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Drag Reduction of a Car by Using Vortex Generator

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Abstract— Any physical body being propelled through the air has drag associated with it. In aerodynamics, drag is defined as the force that opposes forward motion through the atmosphere and is parallel to the direction of the free-stream velocity of the airflow. Drag must be overcome by thrust in order to achieve forward motion. Drag is generated by motion of air particles over the aircraft. There are several types of drag: pressure, skin friction, parasite, induced, and wave. A vortex generator is an aerodynamic surface, consisting of a small vane or bump that creates a vortex .Vortex generators can be found on many devices, but the term is most often used in aircraft design .Vortex generators delay flow separation and aerodynamic stalling; they improve the effectiveness of control surfaces [2]. The boundary layer normally thickens as it moves along the aircraft surface, reducing the effectiveness of trailing-edge control surfaces, vortex generators can be used to remedy this problem, among others, by "re-energizing the boundary layer". The goal of research is to delay flow separation on the downstream side on the roof of the car on account of decreasing pressure difference between the upstream and downstream sides by creating vortex at the rear end of the car roof . So vortex generators are commonly used on aircrafts to prevent downstream flow separation and improve their overall performance by reducing drag.

Index Terms— Vortex Generator, Delta Wings, Flow Visualization technique, Aerodynamics Properties enhancement.

1 Introduction

Every moving Physical body having relative motion with other fluid must associated with drag force which should be overcome by thrust in order to achieve forward motion. Air particles over the aircraft makes different types of drag i.e. pressure, skin friction, parasite, induced, and wave. A vortex generator is an aerodynamic surface, consisting of a small vane or bump that creates a vortex .Vortex generators can be found on many devices, but the term is most often used in aircraft design .Vortex Generator was first introduced in England but who invented is unknown. Vortex Generator was first used on Transport Jets and Biz jets. It was used as a "band-aid" for localized mach buffeting problems. The first GA application was on Cessna 206 and Baron D-55 [1]. A vortex generator creates a tip vortex which draws energetic, rapidly-moving air from outside the slow-moving boundary layer into contact with the aircraft skin. The boundary layer normally thickens as it moves along the aircraft surface, reducing the effectiveness of trailing-edge control surfaces; vortex generators can be used to remedy this problem, among others, by "re-energizing the boundary layer".

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To save energy and to protect the global environment, fuel consumption reduction is primary concern of automotive development. In vehicle body development, reduction of drag is essential for improving fuel consumption and driving performance, and if an aerodynamically refined body is also aesthetically attractive, it will contribute much to increase the vehicle's appeal to potential customers. However, as the passenger car must have enough capacity to accommodate passengers and baggage in addition to minimum necessary space for its engine and other components, it is extremely difficult to realize an aerodynamically ideal body shape. The car is, therefore, obliged to have a body shape that is rather aero-dynamically bluff, not an ideal streamline shape as seen on fish and birds. Such a body shape is inevitably accompanied by flow separation at the rear end. The passenger car body's aerodynamic bluffness, when expressed by the drag coefficient (CD), is generally between 0.2 and 0.5, while that of more bluff cubic objects is greater than 1.0 and that of the least bluff bullets is less than 0.1 [5]. Two elements that have major influence on the drag coefficient of a bluff object are the roundness of its front corners and the degree of taper at its rear end. Because of the presence of a trunk at the rear, the flow separates at the roof end and then spreads downward. As a result, the flow around the car is similar to that around a streamline-shaped object with a taper at the rear. For this reason, a vehicle with a trunk tends to have smaller drag coefficient value than a wagon-type car. In other words, taper at the rear has the effect of delaying flow separation (or shifting the flow separation point downstream).

2 Methodology

Vortex generators were studied to install immediately upstream of the flow separation point in order to control separation of airflow above the vehicle's rear window and improve the aerodynamic characteristics. To delay flow separation, bump shaped vortex generators are tested for application to the roof end of a sedan [5]. Commonly used on aircraft to prevent flow separation, vortex generators themselves create drag, but they also reduce drag by preventing flow separation at downstream. The overall effect of vortex generators can be measured by totaling the positive and negative effects. So the effectiveness of the delta-wing-shaped VG is more than bump shaped vortex generator. The reason for why delta-wing-shaped VGs are more effective than bump-shaped VGs can be explained as follows: Delta-wing-shaped VGs have a smaller frontal projection area, which means that they themselves create smaller drag [3]. Moreover, the vortex generated at the edge of a delta-wing-shaped VG keeps its strength in the flow downstream of the edge since it barely interferes with the VG itself because of the VG's platy form [4]. With bump-shaped VGs, on the other hand, the vortex is generated at a point close to the downstream edge of the bump, which causes the vortex to interfere with the bump and lose its strength Many aircraft carry vane vortex generators from time of manufacture, but there are also after-market suppliers who sell VG kits to improve the STOL performance of some light aircraft [2]. Installation of vortex generators can usually bring about a slight reduction in stalling speed of an airplane and therefore reduce the required one-engine-inoperative climb performance. The reduced requirement for climb performance allows an increase in maximum takeoff weight, at least up to the maximum weight allowed by structural requirements [7].

Flow Visualization is a powerful tool in experimental fluid mechanics. The unique advantage of this technique is that certain properties of the flow field become directly accessible to visual perception and the insight into a physical process becomes clearer. Most fluids are transparent media and their motion remains invisible to the human eye during direct observations. However, the motion of such fluids can be recognized by making use of techniques by which the flow is made visible and such techniques are called flow visualization techniques.

It is also possible to derive quantitative data from the flow pictures obtained by such techniques. Information about the complete flow field can be arrived without physically interfering with fluid flows. Flow measuring methods involve the use of a sensing device or probe causing disturbance to the flow field. Also probe measurements provide data at only one point at any given instant. It is therefore necessary to introduce a number of probes to collect data from many points in a section at any given instant. Introduction of a number of probes may completely change the flow conditions. Such difficulties can be overcome by use of flow visualization techniques.

The methods of flow visualization can be normally classified into three groups (l) Injection of foreign material to the flowing fluid, (2) Optical method for compressible flows, and (3) Introduction of contaminants in the form of heat or electrical energy.

First methods involve foreign material which involves hydrogen bubble if water is the flowing medium since the basic process involved is electrolysis of water. This process needs a electrolysis process in which Very thin wires produce very small hydrogen bubbles in size and the buoyancy forces become negligible compared to hydrodynamic drag forces causing little disturbance of actual flow conditions. That is why this process has some bindings in flow visualization.

For the purpose of visualization in air in wind tunnel experiments smoke lines are used in the same way as dyes and other injecting materials in liquid flows. Smoke is usually generated by vaporization of a mineral oil or by the burning or smoldering of wood, paper or tobacco. Velocity profiles can also be visualized in liquids and air by electrolytic and photochemical dye production. Controlled rate of dye production is done electrically to determine the time and magnitude of voltage applied between electrodes. The dye production can be carried out at all points or along a defined curve, but exact temporal control should be maintained for better and accurate results. Recent developments indicate that smoke visualization in wind tunnels, one of the oldest flow visualization techniques, will continue as an important experimental tool in the study of complex flow dynamic phenomena.

Improvements in generation and injection of smoke as well as in lighting (laser as a light source), in techniques of acquisition and computation have continued to increase the scientific value of this method. Similar results are obtained by flow visualizations with fog and vapor.The smoke can be very useful in a wind tunnel with low turbulence. There exists no upper limit of speed for smoke line visualization (it was possible to extend the range of smoke line visualization even to supersonic flow velocities). Smoke line can be generated in a wind tunnel (smoke tunnel) by introducing smoke (produced by smoke generated devices) through small pipes placed in front of a test model, or through holes on the model surface. The choice of using smoke in a wind tunnel depends on several aspects. The smoke must be dense and white for visibility, non toxic and non corrosive. The quality of the observed or photographed smoke line depends also on the choice of the illumination system.

There are three basic types of smoke suitable for wind tunnel experiments: smoke generated by the vaporization of a mineral oil (paraffin, kerosene) mist resulting from the vaporization of certain substances containing bromide or chloride and smoke from burning or smoldering wood, paper or tobacco. The burning or vaporization is done in a smoke generator.

3 Modification and Experimental Setup

3.1 Modification

The selected car model for this experiment had to extend on its rear end for supporting the flow, because of visualizing the effect of flow separation without and with vortex generator. Around 2 inch has been extended on its rear end.

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Fig 1. Experimental model of car

To select appropriate shape and size of the VG which generates stream wise vortex the most efficiently (with the least drag by itself) is important to achieve objectives. In connection with the size, the thickness of the boundary layer is measured based on the assumption that the optimum height of the VG would be nearly equal to the boundary layer thickness. From the calculation, the boundary layer thickness at the roof end immediately in front of the separation point is about 5 mm. Consequently, the optimum height for the VG is estimated to be up to approximately 5 mm.

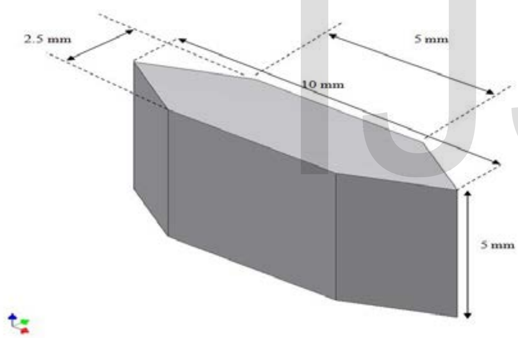

Fig 2. 3D View of Vortex generators with dimensions.

The quick and easy 3 step installation can be found on each guide. Below is the expanded version where only need alcohol and everyday household tape to avoid hurting of vehicles paint job. The air flow separation point is when the air flowing over the car hits the point where the cars body design declines. On most vehicles it's the point where the rear of the roof transitions to the back windshield. The optimal point of installation would be 100MM before the air flow separation point. On many vehicles the point is 100MM from their roofline. In the case of a dome shaped vehicle the Vortex Generators Delta Wings should be optimally placed 100MM before the highest point in the roof and will need to be lined up accordingly.

3.2 Procedure to install

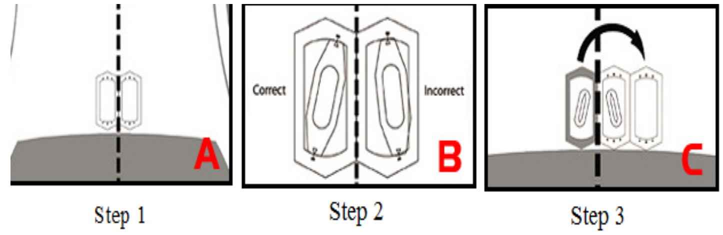

Fig 3. Steps of Installation

Step-1
The surface of the roofline was cleaned with alcohol and the center line of the vehicle was found. The guides were Punched out along the perforations, only the two middle pieces were needed for installation. Guides flush on both sides with edge resting on the roofline was placed (A). Taping down the guides helped keeping them in place as moving on to Step 2.

Step-2
The inner guide was rotated to the desired placement degree. It was made sure to line up the degrees on both sides for proper alignment (B). Recommended degree chart below for the angle of each wing was used. One side of the 3M pad was stripped off and attached it to the Delta Wing inside the outer lip. Then the other side of the pad was removed and placed Delta Wing in the center of the guide and press down firmly for 20-30 second around the base of the Delta Wing.

Step-3
Keeping one guide in place, the second guide to it's opposite side was shifted(C). Repeated Step 1 and 2 was done until one side of the car finished. Then mirror the angles on the opposite side of the center line was done. It can also print out additional guides from the downloads section below and layout multiple guides alongside each other for even quicker results.

Fig 4. Experimental model of car with vortex generator

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A sub-sonic wind tunnel was used for this experiment in Fluid Mechanics lab, Department of Mechanical engineering at KUET.. Flow visualization can be done in many ways. "Smoke wire" method is one of them. In this experiment, the effect of drag reduction was visualized by "Smoke-wire" method. Here voltage was applied on two sides of a Tungsten wire by using Voltage regulator. The main reason of choosing Tungsten wire is that, it has a very high melting point, almost 3695 K. A mixer of Caster oil and Paraphin was used for creating smoke in the testing section. Here paraphin creates smoke and caster oil is used to increase the viscosity of the mixer. The ratio of caster oil and paraphin used in the mixer was 1:3. For creating smoke on the testing section the velocity of the air was 2 m/s and the voltage applied was 2 volts. A clamping device of 12 inch long, 7 inch width and depth of 1.5 inch was used to keep the car in place. The experimental setup of the experiment is shown below by a schematic figure.

Fig 5. Experimental Setup of Car model with Vortex generator under sub sonic Wind tunnel

In connection with the size, the thickness of the boundary layer is measured based on the assumption that the optimum height of the VG would be nearly equal to the boundary layer thickness [2].

For laminar flow boundary layer thickness δ can be written as,

$$\delta = 5\sqrt{\frac{xv}{V}} \tag{1}$$

Where,
x = Length to the point of flow separation

In order to check whether the drag is reducing or not, drag force for the model both with and without vortex generator was calculated from the drag balance of wind tunnel. From the experimental values plotting coefficient of drag Vs Reynolds number graph was plotted.

Drag force is calculated by using formula,

$$F_d = \frac{1}{2} C_d A \rho v^2 \tag{2}$$

Reynolds number calculated by using formula,

$$R_e = \frac{V\,l}{v} \tag{3}$$

Here,
A = Surface area, 0.024 m^2
v = Free steam velocity of air
F_d = Drag force
ρ = Density of air
ν = Kinematic viscosity of air

TABLE 1
Experimental data for without vortex generator

Velocity, V (m/s)	Drag force, F_d (N)	Reynolds number, Re x 10^4	Coefficient of drag C_d
0.9	0.08	1.2	6.859
1.8	0.15	2.4	3.215
2.8	0.26	3.7	2.303
3.8	0.40	5.06	1.924
4.8	0.81	6.4	2.441

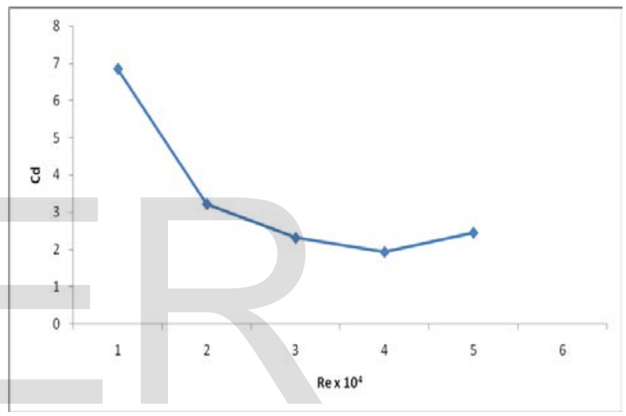

Fig 6. Reynolds number (Re) Vs Coefficient of drag graph without vortex generator

TABLE 2
Experimental data for with vortex generator

Velocity, V (m/s)	Drag force, F_d (N)	Reynolds number, Re x 10^4	Coefficient of drag C_d
0.9	0.07	1.2	6.001
1.8	0.14	2.4	3.00
2.8	0.23	3.7	2.037
3.8	0.37	5.06	1.779
4.8	0.79	6.4	2.381

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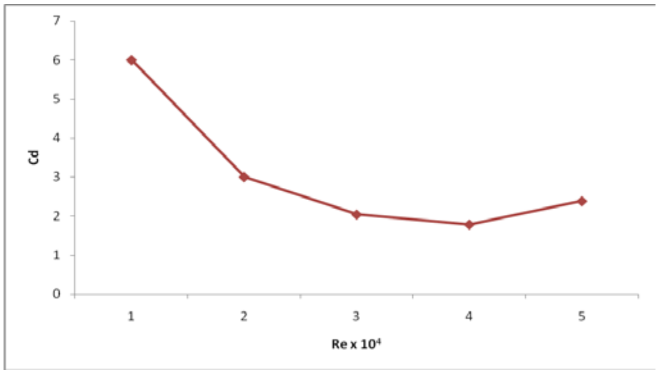

Fig 7. Reynolds number (Re) Vs Coefficient of drag (Cd) graph with vortex generator

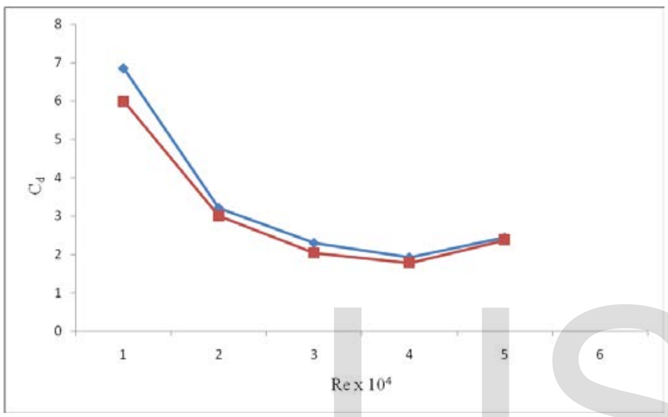

Fig 8. Comparison of Cd between with vortex and without vortex Generator

4 RESULT AND DISCUSSION

Here from the experimental figures it can be clearly seen that the flow is getting separated at its rear end when no vortex generators are used at its rear end. On the other hand the separation of flow is being controlled when the Vortex generators were installed at its rear end.

From figure 6 and figure 7, it is clear that the Cd is decreasing with the increase of Re for both with and without vortex generator. For comparison, figure 8 is given here. Here for a fixed Re, Cd with vortex generator is less than, Cd without vortex generator. This indicates reduction of drag because of the vortex generator. Vortex generator has a vital role in increasing the fuel economy and aerodynamic stability. This enables them reduce the drag force acting on it. Vortex generators are used to put energy back into the boundary layer, so causing the airflow to better stick to the body on the transition from the roof to the rear window. Vortex generators (VGs) were studied to install immediately upstream of the flow separation point in order to control separation of airflow above the sedan's rear window and improve the aerodynamic characteristics.

5 CONCLUSION

Vortex generators (VGs) were studied to install immediately upstream of the flow separation point in order to control separation of airflow above the vehicle's rear window and improve the aerodynamic characteristics. Vortex generators on cars can achieve measurable, scientifically proven improvements in car aerodynamics reducing both lift and drag. Even a single vortex generator will alter local flow behavior, something to keep in mind when considering airflow into bonnet scoops and at specific problem areas. Positive gains can be achieved only by practical experimentation. Vortex generators are easy to temporarily stick into place with masking tape, and just as easily removed if they are not achieving the desired result. The use of vortex generators under cars has zero visual impact and looks to have excellent potential for reducing lift without increasing drag. In this experiment coefficient of drag is reduced 0.215 by using vortex generator.

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