iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** VIII **Month of publication:** August 2021

DOI: https://doi.org/10.22214/ijraset.2021.37635

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

Design and aerodynamic analysis of an Automotive Adaptive Rear Diffuser

Heet Patel[1], Yash Shinde[2], Smit Shendge[3]
[1, 2, 3]*Students at University of Wolverhampton*

Abstract: Traditional vehicles are designed to bring out the best performance, good fuel economy, fewer emissions, and good high-speed stability. In this process of designing a vehicle, the underbody geometry of a car plays a vital role and is often neglected because of its complicated design bits. Though the presence of uneven surfaces causes the layers of air to separate resulting in generating turbulence. This report is about designing an active rear diffuser of a car. The rear diffuser is an aerodynamic device that is installed in the end part of the underbody of a car. Diffuser now a day is quite a common aerodynamic device that is used in performance cars. The main moto of attaching a diffuser is to reduce the wake produced behind the car and help the streamlines to converge better. The prime focus of this study is to design an active rear diffuser that will not only help in providing great high-speed stability and aerodynamic efficiency but will also use the aerodynamic forces adversely to help the car stop faster and on its track. This is made possible first by understanding the effects of diffuser angle on the aerodynamic forces acting on the car. Further, to actually transform the computational values into a working model, an electronic circuit is designed which mimics the exact movement of the diffuser according to the speed and other driving conditions.

Keywords: Adaptive, diffuser, automobile, aerodynamic, aerodynamic Drag, aerodynamic Lift

I. INTRODUCTION

Looking back in the recent ten years, the automobile fuels like petrol and diesel prices have almost doubled. This is because the government is taking actions considering the severe CO2 emissions and yes of course, due to the increased taxation. As a result, improving fuel efficiency has become a prime aspect while making a car. The fuel efficiency of the car is an aspect that is dependent on many different parameters like the tuning of the powertrain, loading conditions, weight of the vehicle, aerodynamic drag, and a very obvious one, the driving style. In the past decade, most of the freshers' in the automobile domain are into automobile designing because of which a lot of advances have been seen. Though it could be seen that to improve the efficiency of the vehicle, aerodynamics is the most understated topic compared to other areas, as aerodynamics is not something which is used as a power source of the vehicle like in the case of an airplane.

A. Importance of Underbody Aerodynamics

It is studied that vehicle aerodynamics not only holds a stake in improving the vehicle's fuel efficiency but it is also believed that it is used to improve the overall performance of the car. It is seen that approximately 25% of the overall vehicle aerodynamics is influenced by the underbody[1]. One of the major components that are included in that 25% is the diffuser. Many studies have been done [2] which show that streamlining the complete rear part which includes the boot and the underbody has high potential to improve. My main focus is to design an active diffuser of the vehicle. The advantage of having such aerodynamic devices is that it also improves the aesthetic appearance and appeal of the car and will also grab the attention of people who want all the glamour and materialistic attention. Such an audience is limited to some extent as a result more focus is given to improve the vehicle efficiency by altering the engine and transmission.

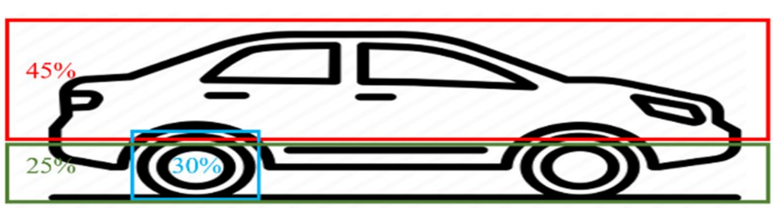

Figure 1: showing contribution of each part of a car for aerodynamic forces.

According to [1] 45% of the car that is the upper body, contributes to the aerodynamics of the vehicle. The wheels and wheel housing hold a 30% stake and the remaining 25% is the underbody geometry.

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B. What is a Diffuser!

One of the most common aerodynamic devices is used in performance vehicles like F1 cars. Though, now it can be seen on ordinary vehicles also. A diffuser aids a vehicle in both reducing the drag and increasing the downforce. As a result, not only the operating stability improves but also the fuel economy is positively affected. The wake structures produced behind the rear wheel have a significant impact on the. Many studies also show that the diffuser angle and the ground clearance have a significant impact on vehicle aerodynamics[3].

II. WORKING OF MY PROPOSED SYSTEM:

The whole world knows that aerodynamic devices are attached to enhance the vehicle performance though sometimes to make it faster and sometimes to get a better fuel economy. Devices like spoilers and diffusers are moreover used to make the vehicle faster and get better high-speed stability and handling. My thought was to design a diffuser that not only increases the stability and handling ability but also adapts itself in such a way that it would also help to make the car stop faster while panic braking by increasing the drag produced. My designed system will be an electro-mechanical system. It will be receiving data from sensors like the wheel speed sensor also known as the rpm sensor. The microprocessor on the diffuser end will be continuously reading the signals of the wheel speed sensor. Whenever the vehicle will start traveling at a speed higher than 40kmph the diffuser will automatically align itself at an angle that will reduce the drag and the wake produced behind the vehicle. The next scenario will be that if the readings are such that a sudden drop in the vehicle speed is detected the diffuser will align itself at such an angle that the drag will increase and will reduce the aerodynamic efficiency thereby helping the car stop faster.

III. LITERATURE REVIEW

[4] in this paper, the author has designed an active translating diffuser. As the name itself suggests the diffuser translates which means it moves to and fro, and the word active means it will adapt its movements according to the speed of the vehicle. By designing such a diffuser, the main objective of the author was to reduce the aerodynamic drag experienced by the vehicle, to be more specific, “passenger cars.” This active diffuser was installed in the bottom part of the rear bumper. The core shape of the extendable diffuser was identical for all the samples that had to be tested in the CFD analysis. There were a total of 7 different geometries created having the difference of the length of the diffuser. To get the best possible results from the analysis author had kept the tires rotating and the floor moving. By doing this analysis he wanted to explain the influence of the actively translating diffuser on the passenger car’s aerodynamic drag reduction. With his CFD analysis report, the author gets to know that desirable changes in the pressure in the underbody of the car helped to reduce the drag significantly. The author also provided statistical data showing an average of more than 4% reduction in the drag resulting in a better fuel economy by approximately 2% at vehicle speeds more than 70kmph.

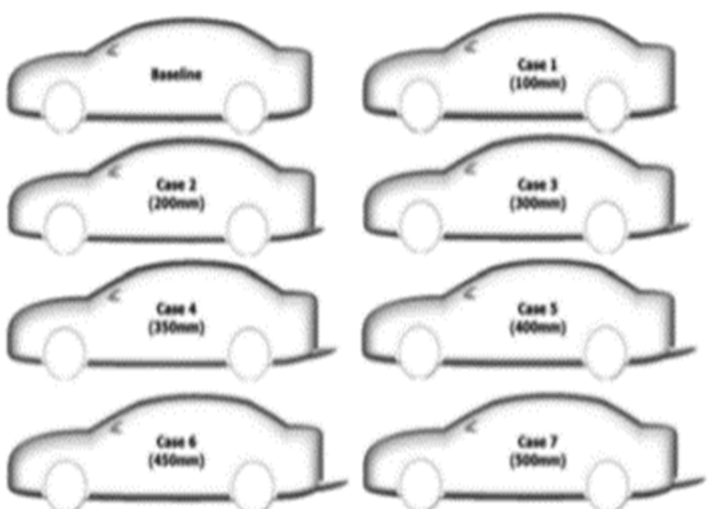


Figure 2:Figure showing the side view of the seven different conditions the author has considered.

[2] using an artificial neural network the author presents a study in which he optimizes the outer shape of a sedan and channelizes his prime focus on optimizing the rear side of the car. He calculated the fluctuations of the pressure and the drag coefficient under different design conditions by conducting a CFD analysis where the optimization variables were also determined. Initially, the design of the sedan was kept completely normal i.e. no additional aerodynamic devices were added. CFD analysis was conducted and the results obtained were then counted as the reference for the rest of the modifications. There were a total of 6 aerodynamic devices added and the results were quite desirable. A significant improvement of 5.64% was seen in the aerodynamic performance compared to the results recorded in the unmodified car. In the end, the author concluded with a statement that, “within the accepted range of shape modifications for a rear body, the aerodynamic performance of a sedan can be enhanced so that the fuel efficiency of the sedan can be improved.”[2]

[5] in this paper, the author first understood the effects of having poor underbody geometry. Then he stated that the airflow in the underbody is decelerated and there is an unfavorable pressure change observed thereby reducing the overall aerodynamic efficiency of the vehicle. In his study, he conducted a numerical analysis, initially on an Ahmed-type body having three different conditions. Later the study was continued on a sedan where the length of the diffuser was varied and the results were recorded and analyzed. A conclusion was made which stated that by adding a diffuser on a vehicle the drag values decreased significantly with an increase in the downforce.

IV. METHODOLOGY

The first task was to select a suitable topic of research that not only was in my field of interest but also was something completely new. I was always fond of sports and supercars. Their stance and especially the aerodynamic devices like spoilers, diffusers, wide-body kits attracted me a lot. As a result, I was very sure that I had to do some research on a vehicle aerodynamic device. With that lead, I started basic research by reading about different aerodynamic devices and their technologies which were the latest and are used in today’s automobile industry. By doing so I noticed that not much research had been done to develop the rear diffuser. Where many other devices were actively or adaptively translating, the diffuser was static and way too away from the electronics. This is when I decided to design a diffuser that was adaptive. The advantages that an active diffuser could provide was, it not only would help to provide high-speed stability but also aided to reduce the stopping distance. The second advantage is that it can produce different downforces depending upon the speed at which the car is traveling. With such a feature the car will have a proper balance and proportion of producing downforce.

After finalizing the topic and getting it approved, my next step was to do proper research (literature review) to understand the effects of different angles on the lift and drag produced. This got me a clear idea of all things I will have to consider while doing my CFD analysis. After completing my literature review, the next step was to start designing the car which I had to use for the analysis.

A. Creating Geometry

A CAD designing software “Onshape” was used to make the design of the car with the diffuser.

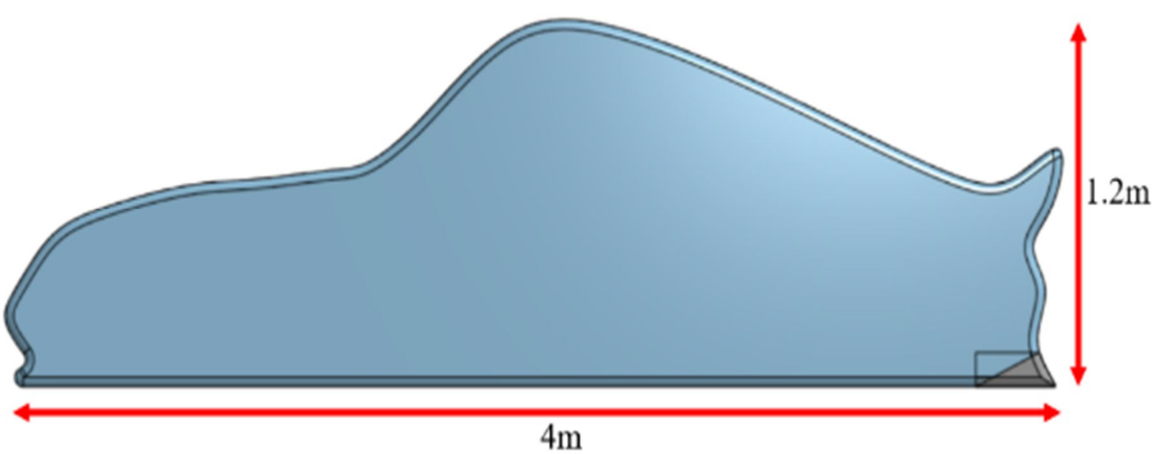


Figure 3: side view and dimensions

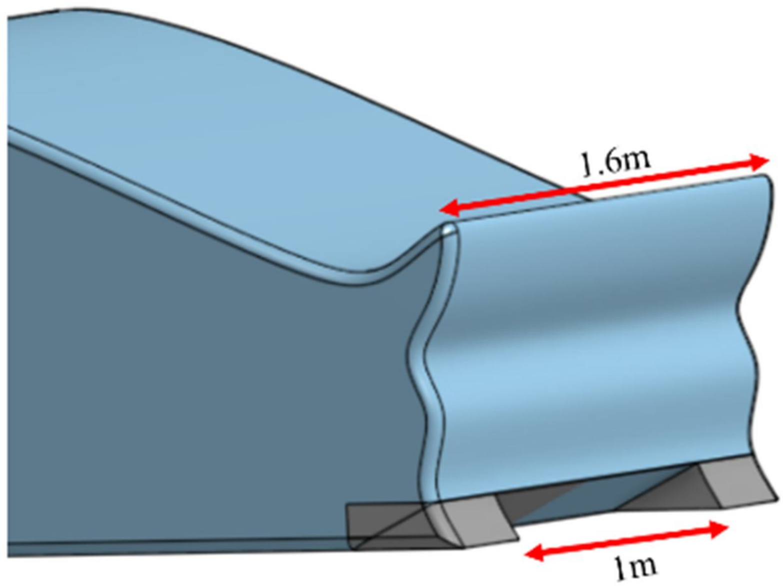


Figure 4: isometric view with dimentions

This design surely looks very simple when compared to an actual car. The car has been simplified which means, the door handles, windshield, outside rearview mirrors, wheels, etc. have been eliminated to simplify the car. This is done because the prime focus of this research is to only understand and study the effects of the angle of the diffuser on the downforce and the drag produced to get that exact proportion of, the diffuser angle to speed ratio. Multiple geometries have been created keeping the angle of the diffuser as the variable, varying it from 0 degrees to 25 degrees keeping the interval as 5 degrees.

B. Simulation model

There are two commonly used models used for measuring the turbulent effects in a CFD analysis. The two models are K-Omega and K-Omega SST respectively. K-Omega is one of the most commonly used turbulence models specifically designed to capture the effects of turbulent flow conditions. It belongs to the Reynolds-averaged Navier-Stokes (RANS) family of turbulence models where all the effects of turbulence are modeled [9]. K-Omega model solves two equations simultaneously to give the results. One equation is the conservation equation and the second one is the, "two transport equation." The two variables are, the turbulent kinetic energy (k)which is used to determine the energy in the turbulence. The second variable is the specific turbulent dissipation rate (ω). Ω is also referred to as the scale of turbulence.

The second model is the K-Omega SST. SST stands for shear stress transport. The formula of this model changes from $k-\omega$ to $k-\epsilon$ where the advantage attained is that the post-processing results get less affected by the turbulence of the inlet free-stream. "The $k-\omega$ SST model provides a better prediction of flow separation than most RANS models and also accounts for its good behavior in adverse pressure gradients. It can account for the transport of the principal shear stress in adverse pressure gradient boundary layers. It is the most commonly used model in the industry given its high accuracy to expense ratio." [9].

As seen from the above descriptions I selected the K-Omega SST model for my simulations. Its advantages like not getting affected by the inlet free-stream turbulence, good behavior in adverse pressure gradients, and having a higher accuracy helped me in deciding on choosing it over the normal K-Omega model. Below is the screenshot showing the simulation model used.

C. Boundary conditions

After selecting air as the material for the flow region, the following boundary conditions were assigned. The boundary conditions have been assigned keeping in mind that all the analyses have to be done at a velocity of 28m/s i.e. 100kmph. As a result, the velocity magnitude provided at, "velocity inlet" and "moving wall (road)" is 28m/s.

D. Meshing

Meshing was quite a bit of a task to do. It took many trials to get the exact value for the maximum edge length to get an extremely good quality mesh. Eventually, the numbers decided after multiple attempts for the minimum and maximum edge length were 0.001m and 0.015m respectively. The enclosure is 80 meters long. So it can be seen that the maximum edge length is way too small when compared to the length of the enclosure. The image below can be seen which looks almost black. Black color is a group of cells/elements. The denser the color the smaller is the size of the elements. This means that the mesh is very fine.

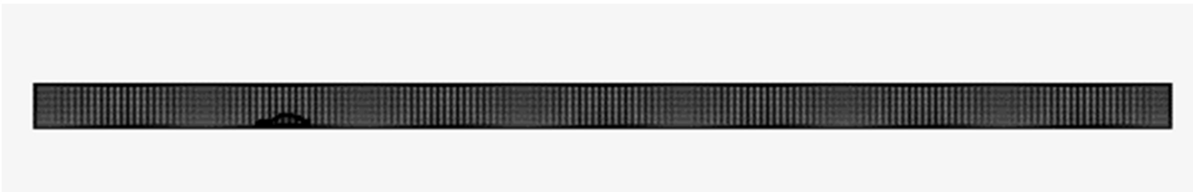


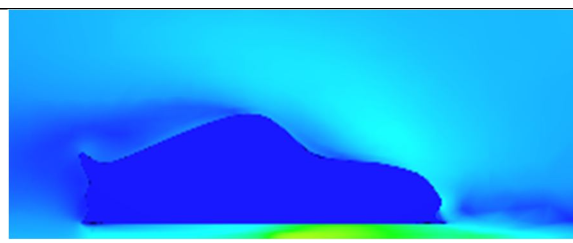
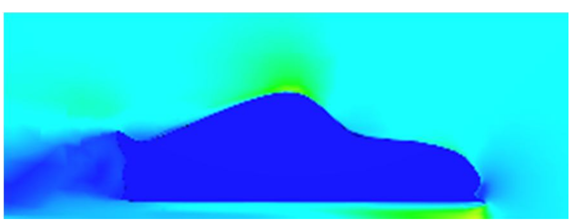
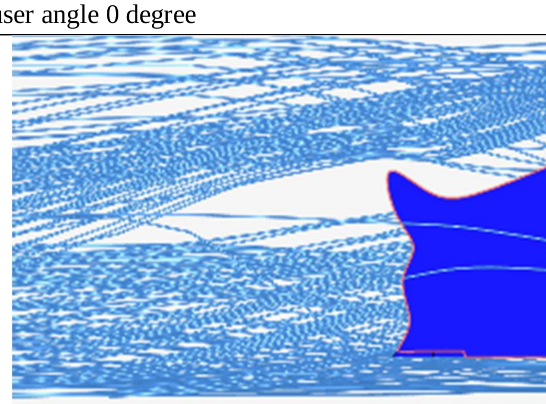
Figure: Translucent view of the mesh

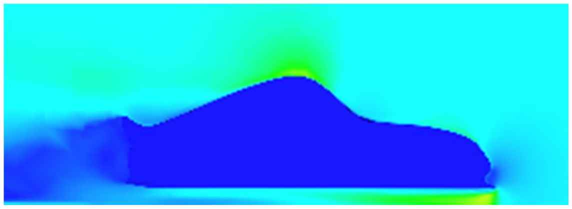
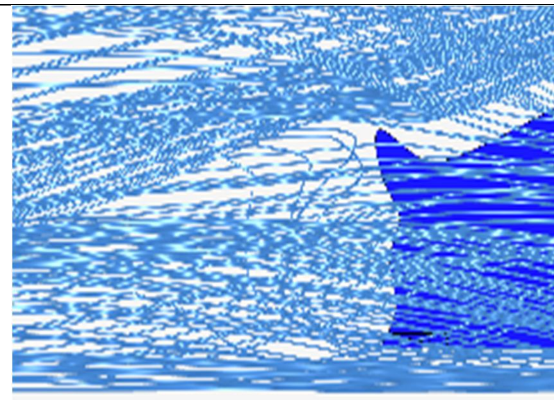
V. RESULTS AND DISCUSSION

An extremely simplified 3D car model was considered which was not having any external features of an actual car like the door handles, outside rearview mirrors, wheels, etc. It was also having an absence of the underbody geometry of a car which probably could have played a vital role in this experiment. This was done because the prime focus of this study was only to explore the effects of changing the diffuser angle on the downforce produced and further use the adverse effects of aerodynamics to help the car stop faster. The values recorded are quite different than what might have been recorded in real-life scenarios because of the simplified model, but at least with the help of this analysis, it can be said that the values in the real-life scenarios will follow a similar fashion. Let us first start with the velocity contour plots and see what effects does they have on the car.

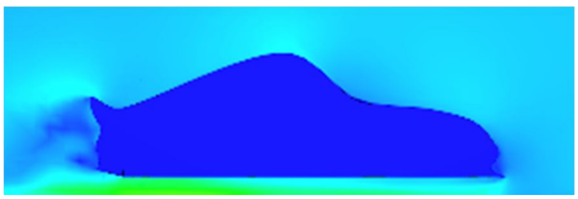
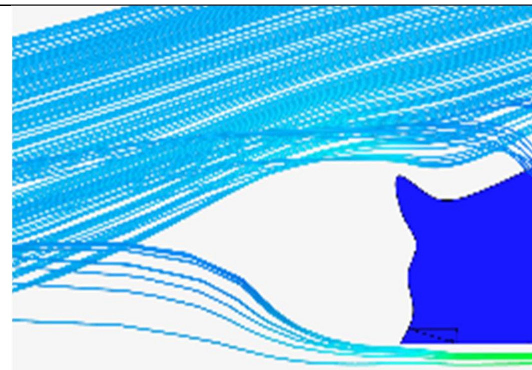
A. Velocity and Streamline Contour Plot

Table 1

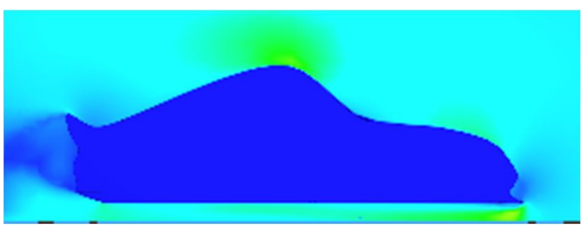
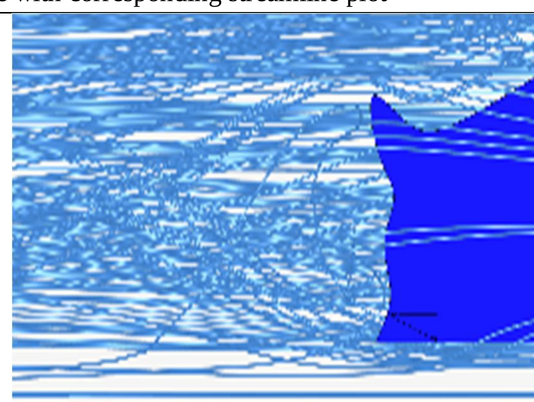
	
Velocity contour plot at diffuser angle 0 degree	
	
Velocity contour plot at diffuser angle 5 degree with corresponding streamline plot	

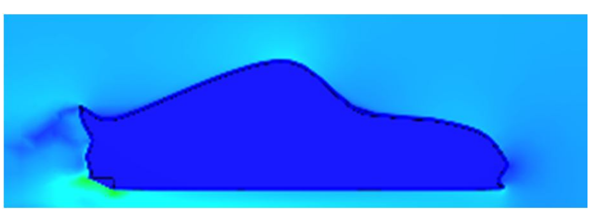
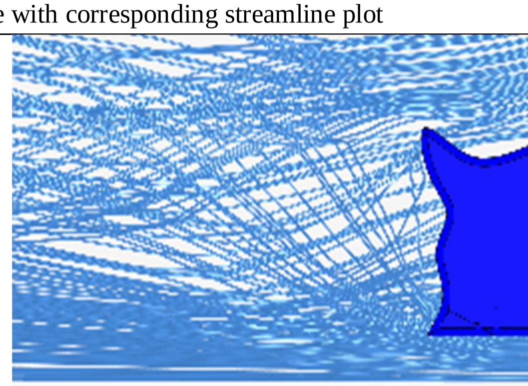
Velocity contour plot at diffuser angle 10 degree with corresponding streamline plot

Velocity contour plot at diffuser angle 15 degree with corresponding streamline plot

Velocity contour plot at diffuser angle 20 degree with corresponding streamline plot

Velocity contour plot at diffuser angle 25 degrees with corresponding streamline plot

Figure 5: contour and streamline plot of velocity

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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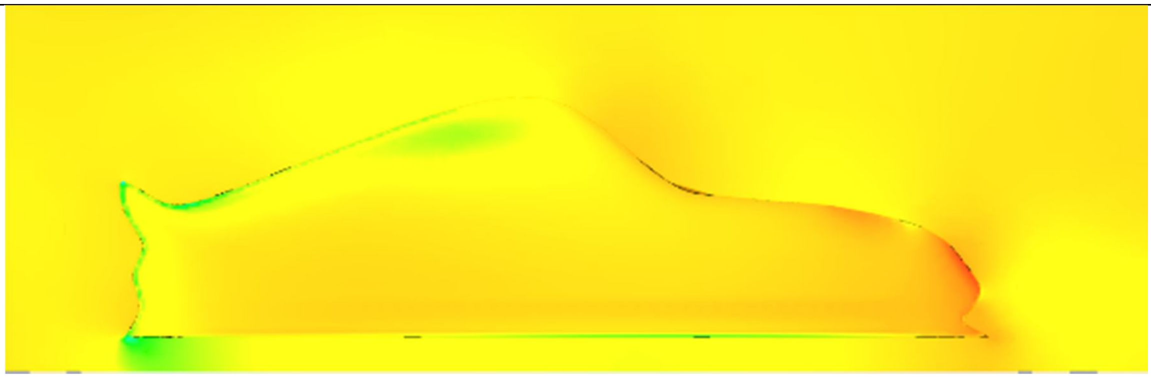
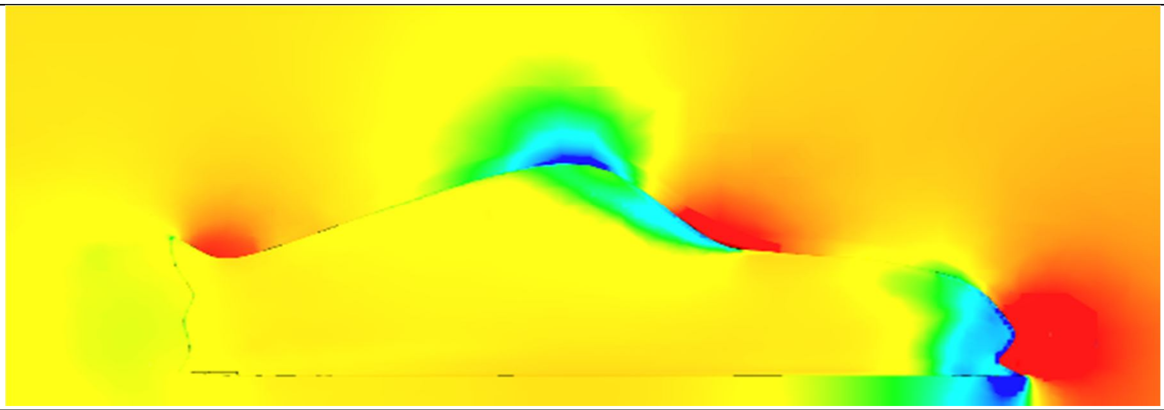
B. Pressure Contour Plot

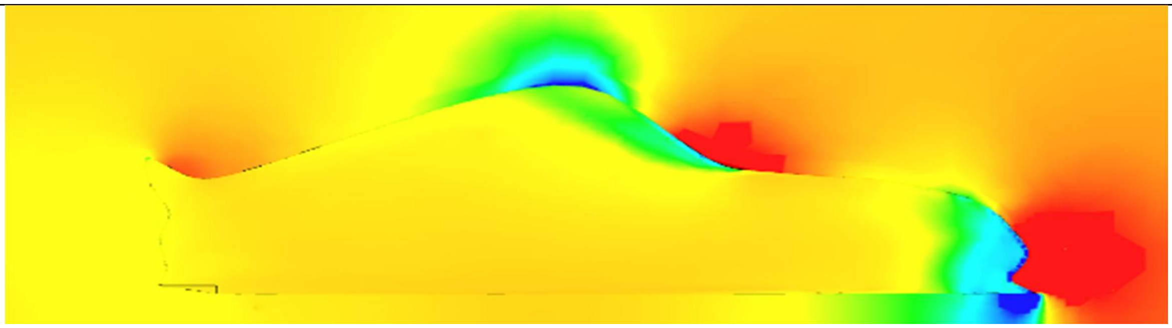
Table 2



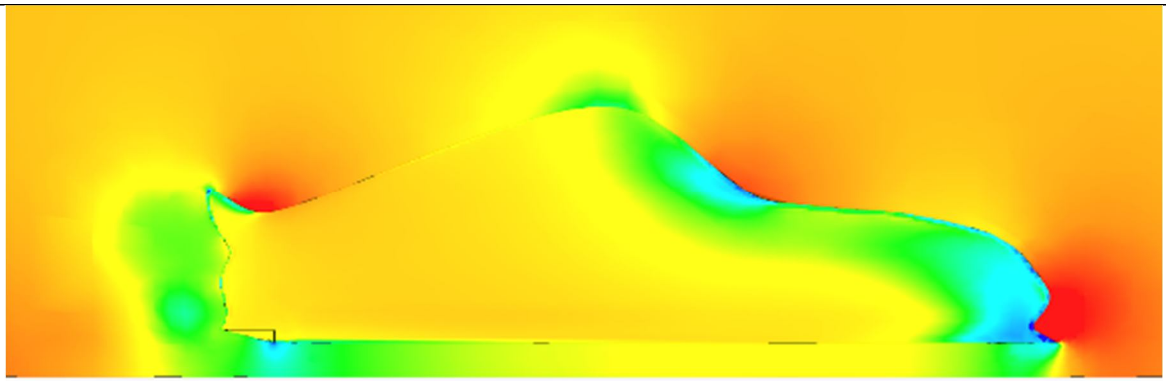
Pressure contour plot at diffuser angle 0 degree



Pressure contour plot at diffuser angle 5 degree



Pressure contour plot at diffuser angle 10 degree



Pressure contour plot at diffuser angle 15 degree

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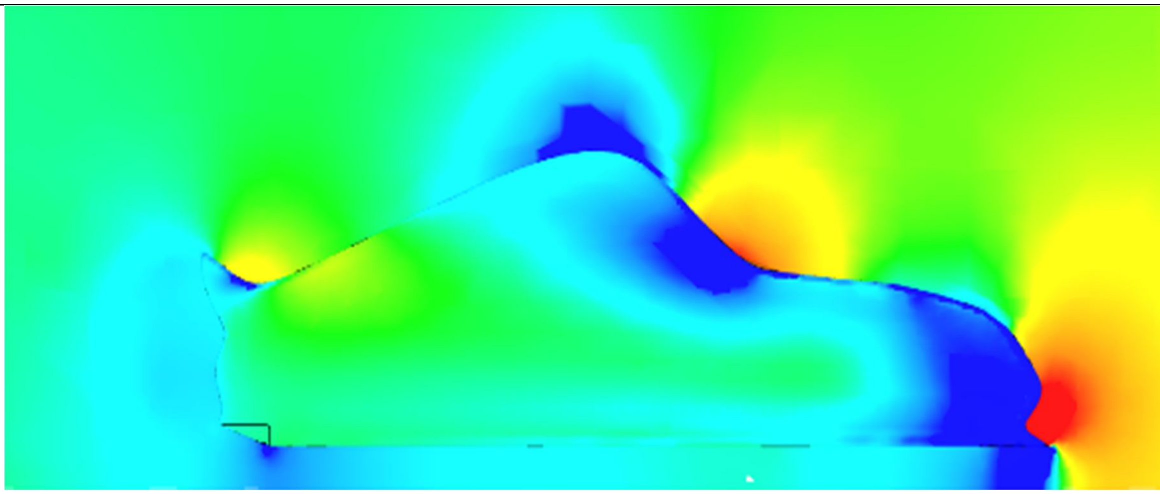
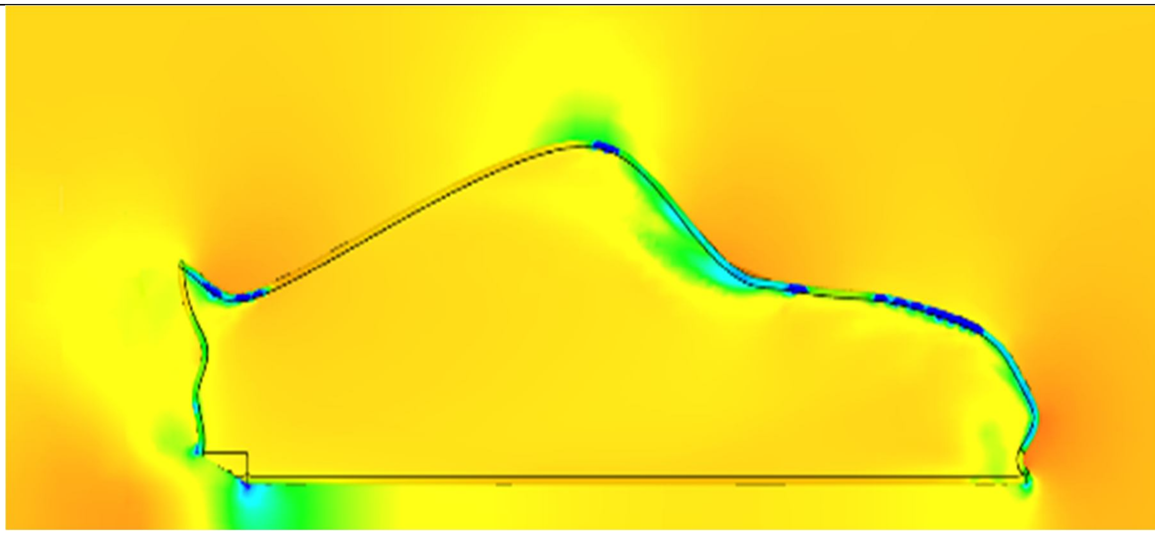


Pressure contour plot at diffuser angle 20 degree



Pressure contour plot at diffuser angle 25 degree

Figure 6: pressure plot

From the pictures in the table of figure 21 it can clearly be inferred that the flow is initially approaching the vehicle, it is slowing down, it is then flowing above the vehicle surface and is again picking up some pace after the windshield area ends. From the contours captured it is evident that in the front end of the car there is an increase in the static pressure. There is a decrease in the pressure from the top of the vehicle to the end part of the vehicle. From the velocity contour plots, it can be seen that the speed of the air exiting the vehicle through the diffuser is having a higher speed than what it is in the front and the mid-section of the underbody of the car. According to the theories explained in [10], such a difference in the airstream velocity tends to develop a negative pressure in the lower part of the car which is the underbody. This creates a vacuum and thus pulls the car lower to the road thereby increasing the aerodynamic efficiency and stability. The same thing (pressure drop) can be seen in the pressure contour plots in figure 21. In addition to the velocity and pressure differences, many other things have been observed.

From the pictures of the velocity contours in figure 20, it can be seen that the wake produced is inversely proportional to the angle of the diffuser. In the contour plot captured at 0 degrees, it can be seen that the airstream flow is not meeting anywhere in the part of the screenshot. Going ahead, it can be seen that as and how the angle of the diffuser increases the airstreams are converging behind the vehicle and the best converging streamlines can be seen at an angle of 25 degrees. The same can be seen in the corresponding streamline plots in figure 20. Now since we have examined the contour plots it is important to evaluate the results so that it can be determined which angle will be suitable for what speeds and conditions.

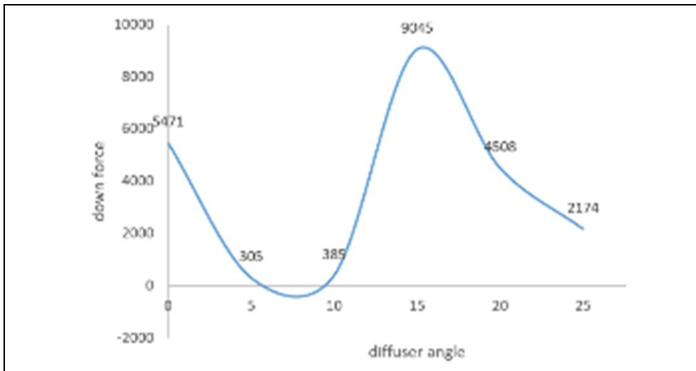
Let us first take into consideration the downforce and the corresponding coefficients. Below are the table and the graph showing the values captured during the analysis.

C. Downforce values

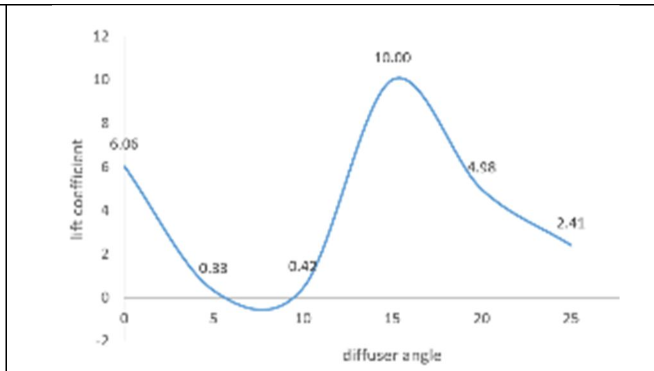
Table 3

Diffuser angle	Downforce (N)	coefficient
0	5471	6.06
5	305	0.33
10	385	0.42
15	9045	10.00
20	4508	4.98
25	2174	2.41

Table 4



Graphical representation of the downforce produced.



Graphical representation of the coefficient of downforce

Figure 7

From the graphs, it can be inferred that when the angle of the diffuser is 0 degrees the value of the coefficient is high and keeps decreasing. But a very important aspect can be seen that the value of the downforce between the angles 5 and 10 is showing a negative value which means that instead of producing downforce it is producing lift. In such a case it becomes dangerous for the car and its occupants. In such cases, there will be a lack of traction felt which will deteriorate the stability of the car. Though from the angle of 10 degrees there is an exponential increase in the value of the force seen. This is actually a positive sign, this clearly means that the angle between 10 and 15 degrees can be used when there is heavy acceleration encountered. This will provide optimum traction and stability. It can be seen that the values at the diffuser angle of 15 degrees are having the highest downforce magnitude so this angle can also be used while going through corners at high speeds. It will provide great grip levels and the car will not shift from its track. However, after 15 degrees the value of the downforce gradually decreases as the angle of the diffuser increases above 15 degrees. How can we use this decreased value of the downforce can be concluded after seeing the values of the drag force and the corresponding coefficients.

D. Drag force Values

Table 5

Diffuser angle	drag force (N)	drag coefficient
0	243	0.08
5	603	0.7
10	595	0.69
15	3530	4.07
20	3492	4.02
25	1209	1.42

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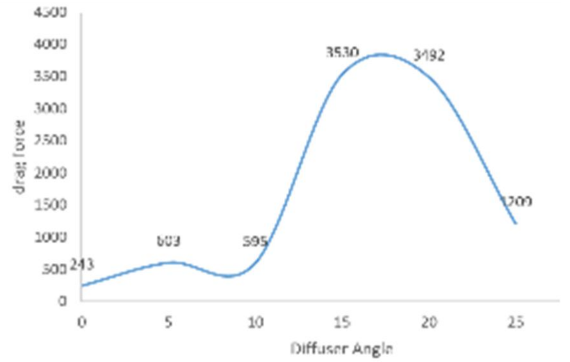
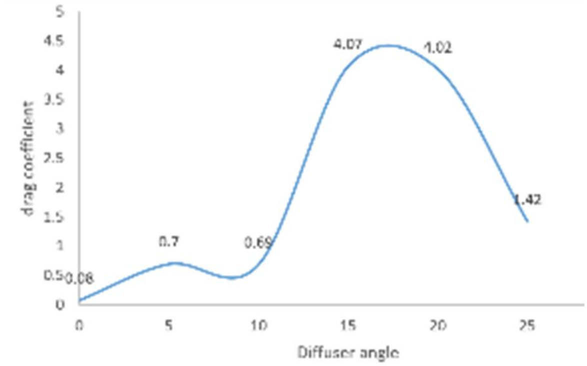
Table 6





Graphical representation of the drag force produced.	Graphical representation of the coefficient of drag force.

Figure 8

The drag force also follows the same fashion as the downforce but after the diffuser angle is 10 degrees. It can be seen that the drag values are significantly less before the angle of the diffuser is 10 degrees. Then there is an exponential increase seen in the value. But, one aspect that has definitely aided here is that the drag values decrease after reaching the peak at 15 degrees. So as said earlier let us now compare both the graphs by overlapping them and see how it helps.

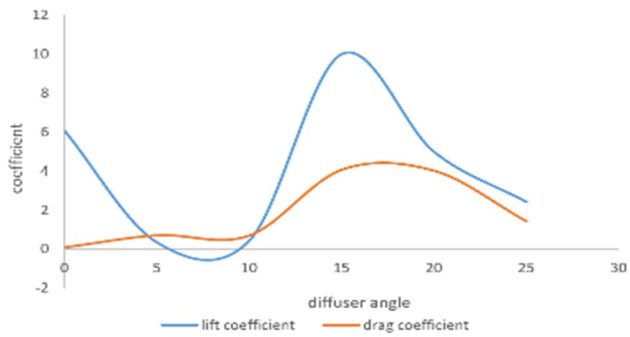


Figure 9

In this graph, it can be seen that the value of both, the drag and lift coefficients are decreasing after the diffuser angle is increased from 15 degrees. These are the angles that can be used when cruising at high speeds. It is not necessary to have as high as ones captured at a diffuser angle of 15 degrees. It is a fact, that for cruising at high speed if the downforce is high it will actually tend to slow the car and also aid in increasing the drag. Now the question is to use the adverse aerodynamic forces to stop the car faster. It can be seen that the peak drag force is recorded at around where the diffuser angle is 17 degrees. So when emergency braking is done this high value of the drag force will tend to push the car backward and the high values of the downforce will push the car towards the ground which will increase the traction and grip immensely thereby stopping the car faster maintaining its track. But, rather than relying on a high value of drag, it would be much better to use the wake produced behind the car. One disadvantage that could be faced at 17 degrees is that the wake produced behind the car would be less. The picture below was presented by [10].

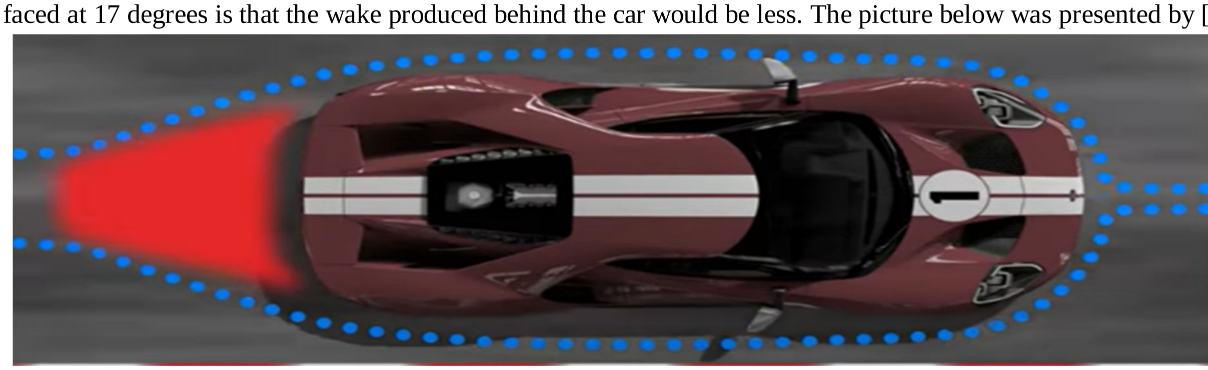


Figure 10

By presenting this image the presenter states that the wake produced behind a vehicle creates a low-pressure region behind the car. As a result, that change in pressure tends to pull the car backward and slows it down. Therefore, it would be more advantageous to use the wake for the adverse effects of the aerodynamics for more efficient braking. Hence the angle of the diffuser that has to be used while braking is 0 degrees.

So now for an intermediate conclusion, it can be said that:

1) The active diffuser will only come into the picture when the car will cross a speed of 40kmph as the aerodynamics matter only after this baseline speed.
2) The default setting of the diffuser angle when the car is traveling at a speed of 40kmph or slower will be 10 degrees.
3) When there is heavy acceleration experienced. That is when the car will be accelerated from 40kmph to 100kmph the diffuser angle will gradually be changed from 10 degrees to 15 degrees.
4) After the car reaches cruising speed which is above 100kmph the diffuser angle will between 15 degrees and 25 degrees. And once a speed of 120kmph is reached the diffuser angle will remain static at 25 degrees.
5) When brakes are applied the diffuser angle will immediately change to 0 degrees and then will gradually decrease with respect to the speed of the car.

Now we have just understood the effects of angle on the aerodynamic forces acting on the car. But now it is time to make this diffuser an active diffuser by giving it some electronics.

E. Hardware Design

To design the circuit, it is important to first know all the components that are going to be used to develop the circuit. There are mainly 4 electronic devices that I will be using to make the circuit.

1) Microcontroller/developing board
2) Potentiometer
3) Slide switch
4) DC servo motor

F. Micro-controller ATmega328P:

It is a single-chip microprocessor having the capabilities of storing a memory of 32 KB. It is equipped with 32 general-purpose working resistors, internal and external interrupts, 3 flexible timers with compare modes, serial programmable USART, 6 channel 10-bit analog to digital converter, byte-oriented 2-wire serial interface, five software selectable power saving modes, and programmable watchdog timer with an internal oscillator [11].

G. Technical Specification

parameters	Value
CPU type	8-bit AVR
Performance	20 MIPS at 20 MHz
Flash memory	32KB
SRAM	2KB
EEPROM	1KB
Pin count	28 or 32 pins
Maximum operating frequency	20MHz
Number touch channels	16
Hardware Qtouch acquisition	No
Maximum I/O pins	23
External interrupts	2
USB interface	No
USB speed	-

Figure 11

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
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H. Potentiometer

This is not a component that will be used in an actual circuit. In this circuit, it is just used so that the demonstration of the speed can be done. The slider of the potentiometer will be moved to alter the speed of the car and the value will be displayed on the serial monitor of the software.

I. Slide Switch

This is also a component that is not going to be used in an actual circuit which will be installed in the car. Here in this circuit, the function of the slide switch is to mimic that the brakes have been applied. If the slide switch is on it means that the brakes are applied and if it is in off position it means that the brakes are not applied.

J. Block Diagram

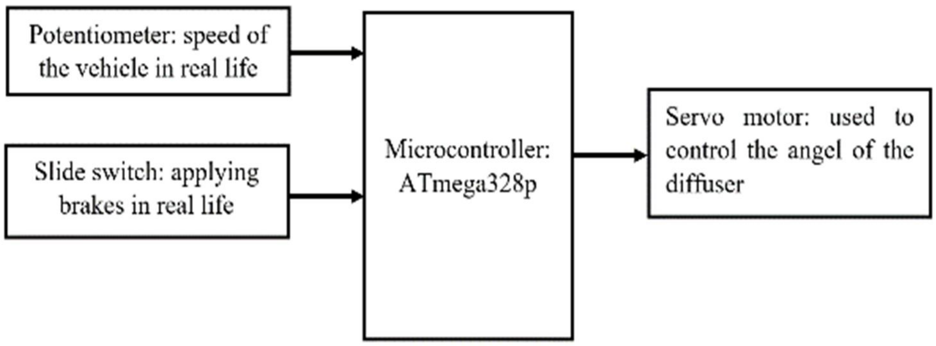

Figure 12

K. Functional program flowchart

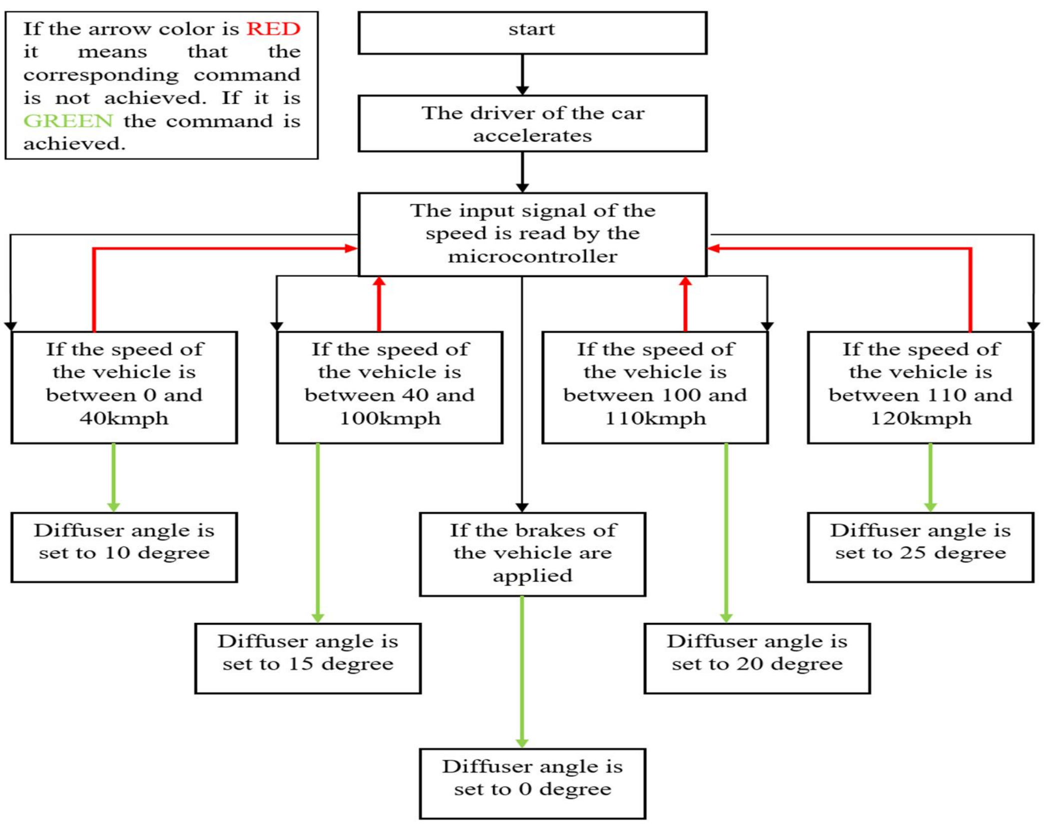

Figure 13

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L. Results of the Electronic Circuit

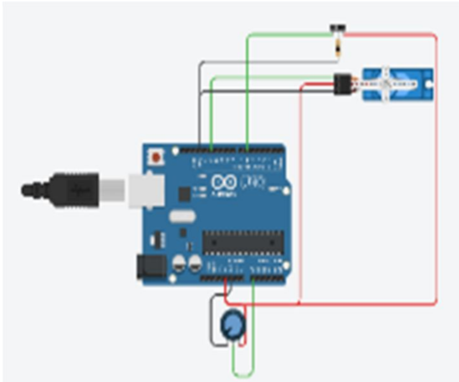

Figure 14

This is the image of the circuit before the inputs have been assigned. Let us now see how the angle of the diffuser changes with respect to the speed. The potentiometer used in the circuit is used to give the input values of the speed.

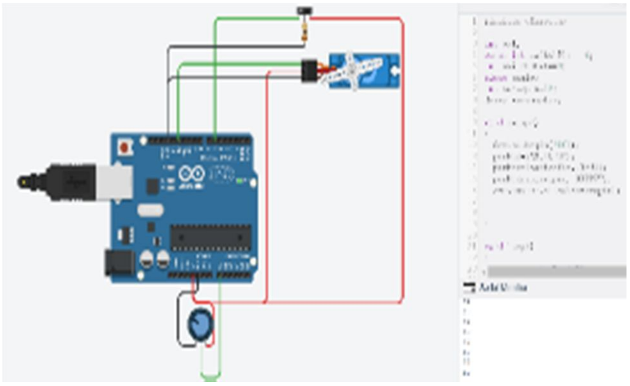

Figure 15

In this picture, it can be seen that the speed of the car is set just below 40kmph. In the intermediate conclusion, it was said that the angle of the diffuser at speeds of 40kmph or less should be 10 degrees. By comparing the angles in Figures 29 and 30 it can be seen that the angle of the servo motor has changed slightly. Here the angle is set at 10 degrees.

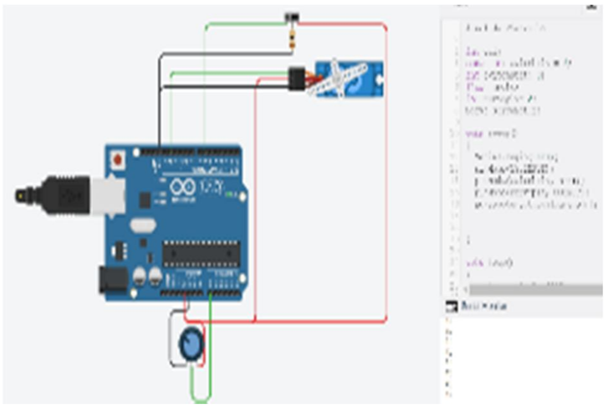

Figure 16

In figure 31 it can be seen that the speed is slightly above 40kmph. In the intermediate conclusion, it was said that the angle of the diffuser at speeds between 40 and 100kmph should be 15 degrees. By comparing the angles in Figures 30 and 31 it can be seen that the angle of the servo motor has changed slightly. Here the angle is set at 15 degrees.

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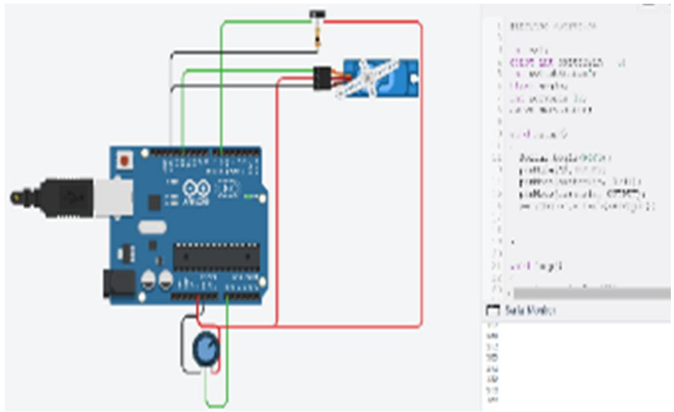

Figure 17

In figure 32 it can be seen that the speed is slightly above 100kmph. In the intermediate conclusion, it was said that the angle of the diffuser at speeds between 100 and 110kmph should be 20 degrees. By comparing the angles in Figures 31 and 32 it can be seen that the angle of the servo motor has changed slightly. Here the angle is set at 20 degrees.

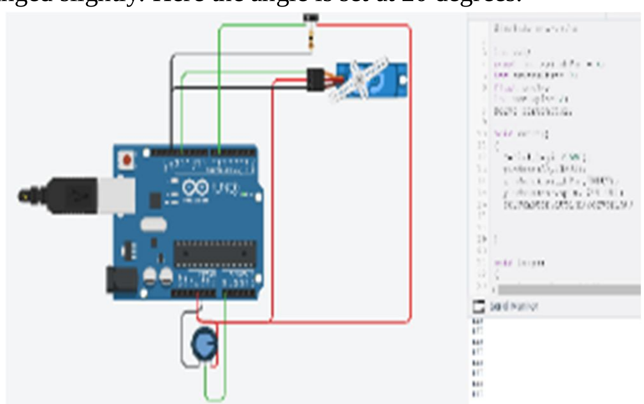

Figure 18

In figure 33 it can be seen that the speed is slightly above 120kmph. In the intermediate conclusion, it was said that the angle of the diffuser at speeds 120kmph and above should be 25 degrees. By comparing the angles in Figures 32 and 33 it can be seen that the angle of the servo motor has changed slightly. Here the angle is set at 25 degrees.

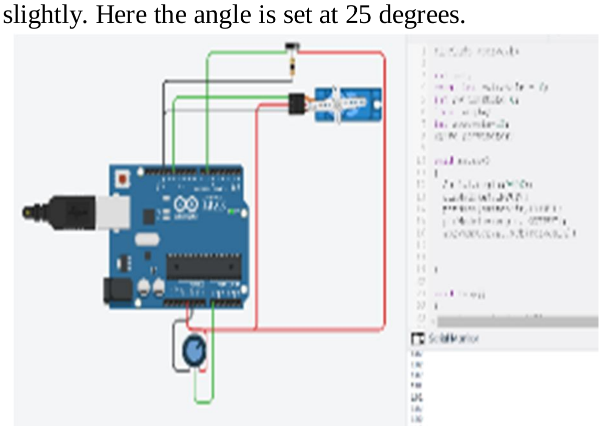

Figure 19

In figure 34 it can be seen that the speed of the car is set at 102kmph, but, the position of the slide switch has been changed when compared to the position in figures 29, 30, 31, 32, and 33. This position of the slide switch indicates that the brakes have been applied. As said in the intermediate report, when the brakes are applied the diffuser angel has to be set to 0 degrees as a lot of wakes was produced behind the vehicle which could be seen in figure 20.

VI. CONCLUSION

In this study, an active rear diffuser is designed. Initially, after doing the literature review the design was created and analysis was done on cloud-based software. This device was proposed so that the aerodynamic forces acting on the vehicle can not only be used for better stability at higher speeds, but also for using the adverse effects of the forces acting for better braking thereby reducing the stopping distance. With the help of the CFD analysis, first, the effects of the angle of the diffuser on the downforce and the drag were understood and evaluated. Based on the results captured further steps were taken. Just doing the CFD analysis was not enough to tell that the proposed diffuser was adaptive. However, it can be stated that with the help of the CFD analysis it can be analyzed, what angle will be suitable for what conditions, to actually make an active diffuser it was important to design a fully automated electronic circuit using a developer board, sensors, and actuators. The circuit was programmed according to the results captured from the CFD analysis and the results were presented. Now that the circuit was designed and was an operation on its own it can finally be said that an Active Rear Diffuser is Designed. Finally, after all the analysis the following conclusion can be made:

A. When the car will be traveling at a speed of 40kmph or less the angle of the diffuser will be set to 10 degrees. This conclusion was made based on the values of the drag and the downforce produced at the stated angle in figures 22 and 23. Such a conclusion was drawn because the value of the downforce and the drag were significantly less when compared to any other angle. According to the theories aerodynamics of a vehicle only come into the picture when the vehicle is traveling at a speed of 40kmph or higher. Since it did not have such a positive significance it was rather decided to have a diffuser angle producing a lower drag and downforce.

B. The next condition set for the angle of the diffuser was that at a speed of 100kmph the angle of the diffuser has to be set at 15 degrees. There was an exponential increase in the value of both the downforce and the drag force. This was decided because generally the speeds between 40kmph and 100kmph experience heavy acceleration. In conditions of heavy acceleration, it is important that the car maintains its track and gets an ample amount of traction. Keeping this in mind it was decided to have an angle of 15 degrees as it can be seen the figures 22 and 23, the value of the downforce peaks at an angle around 15 degrees.

C. After the speed of 100kmph is crossed, the speeds above are called cruising speeds. At such speeds having a very high downforce is not very important as it has adverse effects on the speed of the car. It can be seen the figures 22 and 23 that after the peak values are recorded at 15 degrees the magnitude starts decreasing. That means that the drag faced by the car reduces which is perfect for high-speed cruising. Keeping this phenomenon in mind it was decided to gradually increase the angle of the diffuser from 15 degrees to 20 degrees in proportion to the speed when the speed increases from 100kmph to 110kmph. The same case is followed for the speeds between 110kmph and 120kmph. The angle of the diffuser gradually and proportionally increases with respect to the speed. Well, the values of the drag and downforces were not the only parameters based on this conclusion was made. The wake produced behind the car also played an important role. In figure 20 it can be seen that the wake produced behind the car is the least when the diffuser angle is 20 and 25 degrees. The streamlines are converging.

D. The last conclusion brought about was for deciding the angle which was supposed to be used while braking. For braking having a high value of downforce, drag force and the wake produced play an important. Out of these 3 parameters, using downforce and the wake produced was given more importance for deciding the angle of the diffuser for braking. The angle selected was 0 degrees. This was decided as the values recorded in figure 22 show that the downforce produced by the car is very high. Along with the downforce it can be seen in figure 20 that the wake produced behind was obnoxiously very high which created a negative pressure behind the car. This negative pressure will further tend to pull the car backward, thereby reducing the stopping distance.

REFERENCES

[1] K. Jory and S. Anbalagan, Computational drag analysis in the under-body for a sedan type car model. 2013, p. 770. doi: 10.1109/ICEETS.2013.6533481.
[2] K. Song et al., "Aerodynamic design optimization of rear body shapes of a sedan for drag reduction," Int. J. Automot. Technol., vol. 13, Oct. 2012, doi: 10.1007/s12239-012-0091-7.
[3] X. Hu, R. Zhang, J. Ye, X. Yan, and Z. Zhao, "Influence of Different Diffuser Angle on Sedan's Aerodynamic Characteristics," Phys. Procedia, vol. 22, pp. 239–245, 2011, doi: 10.1016/j.phpro.2011.11.038.
[4] S. O. Kang et al., "Actively translating a rear diffuser device for the aerodynamic drag reduction of a passenger car," Int. J. Automot. Technol., vol. 13, no. 4, pp. 583–592, Jun. 2012, doi: 10.1007/s12239-012-0056-x.
[5] K. Jory and A. Satheesh, "Computational drag analysis in the under-body for a sedan type car model," in 2013 International Conference on Energy Efficient Technologies for Sustainability, Nagercoil, Apr. 2013, pp. 765–770. doi: 10.1109/ICEETS.2013.6533481.

[6] S. Dasgupta, “Everything about active aerodynamics in the new Porsche 911 Turbo S,” https://auto.hindustantimes.com, Apr. 18, 2020. https://auto.hindustantimes.com/auto/news/everything-about-active-aerodynamics-in-the-new-porsche-911-turbo-s-41587184400841.html (accessed Nov. 09, 2020).

[7] “New 911 Turbo S: the ideal aerodynamic setup for every driving situation,” Porsche Newsroom. https://newsroom.porsche.com/en/2020/technology/porsche-active-aerodynamics-911-turbo-s-20497.html (accessed Nov. 09, 2020).

[8] “Active Aerodynamics: the most extreme hypercar heroes,” WhichCar. https://www.whichcar.com.au/features/active-aerodynamics-the-most-extreme-hypercar-heroes (accessed Nov. 10, 2020).

[9] “K-omega SST | Global Settings | SimScale Documentation,” SimScale. https://www.simscale.com/docs/simulation-setup/global-settings/k-omega-sst/ (accessed Apr. 05, 2021).

[10] Arun Panwar, How The Ford GT Was Aerodynamically Designed | The Car Design Show, (Jul. 07, 2020). Accessed: Apr. 08, 2021. [Online Video]. Available: https://www.youtube.com/watch?v=3vVimm3y4Ig

[11] “ATmega328,” Wikipedia. Aug. 16, 2020. Accessed: Nov. 28, 2020. [Online]. Available: https://en.wikipedia.org/w/index.php?title=ATmega328&oldid=973252504