

Design and Analysis of a Wing for a Formula Style Race-car

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Abstract—Car racing is a popular sport, and its popularity is growing as technology and globalisation bring the world closer together. Formula 1 racing is one of the most technologically advanced sports. The aerodynamics of open wheel race cars are critical to race performance. A race car's front wing generates approximately 30% of the total downforce. Several authors are conducting research on front wings for open wheel race cars. Several research studies have been conducted, including single element airfoils in ground effect and undisturbed flow. Because this is a racing event, the car must be lightweight and have good aerodynamic features. Aerodynamics play a significant role in increasing car performance and speed. A study of aerodynamic parts is carried out in this project. A thorough investigation of features such as drag, downforce, Bernoulli's principle, and the boundary layer theorem has been conducted. A special emphasis is placed on the study of the front wing and rear wing which are the most important components of the race car's aerodynamic package. In our analysis, we used Airfoil - s1223, e423. A complete CFD analysis of all the parts was also performed. Finally, we investigated composite materials such as cfrp and gfrp, which have useful applications in the racecar domain.

Index Terms—F1 race-car ,drag, downforce, front wing, rear wing, airfoil, analysis, composite material.

I. INTRODUCTION

With the advancement of technology, many people have begun to participate in various sports activities. Racing is one of the sports that has evolved significantly over time. F1 has grown in popularity in recent years. There are many other platforms for car racing, but F1 is the pinnacle of them all. For racing at such a high level, the car must have the capability to compete on a global scale. The aerodynamics of a car play an important role in its performance. The science of how air travels around and inside things is known as aerodynamics. More broadly, it is known

as "Fluid Dynamics," because air is simply a type of very thin fluid. The air flow around and through a vehicle begins to have a more pronounced effect on acceleration, top speed, fuel efficiency, and handling at higher speeds. To build the one of the most efficient race car possible, it is of utmost importance to understand how fluid travels around and through the body, its openings, and its aerodynamic devices. It is now well established that aerodynamics plays an important role in the performance and also in the efficiency of an racing car, even when it moves at lower speeds on the track like a F1 race car. A well-designed aerodynamic car can use the airflow around it to generate as much vertical-to ground force as possible while keeping the air resistance force low. Downforce is the vertical force in Motorsport, and Drag is the resistance force. As a result, the grip and thus performance of the tires improve, and the car is able to achieve higher speeds while turning also consuming less fuel due to reduced air resistance. These race terms will be defined further in a later section of this report. In the view of driver and the safety of his car, conventional race tracks are constructed in such a way that it contains sharp turns and long straights. This layout led most of the racing teams to ascertain a fact that the racer can easily be a winner by just improving car's performing while it takes turn also called as cornering. This increases the importance of an efficient aerodynamic design due to the significant difference in cornering speed, which can significantly reduce the lap-time of a car that uses aerodynamic devices.



Fig. 1 F1 race car

II. LITERATURE REVIEW

Automotive industry tops consumerism in the world of construction materials [1]. A legitimate and significant challenge in materials science is enhancing the reliability and durability of automotive components. The creation and deployment of novel techniques and products are required by the expansion of the automotive sector, which raises the standard for the quality and safety of recycled materials. Simultaneously, the increase in resource requirements creates competition among material manufacturers, which quickens progress in developing new types and improving quality [2-4]. Car performance is consistently improving as engines run more efficiently, the body becomes more aerodynamic, transmissions are improved, and tyre rolling resistance is reduced. It is critical to reduce the mass of a car when designing it. This allows the car's basic characteristics to be maintained while using low power engines that consume less fuel and emit less harmful substances into the environment. Furthermore, the car inertia decreases, requiring less energy for acceleration or braking. Making the car lighter makes the suspension system more reliable and less wearing as the stress on it decreases [5]. In order to reduce the weight of the automobile, new, lighter but more expensive materials must be used; at the same time, cars are getting more complicated and, thus, more challenging to drive. Weight should be countered by new lightweight building materials, additional units, active and passive safety measures, decreased toxicity, and ongoing comfort improvements.[6]. Non heavy constructions are hugely used in the automotive, aerospace, and construction industries because it helps in better weight reduction of the structure due to low density. This can give rise to significant fuel savings and a lower amount of carbon footprint in transportation, as well as facilitating the manipulation of details in civil applications[7]. By using less material to produce consumer items, the low material density also protects natural resources. Due to the application of the most recent scientific findings, polymer compounds today perform better in terms of hardness, toughness, and strength than previously used steel. A strong frame is created by weaving together synthetic fibres to stiffen the part and evenly distribute weight across its whole surface. Carbon fibre parts also weigh around three

times less than steel-like strengths.[9]. Polymer materials have an almost limitless service life. They are corrosion resistive and can withstand significant loads and have a good vibrations dampening ability. The strong and stiff synthetic fiber-based car body elements can notably improve the car's reliability and safety while also keeping it lightweight. The only reason which is keeping manufacturers to use fully carbon fibered body is its abnormally high production costs which in general makes it too costly. A synthetic fiber part is 30-40 times more expensive than a steel part of the same size. As a result, components made of carbon fiber materials are rarely used in the production of tuning cars which are singly assembled. However, as progress in carbon fiber technologies will rise, eventually their costs will soon be equaled to carbon and aluminum alloys. In relation to the foregoing, the primary development direction of the automotive industry should be a significant increase in product quality through scientific and technological advances, as well as the development of new materials used in the automotive industry. And this advances the scientific direction of applied material science in the automotive industry. One of the most inventive and technologically sophisticated types of engineering materials that may be employed in any area of engineering or other discipline is composite material. Many researchers are drawn to the advantages of composite and nanocomposites, which include their high specific strength, stiffness, and fatigue resistance as well as their straightforward manufacturing method for use in innovative applications in the automotive, aerospace, and other industries. The strength-to-weight ratio of metals is noticeably lower than that of composite materials, which, in some situations, is up to 20% better. The development of novel engineering materials for a variety of sectors, including the aerospace, automotive, marine, electrical, and civil constructions, has a great potential for the use of composite materials.

In composites research, the choice of fillers and matrix greatly influences a variety of needed qualities. Recently, the utilisation of carbon materials in engineering applications has attracted a lot of study attention. According to recent studies, traditional metals may someday be replaced by carbon fibre reinforced plastic (CFRP) in automobile applications. It does so because it has better specific stiffness, strength, and fatigue properties when compared to

regular metals. This qualifies it for use in load-bearing structures such as aviation wing and fuselage structures and frame structures in the automotive industry.. According to John et al [7], carbon fibre reinforced epoxy and carbon fibre reinforced plastic (CFRP) are highly strong and light fibre reinforced polymers. Carbon fibre and epoxy, which are the two separate components that make up CFRP, dictate the material's qualities. The CFRP will have stiffness and strength thanks to the reinforcing. Unlike isotropic substances like steel, CFRP possesses directional strength characteristics. The arrangement and percentage of carbon fibre affect the characteristics of CFRP. Due to a number of beneficial qualities including a low coefficient of thermal expansion, high fatigue resistance, and ease of manufacture of complicated materials, CFRP have emerged as viable substitutes for conventional materials like steel and iron in many applications. A car spoiler is a wing-like device that is often fixed on top of the trunk, placed under the front bumper, or connected to the back of the car. Frontal automobile spoilers are also known as "air dams," whereas the rear spoiler is also referred to as a "wing." Car spoilers dynamically enhance the outer appeal of the car, enhancing its appeal in a crowd and giving it a more fashionable, athletic appearance. A spoiler is an automobile industry term for an aerodynamic addition to a vehicle. The purpose of this device is to "spoil" unfavourable air circulation over a moving body of a vehicle of some sort. On racing and other high-performance sports vehicles, spoilers are frequently employed. Nowadays, spoilers are widely used on passenger cars as well. In other words, a car spoiler enhances the vehicle's performance and, in certain situations, raises its resale value. According to Kamprasad's work, the [45 degree] orientation of the fibre is ideal for creating the spoiler. The [45 degree] orientation with foam performs best when compared to the identical [45 degree] orientation of the fibre without foam. The spoiler was constructed utilising the sandwich approach. Due to the sandwich construction's localised buckling effect, the theoretical calculation and simulation provide different results.

III. SOFTWARE

A. Software

Dassault Systèmes' SolidWorks is a powerful displaying PC-aided plan (CAD) and PC-aided design (CAE) PC program that runs primarily on Microsoft

Windows. SolidWorks is an excellent modeller that employs a parametric element-based methodology developed by PTC (Creo/Pro-Engineer) to create models and assemblies. The product is built with Parasolid-bit. We will draw and import the airfoils in Solidworks, which will then be imported into Ansys.

B. Ansys

Ansys is a corporation based in Canonsburg, Pennsylvania. It creates and promotes CAE/Multiphysics designing recreation programming for item configuration, testing, and activity, and it offers its products and services to clients all over the world. Ansys develops and exhibits reproduction programming for use throughout the item life cycle. Ansys Mechanical limited component examination programming is used to simulate PC models of structures, devices, or machine parts in order to analyse the strength, sturdiness, flexibility, temperature distribution, electromagnetism, liquid flow, and other characteristics. We are analysing air flow around the wings in Ansys using Fluid flow, which we imported from Solid Works.

C. airfoiltools.com

airfoiltools.com is a website that has a database of various types of airfoils. The site provides a variety of options, such as an airfoil plotter, an airfoil comparison, a Reynolds number calculator, and so on.

IV. IMPORTANT TERMINOLOGY

A. Downforce

Every item in motion through the air produces either lifting or downforce. A wing can lift a plane into the air, but when it's flipped on its side, it can stop a fast race car in its tracks. The race car is pressed against the track surface by the same concept that lifts an aeroplane off the ground by using its wings to generate lift. Any sort of aerodynamically produced force exerted on a surface is generally referred to as "lift." The majority of aerodynamic devices include a direction indicator, either "positive lift" (up) or "negative lift," because they were created for aeroplanes and were intended to raise them into the air (down). A car wing is used to keep the vehicle on the ground.

B. Drag Force

A surface impedes a fluid's motion as it passes over it. Drag is the fluid force experienced by every moving

solid body in the direction of the fluid free stream flow in aerodynamics. Race cars experience aerodynamic drag as a result of friction, form, and pressure working together. When air molecules cross a car's surfaces, the ones nearest to the surface stick, causing friction drag. The actual contact of air particles with the surface of the moving item results in skin friction drag. The connected particles glide across the layer above them, while the surface-stationary particles impede their motion. This layer moves more slowly than the ones above it. As the layers advance away from the surface, they slow down until they ultimately approach freestream speed. Every surface has a boundary layer, or region of slow motion, which produces one of three forms of drag. Form drag is a second sort of drag that results from the force needed to push the air molecules out of the path. This process results in fewer molecules needing to be moved, which requires less energy to push through the air, the smaller a vehicle's frontal area. For a given engine power, the car will drive farther because less engine power is required to move the air than is required to move the automobile down the track. The forms of drag known as form drag and pressure drag are quite similar. Air separation results in pockets of low and high pressure that produce turbulence and leave a wake behind the vehicle. This works against forward motion and adds to overall drag. A moving item may be made more aerodynamic by streamlining it, and race cars have fairings to conceal the areas that cannot be streamlined. Thus, the main components of drag in race vehicle aerodynamics are these three forces:

- Frontal pressure, which is the result of a car's body pushing air aside.
- Rear vacuum, which occurs when there is a gap left by the car's body and air cannot fill it. the boundary layer, or the result of air friction on the surface of a moving vehicle.

C. Front wing

An F1 car's front wing makes initial contact with the air. This demonstrates how important it is to locate the under-stream flow across the remainder of the automobile because it is the first component of the car to interact with the air flow. To efficiently transmit downward loads of force and create downforce to press the front wheels' tyres into the ground and increase grip levels, front wings are often positioned on the mounts or even close to the suspension. 20% to

30% of the total downforce produced by the vehicle is contributed by the front wing.



Fig. 2, Distribution of importance of various parts

D. Rear wing

Unquestionably, a key factor in an F1 car's performance is the rear wing. This device weighs between 3 and 4 kg and generates around one-third of the vehicle's overall downforce. The main purpose of the rear wing is to help the rear tyres with braking and cornering forces, reducing oversteering. A multi-element airfoil with three or four sets of elements joined by wing endplates makes up the rear wing. Utilizing several wings and flaps, the rear wing's downforce is increased. There won't be twice as much downforce produced by two wings as there is by one. The lift coefficient increases and the lift/drag ratio decreases as the number of airfoils increases. A slot is inserted before the flap nose for boundary layer control to delay the flow separation on a deflected flap element. The 2-3 higher and smaller airfoils, which are smaller and create less downforce than the bottom one, can increase the lower one's efficiency by preventing airflow stalling. The lowest and biggest airfoil produces the greatest downforce. A slightly lower additional airfoil may occasionally be installed over the diffuser exit to help the diffuser produce more downforce beneath the car. This low pressure area is created right under the wing.

E. Coanda effect

Due to the Coanda effect, the air flowing along the sidepods' flanks adheres to their contours at the back. This accelerated airflow causes a decrease in pressure. There is no net force because the transverse pressure differences on either side of the car cancel out.

F. Boundary Layer

A boundary layer is a small layer of a moving gas or liquid that makes contact with a surface, such the interior of a pipe or an aeroplane wing, in the field of fluid mechanics. The fluid within the boundary layer is subject to shearing forces. The boundary layer has a

range of velocities from maximum to zero if the fluid is in touch with the surface.

G. Bernoulli's theorem

If compressibility and viscosity (internal friction) are small and the flow is constant or laminar, the relationship between pressure, velocity, and elevation exists in a flowing fluid (liquid or gas). The theorem states that the total mechanical energy of a flowing fluid, which includes the energy related to fluid pressure, the gravitational potential energy of elevation, and the kinetic energy of fluid motion, remains constant. It was first derived (1738) by the Swiss mathematician Daniel Bernoulli. Bernoulli's theorem, which asserts that energy is conserved for ideal fluids in steady, or streamline, flow, serves as the foundation for several engineering applications.

H. Airfoil

Low-drag, low-lift airfoils that are slim and smoothed out are commonly used in rapid aeroplanes. Slow planes that transport heavy loads use thicker airfoils with high drag and lift.

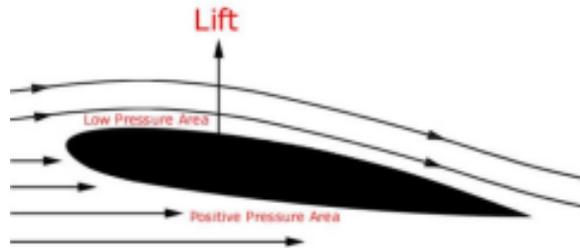


Fig. 3, A basic pictorial representation of the working of the Airfoil

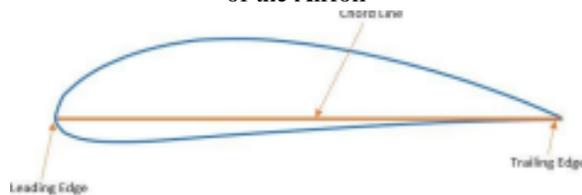


Fig. 4, A normal Airfoil defining its peculiarities

V. CFD METHODOLOGY

CFD is an abbreviation for computational fluid dynamics. Because it is extremely difficult to test our model in an actual wind tunnel, we have heavily relied on the use of ANSYS software to create a suitable environment for testing our wings in this project. The analysis began with the creation of a 3D CAD of the front wing, followed by the construction of an

enclosure for the airflow path. Before meshing, the enclosure's inlet, outlet, walls, and ground were all defined. In the enclosure, the front wing was kept as a Boolean to prevent airflow from passing through it. This CFD analysis was carried out using the viscous K- omega SST model. The inlet velocity of air was kept at 15m/s because elastic forces begin to dominate beyond that point. Second order upwind momentum is the solution method used. The analysis was carried out over 500 iterations.

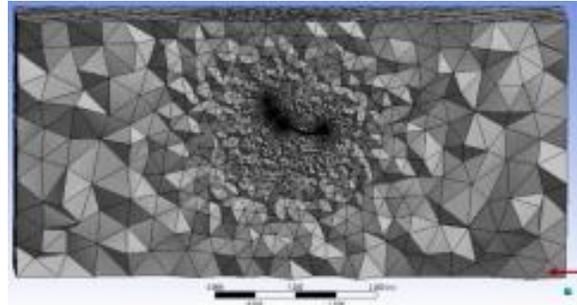


Fig. 5, Tetrahedral mesh of our specimen

VI. DESIGN AND ANALYSIS OF REAR WING

A very detail and systematic process was followed in order to get a result which is as accurate as possible. Also, as mentioned before this is a study between wings with various number of elements. S-1223 was chosen as the primary airfoil was the rear wing. The main reason was that it has a low Reynolds number and high downforce to drag ratio. According to our previous study, S1223 exhibits the optimum downforce to drag ratio at an angle of attack of 6 degrees. As a result, the AoA was left at 6 degrees for the sake of our single-element study. The next step involved addition of remaining elements. One s-1223 was added and on e423 airfoil were added as the secondary and tertiary members. According to (1), it is mentioned that the spacing between multiple elements must be adequate. If the spacing is kept more than required, the area will increase. Naturally, the fluid will have to travel more in order to reach the second element. According to the Coanda effect, the tendency of the fluid is to stay attached to the convex flow surface and after flow separation, to try and maintain its trajectory. Therefore the fluid will not be able to move on to the next element. The next part which comes into picture while using multiple

element is that of the angle of attack of the secondary and tertiary elements. This is purely dependent upon the AoA of the primary element. Generally, according the airfoil chosen, the ideal AoA is given for that airfoil with respect to the primary airfoil. In our case, the secondary member is NACA 6412. For this airfoil too, the ideal angles of attack range from 6 to 9 deg. The ultimate angle of the secondary element was therefore determined to be at an angle of 36 degrees, or 6 degrees, w.r.t. the main element after computing the angle of the trailing edge of the primary element. Similarly, the angle of the third airfoil was determined and therefore the final multi-element airfoil was obtained. Single-Element Rear Wing.

- The 2d curve was taken into the CAD software with an AoA of 6 deg

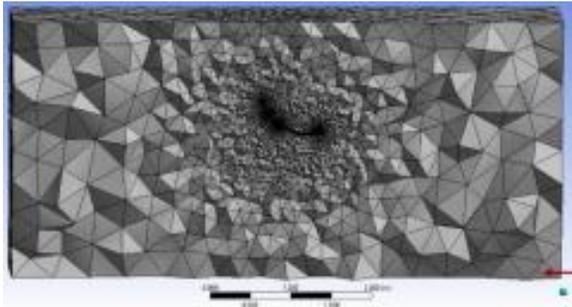


Fig. 6, 2D geometry

- 3d profile was created and side plates were added



Fig. 7, 3D geometry

- CFD analysis was carried out using the above methodology

A. Results

The results of this analysis were as expected. As compare to the size of the wing, the downforce is relatively less with a substantial drag. Also, there is wake formation which is practically unavoidable but it can be minimized. The wake region is also comparatively more resulting in more drag. The

pressure and velocity contours and velocity streamlines are given below. The results can be clearly interpreted from these.

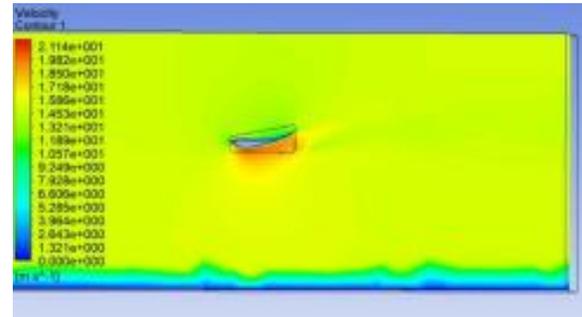


Fig. 8, Velocity contours

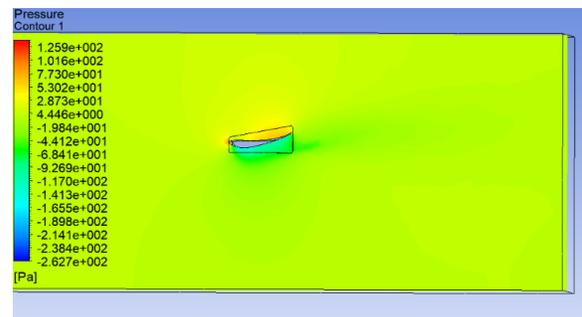


Fig. 9, Pressure contour

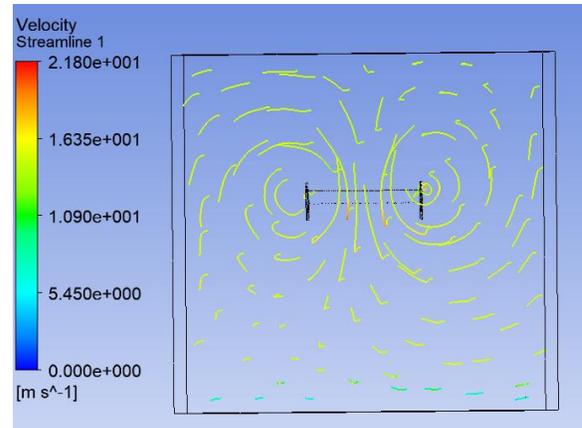


Fig. 10, Velocity streamline 1

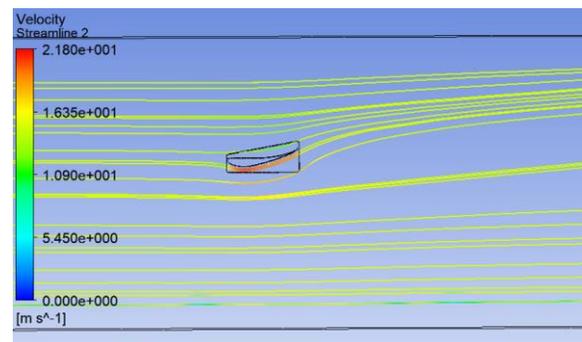


Fig. 11, Velocity streamline 2

Drag	19.1554 N
Downforce	97.2797 N

Table 1, Single element final result

B. Multi-Element

As mentioned above, the 2d sketch of the multi element wing was designed and created. Similar to the single element wing, the wing was extruded and made solid and side plates were added. Since, a direct comparison or relation was trying to be established between multi element and single element wings, the same boundary conditions were maintained for both the analyses. Thus a direct comparison could be established between the two obtained results. The total area of the geometry was also kept constant for both the wings.

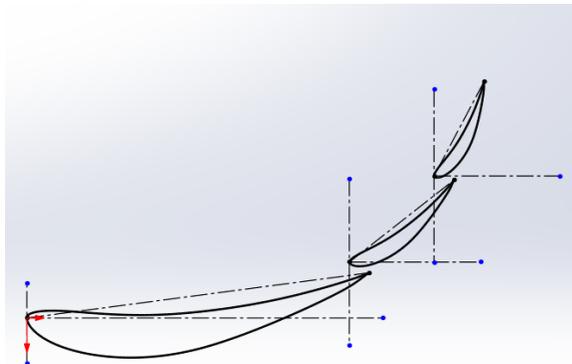


Fig. 12, Multielement 2D geometry

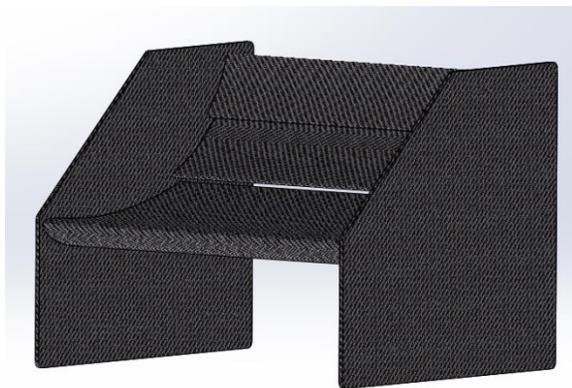


Fig. 13, Multielement 3D geometry

Results

A clear upgrade was visible when the elements were increased. Though the drag also reduces due to increase in the number of elements, the increase in downforce is significant. Also weight of the wing was reduced when multiple elements were introduced. The

wake region also decreased. One of the conclusion drawn was that the side plates were a major contributor in the formation of the wake region. But, if the side plates are removed, the fluid can travel through that part to the lower region causing a lift. This is very risky and thus a trade-off was needed to be made by using the side plates.

Similar to before, the pressure contours, velocity contours and streamlines are displayed below:

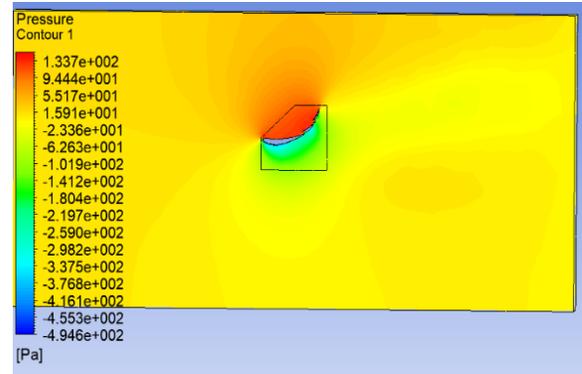


Fig. 14, Pressure contour

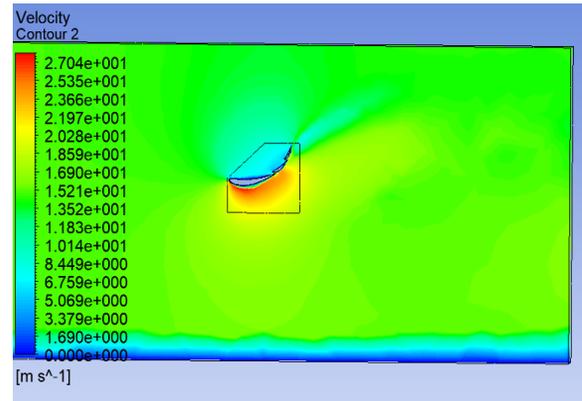


Fig. 15, Velocity contour

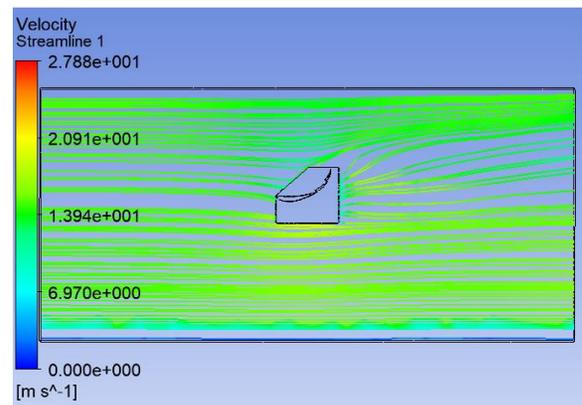


Fig. 16, Velocity contour

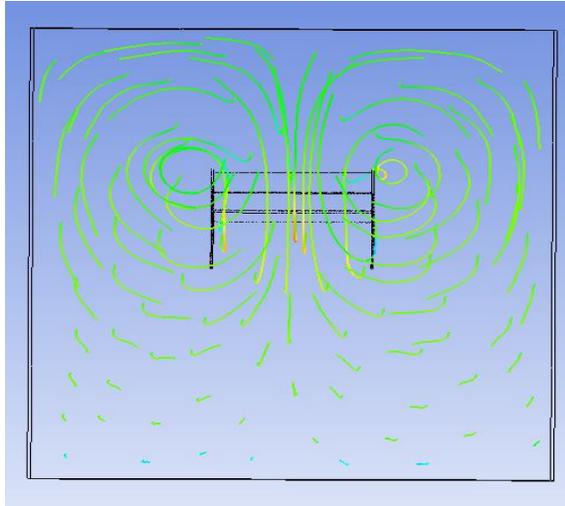


Fig. 17, Velocity streamline 2

Table 2, Multielement final result

Drag	98.8402 N
Downforce	267.212 N

Thus, from all the data gathered and observations made, it was concluded that a multi element airfoil offers a better performance as compared to a single element airfoil. Factors like flow separation, downforce and wake formation are positively affected by this. Drag was the only factor which increased with increase in elements but it is compensated with the increase in downforce.

VII. DESIGN AND ANALYSIS OF FRONT WING

Front wing has been designed using the S1223 and e423 airfoils. The primary and secondary airfoils comprise of S1223 whereas the tertiary airfoil is e423. Multiple airfoils have been used in the component to prevent flow separation and wake which ultimately increases the induces drag. End flaps have been used to support the airfoils as well as to prevent the airflow from high pressure to low pressure. The secondary and tertiary airfoils are placed at a distance considering it should minimize the coanda effect. The angle of attacks for the airfoils were finalized after the analysing which angle would give the best results. CFD analysis of the front wing has been done by keeping the wing in an enclosure where air is flown through one end the wing is placed close to the ground. Solving and meshing process is similar to the rear wing.

Table 3, Front wing final result

Drag	20.799 N
Downforce	121.275 N

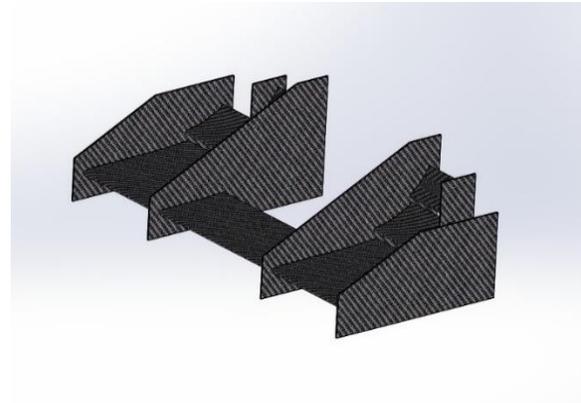


Fig. 18, 3D geometry of front wing

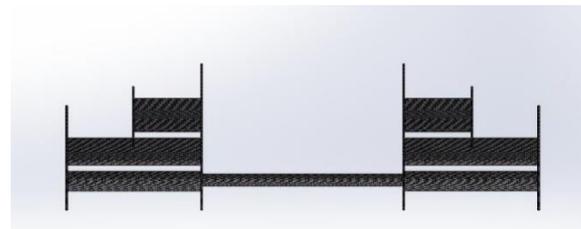


Fig. 19, Front view of 3D geometry of front wing

Following is the flow pattern of air after it exists the front wing.

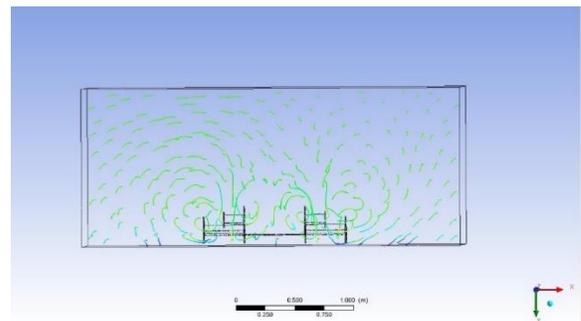


Fig. 20, Air Streamline

In the following image high velocity region is found to be under the airfoils and the low velocity regions were found to be above the airfoils.

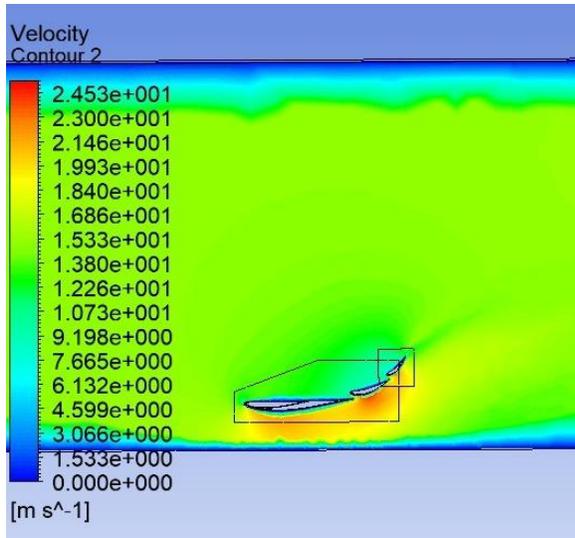


Fig. 21, Velocity regions 1

Low pressure region is found to be under the airfoils and the high velocity regions were found to be above the airfoils

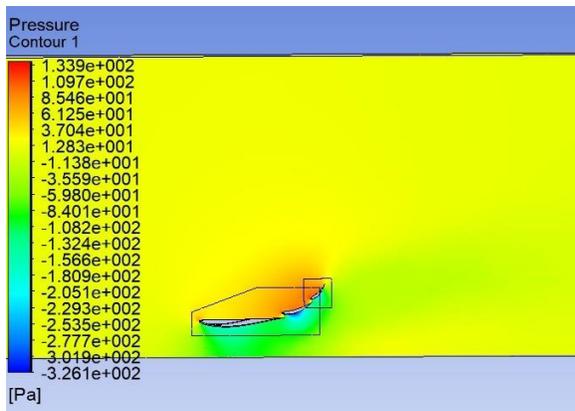


Fig. 22, Velocity regions 2

VIII. MATERIAL MANUFACTURING

So the cfrp manufacturing process is a step-by-step process. The first task is to gather carbon fibre, which is relatively easy because it is abundant. The Hand lay up technique is used to create Cfrp material. An open moulding process called hand lay-up may create a broad variety of composite products, ranging in size from very small to very big. Despite the limited manufacturing capacity per mould, several moulds can be used to manufacture enormous numbers. The simplest composites moulding technique is hand lay-up, which has a wide variety of part sizes, minimal tooling costs, and straightforward processing. The design is easy to modify. A little equipment investment is required. With trained operators, high

production rates and consistent quality are possible. Precision wire cutting is used to create a thermocol mould, which is subsequently coated with PVA using a sprayer. As a result, the surface is of great quality. After that, a thin coating of wax is applied over the PVA layer.. After the wax has settled, a layer of epoxy resin and hardener is applied to it. The epoxy and hardener mixture has a 2:1 ratio and is proportional to the mass of carbon fibre used. After some simple calculations, the exact amount required is obtained. Once the epoxy and hardener are mixed together, the process must be completed within an hour or it will dry out and become unusable. After the first layer of epoxy and hardener has been applied, a carbon fibre sheet is placed on top and left for about 15 minutes. Finally, another layer of epoxy and hardener is applied by pouring, brushing, spraying, or rolling with a paint roller. To consolidate the laminate, FRP rollers, paint rollers, or squeegees are used to thoroughly wet the reinforcement and remove entrapped air. After completing the following steps, the entire thing is vacuum bagged and cured. The model must be kept in a vacuum bag, and a vacuum is created inside using a vacuum pump so that no air bubbles form during the hardening process. The setup is vacuumed for one day to dry and settle. Comparing vacuum bagging to conventional wet lay-up methods, the fiber-to-resin ratio is greater. A vacuum bag optimises fibre wet-out and eliminates extra resin when used as a counter mould. surfaced composite wing is obtained. Finally, the entire model is complete.

IX. COCLUSION

In this project we have successfully designed and prototyped an aerodynamic package consisting of a front wing and rear wing for a formula type vehicle. We have also established a conclusive comparison between single element vs multiple element type of wings.

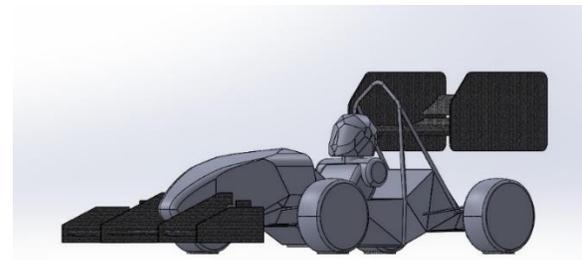


Fig. 23, Our package of Formula style car

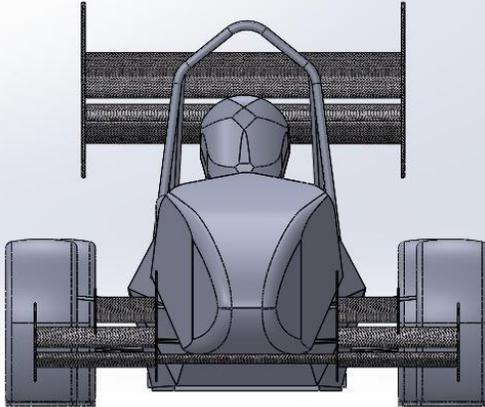


Fig. 24, Front view

X. LIMITATION

The only limitation of this project is the lack of relative pressure around the wings which would affect the forces in real life. Due to the limitations of the system that we are using, we couldn't compile the results in relative pressure. Physical testing of the wing was not possible due to unavailability of wind tunnel.

XI. FUTURE SCOPE

Assembly of the complete aerodynamic package. Actual physical testing of various parts in order to confirm the CFD results.

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