Faculty of Mechanical Engineering

EXPERIMENTAL STUDY OF YAW ANGLE EFFECT ON AERODYNAMIC PERFORMANCE OF ROAD VEHICLE WITH REAR SPOILER

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A thesis submitted
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DECLARATION

I declare that this thesis entitled "Experimental Study of The Yaw Angle Effect on The Aerodynamic Performance of Road Vehicle Equipped with Rear Spoiler" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………………

Name : ………………………………

Date : ………………………………

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature	:	…………………………………………
Supervisor Name	:	…………………………………………
Date	:	…………………………………………

DEDICATION

To my beloved parents and sister

ABSTRACT

A spoiler is an external structure added to the trailing edge of the roof of a vehicle to increase the downward force, and hence, improves its traction. To date, the performance of spoilers had mainly been optimized for the straight-ahead driving condition. However, during cornering, good traction is critical to ensure that sufficient centripetal force is generated for the vehicle to drive through the curve without slip. Hence, this research aims to investigate the effects of yaw angle change corresponding to cornering on the flow characteristics of various typical spoiler configurations, and the subsequent influence on the aerodynamic performance of vehicles. The vehicle type tested is the hatchback vehicle while the rear spoiler configuration employed are those typically found in real-life applications, namely, strip type, standing wing type, and the combination of the strip and wing (i.e. combo type). Ahmed model which had been scaled down to 75% of the original model was adopted to simulate the idealized hatchback type vehicle. The rear spoilers are being mounted on the roof end of the vehicle model. The experimentations are conducted in a low-speed wind tunnel at the Reynolds number of 2.7×10^6. The yaw angle tested ranges from 0° to 14°, at 4° increment. At zero yaw angle, the C_l of the vehicle model fitted with either of the three spoiler types is lower as compared to the vehicle model without a rear spoiler. Although the Strip-type spoiler provides the same advantage when comes to the C_d performance, however, the Wing-type and Combo-type spoilers show an increase in C_d. Under the influence of the yaw angle, both the C_d and C_l of the vehicle model increase disregard the use of the rear spoiler. When without a spoiler, there exists a critical yaw angle value where the C_d and C_l of the vehicle model will surge by as much as 29% and 91%, respectively. However, the application of the three spoiler types could prevent such an undesirable tendency. In addition, at low yaw angle range, the vehicle model fitted with the strip-type spoiler shows a reduction in C_d, whereas the cases fitted with the wing-type and combo-type spoilers show a higher C_d. However, all the cases fitted with a spoiler produce a lower C_l as compared to the without spoiler case. Overall, the use of the rear spoilers could improve the driving stability and safety of the vehicle. However, the wing type and combo type could cause an increase in the aerodynamic drag of the vehicle operated at zero yaw angle or low yaw angle range.

KAJIAN EKSPERIMEN KESAN SUDUT REWANG KE ATAS PRESTASI AERODINAMIK KENDERAAN DARAT YANG DILENGKAPI SPOILER BELAKANG

ABSTRAK

Spoiler merupakan suatu struktur luaran yang ditambah pada tepi bumbung pada belakang kenderaan demi meningkatkan daya ke bawah dan oleh itu, meningkatkan daya tarikannya antara tayar dengan muka jalan. Sehingga kini, kebanyakan prestasi spoiler telah dioptimumkan untuk keadaan memandu lurus. Walau bagaimanapun, semasa membelok, daya tarikan yang baik adalah penting untuk memastikan daya sentripetal yang mencukupi dihasilkan untuk kenderaan itu supaya kenderaan tersebut dapat membelok tanpa tergelincir. Oleh itu, matlamat penyelidikan ini adalah untuk mengkaji kesan perubahan sudut rewang (sepadan dengan keadaan memandu melalui lengkung) terhadap ciri aliran yang dihasilkan oleh pelbagai konfigurasi spoiler, dan pengaruh selanjutnya terhadap prestasi aerodinamik kenderaan. Jenis kenderaan yang dikaji adalah kenderaan hatchback manakala konfigurasi spoiler belakang yang digunakan adalah yang biasanya terdapat dalam aplikasi kehidupan nyata, seperti jenis jalur, jenis sayap berdiri, dan gabungan jalur dan sayap (iaitu jenis kombo). Model Ahmed yang dibina untuk eksperimen ini adalah 75% dari model asli yang digunakan untuk mewakili kenderaan jenis hatchback yang ideal. Spoiler belakang pula dipasang pada hujung bumbung model kenderaan. Eksperimen dijalankan di terowong angin berkelajuan rendah dengan nombor Reynolds sebanyak 2.7 x 10^6. Sudut rewamg yang diuji adalah antara 0° hingga 14°, dengan kenaikan 4°. Apabila sudut rewang ditetapkan sebagai 0°, C_l yang tercatat oleh kenderaan yang dilengkapi dengan salah satu daripada tiga jenis spoiler adalah lebih rendah berbanding dengan model kenderaan tanpa spoiler belakang. Walaupun spoiler jenis Jalur memberikan kelebihan yang sama dalam prestasi C_d, namun spoiler jenis Sayap dan Kombo menunjukkan peningkatan dalam nilai C_d. Di bawah pengaruh sudut rewang, kedua-dua C_d dan C_l tercatat oleh model kenderaan meningkat walaupun dilengkapi dengan spoiler belakang. Apabila eksperimen dijalankan dengan model kenderaan tanpa spoiler, nilai sudut rewang kritikal tercatat di mana C_d dan C_l model kenderaan akan meningkat sebanyak 29% dan 91% masing-masing. Walau bagaimanapun, penggunaan ketiga-tiga jenis spoiler berupaya mencegah kecenderungan begini yang tidak diingini. Di samping itu, bagi sudut rewang yang rendah, model kenderaan yang dilengkapi dengan spoiler jenis jalur menunjukkan penurunan C_d, manakala kes yang dilengkapi dengan spoiler jenis sayap dan kombo menunjukkan C_d yang lebih tinggi. Tetapi, semua kes yang dilengkapi dengan spoiler menghasilkan C_l yang lebih rendah berbanding dengan kes tanpa spoiler. Secara keseluruhan, penggunaan spoiler belakang mampu meningkatkan kestabilan dan keselamatan pemanduan kenderaan. Namun, spoiler jenis sayap dan kombo boleh menyebabkan peningkatan seretan aerodinamik kenderaan yang apabila sudut rewang ialah 0° atau pada masa sudut rewang rendah.

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LIST OF ABBREVIATIONS AND SYMBOLS

θ	-	Inclination angle
ψ	-	Yaw angle
μ	-	Dynamic viscosity of the fluid
A	-	Reference area
AOA	-	Angle of attack
c	-	Chord length
C_d	-	Drag coefficient
C_{my}	-	Pitching moment coefficient
C_l	-	Lift coefficient
C_p	-	Pressure coefficient
F_d	-	Drag force
F_l	-	Lift force
Hz	-	Hertz
l	-	Length
m	-	Metre
mm	-	Millimetre
m/s	-	Metre per second
Re	-	Reynolds number
p	-	Static pressure

p_0	-	Reference pressure
Psi	-	Pounds per square inch
Pa	-	Pascal
t	-	Maximum thickness as a fraction of the chord
ρ	-	Mean density of the gas
$\rho(T)$	-	Air density at a specific temperature
U	-	Freestream velocity
x	-	Position along the chord (from 0 to c)
y_t	-	Thickness of centreline to surface at a given value of x

LIST OF PUBLICATIONS

Chin, K.Y., Cheng, S.Y., and Mansor, S., 2019. Yaw Angle Effect on the Aerodynamic Performance of Hatchback Vehicle Fitted with Wing Spoiler. *Malaysian Journal of Fundamental and Applied Science*, Vol. 15(3), pp.389-393.

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CHAPTER 1

INTRODUCTION

1.1 Background

A spoiler is an external structure added to the trailing edge of the roof of a vehicle to improve the aerodynamic performance of the vehicle. The focus is mainly on enhancing the downward force for improving the vehicle's traction, although its intended purpose sometimes includes improving the aerodynamic drag for better fuel efficiency. To date, the performance of spoilers had mainly been optimized for the straight-ahead driving condition. However, during cornering, good traction is critical to ensure that sufficient centripetal force is generated for the vehicle to drive through the curve without slip. Hence, the aim of this research is to investigate the effects of yaw angle change corresponding to cornering drive situation on the flow characteristics of various typical spoiler configurations, and the subsequent influence on the aerodynamic performance of the vehicle.

1.2 Problem statement

When a vehicle turns through a curve, it needs sufficient frictional forces (i.e. wheel traction) between its tires and the road to provide the centripetal force for it to drive past the curve without slip. The frictional forces are directly proportional to the downward force exerted on the vehicle. The downward force is depending on the vehicle's weight and the downward component of the aerodynamic force. Although it is possible to increase the weight of the vehicle to improve the traction, there is a drawback of this approach. That is, a heavier vehicle will have higher inertia, hence, making it more difficult to drive through the curve. So by making a vehicle heavier will not improve its cornering performance.

Moreover, making a vehicle heavier is less economical because, for the same engine and mechanical efficiencies, a heavier vehicle will have a higher fuel consumption rate. Therefore, the only way to improve the cornering performance of the vehicle is to employ aerodynamic effects which can be created by aerodynamic devices such as spoiler.

A spoiler can increase the downward force of a vehicle by changing the airflow going over it to increase the downward pressure, essentially pushing the vehicle down and improve its traction. According to McBeath (2006), when the vehicle creates downward force, the maximum frictional forces are correspondingly increased. As a result, a vehicle with downforce can accelerate, brake and corner with greater force and more stable when compared with a vehicle with no or less downforce. Besides, according to Chilbule et al. (2014), for a diesel powered truck, a decrease in the aerodynamic drag of up to 21% can lead to reduction in fuel consumption by 4 litres for the drive distance of 100 km.

To date, the performances of spoilers had mainly been assessed for the condition in which the oncoming flow is in the longitudinal direction of the vehicle, thereby simulating the flow condition of a vehicle driving along a straight path, and without any crosswind (i.e. zero yaw angle). Thus, such an approach fails to address issues associated with cornering. In practice, the effect of a spoiler is most needed when a vehicle makes a turn during cornering. The spoilers being designed and assessed for straight-ahead driving may become less effective during cornering because the air is no longer passing exactly fore-aft (i.e. the yaw angle of the flow is none zero). In practice, the yaw angle encountered by a vehicle could increase to about 10° (Hucho, 1998). Hence, it is important to understand the performances of spoilers under the influence of yaw angle change as this could help to improve the spoiler configurations so that sufficient traction can be achieved.

1.3 Objectives

This study embarks on the following objectives:

1. To develop three types of typical roof spoiler use on passenger cars, namely (i) the strip type, (ii) the standing wing type, and (iii) the type that combines a strip and a wing into a single spoiler structure.
2. To assess the aerodynamic performance of the spoilers after installed on a hatchback type vehicle by wind tunnel experimentation.
3. To examine the effects of yaw angle on the flow characteristic of the three spoiler types, and the subsequent influence on the aerodynamic performance of the vehicle model mounted with the spoilers by wind tunnel experimentation.

1.4 Scope of project

The vehicle model used in the present study was a simple bluff body geometry that resembles the basic shape of a hatchback type vehicle. The scale of the model is 75% of the original design. Except for the spoiler, no other protruded body part exists. Therefore, the effect due to the interaction between the flow structures generated by various protruded body parts is not considered. The three types of spoiler tested were the strip type, the standing wing type, and the type that combines a strip and a wing into a single spoiler structure. The wind tunnel experiments were done at the Raynolds number of 2.7×10^6. The yaw angle range of the study was from 0° to 14° yaw.

1.5 Importance of the study

Often, automobiles are equipped with a spoiler, which is implemented by car manufacturers or vehicle enthusiasts. When carrying out a study to test the performance of the spoiler, such a study is normally performed by car manufacturers. Thus, the outcomes of the test are normally subjected to proprietary rights.

Meanwhile, in the realm of scholarly works and communication, the literature concerning spoiler is scarce. When available, the focus is mainly on the flow condition in which the vehicle is moving in a straight path and without crosswind. In reality, however, the path that the road vehicles follow is made of a series of straight and curved segments. When the vehicle is not going straight or when crosswind exists, the yaw angle encountered by the vehicle will no longer equal to zero. Therefore, the aerodynamic performance of a vehicle which is mounted with a spoiler should be investigated at nonzero yaw angle condition.

Hence, this study is important because it is aimed to address the issues related to the effectiveness of the use of spoiler to improve the aerodynamic performance of the vehicle in both the straight-ahead driving condition and during cornering when the yaw angle becomes an influential factor.

1.6 Outline of the thesis

Chapter 1 introduces the background of the study and followed by the problem statement. Then, the objectives of the study are given. Next, the scope of the project which states the limitations of the study is provided and is followed by the importance of the study. Finally, the outline of the thesis is described.

Chapter 2 reviews the literature of spoiler. The relevant terminology which includes aerodynamics, bluff body, aerofoil, yaw angle, and wind tunnel are defined and introduced in this chapter.

Chapter 3 describes the methodology of the present study in detail. It first started with the creation of the simplified vehicle model and the various spoiler configurations by commercial CAD software, namely, CATIA V5R21. Then, the model and the spoilers were fabricated for wind tunnel tests. The force and pressure acquisition methods are also described in this chapter.

Chapter 4 presents the obtained results and discusses the result analysis in detail. First, the wind tunnel experimental results of the Baseline case (i.e. the simplified vehicle model without a spoiler) are provided. Then, the aerodynamic forces and surface pressure coefficients of all the cases with the use of spoiler are compared. Lastly, the analysis of the effect of the yaw angle on all the test cases is given.

Chapter 5 provides a summary of the thesis and concludes the main findings of the aerodynamic forces and surface pressure coefficients obtained from all the test cases. Finally, the chapter provides some recommendations for future works in which the scope of the project can be extended.