International Conference on Mechanical, Industrial and Energy Engineering 2014
25-26 December, 2014, Khulna, BANGLADESH

ICMIEE-PI-140392

Effect of Location of Cambered Spoiler on Aerodynamic Characteristics of a Car

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ABSTRACT
In the present study, the effects of locations of Cambered Spoiler on aerodynamic stability of a car are investigated numerically. A car model and a cambered spoiler are designed in CAD software. Afterwards the spoiler is placed on the rooftop and rear position of the car. The CAD data is then analyzed in CFD software. The analysis shows that spoiler in rear position develops maximum down force than rooftop and thus increases road traction and stability of the car while driving. So, for efficient performance of the vehicle, spoiler placement at rear is well suited than rooftop.

Keywords: Cambered Spoiler, down force, lift force, drag force, stability.

1. Introduction

In general, aerodynamic is simply how air flows around a car, truck or airplane. The main concerns of automotive aerodynamics are optimizing drag, improving vehicle stability and preventing unwanted lift forces [1]. Having more power under the hood leads to higher speeds for which the aerodynamic properties of the car given by the designer are not enough to offer the required down force and handling. The performance, handling, safety, and comfort of an automobile are significantly affected by its aerodynamic properties [2]. Extra parts are added to the body like spoilers, lower front and rear bumpers, air dams and many more aerodynamics aids as to direct the airflow in different way and offer greater drag reduction to the car and at the same time enhance the stability. In spite of this, many aerodynamics aids are sold in market mostly spoilers. It is an aerodynamic device that design to 'spoil' unfavorable air movement across a car body. A spoiler also can be attached to front or rear bumper as air dam. It can also be mounted at the rear of the vehicle or at the end to rooftop of the vehicle. Spoilers contributed some major aerodynamics characteristics as lift and drag. Increase of down force of the vehicle enables the manufacturer to design light weight vehicle and thus saving fuels and moreover spoilers can also be used to control stability during driving especially at cornering.

When a driver drives a car in high speed, especially at highway at speed 60 m/sec, the car has high tendency to lift over. This is possible to happen because as the higher pressure air in front of the windshield travels over the windshield; it accelerates, causing the pressure to drop. This lower pressure literally lifts on the car's roof as the air passes over it. Once the air makes its way to rear window, the flow of the air leaves a vacuum or lower pressure space that the air is not able to fill properly [3]. The flow is said to be detached and the resulting lower pressure creates lift that then acts upon the surface area of the trunk. To reduce lift that acted on the rear trunk, a spoiler can be attached on it to create more pressure. Spoiler can be mounted on both on the rooftop and rear of the vehicle. The most suitable and optimized position for spoiler is determined through this investigation.

2. Mathematical Formulation

2.1 Continuity Equation

A continuity equation in physics is an equation that describes the transport of a conserved quantity [4].

$$[(\delta u/\delta t) + (\delta u/\ \delta x) + (\delta u/\delta y) + (\delta u/\delta z)] = 0$$

2.2 Navier Stoke's Equation

Taking the incompressible flow assumption into account and assuming constant viscosity, the Navier Stokes equations is in the vector form [5]:

$$\overbrace{\rho\Big(\underbrace{\frac{\partial \mathbf{v}}{\partial t}}_{\substack{\text{Unsteady}\\ \text{acceleration}}} + \underbrace{\mathbf{v}\cdot\nabla\mathbf{v}}_{\substack{\text{Convective}\\ \text{acceleration}}}\Big)}^{\text{Inertia (per volume)}} = \overbrace{\underbrace{-\nabla p}_{\substack{\text{Pressure}\\ \text{gradient}}} + \underbrace{\mu\nabla^2\mathbf{v}}_{\text{Viscosity}}}^{\text{Divergence of stress}} + \underbrace{\mathbf{f}.}_{\substack{\text{Other}\\ \text{body}\\ \text{forces}}}$$

Note that gravity has been accounted for as a body force, and the values of g_x, g_y, g_z will depend on the orientation of gravity with respect to the chosen set of coordinates

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + \rho g_x$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) + \rho g_y$$

$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) + \rho g_z.$$

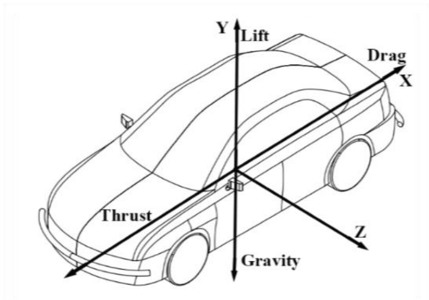

Fig.1: Forces acting on a car.

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2.3 Drag Force

Aerodynamics drag force is the force which opposes the forward motion of the vehicle when the vehicle is traveling. This drag force acts externally on the body of a vehicle. Aerodynamic drag force is characterized by,

$$\text{Drag force, } F_D = \frac{1}{2}\rho v^2 C_d A$$

2.4 Lift Force

The aerodynamic drag force is acted horizontally to the vehicle and there is another component, directed vertically, called aerodynamic lift. It reduces the frictional forces between the tires and the road, thus changing dramatically the handling characteristics of the vehicle. This will affect the handling and stability of the vehicle. The lift force, L is quantified by the below equation

$$\text{Lift force, } \quad F_L = \frac{1}{2}\rho v^2 A C_L$$

3. Generic Model Preparation

3.1 Generic Model of Vehicle

A Sedan type of car is selected, a generic model of a Sedan car is prepared with the help of CAD software.

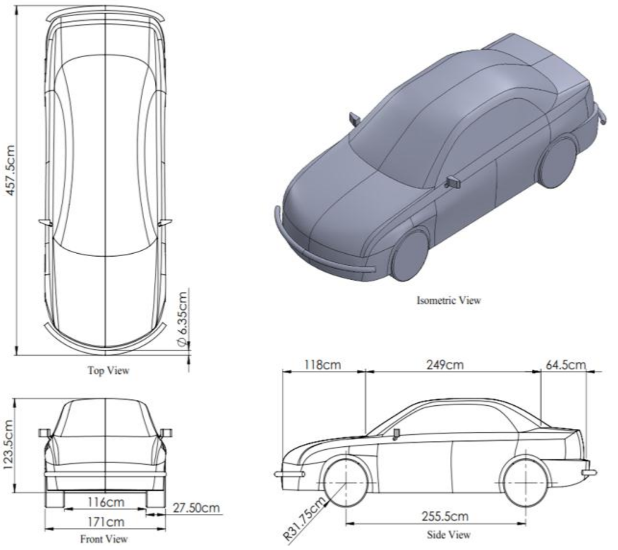

Fig.2: Generic model of the vehicle.

3.2 Generic Model of Spoiler

For the cambered shape, NREL's S821 airfoil is used.

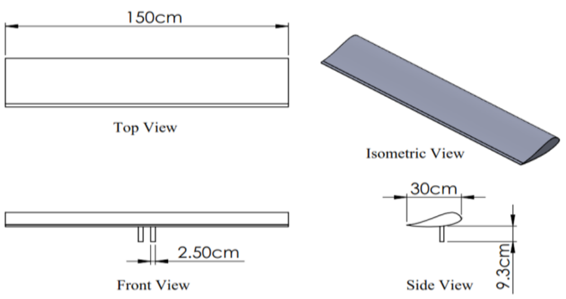

Fig. 3: Generic Model of Spoiler Assembly

The spoiler is assembled together with the car body and they are used for numerical analysis in CFD Software. These assemblies are shown in Fig. 4 below:

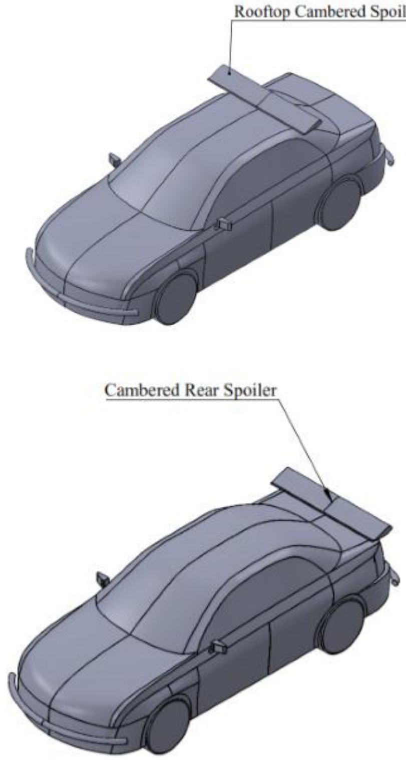

Fig.4: Car body assembly with different types of spoiler position.

3. Virtual Wind Tunnel and Vehicle Orientation

The vehicle with different spoiler positions shown above in Fig 4, have been orientated in the virtual wind tunnel one-by one to perform simulation for different conditions. A virtual air-box has been created around the 3D CAD model shown in the Fig. 5 below. More space has been left in the rear side of the vehicle model to capture the flow behavior mostly behind the vehicle [7].

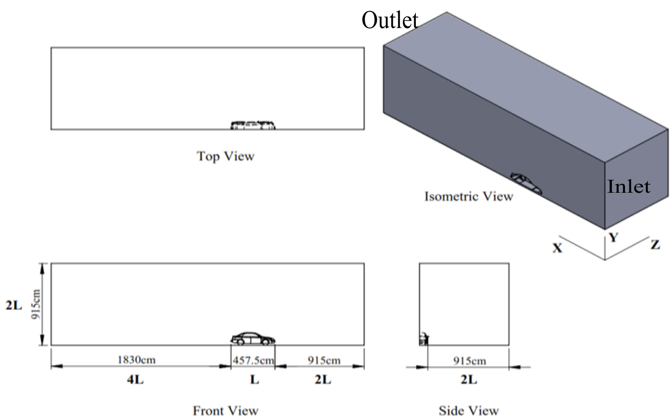

Fig.5: Virtual Wind Tunnel.

4. Mesh Generation

The triangular shape surface mesh was used due to its changing curves and bends. With the global mesh sizing setting, there is some curvature around the body. With some parameter sizing is done for getting better result [6]. To capture car surface phenomena more accurately, inflation layer is also added.

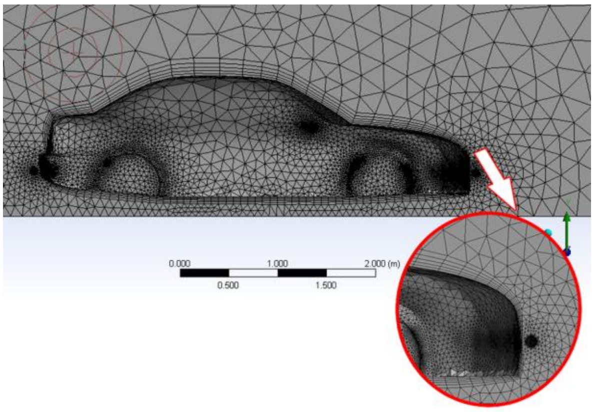

Fig.6: Mesh Generation.

This mesh is generated for the geometry with rooftop spoiler and rear spoiler.

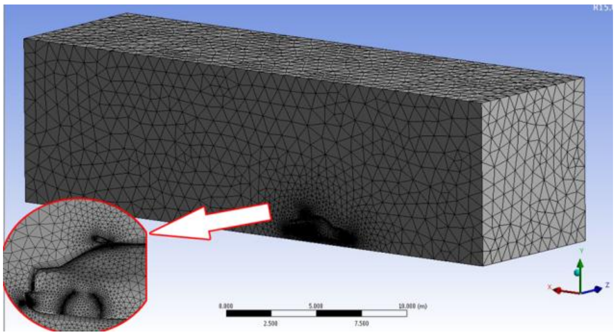

Fig.7: Vehicle with Cambered Roof Spoiler Mesh.

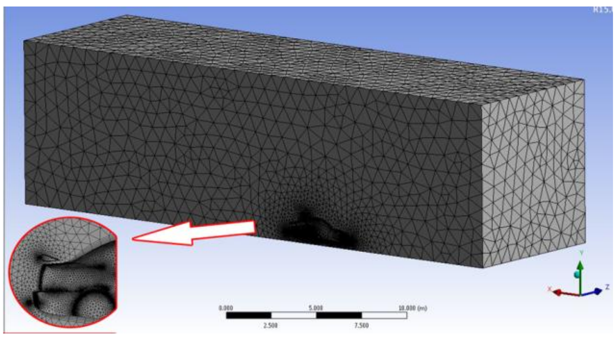

Fig.8: Vehicle with Cambered Rear Spoiler Mesh

5. Boundary Conditions

After the completion of required quality of mesh, it is transferred to the solver where respective boundary conditions are provided to solve the problem. The inlet of the wind tunnel is defined by velocity inlet and the outlet is defined by pressure outlet. The car body and road is defined as wall with no slip and surrounding boundary is defined as symmetry zone. Afterwards the solver is set according to the following conditions:

Table 1 Solver Settings

Simulation		
Turbulent Model	k-epsilon (2 eqn)	
Scheme	Coupled	
Velocity Inlet	Velocity Magnitude	15 m/sec, 30 m/sec, 45 m/sec, 60 m/sec
Pressure Outlet	Gauge pressure	0 Pascal

6. Results and Discussion

After simulation being completed, the numerical value of the coefficient of lift (C_l) and coefficient of drag (C_d) are obtained. Also result can be displayed in various contours like pressure contours, velocity contour, velocity vectors etc.

For each simulation process, first 100 iterations is carried out using First Order Upwind scheme. After that, Second Order Upwind scheme is applied. Each time, from monitoring section, Co-efficient of lift (C_l) and Co-efficient of drag (C_d) is calculated and plot is done against iteration. For some certain time, the C_l & C_d curve fluctuates in large amplitude with the increase of iteration. Then as simulation progresses, these fluctuations come to a steady state condition and that remarks the convergence of the whole simulation process.

Now, for all cases and for different speed set the obtained value of Co-efficient of lift (C_l) and Co-efficient of drag (C_d) are shown in graphical form in Fig.9 and Fig.10. And the percentage increase of C_d and C_l in all cases is given in Table 2 & 3.

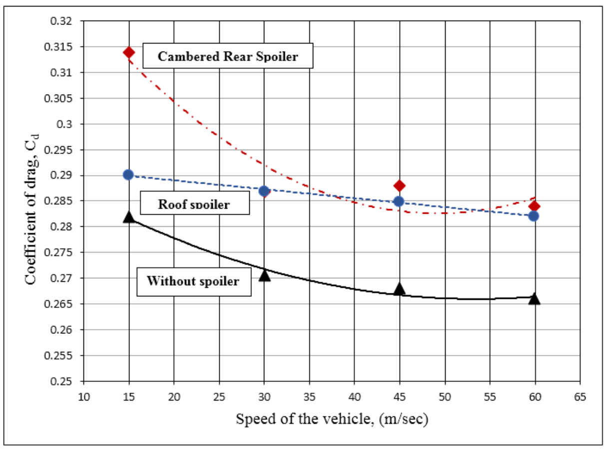

Fig.9: Variation of Coefficient of drag with Speed of the car.

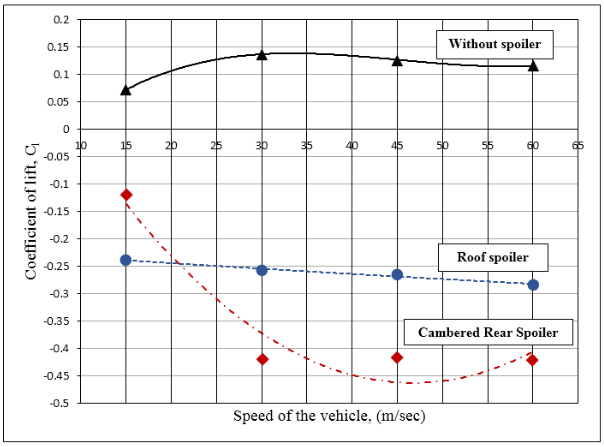

Fig.10: Variation of Coefficient of lift with Speed of the car.

Table 2: Percentage increase in Coefficient of drag for different case at different speed:

	Roof Spoiler	Cambered Spoiler
Speed (m/sec)	% increase C_d	% increase C_d
15	2.84	11.34
30	6.10	6.70
45	6.34	7.46
60	6.02	6.77

Table 3: Percentage increase in Coefficient of lift for different case at different speed:

	Roof Spoiler	Cambered Spoiler
Speed (m/sec)	% decrease C_l	% decrease C_l
15	76.72	62.63
30	65.23	75.32
45	67.68	76.61
60	70.93	78.40

Table 4: Forces acting on the vehicle at different speed:

Vehicle with Cambered Spoiler at Rear		
Speed	Down Force (N)	Drag Force (N)
15	16.83	43.68
30	232.56	159.687
45	520.76	360.53
60	936.93	632.04
Vehicle with Cambered Spoiler at Rooftop		
Speed	Down Force (N)	Drag Force (N)
15	33.10	40.35
30	143.0	159.70
45	333.0	356.77
60	630.0	627.60

Now, from the obtained data, various contours are generated and some are given bellow:

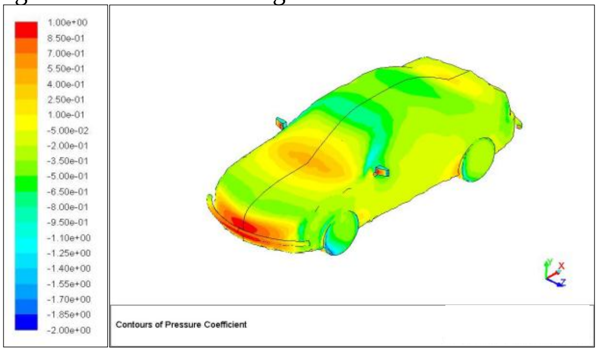

Fig.11: Pressure distribution on the car body for Vehicle model without spoiler at 45 m/sec.

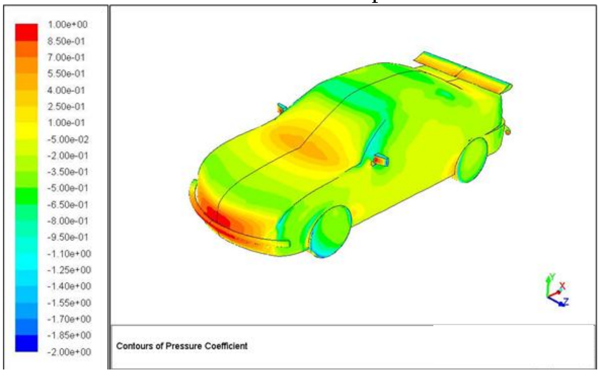

Fig.12: Pressure distribution on the car body for Vehicle model with rear spoiler at 45 m/sec.

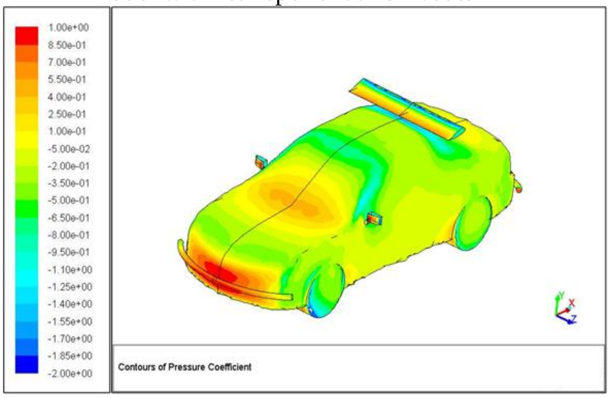

Fig.13: Pressure distribution on the car body for Vehicle model with rooftop spoiler at 45 m/sec.

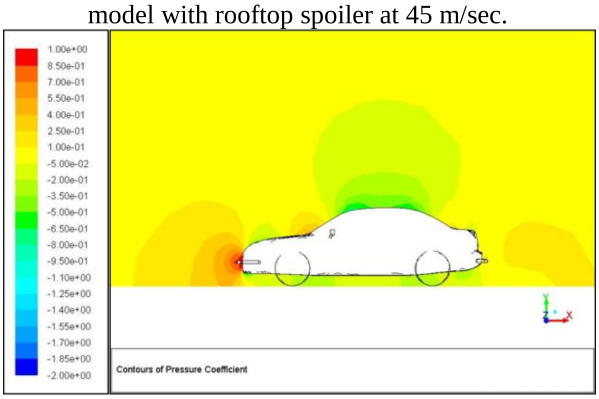

Fig.14: Pressure distribution in the symmetry plane for Vehicle model without spoiler 45 m/sec.

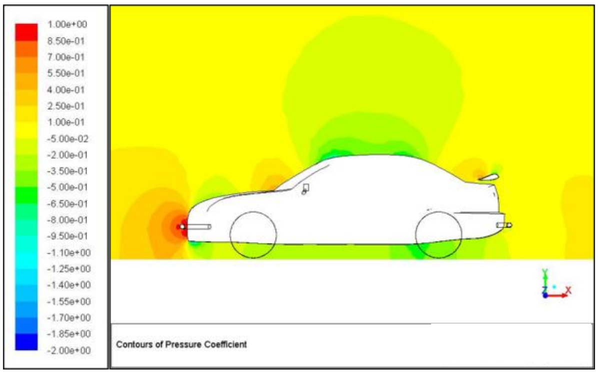

Fig.15: Pressure distribution in the symmetry plane for vehicle model with Cambered rear spoiler at 45 m/sec.

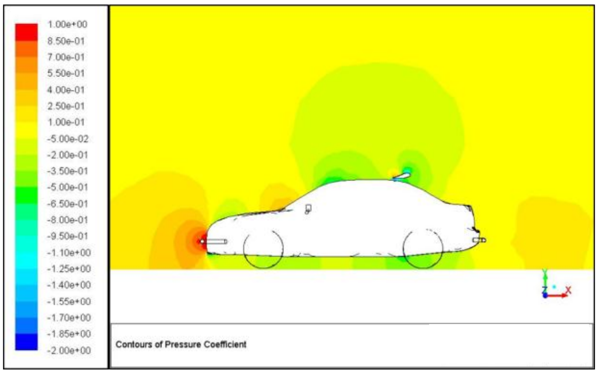

Fig.16: Pressure distribution in the symmetry plane for vehicle model with Cambered rooftop spoiler at 45 m/sec.

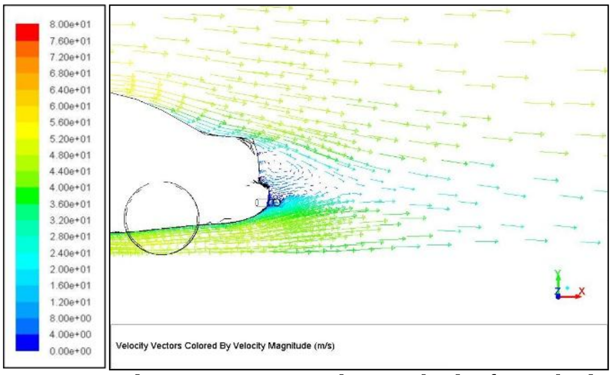

Fig.17: Velocity Vector on the car body for vehicle model without spoiler at 45 m/sec.

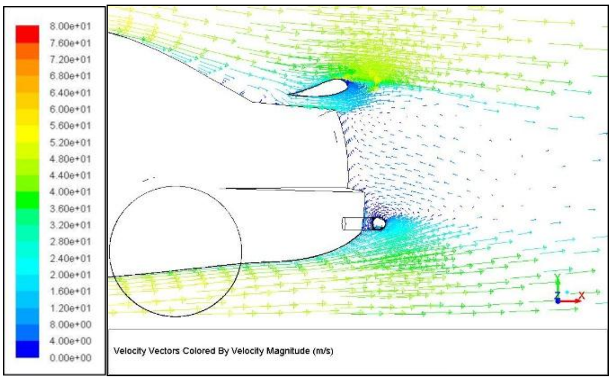

Fig.18: Velocity Vector on the car body for Vehicle model with Cambered rear spoiler at 45 m/sec.

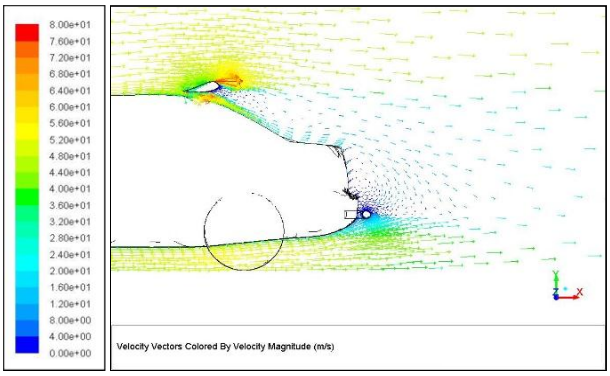

Fig.19: Velocity Vector on the car body for Vehicle model with Cambered rear spoiler at 45 m/sec.

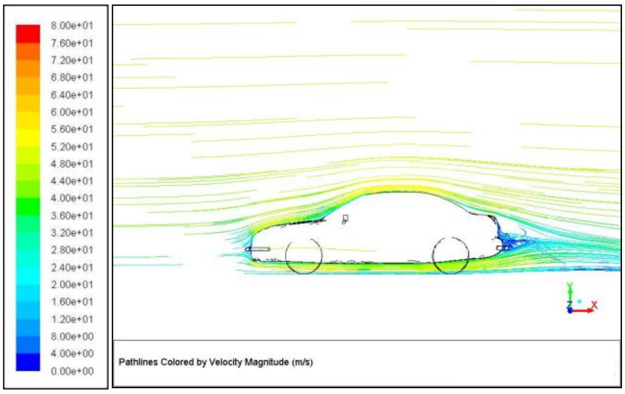

Fig.20: Streamlines of flow in the symmetry plane for vehicle model without spoiler at 45 m/sec.

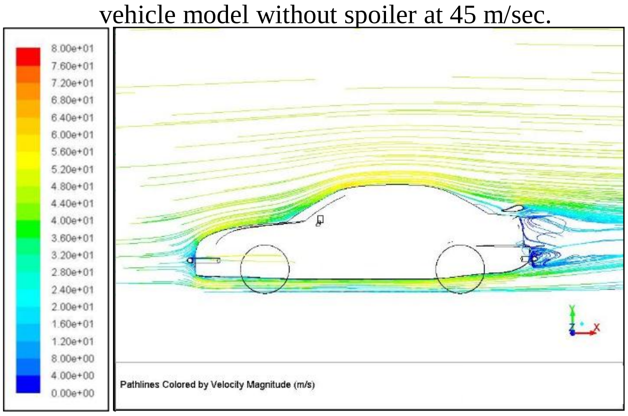

Fig.21: Streamlines of flow in the symmetry plane for vehicle model with Cambered rear spoiler at 45 m/sec.

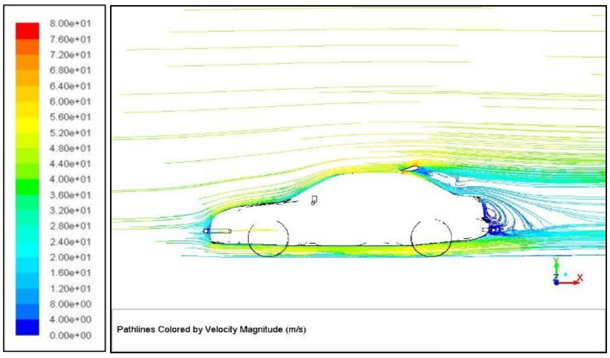

Fig.22: Streamlines of flow in the symmetry plane for vehicle model with Cambered rooftop spoiler at 45 m/sec.

From the obtained data and analysis, the following result can be produced to achieve the predetermined objectives of this investigation.

Fig. 9 shows the drag coefficient with the speed of the car and it is observed that the drag coefficient decreases with the increase of speed of the car. Again, it is observed that the drag shows higher value for the cambered spoiler at the rear location at 15 m/sec speed of the car whereas lower value at the speed of 45 m/sec. Fig.10 shows that the lift coefficient with the speed of the car and it is observed that the down force increases with the increase of speed of the car. Again, it is observed that the down force shows higher value for the cambered spoiler at the rear location at 45 m/sec speed of the car whereas lower value at the speed of 15 m/sec. From Table 4, for 45 m/sec speed, the acting drag force is about 159.0 N and lift force is 335.5 N. Now, from the analysis of rooftop spoiler and rear spoiler, it is found that for all cases, there is a significant change in down force. But, all of them have a slightly contribution to the change in drag force. But, taking into account the percentage increase in down force, the negligible increase of drag coefficient means the stability of the vehicle.

Fig. 15 shows, pressure contour at speed 45 m/sec for Cambered spoiler located at the rear of the car and Fig. 16 shows the pressure contour at same speed but located at the rooftop of the car. It is observed that the pressure increases more at the rear Cambered spoiler than at the rooftop Cambered spoiler. Fig. 17-19 shows the velocity vector at a speed 45 m/sec of the car for without spoiler, with Cambered spoiler at rooftop and rear of the car. It is observed that the two wakes developed, one behind the spoiler and other rear of the car for spoiler at rooftop. But for spoiler at rear of the car a single wake is developed at the rear of the car, which is away from the car body. Similar phenomena observed from Fig. 20-22, which show the streamlines at a speed 45 m/sec of the car.

Again, as for the consideration of the position of the spoiler on the vehicle, it is observed that the drag force for both the cases is same. But down force for Cambered rooftop spoiler is about half of the down force generated by the Cambered rear spoiler. It is observed from the Table 4 that at a speed 45 m/sec, 333N down force is produced in Cambered roof spoiler whereas Cambered rear spoiler produces about 520.76N down force. So, for better road stability and traction control, it is effective to use Cambered spoiler at the rear of the vehicle.

7. Conclusion

The above investigation shows that the location of Cambered spoiler at the rear of the car produces more down force than at the rooftop of the car. So, for the good stability of the vehicle, rear Cambered spoiler is the best choice than rooftop Cambered spoiler.

NOMENCLATURE

ρ : Density
υ : Viscosity
A : Projected area of the vehicle on the inlet surface.
F_L : Lift Force
F_D : Drag Force
C_d : Co efficient of drag
C_l : Co efficient of lift
V : Velocity of the flow

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