Performance Evaluation of Vortex Generator for Drag Reduction in Automobiles

Akhila Rupesh, Maddireddy Greeshma, and Sabiha Parveen

Abstract The world is facing a serious challenge of global warming. The scientist estimates 1.5 °C rise in global temperature till 2025 due to the pollution in various sectors. The automobiles, the key component of the world's growth, account nearly 45–75% of the total pollution and have a major scope of transformation. This problem can be solved by using alternative/renewable fuels or using the aerodynamic principles. In this article, 'vortex generators,' an application of aerodynamic solutions is studied using computational method for drag reduction. Vortex generator is a very tiny and cost-effective instrument has shown its applications in the airplane performance and the Formula 1 front wing. Vortex generators reduce the air resistance of the car by delaying the flow separation at the rear of the car. It uses the momentum transfer principle to delay the flow separation. It enables the boundary layer to overcome the skin resistance. The vortex generators are available in various shapes, among them six major types are tested in this study. An Audi A4 model is used for the testing purposes and modeled in the SOLIDWORKS software. The A4 is a 5 seater Sedan and has a length of 4726 mm, width of 1842 mm and a wheelbase of 2820 mm. The three types of vortex generators are applied on the model and tested in the computational fluid dynamics model using ANSYS workbench module. The computational results are compared with the original car at various speed and the iterations of the heights. The results are compared in terms of drag, lift, velocity distribution, pressure distribution and streamline visualization. The vortex generator improves the aerodynamic performance of the car with the 10% of the drag reduction. This will improve the fuel efficiency of the sedan automobiles and reduction in the CO_2 emission without adding any significant cost in manufacturing.

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P. Joshi et al. (eds.), *Advances in Engineering Design*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-33-4684-0_16

Keywords Aerodynamics · Flow separation · Vortex generator (VG) · Computational fluid dynamics

1 Introduction

The invention of the engine and the evolution of the automobiles are termed as the greatest revolutions in the history of mankind. It enables fast transportations and brought the world closer to each other. The automobiles are the greatest contributor of today's economic activity and prosperity of the world. Automobiles have played a key role in improving the standards of human lifestyle.

The coin has two sides. The automobiles also come with the major drawback of hazardous pollution due to tailpipe emission. In India, the automobiles contribute nearly to 45–75% of the overall air pollution [1]. The world remains ignorant about the dangerous effect of the tailpipe emission, but at the end of the twentieth century, it starts to show its adverse effects. The major developed cities facing smoke problem affecting the visibility and human health of the citizen. The world remains eye opening after the discovery of 'ozone layer depletion.'

Global warming is putting questions on the existence of the island countries and health of citizens. The scientist believes the unpredictable behavior of nature and severe droughts in many parts of the world and just a trailer and picture will be awful if proper and stricter actions are not taken. This brings global lawmaker to the table and to develop policies like 'Paris Accord'. These problems concern with an automobile can be solved by hybrid and electric car, low emission alternating fuels and aerodynamic solutions.

This paper deals with the aerodynamic solution for the reduction of the emissions.

2 Methodology

The methodology is based on the study of 'vortex generators,' their various types and its effectiveness in the drag reduction. This is achieved by delaying the flow separations at the rear of the sedan automobile. The flow separation is delayed by tripping or the energizing the boundary layer developed around the profile of the automobile. The delay in the flow separation helps to reduce the low-pressure area which develops at the rear end [2, 3]. The low-pressure area is the major reason for the drag generation. The vortex generators energize the boundary layer at the possible position of the flow separation by momentum transfer phenomenon [4]. This phenomenon makes boundary layer capable of overcoming the surface friction and hence delays the flow separations.

The vortex generators are very smart and cost-effective aerodynamic tool which helps to reduce the drag of the automobile and also helps to increase the downforce without adding any drag [5]. The aviation sector and the pinnacle of automobile research 'Formula 1' also using the application of vortex generators for the same outputs. The vortex generator allows efficient use of engine power and thus it is a beneficial solution to the instability in the Middle East and fuel prices are rising. The use of vortex generator is also beneficial for solar/electric cars as it allows the efficient use of battery energy and helps to improve the range without increasing the battery capacity.

2.1 Phenomenon of Flow Separation

When air comes in contact with the sedan car, it develops a boundary layer across the contour of the car. The air in contact with car experienced surface resistance which makes the velocity of air zero known as stagnation point. The air flow follows the contour of the car but experiences the difficulty to remains in contact with the car. This is because the increase in the surface resistance and the pressure at the rear of the car where geometry changes suddenly [6]. This results in flow separation at the rear of the car. The flow separation causes vortices at the rear of the car which develops a low-pressure area. This low-pressure area is largest constitute of a drag force and needs to minimize to reduce the drag by delaying flow separation [7, 8]. The vortex generators, a tiny device helps to delay the flow separations by creating turbulence at the surface level. This causes a phenomenon called 'momentum transfer' which adds up extra energy in the surface layer and helps to overcome the surface resistance, and thus delay the flow separation. This principle of delaying flow separation can be also seen on the potholes on the golf ball.

To check the effectiveness of vortex generator for the aerodynamic benefits like reduction in drag and increase in downforce, an Audi A4 model is selected. The modeling of the vehicle is done in the SOLIDWORKS software as shown in Fig. 1.

To find the dimension of the vortex generator initially, the Reynolds number for the vehicle at 30 m/s is calculated. Reynolds number, $\text{Re} = v \times \frac{L}{\mu} = 9502358$ where, V = velocity of the car = 30 m/s; L = length at point of separation = 3.5 m and μ = kinematic viscosity = 1.511×10^{-5}. This followed by calculating height of

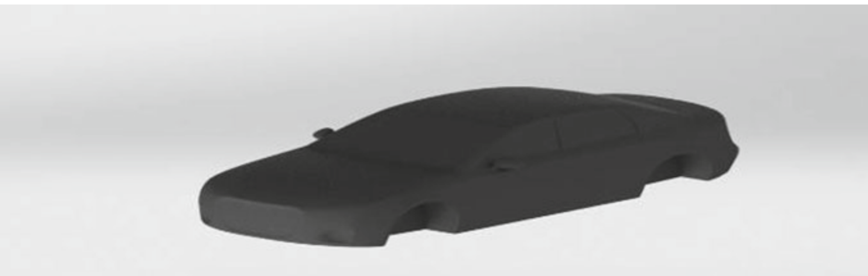


Fig. 1 Modeled car in SOLIDWORKS

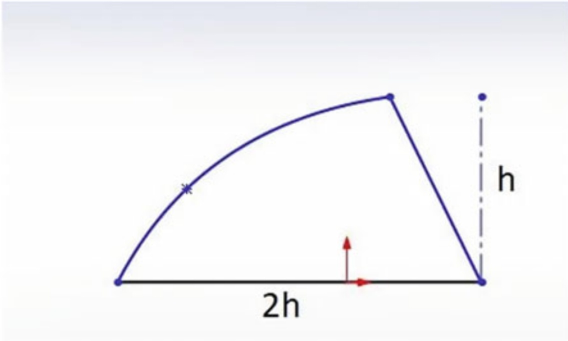


Fig. 2 Designing parameter of vortex generator

the boundary layer in the Y-axis. BL Thickness $= 5 \times \frac{L}{\sqrt{\mathrm{Re}}} = 6$ mm [8]. By the principle of VG, height of VG = height of boundary layer [4], the 6 mm is selected as a reference height for the iterations (Fig. 2).

There are basically three types of the vortex generators studied in this paper. Among them, bump-shaped VG is selected for the initial iterations. The bump-shaped VG is then tested at a various height ranging from 2 to 30 mm using ANSYS FLUENT model, and the values of drag and downforce are then compared with the original model. The vortex generators are placed at the rear side of the car, where flow is prone to separated due to sudden geometry change [4]. The position of the flow separations is observed with computational streamline results (Fig. 3). The result indicates the zone for height ranging 2–6 mm is favorable for the drag reduction. The remaining VGs are then tested for this height variation. The results of all the vortex generators are then tabulated and compared themselves for the drag and downforce values. The best performing VG among all is further compared with the original car at the various speed of 10, 20, 30, 35 m/s as shown in Table 1. The results are also displaced with the help of pressure distribution, velocity distribution and streamlines

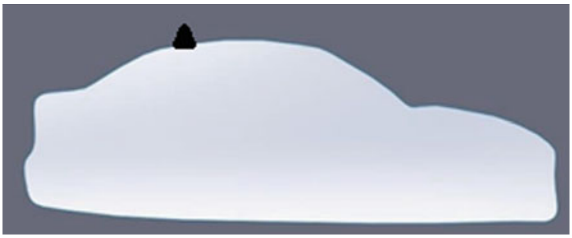


Fig. 3 Positioning of vortex generator

Table 1 Drag and lift of car without VG

Velocity	10 m/s	20 m/s	30 m/s	35 m/s
Drag (N)	17.3029	66.046	144.732	189.83
Lift	-8.17	−38.844	−95.04	−132.108

visualization. The results will be validated in terms of streamline flow, pressure and velocity distribution. The study of point of separation will be carried out using a streamline visualization technique.

3 Result and Discussion

The computational results of the car without application of the vortex generator are shown as follows:

The flow separates rapidly at the rear end with the increase in the speed as it is unable to follow the contour with increases in the speed. This leads to the more low-pressure area and thus the drag (Fig. 4).

3.1 Bump-Shaped VG

The computational results of the car with bump-shaped VG (Fig. 5) at 30 m/s are shown in Fig. 6.

From Table 2, it is clear that the optimum usage of VG's height from 2 mm to 6 m, if it further increase the vortex generator produces the self-drag due to momentum transfer phenomenon where VG helps to overcome the surface friction with added

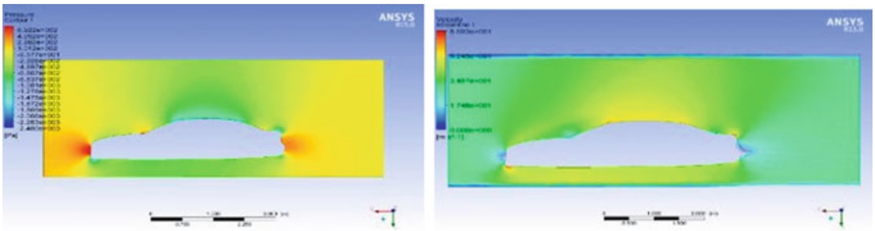
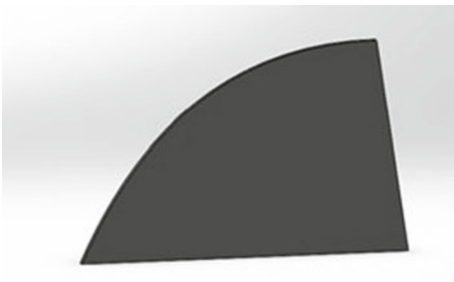


Fig. 4 Pressure and velocity distribution without VG at 30 m/s

Fig. 5 Bump-shaped VG



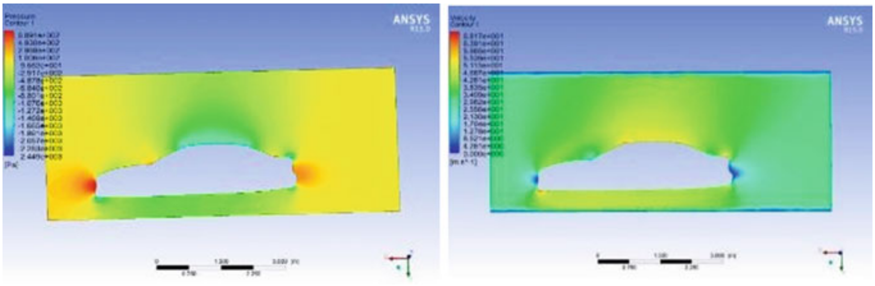


Fig. 6 Velocity and pressure distribution with bump VG of 6 mm height at 30 m/s

Table 2 Lift and drag of car with bump VG at 30 m/s

Height	2 mm	4 mm	6 mm
Drag(N)	139.303	142.83	142.83
Lift(N)	−95.32	−94.318	−112.118

velocity. The effect gets diminishes with height as the vortex generator produces self-drag.

3.2 Delta-Shaped VG

The computational results of the car with delta-shaped VG (Fig. 7) at 30 m/s are shown as follows:

Fig. 7 Delta-shaped VG

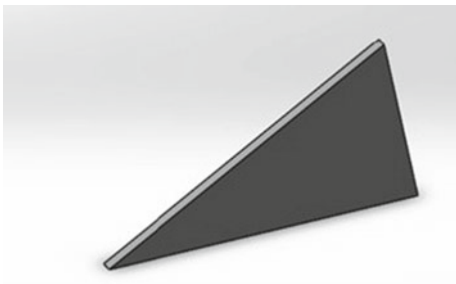


Table 3 Lift and drag of car with delta VG at 30 m/s

Height	2 mm	4 mm	6 mm
Drag(N)	144.054	150.271	152.495
Lift(N)	−69.451	−71.84	−73.15

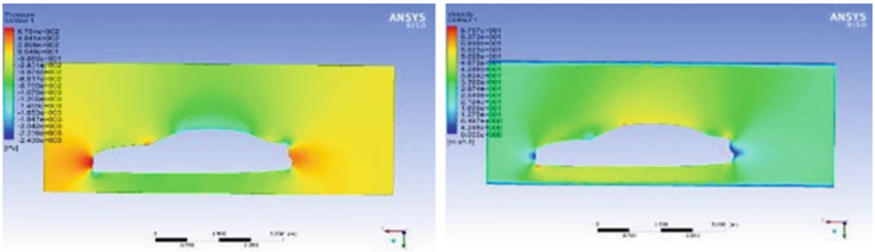


Fig. 8 Velocity and pressure distribution with delta VG of 6 mm height at 30 m/s

Table 3 shows the drag and lift values at 30 m/s, and Fig. 8 shows the velocity and pressure distribution with delta VG of 6 mm height at 30 m/s

3.3 Triangle-Shaped VG

The computational results of the car with triangle-shaped VG (Fig. 9) at 30 m/s are shown as follows:

The triangular-shaped VG shows the superior performance. The low-pressure area is decreased considerably due to delay in the effective flow separation. This is can be seen from the velocity distribution in Fig. 10 where a large rise in the velocity occurs at the upper contour of the car. The 6 mm height VG shows around 10% reduction in the drag without the expense the downforce performance. The triangular VG's vortices form at the separation point and are not harming the drag performance. Table 4 shows the lift and drag of car with triangle VG at 30 m/s.

Figure 11 shows the comparison between drag produced when bump, delta and triangle VG are evaluated at 30 m/s.

Fig. 9 Triangle-shaped VG

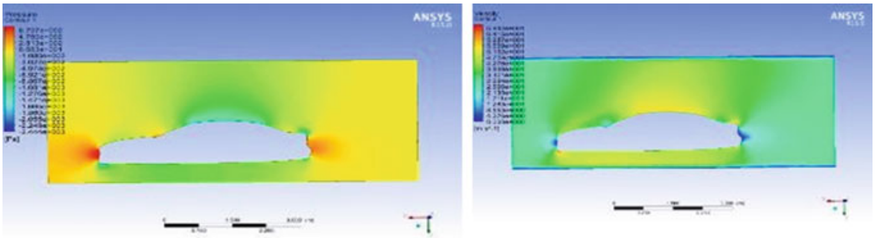


Fig. 10 Velocity and pressure distribution with triangle VG of 6 mm height at 30 m/s

Table 4 Lift and drag of car with triangle VG at 30 m/s

Height	2 mm	4 mm	6 mm
Drag(N)	142.78	138.013	130.92
Lift(N)	−101.35	−72.9205	−97.7816

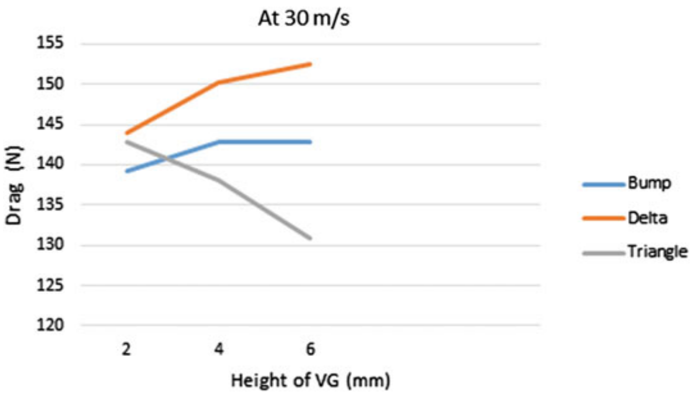


Fig. 11 Comparison between different types of VG at 30 m/s

After comparing the results obtained in Tables 2, 3 and 4 with original values in Table 1, it is very evident that the triangular-shaped VG shows the superior performance among the above VG. The low-pressure area is decreased considerably due to delayed in the effective flow separation. This can be seen from velocity distribution figure where large raise in velocity occurs at the upper contour of the car. It is evident that the triangular vortex generator with 6 mm of height shows excellent performance in terms of drag and downforce. Hence, these parameters of rectangular vortex generator are tested at a different speed and compared with the original results as in Table 5.

From the Table 5, the application of triangle-shaped vortex generator helps to reduce the drag force up to 10% without hampering downforce performance.

Table 5 Drag comparison with and without applications of vortex generators

Spec.	Without vg (10 m/s)	Triangle (10 m/s)	Without vg (20 m/s)	Triangle (20 m/s)	Without vg (30 m/s)	Triangle (30 m/s)	Without vg‘ (35 m/s)
Drag(N)	17.3029	15.646	66.046	61.561	144.732	130.92	175.183
Lift(N)	−8.17	−8.65	−38.844	−40.533	−95.04	−97.786	−132.108

4 Conclusion

As vertex generators are used for drag reduction selection of VG design and shape plays a vital role for optimum reduction of drag. Among four discussed designs of VG's above, the triangle-shaped vortex generator gives the best results. As the VG height raises above the height of boundary layer. The VG's height ranges from 2 to 6 mm, if the height exceeds this range self-drag gets added. From this paper, we conclude that results with triangle-shaped vortex generator with height 6 mm shows excellent characteristics of drag reduction without hampering the performance of the downforce.

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