AERODYNAMICS REPORT

Team Trident

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The following report details the thorough aerodynamic design process executed by Team Trident, IIT(BHU), Varanasi, for the Supra SAE competition. The primary objective of this design and manufacturing endeavor was to enhance the efficiency of the nosecone.

1. NOSE CONE DESIGN:

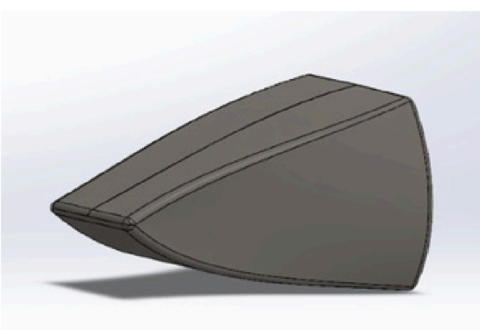
The nose cone enhances aerodynamic performance, improves stability, and reduces drag.

The aerodynamic design: prioritizes minimizing the drag coefficient (Cd) and attaining laminar airflow across the vehicle.

Material selection and weight reduction: are critical aspects of vehicle performance improvement. The nose cone design prioritizes minimizing mass while ensuring structural integrity and strength. Therefore, considering aerodynamic efficiency, the nose cone material selection is Carbon Fiber. It maintains a low-weight profile for the vehicle while providing structural integrity.

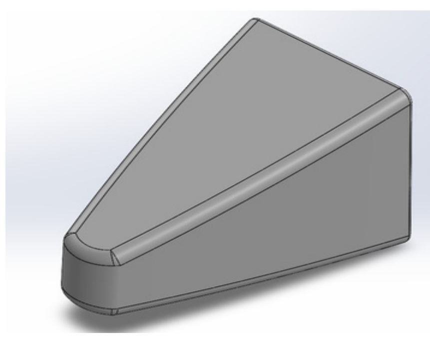
Safety: is of utmost importance in the design process, focusing on optimizing impact absorption and ensuring structural integrity to safeguard the vehicle occupants in the event of a collision.

DESIGN PROCESS: Multiple iterations of nose cone designs were developed and evaluated for optimal aerodynamic performance.



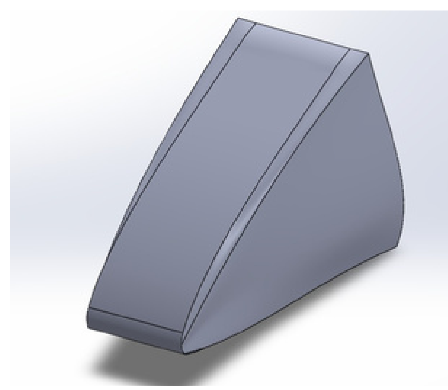
MODEL 1:
Downforce: 12.95N
Drag Force: 30.36N

REMARK: Didn't follow the Supra SAE rule quoting, "All forward facing edges on the bodywork that could impact people, e.g., the nose, must have forward facing radii of at least 38 mm (1.5 inches)."



MODEL 2:
Downforce: 12.22N
Drag Force: 16.61N

REMARK: It created less drag force, but still, this design was not selected because it created a hig wake region near its rear part.



FINAL MODEL:
Downforce: 3.66N
Drag Force: 13.377N

REMARK: This model was finally selected because it created the least drag force, complied with all the Supra SAE rules, could house the impact attenuator, and didn't create a high wake region behind it. The loss in downforce is compensated by the downforce generated by the front wing and the undertray.

FINAL NOSECONE MODEL

We opted for a comprehensive vehicle simulation incorporating all the aerodynamic components to assess the overall aerodynamic performance of our vehicle with integrated parts. However, the computational complexity and cost led us to opt for a 2D simulation of the vehicle that includes all aerodynamic components. The nose cone model 2 was utilized for the following simulation.

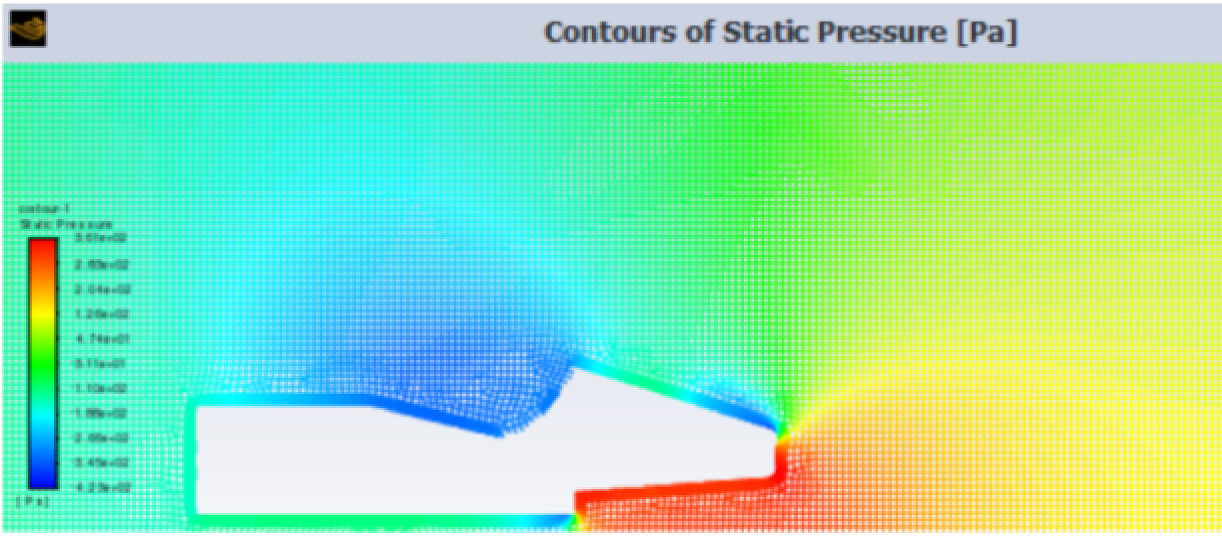
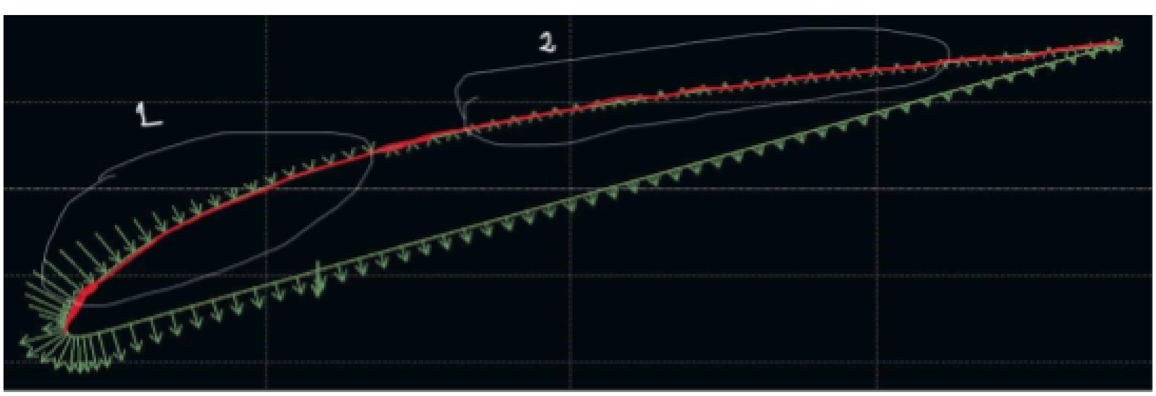
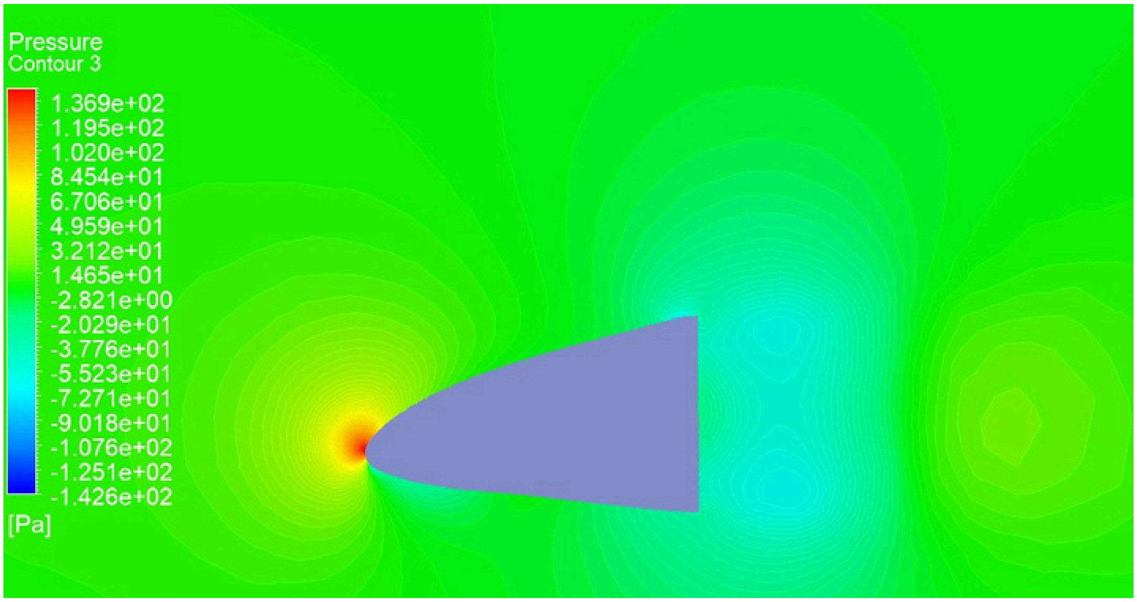


Figure showing the pressure contour with the existing nosecone. We can clearly see that there is a low pressure region at the central part which drastically reduces majority of the downforce creation that would have been created by the underplate.

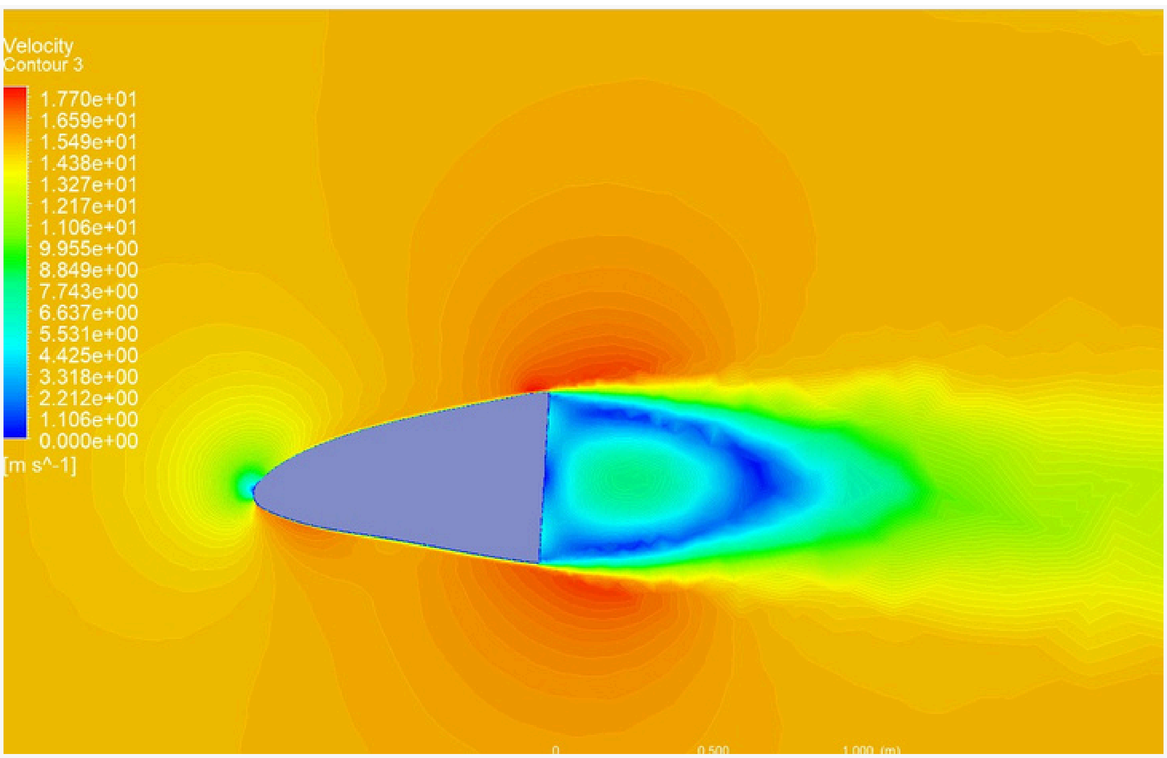
With this in consideration, we endeavored to modify the nosecone configuration. To address the aforementioned issue, we have devised a straightforward approach of configuring the upper contour of the nosecone to resemble that of an airfoil when observed from a cross-sectional perspective. The graph indicates that there is a low-pressure region in Region 1. In contrast, Region 2 exhibits a high-pressure region, resulting in a high-pressure zone above the cockpit's central part. We performed a 2D computational fluid dynamics simulation, similar to previous ones, but with the inclusion of the updated nosecone design. Ansys Fluent was used to conduct CFD simulations on all models to determine the generated downforce and drag force. Here, the pressure and velocity contours of the chosen model are displayed.



The figure above shows the pressure distribution along the airfoil(AQILA_4%). The red part is the part that we will use as the top surface of the nosecone. We have kept the angle of attack as -16 degree in order to fit it completely into the nosecone.



Pressure contour for the final nose cone model.

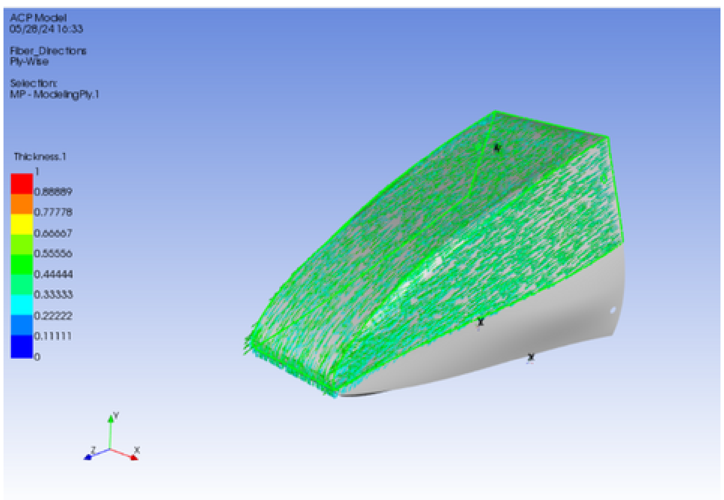


Velocity contour for the final nose cone model.

2. NOSE CONE MANUFACTURING:

a) Structural and Composite Analysis:

We have chosen Carbon Fiber as the main component for manufacturing of the nosecone because Carbon fiber composites have emerged as a superior material for manufacturing aerodynamic components due to their exceptional strength-to-weight ratio, durability, and resistance to corrosion. Carbon fiber composites are renowned for their lightweight nature, making them ideal for aerodynamic applications where weight reduction is critical. Carbon fiber offers exceptional strength and rigidity, providing superior structural integrity to nosecone. Nosecones manufactured from carbon fiber composites exhibit high impact resistance which enhances the safety and reliability of the vehicle. While carbon fiber composites may have higher initial production costs compared to traditional materials, their long-term benefits outweigh the invest.



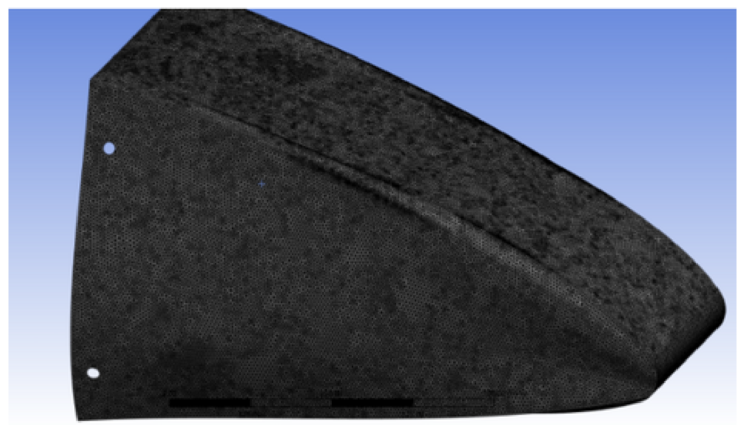


Fig: 5

Fig : 6

From the study of Static Structural analysis, it was found that three layers of carbon fiber stackups are required so that the aerodynamic loads that we found out from CFD simulations can be sustained by the nosecone . During static structural analysis, the computational domain shown in the above figure is meshed in ANSYS Mechanical using a structured multiblock approach. All grid cells are of triangular shape (Fig. 6) with high quality in skewness, smoothness, orthogonality, Jacobian, and conformality.

Number of Nodes present in the nosecone : 59263
Number of Elements present in the nosecone : 118076

Required forces, pressure and fixed supports are applied on the nosecone when moving at an speed of 12 m/s2.
When performing static structural analysis on a nosecone, especially one made from composite materials, it's crucial to evaluate the potential for failure accurately. Composite materials in nosecones typically consist of a matrix (such as epoxy) and reinforcement fibers (like carbon or glass fibers). These materials are chosen for their high strength-to-weight ratio, but their failure mechanisms are different from traditional materials like metals.
There are various theories of failure that are applied while performing static structural analysis. These are:
1)Maximum Stress Theory
2)Tsai-Wu Theory
3)Tsai-Hill Theory
4)Hoffman Theory
These theories were used in the ACP analysis to predict the failure using the inverse reverse factor . The inverse reverse factor and the total deformation over the entire nosecone are shown in Figures 7 and 8 . In our simulation we have kept a factor of safety of 5 ,i.e., we applied loads 5 times greater than those obtained from CFD simulations and kept increasing the number of carbon fiber layers until the inverse reverse factor was much less than 1 .(as seen in Fig : 7)

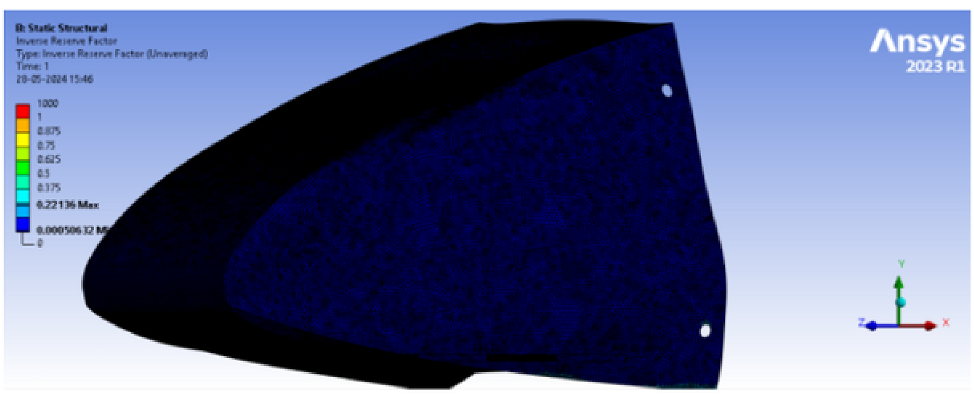


Fig : 7 Inverse Reverse Factor

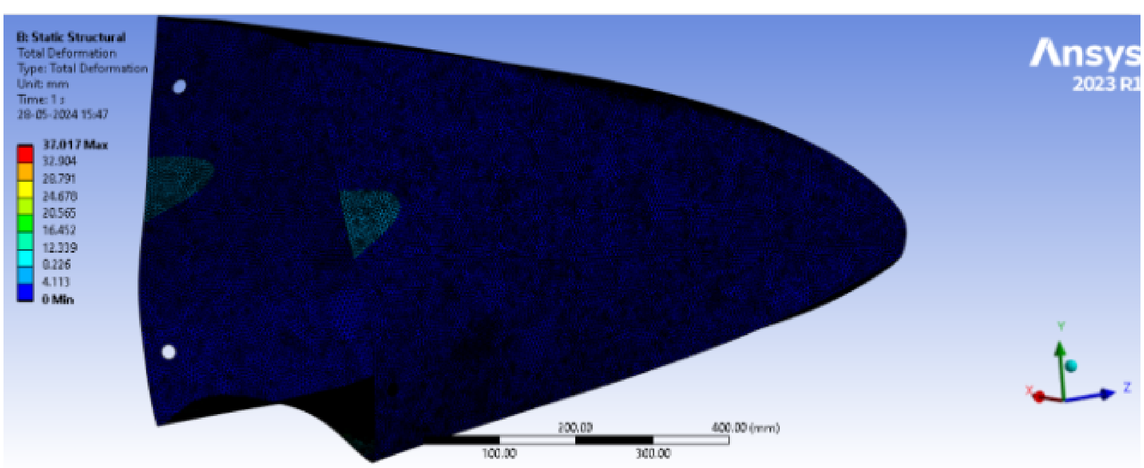


Fig : 8 Total Deformation of Nosecone

b) Manufacturing Process :

Manufacturing with carbon fiber involves several methods tailored to different applications and product needs:

1. Filament Winding: Continuous fibers are wound onto a rotating mandrel and cured, ideal for cylindrical structures like pipes and tanks.

2. Lay-Up (Hand and Spray): Layers of carbon fiber fabric are placed in a mold, impregnated with resin, and cured. This is versatile for complex shapes.

3. Resin Transfer Molding (RTM): Carbon fiber fabric is placed in a mold, and resin is injected under pressure and cured, suitable for medium to high volume production.

4. Prepreg Lay-Up: Pre-impregnated carbon fiber sheets are laid in a mold and cured under heat and pressure, often in an autoclave.

5. Pultrusion: Continuous fibers are pulled through a resin bath and heated die to form long, continuous profiles, ideal for uniform cross-sections.

6. Compression Molding: Preforms or prepregs are placed in a heated mold, compressed, and cured, used for high-volume production of complex shapes.

7. Vacuum Bagging and Autoclave: A vacuum bag compacts the lay-up by evacuating air, and the part is cured under heat and pressure in an autoclave, enhancing part quality.

We have utilized **vacuum bagging combined with autoclave processing** for the manufacturing of our formula car nosecone. This method offers several key advantages, producing high-quality parts with superior mechanical properties and high fiber volume fractions, ensuring uniform resin distribution and strength. It significantly reduces voids and air pockets, resulting in a stronger, more reliable nosecone. The process also improves resin flow and impregnation, reducing dry spots. It is suitable for creating complex and intricate shapes with high precision and consistency. The nosecone, manufactured using this method, exhibits an excellent strength-to-weight ratio, making it ideal for high-performance applications. Overall, vacuum bagging and autoclave processing have been critical in ensuring the nosecone's material performance and reliability.

a) **Preparation:**

- **Mold Preparation:** We started by constructing a skeleton of plywood for the mold. The gaps in the plywood skeleton were filled with epform, chosen for its lightweight properties and ease of removal during the demolding process. To achieve a smooth surface on the mold, we covered the skeleton with a layer of plaster of Paris (POP) followed by white wall putty.
- **Material Cutting:** Composite materials that was the carbon fiber were cut to the required size along with other necessary materials like peel ply, release film, breather fabric, and vacuum bagging film.

b) **Layup:**

- **Layer Placement:** Layers of composite fabric were laid onto the mold. Each layer was positioned according to the design specifications to optimize strength and stiffness.
- **Resin Application:** Epoxy resin was applied to each layer manually using a brush. This hand layup method ensured thorough saturation of the fibers with resin.

c) **Vacuum Bagging:**

- **Peel Ply:** A peel ply was placed over the final layer of the layup. This porous layer allowed excess resin to pass through and would be removed after curing to leave a clean, textured surface.
- **Release Film:** A perforated release film was placed over the peel ply to control resin flow and ensure the breather fabric did not stick to the laminate.
- **Breather Fabric:** A breather fabric layer was added on top of the release film. This non-woven material allowed air and excess resin to be drawn out of the laminate.
- **Vacuum Bag:** The entire setup was covered with a vacuum bagging film, which was sealed around the edges to create an airtight enclosure.

d) **Vacuum Application:**

- **Vacuum Pump:** A vacuum pump was connected to the vacuum bag via a hose. When the pump was turned on, it created a vacuum inside the bag, compressing the composite layup and removing air bubbles and excess resin.
- **Pressure Monitoring:** The vacuum pressure was monitored and maintained throughout the curing process to ensure consistent compaction of the laminate.

e) **Curing:**

- **Curing Process:** The resin was allowed to cure at a controlled temperature of 60 degrees Celsius. This elevated temperature helped speed up the curing process and achieve better material properties.
- **Post-Curing:** For some composites, a post-curing step might be required to further enhance the mechanical properties of the laminate, though this step may vary based on specific requirements.

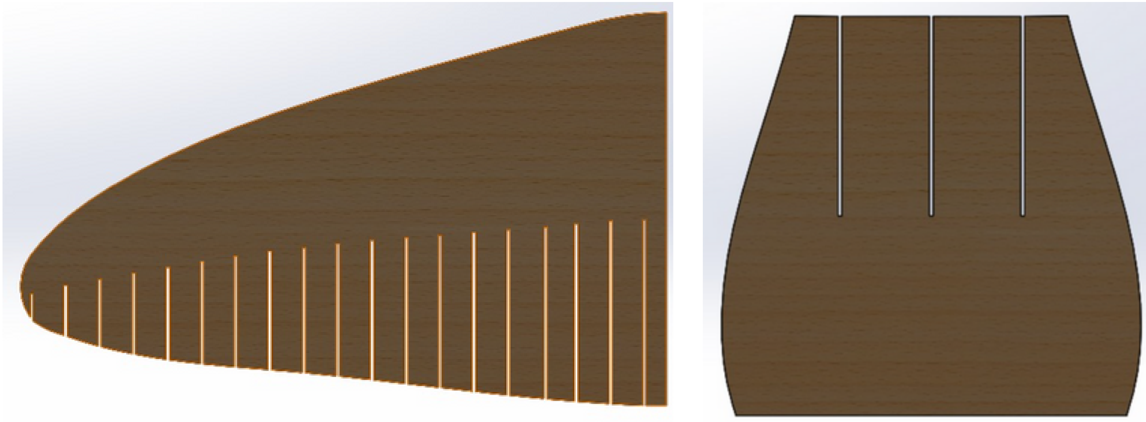
f) **Demolding:**

- **Bag and Peel Ply Removal:** Once the resin had cured, the vacuum bag, breather fabric, release film, and peel ply were removed.
- **Part Removal:** The cured composite part was carefully removed from the mold. The epform filler was easily removed, leaving the plywood skeleton intact for future use.

g) **Finishing:**

- **Trimming and Sanding:** The part was trimmed to the final dimensions and any excess material was sanded down.
- **Inspection and Testing:** The part was inspected for defects and tested to ensure it met the required specifications.

Manufacturing schematic:



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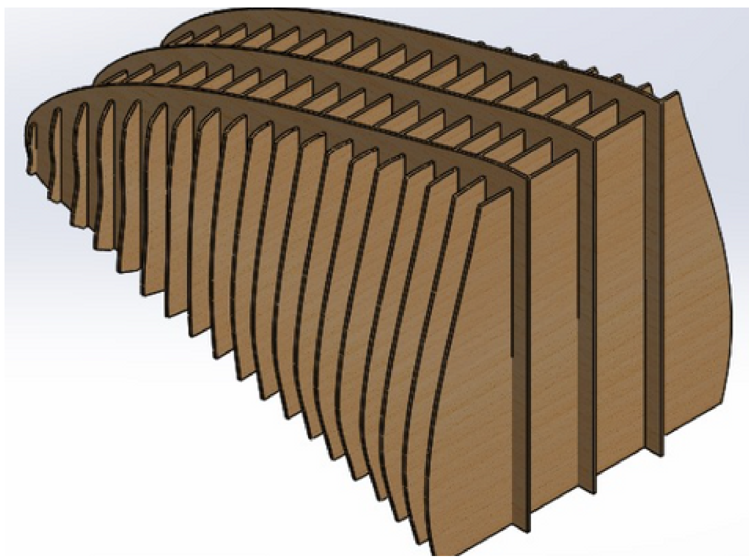

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FRONT WING DESIGN REPORT

The front wing's function is to generate downforce, which improves the car's ability to turn and traction. The front wing controls the direction and streamlines of the incoming air. It can prevent tyre wakes and tyre squirts if it is properly designed to divert air from striking the tyre. Airfoil selection is the first step in any wing design. We ultimately decided to use airfoil E216 (10.4%) based on our requirements for the following reasons: At zero AOA, this airfoil has a relatively uniform lift distribution. We can choose higher AOA (for more lift and closer proximity to the ground) without running the risk of early velocity separation because the lift distribution is uniform at zero AOA. Additionally, the bending moment experience is less due to the uniform lift distribution, which guarantees stability at high speed.

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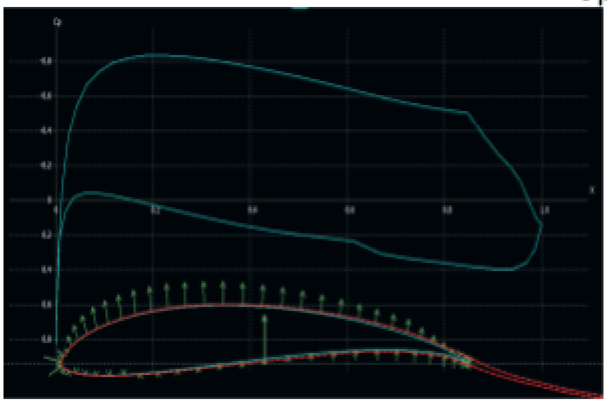
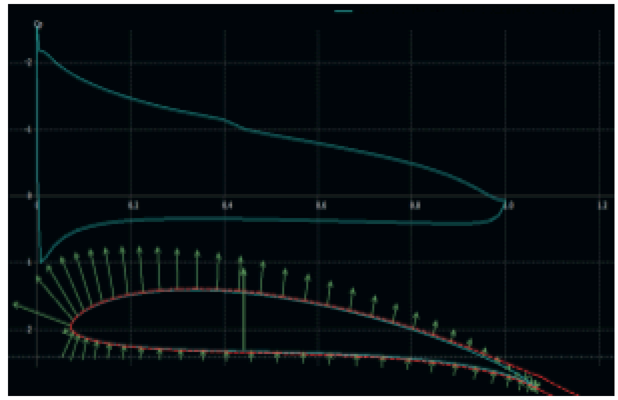
AIRFOIL ANALYSIS REPORT

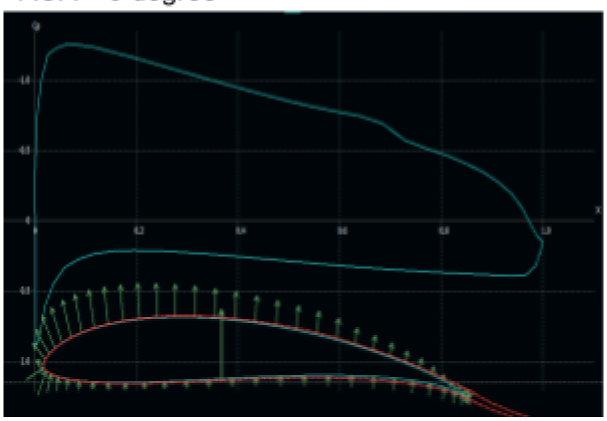
Cp vs x



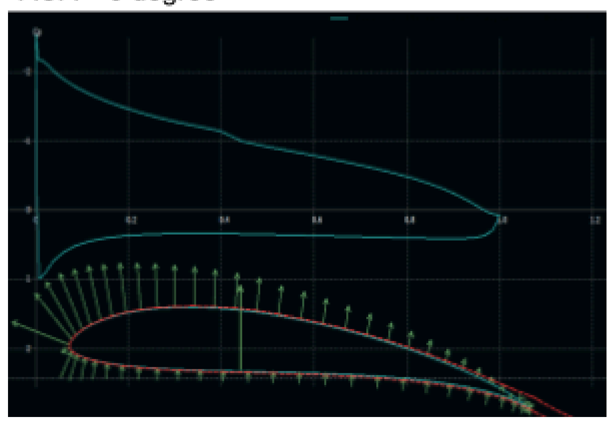
AOA = 0 degree



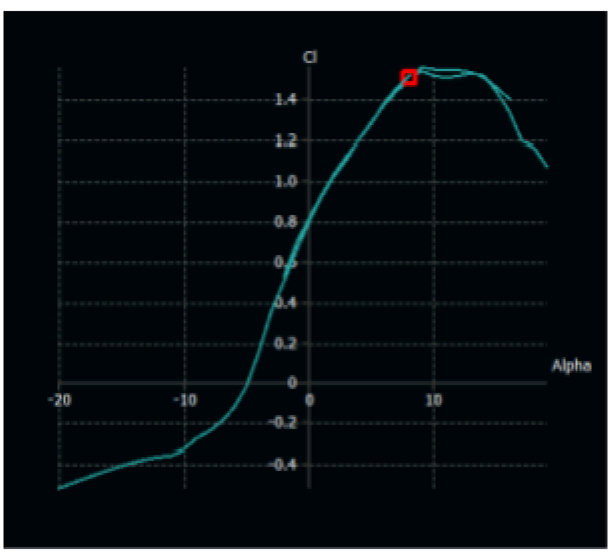
AOA = 6 degree



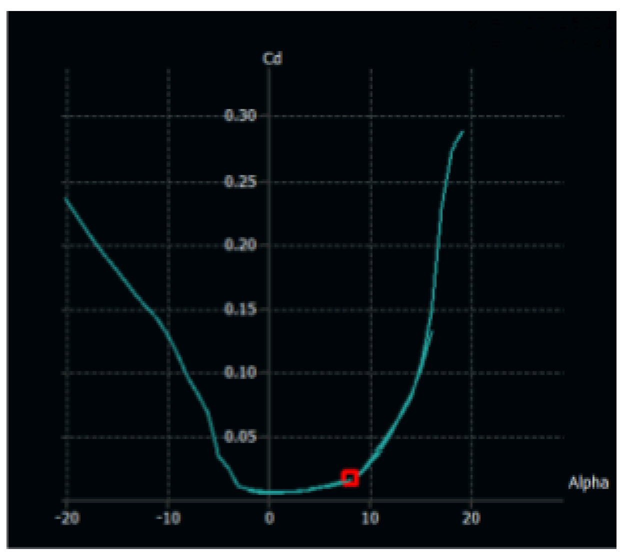
AOA = 3 degree



AOA = 8 degree



Cl vs Alpha



Cd vs Alpha

After airfoil selection, the next task is to design the wing using the airfoil. We have used only one airfoil (E216 (10.4%)) to reduce complexity throughout the wing span.

WING DESIGN:

The primary objective during wing design is to achieve a uniform lift distribution across the entire wing. The elliptical wing is the wing planform that demonstrates the ideal lift distribution in theory. Elliptic planforms exhibit certain drawbacks. The elliptical planform's uniform distribution is favorable for cruising, but unfavorable in the vicinity of stalls. In addition, the fabrication of such a wing poses huge challenges from a production perspective. Hence the following iterations were done to accommodate all the necessary factors.

Straight Tapered planform

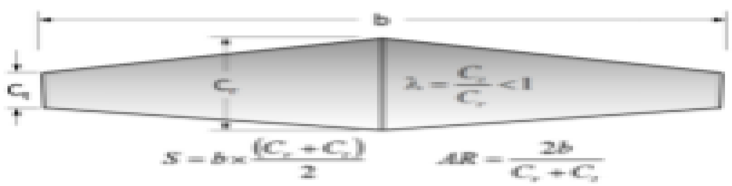


Fig 10: basic geometry of a straight taper wing

Having seen rectangular and elliptic wings, now let's see about straight taper wings.
The primary advantage of straight taper wings is a reduction in bending moment and lift-induced drag. Straight taper wings offer improved efficiency over the rectangular wing as the section lift coefficients are higher towards the tip. Consequently, the wing tips contribute more to the total lift. Also, because of linear taper, it's relatively easy to manufacture.

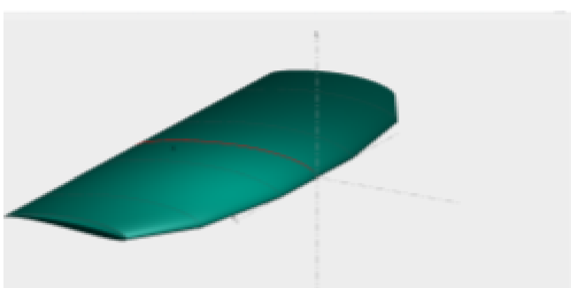
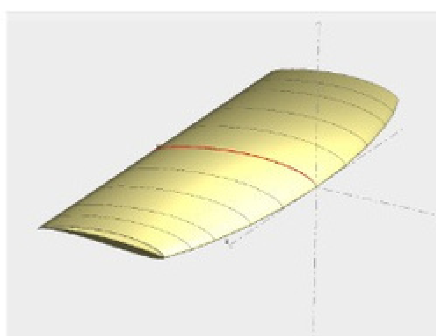


Fig 11: isometric image of the wing in 1st iteration

In this iteration, we tried to approximate the wing's leading edge like an ellipse keeping the rear end straight. This almost flattened the lift distribution near the center.



In this iteration, we further smoothened the leading edge to approximate an ellipse, keeping the rear edge straight more accurately. This further This further flattened the Cl vs span curve.

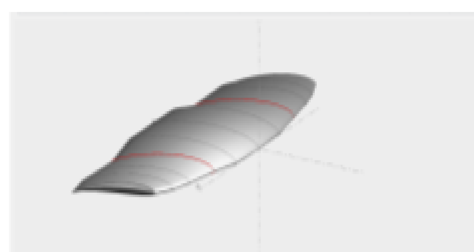


Fig 13: isometric image of the wing in 3rd iteration (twisted wing)

We designed a twisted wing to improve the lift coefficient. A twisted wing typically pertains to a specific configuration where the angle of attack varies along the wing's span. The twist in the wings allows lift distribution optimization across the entire span, improving performance and handling characteristics.

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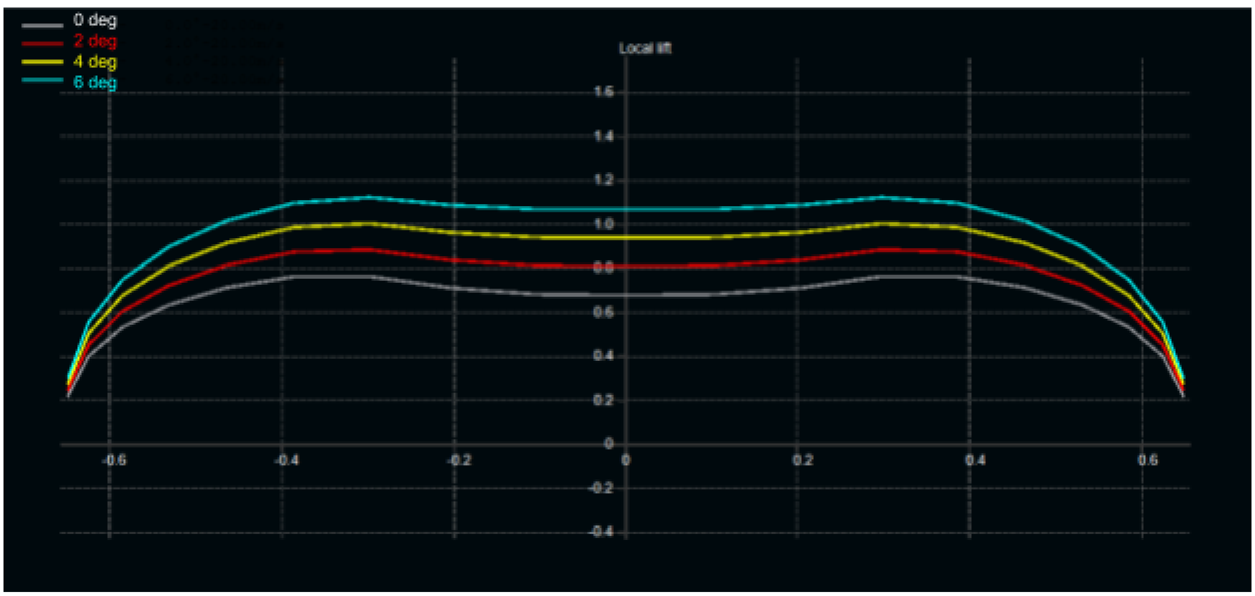
Angle of Attack (in degrees)	Cl (coefficient of lift at 20m/s)
0	0.48839
2	0.60083
4	0.71082
6	0.81959

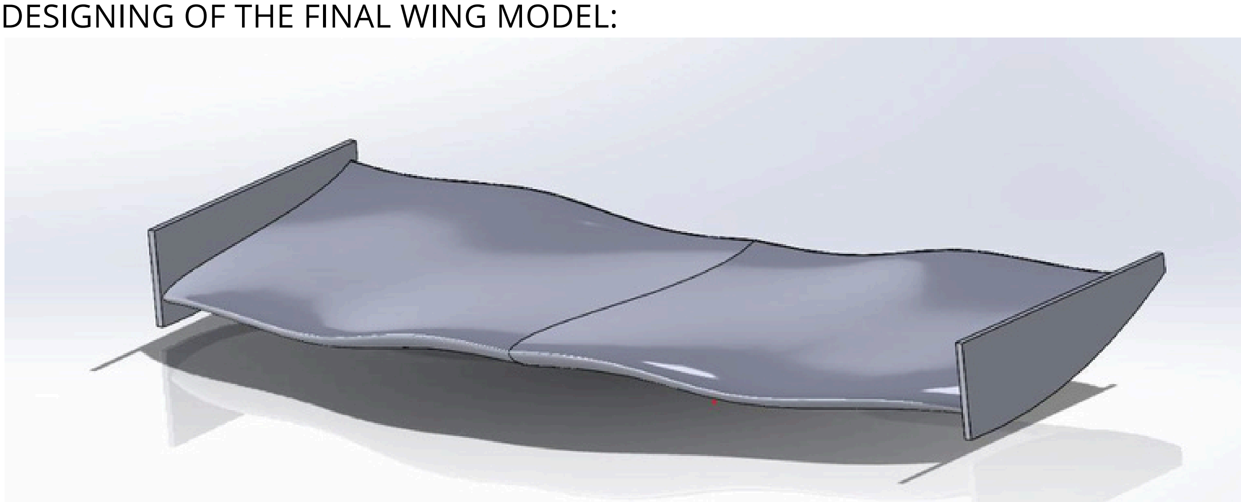
Angle of attack (in degree)	Cl (coefficient of lift at 20m/s)
0	0.48340
2	0.59489
4	0.70399
6	0.81184

Angle of attack (in degree)	Cl (coefficient of lift at 20m/s)
0	0.67106
2	0.77948
4	0.88705
6	0.99428

Lift vs Span



DESIGNING OF THE FINAL WING MODEL:



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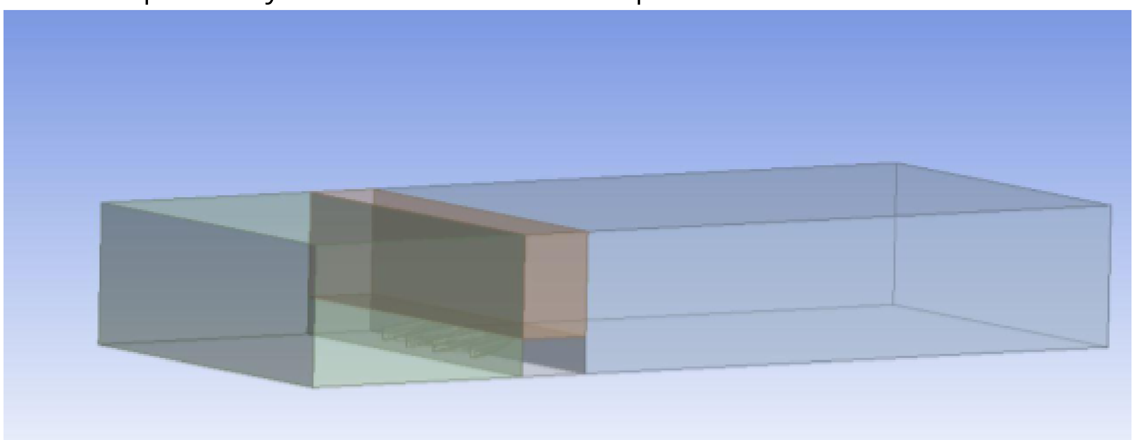
Cad model with winglets(side plate) to reduce further downwash and drag

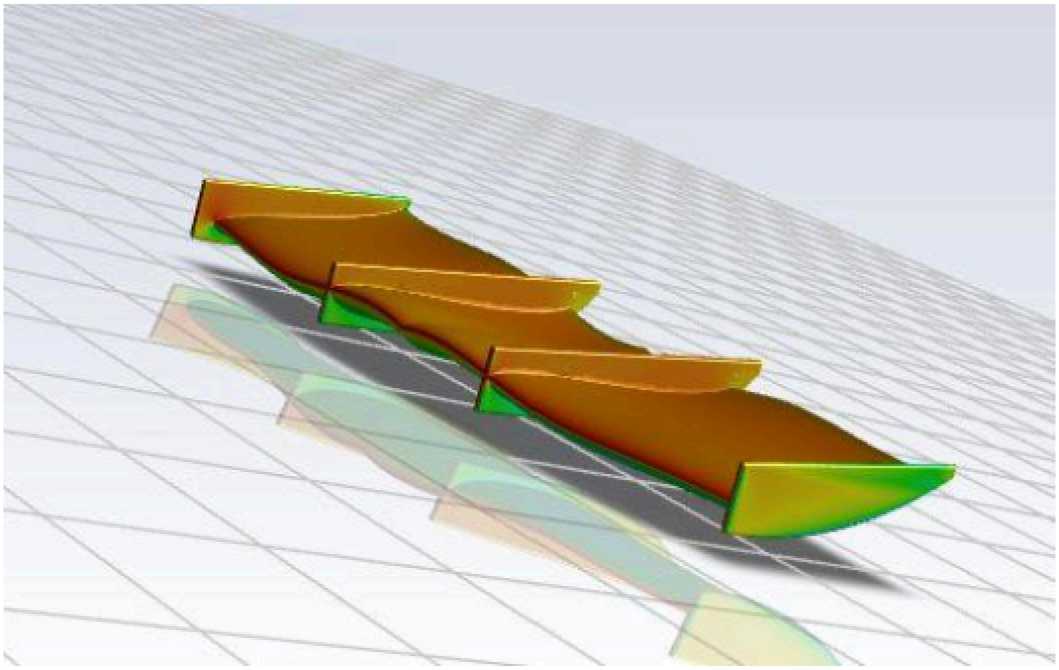
Numerical Simulation Of Wing :

Upon concluding the preliminary wing configuration utilising low-fidelity software (such as XFLR5), we conducted a finite volume simulation of the fluid dynamics surrounding the wing utilising Ansys Fluent.

Model Adopted: ansys > fluent > viscous flow > spalart allmaras turbulence model



Division of the computational domain into divisions for generating structured grids



Pressure distribution over the wing as seen from an isometric view. This clearly shows a high pressure region on the top

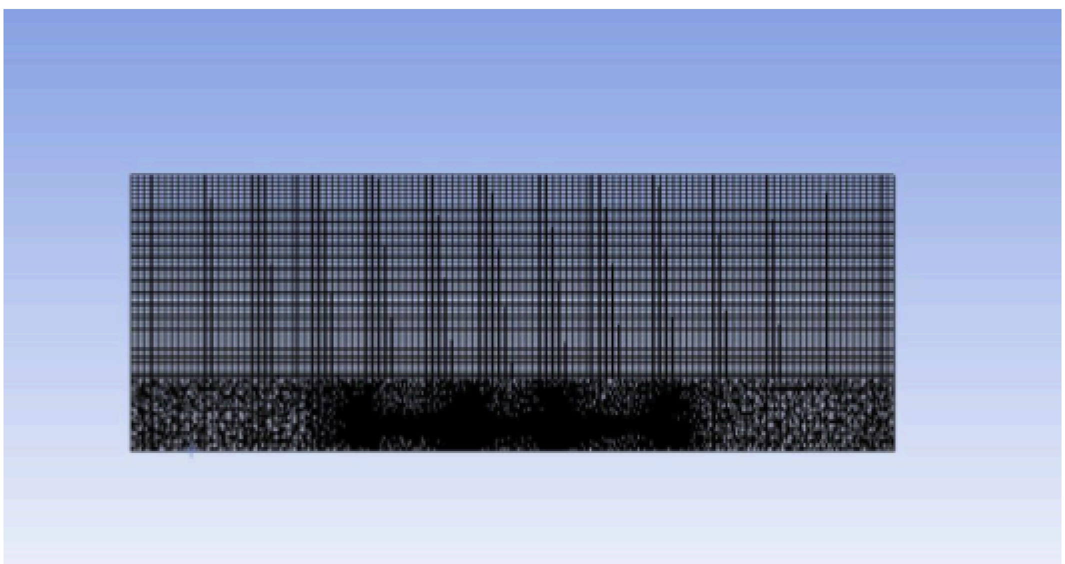
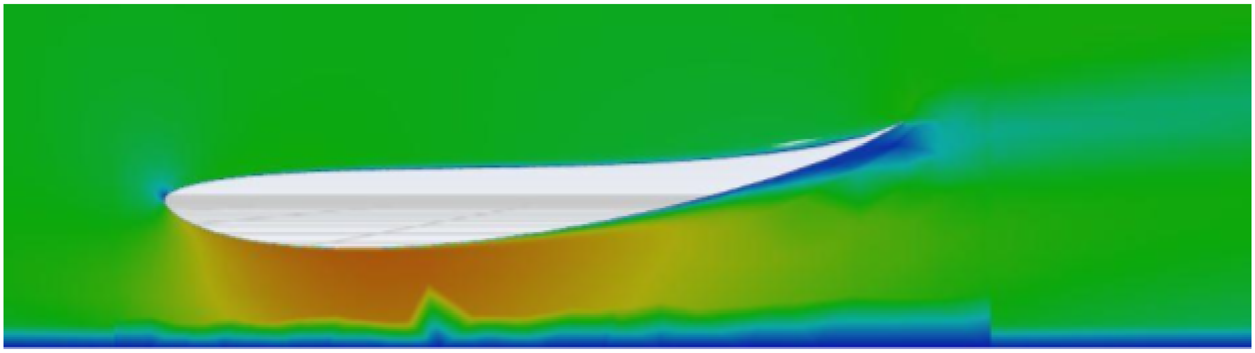


Figure showing the mesh generated. As we can see that the region near to the wing has unstructured grids rest all the parts have structured grid. This increased computational speed and accuracy



Velocity contour as seen from side view. Here we can clearly se that the high velocity region at the bottom is because of ground effect that we exploited by keeping the AOA at 6 degree.

RESULT:

The downforce generated by the final wing design model is 216 N.

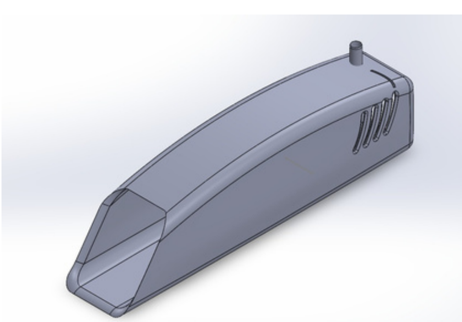
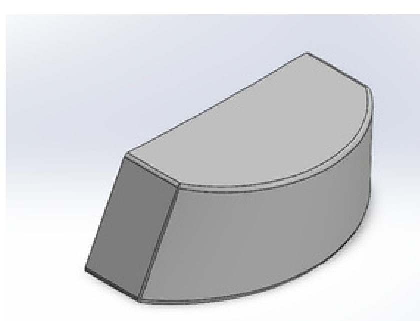
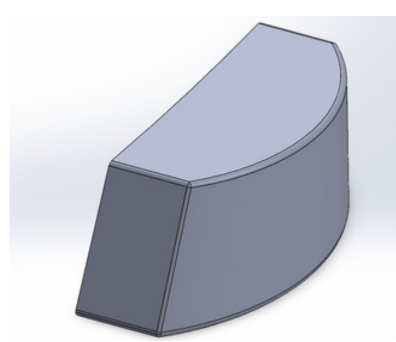
MATERIAL SELECTION:

Carbon Fibre Reinforced Polymer has been chosen for the wing design because it keeps the vehicle lightweight and strengthens it.

SIDEPODS

Sidepods are versatile aerodynamic devices with many uses. They are intended to control the airflow around the vehicle, produce downforce, and lessen drag. They are in charge of housing the radiator and guiding the airflow through its channels.

We developed the following three sidepod designs after taking into account all the regulations:

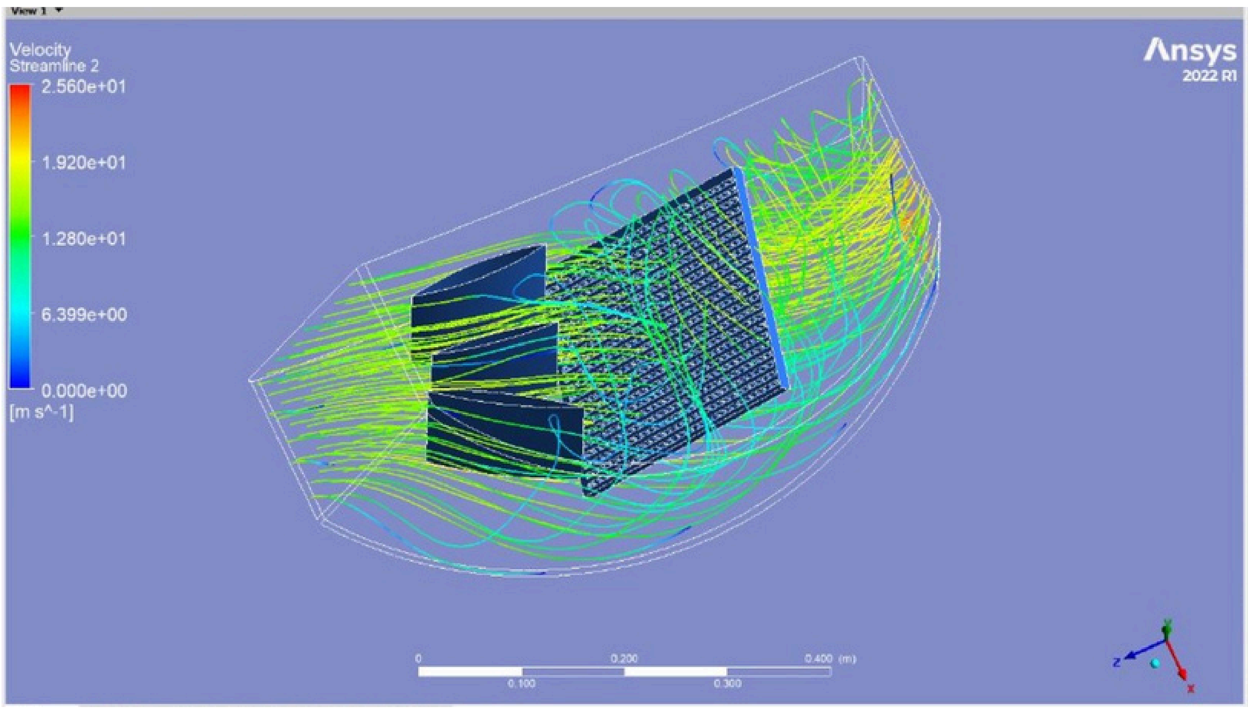




ANALYSIS REPORT OF FINAL SIDEPOD

The third model is the final selected model for the sidepods.

INNOVATION IN SIDEPOD DESIGN:

Streamline-shaped plates have been incorporated to direct the airflow within the sidepods. This guarantees streamlined airflow towards the radiator, optimizing its efficiency and cooling capabilities.



Velocity Streamline contour for the 3rd sidepod design.