

| ACCELERON ENGINEERING PORTFOLIO



ENGINEERING PRIORITIES

CAR CRITERIA

We attempted to get as many points as possible by building the car following the marking criteria. We conducted systematic checking at each iteration of the model to make sure that the rules and the marking rubrics were followed to make sure we adhered to the rubrics. By the marking rubrics, we divided the four main categories for evaluation. We decluttered and organized our workstation by doing this and came up with a priority list. This also made it easier for us to recall every area indicated by the marking rubrics.

Speed: - Smooth Wheel System - Aerodynamic Car Body - Low Drag Coefficient - Lower Mass	Finish: - Even Coats of Paint - Primer and Varnish used as Required - Decals done Neatly - All Components Aligned Perfectly
Strength: - Materials Used - Manufacturing Approach - FEA Analysis Done - Stress Simulations Run	Compliance: - Scrutineering - All Regulations Met - Expenditure - Safety

MASS AND INERTIA

Minimal mass is our first and most important priority that goes during engineering, According to Newton's Second Law of Motion,

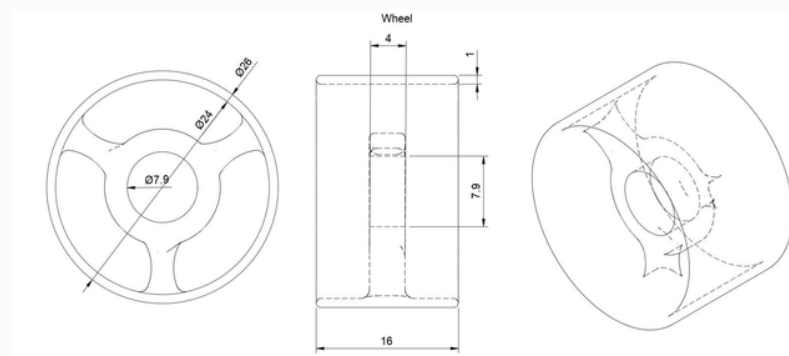
FORCE= MASS*ACCELERATION

This suggests that the car's mass should be as low as feasible to maximize the acceleration provided by the CO2 canister that produces thrust. Moreover, it is commonly recognized that decreasing the mass greatly lessens the car's resistance to motion from rest, called inertia. We have consistently tried to maintain mass as low as possible to guarantee that the best times on tracks are acquired. Every car weighs exactly 50 grams.



SURFACE FRICTION AND EFFICIENT WHEEL SYSTEM

The smooth surface finishings and minimal rolling resistance of the wheels were our second priority, as a rough surface that creates high air resistance can significantly impact the car's performance, even with a creative design. Additionally, the rotational inertia of the wheels is another factor that can limit the car's top speed, so the team experimented with various wheel configurations and orientations to reduce this effect. The total friction and energy losses are also influenced by the wheel system and material, as well as the bearing material



WHEEL DRAWINGS

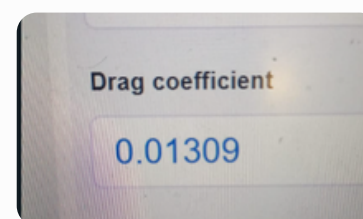
AERODYNAMICS

The timing that the car will attain is also determined by its airflow. The airflow surrounding the car should be as smooth as possible. Every part of our car has been designed to have the lowest drag coefficient and drag force possible by being as streamlined and tapered as feasible. This is our attempt to attain the best aerodynamics.

Our Aim for achieving the drag coefficient is anywhere between 0.01-0.1

$$F_D = \frac{1}{2} \rho v^2 C_D A$$

The drag forces are closely correlated with the cross-sectional area, car velocity, and fluid density. Therefore, our car will experience reduced drag forces acting on it by drastically reducing the frontal area and cross-sectional area, greatly lowering the coefficient of drag. Following a thorough analysis of the various computational fluid dynamics components, the various components will continue to be edited to achieve the necessary mass and desired drag forces acting on the body.

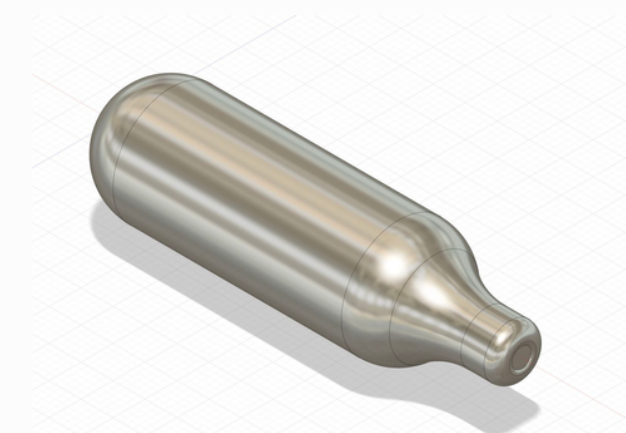


CALCULATED DRAG COEFFICIENT OF OUR FINAL PROTOTYPE

CENTRE OF GRAVITY AND CO2 CANISTER THRUST

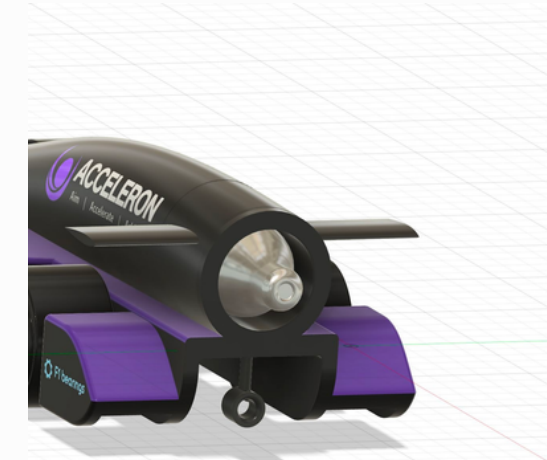
After inspections of various F1 World Finals cars, and reading aerospace research papers, we concluded that there the best positioning of the CO2 canister would be:

i) **As close as possible to the center of Gravity:** Placing the COM closer to the source of force, such as the engine or thrust, can improve traction during acceleration. This configuration is often seen in rear-engine or mid-engine designs, where the weight over the drive wheels helps increase traction, especially during acceleration.



CO2 CANISTER

ii) **Aligned horizontally with the Centre of Gravity:** If not rotational forces about the center of gravity will be produced resulting in unwanted lift or drag which will compromise our priorities on engineering the car and produce unwanted drag and forces acting against the car and slow its timing down reasonably.

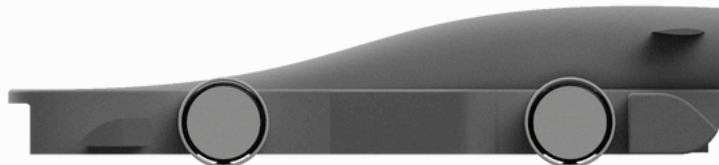


GENERATION OF THRUST

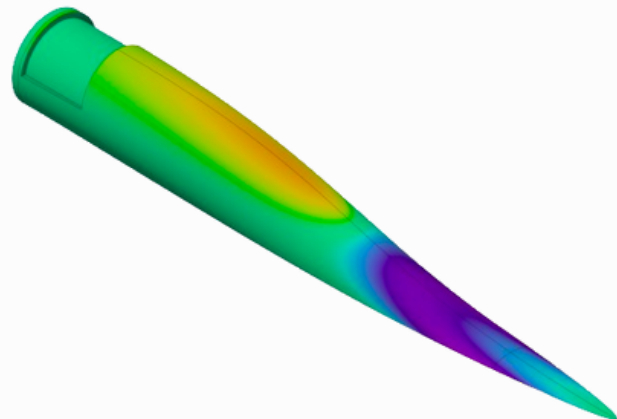
COMPONENT DESIGN

OVERALL SHAPE

Our car body features an elegant curve that seamlessly blends the nose cone with the main body. It features a logarithmic rather than a linear slope because it reduces drag and encourages smoother airflow.



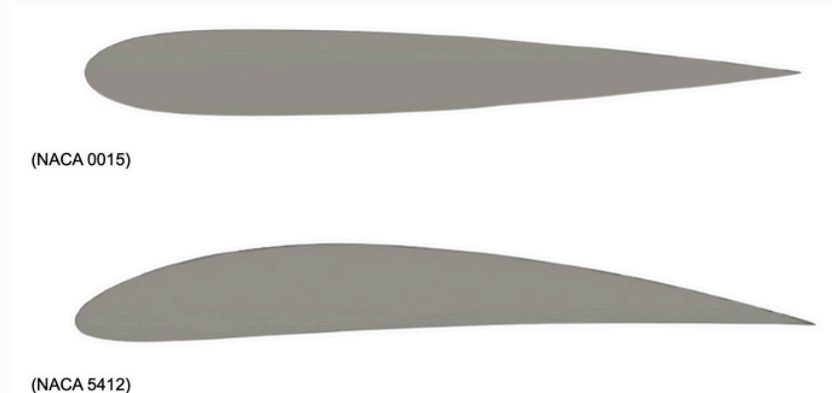
CURVATURE ANALYSIS OF FINAL CAR CHASSIS



REAR WINGS

The purpose of our rear wings is to minimize drag. Our design was influenced by the aerofoil series developed by the National Advisory Committee for Aeronautics (now a NASA division). We concluded that the symmetrical and non-cambered NACA 00XX series was the best option for our rear wings. We chose to use an aerofoil that resembles the NACA 0015. To cut through the air, we chose to maintain the aerofoil's razor-sharp edges on both ends.

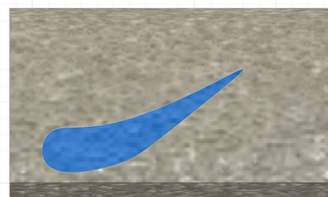
Previously, we had tried to use aerofoils such as the NACA 5412, but we found that it created unnecessary downforce, which led to us not choosing this wing.



REAR WING VARIATIONS

- **V1:**

An adaptation of the NACA 5412 aerofoil design served as our first rear wing. However, after conducting a few experiments, the team discovered that the air would flow above and below the wing at different speeds. The air pressure difference surrounding the rear wing would cause some force to be exerted as a result.



V1



V2

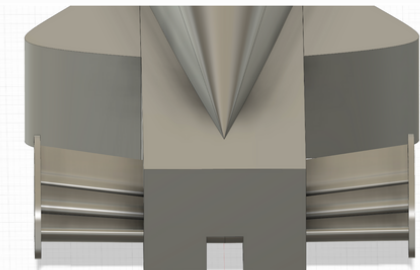
- **V2:**

For our second attempt at the rear wing, we took inspiration from the NACA 00XX aerofoil series. The number 00XX in the series' name signifies that there is no cambering of the aerofoil, and it is symmetric. The symmetry of the wing means that the airflow around the wing will be even, and there will be no irregularities in the pressure around the wing. So, the wing would not experience any unbalanced forces from the air around it. Once again, we made the edges of the wing razor-sharp to cut through air easily.

FRONT WING VARIATIONS

- **V1:**

The first wing we tried was inspired directly by real-life Formula 1 cars. It featured multiple aerofoil components arranged together to encourage airflow above our wheels. However, we quickly realized that this wing created more downforce than needed. This is necessary in real F1 cars, as it is necessary for them to stay on the track. However, in F1 in Schools, where the car is tethered to the track safely using tether lines, such amounts of downforce are not needed.



FRONT WING V1

- **V2:**

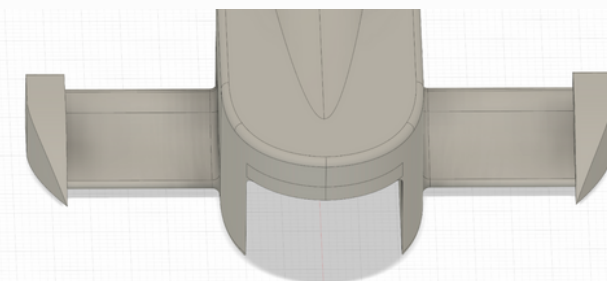
Our second front-wing variation constituted a ramp-like structure that went over the front tether line guide. The wing's ends supported a structure that redirected incoming air to the sides of the car, effectively deviating the air away from the front wheel and reducing the effect of Wheel Wake and the Magnus Effect. However, this wing was found to be too weak as it was very thin and thus we decided to move further with another wing.



FRONT WING V2

- **V3:**

Our final front-wing design contained two major parts. The flat ramp had an angle of attack sufficient for the air to get pushed over the car's front wheels, minimizing wheel wake, and the ends of the wings each pushed the air sideways, further streamlining the airflow around the car's wheels. This wing was also thick enough to be sturdy, and coupled with our choice of materials and printing method, we decided it was best to move on with this wing design.



PROTOTYPES

FIRST MODEL

This project helped our team become acquainted with Autodesk Fusion 360's functionality at a time when we were still learning the program. We were able to investigate and comprehend the several features and functionalities of the program, which was a valuable learning experience.

APEX

Our prototype, Apex, features a virtual cargo design inspired by bullet trains. Its sleek silhouette is crafted to minimize air resistance, with hollowed-out elements to reduce the car's overall mass while optimizing airflow. The tapered nose and minimal edges further enhance its aerodynamic efficiency, making it a prime example of our commitment to innovative design and performance.

THIRD MODEL

Our next prototype drew inspiration from a bullet or a rocket. The new virtual cargo was designed with a curved and rounder shape, instead of a flat one. This design aimed to divert air smoothly around the car, enhancing aerodynamic efficiency and overall performance.

FOURTH MODEL

For this model, we decided to round out the side pods, taking inspiration from the shape of a peregrine falcon during its nosedive. For the wings, we initially sought inspiration from real F1 cars. However, we discovered that real F1 wings generate downforce, which is necessary for keeping real F1 cars on the track. Since no such downforce was needed for F1 in Schools, where the car is tethered to the track, we decided to go back to the drawing board and revise our design.

FINAL CAR – AEROPULSE V3

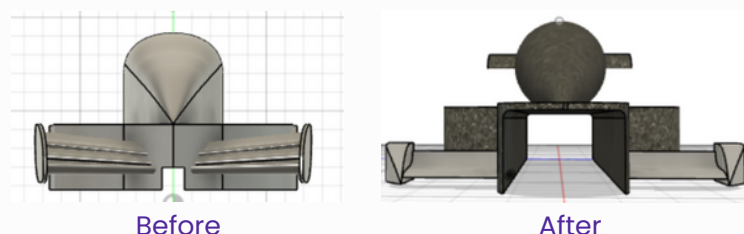
Our final model featured a logarithmic virtual cargo that seamlessly blended with the front wing and the nose cone. We made several adjustments to the Aeropulse V2 to facilitate easier manufacturing. For instance, we increased the thickness of areas that were too thin to at least 3mm, ensuring that the body could be CNC-milled without any issues. Additionally, we sharpened the rear wings near the back of the car to direct air smoothly to the rear, minimizing turbulent areas. The body was split into three parts: the main chassis, which was CNC-milled, and the nose cone and rear wing, both of which were 3D printed. These modifications and others were made to ensure the design was manufacturable while maintaining aerodynamic efficiency and structural integrity.

AEROPULSE

The Aeropulse was the first of our models to closely resemble our final car, representing the culmination of everything we learned from previous prototypes. We made a significant step in reducing the car's frontal area to minimize drag.

We carefully designed the area around the cartridge hole to be circular, adhering to the 3.5mm surrounds technical regulation. The side pods, inspired by the world's fastest bird, the peregrine falcon, were retained from the previous model. The overall car body took on a teardrop shape, which is one of the most aerodynamic shapes in the world.

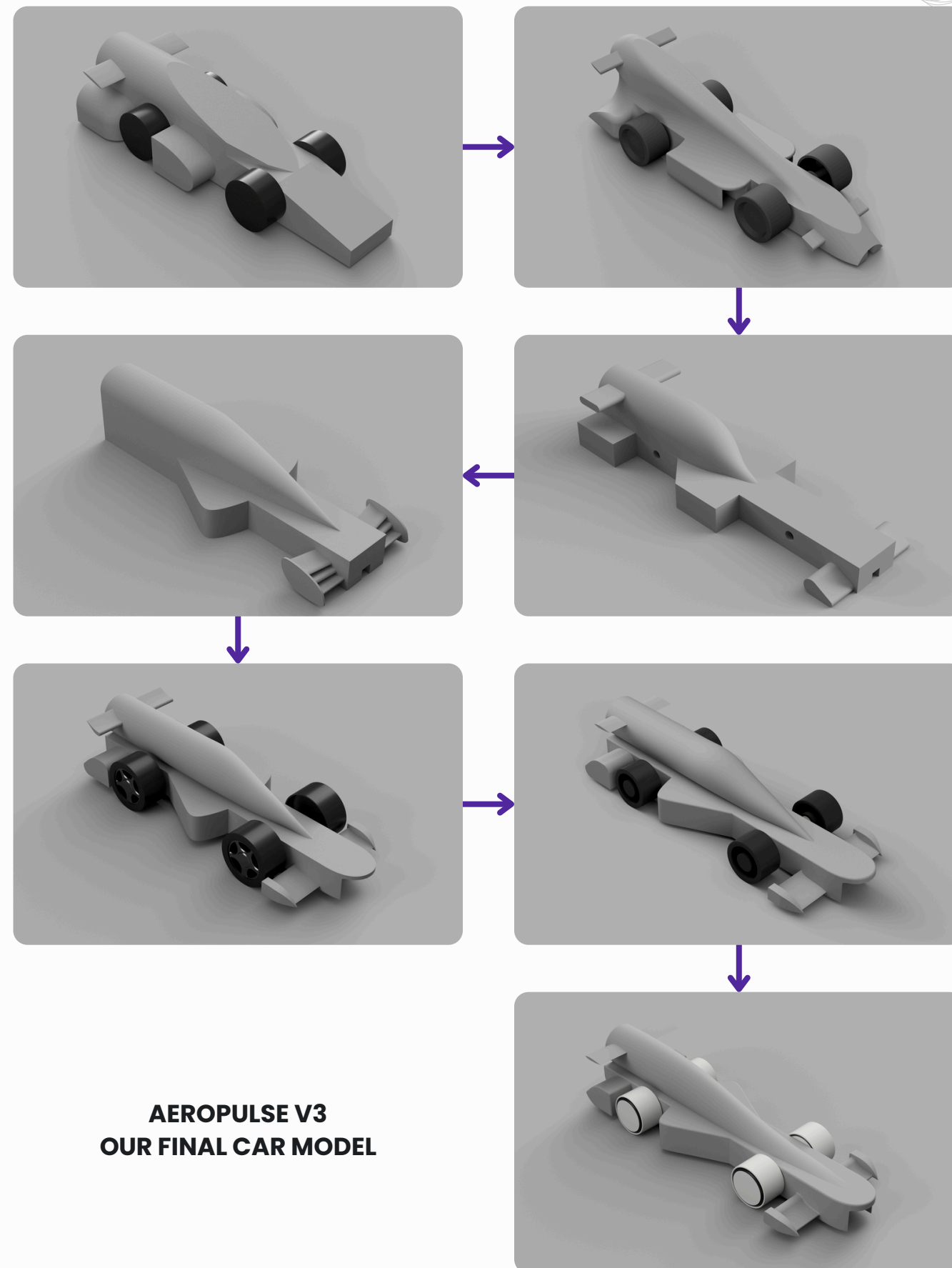
Our rear wings initially followed the NACA 5412 design. However, after further research, we discovered that the NACA 5412, much like the front wings of the previous model, provided unnecessary downforce. Given that downforce is not needed for F1 in Schools cars, which are tethered to the track, we decided to redesign the wings.



AEROPULSE V2

We observed that the side pods of the Aeropulse V1 were directing air directly to our rear wheels, leading to unwanted drag forces. To address this, we inverted the side pods to drive the air away from the rear wheels.

Additionally, we replaced the rear wings with a design resembling the NACA 0015 wing, which would eliminate the unnecessary downforce. We decided to keep the front wings the same as those on the Aeropulse V1, as they were effective in diverting air around the wheels.



SOFTWARE INTEGRATION

APPLICATIONS USED

- Fusion
- DENFORD QuickCAM PRO software.
- Blender
- AutoCAD CFD
- Ansys Discovery and Mechanical

CAD/CAM SOFTWARE CHOICE

Choosing the right Computer-Aided Design software for designing your car is one of the most important steps in an FI in Schools competition. Our team was relatively new to CAD, so we decided to choose a program that was beginner-friendly. Eventually, we settled on Autodesk Fusion 360.

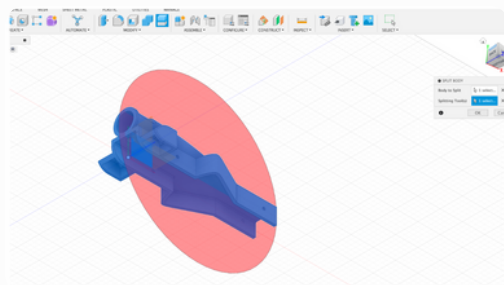


Its advantages were that it was easy and quick to learn. It is widely used for 'FI in schools' competitions, and so there was a wide variety of sources to learn CAD modelling.

- Different tools used in Fusion 360:

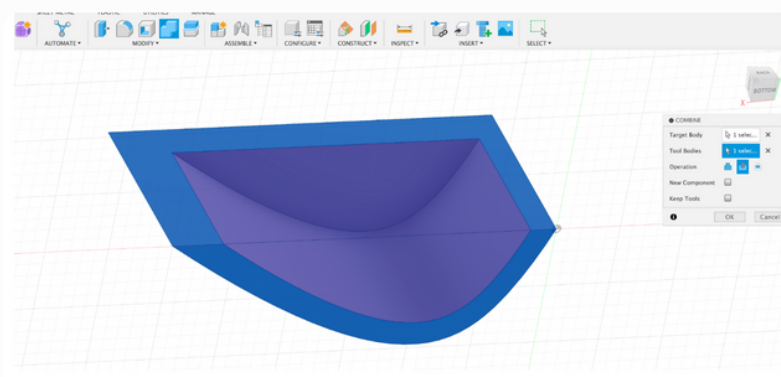
- **Split Body:**

In Fusion, we employed the split body tool to design individual components without affecting other elements. After we had finished modifying them, we would reunite the split bodies using Fusion's Combine tool.



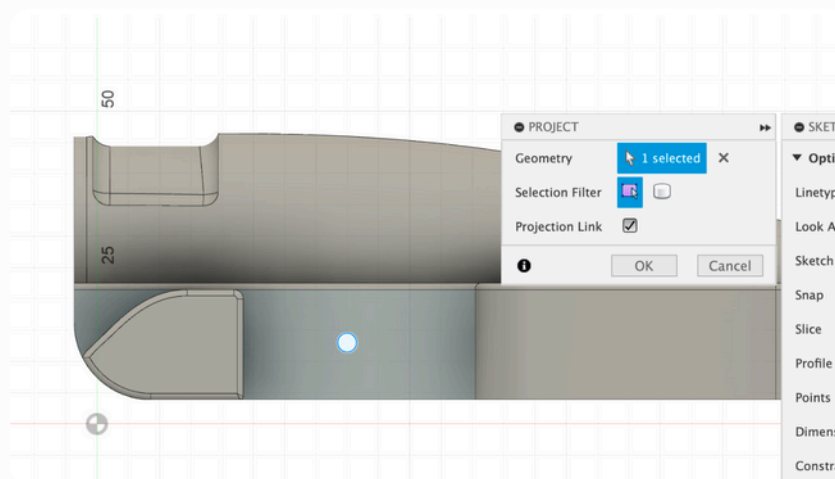
- **Combine Bodies:**

We used Fusion's "Combine" tool in various ways. For instance, we used the combine tool heavily while hollowing out our side pods. First, we separated the side pods from the main body using the "Split Bodies" tool. Then, we duplicated the solid side pods and scaled the copy down. Next, we used the 'Combine' tool to cut the smaller side pod from the bigger side pod, hollowing the side pods perfectly.



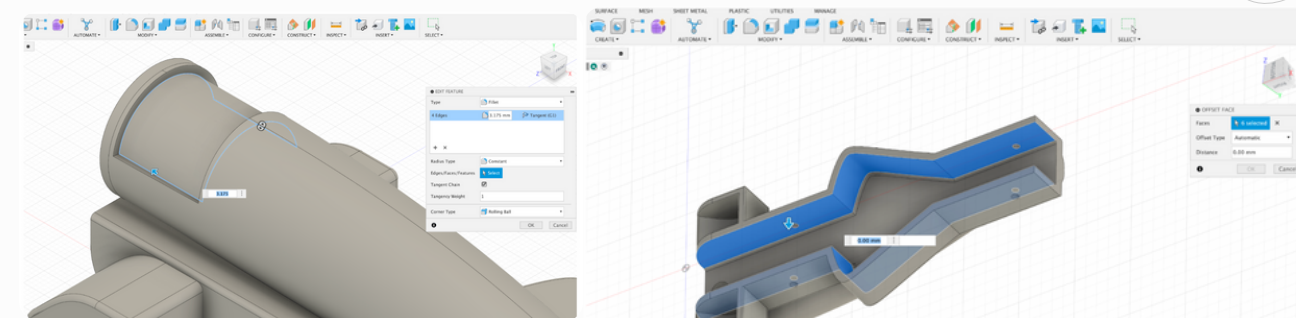
- **Project Tool:**

To make our sketches accurate, we used the project tool to make duplicating sketches easier.



- **Fillet Tool:**

The fillet tool was essential to making our car model manufacturable. We used it for multiple purposes, the most significant being adjustments for CNC milling.



FILLET TOOL

OFFSET FACES TOOL

- **Offset Faces Tool:**

This tool made it very easy to change the thickness of the walls of the car, without having to repeat the hollowing process again and again.

RENDERING SOFTWARE CHOICE

The software we chose to create our renders in was Blender. Veeraj, our Chief Engineer, had prior experience with Blender, which made our choice easier. Using Blender, we were able to create animations for our Instagram posts and our portfolios. Blender's extensive features allowed us to produce high-quality 3D models and realistic textures. Its open-source nature also meant we could customise tools to fit our specific needs; the active Blender community provided valuable tutorials and support.



CFD SOFTWARE CHOICE

Despite being unfamiliar with Computational Fluid Dynamics (CFD), our team was able to effectively learn and use Ansys Discovery for simulating car designs. The wide range of tools offered by Discovery made it easy to see how air affects the aerodynamics of the car. Additionally, this software provided adaptable simulation configurations that allowed us to modify air speed and car composition as we conducted research and development. Our Chief Engineer, Veeraj, attempted to use Ansys Mechanical to perform other energy loss calculations and wheel system calculations as well, but we ultimately stayed to Ansys Discovery alone because its use for CFD in general was too complicated.



PHYSICS – BASED RESEARCH AND DEVELOPMENT

MOMENT OF INERTIA

The wheels of an 'F1 in Schools' car can reach speeds over 1500 rad/s. Therefore, it is important to ensure that the moment of inertia (MOI) is carefully considered. The MOI should be such that the wheel remains structurally sound under high-speed conditions.

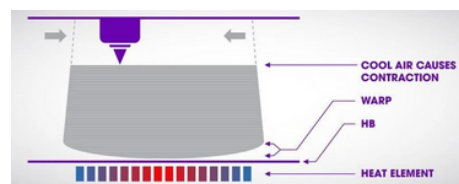
At the same time, the MOI needs to be low enough to allow the wheels to accelerate as quickly as possible.

AXLE ROD

The moment of inertia of a solid cylinder (rod) is given by $\frac{1}{2}mr^2$. To reduce our moment of inertia, we have made our axle rod stationary, so it does not contribute to the net moment of inertia of the wheels. This is achieved by gluing the inner ring of the bearing to the axle and the outer ring of the bearing to the wheel.

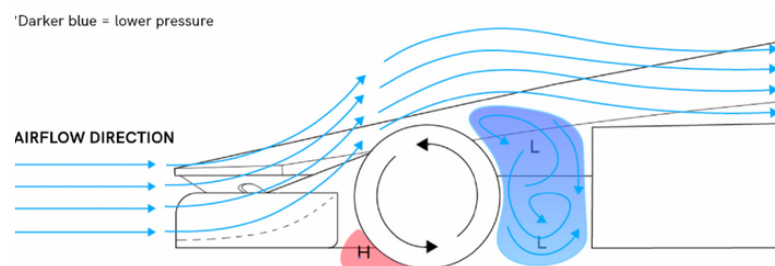
THERMAL CONTRACTION

To minimize the use of glue, we used the concept of thermal contraction by printing dimensions that are the same as the bearing's dimensions, so that the bearing could fit into the wheel in such a way that it does not move or get separated on stress. This minimizes the risk of glue getting into the bearings and ruining them.



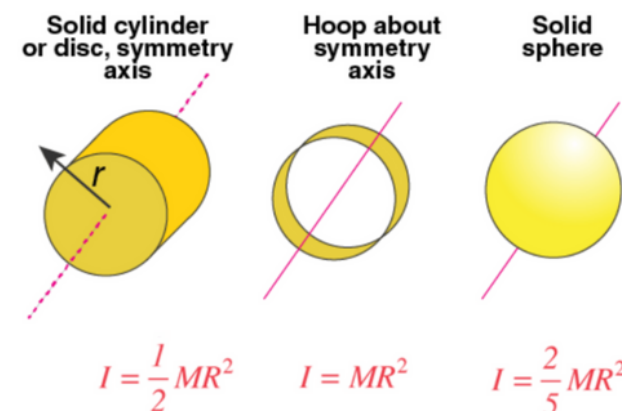
MAGNUS EFFECT

The Magnus effect is a phenomenon that occurs when a spinning object is in translatory motion in a fluid. The fluid moves faster and creates a low-pressure region in the fluid (Bernoulli's equation). Thus, to prevent this phenomenon, we planned to cover the wheel as much as possible and deviate air around it so that its motion remains uninterrupted.



BEARINGS

The bearings we chose are ceramic hybrid bearings. To keep the moment of inertia as little as possible, we kept the bearing size smaller, since the moment of inertia depends on the mass of a rotating object.

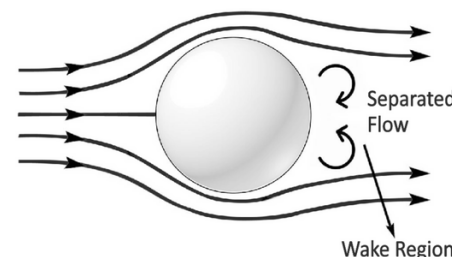


SKIN FRICTION

Skin Friction is the resistance to the laminar flow of an object that is moving through a fluid. This would increase the drag on the car. So, to minimize skin friction, we employed various techniques, such as applying a final clear coating on the car body to make it glossy and smooth and having decals go under the varnish (clear coating). Additionally, we tried to minimize the surface area in contact with the air so the skin friction would affect the airflow around the car less. Skin friction is caused by the viscosity of the moving fluid.

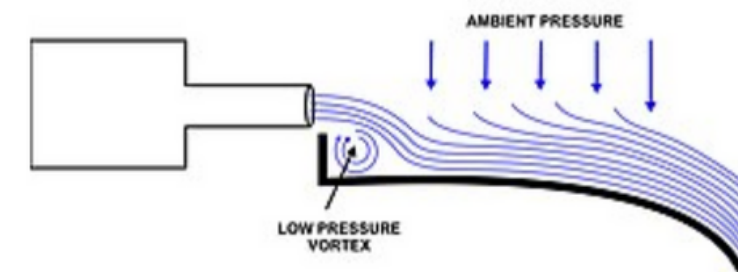
WHEEL WAKE

Wheel Wake is produced when a wheel's rotational motion causes an inflow of air into a zone of elevated pressure. This is followed by lateral displacement. This phenomenon causes significant air separation in the area behind the wheels. As a result, it increases drag and turbulence in the airflow behind the wheel. This dramatically impacts the aerodynamic capacity components behind the front wheel.



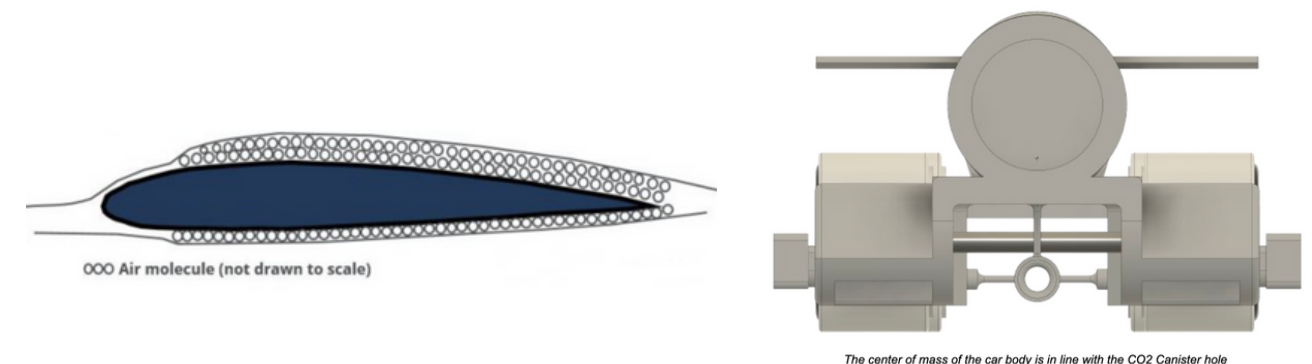
EMPHASIS ON COANDA PHENOMENON

The Coanda effect is a phenomenon in fluid mechanics in which a moving fluid tends to attach to and flow along a surface. When a fluid moves across a surface, friction between the fluid and the surface occurs, causing the fluid's motion to slow. This resistance to fluid flow pulls the fluid towards the surface, causing it to remain stuck. We tried to use this phenomenon to our advantage, by shaping our main side pods in such a way that the air stuck to the side pods would be blown away from the rear wheels.



CENTER OF MASS

The center of mass is an imaginary geometrical point where all the mass of a body is considered to be concentrated. All force acting on the body can be considered to act on its center of mass. Our car was designed in such a way that its center of mass lay in line with the CO2 canister. This helped direct most of the thrust from the CO2 canister to translatory acceleration. Through some research, our team was able to predict that the car would move faster without its wheels than with its wheels. This is because the acceleration obtained by the CO2 canister would then be directed in only translatory motion, thus giving higher acceleration to the car's body, whereas in the case of the body with the wheels, the car had to distribute the force from the canister into translatory and rotational motion. Bringing the Center of mass closer to the CO2 canister reduced the tipping moment of the car. Concentrating the weight of the car in the Main body, constituting the logarithmic slope and the rear wing, brought the Center of mass higher and closer to the back, effectively reducing the car's tipping moment. This assisted the car by decreasing the front wheel load.



$$x_{cm} = \frac{\sum_{i=1}^N m_i x_i}{M} \quad y_{cm} = \frac{\sum_{i=1}^N m_i y_i}{M} \quad z_{cm} = \frac{\sum_{i=1}^N m_i z_i}{M}$$

MANUFACTURING AND FINISHING

MATERIAL CHOICE

For the 3D-printed components of our car, we sought a material that was stable, strong, lightweight, and sustainable. After extensive research, we identified Polyamide 12, commonly known as Nylon 12, as an ideal choice. Nylon 12 is a synthetic thermoplastic polymer with a melting point of around 176°C. To optimize our 3D printing process, we determined that Selective Laser Sintering (SLS) was the most suitable method for using Nylon 12. This material is particularly advantageous for printing complex and detailed parts because it does not require support structures when used in SLS printing. Nylon 12's strength lies in its resistance to cracking under stress, bending before it breaks. Its tensile strength is 48 MegaPascals, and its flexural strength is 41 MegaPascals, making it an excellent choice for our project.

3D PRINTING

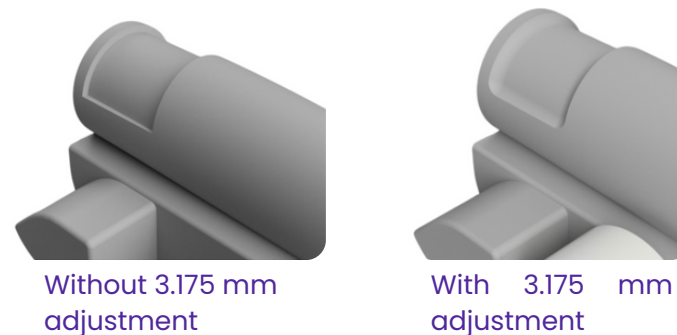
The **Selective Laser Sintering** printing method is unique in that it uses Nylon 12 powder as the raw material rather than filament. This method works by spreading a sheet of powder uniformly and then using a laser to fuse some of the powder into a solid material, continuing layer by layer until a complete solid is obtained. We chose this method because it allows for highly accurate 3D-printed components that can easily be finished. Additionally, SLS printing does not require support structures, unlike traditional 3D printing. It also provides tight adhesion between layers, making the final component more aesthetic and sturdy. SLS-printed components exhibit near isotropic mechanical properties, meaning they are strong in all directions, unlike parts printed with filament, which are weak in the direction perpendicular to their layers.

CAM

CAM or Computer Aided Manufacturing is a way to control manufacturing machines using software. By efficiently utilising the DENFORD QuickCAM PRO software, we simulated a CNC milling sequence by programming a 3-axis Denford Router. We used a combination of 3D and 2D setups to ensure precise and controlled milling, minimizing discrepancies. This proved to be helpful later on as we adjusted our models based on Yas' milling machine's edge radius. We utilized a 50% stepover value to efficiently remove material from the model block. We employed parallel finishing with a 0.45 step down at a 90° angle to achieve intricate cuts within the car design.

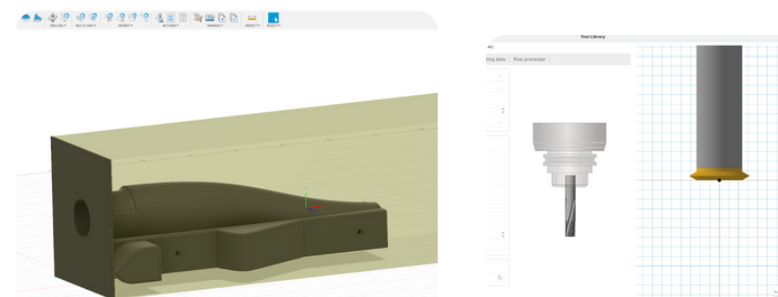
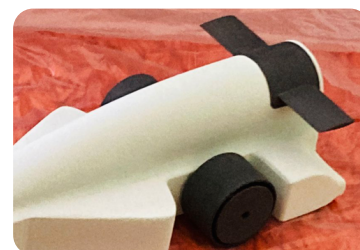
MANUFACTURING

Our first step was to design the car's main body and send it to Yas for CNC milling. Once our car model was finalized, we sent four copies of the main body to be manufactured by Yas. After conducting some research, the team discovered that discrepancies in the car's bodies could be significant, potentially causing issues later on, such as the attachment of the rear wings. To address this, we contacted Yas and learned that the radius of their CNC milling machine is 3.175 mm. Consequently, we filleted all the sharp edges of the car's body with a radius of 3.175 mm to ensure a perfect fit. We also filleted the sharp edges of the 3D-printed components so they could fit perfectly onto the car without sanding.



REAR WING

As we eliminated the need for unnecessary sanding, the rear wing was a perfect fit for the car.



SIMULATION OF THE CNC MILLING PROCESS USING DENFORD QUICKCAM PRO

SANDING

To ensure an extremely smooth finish, we used different grits of silicon carbide sandpaper to sand the car body, gradually increasing the grits, effectively making the car surface smoother at every level. The grits we used to ensure a smooth finish were 180, 240, 400, 1000, and 2000. By gradually increasing the grits, we were able to remove even the smallest ridges in the car body and this eventually would help in our car's aerodynamics due to its skin friction.



Vernier Caliper and Sandpapers of Various Grits



Sanding the Car bodies

PRIMER

We applied two coats of primer to our car, to even the surface to make it suitable for painting. It helped eliminate any ridges that were too small to sand. We used masking tape to ensure the primer did not enter the CO2 canister hole.

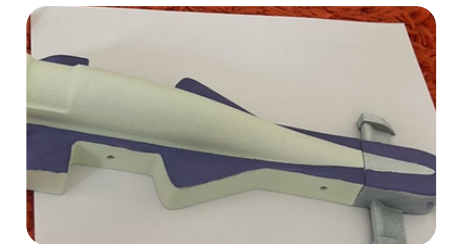


PAINT

To achieve precise borders and detailing, we opted for a manual painting process. Initially, we attempted to use spray painting for the car body, but it did not meet our desired level of detailing. Therefore, we employed acrylic paint, which allowed for greater control over the color and finish. To create a unique shade of royal purple, we mixed the correct proportions of red, green, and blue pigments, resulting in a bespoke color that accurately reflected our design specifications.

DETAIL ORIENTATION

While painting our car, we paid meticulous attention to detail. We used masking tape to ensure the paint did not seep over to places we did not want it.



DECALS

For our decals, we used waterslide decal paper to achieve a sleek look for our car. We added decals on our car before clear coating it, to achieve a perfect glossy look.

VARNISH

Our last step in manufacturing was to clear-coat the body with Varnish, achieving a sleek and elegant glossy look. The varnish also helped smoothen the car's body to eliminate skin friction, effectively reducing our drag.



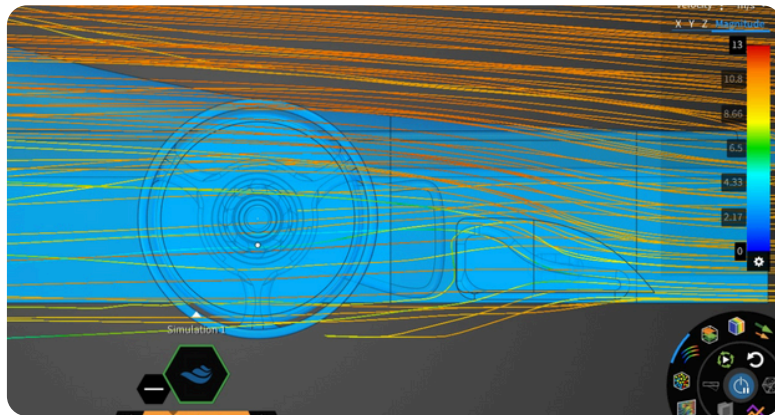
TESTING/ COMPUTATIONAL FLUID DYNAMICS

SETTING UP CFD USING ANSYS DISCOVERY

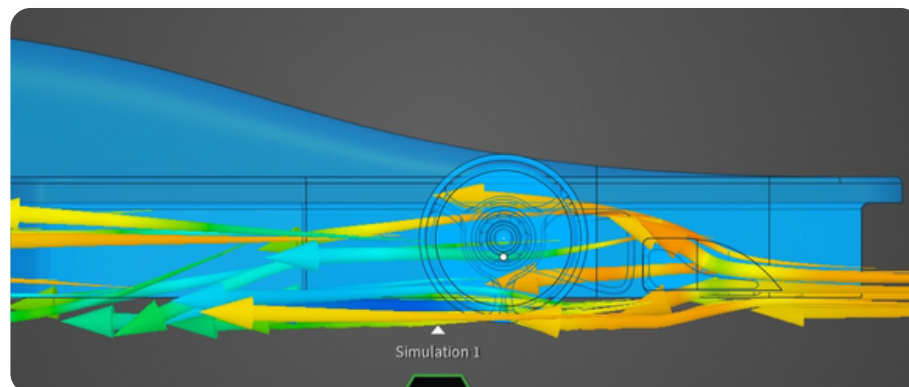
We successfully imported our CAD model into Ansys Discovery, selecting the file from the desired folder and ensuring a seamless integration. The software accepted our native CAD format, allowing us to manipulate views, clean up geometry, and prepare the model for simulation. Next, we defined the fluid domain by extracting the fluid volume and creating named selections using the "Fluid Region Extraction" tool. This crucial step enabled us to apply material properties and boundary conditions to the model, which are essential for accurately predicting the flow behavior. Finally, we solved the simulation and processed the results, gaining valuable insights into the fluid flow behavior and celebrating our successful CFD setup on Ansys Discovery.

WHEEL AERODYNAMICS OPTIMISATION

We aimed to redirect air above and around the car's wheels to reduce the effect of wheel wake and Magnus effect. After extensive research, our team discovered the effects of airflow above the wheel (generating downforce) and below the wheel (generating lift).

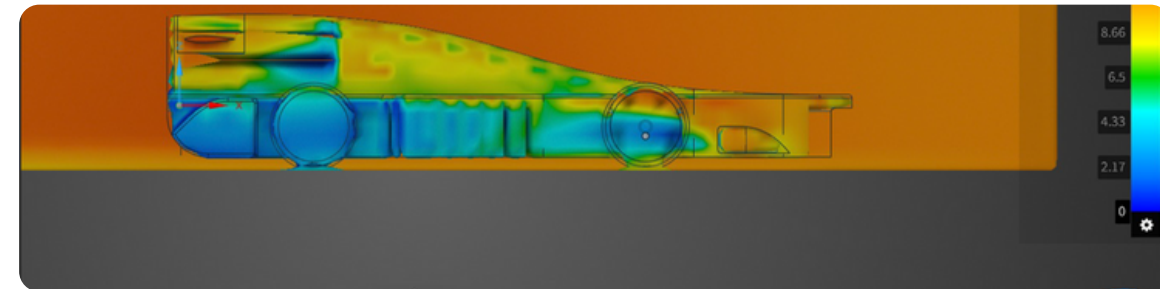


We aimed to reduce downforce and lift in such a way that most of the CO2 Canister's acceleration would result in translatory force in the direction of motion, rather than generating upward or downward force. To do this, we had to settle on a reasonable balance of lift and downforce. Thus we designed our front wing with an angle of attack that gave the perfect amount of downforce, but not so much that it affects our car with unnecessary drag. The below simulation was conducted using an outlet flow of air directed at the car, with data represented in vectors.



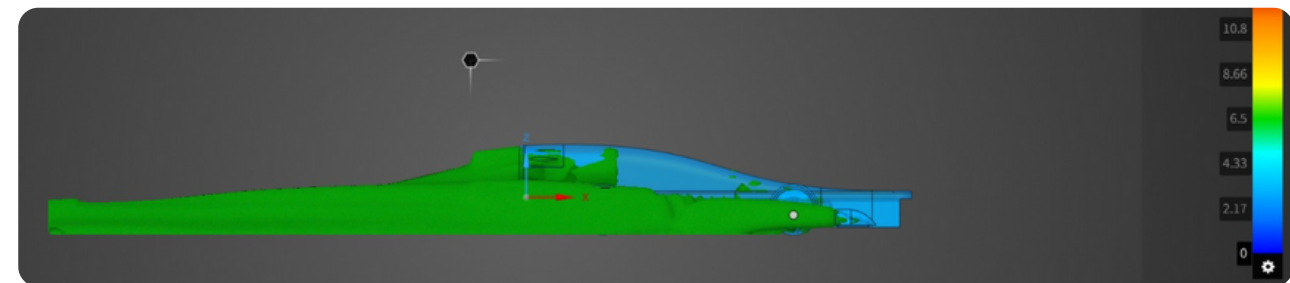
NOSE CONE AERODYNAMICS: DRAG REDUCTION AND PERFORMANCE OPTIMIZATION

Next, we checked the effectiveness of our nose cone. An effective nose cone is able to reduce drag due to air, through an aerodynamic design. As seen, the speed of the air is significantly reduced to a region of approximately 4.5 m/s to 8.83 m/s. The data type of air being analyzed was changed to 'Subsurface' for this test. This change allowed us to focus on the specific aerodynamic characteristics of the nose cone in the subsurface regime, where the flow dynamics are influenced by the interaction between the nose cone and the surrounding fluid. The results demonstrate the nose cone's ability to optimize airflow around the object, reducing drag and improving overall performance.



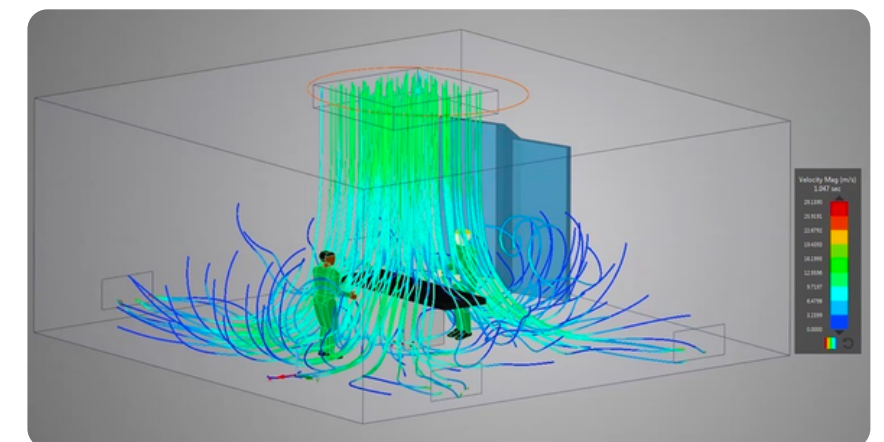
AERODYNAMIC EFFICIENCY OF FRONTAL SIDE PODS

Finally, we checked the aerodynamic efficiency of the car. Our frontal side pods were able to mitigate the flow of air to such an extent that it was maintained for the entire rear portion of the car. The tool used here was 'Iso-Surface', which reported points at which data/magnitudes were equal. This technique allowed us to visualize the flow patterns and identify areas where the air flow was most effectively managed. The green color displayed in the simulation is not representative of the magnitude itself, which was in the approximate range 2.3 - 4.2 m/s.



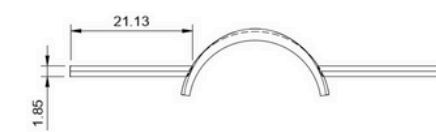
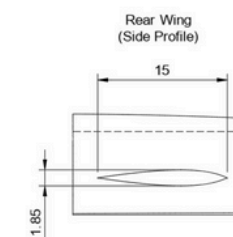
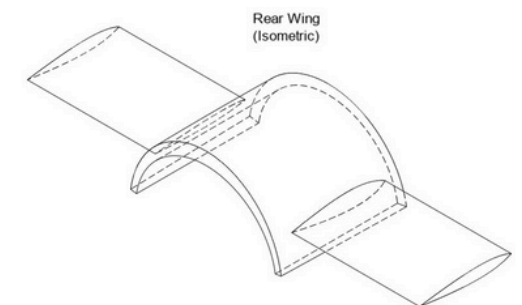
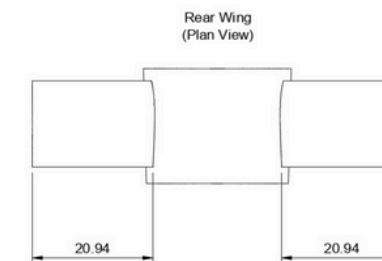
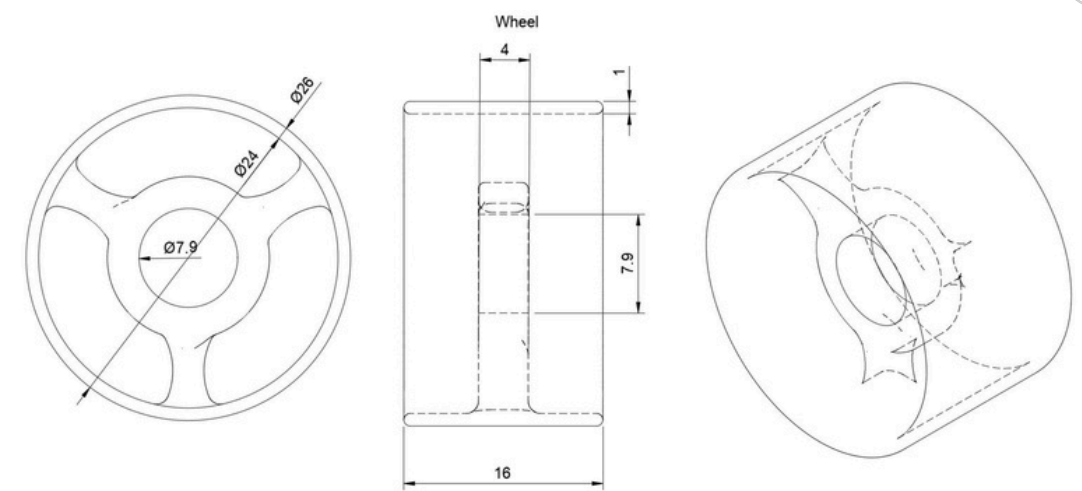
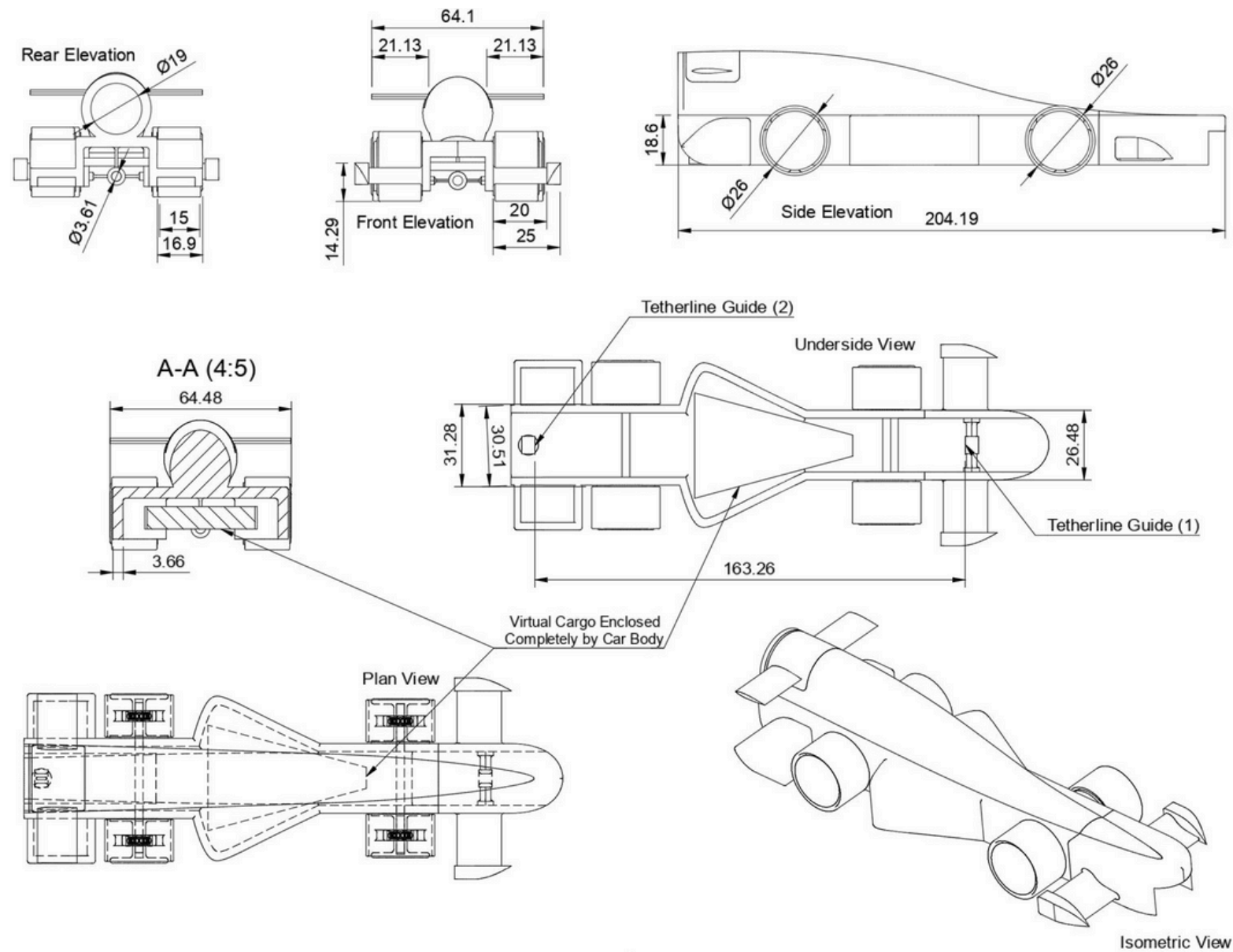
STREAMLINE VECTOR DISPLAY

We in particular made heavy use of a feature called 'Streamline' vector display, which had an advantage in showing large sections of air which were affected by the car's aerodynamic design. This feature allowed us to visualize the flow patterns and identify areas where the air flow was most effectively managed. Discovery also allows for flexible simulation setup, allowing for change in fluid inputs; ie. speed of the air and material of the car were being constantly updated along with our car R&D. Additionally, we leveraged Ansys Discovery's advanced tools to optimize our simulation setup, ensuring that our results accurately reflected the complex aerodynamic interactions at play.



MAGNITUDES ARE DISPLAYED USING VARIANCE IN COLOR.

ORTHOGRAPHIC DRAWINGS



Front Wing Attachment

