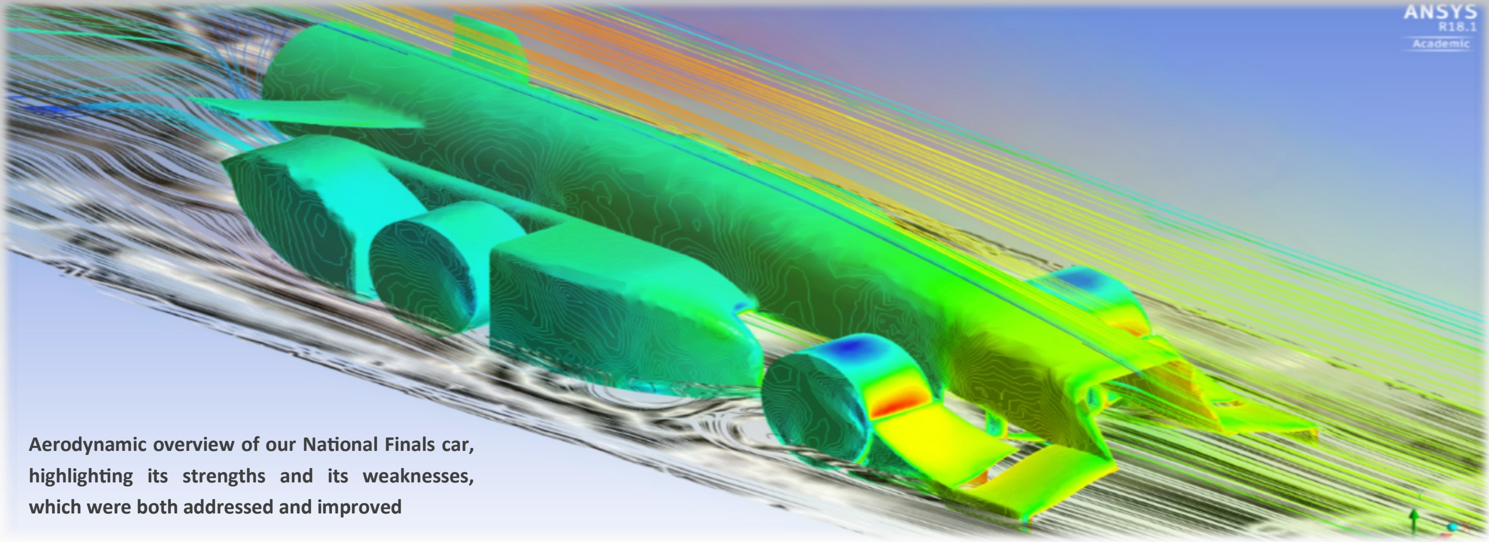
We were very satisfied with the outcome of the iterative method we used to model every component of the car using SolidWorks.

Over many weeks, every part was modelled to match the concept sketches as closely as possible while keeping functionality and manufacturability.

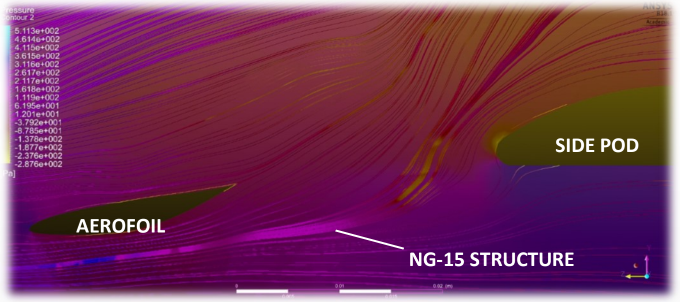
Unfortunately, due to the intricate small faces and tight angles of our front nose, which was modelled this way for aerodynamic purposes, the nose geometry struggled to mesh properly in ANSYS, however, this was soon resolved.

CFD ANALYSIS

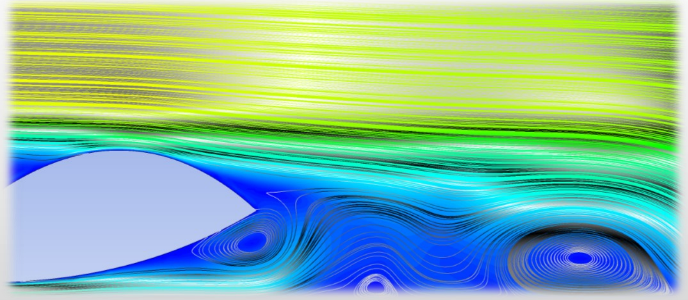
We used some of the world's most advanced simulation software to comprehensively analyse how our car will perform on the track. We found areas that need developing, developed and improved these areas and then re-tested to verify the improvements. We used both ANSYS FLUENT and SimScale in Dublin City University's CFD/FEA studio to test both the car's aerodynamic and structural properties respectively.



Aerodynamic overview of our National Finals car, highlighting its strengths and its weaknesses, which were both addressed and improved

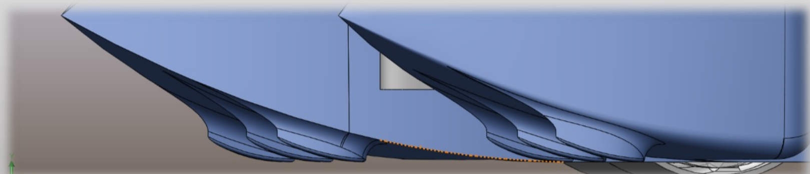


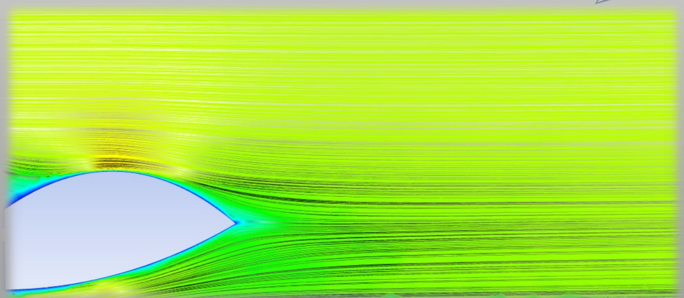
The benefits of the aerofoil located on the front wheel's axel hub were confirmed with this streamline rendering. These two 4mm wide wings create a small region of low pressure on the bottom surface, which causes an upwards suction, forcing air to flow over the side pod. This engineered flow structure creates a region of low pressure, and low drag on this section of the side pod, which otherwise would have been higher.



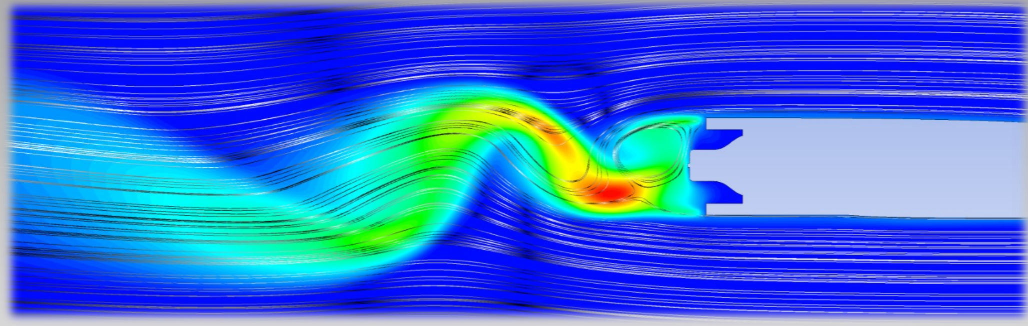
Our rear side pods were designed with the intention to guide air from the wheel and the rest of the car in front in a streamlined fashion, leaving a minimal wake. However, when running a simulation on this area using a K-Epsilon turbulence model, we realised that the gradient of the rear side pod's slope was far too high, creating the dramatic amount of turbulence seen here. This was a massive area of the car that needed to be developed

92% DECREASE *IN TURBULENCE*





To solve this issue, we added vortex generators above and below the rear side pods, which almost completely eliminated the parasitic form drag caused by the side pod gradient. The vortex generators create a stream of small vortices, which force air to stick to the surface of the car, despite it travelling to an area with higher pressure. This innovation has greatly enhanced the performance of our car.



DRAG (Z direction) (N)

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Total
-11.061722
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-11.061722
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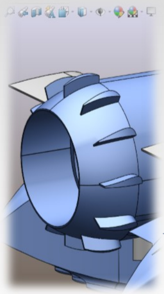
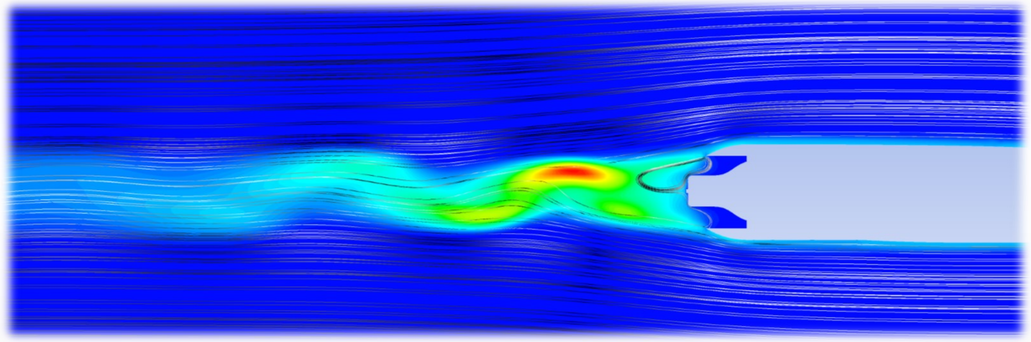
One area of our National Finals car that we knew needed development before analysing it was the rear cylinder section. Due to the regulations, and the very nature of how the cars were raced, this area creates a large low pressure region, causing massive wakes and large amounts of turbulence, as shown above.

Our solution was to place a ring that tapered inwards behind our rear wing fixture. This greatly reduced the wake of our car and the drag that it caused by guiding the streamlines at opposite sides to converge much cleaner. Also, the area behind the car was reduced, reducing low pressure pockets. The dramatic improvement in airflow can be seen below



48% DECREASE *IN DRAG*



DRAG (Z direction) (N)

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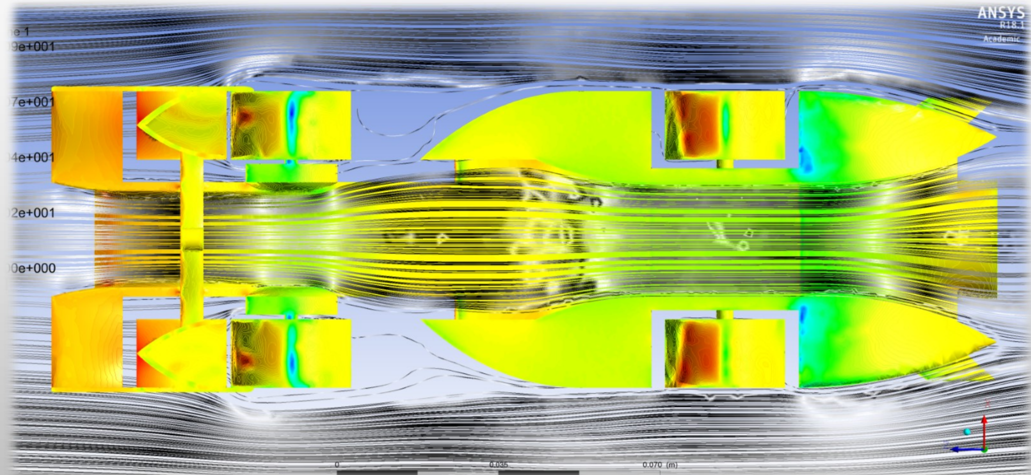
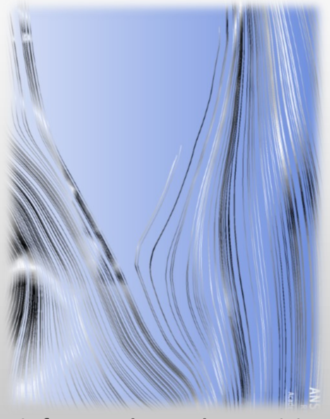


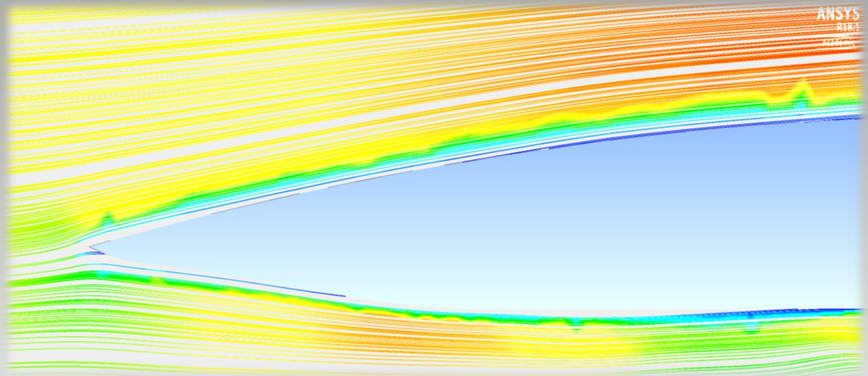


Air from underneath car mixing with air from outside

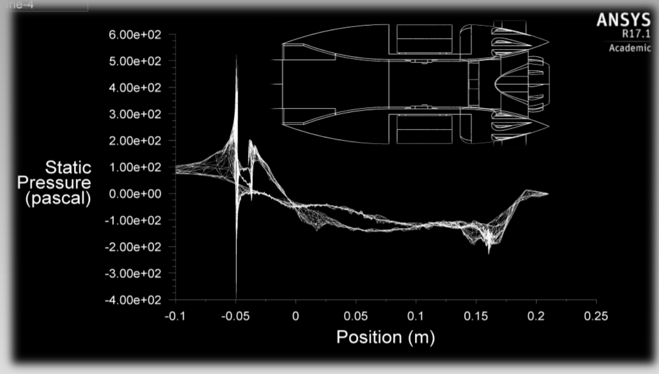
This image clearly shows the general design philosophy of our car, in regards to airflow. Air flowing underneath the car from the nose to the back of the car is completely laminar. The air is slightly compressed, increasing its velocity, before expanding to the same volume that it entered with, allowing air from underneath the car and around the car to merge seamlessly.

The main side pods manage the wake of the front wheels very well, guiding the dirty air around the car, rather than underneath. All of this contributes to an extremely aero-efficient vehicle.

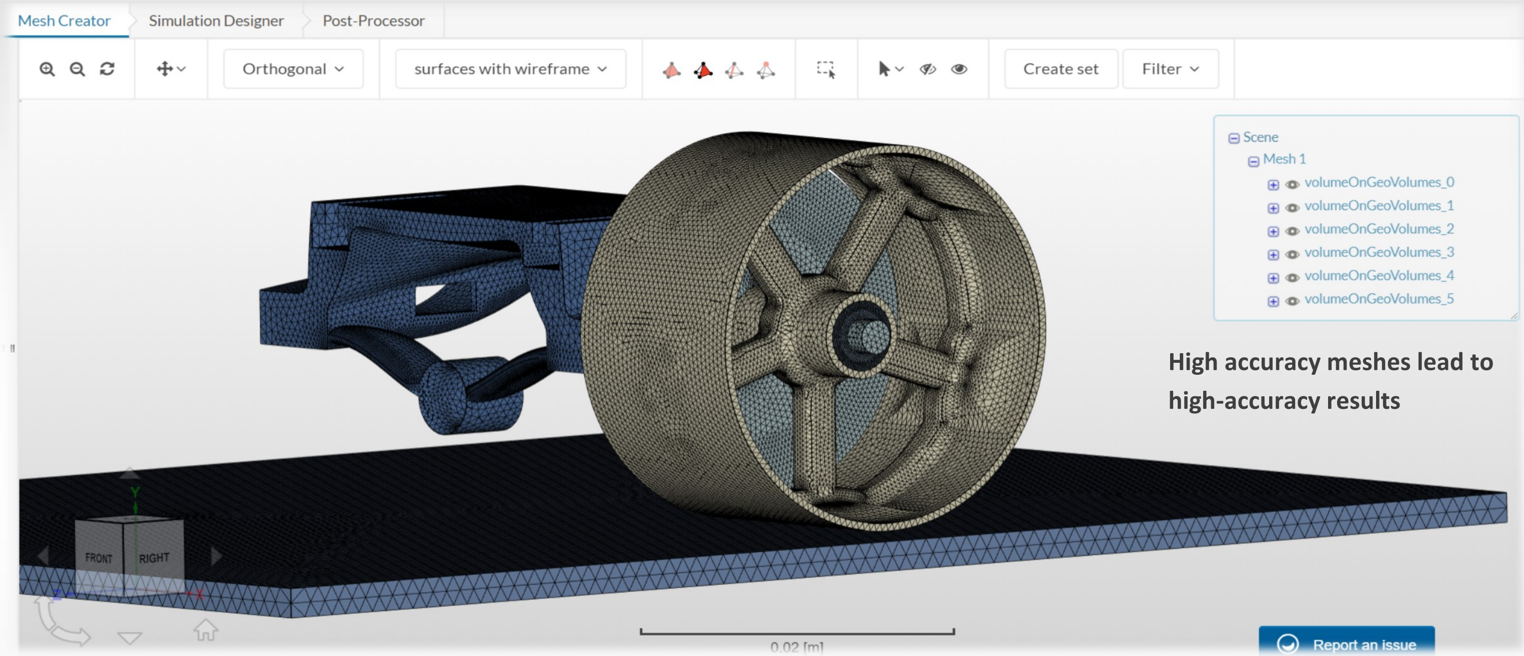
CFD/FEA ANALYSIS



The car's centre body, which can be seen to the left, as a sectioned view, was designed to allow air to flow cleanly above and below the car, with as low a drag profile as possible. The venturi passage underneath the car creates a region of low pressure behind the nose, which forces all high pressure air that would normally build-up at the front object to flow towards the rear of the car, reducing stagnation significantly.



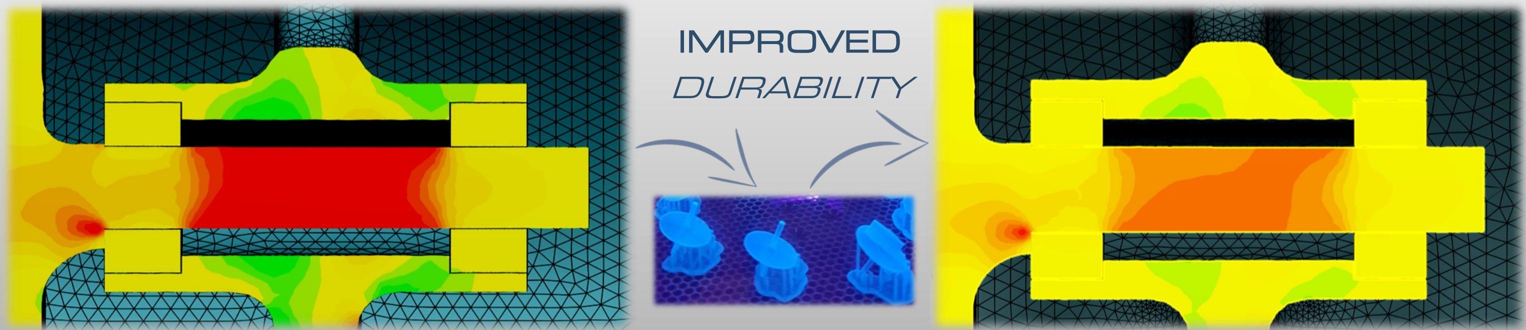
Unlike traditional racing cars which use the Venturi Effect for downforce, our car exploits the effect for improved airflow. As air flows underneath the car, it creates a pocket of low pressure, which higher pressure air at the front of the car flows to, such as the front nose, and the front tether guide. This was an innovation of ours originating from 2017's regional competition, and is still a massively important feature in our car. The graph to the left shows how the static pressure drops significantly in this area, compared to the higher pressure at the front of the car.



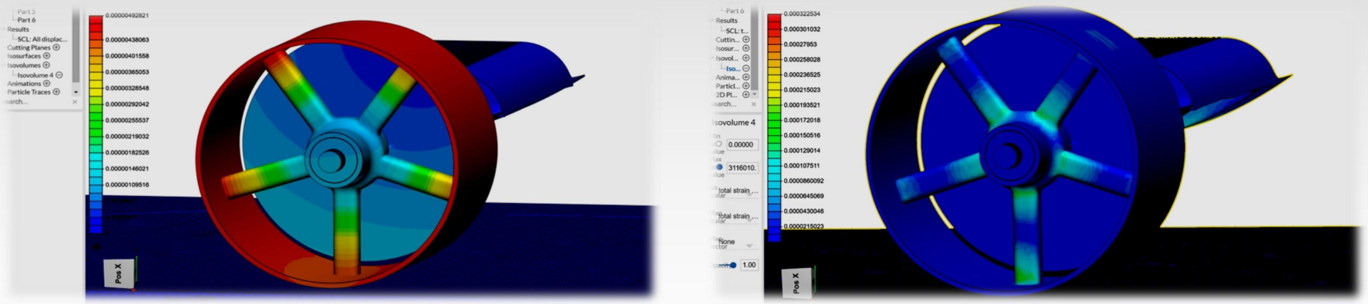
High accuracy meshes lead to high-accuracy results

For the World Finals, we completely overhauled our wheel system, with lightness and simplicity being our primary concerns. However, to ensure that our pursuit for speed didn't forsake the strength of the wheel system, we ran a finite element analysis on the six component system. This simulation, which considered all loads the wheel would experience while racing, including the car weight, centrifugal force when rotating, and the force when decelerating, revealed a number of issues with the new system.

The first issue that we encountered when reviewing the results, was that our PLA axel, intended to be 3D printed, was under a large amount of strain, compromising its durability, and putting the axel at risk of fracture at any moment, which was not acceptable

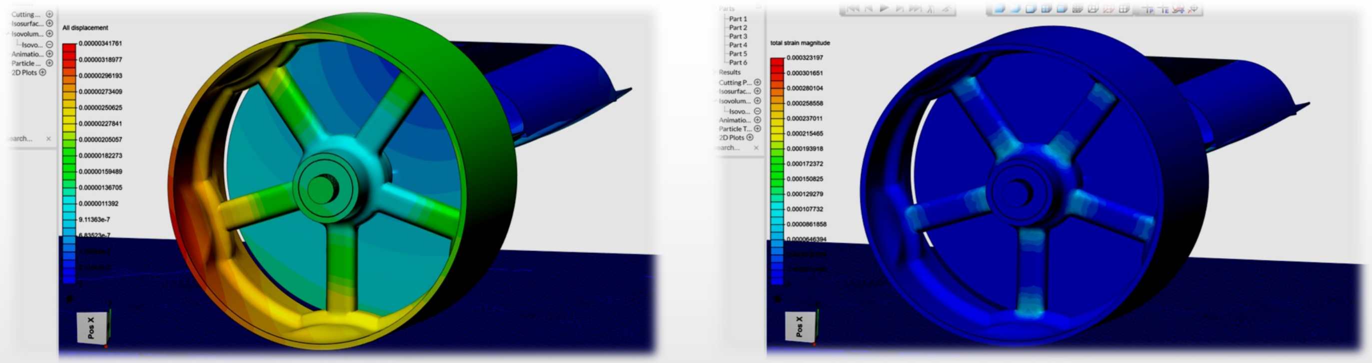


To resolve this issue, after some amount of researching, we decided to manufacture our axels by SLA printing, with a photo-thermoplastic similar to shatter-resistant glass. This greatly improved the strength of the axel, allowing it to race risk-free.



The mass of the rotating part of the wheel has been slashed by over 50% from 3.2 grams to 1.3 grams. This is thanks to cylinder walls less than 0.5mm. However, this improved theoretical performance was not all as it seemed, as we could see that this wheel was subject to a very large amount of deformation and strain, which could cause under-rotation, or a complete structural failure. Either situations would render the car uncompetitive in terms of speed or safety/ability.

INCREASED
RIGIDITY



After testing multiple solutions, we were able to maintain our ultra-thin walls by adding a ridge along the centre of the cylinder, with additional 0.5mm "pillars" extending each way from the 5 spokes. This greatly improved the rigidity and strength of the wheel, while only adding 0.2 grams to the weight of the cylinder, allowing it to rotate at high speeds, as originally intended.

ANALYSIS EVALUATION

It is clear to see by reading through the two pages related to Computer Aided Analysis that ANSYS FLUENT and SimScale have allowed us to improve the quality, strength and speed of our car significantly. It allowed us to verify design concepts, find errors in our design and resolve them, and allowed us to gain a comprehensive understanding of how our car will perform on the track. Many hours have been spent in DCU's lab performing these simulations, and they were worth the time.

With SimScale, we could simulate the wheel rotation for our FEA analyses, however, we were not able to so for CFD simulations with ANSYS FLUENT. This may have affected some of our results slightly, despite every other care to ensure that they are as accurate as possible. In the future, more practise and experience may allow us to do this.

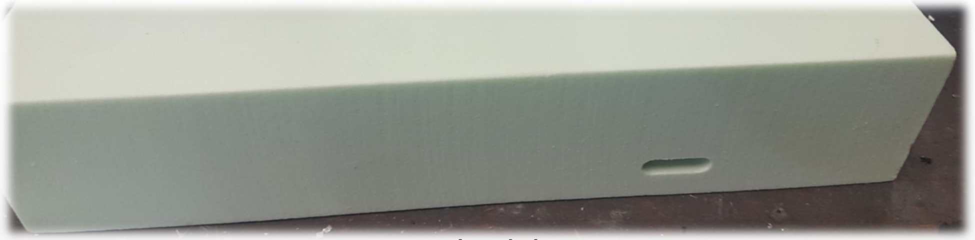
MANUFACTURING

Our team used a Cincinnati Arrow 750 3-axis mill along with AlphaCAM computer aided manufacturing software to manufacture our car body. We developed a multi-stage manufacturing process in order to achieve the best manufacturing result possible with the technology available to us.

Car block during manufacturing

Step 1: Slots

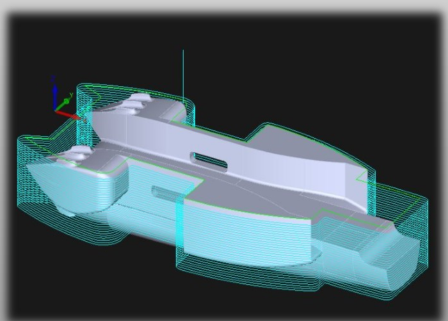
Our first step was to produce the slots on either side of the car that allow the rear wheels to mount. This was done by placing the block on its side and using a 5mm tool to drill through the entire block, using the geometry imported by the CAD file. When the rest of the body was machined, the slots only remained on the two inside walls, as planned.



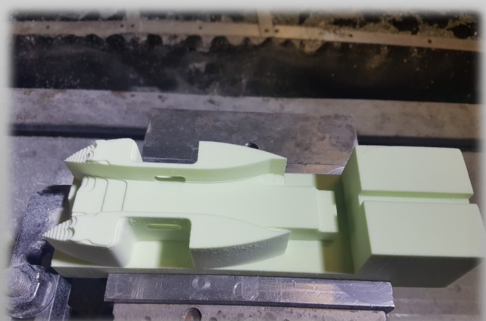
Completed Slot

Step 2: 2D Geometry at Underside

Using the same fixture as the previous step, the underside of the car was machined. Using a 6mm flat tool, we machined all of the 2-dimensional geometry beneath the car, such as the floor and the side pods. This was done with 1mm steps. Despite these settings designed for speed over quality, it was perfect for these surfaces, as there was no intricacy involved. Using Alpha-CAM, we simulated this process to ensure that the base of the spindle did not hit the block as it machined it.



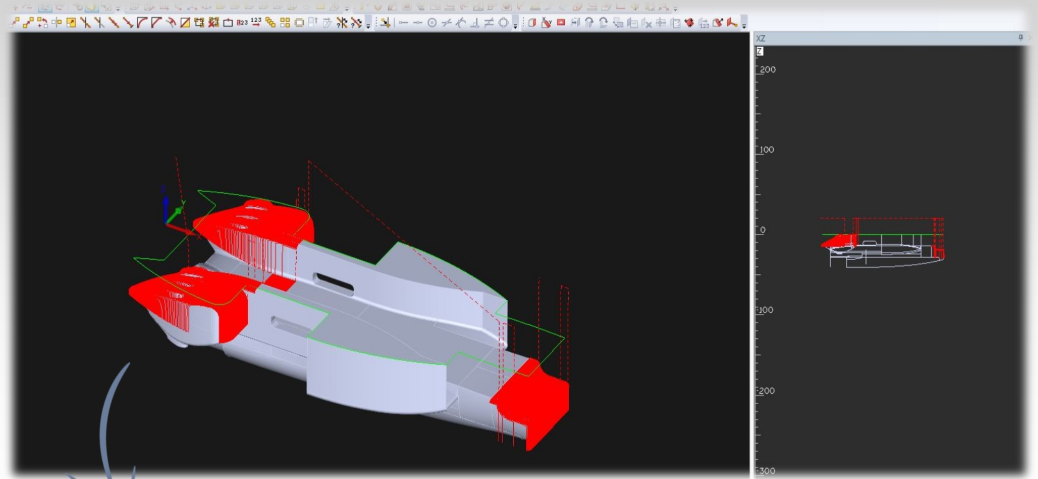
CAM toolpaths used for Step 2.



Block in fixture after completion of Step 2

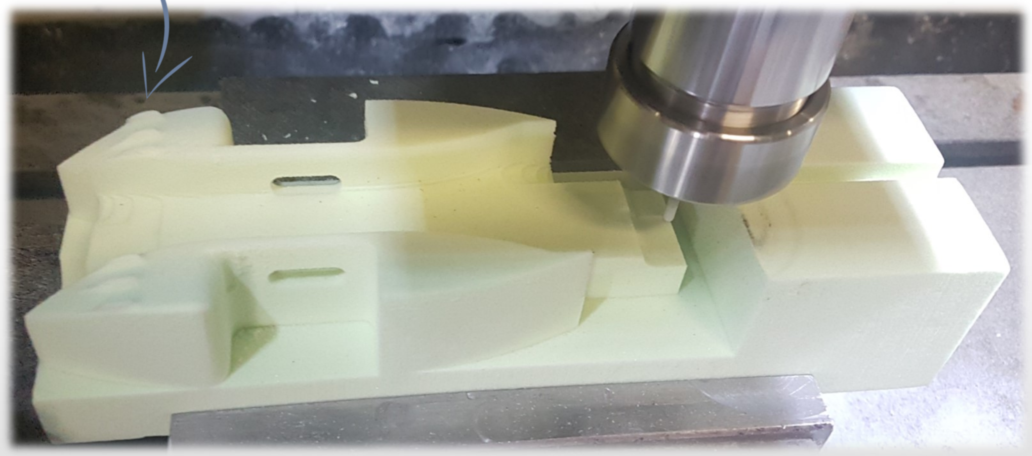
Step 3: Vortex Generators and Rear Diffuser

This step was extremely important as it plays a crucial role in improving our car's performance. Our vortex generators below the car, and the floor that curves upwards could not be machined using the previous tool settings. For this reason, after Step 2, we replaced the 6mm tool with a 3mm ball tool. This tool machined the far more delicate and intricate surfaces shown in red below. The neck of the car, where the nose assembly mates was also machines with these parameters. We were extremely impressed and pleased with the result.



Areas machined with Step 3.

ACCURACY AND *PRECISION*



Finished result with perfectly formed rear side pods and vortex generators.

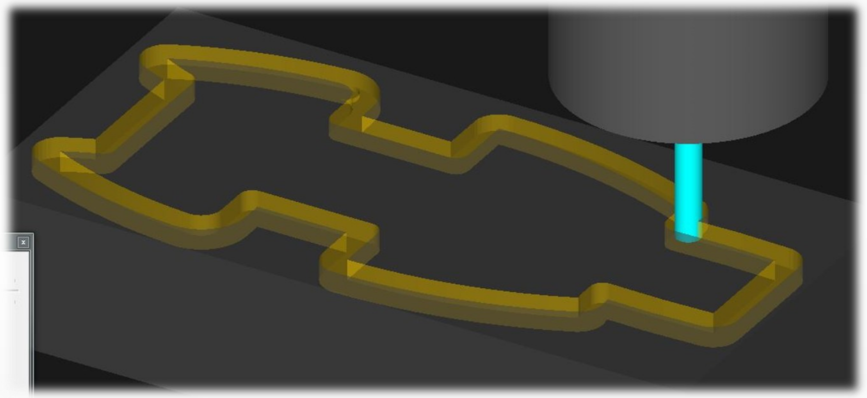
Step 4: Production of Sacrificial plate

For all previous cars, including our National Final car, we used a clamp to hold the top of the block in shape as the rest of the was manufactured behind it. This is was then cut off with a guillotine to release the finished car body. However, for our new car, we manufactured a sacrificial plate that inversed the geometry of the underside of the car, so that it could sit inside the plate, which was in turn held in place with a conventional fixture. We did this using SolidWorks' combine feature, in which the car geometry was cut out of a rectangular plate. This enabled the entire top side of the car to be manufactured more accurately, efficiently and professionally.

Car body locked in sacrificial plate after completion of manufacturing

Step 5: Rough 3D Geometry at Topside

Similar to Step 2, a large amount of material on the top side of the block was removed with a 6mm flat tool with 1mm steps.



Beginning of Step 5 machining process simulated with Alpha-CAM

Step 6: Fine 3D Geometry at Topside

The final process was to manufacture the flawless and intricate upper surfaces of our car, such as the upper surfaces of our side and rear side pods, along with the rear vortex generators. To accomplish this, we used a 3mm ball tool to achieve a much higher quality and accuracy finish, similar to Step 3.

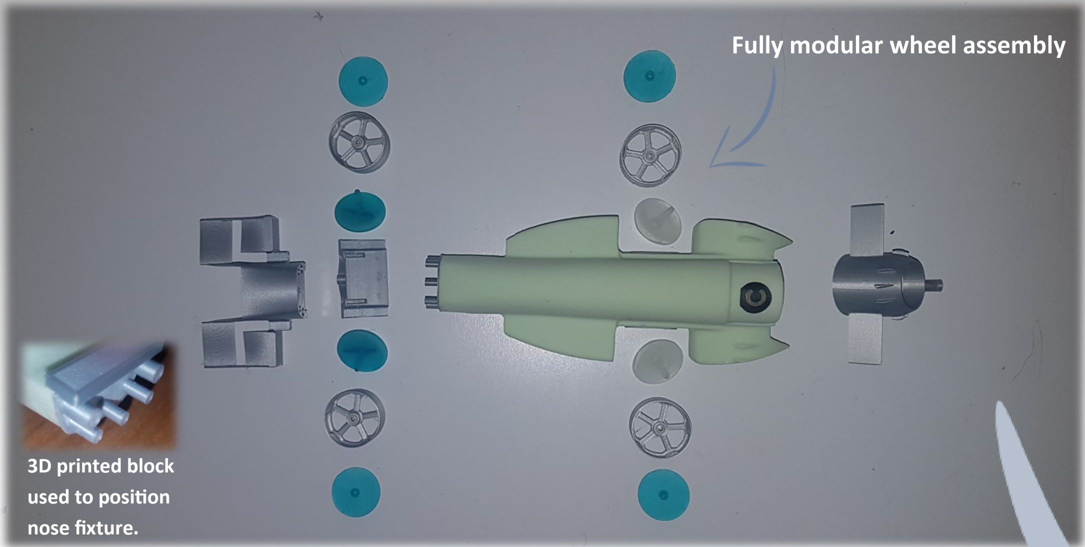
MANUFACTURING EVALUATION

Our manufacturing strategy and method yielded very positive results. When designing the car, we were very concerned whether or not it would be possible to effectively manufacture the rear section of the car as accurately as we wanted to, however, it soon became clear with our multi-stage process that it was indeed possible. We were also very satisfied with our decision to manufacture a more practical and tailored fixture for manufacturing the topside of the car.

One unfortunate consequence of using a 3-axis machine was the presence of a stepover line across the middle of the car, but this was easily sanded down.

ADDITIONAL MANUFACTURING

The primary source of our car's additional components came from two types of 3D printing, which together had the versatility and capability to manufacture all of our car's components, with exceedingly high quality, accuracy and strength. We also 3D printed tools and jigs to ensure that all of our parts fitted together as intended.

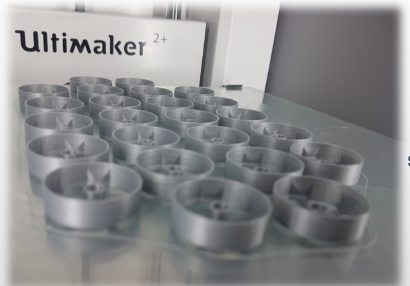


Fully modular wheel assembly

3D printed block used to position nose fixture.

1: Wheels

Sponsored by Ultimaker CREATE, our team's most prized possession is our Ultimaker 2+ Fused Filament Fabrication 3D printer, which was used to manufacture a number of components including the wheels of our car. Using the latest strengthened PLA material technology, we were able to produce very rigid and supportive wheels despite being only half a millimetre in thickness. This material, lighter than standard 3D printing filament was instrumental in bringing the wheel vision from our FEA testing to life. To improve the quality and integrity of the bearing housing, we printed each wheel in two upright halves which were then glued together to form a single, fused wheel part. We also produced a precise tight-fitting cylindrical sleeve to hold the wheels parts in place when the glue cured, to ensure complete concentricity and accuracy.



Our printer produced bearing housings that perfectly fitted the bearings. This was thanks to the 0.25mm nozzle, which could create parts with very fine tolerances. This was very important as our small bearings are very sensitive to inaccuracies

QUALITY *ASSURED*

SAFETY *GUARANTEED*

This sleeve was manufactured with the same accuracy settings as the wheel itself, with a 0.05mm tolerance. Pliers were used when handling the parts to prevent the adhesive from harming skin. This assured the alignment of the two wheel parts.

Our strengthened PLA has a very impressive strength-to-weight ratio It also features a fitting metallic finish, eliminating the need for paint

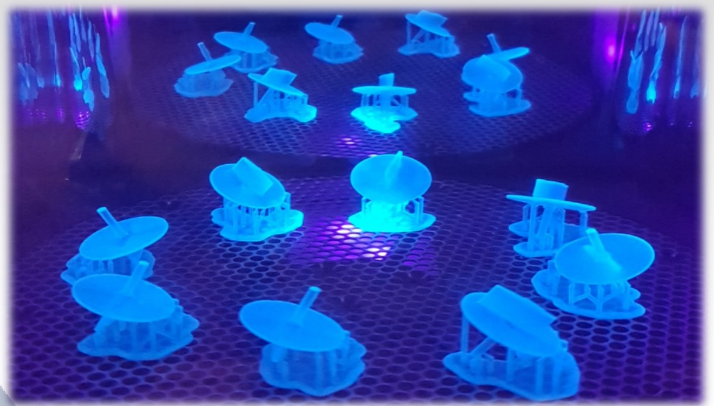
Finished wheel with bearings installed

60 HOURS OF *3D PRINTING*

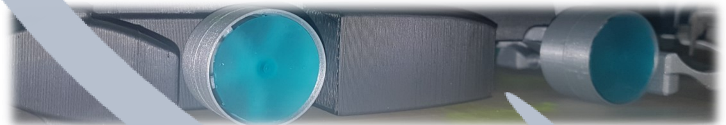
2: Axels and Wheel Plates

As shown in Page 7, it became apparent to us that 3D printing was not a viable option for the production of our car's axels. After researching multiple options such as CNC Machining and Selective Laser Sintering, we established that Stereolithographic (SLA) manufacturing was indeed the best option. This method offered unrivalled accuracy and strength, using Formlab's "Tough Resin", a photopolymer used in the production of shatter-proof glass.

We partnered with NexLay, a new manufacturing start-up from the UK to fabricate these components with their equipment. The quality of the finished axels allowed the bearings and the wheel to slide on perfectly,



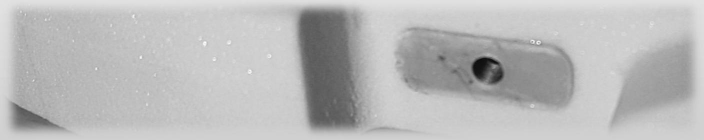
SLA-printed axels with support material during post-curing process



The cylindrical plates attached the end of the axel with a transition tolerance fit. These locked the wheel in position. They were also made with SLA printing, completing a perfect wheel assembly.

3: Rear wheel mounts

A very simple yet effective solution was used to connect the wheels to the car body. Using the Ultimaker 2+, we produced components that were fitted inside the car body's machined slots. The rear SLA printed axels could then fit into the circular slot in the geometry of this piece. This allowed the rear wheels to be accurately aligned with each other.



Rear wheel mount assembled onto car body, with slot for axel

4: Rear Wings

From our experience with F1 in Schools Racing and the materials that we use, we determined that the Rear Wing module was a low risk area and was not susceptible to damage or to need replacing. During testing, the wing module could attach to the car temporarily with friction, however for the finished car, we used adhesive to permanently secure it in place, positioning it so that the wings are perfectly parallel to the track.

5: Nose Assembly

Partially inspired by the nose of a real Formula One Car, our nose geometry is relatively complex, and needed the full functionality and versatility of our Ultimaker 2+ produce very accurate and high quality results.

Using the slicing software Cura, we simulated the print of this part using a variety of orientations and support configurations. We analysed the print to ensure that there were no overhanging surfaces with no support, and that the print-head didn't travel over any thin structures which could cause damage.

We decided to print the part upright, with the nose pointing upwards. We used a hexagonal infill pattern for the most efficient material arrangement for strength and low-weight. The highly capable 0.25mm nozzle was used, along with an exacting 0.06mm layer height. Each nose took just over 8 hours to produce.

To ensure that the extruded material stuck to the build plate, we heated it to 60C. To prevent burning our skin when handling 3D parts, we ensured that the plate was given ample time before cooling to touch it.

Finished nose cone along with the front wheel bogie, which fits to the rear of the nose. This part features slots inside an aerofoil on each side, which allow the SLA printed axels to fit inside.

All of the components of our car unpainted weighed 40 grams, 10 below the minimum. This was to allow for 10 grams of paint, which would ensure a perfect, smooth finish. We used 2 layers of epoxy resin undercoat, before using 3 layers of blue metallic aerosol paints, followed by a semi-gloss overcoat. We wore filtered masks when spraying the car to ensure that we did not inhale any hazardous fumes. The finished car weighed precisely 50 grams.

MANUFACTURING EVALUATION 2

The team is very satisfied with the finished, assembled car. We used the most advanced, lightest and strongest materials, coupled with the most advanced manufacturing methods made available to us, to ensure that our car quality and speed was second-to-none.

Our modular assembly proved very important to the manufacturing and assembly process, as it made the process much more efficient while also allowing for complete guaranteed accuracy and precision in fitting different components together.

Despite there being 6 layers of different coatings, it did not change any of the dimensions of the car significantly, ensuring that all the dimensions were the same as intended, and no aerodynamic surfaces were altered.

TESTING

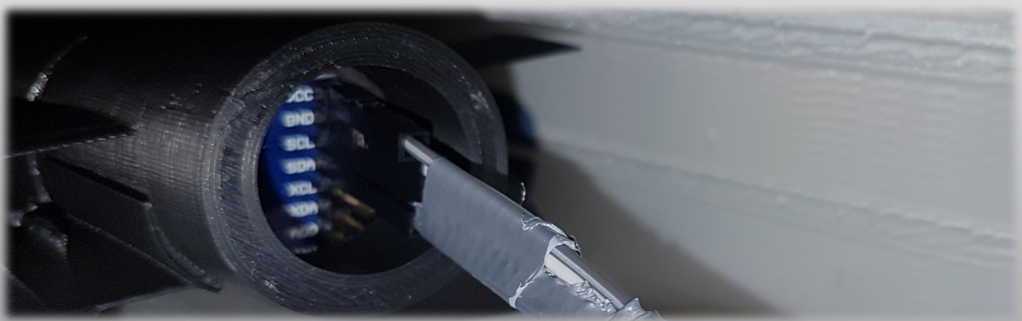
After producing some amazing CFD results on our CAD model, we wanted to ensure that our manufactured car lived up to the same standard that we envisioned. To verify our CFD data, and to gather new knowledge on our car during the research and development period, we constructed a wind tunnel specially built for our F1 in Schools car, featuring two high-speed 12V DC fans and an array of sensors to create the perfect testing environment and proving ground for our car.

Our wind tunnel was fully 3D printed using our Ultimaker 2+

Test 1: Rear Wing Module.

After analysing and comparing multiple different rear wing modules on our car, we determined that adding a curve would reduce drag by 48% and significantly reduce turbulence. We wanted to verify that this was also the case with the physical model. We 3D printed an identical modular and interchangeable car replica that featured a modified fitting in the CO2 chamber that would allow a 6DOF inertial measurement unit to fit inside. Using an Arduino micro controller, we analysed different rear designs on the car to determine if they were generating large amounts of turbulence, which would in turn generate large amounts of vibration on the car, compromising speed.

The two rear modules initially tested and compared

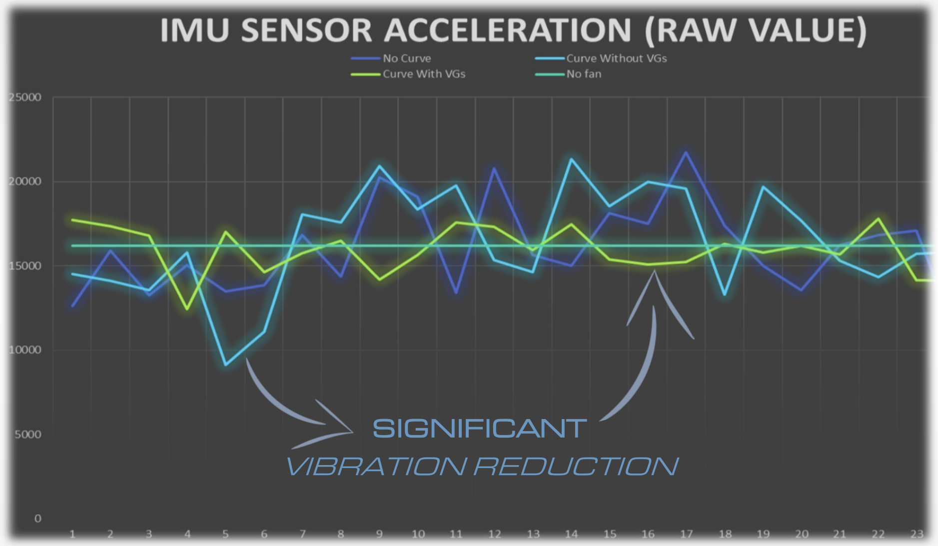


Accuracy was very important in our tests. The car was stuck to the track using temporary adhesive to ensure that it's position didn't change relative to the wind during testing, skewing results. The position of the sensor also stays constant, even when changing parts. This leaves the only independent variable to be the air flow over the car.

Surprisingly to us, there was a much lower improvement with the curved module than predicted. We decided to add our recently tested vortex generators that were present on our rear side pod to the rear curve., to see if they could contribute to an improvement in reducing oscillations at the rear of the car.

Earlier Vortex generator variant tested in the wind tunnel

The new rear structure with the added vortex generators resulted in a significant reduction in vibrations at the rear chamber. For this reason, it was further developed and included in our final design.



We processed all of the raw sensor data to generate a visual representation of the oscillations caused by the three different components versus the car in the tunnel with the fan switched off. The bright electric green line in the above graph is clearly experiencing the least amount of movement. This tested was very important to us as it conclusively determined the best rear wing module to use on our race car.

Test 2: Rear Side Pod Vortex Generators

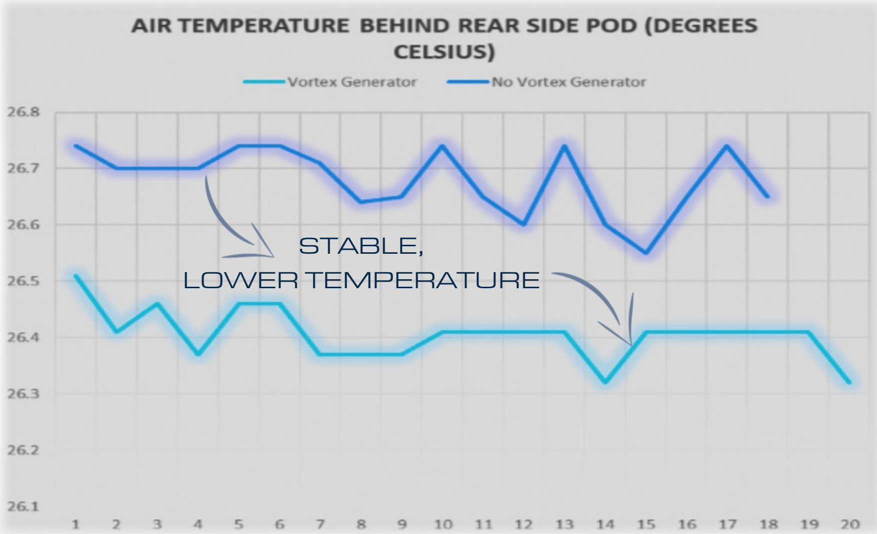
The vortex generators that we added to our rear side pods, to complement the rear diffuser beneath have been a revolutionary addition to our car design, massively cutting down on turbulence and form drag caused by flow separation and the wake behind the car. This happens because the aerofoil-shaped horizontal cross section of the vortex generators induce small vortices due to the pressure difference, which cause air to stick to the surface of the car.

As can be seen in page 8, every care was put into manufacturing this section with as much quality and precision as possible. We needed to ensure that the manufactured aerofoils, coupled with the paint and finishing were close enough to the CAD model to still generate the laminar airflow needed to make them a viable addition to the car.

We devised an experiment, based on Bernoulli's Principle to determine the effectiveness of our manufactured rear section.

Bernoulli's principle states that as air velocity increases, air pressure and temperature decreases. Reviewing our CFD data showed that there was a distinct drop in air velocity over and behind the rear side pod and diffuser without vortex generators. This would in turn result in an increase in air temperature at this region. For this reason, our vortex generators should cause a decrease in air temperature.

We placed a temperature sensor exactly 2cm behind the rear side pods of both our cars. This was then compared to an identical 3D-printed mock-up which did not possess vortex generators, as a control. We measured temperature over a period of 2.5 seconds, and tested each car three times to ensure that there were no abnormal temperature fluctuations in the lab which could skew our results.



Our temperature sensors recorded a drop in average temperature, as expected and hoped for, at the rear side pod with vortex generators, compared to the rear side pod without. This is because of the increase in laminar flow velocity. The higher temperatures without VG's also fluctuated more, due to the increased flow disruption. This test concluded that the finished car had the planned aero-efficiency as the virtual model.

TESTING EVALUATION

Our physical testing on the car has allowed us to do two things that would not have been possible without it: analysing different components to evaluate which is the most efficient, and determining that our fully manufactured car performs as the design intended. This has allowed us to develop a much higher quality final product.

In the future, more on-track testing could have given us a more clear picture of the performance of our car, however we feel that we have been able to reach our desired quality without it.