The influence of gurney flap to the stability of formula car rear wing with simulation

Y Venti Yoanita¹, S T Pinindriya², E Kumolosari³, Bayu Gilang P¹, Didik R¹

¹Faculty of Teacher Training and Education Universitas PGRI Yogyakarta Indoensia,  
²Center of Aviation Technology, Lembaga Penerbangan dan Antariksa Nasional (LAPAN),  
³Departmentof Mechanical Engineering Sekolah Tinggi Teknologi Adisutjipto Yogyakarta

¹yventiyoanita@upy.ac.id, ²sinung.tirtha@lapan.go.id, ³elikumolosari@stta.ac.id

Abstract. The rear wing on the racing car is used to maintain the vehicle's stability when driving at high velocity. However, in reality when a racing car runs at high velocity, it does not function optimally because of the maximum limit of compressive force generated. Therefore, modifications of the rear wing are needed to increase the compressive force. The common modification is varying the number and shape of the spoilers or change the angle of attack. This study used a single spoiler variation with the addition of gurney flap attached to the rear wing spoiler. The addition of gurney flap was expected to improve the aerodynamic performance, resulting the greater downforce. This study was conducted with a simulation using Solidwork 2018 student version. The variations applied were rear wings using gurney flap and without gurney flap at velocity of 25 m/s, 50 m/s and 88.89 m/s. The results of the variation of gurney flap addition on the rear wing produced a greater variety of downforce based on the value of the resulting lift coefficient. As velocity increased, the pressure and the coefficient lift were also increased. The effect were the greater the compressive force so as the stability was increased.

Keyword: rear wing, gurney flap, downforce

1. Introduction

The object of this study is vehicle that is installed a rear wing system. The aim is not only to produce the fastest racing car, but furthermore to find out how to build the best racing car in terms of construction, performance, financial, and marketing plans. The rear wing itself has a function to block the flow of wind passing the top of the vehicle so that it can push down the vehicle to make it more immersed. There are high challenges in building and assembling cars by considering the safety and economic aspects in the automotive industry. The result will be good driving characteristics when accelerating, decelerating, and maneuvering. The part that will be developed in this study is the rear wing system, which has a big influence. The design of a rear wing requires knowledge of how the rear wing works optimally, in terms of both function and efficiency.

Different fluid flow characteristics resulted from the influence of the angle of the gurney flap attached to the rear wing. Until recently researchers have not been able to find a precise solution to
diagnose and analyze the flow structure of the rear wing with the addition of a gurney flap. Therefore, it needs to be studied continuously. One of them is by using the help of a Solidwork 2018 student version software. The effect of aerodynamics will produce a downforce, where the force is strongly influenced by the $C_L$ (lift coefficient) value. The effect of downforce on aerodynamics is heavily exploited in designing modern racing cars [6]. The $C_L$ value will increase as the angle of attack increases, and will decrease to a certain degree due to the stall phenomenon. When lift is generated, it also results in drag or $C_D$ (drag coefficient). In designing an aerodynamic vehicle, the downforce is negative from $C_L$ because what is needed is the compressive force, not lift one. Maximizing the application of downforce to formula cars will optimize cornering performance on the track. It is a challenge to create a design that produces a minimum value of $C_L$ and optimum value of $C_D$ based on regulations made by the Japanese Society of Automotive Engineers (JSAE). The downforce value is very dependent on the lift coefficient ($C_L$), so it is necessary to conduct a study to determine the simulation results of the downforce value that can be generated by the rear wing with the addition of a gurney flap.

This study will analyze the rear wing with additional variations of the gurney flap on a formula car with a single spoiler. The aerodynamic system plays an important role in the design of modern racing cars. In this case, aerodynamics has become one of the main studies in racing for the last 40 years with the aim of increasing the downforce value on the rear wing to increase the grip on the track without giving additional mass to the vehicle [1]. With resulting the downforce (negative lift force), there will be benefits, namely increasing the ability of tires when cornering, stabilizing the vehicle at high velocity, improving the braking system, and providing good traction [7].

The addition of a gurney flap has an effect on increasing the characteristics of the airfoil, which results in increasing the angle and velocity, then finally increasing the downforce [4]. Reducing drag and provide a front spoiler can increase the downforce and reduce the lift (positive lift force) to several values [5].

![Figure 1. Rear wing dimension of formula car](image)

Figure 1 shows the dimensions of the Formula Mazda rear wing with a single element. The inclination angle was measured based on SCCA, Inc measurements and aerodynamic standards [8].
Figure 2. Rear wing with AoA=0°

Figure 2 shows that with AoA = 0°, the velocity of air under the airfoil is greater than that of the upper airfoil, so that the pressure distribution at the bottom is low. It is shown in Figure 3, where the air velocity distribution is reversed. On an airfoil with an increase in angle of attack (AoA), the $C_D$ will be higher, especially at angles above 15° [2].

Figure 3. Velocity distribution of rear wing at AoA=0°

2. Methods
This study focused on increasing the lift force on the rear wing. This rear wing spoiler is single. The variation used in this study was adding gurney flap and vary the velocity. The assumption is knowing the effect of small elements, which are placed in a well-selected area that is particularly sensitive to changes in flow, can have a significant impact. Data were collected without a gurney flap and with a gurney flap. This was conducted in order to get the effect of the gurney flap at various velocities. The rear wing dimensions are shown in Figure 4 and 5.
Figure 4. Angle of Attack of rear wing without gurney flap

Figure 5. Rear wing dimension with gurney flap

The lift force simulation was conducted using the Solidwork 2018 student version software with a 2D model. The length of the spoiler chord dimensions was 451.104 mm with a length of 381 mm. The gurney flap itself had dimensions of 6 x 11 mm, extending according to the length of the spoiler. The velocities used were 25 m/s, 50 m/s, and 88.89 m/s. Meshing and volume control were carried out in each variation with the cross-sectional dimensions without the gurney flap, namely 76.2 x 381 mm and with a gurney flap of 79.76 x 381 mm. The simulation was only conducted on the rear wing, ignoring the vehicle body.

Figure 6. Force direction on rear wing
Figure 6 shows the direction of the simulation obtained in the form of a downward pressure (lift force) and in one direction with the wind drag force. The magnitude of the lift force is the same as the down force, what distinguishes it is the value and direction. Lift force was analyzed in terms of lift coefficient dimension ($C_L$). The decrease in downforce value due to changes in Angle of Attack can result in instability of the vehicle [3].

The flowchart simulation is shown in Figure 7. The first step was making the rear wing geometry, then adding it with a gurney flap. After completion, a meshing grid was conducted for each geometry then simulated it by varying the velocity (m/s). After the simulation results were completed, the results should be checked whether it was convergent or not. If so, the resulting aerodynamic characteristics ($C_L$, $C_D$) will appear. If not convergent, the simulation should be repeated. After the results were obtained, the analysis was conducted, and finally the conclusions were drawn. The lift coefficient ($C_L$) was obtained using Equation (1) which is the ratio between the lift force ($F_L$) and the density of air ($\rho$), air velocity ($v_a$) and cross-sectional area ($A_L$).

$$C_L = \frac{F_L}{\frac{1}{2} \rho v_a^2 A_L} \quad (1)$$

From Equation 1, it can be seen that the lift coefficient ($C_L$) is proportional to the square of the velocity. It can be concluded that when the vehicle is traveling twice as fast, the lift force will increase fourfold. The larger the cross-sectional area of the rear wing, the greater the compressive force. However, the larger the area will certainly increase the weight of the vehicle, which will
produce the greater friction. The cross-sectional area without using the gurney flap was 29.03 mm², while with the gurney flap was 30.39 mm².

3. Results and Discussions
The result of the 2D simulations were lift force, pressure, and velocity. Based on those result parameters, the effect of the gurney flap on the rear wing could be investigated.

3.1. The pressure without gurney flap

![Figure 8](image)

**Figure 8.** Pressure distribution without gurney flap at velocity of (a) 25 m/s; (b) 50 m/s; (c) 88.89 m/s

Figure 8 shows the pressure distributions, which indicates that increasing velocity causes the smaller pressure at the end of rear wing. At velocity of 25 m/s the pressure at the end of the rear wing was homogeneous. However, the greater velocity, namely at 88.89 m/s, causes the pressure under the tail was smaller. This happens due to the flow rate forms the streamlined flow.

3.2. The velocity without gurney flap

![Figure 8](image)
The effect of air velocity that occurs on the rear wing body is shown in Figure 9. The greater the velocity, the greater the airflow. It can be seen that increasing the velocity causes the airflow above and below the rear wing body are getting smaller. This shows the effect of the existence of rear wing. The airflow under the tail of rear wing is also seen to experience a difference in velocity resulting large airflow separation.

3.3. The pressure with gurney flap

The effect of air velocity that occurs on the rear wing body is shown in Figure 9. The greater the velocity, the greater the airflow. It can be seen that increasing the velocity causes the airflow above and below the rear wing body are getting smaller. This shows the effect of the existence of rear wing. The airflow under the tail of rear wing is also seen to experience a difference in velocity resulting large airflow separation.

3.3. The pressure with gurney flap
Figure 10 shows that adding gurney flap causes the change of pressure. As the velocity increases, the pressure on the rear wing is getting smaller. At a velocity of 25 m/s the pressure at the end of the rear wing is homogeneous distributed. However, as the velocity increases, the pressure under the tail is getting smaller. This happens due to the flow rate forms streamlined flow.

3.4. Velocity with gurney flap

![Figure 11. Velocity distribution without gurney flap at velocity of (a) 25 m/s; (b) 50 m/s; (c) 88.89 m/s](image)

The effect of air velocity that occurs on the rear wing body is shown in Figure 11. As the velocity increases, the airflow is also increase. It is shown in figure 11c that velocity at the end of the rear wing is 88.89 m/s. The higher velocity causes the airflow above and below the rear wing body are getting smaller. This shows the effect of the rear wing. The airflow under the tail of rear wing is also seen to experience a difference in velocity resulting large airflow separation.

![Figure 12. C_l, C_D at various AoA on the rear wing [8]](image)
Figure 12 shows the result study of the [8] which performs lift coefficient and the drag coefficient with the variation of the angle of attack (AoA). From the graph, it can be seen that the drag coefficient increases as the AoA were varied. In addition, the lift coefficient are also increases until the angle of attack reaches 12 degrees. Above 12 degrees of AoA, there is a decrease in lift or it has already occurred stall.

It can be seen in Figure 13 that as the vehicle velocity increases, the lift coefficient is also increases. It is shown that at velocity above 90 m/s, the increase in the lift coefficient is greater. It can be compared to the velocity below 90 m/s, which shows that the lift coefficient seems like constant. Then it can be concluded from these changes that the effectiveness of adding gurney flap will appear significantly at high velocity, namely above 90 m/s. It can also be predicted that as the velocity increases, the compressive force will also increase.
Figure 14. Pressure at various velocity

Figure 14 shows that as the vehicle velocity increases, the pressure will also increase for both without the gurney flap and with the gurney flap. However, at velocity of 40 m/s without a gurney flap the increment pressure is smaller. This is due to the effect of the cross-sectional area that has not captured air optimally.

4. Conclusions
Based on the results of the study, it can be drawn some conclusions as follows:
1. The addition of a gurney flap on the rear wing can increase the downforce or negative lift force in racing car.
2. As the velocity of the racing car increases, the downforce also increases so that the vehicle is more stable.
3. The effectiveness of adding gurney flaps can be seen at high velocity, namely above 90 m/s.

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6. References
[1] Dahlberg, H. (2016), Aerodynamic Development of Formula Student Race Car (Thesis). KTH Mechanics. Retrieved 27 November 2016 from http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-148799.
[2] Herdiana, Dana, Tirtha P., S., (2013). Selection of Airfoil for LSU-05 Aircraft Wing with Numerical Aerodynamic Analysis, Proceedings International Seminar of Aerospace Science and Technology 17th, Vol 1, pp 1-6.
[3] Jackson, F. (2018). Aerodynamics Optimization of Formula Student Vehicle Using CFD, Journal of Huddersfield Student Research, https://doi.org/10.5920/field.2018.2.
[4] Liebeck, Robert, H. (1978). Design of Subsonic Airfoils for High Lift, AIAA Journal of Aircraft Vol. 15 No. 9, pp 547–561.
[5] Maulesh, H.P., Krushal U. S., Parth A. G, Aliasgar T. M., (2018). Aerodynamic Optimization of Formula Student Racing Car, International Journal of Engineering Science and Computing Vol.8, No 7, pp 18633-18639.
[6] McBeath, S. (2006). Competition Car Aerodynamics, Spackford: Haynes.
[7] Mustafa, Cakir. (2012). CFD Study on Aerodynamic Effects of A Rear Wing/Spoiler on A Passenger Vehicle, Mechanical Engineering Master Thesis.
[8] W. Kieffer, S. Moujeas, N, Armbya, (2006). CFD Study Of Section Characteristics of Formula Mazda Race Car Wings, Mathematical and Computer Modelling 43, Issues 11-12, pp 1275–1287, 2006.