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Simulation and validation of an aerodynamic device for an FSAE vehicle.

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Abstract—Aerodynamics and Computational Fluid Dynamics have made a major impact on the field of automotive design. The external flow of air around a fast moving vehicle will result in forces such as Drag and Lift, which in almost all cases can be used to optimize the performance of the racecar. Devices such as undertray and wings produce an amount of downforce with the tradeoff being the creation of drag.This study focuses on the impact that an undertray has on the performance of a Formula Student vehicle design. The undertray and incorporated diffuser produces a suction force underneath the surface of the car which results in an increase in traction at the wheels. This will result in an increase in speed carried through the corners by the vehicle and hence decrease in lap times in a race. The comparison carried out via CFD, with and without an undertray, shows the difference of airflow around the car with a decrease in coefficient of lift. Validation has been done through track testing which has shown a reduction in lap times owing to the additional downforce created.

Index Terms— Undertray, Aerodynamics, Diffuser, Lift, Drag, Track Testing.

1 Introduction

Formula SAE is an inter-collegiate design competition organized by the Society of Automotive Engineers (SAE) in which student engineers design, build, test and race an open wheeled formula style race car. Since the competitions inception in 1981, the cars have been evolving and changing and there has been no single design that stands out as "the best". One development that seems to be more common of late is the use of downforce producing aerodynamic elements. Downforce is the vertical force that is produced from aerodynamic loads instead of mass. A tires coefficient of friction will decrease with added vertical force. This means that a lightweight car will be able to make more efficient use of its tires than a heavier car and will be able to accelerate faster in any direction. Aerodynamic elements, however, produce vertical load on the tires with very little added mass, giving the tires more grip and allowing the car higher acceleration.

2 Literature Review

2.1 Aerodynamics

Automotive aerodynamics is the study of the aerodynamics of road vehicles. Its main goals are
reducing drag, preventing undesired lift forces and other causes of aerodynamic instability at high
speeds. Air is also considered a fluid in this case. For some classes of racing vehicles, it may also
be important to produce downforce to improve traction and thus cornering abilities.

2.2 Bernoulli Principle

The concept used in designing a diffuser is the ground effect, that is, to cause a venturi-like effect under the vehicle. Under such a vehicle, there is a nozzle that proliferates the velocity of the air below the vehicle and a throat is formed where the maximum velocity exists and then a component called undertray slows this air back down to free stream velocity. As per Bernoulli's Equation , we know that when the local velocity increases, the local pressure is decreased. Because of this lower pressure under the vehicle and the higher pressure on top, a force called downforce is applied on the vehicle

3 Design

3.1 Design Iterations

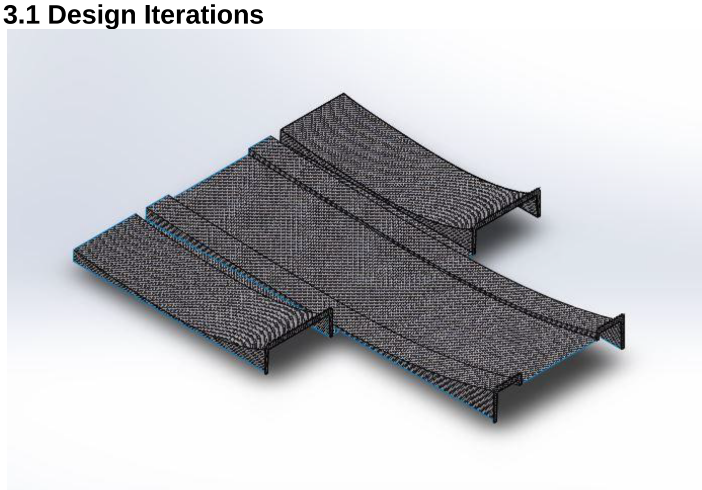

Fig. 1: Cad model of Undetray

While designing an undertray the most important part is to determine the optimum diffuser angle. An optimized diffuser angle will allow proper diffusion of accelerated air beneath the

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tray with the normal air behind the car, thus minimizing the chance of vortex generation.Once you decide the optimized angle for diffuser, your further work is to improvise the design of tray to generate good amount of downforce.As you can see in Fig.1, we have provided 3 tunnels and the tray is given a progressive curve.This was done mainly for 2 reasons.

1. To create gradual variation in the surface arear between ground and tray, that prevents flow from separation.
2. To provide perpendicular air flow to the radiator, which rest's on one of the side tunnel.

3.2 Cad Model

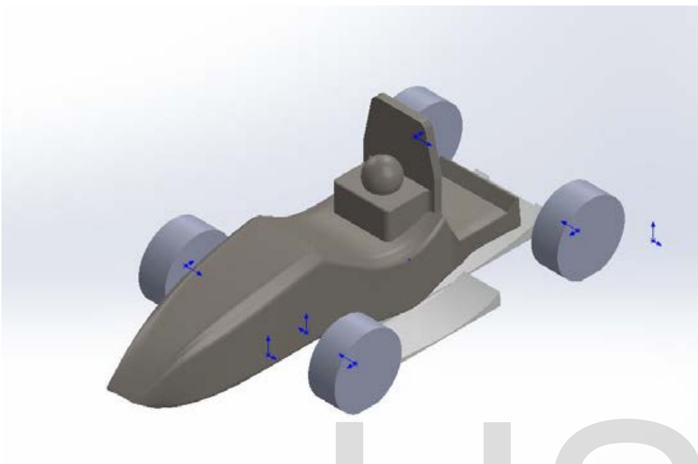

Fig. 2: Complete 3D Cad model

To understand the true effect of the undertray on the airflow over the car, we created a simplified surface CAD model of the car, with and without the undertray to have a direct comparison between the two.The surface model was created on solid works 2015. The main components that would affect the airflow around the car are

1. Nose 2. Driver's helmet 3. Firewall 4. Tires 5. Undertray
6. Driver's body.

The reason of creating a surface body, rather than solid, was to help in simplifying the process of meshing in the next steps of the analysis process.

Also the shape of the car will affect the flow of air near the car.The variation of shape from the nose cone to cockpit to the firewall should be smooth so that it is easy to mesh the car.

4 Simulation

4.1 Meshing

Meshes can also be classified based upon the dimension and type of elements present. Depending upon the analysis type and solver requirements, meshes generated could be 2-dimensional (2D) or 3-dimensional (3D). Common elements in 2D are triangles or rectangles, and common elements in 3D are tetrahedra or bricks. As noted above, some connectivity choices limit the types of element present, so there is some overlap between connectivity-based and element-based classification.

For a 2D mesh, all mesh nodes lie in a given plane. In most cases, 2D mesh nodes lie in the XY plane, but can also be confined to another Cartesian or user defined plane. Most popular2D mesh elements are quadrilaterals (also known as quads) and triangles (tris), shown below.

3D mesh nodes are not constrained to lie in a single plane. Most popular 3D mesh elements are hexahedra (also known as hexes or hex elements), tetrahedra (tets), square pyramids (pyramids) and extruded triangles (wedges or triangular prisms), shown below. It is worth noting that all these elements are bounded by faces belonging to the above mentioned 2D elements. Some of the current solvers also support polyhedral elements, which can be bounded by any number and types of faces.

Since all 3D elements are bounded by 2D elements, it is obvious that 3D meshes have exposed 2D elements at boundaries. Most of the meshing packages and solvers prefer to club exposed elements together in what is known as a surface mesh (for the purposes of applying boundary conditions, rendering meshed domains and visualizing results). A surface mesh does not have to be 2D, since volume meshes may conform to domains with non-planar boundaries.

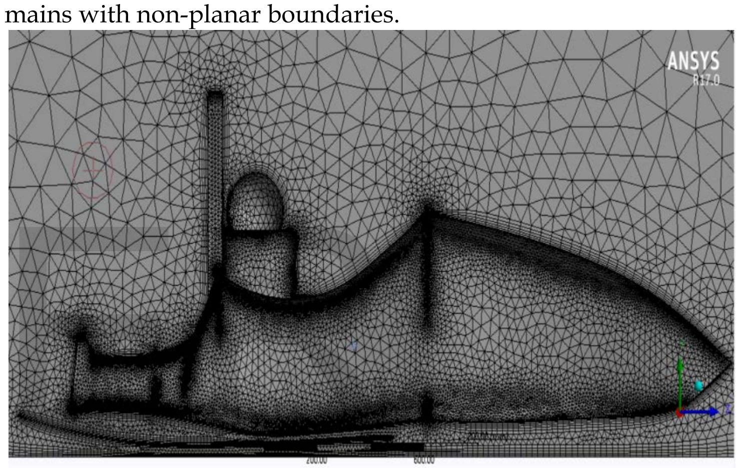

Fig. 3: Growth of Inflation layer

Many meshing algorithms start by meshing bounding surfaces of a domain before filling the interior with mesh nodes (such algorithms are also known as boundary to interior algorithms).

Along with the body of car even tyres are major component that affect the flow of air around the car. Therefore it is necessary to mesh the tyres as well for analysis of the flow.

Apart from body and tyre ground effect also plays a vital role in changing the drag and downforce value of the car. So generating refined mesh near on ground is a must.

4.2 SETUP

4.2.1 Inflation layers

To investigate the flow around a body in detail, we need to capture the boundary layer formed on the critical surfaces that are:

1. Carbody. 2. Undertray diffuser. 3. Ground.

Growing an inflation layer will essentially extrude wedge cells from the surface triangular mesh which is formed on the car and undertray surface.

We have given a programmed controlled inflation of 5 layers having a first aspect ratio of 5 and a growth rate of 1.2, which will cause the wedge cell layers thickness to grow by 20% per layer formed. After these layers, the mesh will form pyramid cells up to the bounding box i.e. the wind tunnel. The transition is smooth in nature and the cells will grow in size up to 150mm in cell face width.

TABLE 1: Mesh Properties

Parameter	Value
Size Function	On proximity and curvature
Smoothing	High
Transition	Slow
Minimum Size	1 mm
Maximum Face Size	150 mm
Growth Rate	1.2
First Aspect Ratio	5
Maximum Layers	5
Growth Rate	1.2

All these settings lead to a mesh of:

Mesh File	**Number of Cells**
With Undertray	7,867,041
Without Undertray	4,419,163

4.2.2 Setup

The role of this section of the project is very vital in in finding a difference that the undertray will provide to the airflow around the car.ANSYS Fluent is the most-powerful computational fluid dynamics (CFD) software tool available, empowering you to go further and faster as you optimize your product's performance. Fluent includes well-validated physical modeling capabilities to deliver fast, accurate results across the widest range of CFD and multiphysics applications. Hence we chose thissoftware for analysis of our racecar.The first step was to import the mesh file to the fluent domain. After the '.msh' file has been read by Ansys Fluent solver we need to enter all the various parameters that will ensure an accurate solution. The steps are:

TABLE 2: Boundary Conditions

Mode:l	Realisable K-epsilon, Non Equilibrium wall Fn
Material	Air
Frontal area(With/Without)	0.3532 m^2, 0.322 m^2
Velocity	23 m/s
Solution method	Pressure – velocity Coupling

The monitors that were set up are
1. Lift. 2. Drag. 3. Residuals.
The last step before initiating the calculation iterations was to initialize the solution. This step runs 10 iterative calculations in the air domain which will give a good starting point from where the calculations can take over, resulting in a better and more accurate solution, in lesser iterations. Hybrid initialization was used for the above purpose, rather than standard initialization which would fill the domain with a starting point velocity which is equal to the inlet velocity that is 23m/s.
After performing 50 iterations using First Order Upwind model, we then switched to Second Order Upwind model for the remaining iterations till it had converged.

4.2.3 Covergence criteria

The Fluent solver will display different monitors as set up by the user before calculations. The criteria that we used to gauge convergence was that the value of cd and cl should be constant up to 3 decimal places, the residual graph should initially slope downward towards the positive X axis and should then level out. We calculated the final solution in steps of 20 iterations and when these criteria were satisfied we terminated the solution and started the post processing of the results.

5 Results

To generate downforce, pressure below the car should be less than pressure above the car.Undertray works on the principal of Bernoulli effect.Following are the pressure and velocity plots of the car with and without undertray,showing how both the pressure and velocity of flow vary along the car length with and without the undertray.

5.1 Pressure variation with and without Undertray

The pressure increases at the start of the nose due to stagnation, the flow further seperates along the nose, as a result the pressure dissipates. Further the pressure below the undertray decreases with decrease in the sectional area between ground and undertray. At the rear end of the car with the help of diffusion, the pressure of air nearly comes back to its atmospheric pressure, thus allowing a smooth diffusion of normal air and accelerated air beneath the undertray.

Another analysis without the undertray was performed. The decrease in pressure below the car was less compared to the decrease in pressure with undertrayattatched, as the sectional area between the car and ground was more compared to the one with the undertray. Also at the rear end of the car the pressure does not increase back to atmospheric pressure,causing improper diffusion of normal air and accelerated air, thus leading to formation of wake.

5.2 Velocity variation with and without Undertray

The velocity at the throat of the undertray increases creating pressure drop and increasing the downforce of the vehicle. Also at the rear the velocity decreases due to the diffusion effect bringing back the velocity almost near to atmospheric velocity.

The velocity of flow beneath the car, without the undertray, does not increase much since the sectional area between ground and bottom of the car is greater and hence less produces less amount ofdownforce. Also the decrease in velocity at the rear of the car without the undertray is less compared to that with the undertray, causing the wake to increase at the rear.

5.3 Lift and Drag coefficients

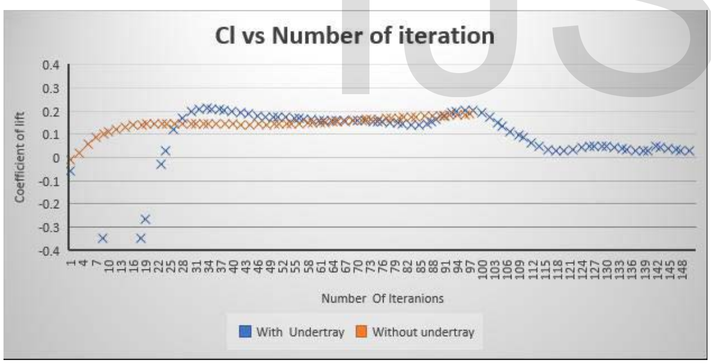

Fig. 4: Coefficient of lift graph

Above graph determines the cefficient of lift values generated by car with and without undertray.It is clear from the graph that, with undertray attached to the car, coefficient of lift decreases,thus increasing the normal load on car.The increased normal load on the car helps in loading of the inner wheel during a corner,thus allowing the car to manoeuvre faster.

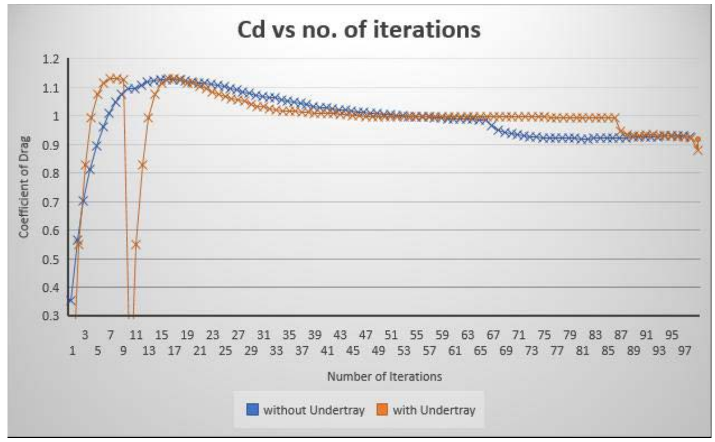

Fig. 5: Coefficient of drag graph

Advantage of installing an undertray is that it provides minimum amount of drag with considerable amount of downforce.As you can see from the graph above, the coefficient of drag with and without the undertray is almost the same.Withdrag being same, undertray in no way is consuming any amount of engine power, thus allowing the car to run faster with greater cornering ability.

6 TRACK TESTING

We selected 2 events: acceleration and skidpad for validation of undertray.

This events have the same layout in the formula student competitions. So this helps us in proper validation of undertray. We measured the lap timings of the car with and without the undertray keeping all the parameters same.

6.1 Acceleration Event

Acceleration event is a straight patch of 75m. In this event undertray helps to reduce the wheel spin during gear change which eventually helps in reducing the lap timing.

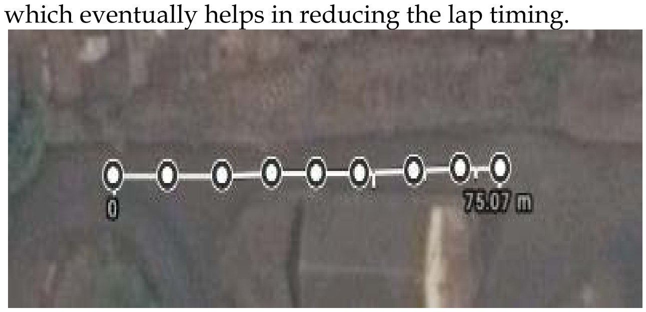

Fig. 10: Acceleration Track Layout

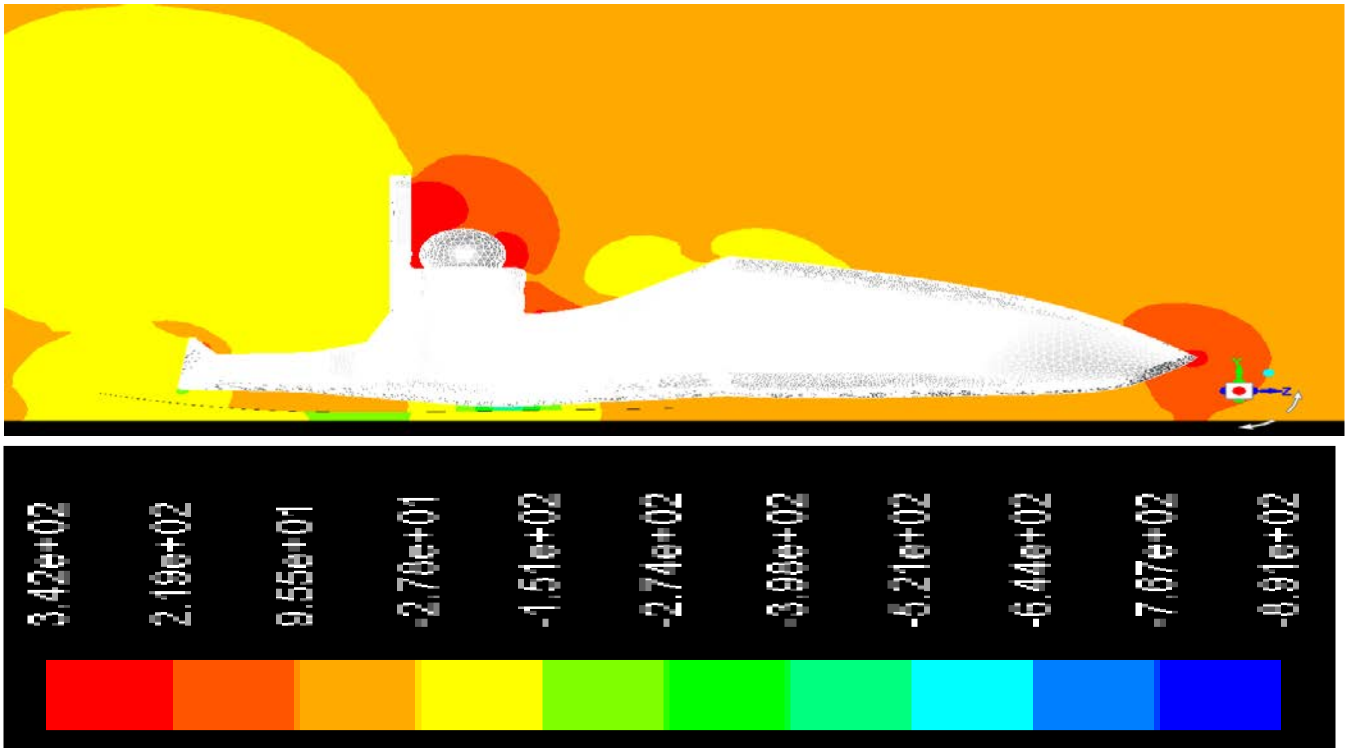

Fig. 6: Pressure variation with Undertray

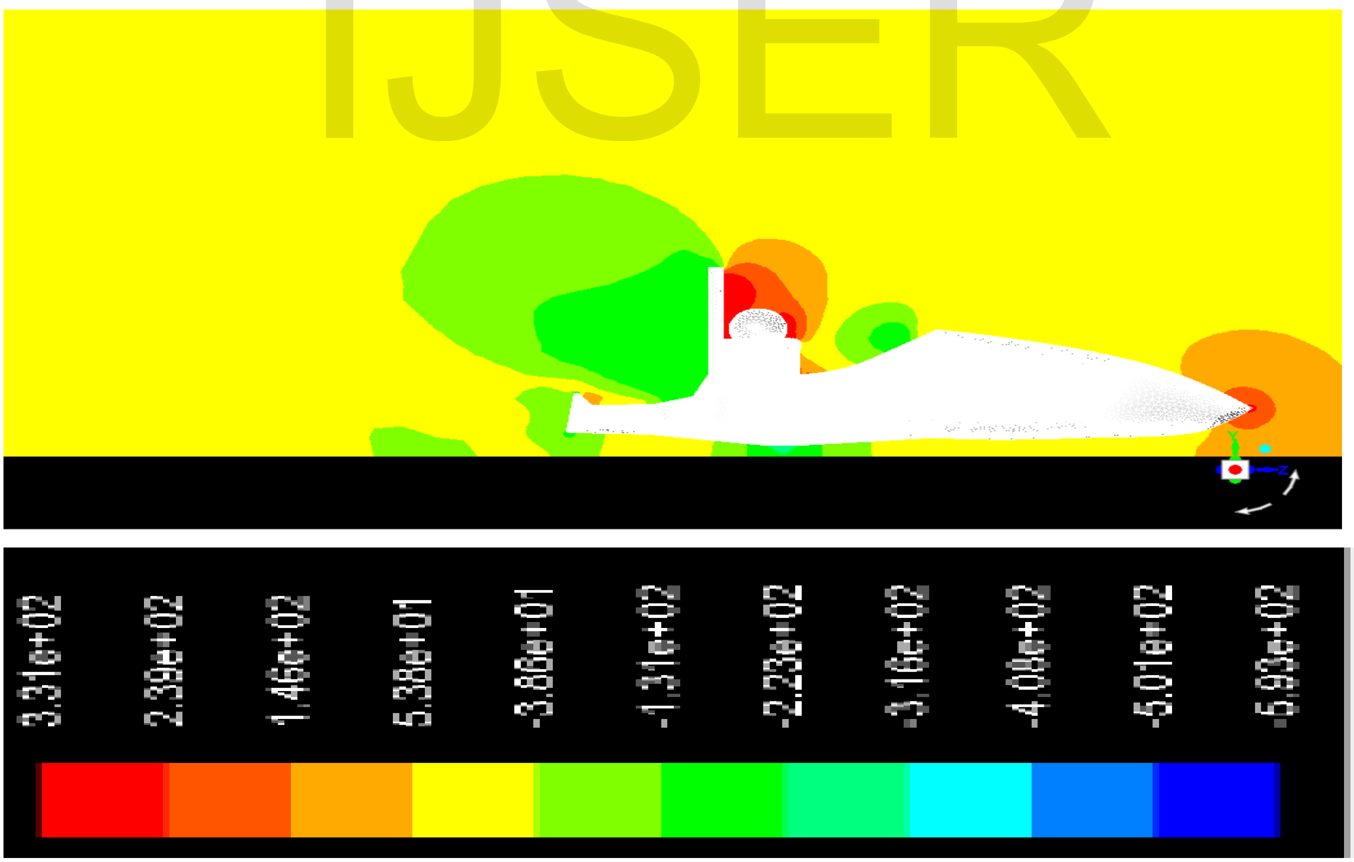

Fig. 7: Pressure variation without Undertray

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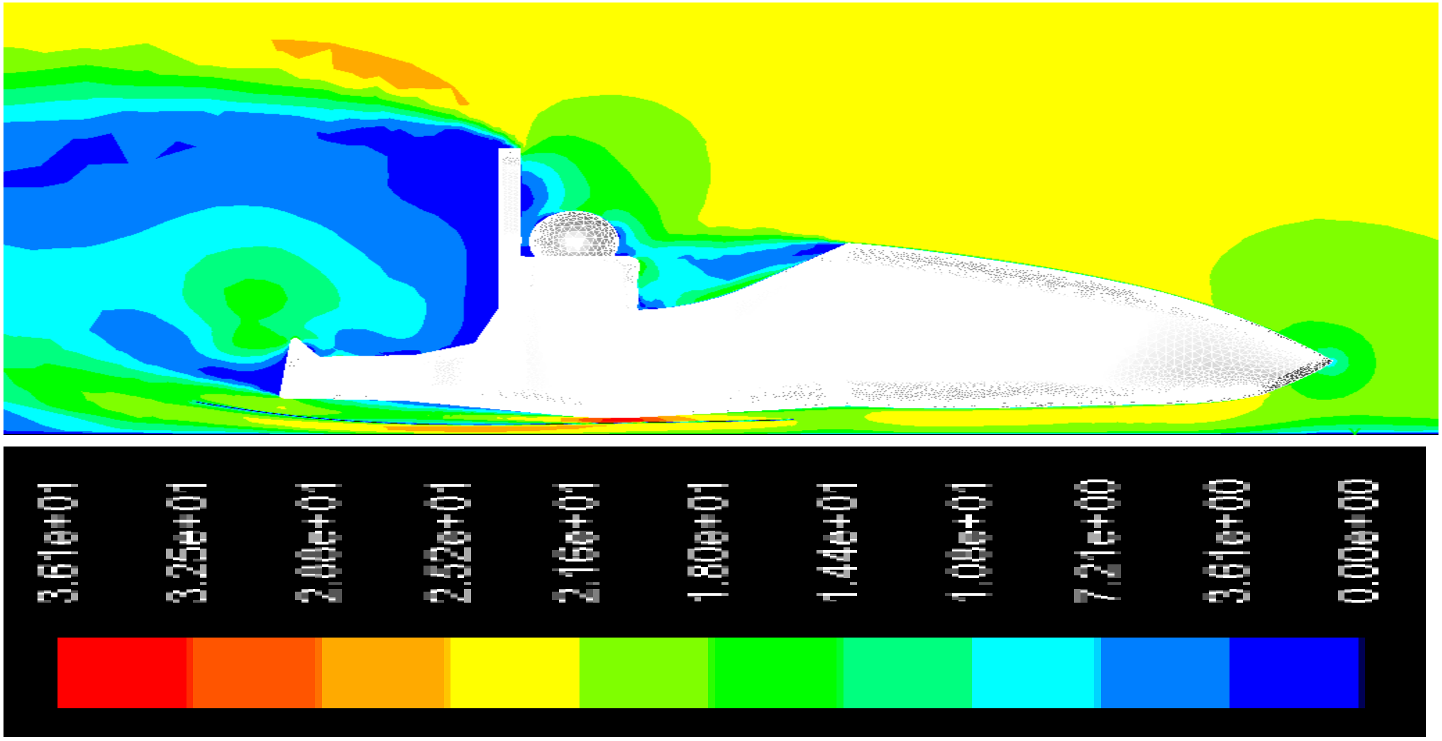

Fig. 8: Velocity Variation with Undertray

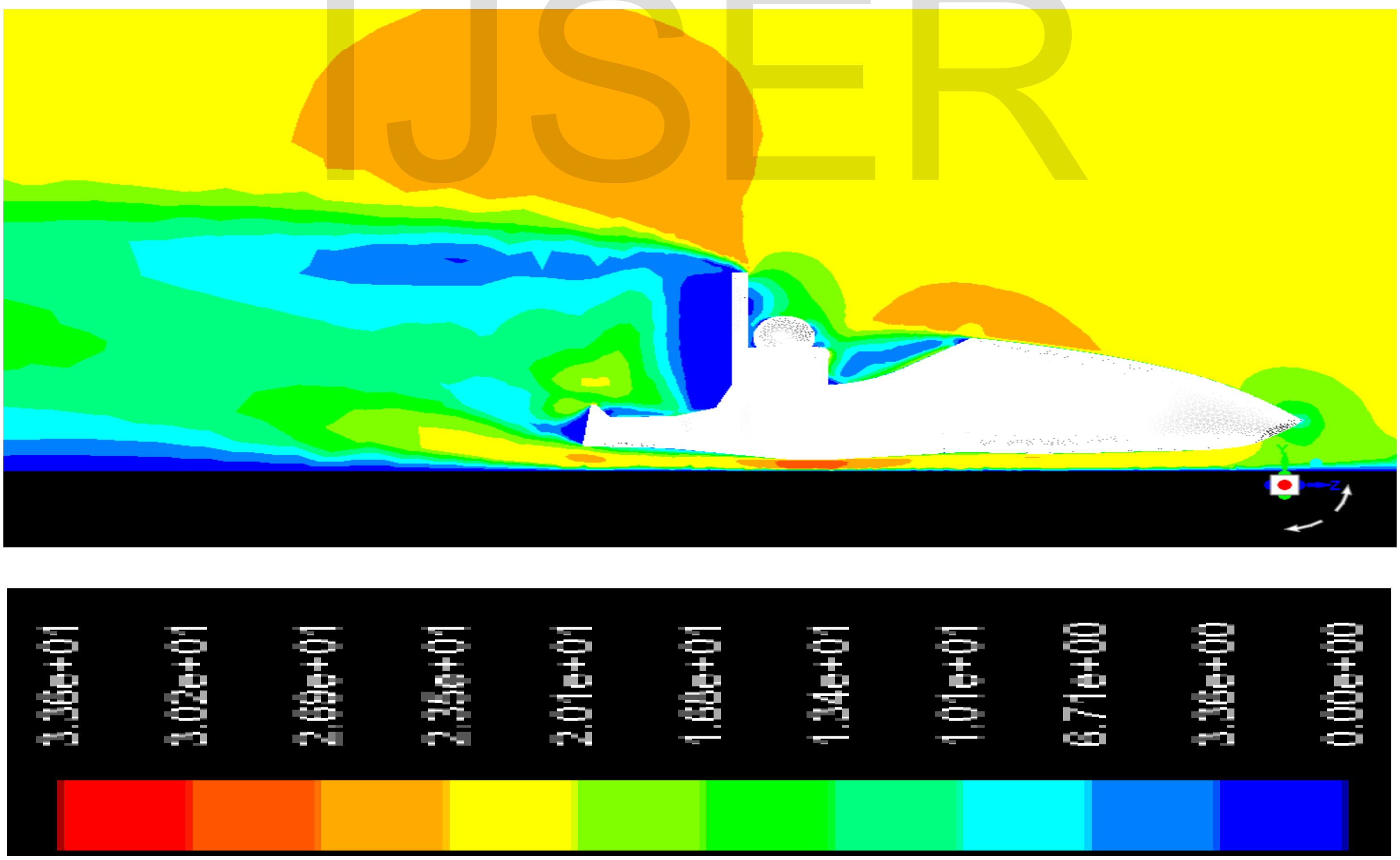

Fig. 9: Velocity Variation without undertray

Table 3: Time Comparision for acceleration event with and without undertray.

Without UT Driver 1		With UT Driver 1	
1	5.8	1	6.05
2	6.4	2	5.63
3	6.35	3	5.63
4	6.42	4	5.35
5	7.11	5	5.76
6	6.79	6	5.33
7	6.33	7	5.36
8	6.68	8	6.46
9	6.64	9	5.16
10	5.79	10	5.32
11	5.69	11	5.22
12	5.7	12	5.63
13	6.1	13	5.52
14	5.55	14	5.8
15	5.93	15	5.35
Average	6.21	Average	5.57

6.2 Skidpad Event

The skidpad course consists of two pairs of concentric circles in a figure of eight pattern.
The centers of these circles are 18:25m apart. The inner circles are 15:25m in diameter andthe outer circles are 21:25m in diameter.
16 cones are placed around the inside of each inner circle. 13 cones are positioned around the outside of each outer circle, in the pattern shown in the skidpad layout diagram.

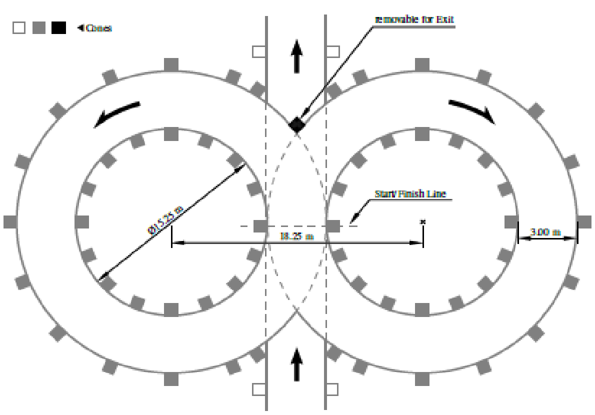

Fig. 11: Skidpad Track Layout

Table 3: Time Comparision for Skidpad event with and without undertray.

With UT Driver 1		Without UT Driver 1	
1	5.935	1	5.45
2	5.72	2	5.25
3	5.07	3	5.8
`4	5.05	4	5.7
5	5.07	5	6.1
6	5.14	6	5.9
7	5.19	7	5.8
8	5.23	8	5.65
9	5.04	9	5.64
10	5.1	10	5.89
Average	5.2545	Average	5.718

7 Conclusion

It is clear from track testing that undertray helps reduce lap times on a straight patch as well as on a circular patch.The increased amount of downforce is improving the cornering ability of the car and is also providing traction needed in a straight patch.In track testing validation it is necessary to maintain the same tyre temperature, same tyre pressure same track temperature, same driver mindset and many other variables while determining the differences in lap timing of car.

8 Acknowledgment

We wish to express our sincere thanks toProfessor VyankateshBagal, our project guide for his expert and valuable guidance, who himself has a vast knowledge on vehicle aerodynamics and computational fluid dynamics.

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