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Research article

Comparative Study and Design of outer body drag of Conventional Side-View Mirror and Vortex Side Camera using CFD

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ABSTRACT

The purpose of this paper is to design a vortex-shaped side camera and to investigate the effect of this shape on reducing the external body drag on the side mirror of a sedan vehicle using CFD. With the recent increase in competition in the automobile sector, aerodynamically induced drag affects the performance of the vehicle due to the change in parameters such as drag and lift forces, which play an important role at high speeds. The side mirror, an important part of the vehicle outer body, not only provides better visibility but also be aerodynamically optimized to achieve better fuel efficiency. Therefore, we have designed a vortex shaped side camera for urban passenger cars, which is not only aerodynamically optimized, but also provides a wide viewing angle and better visibility even in bad weather. We also conducted a comparative study of the drag coefficient of side camera and the conventional side mirror using the CFD tool. The geometries of the camera, the side mirror and the vehicle outer body were designed in a 3D program namely CAD, that is Solid Works and the analysis CFD was performed using the Solid Works Flow Simulation tool. Since the side mirror is bulky and misshapen body, it has a large drag and reduces fuel efficiency. A Vortex shaped side camera provides better fuel efficiency and visibility while improving the mileage of the vehicle.

Keywords: Aerodynamics, drag coefficient, side mirrors, side view camera, wind tunnel, CFD analysis

Introduction

Automobile designers and engineers have been constantly engaged to optimize vehicle outer body design to reduce drag and aerodynamically induced since as early as the 1920s. With advancements in power train, suspension and electronics technologies, a vehicle's aerodynamic drag has become crucial in determining its competency. Outer body drag and unwanted affects speed, stability, and fuel efficiency.

The properties of the fluid flow around the parts, such as the mirror, the wheel, front and back design, play an important role in increasing aerodynamic drag. These parts should be designed regarding the fluid flow around the vehicle. To improve the aerodynamic performance of road vehicles, various drag reduction methods have been used. These methods can be classified as passive or active flow control methods. The most used and oldest drag reduction methods are passive flow control methods and do not consume external energy.

Side mirrors can be commonly found mounted onto the outside of vehicles. The side mirror functions as a visual aid to view the parameters of the car. Otten [1] conducted a survey and found the average frontal area of a pair of side mirrors consists of 2-3% of the overall frontal area. In running conditions of the vehicle, the side mirror contributes to the drag and of the vehicle. The side mirror only contributes to the drag when the velocity is greater than 60 km/h [2]. The solution is to design cameras using vortex generators shape and hence, decrease contribution in aerodynamic drag generation. Therefore, it is recommended to use cameras that are smaller in size than the side mirrors. Vortex shape side cameras are not only aerodynamically optimized but also provide better visibility even in bad weather and wide view angle.

Aerodynamic drag is the force opposing the forward motion of a moving vehicle. Viscous force is the main contributor to drag at lower velocities. Therefore, skin friction drag is the main source of aerodynamic drag in a vehicle at low velocities [3]. However, pressure drag is a main source of drag at cruising speeds. Pressure drag is present when a shape changes abruptly. Pressure drag at the front of a vehicle is found to be higher than the rear [4]. Aerodynamic drag can be reduced by streamlining of the body as it is highly dependent on an object's shape. Magazoni, et al. [5] found that the upper body of a vehicle experiences 45% of aerodynamic drag force. One of the components found in the upper body that contributes to drag is the side mirror. Turbulent wake is formed at the rear of the side mirror due to its shape. The total drag produced by side mirrors is 2-7% of the total drag of a vehicle [6]. Complex aerodynamic characteristics such as drag coefficient can be calculated using Eq. (1) in which FD can be obtained through experiments.

$$F_D = \frac{1}{2} C_d \rho A V^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1 Drag Force}$$

where, FD is the drag force, Cd is the drag coefficient, ρ is the density of air, A is the frontal area, and V is the velocity of the object. Batchelder [7] conducted research with a Smart for two on the different components which enhances the aerodynamic shape of the vehicle. The author studied side mirrors, stock style wheels, door handle, antenna and wheel well cover. The car was meshed using T-Grid and imported into FLUENT to conduct the simulation. The removal of the side mirror reduces the drag coefficient by 4.8%.

Buscariolo and Roshilho [8] considered the applications of side mirror removal and the implementation of outside rear-view cameras using CFD simulation. The research conducted focused on the drag coefficient in respect to the frontal areas of a car. Four cases were studied including car with mirror, without mirror, and two concepts of outside rear view camera housing. The turbulence model used was k-ε to establish pressure, wake profile and drag coefficient. The removal of side mirror and two implementation of camera installation reduce the drag coefficient by 1% and 0.4% respectively.

Ramdan and Lim [9] conducted a research to determine the fuel economy of a PeroduaMyvi within the city and on highways. MATLAB backward-facing discredited simulation was used to solve the fuel consumption of the vehicle. Experiments were physically conducted to compare with the results obtained numerically. The simulation shows an average error percentage of 13% as compared to the experiments conducted. The results obviously showed that the highway routes produce a better fuel economy as it travels constantly at a cruising speed. Similarly, Alam and Mahmood [10] analyzed the effect of side view mirror on fuel efficiency. Two types of mirror geometry were considered, a 13-cm diameter flat back and hemispherical back mirror. The drag coefficient was solved analytically travelling at an average speed of 60 km/h and 120 km/h. The hemispherical back mirror produces a lower fuel consumption which saves 7.33 and 29.3 liters of petrol a year respectively.

Duygu [11] studied the drag coefficient of a bus with classic side mirror was found to be 6.6% higher than the bus without mirror it was determined that using a camera instead of the side mirror decreased the friction coefficient by 3.45%.

Design of Vortex shape side Camera

Under the name "Vortex shape", that means the design of our model is based on the ideology of vortex generates that are used to avoid from separation region; these are very much effective in aerodynamics as well as for sound proofing. Side cameras are being use to replace the side view mirrors which has huge effect on increasing drag force, the design of vortex shape side camera and its place of use are both inspired from the side instigator and small sharp vortex horizontal vortex generators on side doors.

This design has 3 components one is for protective shield on upper side, second is the instigator light and third is the cavity where the camera is fixed and provides batter visualization in rainy days and large angle. The design is more similar to shape of wing and all its parameters are mention in table below;

Sr. No	Description	Dimensions
01	Total Length	200.93 mm
02	Total Wirth	49.61 mm
03	Total Hight	67.23 mm
04	Angle of Attack	119.87°
05	Front inclined length	88.89 mm
06	Back inclined length	154.27 mm

Table 1: Dimensions for camera design

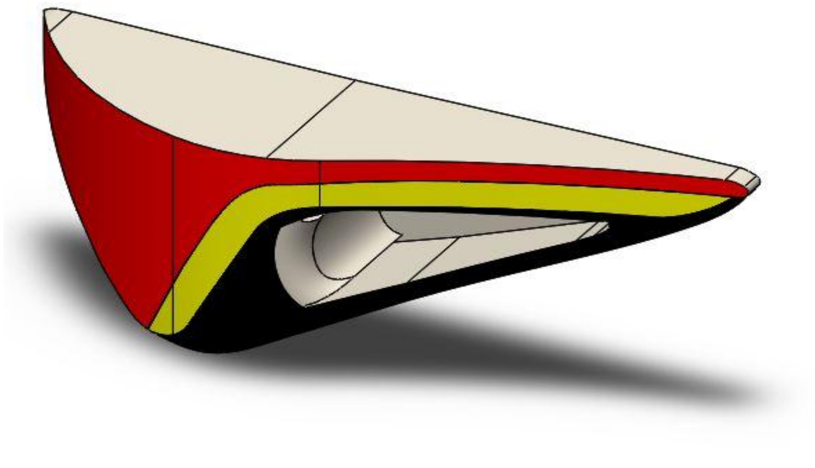


Figure 1: Isometric view of camera design

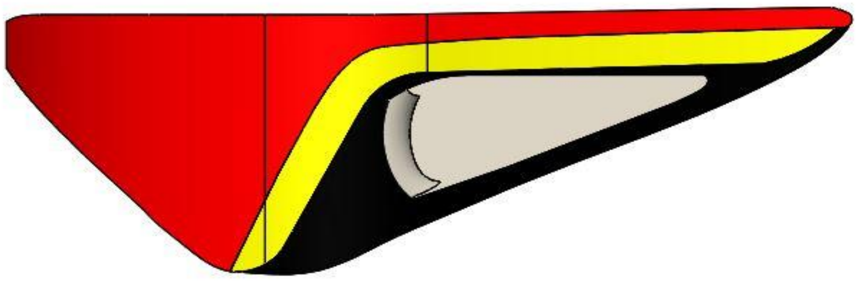


Figure 2: Front view of Camera

Selection of vehicle Model

There are many types of vehicles specially in car category it may be Hatch back, Sedan, MPV and SUV etc. The camera designs we make are suitable for each category just to remove side view mirrors and replace with side cameras. We choose sedan car this is the family passenger car and this type of category is about 70% in Pakistan that is why we are stick with this category. The car model which we are using is 6^{th} generation which is the best sealing car around the world. We took all views of car model from its official website, we did not any part of car and the mirrors which are using is of standard size which are then analysis in CFD analysis and after that they are replaced with the side cameras.

The car model is made of the same material which are officially using in manufacturing and the standard material for side mirrors. These are analyzed on global standards.

The design of car is made from its views which are already been made in past its all parameters are mention in below table;

Sr. No	Description	Dimensions
01	Total Length	4442 mm
02	Total Width	1694 mm
03	Total Hight	1477 mm
04	Wheel base	2600 mm
05	Ground Clarence	225 mm

Table 2: Dimensions for car model

The CAD geometry is formed by using views of already built car model. We use all views which are top, front, back and side, with these views we perform sketching of the outer body parts and then use surface common to extrude after that we use surface cut and surface knit common to make fill 3D model. The body modeled using Solid works 3D CAD surface modeler.

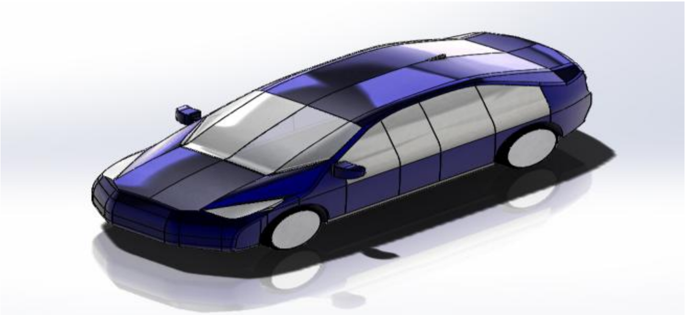


Figure 3: Isometric view of sedan car with conventional mirror

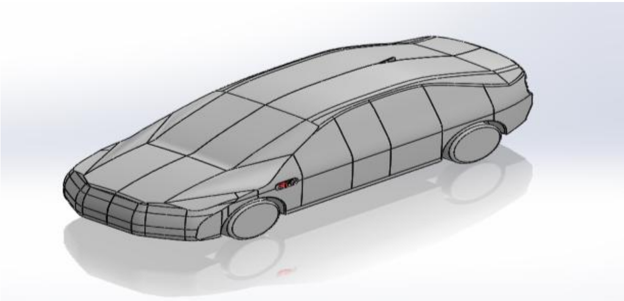
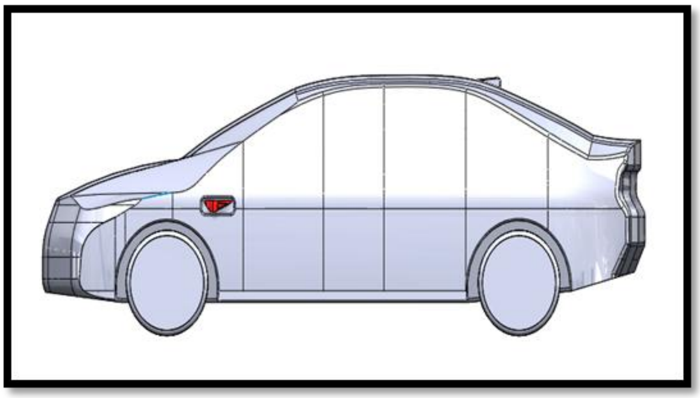


Figure 4 Isometric view of car model with camera placement

Camera Model Constrain

SR. NO	DESCRIPTION	DIMENSIONS
01	Total Length	200.93 mm
02	Total Wirth	49.61 mm
03	Total Hight	67.23 mm
04	Angle of Attack	119.87°
05	Front inclined length	88.89 mm
06	Back inclined length	154.27 mm



Methods

Flow analysis is carried out at different speed using of K epsilon turbulence model so in result drag force generates which is calculated using computational approach and after that we calculate numerically drag coefficient in which we are using ideal air density value, for area it will be the project area of bluff body and velocities are varies for different cases are explained in details below,

Mesh Generation

Mesh generated which is differing for model and wind tunnel and mesh size is reduced to get high approximation of the final results. For wind tunnel we used face mashing for equidistance cells. For the geometry we used default mesh due to the low power CPU and minimize the size of cells to get high approximation of results.

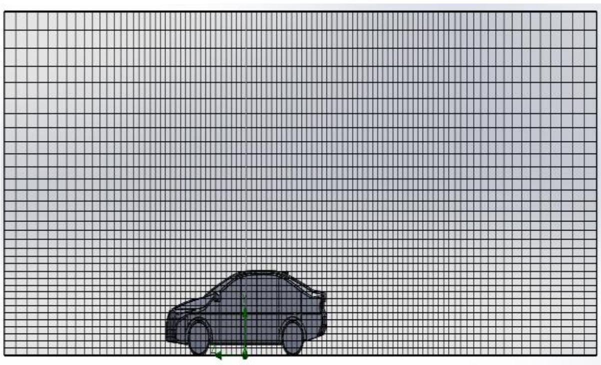


Figure 5: Complete mesh model

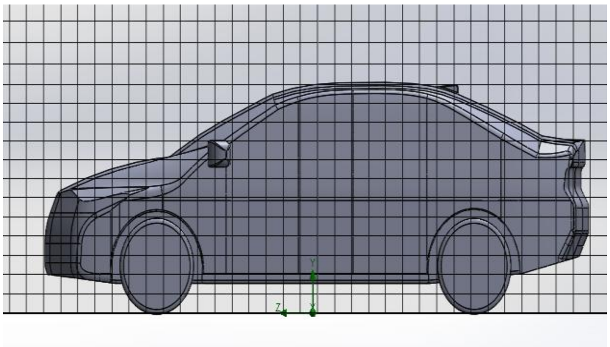
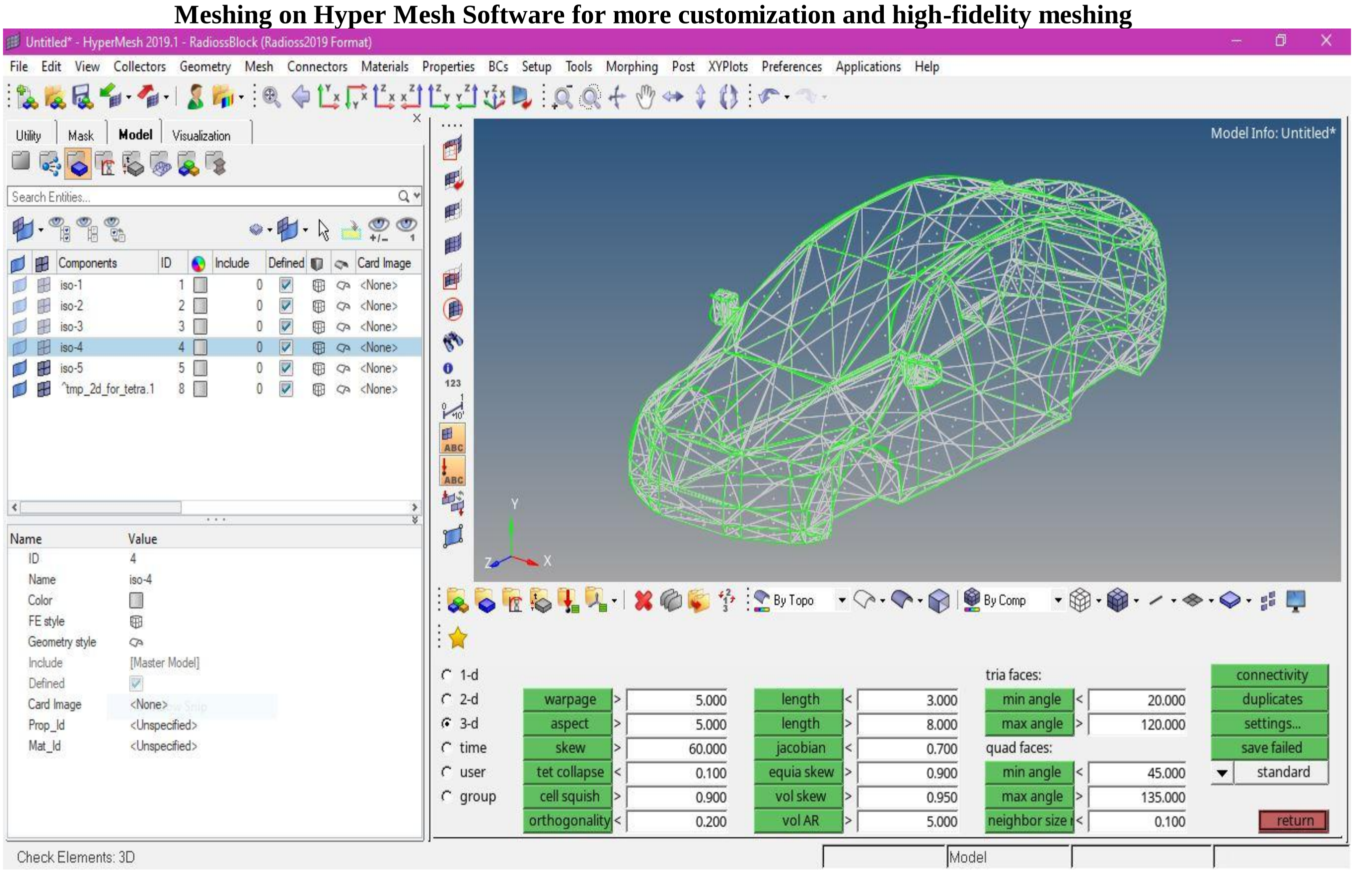
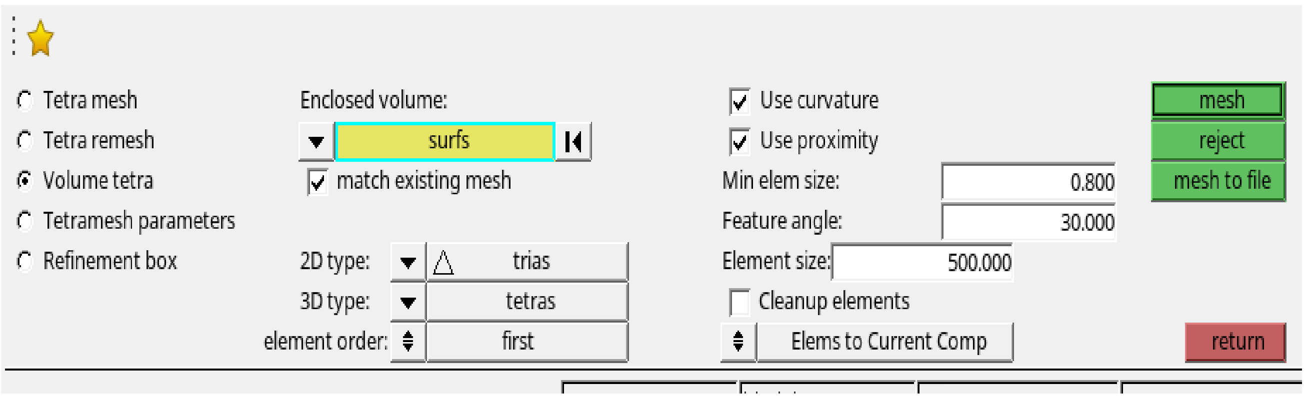


Figure 6: Close mesh car model

Meshing on Hyper Mesh Software for more customization and high-fidelity meshing



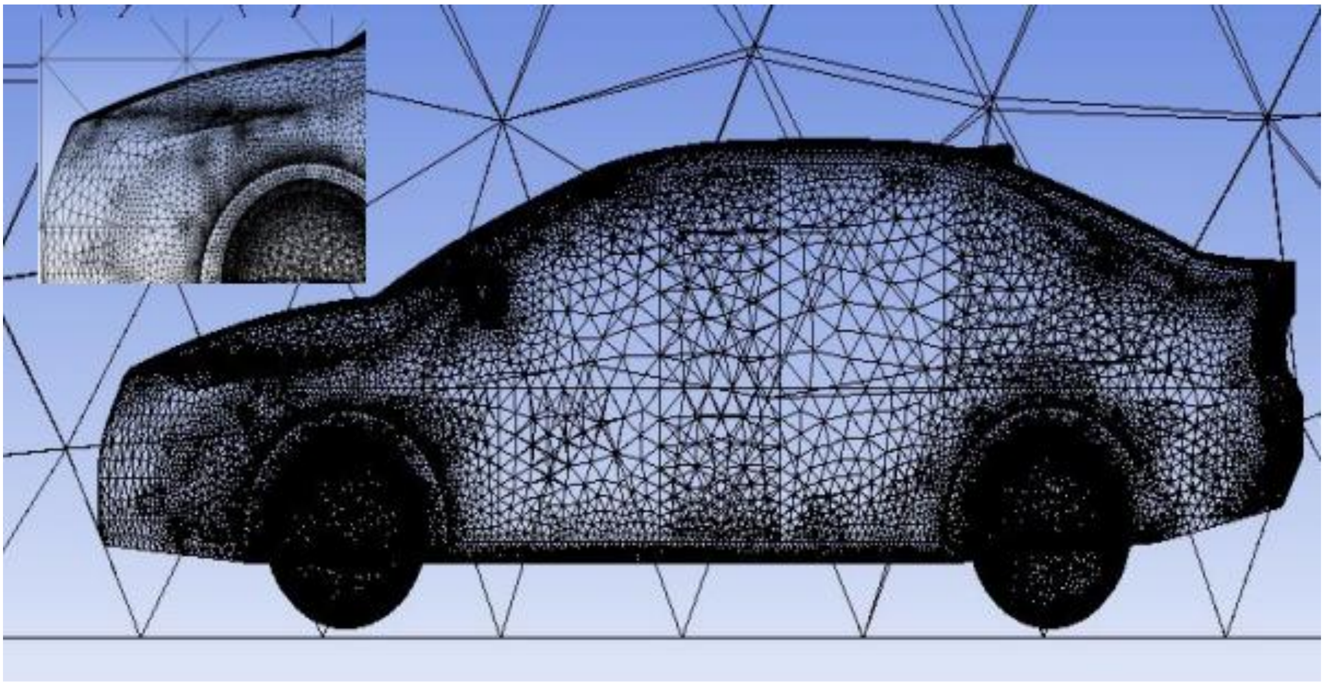


Meshing on Ansys

Mesh generated which is differing for model and wind tunnel and mesh size is reduced to get high approximation of the final results. For wind tunnel we are using face mashing for equidistance cells its nodes and elements are mention below in table. For the geometry we are using hyper mesh software mesh due to the low power CPU but we minimize the size of cells to get high approximation of results.

MESHING

SR. NO.	With Mirror	Without Mirror	With Camera
ELEMENT SIZE	500.0 mm	500.0 mm	500.0 mm
GROWTH RATE	1.2	1.2	1.2
SKEWNESS	0.9	0.9	0.9
NODES	446390	474098	488423
ELEMENTS	2403776	2550921	2632712



Boundary Conditions

The types of parameters that can be applied in fluid analysis are as follows:

Fluid use for analysis	Air
Velocity (Used for Inlet)	1) 23m/s, 2) 30m/s ,3) 33m/s, 4) 35m/s
Temperature	293.2K
Pressure	101325 Pa
Density	1.225 kg/m^3
Surface Roughness	0.5 micrometre
Wind Tunnel Walls	Adiabatic & No slip
Turbulence Intensity	5%
Outlet (pressure)	1 ATM

Table 3: Boundary conditions

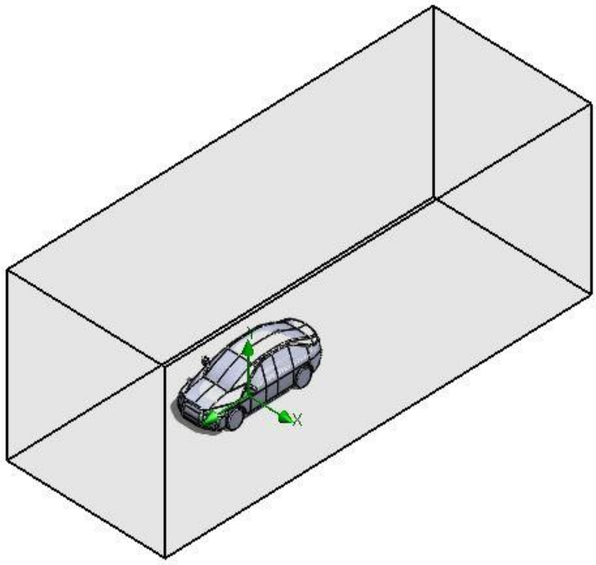


Figure 7: Wind tunnel

Along Z-axis force creates drag force which is parallel to model, also air flows through this path and Y-axis creates lift force which is perpendicular to model.

Axis	Length (L=1000mm)	Dimensions
(+) X	3L	3000mm
(+) Y	6L	6000mm
(+) Z	3L	3000mm
(-) X	3L	3000mm
(-) Y	0.03L	30mm
(-) Z	9L	9000mm

Table 4: Dimensions of wind tunnel

A high drag coefficient is cause by poor streamline of the body (mirror) profile so that there is a high air resistance when the vehicle is in motion. We have seen in calculation and different results due to side mirrors we have the high drag coefficient that generates the large eddies behind the mirror and the separation region.

The types of parameters that can be applied in fluid analysis are as follows:

Fluid use for analysis	Air	
Velocity	1) 23m/s	2) 30m/s
(Used for Inlet)	3) 33m/s	4) 35m/s
Temperature	293.2K	
Pressure	101325 Pa	
Density	1.225 kg/m^3	
Surface Roughness	0.5 micrometer	
Wind Tunnel Walls	Adiabatic	
Turbulence Intensity	5%	
Relative Humidity	50	

Inlet wall	Used for velocities which are 23m/s,30 m/s,33 m/s,35 m/s
Outlet Wall	Pressure of 1 ATM is given to outlet
Side Walls	No slip and adiabatic conditions are given

Walls	**BCs**
Inlet wall	Used for velocities which are 23 m/s,30 m/s ,33 m/s,35 m/s
Outlet Wall	Pressure of 1 ATM is given to outlet
Side Walls	No slip and adiabatic conditions are given

Drag Coefficient

A high drag coefficient is cause by poor streamline of the body (mirror) profile so that there is a high air resistance when the vehicle is in motion. We have seen in calculation and different results due to side mirrors we have the high drag coefficient that generates the large eddies behind the mirror and the separation region.

With Side mirrors			
Sr. No.	**Analysis Type**	**Drag Force**	**Drag Coefficient**
1	V = 23	271.406113	0.343422526
2	V = 30	461.1572564	0.342994853
3	V = 33	557.552707	0.342727756
4	V = 35	626.7245613	0.342484657
C_d Approximate Value = 0.34			

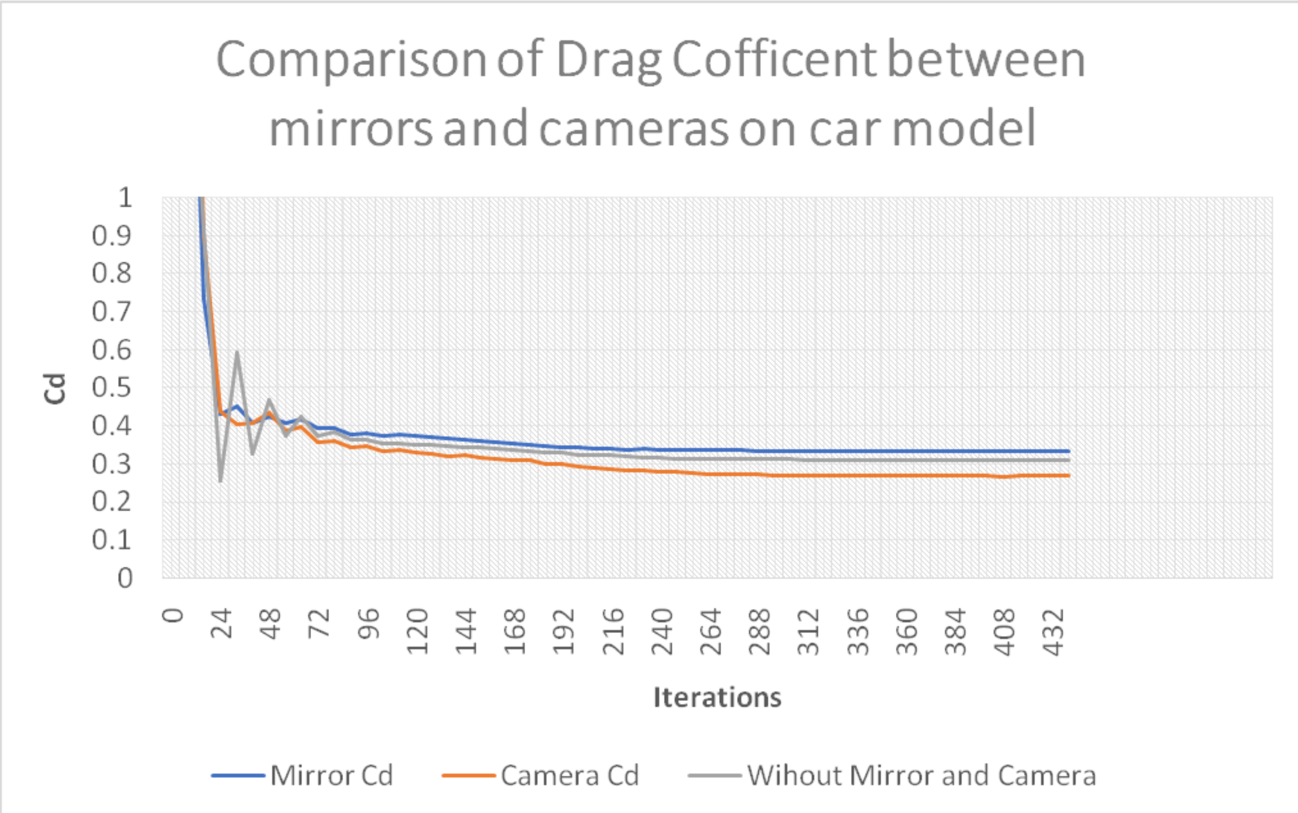
After removing side mirrors over a simple car model, we have decrease in the drag coefficient of 4.6% reduction, we get value of 0.30. We have seen in pressure and velocity distribution this car model is not much stable and also drag coefficient values are varies with speed that cause the instability.

Without Side mirrors and camera			
Sr. No.	**Analysis Type**	**Drag Force**	**Drag Coefficient**
1	V = 23	251.1390081	0.308524378
2	V = 30	430.3466853	0.310746994
3	V = 33	517.315983	0.308715901
4	V = 35	582.8174645	0.309191433
C_d Approximate Value = 0.30			

A low drag coefficient implies that the streamline shape of the vehicle's body is such as to enable it to move easily through the surrounding various air with the minimum of resistance.

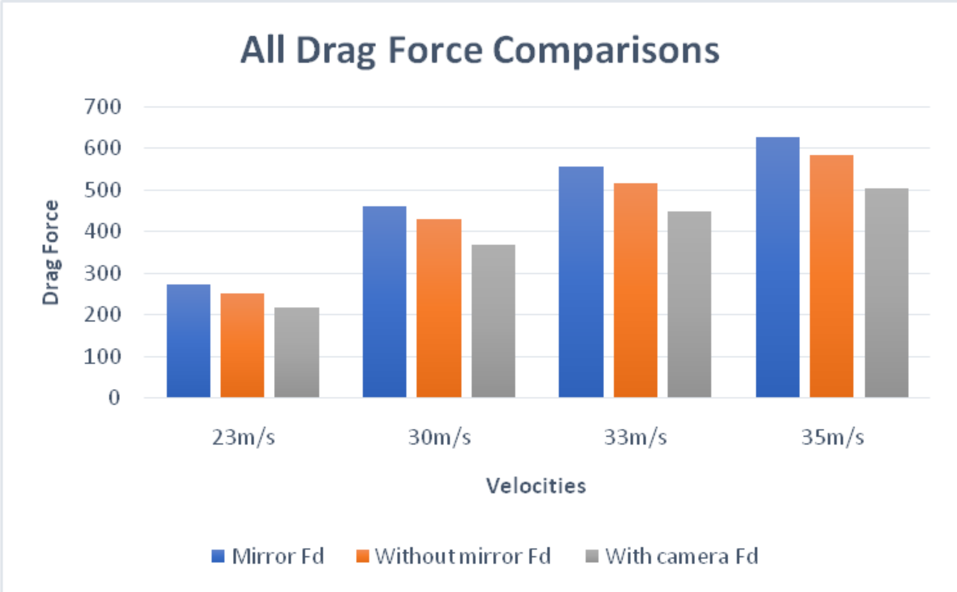
With side cameras			
Sr. No.	**Analysis Type**	**Drag Force**	**Drag Coefficient**
1	V = 23	218.4601746	0.268378417
2	V = 30	370.1057386	0.267247895
3	V = 33	448.579236	0.267696239
4	V = 35	504.4713627	0.267627916
C_d Approximate Value = 0.26			

Therefore, we have the stable handling because the design of vortex camera is based on VGs that convert turbulence flow into laminar flow which makes the car stable on sharp corners.



Drag Force

A low drag coefficient implies that the streamline shape of the vehicle's body is such as to enable it to move easily through the surrounding various air with the minimum of resistance. While high drag coefficient is cause by poor streamline of the body (mirror) profile so that there is a high air resistance when the vehicle is in motion. Therefore, same with case of drag force it shown in above equation drag force is directly proportional to drag coefficient ($F_D \propto C_D$) We know that the drag force is the opposing force and from the formula of drag force we know that if force increases then velocity also increase with its square ($F_D \propto v^2$).



CFD Analysis

CFD analysis is carried out in three steps which are with side mirrors, without side mirrors and with side cameras their results and observations values, calculated values and graph are mention below;

Flow analysis is carried out at speed of23m/s,30m/s,33m/s, 35m/s using turbulence model of K epsilon and the boundary conditions which are mentioned above so in result drag force generates which is calculated using computational approach.

Velocity Distribution

The velocity distribution is being taken from top view and it shows the cut section at the middle of side mirror. The various colorful regions show the velocity variation along the length hence it is very large as shown in figure below. It represents that using of these aerodynamics side mirrors and under high resistance of velocity treatment increases the velocity drop in car model.

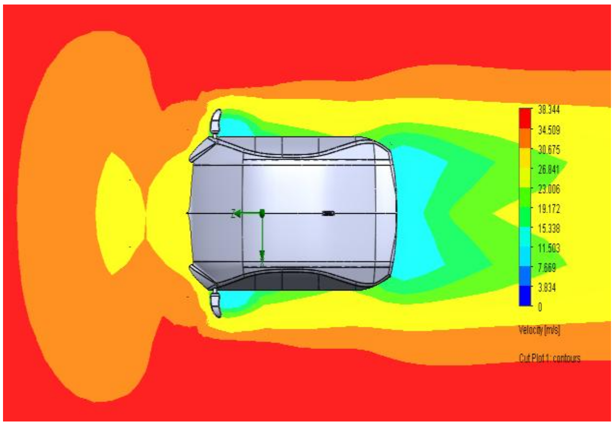


Figure 8: With Conventional mirror

The velocity distribution is being taken from top view and it shows the cut section at the middle of side mirror. In below figure the velocity distribution is much lower than simple car because we remove side mirrors which reduces the drag of 4.6%.

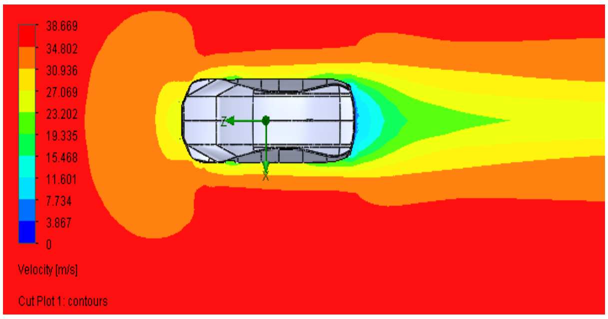


Figure 9: Without mirror and camera

The velocity distribution over a car model which have been modified by using smooth aerodynamic property of car. Here, the various colorful regions show the velocity variation along the length hence it is very small as shown in figure below, which is better than the simple car model. It represents that using of these aerodynamics vortex shape edges side camera and under low resistance of velocity treatment reduce the velocity drop over the simple car model.

The velocity distribution is being taken from top view and it shows the cut section at the middle of vortex side camera.

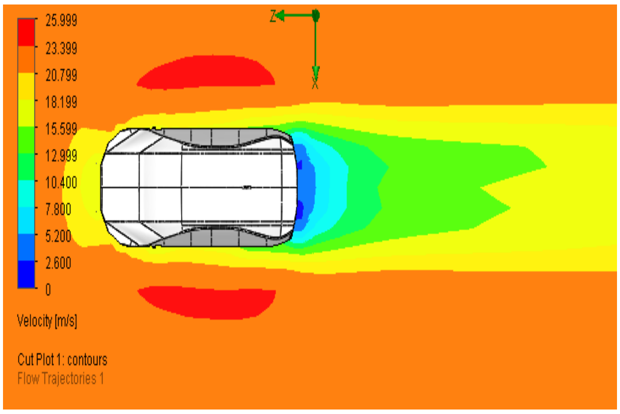


Figure 10: With vortex side camera

Pressure Distribution

Pressure distribution also analyzes by using surface plot distribution and observes the pressure variation on whole surface of the model. It represents that using of these conventional side mirrors results in reduces the pressure effect over the car model while side camera has less pressure effect over car model. Pressure distribution also analyses by using surface plot distribution and observe the pressure variation on whole surface of the model. The frontal red region of the car shown below in various colors.

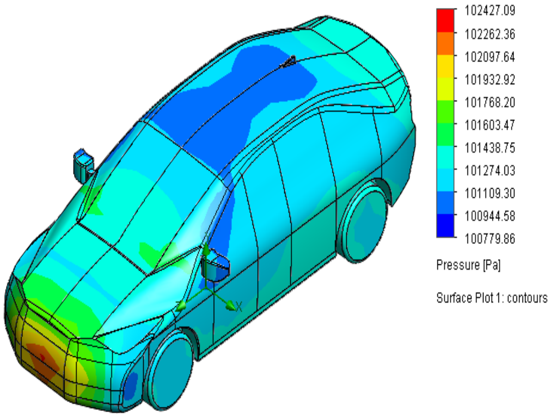


Figure 11: With conventional mirror

Pressure distribution analyses by using surface plot distribution and observe the pressure variation on whole surface of the model. In below figure the pressure distribution is much lower than simple car because we remove side mirrors so that the low-pressure region become minimize.

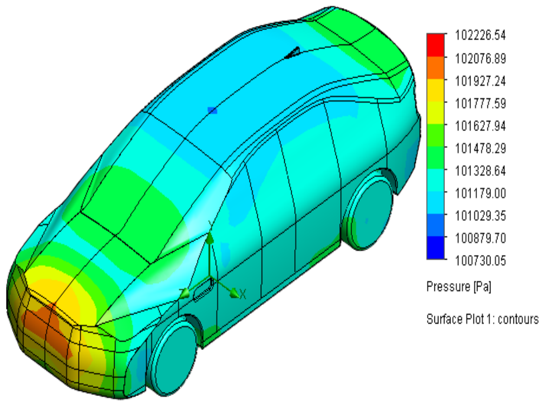


Figure 12: Without mirror and camera

The pressure distribution over a car model which have been modified by using smooth aerodynamic property over the car and the smooth curve vortex shape at side mirror of the car. It represents that using of these aerodynamics vortex shape edges side camera and under modified shape treatment reduces the pressure effect over the modified car model.

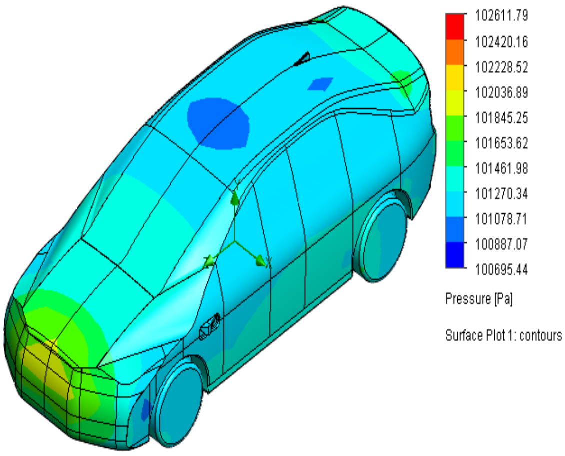


Figure 13: With vortex side camera

Flow

Flow distribution are analyzed using cut plots in middle of vortex side camera, in below picture we have seen that after the vortex side camera there is no separation region that generates vortex shading and unwanted mechanical vibration like in simple car model. Therefore, we have the stable handling because the design of vortex camera is based on VGs that convert turbulence flow into laminar flow which makes the car stable on sharp corners.

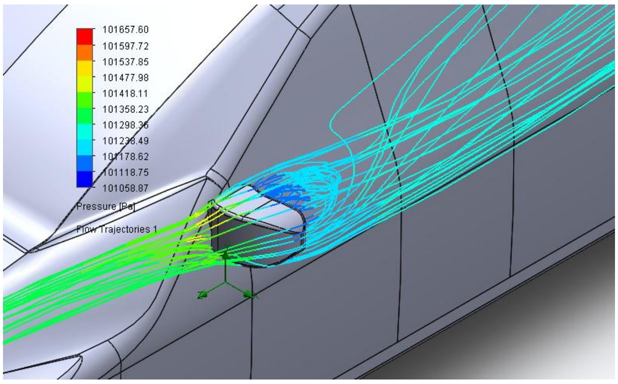
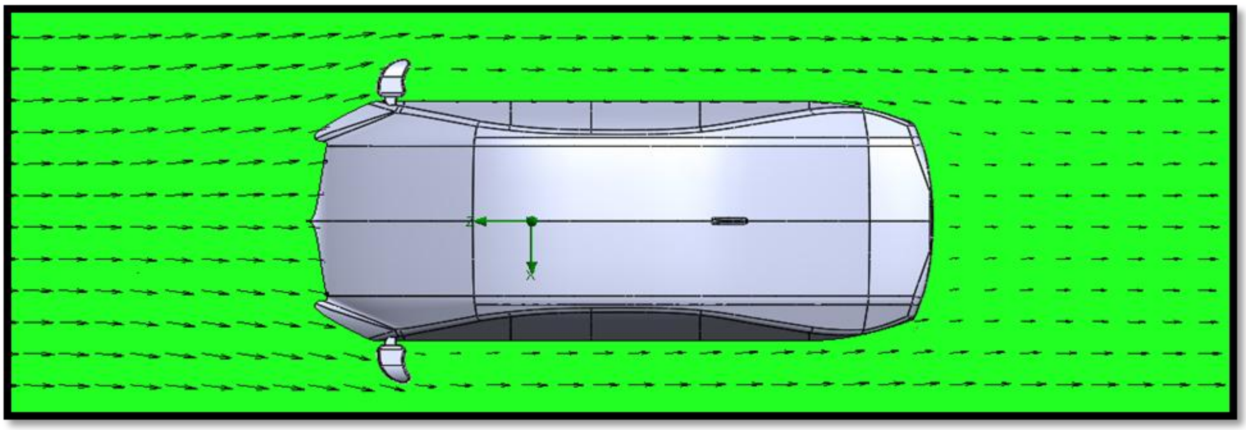


Figure 14: Mirror attached with car model

Now the flow trajectories are analyzed on separate vortex side camera (detach from the model) and the pressure and velocity flow variation are explained below;



Pressure variation also analyses by using flow trajectories and observe the pressure variation before and after the side camera.

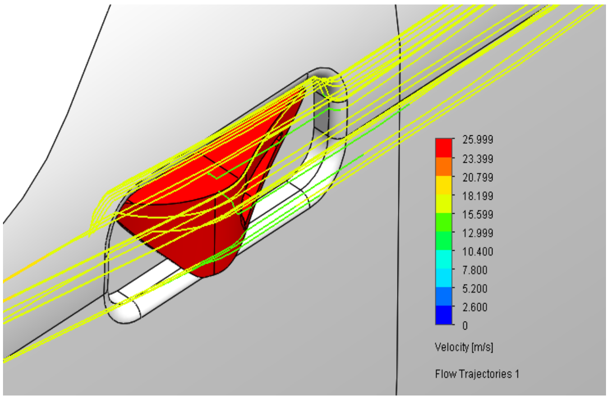


Figure 15: Camera attached with car model

Pressure variation also analyses by using flow trajectories and observe the pressure variation before and after the side mirror and camera without car model.

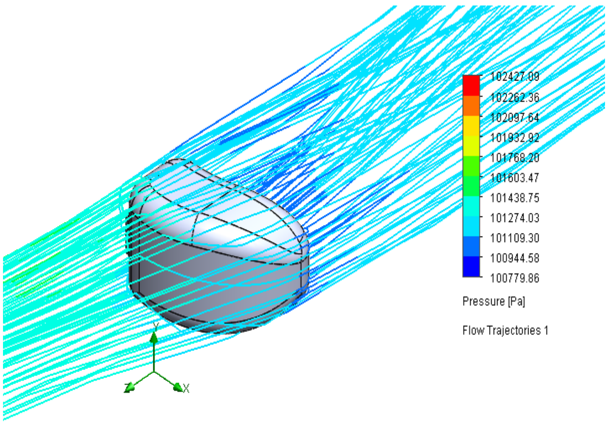


Figure 16: Mirror without car model

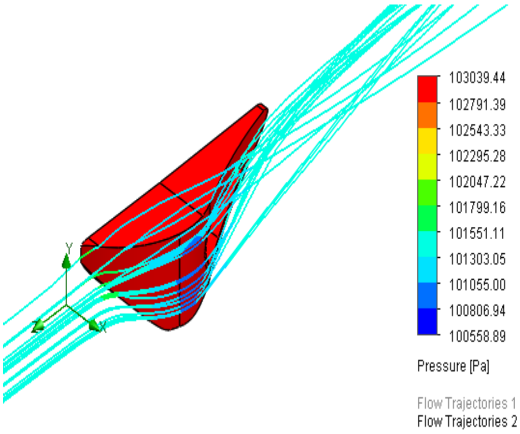


Figure 17: Camera without car model

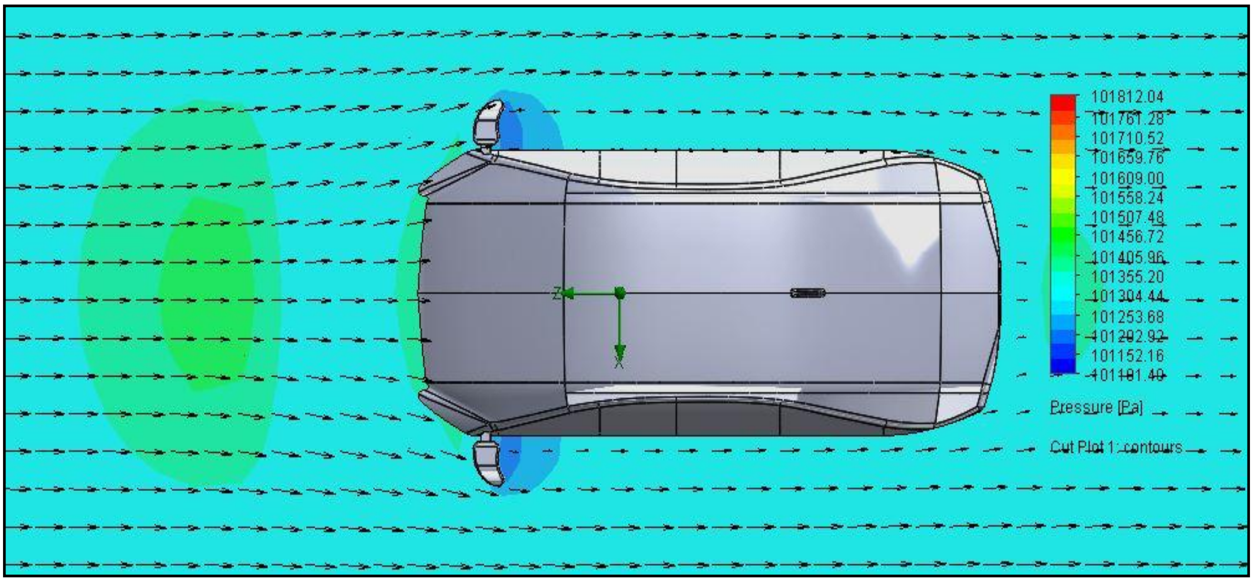


Figure 18: Top view of vehicle with side mirror showing wake region

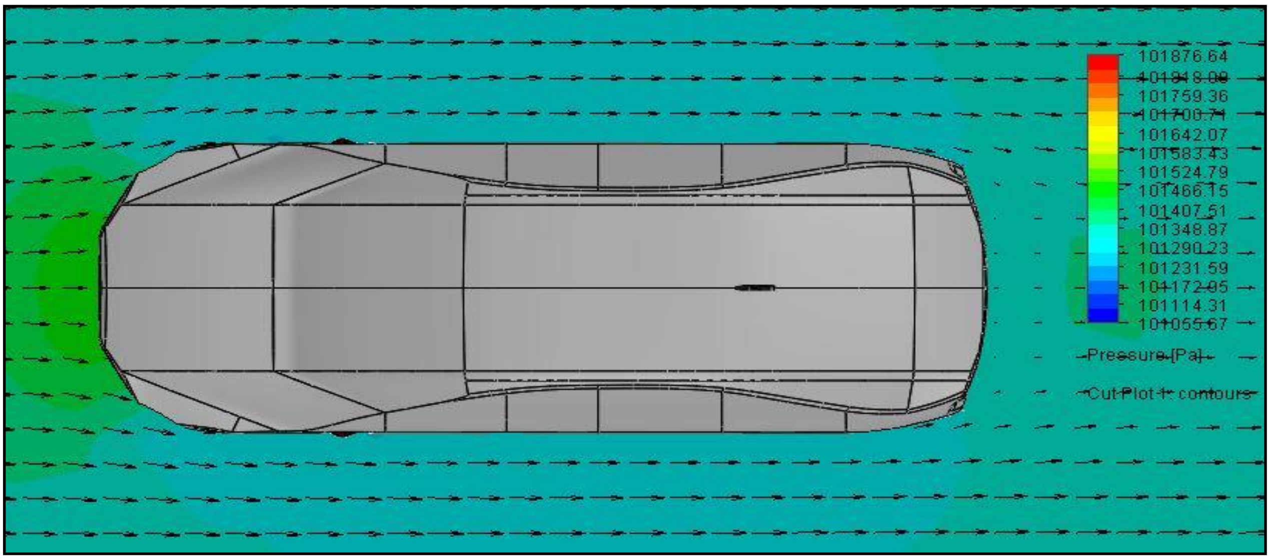


Figure 19: Top view of vehicle with vortex shape camera showing no wake region

Conclusions

In our study we concluded that decreasing the frontal area would decrease drag force. In this study, it is found that the side mirrors have a 4.8% influence of total drag. The removal of the side mirrors would help reduce fuel consumption. Therefore, we designed side camera system having vortex generator shape. When we did CFD simulation to study drag of those cameras, we came to know that overall drag is reduced by 0.8 as compared to bulky and bluff mirrors. And vortex shape side cameras are not only aerodynamically optimized but also provide better visibility even in bad weather and wide view angle.

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