A

Technical Paper Presentation

On

"Aerodynamic drag reduction techniques"

Submitted by

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CERTIFICATE

This is to certify that **"Takalkar Chetan Ramdas** of B. E Production Sandwich (Exam Seat No:B120087561) has satisfactorily completed his Technical Paper Presentation on **"Aerodynamic drag reduction techniques "** in partial fulfillment of the requirement of BE Production Sandwich Course of Savitribai Phule Pune University during academic year 2018-19.

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Name of Student:

Takalkar Chetan Ramdas

ABSTRACT

This paper discusses about techniques that can be adopted to reduce the aerodynamic drag on vehicles .As Aerodynamic drag is also one of factor which plays a major role in vehicle stability, power consumption and overall efficiency .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. By 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 a plate is fixed behind the back of a car.

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List of Abbreviations

D = Drag Force

ρ= Density of free stream air

V = Velocity of free stream air

A_d= Cross sectional area or drag area

C_d = Coefficient of Drag

R_e= Reynolds number

$\boldsymbol{v}_s$= Speed of the object relative to the fluid

A= Cross sectional area

$\boldsymbol{v}$=Kinematic viscosity of the fluid

F =lift coefficient

1.0 Introduction:

"Aerodynamics" is the branch of fluid dynamics concerned with studying the motion of air, particularly when it interacts with moving objects. There are two major part of aerodynamics, External aerodynamics that deal with flow over the solid body with different shape and second one is internal aerodynamics that deal with flow pass through inner compartment of solid body. Aerodynamic drag is also one of factor which plays a major role in vehicle stability, power consumption and overall efficiency. Aerodynamic drag consist mainly two component skin friction drag and pressure drag. Perfect aerodynamic car not only consume less fuel but also overcome drag exerted by air while running at high speed and also provide good stability and handling behavior.

Aerodynamic drag accounts for a sizable portion of transportation energy consumption. This opposing force can account for more than 60% of power consumed by a ground vehicle. At highway speeds, more than 60% of the useful energy input into the vehicle is dissipated to overcome drag.

The drag force of the vehicle can be reduced by altering the shape of the vehicle. For the ground vehicle this is particularly important due to the large number of vehicles being driven globally. The drag force of the vehicle can be reduced by altering the shape of the vehicle. In many cases the need for a particular form, due to aesthetics or for a specific functionality such as cargo capacity or visibility, overrules the desire to minimize drag.

Understanding the motion of air around an object enables the calculation of forces and moments acting on the object. Typical properties calculated for a flow field include velocity, pressure, density and temperature as a function of position and time. Many researchers and authors have described different forms of drag, possible reasons behind them and several ways of minimizing the drag to improve the Drag reduction of the vehicle

Simulating road conditions has an effect on drag in the wind tunnel and it is concluded that use of smooth immovable screen gives good result for comparative tests. The rear part of the vehicles make large contribution to the total drag and different forms of vehicle rear section has been studied , In an interesting study , effect of variation in front and rear sections of minibus on total drag coefficient was presented. There is a good publication evaluating different designs of vortex generators.

The vehicles operate under different speeds, air flow rate and direction, and road conditions. No one streamline body will minimize drag for all conditions. Therefore, there is need to develop passive devices that will keep drag coefficient low for large range of conditions or active methods that can dynamically change configuration to meet different speeds.

2.0 Theory

2.1 Aerodynamics of Road Vehicles

When the vehicle is moving at an undistributed velocity, the viscous effects in the fluid are Restricted to a thin layer called boundary layer. Outside the boundary layer is the in viscid Flow. This fluid flow imposes pressure force on the boundary layer. When the air reaches the Rear part of the vehicle, the fluid gets detached. Within the boundary layer, the movement of The fluid is totally governed by the viscous effects of the fluid.

The Boundary layer does not exist for the Reynolds number which is lower than 104. Reynolds number is dependent on the characteristic length of the vehicle, the kinematic viscosity and the speed of the vehicle. Apparently, the fluid moving around the vehicle is dependent on the shape of the vehicle and the Reynolds number. There is another important phenomenon which affects the flow of the car and the performance of the vehicle. This phenomenon is commonly known as 'Wake' of the vehicle. When the air moving over the vehicle is separated at the rear end, it leaves a large low pressure turbulent region behind the vehicle known as the wake. This wake contributes to the formation of pressure drag, which is eventually reduces the vehicle performance. Automotive aerodynamics differs from aircraft aerodynamics in several ways. First, the characteristic shape of a road vehicle is much less streamlined compared to an aircraft. Second, the vehicle operates very close to the ground, rather than in free air. Third, the operating speeds are lower (and aerodynamic drag varies as the square of speed). Fourth, a ground vehicle has fewer degrees of freedom than an aircraft, and its motion is less affected

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1.3 Scope Of Automotive Aerodynamics

2.2 Aerodynamic Drag:

In fluid dynamics, drag (sometimes called air resistance, a type of friction, or fluid resistance, another type of friction or fluid friction) is force acting opposite to the relative motion of any object moving with respect to a surrounding fluid. This can exist between two fluid layers
Or a fluid and a solid surface. Unlike other resistive forces, such as dry friction, which are nearly independent of velocity, drag forces depend on velocity. Drag force is proportional to the velocity for a laminar flow and the squared velocity for a turbulent flow. Even though the ultimate cause of a drag is viscous friction, the turbulent drag is independent of viscosity. The drag acting a body can be classified based on its applications. The variation of drag force as a function of airspeed looks like a graph of parabola. This indicates that the drag initially reduces with airspeed, and then increases as the airspeed increases. It demonstrates that there are some parameters that will decrease drag as the velocity increases; and there are some other parameters that will increase drag as the velocity increases.

Drag: $D=\frac{1}{2}\rho V^2 A_d C_d$

Reynolds number: $R_{e=\frac{v\,s}{v}}*D$

2.3 Types of drags:

2.3.1 Skin friction drag:

The drag on a body resulting from viscous shearing stresses (i.e., friction) over its contact surface (i.e., skin). The drag of a very streamlined shape such as a thin, flat plate is frequently expressed in terms of a skin friction drag. Drag is function of Reynolds number The Reynolds number is based on the total length of the object in the direction of the velocity. In a usual application, the boundary layer is normally laminar near the leading edge of the object undergoing transition to a turbulent layer at some distance back along the surface at some distance from the leading edge the laminar boundary becomes unstable and is unable to suppress disturbances imposed on it by surface roughness or fluctuations in the free stream.

2.3.2 Pressure drag:

The drag on a body resulting from the integrated effect of the static pressure acting normal to its surface resolved in the drag direction.

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Sr no	Body	Laminar/Turbulent	C_d
1	Cube	$R_{e.}$>10,000	1.05
2	Thin circular disk	$R_{e.}$>10,000	1.1
3	Cone (30deg.)	$R_{e.}$>10,000	0.5
4	Sphere	Laminar $R_{e.} > 2 \times 10^5$	0.5
5	Ellipsoid	Laminar $R_{e.} > 2 \times 10^5$	0.3
6	Hemisphere	$R_{e.}$>10,000	0.4
7	plate	$R_{e.}$>10,000	1.2

Table 2.1 Effect of body shapes on drag coefficient

2.4 Advantages of Drag Reduction:

1. **Improves fuel efficiency:** Optimizing the shape of a vehicle to reduce aerodynamic Drag can allow vehicle designers to build cars with increased fuel economy. Little effort is needed to reveal the ever-increasing importance of fuel economy for production vehicles.
2. **Improves acceleration:** Due to reduction in overall drag, the resisting forces on the Vehicle which act opposite to the acceleration are minimized, thus gaining speed in no time. This reduces the time required to accelerate to high speeds.

3. **Increases maximum speed limit:** This increases the maximum speed limit resisted by the pressure drag, is also increased. Due to shape modifications, the overall performance of the vehicle can be improved to attain high speeds.

3.0 Literature review:

3.1 Methods of Reducing Vehicle Aerodynamic Drag:
Publisher: Upendra S. Rohatgi
Presented at the ASME 2012 Summer Heat Transfer Conference Puerto Rico, USA July 8-12, 2012

A small scale model (length 1710 mm) of General Motor SUV was built and tested in the wind tunnel for expected wind conditions and road clearance. Two passive devices, rear screen which is plate behind the car and rear fairing where the end of the car is aerodynamically extended, were incorporated in the model and tested in the wind tunnel for different wind conditions. The conclusion is that rear screen could reduce drag up to 6.5% and rear fairing can reduce the drag by 26%. There were additional tests for front edging and rear vortex generators. The results for drag reduction were mixed. It should be noted that there are aesthetic and practical considerations that may allow only partial implementation of these or any drag reduction options.

3.1.1Investigation methods:

The concepts which are broadly explained about the methods of drag reduction are as follows

- Rear Fairing
- Rear screens

Computational Fluid Dynamic (CFD) approach and testing large models in the wind tunnel under simulated conditions are two methods are used for investigation.
The investigations were carried out in wind tunnel TAD-2 of the National Aviation University of Ukraine (NAU). Wind tunnel has the following main characteristics:
1. Maximum speed of air flux in working section without model installed is 42 m/sec
2. Degree of initial turbulence of air flux in working section without model, defined using ball method, is 0.9%
3. Length of working section is 5.5 m
4. Overall dimensions of octagonal working section cross-section are: 4.0 m width, 2.5 m height as shown in fig.3.1

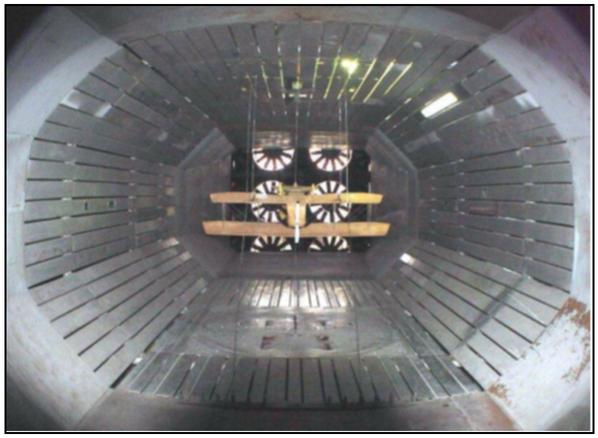

Fig 3.1 Wind Tunnel

Model investigated:

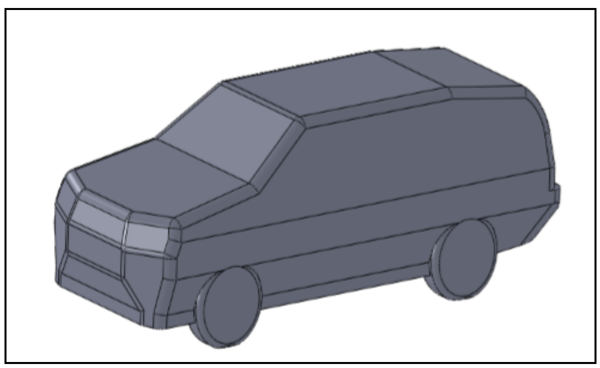

Fig 3.2 Vehicle basic model

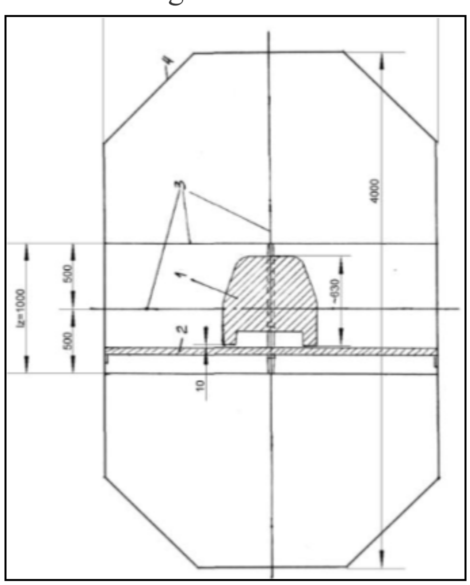

Fig 3.3 Diagram of Vehicle Model Installed in Working Section of Wind Tunnel (front view)

3.1.2 Test a model with rear screen:

The expected effect of aerodynamic drag reducing is achieved for the sake of vortex that originates between vehicle model's rear wall and screen; the vortex enables no-separation flow of external air flux. This results in bottom trace narrowing and thus to reducing of base drag for the sake of pressure increase. The screens were installed at various distances h from model surface. Screen contour took after back view vehicle contour on a scale of *D* =0.6 and 0.8 with the screen thickness of 7.5 mm. Also the tests of screen of 1 mm thick were also considered with similar scale size of rear part contour

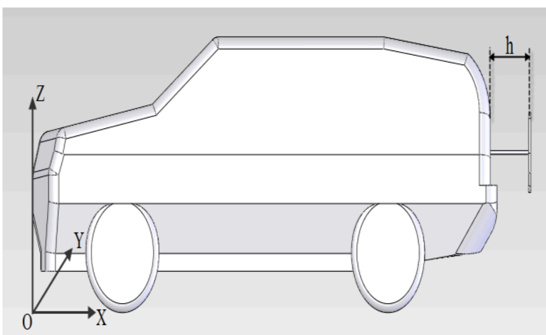

Fig4 Side view of rear screen

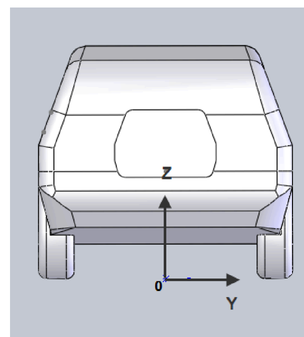

Fig 3.5 Rear view of rear screen

Results:

In all cases use of rear screens reduces vehicle model's aerodynamic drag. Among the investigated cases the most effective one was use of screens $D = 0.6$ and $D = 0.8$ and 0.6 and the resistance decrease was 5.5% to 6.5% (Fig.6).

Visual observation let to see vortex in the clearance between screen and model's rear wall, at least, on top. On sides flux stall was observed directly behind the model. It is worth mentioning that for this vehicle configuration it was not possible to form stable oval vortex in the clearance between screen and model's rear wall, which could provide more aerodynamic drag reducing. Preliminary CFD calculations also showed higher pressure behind the screen that provided additional reduction in opposing force.

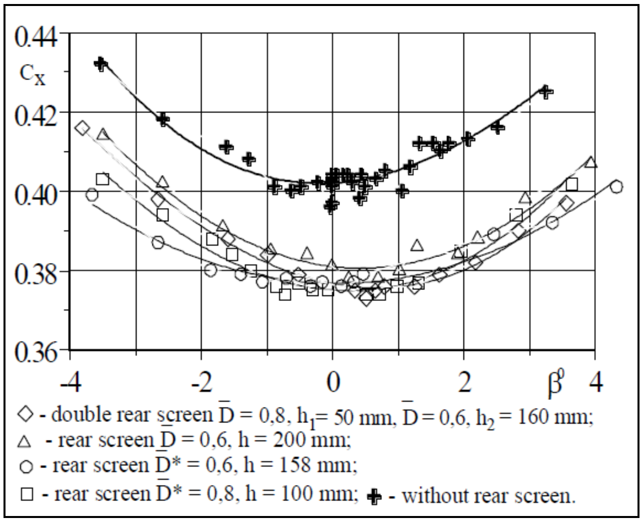

Fig 3.6 Impact of Rear Screen on Aerodynamic Drag Factor Cx

h, mm	Cxmin
224	0.378
200	0.378
158	0.387
100	0.392
Without rear screen	0.402

Table 3.1 Effect of gap on drag coefficient-rear screen □D=0.6

3.1.2 Test model with rear fairing:

Rear fairing, implies a structure in vehicle's back part, included into the separation area, and, in a perfect case, providing no-separation flow of modified configuration vehicle model. The purpose of tests was also obtaining of experimental test base for testing of design methods and analysis of possibility of separated flow design simulation.

Fig 3.7 Vehicle Model with Four-Section Rear Fairing

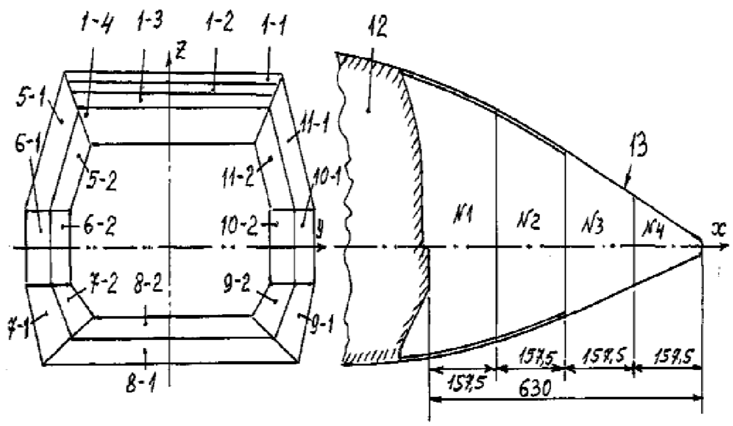

Fig 3.8 Geometry of Rear Fairing

Results:

Use of idealized aft rear fairing for the vehicle model under consideration also showed high efficiency of such a structure. At installation of full-size rear fairing, head aerodynamic drag factor of vehicle model has decreased by26%. Half-length truncated rear fairing also has high aerodynamic efficiency and allows reducing aerodynamic drag factor by 22.6%. At aft rear fairing length being 25% of its full length vehicle model drag factor is reduced by 16.1%.

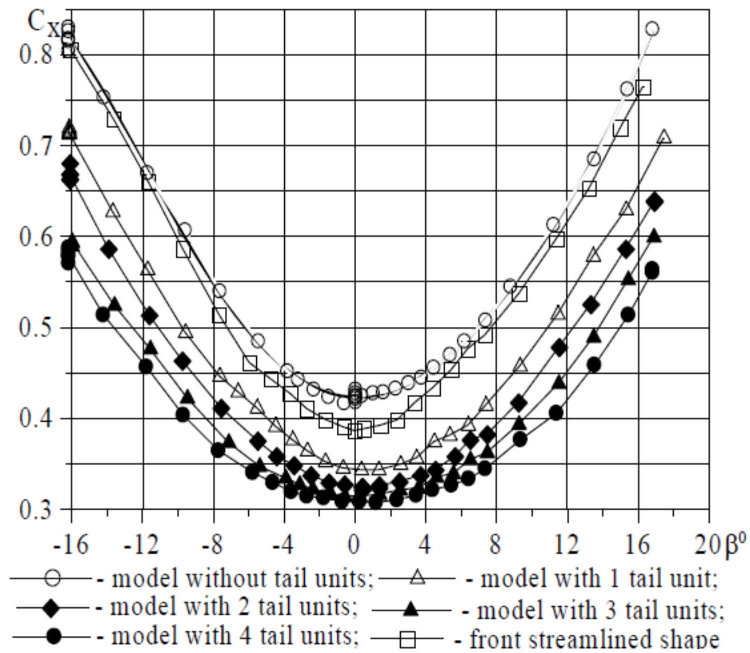

Fig 3.9 Dependencies of Aerodynamic Drag Factor of Slide Angle (base drag coefficient Cx=0.415)

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

L. Anantha Raman, Rahul Hari H.

Journal of Advanced Engineering Research ISSN: 2393-8447 Volume 3, Issue 1, 2016, pp.26-32

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 a plate is 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.

3.2.1 Drag reduction by using vortex generators vortex generators

Is a kind of passive device 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.

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.

Fig 3.10 air flow around sedan

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.

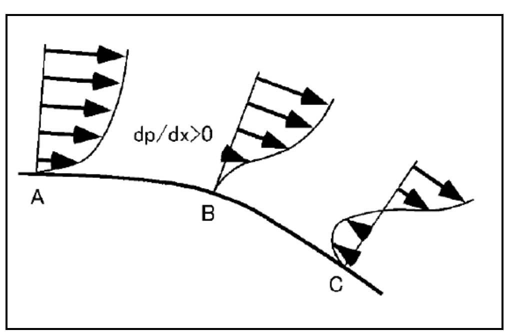

Fig 3.11 Velocity profile at vehicle's rear end

To 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.

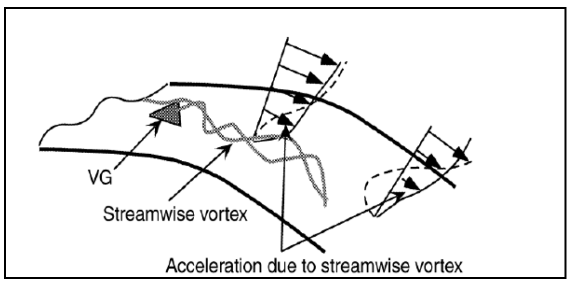

Fig 3.12 Change in flow after installing vortex generator

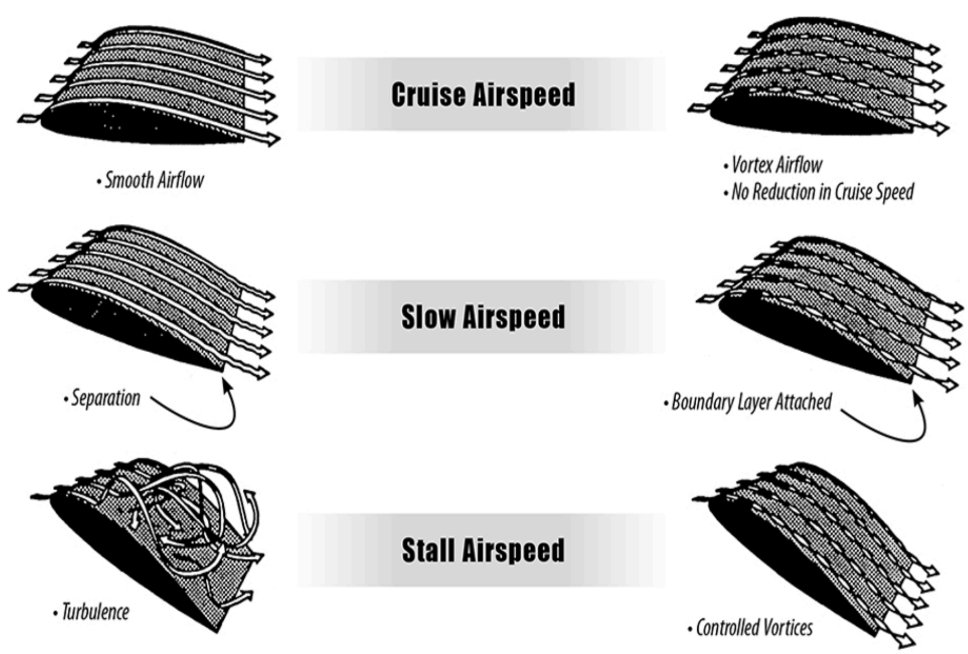

Figure 3.13 Differences in flow with and without vortex generators

3.2.2Advantages:

By using vortex generators at required locations, the following features can be obtained.

1. Lower stall speed
2. Lower approach speed
3. Higher angle of attack
4. Gentle stall characteristics
5. Increased stability at low speeds
6. More effective control
7. Easy and quick installation

3.2.3Types of vortex generator:

3.2.3.1. Bump shaped vortex generator

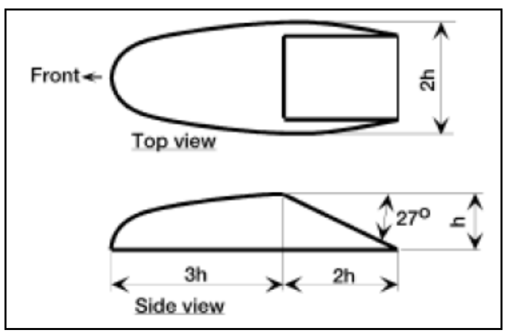

Fig 3.14 Bump shaped vortex generator

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.

Results:

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 13and 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 CD= 0.003.

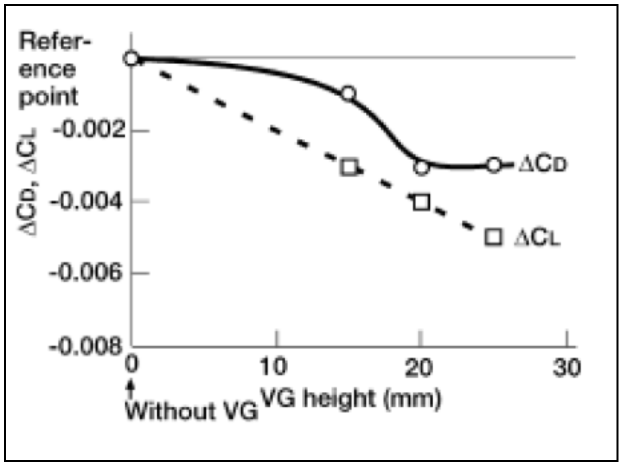

Fig 3.15 Effects of using a bump shaped vortex generator

3.2.3.2. Delta wing shape vortex generator:

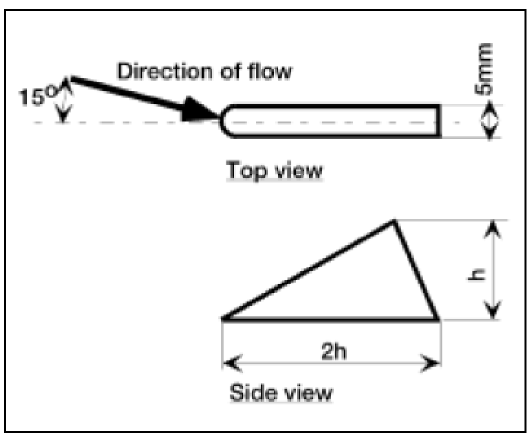

Figure 3.16 Delta-wing shaped vortex generator.

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 was all the same and was equal to 0.006.

Results:

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.

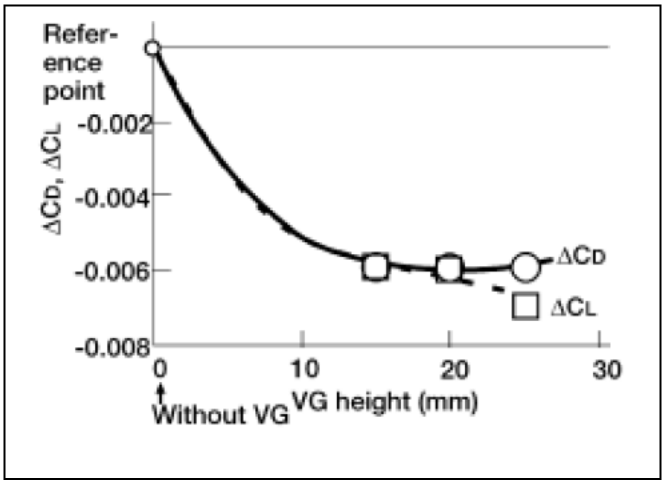

Figure 3.17 Delta-wing shaped vortex generator

4.0 Future scope of automotive aerodynamic drag reduction:

by aerodynamic forces. Fifth, passenger and commercial ground vehicles have very specific 3

design constraints such as their intended purpose

Aerodynamic characteristics of ground vehicles are responsible for all properties from energy efficiency to aerodynamic drag and safety to environmental influence of vehicles on their surroundings including air pollution and noise. Prediction of aerodynamic properties of ground vehicles is a complicated task and both numerical and experimental techniques are required for accurate predictions and understanding of the flow behaviour. The reduction of vehicle drag is a key motor for improvement of numerical and experimental tools. However, there are many other aerodynamic aspects such as crosswind stability, unsteadiness from passages of tunnels, platforms or other vehicles, ballast projection for high-speed trains, aero acoustics and soiling which require new improved approaches in flow predictions. More advanced facilities and experimental techniques have been developed on the experimental side. Introduction of time-dependent simulations is the most important improvement in the numerical vehicle aerodynamics. Both approaches are today used in development of techniques for improvement of vehicle properties by flow control or aerodynamic shape optimization. Aerodynamics is used by design engineers for cooling the engines, improving the performance of the vehicle, enhancing the comfort of the rider, stabilizing the car in external wind conditions and also increasing the visibility of the rider.

5.0 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. Passive methods include 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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