Effect of NACA 0010 Airfoil Car Spoiler Towards Downforce and Drag Force

Muhammad Azraai Bin Ahmad Fisal

Faculty of Electrical Engineering (FKE)
Universiti Teknologi MARA (UiTM)
40000 Shah Alam, Selangor
azraai.fisal@gmail.com

Abstract— **This project presents the analysis of downforce and drag force theory of a spoiler in MATLAB and DesignFOIL software. The observed car spoiler characteristic is an airfoil shape of NACA 0010 airfoil spoiler, 1.65m wingspan and 0.25m chord length. The analysis is tested by varies the speed of the vehicle and the angle of attack of the spoiler toward the air incident on the spoiler. The results obtained from the analysis were recorded in table and plotted on graph. Conceptual assumptions were verified as the down force increase to eliminate lift of the car, the drag is also increase that obeys the basic function of a spoiler.**

Keywords: Spoiler, Downforce, Drag Force, Coefficient of lift, Coefficient of drag, Angle of attack.

I. INTRODUCTION

Nowadays, automobile become faster and faster, it was notice that the vehicle experienced an uplift force at higher speeds. As a car moves at higher speed through the air, the air flow is split and passes above and below the car. The split air flow creates a pressure different since the air above the car move in higher velocity than the air below the car. The higher velocity of air above the car experience lower pressure and the lower velocity of air under the car experience high pressure. Therefor the car experience uplift force from the ground and the stability of the car become lesser.
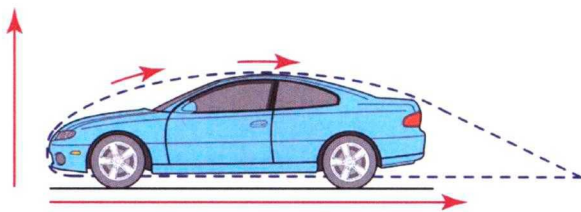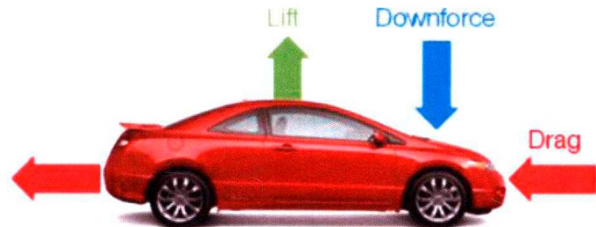

Figure 1. Aerodynamic of car

Figure 2. Lift, Downforce and Drag direction experience by car

To counteract this uplift force, spoiler was invented. It is purposely to eliminate the uplift force by diffusing the airflow passing over and around a moving vehicle. This diffusion accomplished by increasing amounts of turbulence flowing over the shape, "spoiling" the laminar flow and providing a cushion for the laminar boundary layer [1] creating a down force and at the same times increase the traction of the vehicle. At the same time, spoiler also increases the drag which slows the vehicle down. A good vehicle is a vehicle that has a good downforce for handling and stability and also with lower drag force for low fuel consumption.

A. NACA 0010 airfoil

The NACA 4digit series airfoil shapes are universally accepted standard designs generally used for wind turbine blades, helicopter rotor blades and car spoilers developed by the National Advisory Committee for Aeronautics (NACA). The shape of NACA airfoils is described using a series of digits following the word "NACA". The parameters for 1st digit is camber as percent of chord, 2nd digit is distance of max camber from leading edge in tenths of chord, 3rd and 4th digits are maximum thickness as percent of chord. So, NACA 0010 airfoil is an airfoil with no camber, and has 10% of thickness from the chord length.

29

B. Downforce

Downforce is the force exerts normal to the direction of the flow [3]. Dowforce is creates when air moves through car spoiler at certain angle which force the air up and through it. As the air forced upwards, the spoiler experience a force pushing downward call as downforce [5]. The other theory is when the air flow toward the spoiler at certain angle, the spoiler, spoils the air flow creating a difference in air flows above and below the spoiler. The higher air flow below the spoiler experience low pressure than above the spoiler. The differences in pressure creating a downward force call the downforce. As the vehicle speed is increasing, the air flows toward the spoiler also increasing in result, the downforce also gradually increasing with the speed of moving vehicle.
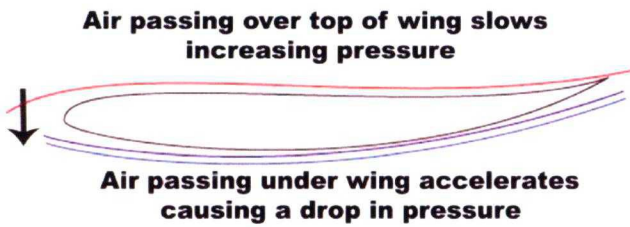

Figure 3.   The difference in pressure due to air flow different creating downforce

C. Drag force

The drag force is the force the flow exerts on the body in the direction of the flow [3], meaning that it is a force which opposes the forward motion of the vehicle. When the vehicles travel, the frontal area of the vehicle incident with air molecule, this will cause a backward force on the vehicle. As for the spoiler, when the angle of attack of the spoiler is increasing, the frontal areas of the spoiler also increase. This results in greater drag force experience by the spoiler.
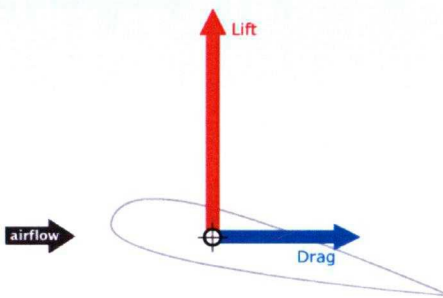

Figure 4.   Direction of drag experience on the airfoil against air flow

D. Angle of Attack

Angle of attack is a term used in aerodynamics to describe the angle between the airfoils chord line and the direction of airflow. The amount of downforce and drag force generated by the spoiler is directly related to the angle of attack. With greater angles of attack generating more lift and more drag due to increasing the frontal area exerted to the airflow. This remains true up to stall point, where lift starts to decrease again because of airflow separation [6].
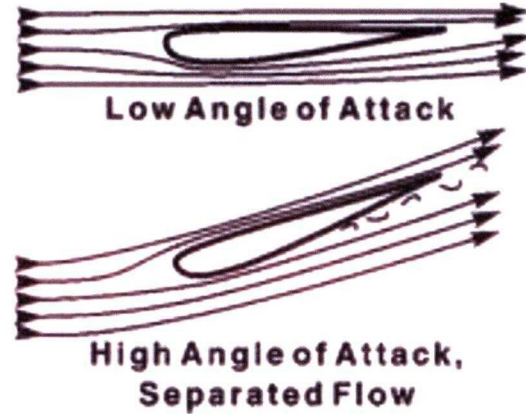

Figure 5.   Differences of laminar air flow against different angle of attack of an airfoil

II.   METHODOLOGY

A. Software Simulation Method

DesignFOIL software is used to generate NACA 0010 Airfoil model and to simulate lift and drag coefficients of the model. The parameter that is inserted is 0% maximum camber height, 0% maximum camber location and 10% maximum airfoil thickness to generate NACA 0010 Airfoil model. The density of air is set to be at standard condition, 1.225kg/m^3 [7]. Then, the NACA 0010 airfoil is simulate using virtual wind tunnel in the software to obtain lift and drag coefficient by varies the angle of attack at $0°$, $5°$, $10°$, $15°$ and $20°$. The data of the lift and drag coefficient is record in Table 1 and Table 2.
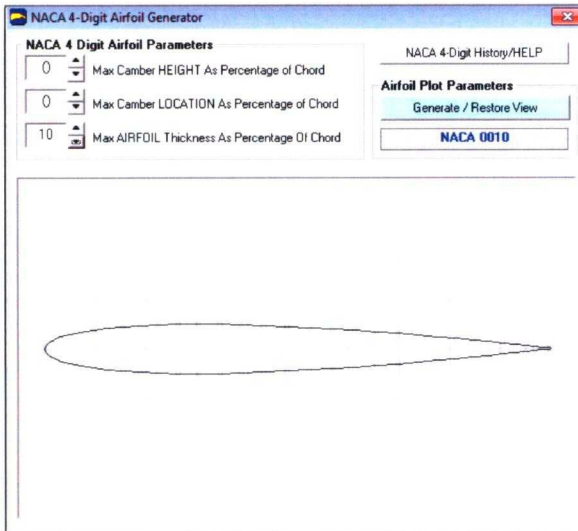
Figure 6. NACA 0010 Airfoil generated in DesignFOIL software

Figure 7. The calculation diagram of Downforce in Simulink Model

B. Theoritical Method

The theoretical method is use to analyze the downforce and drag force using MATLAB software by configured the calculation below.

The equation of down force [4]:

$$F_{lift} = \frac{1}{2}\rho C_l A_f V_r^2 \tag{1}$$

ρ – Density of air

C_l – Coefficient of lift

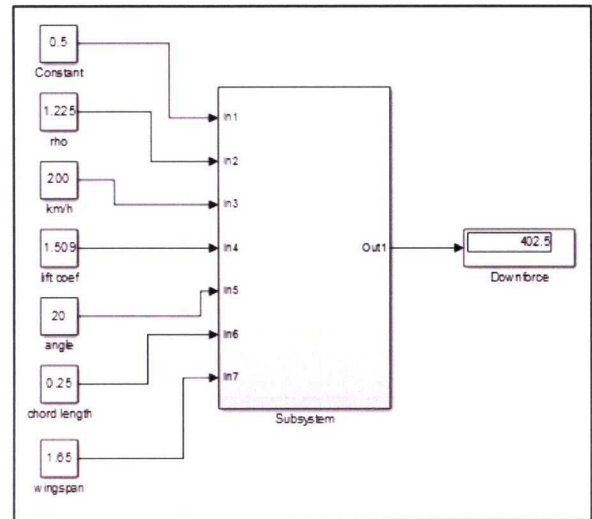A_f – Frontal area of the spoiler

V_r – Vehicle speed

The equation of drag force [4]:

$$F_{drag} = \frac{1}{2}\rho C_d A_f V_r^2 \tag{2}$$

ρ – Density of air

C_d – Coefficient of drag

A_f – Frontal area of the spoiler
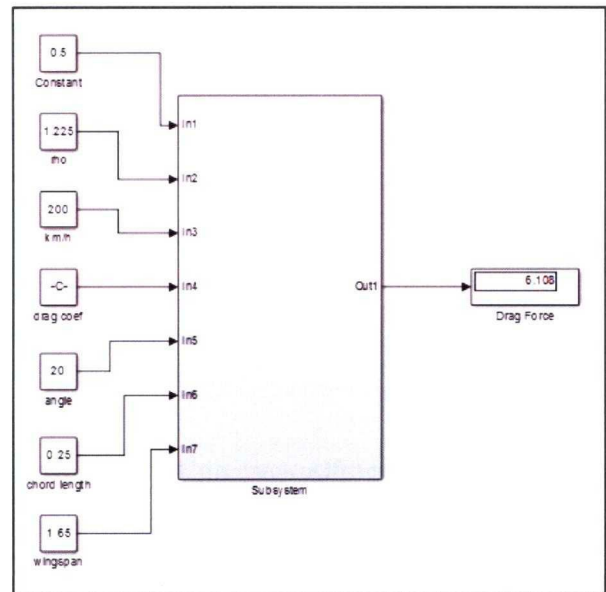
V_r – Vehicle speed

Figure 8. The calculation diagram of Drag force in Simulink Model

31

The equation of frontal area of the spoiler:

$$A_f = W \sin \theta \times L \qquad (3)$$

W – Chord length

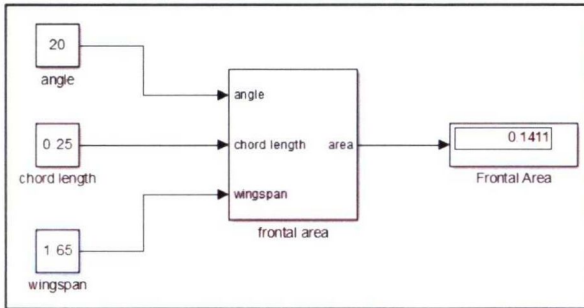L – Wingspan

θ – Angle of attack

Figure 9. The calculation diagram of frontal area in Simulink Model

The coefficients of lift and drag in Table 1 and Table 2 is use in the MATLAB software according to the angle of attack that been used. The speed of vehicle is varies from 0 to 200km/h at 20km/h interval against the angle of attack of the spoiler at $0°$, $5°$, $10°$, $15°$ and $20°$. The physical characteristic of the spoiler is state at fix value, 1.65m wingspan and 0.25m chord length. The density of air is set to be at standard condition, $1.225 kg/m^3$ [7]. The data of the downforce and drag force is record in Table 3 and Table 4.

III. RESULT AND DISCUSSION

A. Lift Coefficient against Angle of Attack

TABLE I. LIFT COEFFICIENT AGAINST ANGLE OF ATTACK, Θ^o

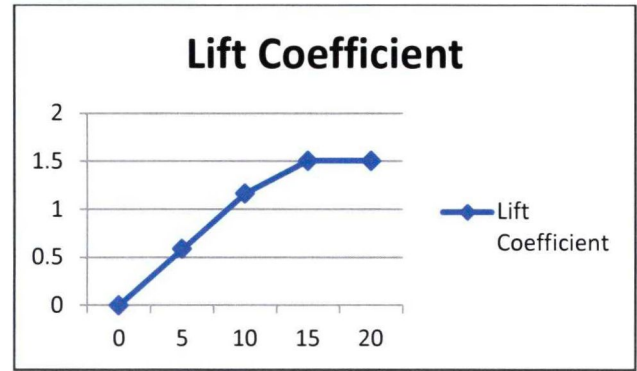| Angle of Attack, θ^o	Lift Coefficient
0	0.0000
5	0.587
10	1.168
15	1.509
20	1.509

Figure 10. Graph of Lift Coefficient against Angle of Attack, θo

From Figure 3, the lift coefficient is gradually increased from $0°$ to $15°$ angle and at the value of $15°$ and $20°$ angle of attack, the value is the same at 1.509. This is because the NACA 0010 airfoil shape is reaches the stall point [6].

B. Drag Coefficient against Angle of Attack

TABLE II. DRAG COEFFICIENT AGAINST ANGLE OF ATTACK, Θ^o

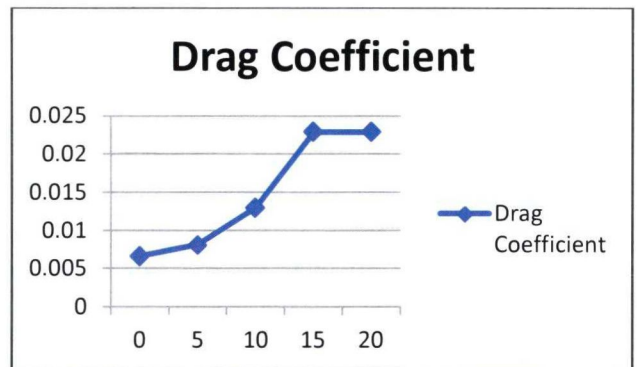| Angle of Attack, θ^o	Drag Coefficient
0	0.0066
5	0.0081
10	0.0130
15	0.0229
20	0.0229

Figure 11. Graph of Drag Coefficient against Angle of Attack, θ^o

From Figure 4, the drag coefficient is gradually increased from $0°$ to $15°$ angle. At $15°$ and $20°$ angle, the value is the same at 0.0229. This is because the NACA 0010 airfoil shape is reaches the stall point [6].

C. Downforce against Vehicle Speed

TABLE III.   DOWNFORCE,N AGAINST VEHICLE SPEED,KM/H VARIES BY ANGLE OF ATTACK,Θ^O

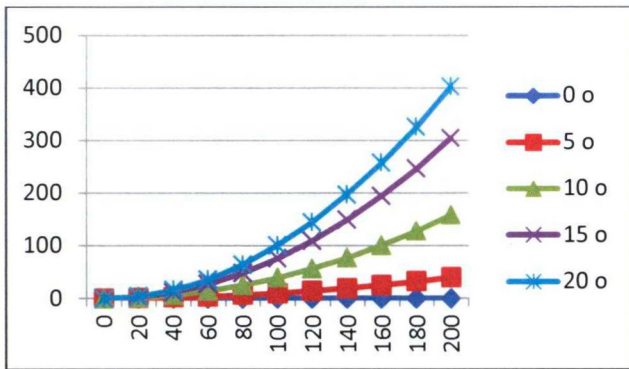| Km/h	0 $^\circ$	5 $^\circ$	10 $^\circ$	15 $^\circ$	20 $^\circ$
0	0.000	0.000	0.000	0.000	0.000
20	0.000	0.399	1.582	3.046	4.0250
40	0.000	1.596	6.326	12.180	16.100
60	0.000	3.591	14.230	27.410	36.220
80	0.000	6.383	25.310	48.730	64.390
100	0.000	9.974	39.540	76.140	100.600
120	0.000	14.36	56.940	109.600	144.900
140	0.000	19.55	77.500	149.200	197.200
160	0.000	25.53	101.200	194.900	257.600
180	0.000	32.32	128.100	246.700	326.000
200	0.000	39.90	158.200	304.600	402.500

Figure 12. Graph of Downforce,N against Vehicle Speed,km/h varies by Angle of Attack,θ°

From Figure 5, the downforce is increasing gradually by the speed of the vehicle and the angles of attack of the spoiler accept for the 0° angle. This is because, at 0°, by the calculation, the resultant downforce calculated is equal to zero for all the speed and angle of attack value. For the 5° angle, the resultant downforce is too small, nearly equal to zero. Even though at the angle of attack 15° and 20° has the same lift coefficient, 1.509, the value of downforce is not the same because of the angle of attack is different. At the same speed selected with different value of angle of attack, the resultant downforce is not the same because of when the angle of attack is increase, the frontal area incident with air flow is also increase. This also valid with the theory when the angle of attack increases, the downforce also increase. The optimum value for angle of attack for NACA 0010 airfoil shape spoiler is 20° because of the ability to generate greater downforce at lower and higher speed beside the other alternative angle of attack that had been verify. The ability to generate downforce at lower and higher speed is needed for the car handling and stability.

D. Drag force against Vehicle Speed

TABLE IV.   DRAG FORCE,N AGAINST VEHICLE SPEED,KM/H VARIES BY ANGLE OF ATTACK,Θ^O

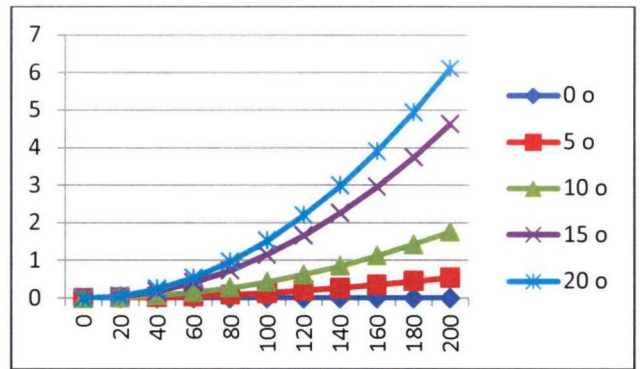| Km/h	0 $^\circ$	5 $^\circ$	10 $^\circ$	15 $^\circ$	20 $^\circ$
0	0.000	0.000	0.000	0.000	0.000
20	0.000	0.006	0.018	0.046	0.061
40	0.000	0.022	0.070	0.185	0.244
60	0.000	0.050	0.158	0.416	0.550
80	0.000	0.088	0.282	0.740	0.977
100	0.000	0.138	0.440	1.155	1.527
120	0.000	0.198	0.634	1.664	2.199
140	0.000	0.270	0.863	2.265	2.993
160	0.000	0.352	1.127	2.958	3.909
180	0.000	0.446	1.426	3.744	4.947
200	0.000	0.551	1.760	4.622	6.108

Figure 13. Graph of Drag Force,N against Vehicle Speed,km/h varies by Angle of Attack,θ°

From Figure 6, the drag force is increasing gradually by the speed of the vehicle and the angles of attack of the spoiler accept for the 0° angle. This is because, at 0°, by the calculation, the resultant drag force is equal to zero for all the speed varies. But, for the actual value of drag force at the angle of attack, 0°, is not zero like had verified by theory. This because, at 0° angle of attack, the frontal area of the NACA 0010 airfoil shape is not zero like verified by calculation due to the airfoil shape, the NACA 0010 airfoil spoiler has the thickness of 10% of its chord length. Even though at the angle of attack 15° and 20° has the same drag coefficient, 0.0229, the value of drag force is not the same because of the angle of attack is different. This because, difference in angle of attack of the spoiler give different frontal area value, hence the resultant drag force is not the same for all difference value of angle of attack. As for selected NACA 0010 airfoil shape of the spoiler, for the selected angle of attack and vehicle speed, the resultant drag force has small value meaning that NACA 0010 airfoil shape of spoiler has great penetrating capability trough the air flow.

IV. CONCLUSION AND RECOMMENDATION

The selected NACA 0010 airfoil shape of spoiler has great credibility to be use as car spoiler because of the ability to generate large downforce with less drag force. The large amount of downforce is needed to counteract the lift force of the vehicle when the vehicle is moving at high speed hence obtain good car handling and stability. NACA 0010 airfoil shape of spoiler also generate low drag force at high speed, its mean that although it produce high downforce for stability and handling of the car at high speed, the fuel consumptions of the car still can be obtain at normal range because of low drag force generated by the spoiler.

Downforce and the drag force is varies with angle of attack and the speed of the vehicle. Increasing the angle of attack and the speed of the vehicle will result higher downforce and drag force. The difference angles of attack generate different frontal area of the spoiler, hence producing different downforce and drag force of the spoiler. The NACA 0010 airfoil shape has stalling point between $15°$ and $20°$, this will results the different in gradient of coefficient of lift and drag against the angle of attack of the NACA 0010 airfoil.

As for recommendation, to generate more downforce, the angle of attack needs to be increase. But, the angle of attack can be varies until the stall point, if the angle of attack pass the angle of attack of stall point, the lift and drag coefficient will decrease because of airflow separation. Also, to generate more downforce at the same speed and at the same angle of attack, the wingspan need to be increase to get larger frontal area hence generate more downforce and resulting more drag force too. In addition, in generating different downforce and drag force, other NACA 4-digit series can be use because different series has different shape hence generate different downforce and drag force at different lift and drag coefficient.

REFERENCE

[1] Kamprasad Chodagudi and T.b.s Rao, "International Journal of Engineering Researh & Technology (IJERT)," Vol. 1 Issue 7, September – 2012

[2] E. L. Houghton, P. W. Carpenter, "Aerodynamics for Engineering Students," Butterworth-Heinemann, Feb 12, 2003

[3] Merle C. Potter, D. C. Wiggert, Bassem Ramadan, "Mechanics of Fluids," Fourth Edition

[4] Harris Yong and Randy Chang, "Lift and Drag Effects of a Rear Wing on a Passenger Vehicle," Fall 1997 Independent Lab Project

[5] Ridwan bin Che Zake, "Aerodynamics of Aftermarket Rear Spoiler," November 2008

[6] J. Jagadeep Reddy and Mayank Gupta, "Finding The Optimum Angle of Attack for The Front Wing of an F1 Car using CFD," Proceedings of the 4th WSEAS International Conference on Fluid Mechanics and Aerodynamics, Elounda, Greece, August 21-23, 2006 (pp29-34)

[7] Mustafa Cavcar, "The International Standard Atmosphere (ISA),"

[8] David M. Smiadak, "Lift Coefficient for an Airfoil,"

[9] Zakaria B. Hamzah, "The Study of Aerodynamic Effect on Spoiler,"

[10] Mohd Shahmal Bin Mohd Shahid, "Study of F1 Car Aerodynamic Rear Wing Using Computational Fluid Dynamic (CFD),"

[11] F Mortel, "Cranfield Team F1: The Front Wing,"

[12] Satyan Chandra, Allison Lee, Stevan Gorrell and C. Greg Jensen, "CFD Analysis of Pace Formula-1 Car,"