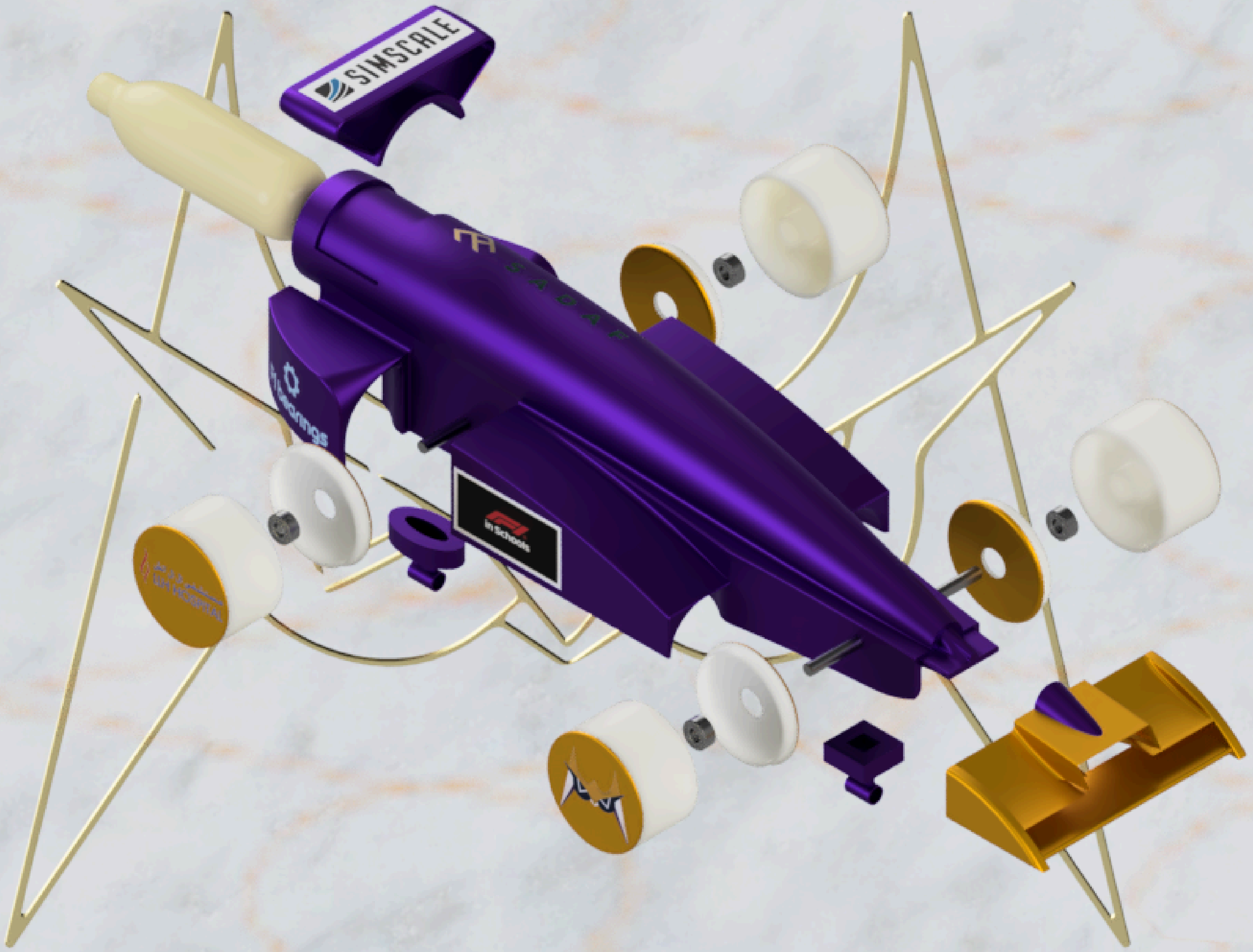
MINERVA



ENGINEERING PORTFOLIO

مستشفى ال ال اتش
LLH HOSPITAL

SIMSCALE

SADAF
PREMIUM INTERIORS

F1 bearings

Tecpro Solutions
SYSTEMS INTEGRATOR

RESEARCH

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INTRODUCTION

To design a car fit for the competition, the team started off with going through the set regulations. These helped us create a foundation on which we could develop a prototype fit to star in the competition. Thorough research of aerodynamic concepts and the manufacturing process, helped us start coming up with ideas which were sketched and assessed. These sketches helped us realize a design intent. Duly noting positives and negatives, we started off 3D modeling prototypes that we were inclined towards. Further addressing concerning design ideas, we CFD tested the prototypes and hence, further developed them.

Using this process, we iterated many models. With effective communication, this strenuous method was made easier than seemed.
The objective was simple: Creating a car that was aerodynamically efficient, structurally sound and aesthetically pleasing. At the end, we achieved this objective with what we called Prototype Noctua. The chariot of Minerva.

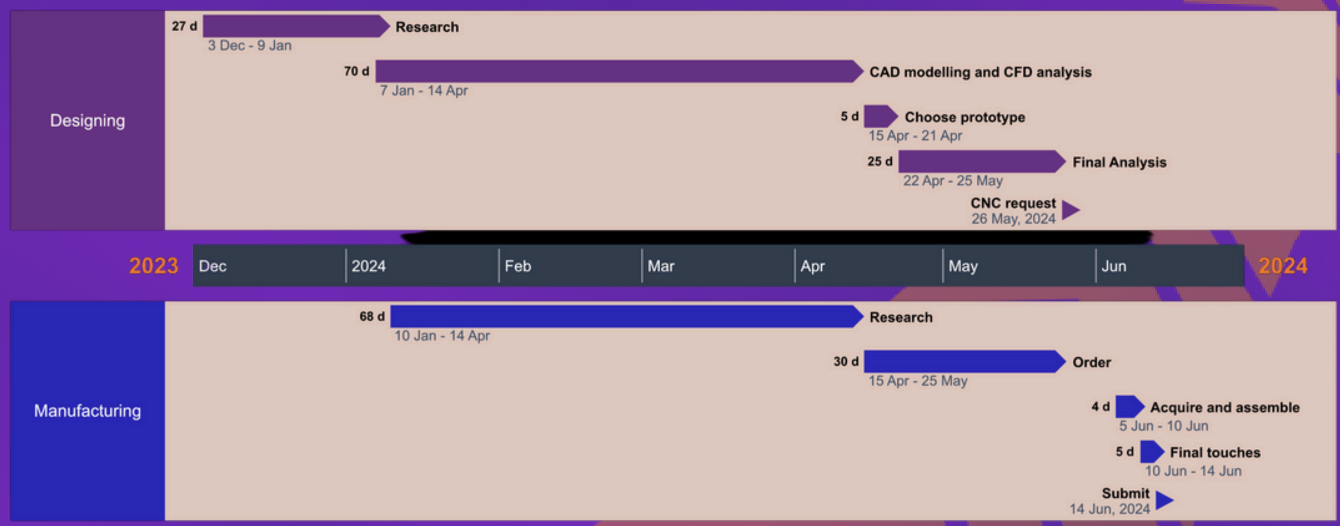
DESIGN OBJECTIVE

Our initial aim was to create a car with a drag force of 0.4 or lower which has directional stability and complies with the regulations.

MANUFACTURING

For manufacturing our aim was to create a model that weighs close to 50g, has a millable design, made with materials that are durable and at the end replicates the CAD model.

TIMELINE



INITIAL RESEARCH

Through our research, we found that the key forces acting on the car are:

- Canister Thrust:

Our goal was to maximize thrust efficiency by reducing inertia of the car and making it more streamlined. The nose cone design achieves the highest thrust minimizing the air resistance and is integrated to the rest of the body.

- Drag:

To reduce drag, we ensured the model had smooth transitions throughout. Applying design techniques and aerodynamic principles, we streamlined the model extensively.
This involved crafting a front wing to efficiently distribute airflow over the wheels and designing sidepods to seamlessly redirect airflow around the rear wheels and over the rear pods.

- Lift and downforce:

To ensure stability on the track and prevent lift from initial thrust, we focused on maximizing downforce. This involved optimizing the aerofoils of the front and rear wings, adjusting the angle of attack of the nose cone, and implementing ground effect principles.

- Weight:

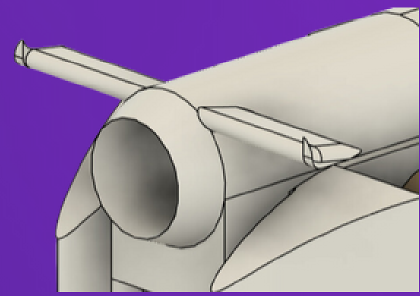
Heavier cars experience higher drag due to their larger frontal area, making downforce generation more difficult. This also affects inertia, reducing thrust efficiency. Thus, our aim was to develop a model close to the 50g weight limit mandated by regulations.

TECHNICAL STUDY

low pressure
high pressure

1. Boundary Layer Separation

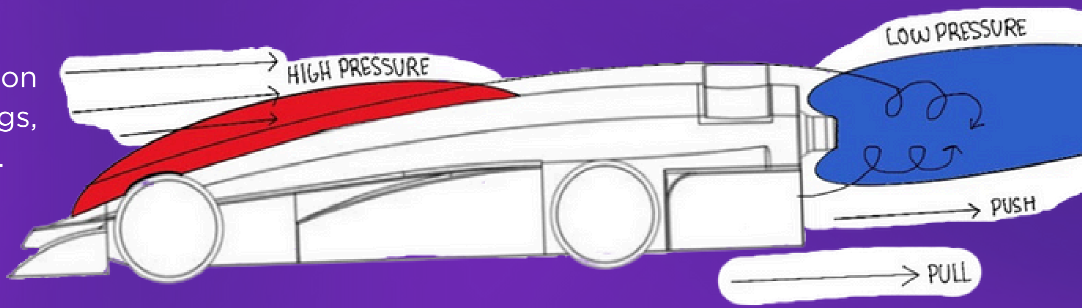
A boundary layer is a slow-moving fluid layer alongside a body immersed in it. Boundary layer separation occurs when this layer detaches, forming a wake due to adverse pressure gradients. To reduce separation, we designed a streamlined model with smooth surfaces and filleted edges to prevent turbulence and vortices.
Using gradual curvature in body shapes proved beneficial by maintaining flow attachment and reducing adverse pressure gradients. We implemented this approach in P7 by chamfering the body ends to create gradual curves.



This reduced drag significantly, but didn't quite achieve the desired gradual curvature. So, we aimed for a body design resembling a teardrop shape, exploring the idea of a penguin shape.

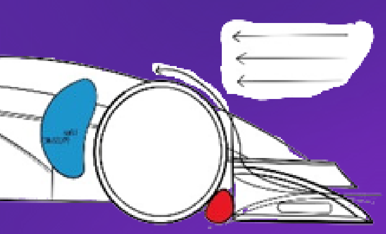
2. Wake

The wake is the turbulent airflow behind a car caused as it moves through air, creating a low-pressure region that increases drag and reduces efficiency. This turbulence results from the boundary layer separating at the car's rear, causing fluctuating pressure differences. High pressure at the front pushes the car forward, while low pressure at the rear pulls it back, creating pressure drag. Turbulence in the wake is more noticeable with box-like rears and affects both handling and overall performance. To reduce the wake, we needed to create a streamlined design that would redirect airflow around the car.



3. Magnus Effect

The Magnus effect occurs when wheels encounter a fluid moving in the opposite direction, causing a force perpendicular to their motion. Here, as the wheels move against the airflow, a high-pressure area forms on the bottom and a low-pressure area on top due to differing relative velocities. This pressure difference induces drag on the wheels, exacerbated by rotational turbulence caused by varying relative speeds.



To mitigate this, we aimed to design a front wing that minimizes airflow interaction with the wheels.

4. Center of Mass determination

The center of mass of an object is the point at which the relative distribution of weight sums up to zero. For a symmetric object, the COM is in its geometric center whereas for an irregular object, the COM is at a point where the object can balance.

We considered the following to determine an approximate position for the COM:

i. Tipping force: (Rear COM)

The thrust provided by the CO2 canister becomes the tipping force for the car and the moment of force provided by the center of gravity of the car helps balance it out. So, our aim was to ensure that the torque provided by the tipping force should always be less than the torque by the COM.

$$T.h > W.d$$

$$T > (W.d)/h$$

where T is the force provided by the canister,
W is the weight of the car,
d is the perpendicular distance between W vector and the center of the front wheel,
h is the perpendicular distance between the T vector and the center of the front wheel.

We needed to ensure that the maximum force exerted by the canister remained less than the (RHS) of the equation. To maximize the RHS, we could increase either W or d, or decrease h. Since increasing the car's weight is undesirable due to increased inertia, and h remains nearly constant across models, we opted to adjust d. This shift would move the center of mass rearward.

However, placing the center of mass too far back promotes oversteer, making the car more responsive but potentially unstable. We balanced this with considerations for the car's directional stability. Another factor to manage was traction, which affects how well the wheels grip the surface during acceleration. Too much traction hampers acceleration, so we aimed for a balanced level that allows sufficient grip without excessive resistance.

ii. Directional stability: (Forward COM)

To induce under-steer, we need to promote directional stability in the body which would make the chances of the car turning or changing paths less. To do so, we visualized and realized that a forward center of mass would help in maintaining the directional stability of the car along with producing lower traction in general.

Forward COM	Rearward COM
Promotes directional stability	Prevents tipping
Promotes understeer	Promotes oversteer

From this table, we thus realized that balancing these factors is crucial and a COM right at the middle would be the most preferable for a favorable race time. Hence, after incorporating in the CO2 canisters in our model and setting the materials of 3D printed parts (i.e. front wing, rear wing, tether line guides, etc.), we achieved a center COM in the car:

The Centre of Mass tool displays a symbol at the observed Centre of Mass of the model. If all the materials are entered correctly, it displays the assumed Centre of Mass of the body. Indicated by

SOFTWARE SELECTION

WHAT IS CAD?

COMPUTER AIDED DESIGN IS THE UTILIZATION OF COMPUTERS IN SUPPORT FOR DESIGNING, OPTIMIZING AND ANALYSIS OF ANY DESIGN. THERE ARE 3 TYPES OF CAD SOFTWARES

2D CAD

AID THE SKETCHING AND ANNOTATING PROCESS OF A DESIGN.

3D CAD

3D CAD PROVIDES AN ADDITIONAL AXIS Z TO FACILITATE 3D MODELING.
3D CAD IS OF THREE TYPES.

FREE FORM CAD

A TECHNIQUE THAT ALLOWS FOR THE CREATION OF MORE ORGANIC AND GRACEFUL SURFACES AND SOLID SHAPES. IT CAN BE COMBINED WITH BOTH PARAMETRIC OR EXPLICIT MODELING TO FORM COMPLEX GEOMETRIES.

PARAMETRIC MODELING

IT ALLOWS USERS TO DEFINE CONSTRAINTS AND DIMENSIONS AND EDIT THEM AS SOON AS THEY HAVE BEEN DEFINED. REPETITIVE MODIFYING IS SIMPLIFIED BUT THE EXISTENCE OF A HISTORY TREE CAN STIR UP ISSUES IF MAJOR CHANGES ARE MADE.

EXPLICIT MODELING

UNLIKE PARAMETRIC MODELING, EXPLICIT MODELING DOES NOT RELY ON A HISTORY TREE.

ASSEMBLY MODELING

THE INCORPORATION OF MULTIPLE PRE-EXISTING GEOMETRIES INTO ONE.

Fusion	Solid Works	Space Claim
Parametric/ Explicit	Parametric	Explicit
Cloud Based	Not cloud based	Not cloud based
Simulation Tools	Simulation Tools	Ansys softwares have to be integrated
Manufacturing Integration	Manufacturing Integration	Ansys softwares have to be integrated
Free for students	Subscription	Free for students
Ease of usage	Ease of usage	Ease of usage

Based on an evaluation, we selected Fusion as the ideal modeling application.

- Fusion stood out for its affordability, user-friendliness, cloud storage capabilities, and access to training resources.
- Solid Works was excluded due to its high cost and demanding hardware requirements (16 GB RAM, quality GPU), which were not practical for our needs.
- Space Claim, being explicit modeling software, presented challenges in editing dimensions and constraints effectively.

Fusion's robust history tree maintains design integrity, its use of constraints and parameters facilitates efficient assembly management and preserves inter-part relationships.

WHAT IS CFD?

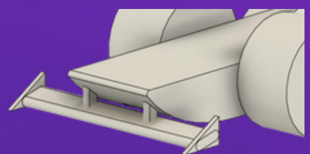
Computational Fluid Dynamics (CFD) is the utilization of computers to simulate the flow of fluids in different situations. It utilizes algorithms to solve the equations of fluid flow.

While running tests, we noticed that the boundary walls created by AutoDesk CFD significantly impacted the calculated drag force. To overcome this issue of variability, we decided to define a boundary box with identical dimensions for every simulation run.

FUS SIMSCALE CFD

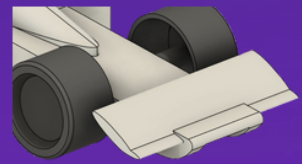
CAR DEVELOPMENT

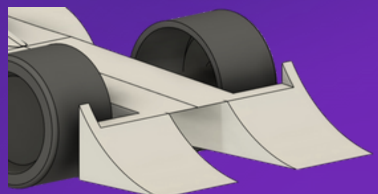
FRONT WING



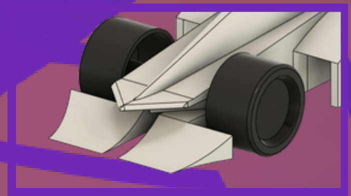
Aim: Our aim was to come up with a front wing design that redirects incoming airflow around the wheels.

Our first approach was to create it at an angle with support structures at the ends. This did not give us favorable results due to poor CAD modeling.
With our 2nd prototype, we decided to design a curved front wing with an abrupt curvature. This showed promising results but we still needed to step up our modeling process.

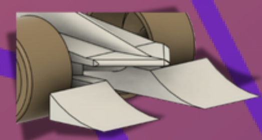




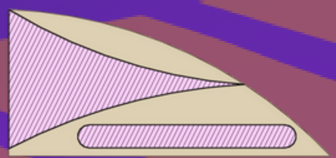
With the third prototype, we managed to achieve a wing with a gradual curve. This design resulted in an overall 20% decrease in drag. We felt confident with this design and decided to improve on the same. In the next few models, we decided to flatten half of the wing. Due to this, there was an abrupt airflow separation which directly impacted the wheels



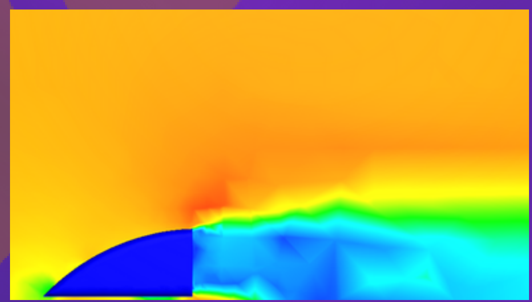
With the 6th prototype, there was a gradual curve on both the top and side of the wing. With this design, our intent was to redirect air flow both on top and to the sides of the wheels. We did not see any significant change due to this addition and did not pursue it.



P7 was the pinnacle of both, a streamline and a well CAD modeled prototype. It achieved a drag force of 0.37 and was chosen as a base model to experiment. After many iterations, we decided to experiment with double elemented front wings with the curved element as basis.



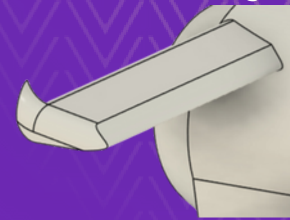
We tested two types of double elemented wings: straight element above (S1) and straight element below (S2). With the S1 iterations, we saw an increase in drag force and chose to not consider it. With S2 iterations, we saw room for improvement.
S2 allowed for better boundary layer control and aerodynamic efficiency. It helps in pressure recovery which reduces drag. Pressure recovery refers to the process of converting the kinetic pressure of a fluid to static pressure. The straight element slows down the flow of fluid, which in turn changes kinetic pressure to static. This allows for equal pressure distributions throughout the surface, decreasing drag.
Keeping the above in mind, we made minor changes to the S2. Our main focus was to come up with an aerofoil and to decide the perfect placement. We came to a conclusion that the placement of S2 will have to be in the front due to both aerodynamic efficiency and regulations which will be discussed ahead.
With the creation of Prototype Noctua, we achieved new horizons. The curved element had curvature both above and below. With the curve below, we aimed to decrease the direct impact of air on the wheels. There is a lesser curvature on the bottom as compared to the top as we did not want to create too much lift. With this iteration of the front wing we achieved an overall drag force reduction of 31.87%. This represents, in the cross-sectional form, the airflow around the final prototype of the front wing. As seen, the curved part of the front wing successfully redirects the passage of air above creating a wake behind the wing.



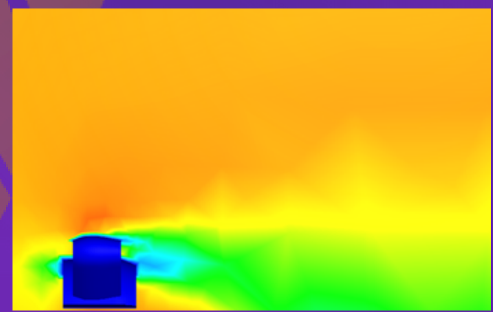
REAR WING

Aim: With the rear wing, our aim was to create a low drag, high downforce model. This was to maintain a balance between the downforce created by it and the front wing.

With the first prototype, we dived in blind to what to expect from a rear wing other than downforce creation. With the next few models, we tried different designs to broaden our domain for the design intent. With thorough simulations, we weren't satisfied with the results. We randomly stumbled upon winglets, directly influenced from airplanes. With all the prototypes created before, one major issue was the creation of vortices by the ends or rear wings. This issue was solved with the implication of blended winglets. These new winglets showed immediate reduction in drag.

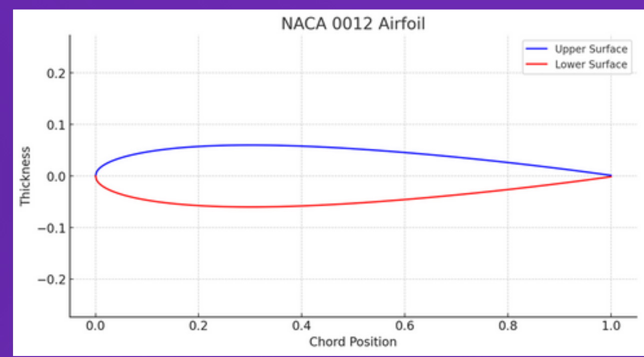


But with the creation of winglets, the issue of creation of vortices was not completely resolved. To completely eliminate vortices we decided to create a wing that resembles a F1 car. The 'curved wing' concept used in F1 reduces drag significantly.

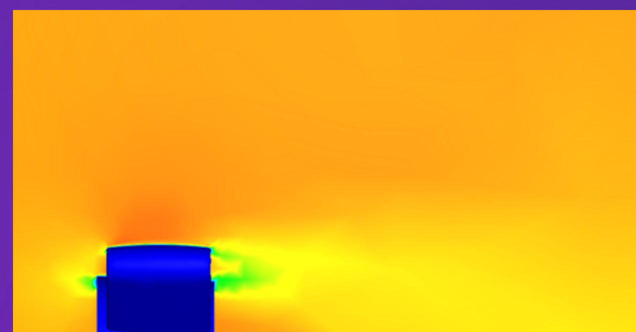


But the regulations of the competition differ from the ones set by F1 In Schools and so we had to modify them so that they follow them. We ended up with an inverted triangle as our rear wing. The first of the two chosen prototypes, though effectively helped in managing the turbulent air flow that would be created in the wake of the car, had us concerned with its structural integrity as it was modeled to be wafer-thin to maintain the low drag aim. Hence, we had to discard this prototype. But this set a foundation for the design intent of the final rear wing.

This final prototype was modeled to have a thicker leading and trailing edge. It was raised higher to maintain the required 3 mm distance mandated by the regulations. The support structures were angled lower to cover a larger area of airflow.
We used the NACA 0012 for these iterations of the rear wing. It provided close to no lift at the 0° angle of attack. Due to its symmetry, it could be easily manufactured with great structural integrity and predictable aerodynamic characteristics.



While being a more streamlined design by almost 30%, it also proved to be more efficient in maintaining the energy of the airflow it faced. Hence, this design was chosen as the final rear wing.

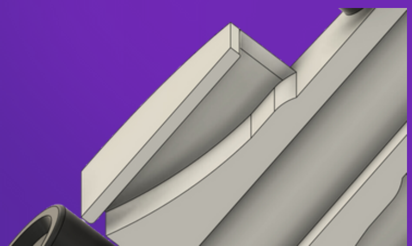


SIDEPODS AND REARPODS

During the initial phase of designing, we focused on perfecting the front and rear wings. Even still, our design intent gets its foundation from the first few models.

Side pods

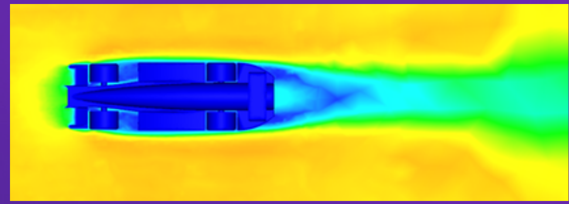
Aim: Our aim was to create sidepods such that they redirect airflow over the rear wheel and to ensure smooth flow along the sides.
Our thought process led us to creating hollow sidepods, which would prove to be helpful in minimizing wake turbulence and increasing downforce and stability of the prototype on the track. Our initial design was an opening right into the rear wing, which remarkably reduced drag but could have been improved.
Then it was decided to create an opening towards the sides of the car. Implementing this on P7, we achieved our first exceptionally streamlined model.



With rigorous analysis through CFD, we realized that this design, with its benefits, also had its drawbacks.

The opening for the airflow to pass was miniscule. This would trap a significant amount of airflow and redirect it under the car diminishing ground effect. Also, due to the use of the 6.35 mm diameter drill bit, the manufacturing of the tiny opening would've been impossible. This was later rectified in P7.
This and the passion for a lower drag prototype led us to hollowing them in such a way that the passage opens to the tether line guide slot.

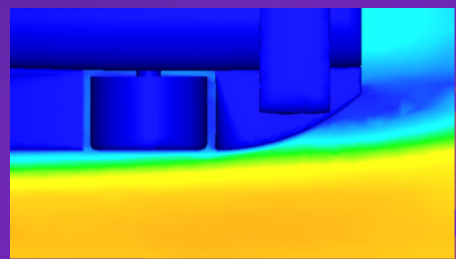
Along with this, we lowered the sidepods significantly. Through analysis we noticed that the airflow right above the front wheels would slip into the low-pressure area created behind the wheel creating turbulent airflow into the sidepods. Hence, it allowed the sidepods to work more efficiently than before and regulate airflow as intended to. Lowering sidepods helped in moving the center of mass down as well.



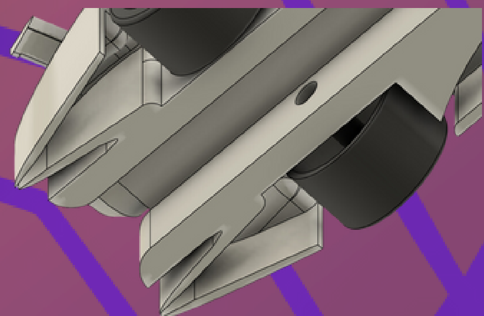
From the CFD analysis of the prototype, it is seen that the low pressure area behind the wheel as well as airflow along the sides is maintained throughout.

Rear Pods

Aim: Our thought process, when we were coming up with designs for the rear pods, was to use them to redirect the passage of air to the rear low pressure area of the car.
We ran through multiple iterations and ended up, once again, with a V. This design allowed for the airflow from the tether line slot to spread up and for the flow from the sides to be averted towards the rear.



Due to the slope of the rear pod, the airflow is not fully pivoted to the rear but there is a late separation of air flow which was ideal.



With P6 and P8, we tried to hollow out the rear pods as some of the airflow would get trapped between it and the rear wheel.

But due to poor CAD modeling, this strategy did not prove fruitful. This plan was originally thought to be discarded but made a return with the final few versions of Noctua.

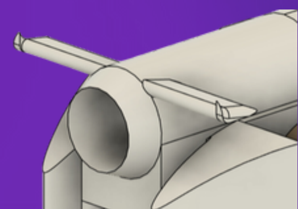
With the improved modeling efforts, this hollowing, though not a cake walk, proved yielding.
All these changes to the side and rear pods helped in streamlining the car the most. It proves how important these two components are for directional stability, aerodynamic efficiency, generation of downforce, etc.

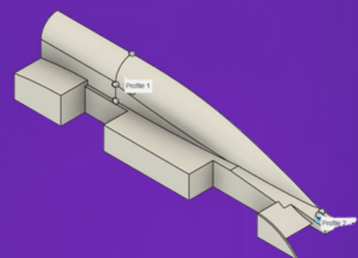
NOSE CONE

Aim: Our aim with the nose cone was to create a flat surface that would not let the airflow flip onto the wheels.
Initial designs led us to realizing that the airflow would roll over into the wheels and hence we decided to go with a more refined nose cone. Taking inspiration from a sword, the nose cone created for models P6-P9 served its purpose right, slashing through the wall of incoming air and significantly reducing the slip-off factor. The junction between the nose cone and the main body was sharp and had to be filleted with a G1 continuity factor to smoothen the transition.
We later switched the design to a wedge as the 'edge of a sword' concept, despite its functionality, resulted in a sudden impact from the incoming air, leading to occasional turbulence.

CAR BODY

The most streamlined shape in the world is the teardrop with a drag coefficient of 0.05. But during the design process of the body, we realized that implication of such a shape would not be possible. We decided it would be best to elongate the body so that there is a gradual flow of air along it. Chamfering further reduced the drag but was not satisfactory. To overcome this we needed to brainstorm a solution that would result in a penguin-like shaped body.

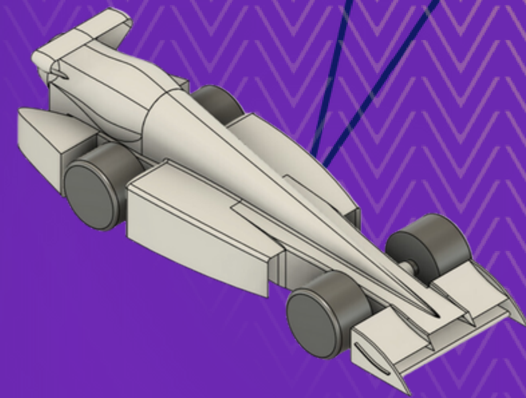




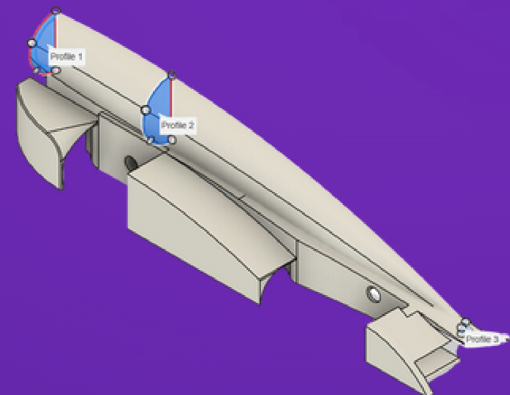
Initially, we would extrude (mentioned above) a CO2 chamber first and then create a sketch further away and loft (mentioned above) the two profiles (the face of the chamber and the created sketch), but this resulted in a gradual curve only at the front of the body.

The air flow would separate over the chamber hence, widening the wake and inducing drag.

Our line of thinking then shifted to using forms to create a curvature around the chamber. This resulted in an increased drag due to the lack of continuity from the loft to the created form.



We decided to create two sketches: one at the rear of the car and one on the face of the chamber, both of which consisted of a semicircle. The semicircle at the face was given a longer base by 2mm. On lofting, we were able to produce a body with an exceptional curve.



- Filleting sharp edges along the side/rearpods, nose cone and the junction between the nose cone and the body, reduced turbulence and flow separation resulting in a model that is easier to manufacture. It also improved stress distribution offered, increasing structural integrity.
- Surfacing provided precise and continuous surfaces which enhanced both aesthetics and simplified milling.

WHEEL SYSTEM

Axles

Material

Axles play a crucial role in the stability and the streamlined movement of the car. It does so by holding the wheels in place and parallel to each other. Thus, making our axles strong and smooth was one of our biggest priorities. We then explored each option in detail:

STEEL	CARBON FIBER
● Popular choice ● Machined to perfection ● Affordable and available ● Strong and corrosion-resistant ● Heavy, so not chosen	● High strength-to-weight ratio ● Tensile strength 2500-7000 MPa ● Slightly lower density than steel Although its attainability was lower than that of steel, our sponsor **F1 Bearings** offered us to them at a discount.
ALUMINIUM	**TITANIUM**
● Lightweight and easy machining ● Reduces car's weight ● Not as durable ● Availability issues, not chosen	● Durable and strong ● Exceeded budget ● Low availability

Axle systems

Plan 1: If the COM of the final body was found to be either too forward or too backward, we planned on using an heavier axle on the opposite side of the COM in order to bring it closer to the center. However, we found no use of this plan in the end as the COM of the final body was in a suitable position.

Plan 2: To make the body more streamlined, we were going to create a modified axle placement system either by covering it up inside the body.
However, this plan too was discarded as it not only increased complexity and also added mass in an unfavorable way which may put our car at the risk of tipping forward.
Hence, the final system was just straight to connect two wheels and keep them parallel.

Bearings

Materials

While looking for bearings initially, the two options which came up almost immediately were steel and ceramic bearings:

CERAMIC BEARING	STEEL BEARING
● Superior speed	● Lower speed
● Resistance to corrosion	● Easier to source
● High temperature tolerance	● Less expensive

Our primary objective while looking for bearings was high speed, so we chose ceramic bearings.

Further, we had to decide on whether we use the normal ceramic or the hybrid bearings:

I. Ceramic bearing rings are more difficult to machine so the roundness achievable with steel rings is not possible leading to higher levels of vibration.
II. After machining, the ceramics would weigh up to 1 gram on an average where as the hybrid's would be lighter with each being 0.4 grams.
III. The hybrid bearings require marginally less efforts to rotate the wheels, hence conserving energy.

Hence, the hybrid ceramic bearings seemed to be the better choice for bearings. Through F1 Bearings, we were able to source the Ceramic Hybrid bearings of the required dimension.

Bearing system

A double bearing axle system adds complexity and weight. More bearings can increase friction if not precisely aligned, raising costs and hindering performance. We opted for a single axle-bearing system, which meets requirements for high RPM and low inertia without the drawbacks of a double bearing system.

Wheels

Before designing the wheel, we aimed to minimize the Moment of Inertia (MOI) to ensure CO2 energy was used for acceleration, requiring minimal energy to start motion. MOI is proportional to mass and the square of particle distance.

I=mr2

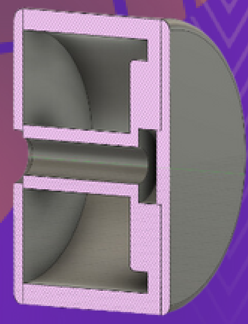
Thus, lighter and thinner wheels lower MOI, reducing energy loss. We aimed for the smallest diameter allowed and reduced mass by eliminating unnecessary parts.
We then settled for the following base dimensions:

Diameter: 28 mm
Width:17.5 mm

Base concept

To create a wheel that is hollow so that it houses the bearings and axles which is covered to prevent lateral movement and reduce drag.

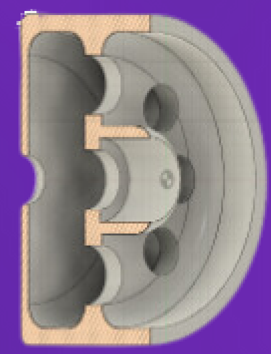
1. Prototype 1



This model comprised an inner area for bearings to slide into, secured by an outer cap. However, it neglected the wheel's center of mass and lacked internal support.

Recognizing these problems, we iterated on the next designs. These modifications aimed to enhance the wheel's tolerance and address the issues.

2. Prototype 2



Utilizing holes in the central structure reduced mass and simplified production, yielding a lower MOI compared to others. Moreover, filleting the inner structure's edges increased surface area, increasing strength. Despite these, the prototype exceeded the 4.5g weight limit, weighing in at 5.7g.

TETHER LINE GUIDES

The tether line guides ensure the car does not deviate from its path, which is crucial for maintaining a straight and controlled movement. To ensure that the car reaches its top speed, we must reduce the coefficient of friction of the inner surface of the tether line guides.

The smoother the surface, the lower amount of force required to overcome the retarding force.

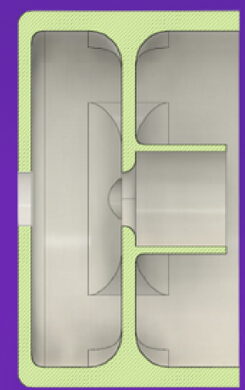
For the structure of the tether line guides, we used different shapes in the front and back due to area constraints.

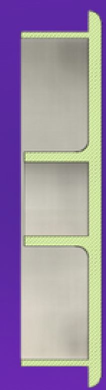
We used concentric square indents with similar indents in the car for it to fit perfectly. Similar design for the rear tether line was used but the difference was that the shape was oval.

Final Model

This model employs the same base concept of a wheel and a cap but features a modified internal structure with four fileted spokes. Spokes provide structural support to the wheel. They help distribute the load evenly across the wheel. The fileted design increases the surface area, compensating for the area lost by the spokes. This enhanced area helps distribute stress evenly similar to the previous prototype. The use of spokes also reduces the wheel's weight, bringing it closer to the desired 3.5 grams.

Additionally, the weight distribution improves the moment of inertia, making this model a more desirable option. Overall, the innovative use of fileted spokes ensures optimal stress distribution and weight efficiency, enhancing the wheel's performance and making it a favorable design choice.

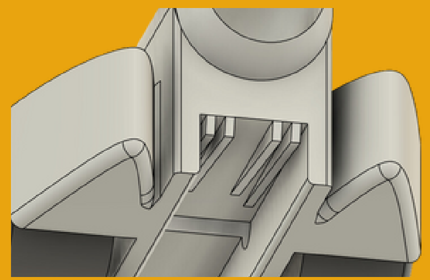




FINAL ANALYSIS

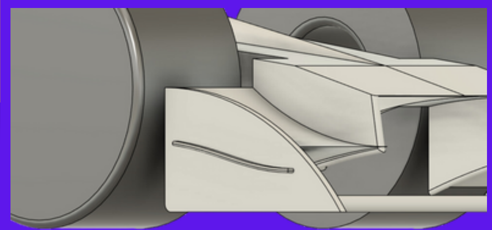
OTHER DESIGN CONCEPTS

Diffusers are parts at the rear which increase cross sectional area to slow down passage of air to redirect it to the low pressure area in the rear of the car. These helped in reducing the drag significantly, but upon revision of the regulations, we realized that it would result in a broken critical regulation and hence, we dropped the idea.



Diffusers

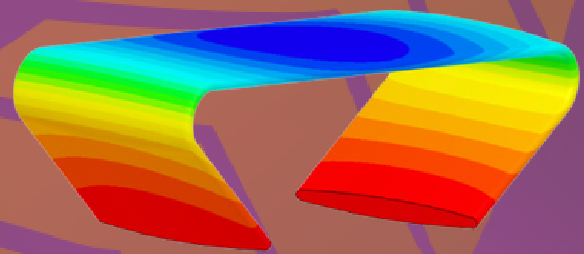
Vortex Generators

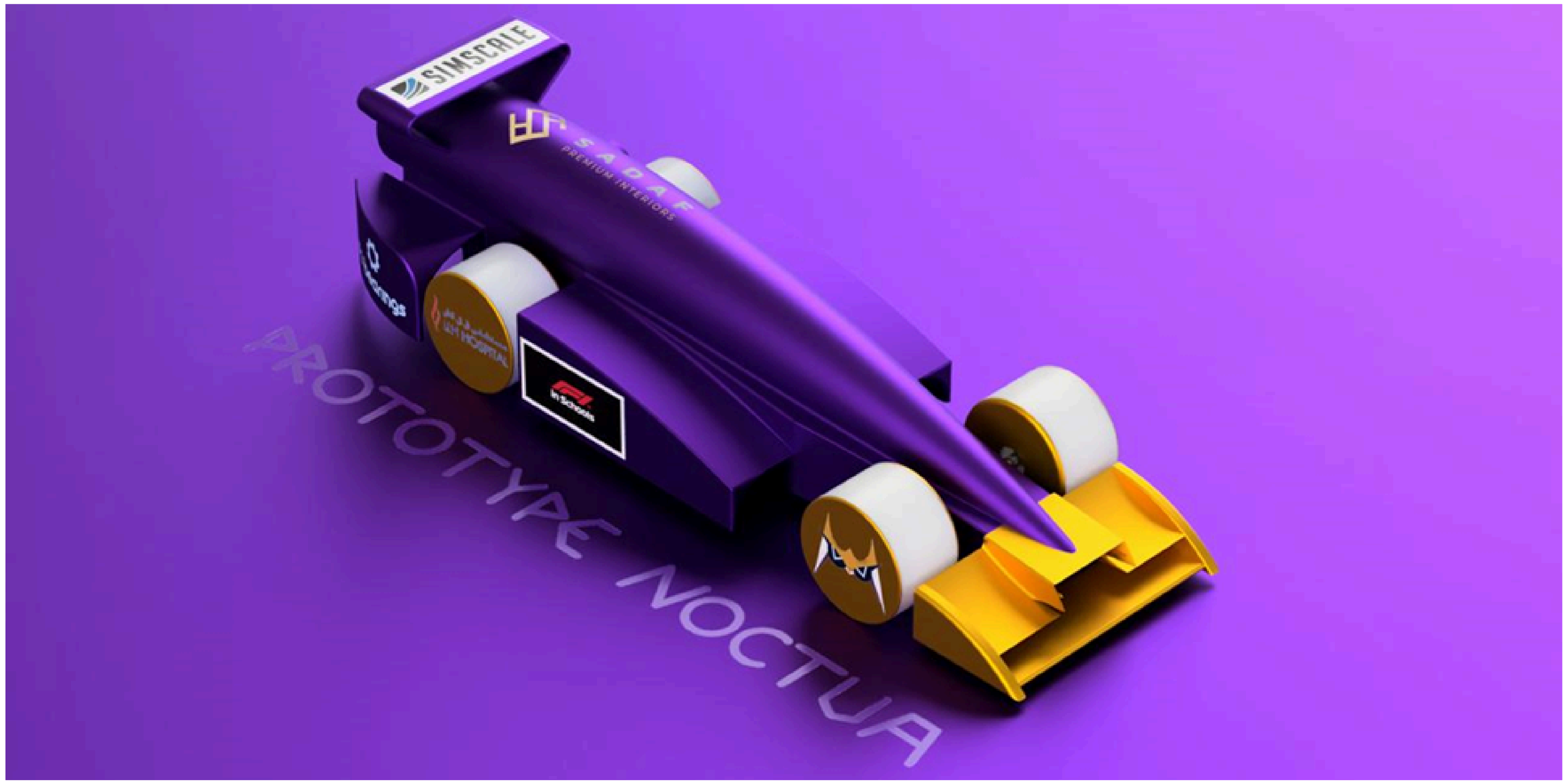


Inspired by F1 cars, we tried to create vortices by adding vortex generators to the front wings to reduce boundary wall separation along the sides of the models but again, we violated critical regulations and had to get rid of them.

FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a computational method used to predict how objects respond to various physical conditions. This technique allows us to determine the stress levels experienced by different parts of a car and the extent of their potential deformation. We utilized the services provided by our sponsor, **SimScale**, to perform FEA on various car components. The results revealed that the rear wing posed a small risk of deformation. Consequently, we concluded that a stronger material would be necessary for the rear wing to ensure its durability and performance under operational conditions.





FINAL CAR ANALYSIS

Prototype Noctua was found to have a drag force of 0.28. After meticulous research and testing, we realized a car that was aerodynamically efficient, structurally sound and aesthetically pleasing.

Our final model, Prototype Noctua, surpassed our initial expectations, compelling us to delve deeply into CAD modeling and achieve new heights in aerodynamics application.

'Noctua' is derived from 'Athene Noctua' or Owl of Minerva. The Owl of Minerva symbolizes the arrival of wisdom and knowledge after the events have unfolded. Georg Hegel, a German philosopher, popularized the phrase "The Owl of Minerva spreads its wings only with the falling of dusk" representing just that.

This is exactly what we experienced during the constant designing of models. We were not equipped with the knowledge to create such a remarkable model, it only came to us after thorough trial and error and extensive research.

Our initial goal of achieving a drag force of 0.4 or lower became obsolete after we realized what the Noctua was truly capable of. Through practice, we managed to achieve a streamlined body that could withstand the forces presented to it during the races. The front wing achieved its initial goal of creating downforce while also keeping the airflow away from wheels. It was also able to energize airflow hence decreasing boundary layer separation and increasing downforce and thus, improving stability and grip. The rear wing realized its task of being a low drag element that redirects airflow towards the wake of the car while providing downforce and hence stability.

The sidepods beautifully carry the oncoming airflow from the wheels and elegantly redistribute it over the rest of the car body adding to the directional stability and grip. The rear pods allow the latency in airflow separation hence, averting the airflow towards the rear of the car. They also carry the airflow over the rear wheels and help reduce turbulence which adds to the overall aerodynamic efficiency of Prototype Noctua.
Hence, Prototype Noctua helped us in realizing our own potentials and to what extent our boundaries could've been pushed to. With Noctua, we achieved new horizons.

MANUFACTURING

COMPUTER-AIDED MANUFACTURING

Computer-Aided Manufacturing (CAM) integrated sophisticated software and hardware into the manufacturing process, significantly enhancing precision and efficiency.

CAM was indispensable for the precise manufacturing of our car components. Advanced machining methods, such as CNC milling and 3D printing, were employed to create everything from streamlined body parts to intricate details.
The analysis data acquired then guided our milling and 3D printing operations, ensuring that each cut and layer adhered to our exact specifications. For example, we used a 6.3mm drill bit on the CNC machine, a standard tool in the F1 in Schools competition.
By analyzing the outcomes and iterating on our processes, we ensured that each component met the highest standards of quality and performance. This integration of analysis data and manufacturing precision not only enhanced the aerodynamics and overall efficiency of our car but also exemplified the advanced engineering skills required in modern automotive design.
Through CAM, we achieved a harmonious blend of design and manufacturing, resulting in a high-performance car ready to compete at the highest levels.

Our mentor, Jayasurya, overlooking the manufacturing process.

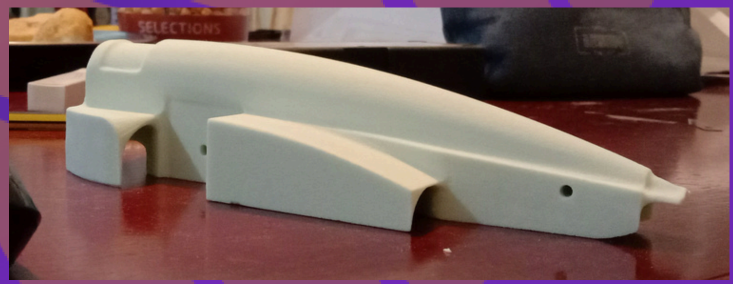
MANUFACTURING

Sanding

The body which we received from the CNC mill had many bumps and crevices, hence the need for sanding the body rose before starting off with any other process. Sanding was a fragile process as the body may have been weak in some areas and took us some time. We chose to sand the body by slowly increasing the grit of the sandpaper from 220 - 1500 to end up with a fully smoothened streamlined car chassis.

Priming

Priming was the essential next step as it fills in small scratches, pores, and imperfections left after sanding and provides a better surface for paint to adhere to, ensuring it stays on longer and more uniformly. It helps also in reducing the interaction between the surface of the cane and the atmosphere which might affect the dimensions by moisture. A thin primer layer was added evenly and then sanded down to a perfect and smooth finish again. Now our body was ready to be painted.



Painting and Adhesive

To decide which paint suited our preferences more we played around with Jenga blocks to try different paints out and reached the following conclusions

S. NO	WEIGHT / CM3	NO. OF COATS	RATING
1	0.00711g/cm3	2	9/10
2	0.00653g/cm3	4	5/10
3	0.00825g/cm3	2	3/10
4	0.00791g/cm3	2	8/10

From the ratings, Paint 1 was the most suitable choice for us. We then applied thin and even coats while holding the spray can far away at a constant distance. Smooth, sweeping motions helped in avoiding building and creating uneven finishes. We also attempted to create very slight dents in the paint layers to leave space for the decals so that the final body would not have any bumps due to the decals.

To decide on what adhesive we once again tested out its strength on a relative scale and calculated its mass:

	Weight per drop	Strength level
Gorilla glue	0.11	09/10
Super glue	0.063	08/10

While both adhesives were almost equally strong, the weight difference was significant. Another reason why super glue was more preferred was due to its easy availability at low prices.

CNC equipment

After giving much thought to where we should have our car body milled, we realized that the safest option was to use CNC services from F1 in Schools. Not only did they ensure a safe and precise milling process, but they also offered a price more affordable than other places, which would have provided almost the same quality. This decision allowed us to maintain high standards for our project while staying within budget, making it the ideal choice for our needs.

3D printed parts

We required the front and rear wings and tether line guides and all the wheels of the car to be printed separately. To decide on which material to select for these, we looked at the datasheets of the most popular choices:

PROPERTIES	ABS	PLA	RESIN	POLYCARBONATE
Density (g/cm3)	1.05	1.25	1.1	1.2
Tensile Strength (MPa)	45	52	69	60.7
Elastic Modulus (MPa)	2200	2500	2940	2480
Coeff. of friction	0.35	0.42	0.29	0.4
Young's modulus (MPa)	2057	4107	1935	2400

From this we concluded that Resin is the safest option to print out our parts with because of the strength and low coefficient of friction it offers at a lower mass when compared to others. Further, another upper hand about Resin was that it's printed using stereolithography. Stereolithography is a form of additive manufacturing technology used for producing models, prototypes, patterns and production parts in a layer-by-layer fashion using photopolymerization. This results in getting our parts with extremely smooth finishes, which also cut down the need for us to sand them.

TOOLS

Tools played a crucial role in the manufacturing of our car. We used vernier calipers and a screw gauge from our school's physics lab to ensure our car adhered to all regulations post-manufacturing. These tools helped us measure how much the dimensions of the car changed after sanding and painting. We also verified that the thickness of the wheel walls met specifications and that the diameter of the carbon axle matched the axle holes. Using these precision tools was essential for forming the housing of the tether line guides and constructing the joints for the front wings.

PROBLEM MANAGEMENT

We encountered a lot of problems while manufacturing the final car body. Some of them include:

PROBLEM	SOLUTION
Tetherline guide housing were imperfectly manufactured	Carve the exact shape required to accurately position the resin tether line guides.
Imperfect joint for the front wing	Using precision tools, we meticulously carved the joint to fit the front wing perfectly, ensuring a seamless appearance.
Fragile rear pod	To enhance durability, we applied an additional layer of primer and paint to reinforce the pods, reducing the risk of breakage due to their thinness.
Defect between joint of CO_2 canister and rear pod	We used precision tools to carve out the part precisely, ensuring the right airflow.
Axle hole misaligned	Adding a slight weight imbalance can help keep the axle and ground parallel by adjusting the positioning of the wheels.
Overweight	Carve parts under the sidepods to reduce weight.

SAFETY MEASURE

RISK	CAUSE	MEASURE
Irritation of the eyes, throat and lungs	Inhaling polyurethane and carbon fiber particles.	Goggles, masks, ensuring proper ventilation and having an accessible first aid kit at all times
Fatigue, dizziness, nausea and vomiting.	Inhaling spray paint and primer fumes.	
Cuts and scratches	Use of precision tools to carve.	

ENGINEERING DRAWINGS