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Aerodynamic Drag Reduction of a Notchback Car Geometry by Delaying Flow Separation using Vortex Generators

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***Abstract*- For any high performance vehicle the aerodynamic properties are significant when attempting to optimize performance. One of the main source of aerodynamic drag is the flow separation which occur near the vehicle's rear end. In aerodynamics, flow separation can often result in increased drag particularly pressure drag which is caused by the pressure differential between the front and rear end as it travels through the fluid.**

For this reason much effort and research has gone into the design of aerodynamic and hydrodynamic surface which delays flow separation and keep the local flow attached to the surface for a long possible time. To delay the flow separation, vortex generator are tested for application to the roof end of the vehicle just before the point of separation of flow. But the vortex generator themselves also create the drag. But the drag created by vortex generator is very small as compared to the drag reduced by it. Example; Fur on tennis ball, Dimples on a golf ball, Leading edge extensions, Vortex generators, Turbulator on a glider.

Keywords—Aerodynamic Drag, Flow Visualization, Vortex Generator, Computational Fluid Dynamics (CFD).

INTRODUCTION

A. General

Drag is the result of interaction between the vehicle shell and the surrounding air molecules caused by relative motion between the air and vehicle which results in a net force opposing motion.To improve the performance of the vehicle one need to reduce the aerodynamic drag. And the problem of aerodynamic drag become more Significant as the speed of the vehicle increases. And one of the main force resisting the motion of vehicle is the Drag which results in increased fuel consumption of the vehicle. And to protect the environment fuel consumption reduction is one of the primary concern for automotive development. In vehicle body development reduction of aerodynamic drag is essential for improving the fuel consumption and if an aerodynamically well designed body is also aesthetically attractive, it will contribute much to increase the vehicle's appeal to customer. Road vehicle aerodynamic design, vehicle attributes affected by the aerodynamic, typical aerodynamic characteristics and method of calculating road vehicle flows. The road vehicle is being essentially a bluff body in very close proximity to the ground. The geometry of the vehicle is complex and flow around its body is fully three dimensional. The boundary layer around it is being turbulent. The flow separation occur at the rear of the vehicle and a very low pressure area exist commonly known as wake region. The passenger car body's aerodynamic bluffness, when expressed by the drag coefficient is generally between 0.2 and 0.5, while that of more bluff cubic objects is greater than 1. Three factors which mainly increases the aerodynamic drag of the vehicle are the roundness of its font corners and speed with which it travels and degree of taper provided at the rear end.

B. Mechanism of flow separation in the vehicle.

Flow separation occur in the vehicle at the rear end of the vehicle because flow is not able to attach with the vehicle surface. The reason behind the flow separation is that the boundary layer travels far enough against the an adverse pressure gradient that the speed of boundary layer relative to the vehicle falls almost equal to zero. And flow gets detached form the vehicle surface and take the forms of eddies and vortices and a low pressure area exist commonly known as the wake region.

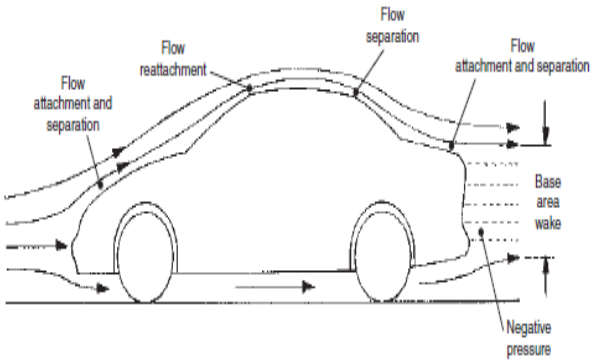

Fig. 1 Air flow around a Notchback Car

C. *Vortex Generator*

Vortex generator is an aerodynamic devices consisting of small vanes commonly attached on the vehicle surface to reduce the aerodynamic drag. When the vehicle is in motion the vortex generator creates the vortex which by transferring the momentum from higher region which has large momentum to lower region where has small momentum delays the flow separation. Vortex generator generally mounted on the vehicle surface at the location just before the separation point. However there is no fix method to place the vortex generator on the surface but the optimum position is to place them 100mm before the point of separation.

It help to reduce the drag by increasing the pressure at the rear of the vehicle and helps in shifting the separation point further downstream. It help in reducing the drag in two ways first is by narrowing the wake region in which low pressure area exist causes the aerodynamic drag and by increasing the pressure of the wake region and help in reducing the drag.

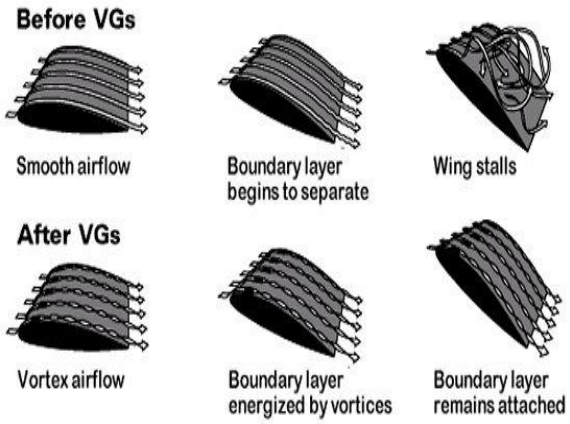

Fig. 2 Vortex Generator

Methodology

Vortex generators have a great influence on delay in flow separation. Vortex generators are placed on external surface where the flow separation takes place. On most notchback vehicles it's the point where the rear of the roof transitions to the back windshield.

In this study an effective simulation based on Computational Fluids Dynamics (CFD) approach is purposed to obtain the flow structure around the vortex generators. A simplified notchback car geometry is used which is a modified Ahmed Body.

An effective drag reduction is expected from vortex generator installation.

Calculation of Thickness of local Boundary Layer

We know that Reynolds number is given by

$Re = \rho vx/\mu$

Where ρ=1.225 kg/m^3

v=50 m/sec

x=3.76 m

μ=1.962*10^{-5} m^2/sec

So the value of Re=117*10^5(>5*10^5)

From Blassius Experiment the thickness of boundary layer when velocity profile is unknown is given by

$\delta = 0.382x/(Re)^{1/5}$

After putting the values of x and Re the thickness of boundary layer found to be around 0.055m.

Analytical Model

The analytical model of the car has been modelled in SOLID-WORKS. The dimension of the car is given by

Wheel Base = 4845 mm
Wheel Track = 1830 mm
Height of the Car =1455 mm
Front Overhang = 965 mm
Rear Overhang = 1085mm

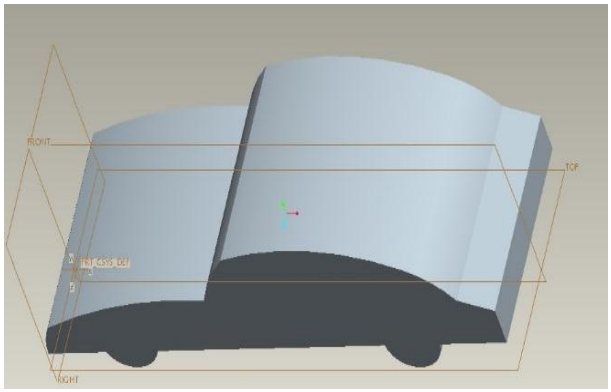

Fig. 3 Model

Comparison of Velocity Contour

Two models of notchback vehicle geometry on without vortex generator and one with a vortex generator are being simulated in CFD respectively. The velocity contours of two models are being taken from the results and are compared and it has been found that wake region of the model with vortex generator get reduced after the installation of vortex generator. It is clear from the velocity contour that vortex generator helps in delaying the flow separation and flow get attached with the vehicle surface.

The plot for variations of coefficient of drag for the model with or without vortex generator is as shown in figure

VELOCITY CONTOUR

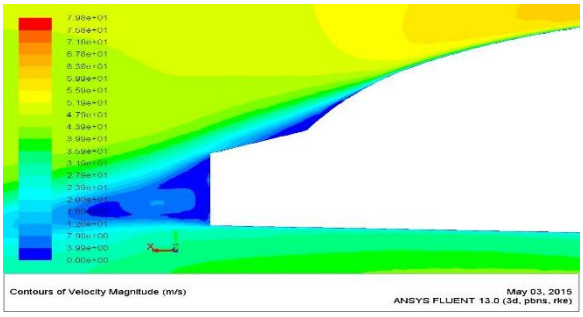

Fig. 4 Velocity Contour (without VGs)

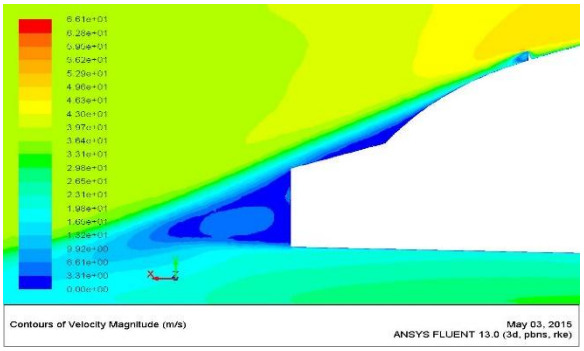

Fig. 5 Velocity Contour (with VGs)

VELOCITY PATHLINES CONTOURS

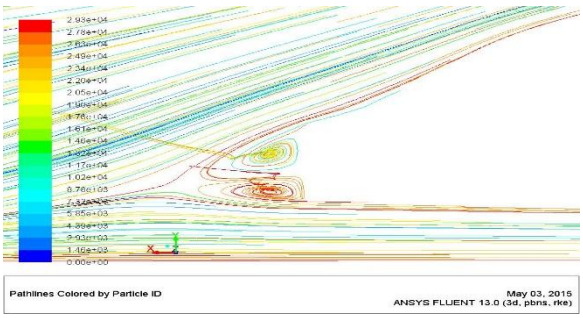

Fig. 6 Velocity Contour Pathlines (without VGs)

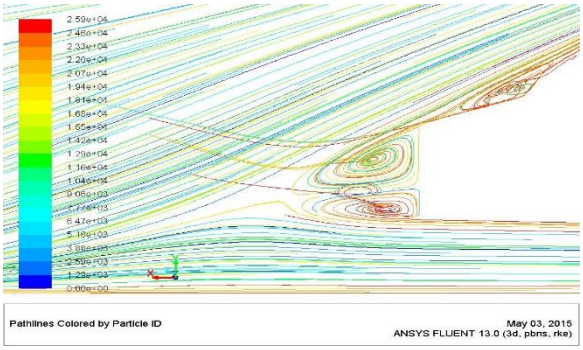

Fig. 7 Velocity Contour Pathlines (with VGs)

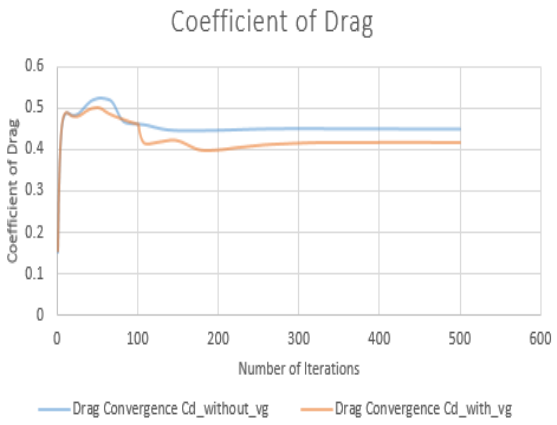

Fig. 8 Effect of Vortex Generators on Coefficient of Drag (C_D)

Inference:

From the graph it is clear that the value of coefficient of drag decreases for model with vortex generator. As the vortex generator help in avoiding the separation of the flow and shift the point further downward and thus avoiding the formation of low pressure region commonly known as the wake region.

The plot for variations of coefficient of lift for both the models is as shown in figure

Fig. 9 Effect of Vortex Generators on Coefficient of Lift (C_L)

The plot for variations of velocity for both the cases on a single scale for comparison basis is as shown in figure

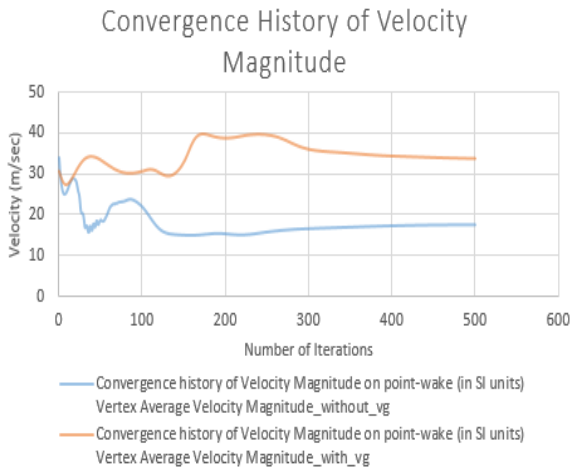

Fig. 10 Effect of Vortex Generators on Velocity Magnitude

Inference:

As evident from the figure, the case with VGs shows an increase in velocity on the surface of the body (rear window) just behind the VG and extension of the high velocity zone downward. This supports our estimation in the previous section that VGs cause airflows above the rear window to attach to the surfaces of the body.

The plot for static pressure distribution is as shown in figure

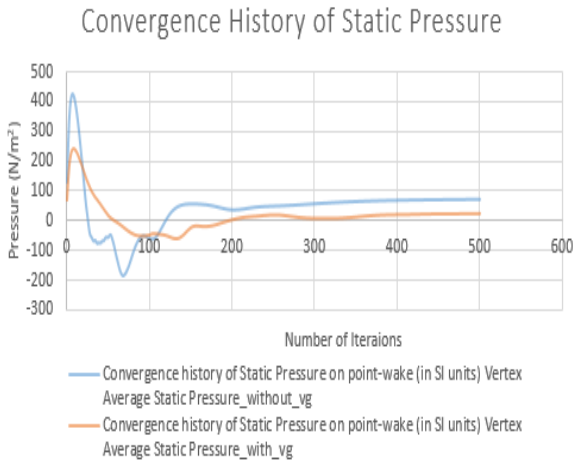

Fig. 11 Effect of Vortex Generators on Static Pressure

Inference:
From the graph it is clear that after the installation of vortex generator on the model the value of static pressure decreases which support our fact that vortex generator help in attaching the flow to the body and to shift the separation point further downward thus avoiding the formation of negative pressure behind the car known as the wake region and help in decreasing the size of base pressure.

CONCLUSION

The conclusion of this research paper is that the study of vortex generators was done to install immediately upstream of the flow separation point in order to control the separation of air flow above the car's window and improve the aerodynamic characteristics. It was found that optimum height of vortex generator was found to be equal to the thickness of boundary layer (15 to 25mm) and optimum method of placement is to arrange them in lateral direction just before the Point of separation. The vortex generator are highly sensitive to these parameters and their optimum value ranges are wide. It is confirmed that VGs create streamwise vortices, the vortices mix higher and lower layer of the boundary layer and the mixture causes the flow separation to shift downward and also wake region is narrowed.

REFERENCES

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