e-ISSN: 2548-060X

International Journal of Energy Applications and Technologies

journal homepage: https://dergipark.org.tr/en/pub/ijeat

Original Research Article

Experimental investigation of spoiler application in on an SUV type vehicle

Hasan Çiftçi[1*], Cihan Bayındırlı[2], İlker Örs[3]

[1] *The Graduate School of Natural and Applied Science of Selçuk University, Konya,42250, Türkiye*
[2] *Nigde Vocational School of Technical Sciences, Nigde Omer Halisdemir University, Nigde, 51200, Türkiye*
[3] *Department of Airframe and Powerplant Maintenance, School of Civil Aviation, Selçuk University, Konya, 42250, Türkiye*

ARTICLE INFO

* Corresponding author
hciftcihasan@gmail.com

Received December 23, 2022
Accepted January 3, 2023

Published by Editorial Board Members of IJEAT

doi: 10.31593/ijeat.1223324

ABSTRACT

In this study, it is aimed to provide fuel economy and driving stability and comfort by reducing the drag coefficient by applying a spoiler to on an SUV model vehicle. The albatross type was preferred as the spoiler and it was mounted to the rear of the vehicle, as high as 10% of the total vehicle height. The model vehicle is 1/32 of its actual dimensions. The experiments were carried out at 4 different free flow velocities in the range of 2.08×10^3-5.35×10^3 Reynolds number. As a result of the experiment, it was determined that the use of spoilers reduced the drag coefficient value by 5.72%. Thanks to this study, it has been revealed that there is an improvement in fuel economy. Thus, it has been shown that aerodynamic performance can be improved by applying different spoiler applications in SUV model vehicles that are widely used today.

Keywords: Flow control; Spoiler; Vehicle aerodynamics, Wings

1. Introduction

The aerodynamic structure of the vehicles significantly affects fuel consumption, driving comfort and safety (road handling, understeer). The aerodynamic force acting on a moving vehicle is created by the vertical and tangential contact of the air to each point of the vehicle surface. Aerodynamic force components are lift force, drag force and lateral force. Lift force is the force that occurs in the direction of movement of the vehicle in the perpendicular direction with respect to the ground. In general, it is important for the vehicle's handling and driving safety parameters. Drag force, on the other hand, is the force that is parallel to the ground, opposite the direction of motion of the vehicle in motion. In particular, it has a significant effect on fuel consumption. The lateral force is the side component of the aerodynamic force that occurs when the movement of the air is not symmetrical with respect to the vehicle shape. This force component makes a right angle with the drag and lift force. In general, it affects the stability of the vehicle in motion.

In particular, the significant effect of drag force on fuel consumption has led researchers to focus on studies aimed at reducing drag force in recent years. Because reducing the drag coefficient will provide fuel economy to a great extent. Drag coefficient is the dimensionless number used to determine the aerodynamic efficiency of the vehicle by streamlining the body shape of the vehicle in order to reduce the drag force that opposes the forward movement of the vehicle. The drag coefficient of a vehicle depends on the density, viscosity, and compressibility of the air, as well as the length, speed, shape, surface roughness, and direction of motion of the vehicle.

The drag coefficient of a vehicle can be lowered by allowing the air flowing around the body of the vehicle to flow as uninterruptedly and smoothly as possible. Flow control is provided by active (with movable elements) and passive (with immobile elements) methods. Most of the studies to date consist of passive flow control methods on vehicles. Because the use of active flow control elements, especially at high speeds, has not been possible. However, nowadays, it is seen that active flow control elements are also used, especially in racing cars [1-4].

Especially the application of a spoiler or wing to the rear of the vehicle are the most preferred flow control elements. Here, the shape, structure and position of the spoiler and wing significantly affect the flow [5-8]. Rear spoilers can be defined as aerodynamic devices that are usually added to the trailing edge of the roof or trunk deck of a vehicle to improve its aerodynamic performance. Primarily, the goal is to improve the downforce despite the subsequent drag penalty. Since downforce is proportional to tractive force, it is imperative for the ride's stability and safety. Furthermore, good downforce performance is vital during cornering when the vehicle needs sufficient traction for it to pass the curve without slipping [9].

When the studies on the effect of spoiler and wing application on the vehicle were examined, Brandt et al. investigated the effect of the roof spoiler applied on the rear window of an SUV on the driving stability with CFD analysis. As a result, they stated that; The improved spoiler showed smaller variations in rear axle cornering stiffness and an understeering characteristic less sensitive to variations in crosswind. This, together with slightly higher variations in yaw velocity when driving in crosswind conditions, led to the conclusion that these higher variations in handling characteristics most likely explain the baseline spoiler's lower subjective ratings of high speed driving stability compared to the improved spoiler [10]. Hetewal et al. studied that to increase the aerodynamic performance of race car, an attempt is made to modify the design of a Formula SAE car. Comparative study is done on three car models by carrying out CFD simulations. Cutting out the section of firewall and providing wing at front end. Drag co-efficient is found to get reduced from 0.85 for the standard race car to 0.70 for the modified car with front wing, whereas negative lift is increased from 0.2 for standard race car to -0.25 for the model 3 [11]. Das and Riyad investigated the design, developments and numeral calculation of the effects of external device, which will be spoiler that mounted at the rear side of the vehicle to make the present vehicles more aerodynamically attractive. The influence of rear spoiler on the generated lift, drag, and pressure distributions are investigated and reported using commercially available Autodesk Simulation CFD software tool. In the investigation, six modifications are simulated 12°-degree spoiler inclination angle model is the most optimum though it creates 1.56% extra C_D than 4-degree inclination angle. Minimum C_L is maintained in the model which is basic concern for better stability of high speedy vehicle [12]. Verma et al. In order to increase the aerodynamic performance of a passenger vehicle, lip spoilers were applied to the rear of the vehicle and examined with CFD. As a result, they showed that the CD value decreased up to 6.9% at the spoiler angles between 6-10, and the CL value improved by an average of 12.9% [13]. Palanivendhan et al. They aimed to reduce the drag coefficient with different vortex generator applications on the spoiler at different spoiler angles. They performed both wind tunnel experiments and CFD analyzes on the model they produced with a 3D printer. As a result, they found a 12-15% reduction in drag force [14].

In this study, the application of spoiler, which is one of the passive flow control methods, to the rear of the vehicle will be experimentally examined in order to achieve aerodynamic improvement on a Sports Utility Vehicle (SUV). As a matter of fact, studies have shown that; At high vehicle speeds, when the aerodynamic drag coefficient is reduced by 2%, fuel consumption can be reduced by 1%. Thus, it is aimed to increase the fuel economy by reducing the aerodynamic resistance or drag coefficient of SUV type vehicles, which have a very wide usage area today and are becoming widespread day by day [15].

2. Materials and Methods

2.1. Experimental Setup

The wind tunnel shown in Figure 1 was used in the experiments. The characteristics of the wind tunnel are presented in Table 1.

Fig. 1. Wind tunnel and test devices [18]

Table 1. Specifications of wind tunnel

Dimensions (mm)	400 x 400 x 1000
Speed (m/s)	3 – 30
F_x, F_y, F_z (N)	±32, ±32, ±100
Mx, My, Mz (Nm)	2.5
Fan diameter (mm)	700
Fan power (kW)	4
Inverter frequency (Hz)	0-50 / 0.1 (sensibility)

While designing the spoiler, it was inspired by the wing of the albatross bird. Spoiler design was designed in SolidWorks program and produced in 3-D printer. The drawing data of the spoiler was given in Fig. 2.

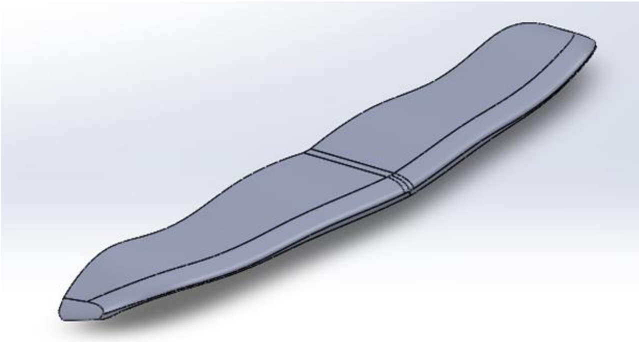

Fig. 2. The drawing data of the spoiler model

The vehicle model used in the experiments is truly a 1/32-dimensioned SUV. Fig. 3 shows the view of the model vehicle in the wind tunnel as with and without spoilers.

Fig. 3. Model vehicle as with and without spoiler

While the front surface area of the base model vehicle is 0.01081 m^2, the area of the spoiler model is 0.01195 m^2. The width, height and length dimensions of the model vehicle are 112 mm, 102.1 mm and 250 mm, respectively. The experiments were carried out for 4 different vehicle speeds as 14.43 m/s, 18.69 m/s, 23.51 m/s and 28.29 m/s. The albatross model was preferred as the spoiler model. The spoiler is placed at the rear of the vehicle at a height of 10% of the vehicle height.

2.2. Similarity and Uncertainty

A licensed model vehicle was used for geometric similarity condition. In the kinematic similarity condition, the blockage rate was 6.43% to provide it. According to Çengel and Cimbala [16], a blockage rate of less than 7.5% is sufficient to meet the kinematic similarity requirement [17]. Kinematic similarity has been achieved both in terms of blockage and free flow velocity profile. However, the relative speed limit condition between the vehicle and the ground could not be met. Reynolds number independence was used to provide dynamic similarity. Experimental studies were carried out at free flow velocities with Reynolds independence.

The uncertainties of experimental setup determine accuracy of experimental results. The uncertainty values of the calculated parameters were presented in Table 2.

Table 2. Uncertainty values of calculated parameters

Parameter	Uncertainty rate (%)
Reynolds Number	3.87
Drag force	4.5
Drag coefficient	4.7

3. Results

As seen in Table 3, drag coefficient of SUV model without spoiler model was calculated as 0.442 in average by wind tunnel tests. It was determined as 0.417 for modified model vehicle by spoiler in same test conditions and Reynolds number. There is 5.72% drag reduction in average. This drag reduction can reduce fuel consumption of vehicle to 3% in high drive speeds. Figure 4 shows that reducing in drag coefficient was obtained with spoiler application in wind tunnel tests. A significantly decrease in C_D was observed with the use of spoiler for each vehicle speed.

Table 3. Drag coefficient of SUV model without and with spoiler model

Flow velocity (m/s)	Reynolds Number	SUV without spoiler	SUV with spoiler	Drag Reduction
14.43	231213	0.435	0.412	5.29%
18.69	353480	0.437	0.412	5.72%
23.51	444537	0.445	0.417	6.29%
28.29	535003	0.450	0.425	5.55%
	Average	**0.442**	**0.437**	**5.72%**

doi: 10.31593/ijeat.1223324

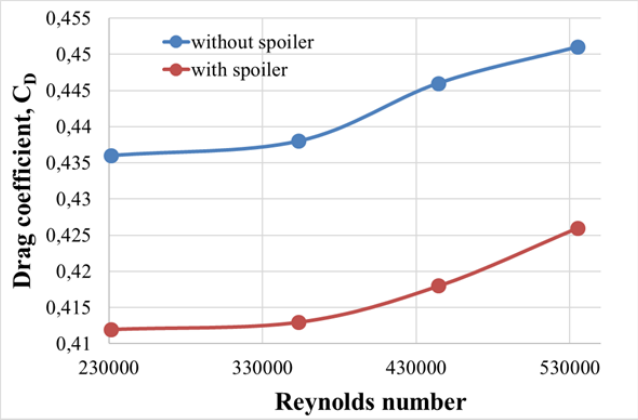

Fig. 4. Drag coefficient curve at different vehicle speed for spoiler application

The use of spoilers resulted in a 5.72% reduction in drag coefficient on average. Because, thanks to the spoiler, the turbulence recirculation at the rear of the vehicle has shrunk compared to the base model. This will allow for better fuel economy.

A smaller turbulence recirculation zone behind the rear end implies that there is higher pressure behind the spoiler than the rear end of the vehicle. The rear spoiler redirects the airflow behind the vehicle, which in turn increases the negative lift of the vehicle. In case of vehicle, a negative lift force stabilizes it at high speed, increases capability to produce cornering force, gives better traction and improves braking performance [13, 15,17,18].

4. Conclusion

This study showed the effect of the use of albatross spoiler reduced to drag coefficient of an SUV model vehicle. According to the results obtained, an average of 5.72% lower drag coefficient was determined thanks to a spoiler mounted at a height of 10% of the total vehicle length. This shows an improvement about 3% in fuel economy with an approximate calculation.

The use of different types of spoilers and the mounting of the spoiler at different heights and positions show that the improvement in drag coefficient can be further increased.

Acknowledgment

The authors have very grateful to Nigde Omer Halisdemir University and Selçuk University for their facilities and support. Besides, the authors thank Selçuk University for the financial support provided by the Scientific Research Projects Coordination Unit of Selçuk University, project which are under the grant number 21201077.

Authorship contribution statement for Contributor Roles Taxonomy

Hasan Çiftçi: Writing - original draft, Investigation, Visualization, Conceptualization, Methodology, Experimental study.
Cihan Bayindirli: Experimental study, Investigation, Conceptualization, Methodology, Supervision, Review& editing
İlker Örs: Investigation, Supervision, Visualization, Conceptualization Writing - Review& editing, Funding acquisition.

Conflict of interest

The authors declares that he has no conflict of interest.

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