Aerodynamic Effects of Rear Spoiler and Vortex Generators on Passenger Cars

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ABSTRACT

For high speed passenger cars, the aerodynamic pressure drag is predominant due to the flow separation particularly on the rear window and on the wheel base. One of the main causes of aerodynamic drag for passenger cars is the separation of flow near the vehicle’s rear end. Large energy losses are often associated with boundary layer separation. The main design goal of a ‘rear spoiler’ in passenger vehicles is to reduce drag at its rear and thereby increasing fuel efficiency. The present investigation is focused on flow control by vortex generators (VG) in combination with the rear spoiler. A test facility is developed to realistically simulate the flow around a geometrically similar, 15:1 reduced scale PoP clay model of a high-speed SEDAN car tested in wind tunnel.

A total of 26 combinations are tested for the car model by changing the flow angles, spoiler angles and orientations of vortex generators (co-rotating and counter-rotating). A marked improvement in static pressure along the car roof, especially at the rear is noticed at a flow angle −30° by subsequent use of rear spoiler at angle = +45° and co-rotating vortex generators. It can be seen in that in general, the surface pressure coefficients are positive and reasonably uniform over the windward face (the side facing the airflow) of the car. It is also observed that suction is present on the roof of the vehicle, and this suction tend to increase from the front to rear of the vehicle. The best combination in terms of pressure coefficient rise (by over 92%) is found while the car is facing wind at a flow angle of 0° and is combined with spoiler at an angle of 0° with co-rotating vortex generators attached at the upstream of the spoiler (x/L = 0.733). For the car with flow angle = 0 degree and with a rear spoiler at angle = +45°, combined with the co-rotating orientation of the VG lined in series, it gives the best performance by reducing the drag coefficient value with an impressive 68.18%.

Keywords: Rear spoiler, Vortex generator (VG), Flow separation, Surface static pressure, Drag reduction.

1. INTRODUCTION

Increasing fuel economy for any automotive vehicles including passenger cars is of a great concern in today’s world. Significant progress has already been made to increase the efficiency of the automotive engines including the use of bio-fuel. Considerable improvement can also be possible by reducing mass, rolling friction and even aerodynamic drag of the vehicle. The reduction of drag co-efficient (C₀), which is mostly influenced by the exterior profile (shape) of the cars [Hucho, 1997] remain one of the major concerns in the field of the

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automotive research. Average $C_D$ values are reduced remarkably over the time, from 0.7 for old box-type cars to merely 0.3 for the recent streamlined shaped modern ones [Katz, 1995]. For high speed passenger cars, the aerodynamic pressure drag is predominant due to the flow separation particularly on the rear window and on the wheel base [Geropp and Odenthal, 2000]. This contribution corresponds to 90% of total aerodynamic drag and 80% of this contribution is due to the rear part of the car [Kourta and Gilliéron, 2009].

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 [Schlichting, 2007]. The importance of the influence of the rear taper in passenger cars can be described as ‘spoiler’ on rear car body. Such spoilers are often fitted to passenger cars at the trunk rear. The main design goal of a rear spoiler in passenger vehicles is to reduce drag and increase fuel efficiency [Katz, 2006]. Rear spoilers, which modify the transition in shape between the roof and the rear and the trunk and the rear, act to minimize the turbulence at the rear of the vehicle. Adding a rear spoiler makes the air ‘travel’ a longer, gentler slope from the roof to the spoiler, which helps to delay flow separation. This decreases drag, increases fuel economy, and helps keep the rear window clean.

One of the main causes of aerodynamic drag for passenger cars is the separation of flow near the vehicle’s rear end. Large energy losses are often associated with boundary layer separation. A common flow separation control method is to add momentum to the near wall flow by redirection of higher momentum from the free-stream or the outer region of the boundary layer into the separation zone. The present investigation is focused on flow control by vortex generators (VG) in combination with the rear spoiler.

In the automobile domain more recently there has been an increasing interest in the link between safety and stability to cross-wind interaction. Common observations show that with stronger cross-flow vehicles lose stability [Gillhaus and Hoffmann, 1998].

There are two major influences on the distribution of surface pressures on bluff-bodies and especially automobiles. One is simply the size of the apparent surface in flow direction and the other is the interaction of flow features with the body. A rise of localized apparent surface (like putting a spoiler or VG) will induce bigger surface pressures on this area and change global surface pressures. Furthermore, a change in upstream flow features (like crosswind situations) can also have an influence in the surface pressure distribution on the body. Hence, there are two ways of varying local surface pressures on a vehicle: by geometrical and/or aerodynamic variation.
The main aim of this work is to evolve an effective method of flow control at the car downstream. Experimental investigation are carried out to optimize aerodynamic drag and surface static pressure using a geometrically similar, 15:1 reduced scale PoP clay model of a high-speed Sedan type ‘Honda City’ car (Fig. 1), differing from actual car only in size and simulating dynamically similar flow situations for it in the wind tunnel. A test facility is developed to realistically simulate the flow around a three dimensional car body tested in wind tunnel for controlling the flow separation of near the vehicle’s rear end using the spoiler and VG on the roof end and trunk of the car model. The overall effects of the rear spoiler and VG depends on the variation of angle and the shape and size of VG.

2. EXPERIMENTAL TECHNIQUES
Experiments are carried out in a blow-down type wind tunnel. The test section is made of perspex sheet for visual observation of car model (Fig. 2). The surface pressure of the car is measured with 47 wall pressure tapings. Pitot tube and pre-calibrated five-hole pressure probe in tandem with a digital micromanometer and a digital pressure scanner (both Furness Controls, U.K. make) are employed to record the experimental readings at an upstream velocity of 30 m/s. Suitable traversing mechanism is used for both all the measuring probes. The car is further rotated with respect to the upstream flow making flow angles ($\beta = 0^\circ, \pm 30^\circ$) to study the cross-wind effects on the car.

A spoiler is designed and is fabricated from perspex sheet to reduce the drag at the rear of the car model. The spoiler is fixed on the back of the car using two mounting struts (refer Fig. 1 and 4). The rear spoiler is oriented at three different angles with respect to the air flow (known as spoiler angle, $\alpha = 0^\circ, \pm 45^\circ$) and is shown in Fig. 3.

The vortex generators are designed based on this boundary layer thickness and are placed along the car width on the rear windshield ($x/L = 0.733$). The maximum height of the vortex generator is 2.0 mm, which is less than the boundary layer thickness available at this plane ($x/L = 0.733$). These vortex generators are seen as immersed in the boundary layer. The vortex generators are further oriented as co-rotating (parallel-shaped) and counter-rotating (V-shaped) depending on the directions of the vortex pairs shed in the flow downstream (refer Fig. 5 and 6).

3. RESULTS AND DISCUSSION
A total of 26 combinations are tested for the car model by changing the flow angles ($\beta = 0^\circ$ and $\pm 30^\circ$), spoiler angles ($\alpha = 0^\circ$ and $\pm 45^\circ$) and orientations of vortex genartors (co-rotating and
counter-rotating) in order to find out the optimum conditions for which drag coefficient is minimum. The following conclusions can be drawn based on this experiential studies.

Referring to Fig. 7, a marked improvement in static pressure along the car roof, especially at the car rear that is noticed at a flow angle \( \beta = -30^\circ \) by subsequent use of rear spoiler (at \( \alpha = +45^\circ \)) and co-rotating vortex generators. Here, the suction reduces to an extent and become very close to zero static pressure values near the rear end of the car. This incident clearly indicates that the flow separation zone gets reduced with the use of spoiler along with VG. It is also observed in Fig. 7 (a to c) that a positive pressure builds up on a little portion of the car roof close to the windward side.

It can be seen in Fig. 8 that in general, the surface pressure coefficients \( (C_{wp}) \) are positive and reasonably uniform over the windward face (the side facing the airflow) of the car. It is also observed that negative \( C_{wp} \) (suction) is present on the roof of the vehicle, and this suction tend to increase from the front to rear of the vehicle (Fig. 8 a). With the increase of flow angle \( (\beta) \) from \( 0^\circ \) to \( +30^\circ \), large negative values of \( C_{wp} \) are noticed at the front of the leeward wall and the suction at the roof, which are suggestive of a flow separation over the leeward roof corner of the vehicle. The best combination (Fig. 8 b) in terms of \( C_{wp} \) rise (by over 92%) is found while the car is facing wind at \( \beta = 0^\circ \) and is combined with spoiler at \( \alpha = 0^\circ \) with co-rotating vortex generators attached at the upstream of the spoiler \( (x/L = 0.733) \).

When the car is at cross-wind condition (say \( \pm 30^\circ \)), a 36.36% more area is exposed to the direct wind. As a result, the drag coefficient \( (C_D) \) increases up to 38.61%. The vortex generators (VG) energize the decelerating fluid, and hence delay the flow separation point to further downstream. For the car with flow angle \( \beta = 0^\circ \) and with a rear spoiler of \( \alpha = +45^\circ \), combined with the co-rotating orientation of the VG lined in series, it gives the best performance by reducing the \( C_D \) value with an impressive 68.18%.

The higher velocity zones are increased with the subsequent addition of a rear spoiler and vortex generators to the car model facing flow at \( \beta = 0^\circ \). The largest velocity zones are obtained in case of spoiler at \( \alpha = +45^\circ \) combined with co-rotating vortex generators. It is worthwhile to note that the results of counter-rotating vortex generators are not found satisfactory.
4. CONCLUSIONS
Conclusions of the present experimentation are drawn below.

- There is a distinct improvement in static pressure along the car roof, especially at the car rear, which is noticed at a flow angle \( \beta = -30^{\circ} \) by successive use of rear spoiler (at \( \alpha = +45^{\circ} \)) and co-rotating vortex generators. A positive pressure also builds up on a little portion of the car roof close to the windward side.

- In general, the surface pressure coefficients \( C_{wp} \) are positive and reasonably uniform over the windward face of the car. It is also observed that negative \( C_{wp} \) (suction) is present on the roof of the vehicle, and this suction tend to increase from the front to rear of the vehicle. The best combination (Fig. 8 b) in terms of \( C_{wp} \) rise (by over 92%) is found while the car is facing wind at \( \beta = 0^{\circ} \) and is combined with spoiler at \( \alpha = 0^{\circ} \) with co-rotating vortex generators attached at the upstream of the spoiler (\( x/L = 0.733 \)).

- For the car with flow angle \( \beta = 0^{\circ} \) and with a rear spoiler of \( \alpha = +45^{\circ} \), combined with the co-rotating orientation of the VG lined in series, it gives the best performance by reducing the \( C_D \) value with an impressive 68.18%.

- The higher velocity zones are increased with the subsequent addition of a rear spoiler and vortex generators to the car model facing flow at \( \beta = 0^{\circ} \). The largest velocity zones are obtained in case of spoiler at \( \alpha = +45^{\circ} \) combined with co-rotating vortex generators. However, no satisfactory result is found while using the counter-rotating vortex generators.

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REFERENCES

Fig. 1 Car model attached with a rear spoiler and vortex generator arrays.

Fig. 2 Car model placed in a wind tunnel test section.
Fig. 3 Spoiler orientation on rear position of car

Fig. 4 Car model attached with spoiler at 0°

Fig. 5 Co-rotating vortex generators geometry

Fig. 6 Counter-rotating vortex generators geometry
Fig. 7 Surface static pressure distribution along car width.
(The values in figures denote static pressure in mm of wc)
[(a): at flow angle $\beta = -30^\circ$, (b): at flow angle $\beta = -30^\circ$ with spoiler at $\alpha = +45^\circ$,
(c): at flow angle $\beta = -30^\circ$ with spoiler at $\alpha = +45^\circ$ and co-rotating VG]

Fig. 8 Effects of rear spoiler and VG on surface pressure coefficient contours of the car.