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Methods for Reducing Aerodynamic Drag in Vehicles and thus Acquiring Fuel Economy

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ABSTRACT

This paper discusses about techniques that can be adopted to reduce the formation of aerodynamic drag on vehicles & thus reducing the fuel consumption. This is a comparative study and hence conclusions based on more than one method are practiced here. One of the major causes of aerodynamic drag on a vehicle is due to the formation of flow separation at the rear end of the vehicle. For reducing such flow separation certain aerodynamic shapes or surfaces can be provided on the vehicle surface. One such improvement is the usage of a bump-shaped vortex generator that restricts flow separation up to an extent & thereby reducing the aerodynamic drag. Another method is by the usage of two passive devices known as rear fairing, which is the aerodynamic extension of a vehicle's rear end and the other is a rear screen, which is a plate fixed behind the back of a car. Drag induced on a vehicle prohibits it for higher acceleration. And hence for attaining higher velocities more fuel has to be burnt, which increases the fuel usage & also leads to higher carbon emissions that will gradually affect the environment.

Keywords - aerodynamic drag reduction, passive methods, rear fairing, rear screen, vortex generator

1. INTRODUCTION

On manufacturing a vehicle, several design parameters should be kept in mind, among which some of them are appropriate space for passengers and goods, cruise speed, fuel efficiency and of course the vehicle should not lack good looks as it is necessary to attract a customer, as it will be the primary factor that one will notice. Among these fuel efficiency is the major focus of this paper. The thought of fuel consumption did not arose today. It had been there since vehicles first arrived on roads. The reason was because, earlier when the vehicles were first manufactured and was being popularized, re-fuelling stations were less, compared nowadays. Therefore after one re-fuelling station the driver had to run several miles to reach another gas station if he needed to re-fuel.

Hence the vehicles had to run more efficiently. The measure of a vehicle's efficiency depends up on several factors. And one of these factors will be the efficiency of the engine. The engine should be highly efficient so that it consumes less amount of fuel for more distance covered. Such an engine consumes less amount of fuel and gives better work output. Another main parameter that forbids the efficient working of a vehicle is the aerodynamic drag acting on the vehicle. The aerodynamic force that opposes the forward motion of a body is known as aerodynamic drag or simply drag. This aerodynamic force accounts for more than 60% of the power consumed by the vehicles. And hence, more power should be generated to push the vehicle forward, past the opposition caused by drag. For generation of more power more fuel must be burnt which in turn leads to higher amount of carbon emissions.

Increased carbon emissions have adversely affected the ecosystem. Higher rates of these emissions accounts for the cause of global warming and numerous other ecological problems.

The shape of the vehicle also plays a vital role in determining the formation of drag around it. As it is necessary to accommodate passengers and carry goods it should be a bluff body. And being a bluff body it tends to form, more drag around it.

The drag acting on the vehicle is mainly from two sources. One is skin friction which is caused due to the viscous interaction of the vehicle’s body with the airstream and the other one is pressure drag that forms due to the relative change in pressure at the back and rear end of the vehicle.

Hence certain methods should be adopted to reduce the formation of aerodynamic drag around vehicles. Generally there are two methods by which we can reduce drag in vehicles. One among them is active method that involves a type of air jet at critical locations on the vehicle shell. Such methods usually require a little or no modification at all in shape. And the other is passive methods that employs additional devices or shape modifications

2. DRAG REDUCTION ON AN AHMED BODY VEHICLE ANALOGUE

Whenever a body moves through air, it accounts for aerodynamic drag. The main disadvantage of the formation of aerodynamic drag in vehicles is that it increases the rate of fuel consumed. Hence certain methods should be adopted to control this increase in drag. In such cases one solution is by the use of active flow control methods. Drag reduction on an Ahmed body can be studied with the help of a fluidic oscillator which is a simple device that converts a steady pressure input into a spatially oscillating jet.

3. USE OF PASSIVE METHODS FOR REDUCING DRAG

Drag can be reduced by the usage of passive devices which are aerodynamic extensions of the vehicle or certain installations provided on the vehicle surface. The use of rear screens and rear fairings have helped considerably in reducing the aerodynamic drag. Experiments are done on an SUV model by aerodynamically extending its rear end (rear fairing) and also by installing a plate at the rear end (rear screen) of the vehicle. By analyzing the results obtained from both the results it is seen that the aerodynamic efficiency of the vehicle has been increased.

4. DRAG REDUCTION BY USING VORTEX GENERATORS

Vortex generators are also a kind of passive devices. One of the main reasons for the formation of aerodynamic drag around a vehicle’s body is due to the flow separation occurring at its rear end. Hence if a method can be adopted to delay the flow separation formed at the rear end, the formation of drag can be effectively reduced. The use of vortex generators thus comes into this scenario. Vortex generators create drag by themselves as it is a projection from the vehicle’s surface. But the drag caused by a vortex generator will be negligible and the overall performance, that is the drag reduction by a vortex generator will be the sum total of its positive and negative effects.

5. USE OF REAR SCREEN

A plate which is installed at the back of a vehicle is said to be a rear screen. Findings from are made use of, to study about the effects of using a rear screen. One of the main reasons for the action of aerodynamic drag is due to the flow separation formed at the rear wall of the vehicle. The drag reduction by the employment of a rear screen is by the generation of a vortex between the rear screen and the vehicle's rear end. The formation of vortex helps in preventing the flow separation.

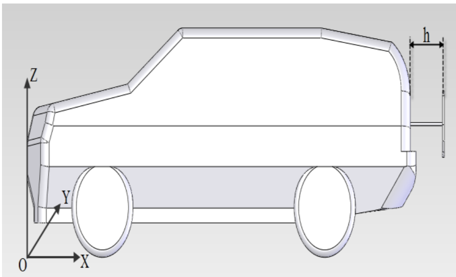


Figure 5.1: Side view of rear screen

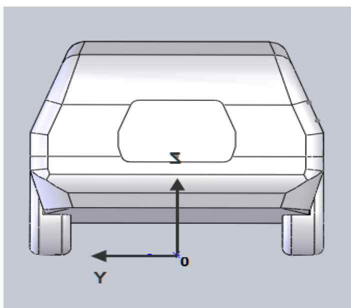
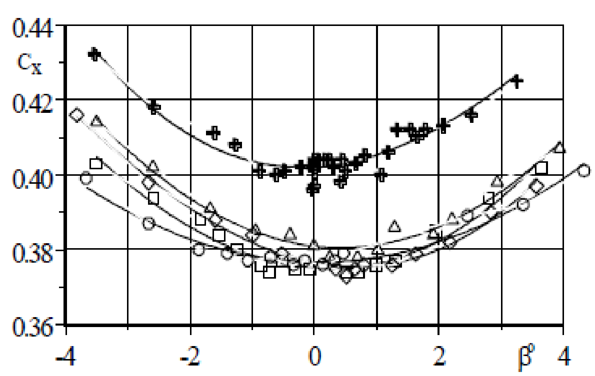


Figure 5.2: Rear view of rear screen

The rear screen contour was scaled from the back view of the vehicle model. Rear screens with contours on a scale of D = 0.6 and D* = 0.8 with a thickness of 7.5 mm and 1 mm were tested. Also the impact of using two rear screens one after the other were also tested.



◊ - double rear screen D= 0.8, h_1= 50 mm, D=0.6, h_2= 160 mm

○ - rear screen D= 0.6, h= 158 mm

□ - rear screen D= 0.8, h= 100 mm

Δ - rear screen D= 0.6, h= 200 mm

╪ - without rear screen

Figure 5.3: Impact of rear screen on aerodynamic drag factor, C_X

From the Fig 5.3 it is clear that after using a rear screen, the aerodynamic drag factor has been considerably reduced. Also if the gap between rear screen and rear wall of the vehicle is increased, it can give better results in drag reduction.

6. USE OF REAR FAIRING

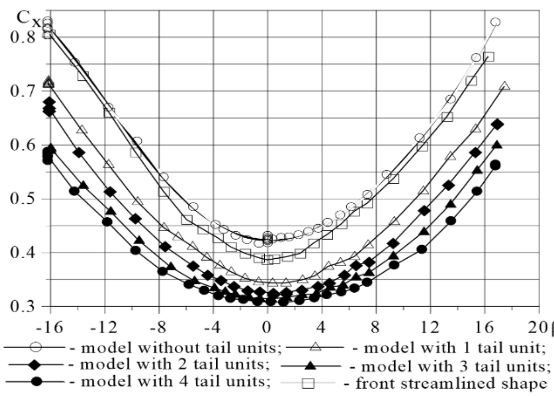
Rear faring is a structure extended from the back of the vehicle into flow separation area in order to reduce the aerodynamic drag. For a perfect case it is also seen that a rear fairing gives no flow separation for a vehicle with modified configuration.

The practical application of such an aerodynamically extended structure at the back of the vehicle is quite difficult. But the results obtained from this experiment can be used to study the preliminary means of reduction of drag for finding minimum possible values.

Figure 6.1: A modified vehicle model having installed a rear fairing

Promising results yielded from tests conducted using rear fairings of different lengths. The use of rear fairing showed high efficiency.

A reduction of 26% in vehicle aerodynamic drag factor can be obtained by installing a full-size rear fairing. A rear fairing having half the length of its vehicle model can reduce the drag factor by up to 22.6% and quarter the length will provide a 16.1% reduction.



7. USE OF VORTEX GENERATORS

The flow separation formed at vehicle's rear end is one of the major reasons for aerodynamic drag in vehicles. Taking a sedan as an example, the height of the car decreases gradually from center to rear. As a result, during motion of the vehicle, an expanded airflow is formed at the rear as the flow moves downstream.

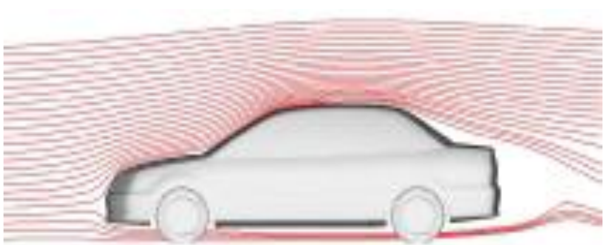


Figure 7.1: Flow around a sedan

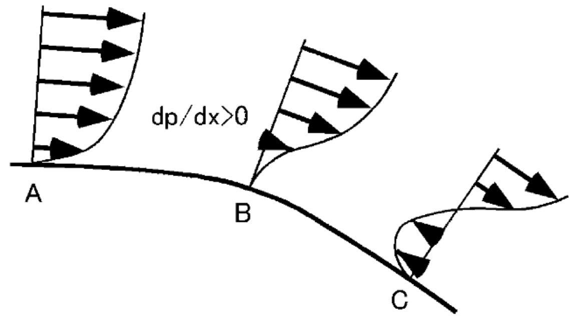


Figure 7.2: Velocity profile at vehicle's rear end

The decrease in height at the rear end causes the downstream pressure to rise. This pressure rise leads to a reverse flow at a point C, acting against the main flow. As the momentum of boundary layer prevails over the pressure gradient (dp/dx), no reverse flow occurs at point A. The pressure gradient and momentum of the boundary layer are balanced at point B. From Fig 7.2 we can see that the flow loses its momentum as it travels downstream, and this happens due to the viscosity of air. The use of vortex generators comes in this scenario.

Fig 7.2 depicts the improved flow over the vehicle's rear end after the usage of a vortex generator. A vortex generator is installed at a point just before where the flow separates. This will generate stream wise vortices that tend to supply momentum from the higher region of the vehicle having larger momentum to the lower part of the vehicle having comparatively less momentum. The result will be a shift in the position of flow separation point which in turn allows the expanded airflow to exist longer than before and reduce the flow velocity at separation point and thus making the static pressure higher.

This static pressure at the flow separation point acts as the governing factor for the overall pressures in the flow separation region and reduces drag by increasing the back pressure. Drag occurs due to the low pressure formed at flow separation region, as the flow separation point gets shifted further downstream; it narrows the separation region and also increases the pressure at the region of flow separation.

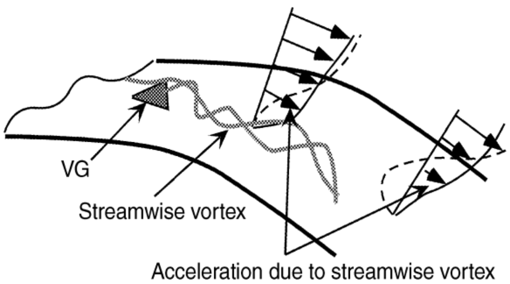


Figure 7.3: Change in flow after installing vortex generator

But as it is true that vortex generators delay the flow separation, it also tends to generate drag by itself. However the increase in size of a vortex generator can effectively delay flow separation it can also increase the drag caused by the vortex generator. Hence an optimum size for a vortex generator should be determined.

8. SELECTION OF THE OPTIMUM VORTEX GENERATOR

For selecting the optimum vortex generator with good stream wise vortex generation and less drag formation by itself, certain factors should be considered, which would be primarily the size and shape of the vortex generator. Concerning about the size, the thickness and height are determined.

The height of the vortex generator is assumed to be same as that of the height of the boundary layer. Based on the experimental results from, the height of the vortex generator is taken as 30 mm.

The optimum location of the vortex generator is yet another factor. As the vortex should be generated from upstream to downstream, its location will be immediately upstream to the flow separation. Now an appropriate shape should be suggested with maximum vortex generation and minimum drag production.

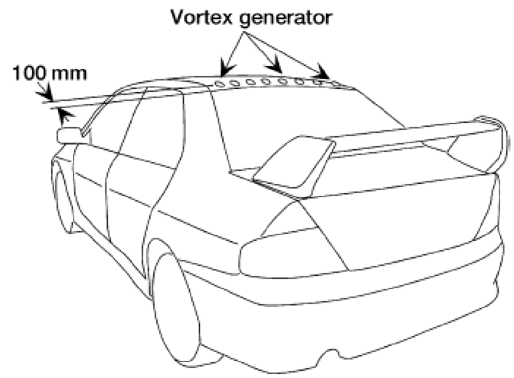


Figure 8.1: Location of vortex generator

9. USE OF BUMP SHAPED VORTEX GENERATOR

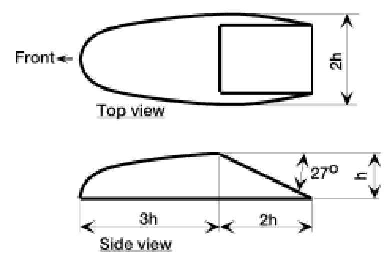


Figure 9.1: Bump shaped vortex generator

A vortex generator with bump shape having a rear slope angle of 25° to 30° is selected considering the fact that a hatchback car with a same rear window angle can produce a strong stream wise vortex. The smoothly curved front face reduces the drag caused by the vortex generator itself and the straight rear half cut in an angle of approximately 27° allows it to produce the vortex effectively.

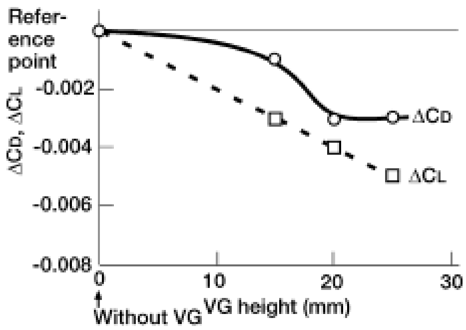


Figure 9.2: Effects of using a bump shaped vortex generator

The results obtained from using three bump shaped vortex generators with various heights (i.e.; h= 15 mm, 20 mm and 25 mm) are used to plot the graph depicted in Fig 9.2 and the results suggest that the optimum height of the vortex generator will be in between 20 and 25 mm. A further increase in height may reduce drag by delaying the flow separation but it also increases the drag caused by the vortex generator. If a bump shaped vortex generator with optimum size and shape can be used, the drag coefficient gets reduced to C_D= 0.003.

10. USE OF DELTA-WING SHAPED VORTEX GENERATOR

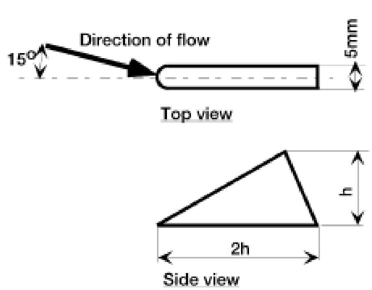


Figure 10.1: Delta-wing shaped vortex generator.

A vortex generator having the shape of a half span delta wing is also advisable, owing to a delta winged aircraft. The vortex generators are installed at an angle of 15° at the center of the vehicle whereas it will be nearly 0° at the outer positions. The reason for such a modification is because the direction of flow will be aligned with the rear end at the center, but it deviates along the sideways moving away from the center.

Vortex generators with three different heights (15 mm, 20 mm and 25 mm) were tested and the reduction in drag were all the same and was equal to 0.006. This shows that delta-wing shaped vortex generators are more effective than bump shaped vortex generators. The reason for such efficiency is because, as the frontal projection area is less for a delta-wing shaped vortex generator compared to the other it will produce less drag by itself. One another reason is that the vortex created by a delta-wing shaped vortex generator does not loses its strength as the flow moves downstream, whereas vortex strength is weakened for a bump shaped vortex generator, since vortex interferes with the bump shape.

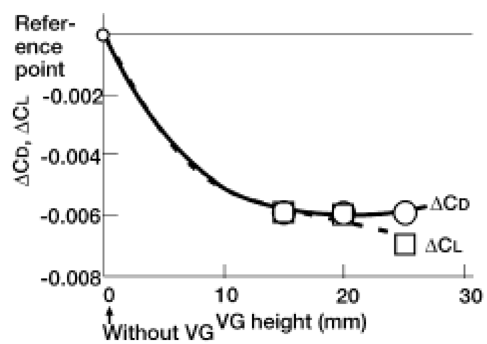


Figure 10.2: Delta-wing shaped vortex generator

11. CONCLUSION

This paper was intended to compare and study the results obtained from various experiments that were adopted to reduce the formation of aerodynamic drag over a vehicle's surface. Generally there are two methods by which the drag over a vehicle surface can be reduced, namely the active methods and passive methods.

The aerodynamic design of a vehicle plays a vital role in reducing the drag. If the body is more blunt it can cause greater generation of drag and making it too sharp can also lead to problems. Active methods involve the action of air jet at critical points of the vehicle surface. Such methods require a little or no shape modifications at all. Whereas passive methods includes the aerodynamic shape changes introduced on the vehicle as well as installation of certain aerodynamic shapes on the vehicle surface.

Rear screens can be used to reduce drag which is a metal plate fixed at the rear end of the vehicle. By installing such a passive device drag could be reduced up to 6.5%, whereas the use of rear fairing which is another passive device that is the aerodynamic extension of a vehicle's rear end could yield drag reduction by up to 26%.

One another method is the usage of vortex generators. Vortex generators are used to create a flow around the vehicle in order to resist the flow separation. Even if vortex generators cause drag by itself overall drag reduction will be obtained after the formation of vortices. Vortex generators are commonly of two shapes – bump shaped and delta wing shaped in which the delta wing shaped is more effective.

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