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Effect of Gurney Flap on The Flow Separation Phenomenon on The Rear Wing Airfoil of Racing Car

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Abstract

Background: A racing car must be able to run at high speeds. To achieve this goal, vehicle aerodynamic modifications are often carried out, one of which is adding a gurney flap (GF). The GF on a racing car function to delay the flow separation, increase the downforce value, and reduce the drag force.

Aims & Methods: In this study, observations of the influence of GF were carried out by numerical simulation using Solidworks 2025 by varying the speed of 250, 320, and 400 km/h at an angle of attack of 0°, with and without GF. The aim is to obtain information on the influence of these variations on the flow separation phenomenon on the rear wing airfoil.

Result: The results showed that the addition of GF caused a delay in flow separation and a decrease in wake/vortex behind the airfoil. The impact was that the drag force increased at low speeds (39.97% at 250 km/h) but showed a decrease at medium and high speeds, namely -7.91% at 320 km/h and -2.31% at 400 km/h.

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1. Introduction

Performance is one of the considerations when choosing a vehicle. However, high performance requires a lot of energy. Therefore, various designs and efforts have been made to ensure that vehicles have good performance but are fuel efficient. This is not only related to environmental issues but also to the limitations of non-renewable energy resources (Jagadeesh Kumar *et al*., 2013; Senthilkumar *et al.,* 2023). In addition, the economic aspect is certainly a crucial consideration.

One type of vehicle that requires high performance is a racing car. Racing cars must be able to drive at high speeds. In addition to modifying the vehicle's aerodynamics, several treatments can also improve its performance, one of which is delaying flow separation. Flow separation must be delayed to minimize wake formation behind the vehicle. A large wake occurrence will impact reduced vehicle speed, increased fuel consumption, and decreased vehicle performance (Hassan *et al.,* 2022; Nath *et al.,* 2021; Ragavan *et al.,* 2014). Flow separation occurs when the flow momentum is unable to overcome the adverse pressure gradient and shear stress. The occurrence of this separation will reduce lift and increase drag, which is very detrimental (Hariyadi & Aries Widodo, 2018; Yoanita et al., 2025). The delay in flow separation itself can be done by adding a component to the rear wing, namely the gurney flap (GF).

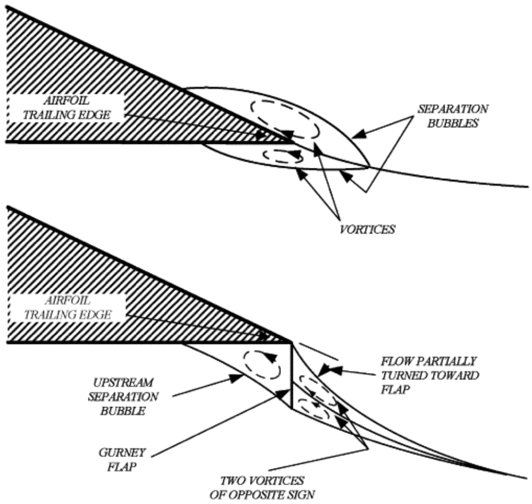


Figure 1. Effect of adding a gurney flap (Tirtha *et al.,* 2020).

A Gurney flap is a small plate added to an airfoil to improve performance (Amini *et al.,* 2018). An illustration of the addition of a GF is shown in Figure 1, where the subsonic airfoil of an aircraft can increases the total pressure on the lower surface. At the same time, the long structure at the tip of the flap containing a pair of counter-rotating vortices can delay or eliminate flow separation near the trailing edge of the upper surface (Wang *et al.,* 2008).

Adding GF to the rear wing of a racing car has the same effect as adding a winglet/wingtip device to an airplane wing. Adding winglets to the wing and increasing the lift force also increase the drag force, namely the drag profile component, due to the increased wing area (Sivakumar *et al.,* 2022; Tirtha *et al.,* 2020). At the tip of the wing, there is an additional device in the form of a winglet that functions to reduce turbulence that occurs in the wingtip vortices, thereby increasing wing efficiency (Aribowo *et al.,* 2012). The phenomenon that occurs on an airplane wing has the same principle as that on the rear wing of a racing car. It is hoped that the addition of GF to the rear wing can reduce drag force due to the influence of turbulence and has an effect on increasing airfoil characteristics, which results in increased angle and speed, resulting in increased downforce (Herdiana *et al.,* 2013; Krishnamurthy & Nagesh, 2022). Figure 2. shows a racing car with the addition of GF to the spoiler.

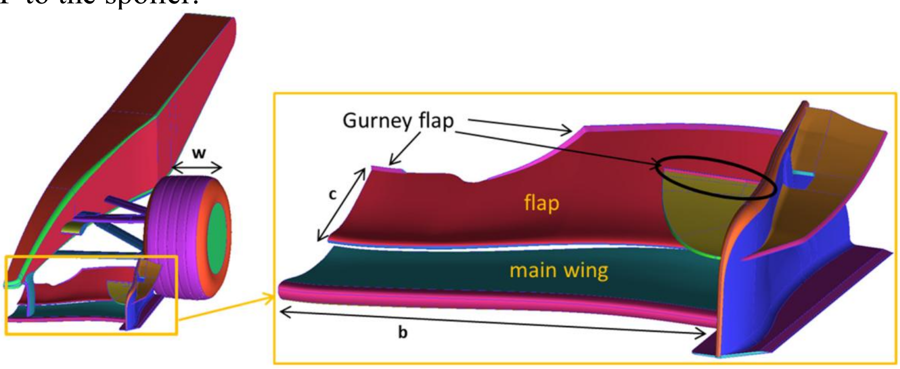


Figure 2. Rear wing geometry with GF (Basso *et al.,* 2021).

Figure 3. is the result of air speed simulation on the rear wing with the addition of a gurney flap on the GTR car. From the figure, it can be seen that at an angle of attack (AoA) = 0◦, the magnitude

of the airspeed under the airfoil is greater than the speed above the airfoil (Kieffer *et al.,* 2006; Yoanita *et al.,* 2021). Therefore, the pressure distribution at the bottom is lower. In addition, Figures 1-3 also show that the airspeed distribution appears to be inverted. According to (Herdiana *et al.,* 2013), increasing AoA will cause the drag coefficient (CD) to increase, especially when AoA is above 15°. Furthermore, Figure 4 shows an example of the variation in speed and pressure distribution at AoA = 0°; as expected for an inverted airfoil, the low-pressure suction area is on the lower surface of the airfoil, with the positive pressure side on the upper surface of the airfoil.

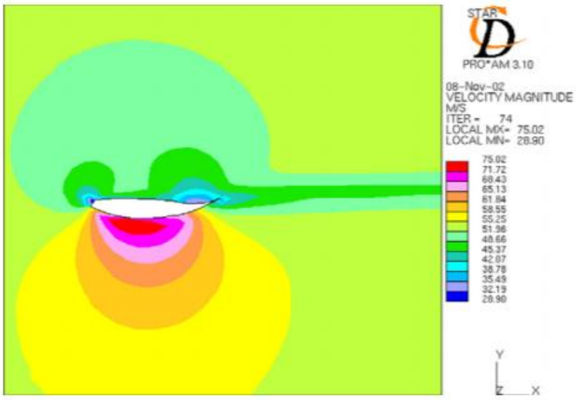


Figure 3. Simulation of air speed on the rear wing with the addition of GF variations on the GTR (Yoanita *et al.,* 2021).

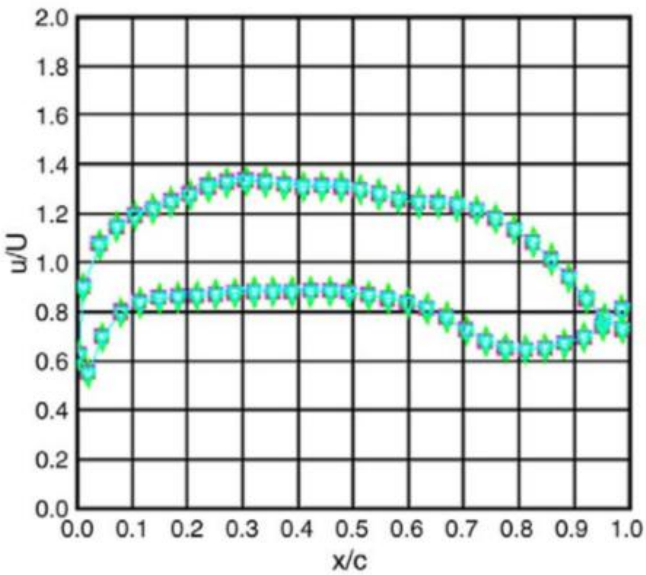


Figure 4. Rear wing velocity distribution when AoA= 0◦ (Yoanita *et al.,* 2021).

Figure 4 shows the rear wing velocity distribution at an Angle of Attack (AoA) of 0° (zero degrees), with the measured velocity divided by the freestream velocity (u/U). This graph illustrates the relationship between the position along the chord axis (x/c) and the ratio of the wing velocity relative to the freestream. The patterns shown likely indicate changes in velocity along the wing surface that aerodynamic factors can influence. By examining how GFs affect flow separation on the rear wing airfoil, this study helps develop the aerodynamic design of racing vehicles. Key findings indicate that adding GFs increases downforce, accelerating the transition from laminar to turbulent flow, which changes the flow characteristics. These findings influence the delay in flow separation and the reduction in the size of the wake and vortex behind the airfoil.

This study identifies the role of GFs in flow dynamics more comprehensively, unlike previous studies that usually only focus on increasing downforce.

2. Materials and Methods

2.1 Modeling and Meshing

The research begins with a literature study, followed by problem formulation, then data collection, simulation using *Solid Works 2025 software* with a 3D model, analysis of results, drawing conclusions, and finishing. This study focuses on improving the performance of racing cars by adding GF to the rear wing to delay flow separation. The variations used in this study are speed variations on the rear wing without and with GF. This study aims to obtain information about the effect of adding GF at various speeds on the flow separation phenomenon. The rear wings model used has dimensions of 1776 mm with a GF height of 37 mm. The details of the dimensions of the rear wing with GF can be seen in Figure 5.

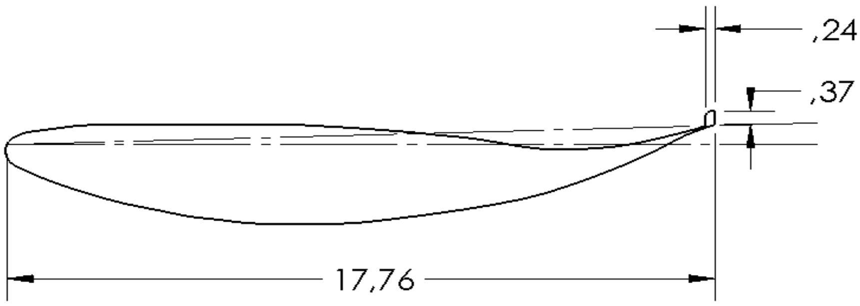


Figure 5. Rear wing dimensions with GF in this study

After the model is created, the meshing process is carried out. The meshing process is carried out using a Cartesian mesh approach, with the number of elements approaching 1.2 million. Local mesh refinement is used in the area around the GF and the trailing edge of the airfoil to collect the complex separation and velocity variation phenomena in the flow. The results of the meshing process are shown in Figure 6. Mesh sensitivity testing was carried out, and the results showed a difference of less than 5% between the fine and medium meshes. This shows that the accuracy of the mesh used is sufficient for simulation purposes.

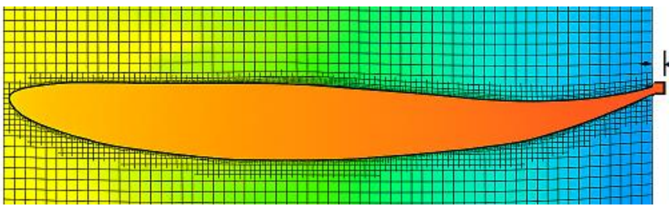


Figure 6. Meshing of the Gurney flap modeling in this study

2.2 Gurney Flap Simulation Configuration

Simulations were performed with speed variations (250, 320, and 400 km/h). The selection of speeds of 250, 320, and 400 km/h in this study represents realistic speed variations commonly found in high-performance racing vehicles. The speed of 250 km/h is assumed to be the acceleration phase after exiting a corner; 320 km/h reflects the cruising speed on a straight track, while 400 km/h is used to simulate extreme conditions approaching the maximum speed limit. Through these three scenarios, the study aims to evaluate how GF affects flow characteristics based on differences in airflow kinetic energy. In addition, this analysis allows the identification of the optimal speed at which GF provides the most significant effect in increasing downforce and reducing aerodynamic drag.

In the simulation results, flow lines are visible, indicating the flow separation point and wake/vortex. In addition, data in the form of drag force and downforce values will also be displayed. The same steps are also carried out in the second case, namely by adding GF. The rear wing that has been drawn is then added with GF, the size of which is shown in Figure 5. From the simulation results, an analysis is then carried out before drawing conclusions.

3. Results dan Discussion

3.1 Results

Table 1 compares the forces generated on the vehicle with and without GF at two types of forces, namely downforce and drag force, at three different speeds: 250 km/h, 320 km/h, and 400 km/h. In the downforce, which is the downward force that provides vehicle stability, it can be seen that the use of GF produces a greater force at each speed. Without GF, the downforce at a speed of 250 km/h was recorded at -140.708 N, while with GF, the value increased to -199.852 N. Similar increases were also seen at speeds of 320 km/h and 400 km/h, where the downforce with GF was greater than without GF. This shows that GF significantly contributes to increasing the vehicle's grip on the road, which is very important for vehicle stability at high speeds. On the other hand, the drag force, which describes the air resistance to the vehicle, was also compared with and without GF. At a 250 km/h speed, the drag force with GF was higher (49.665 N) than without GF (35.4705 N). However, at 320 km/h and 400 km/h speeds, the drag force with GF was slightly lower than without GF. This shows that although GF at low speeds increases drag, GF can help reduce air resistance at high speeds, indicating better aerodynamic efficiency when the vehicle is moving fast. Overall, the results of this table illustrate that the use of GF improves vehicle stability by increasing downforce while maintaining or even reducing drag force at high speeds, leading to an increase in the overall aerodynamic performance of the vehicle. It is explained that the addition of GF to the rear wing causes an increase in downforce and affects the racing car's stability (Yoanita *et al.,* 2021).

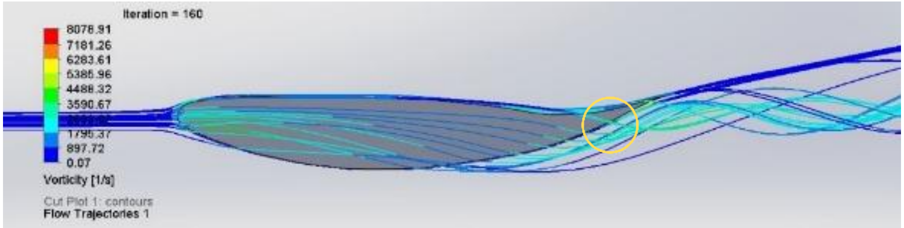
Table 1. Force results at different speeds.

(a) *Down Force*		
Speed (km/jam)	**Without gurney flap (N)**	**With gurney flap (N)**
250	-140.708	-199.852
320	-232.059	-312.458
400	-440.251	-515.112
(b) *Drag Force*		
250	35.4705	49.665
320	89.5014	82.425
400	135.858	132.73

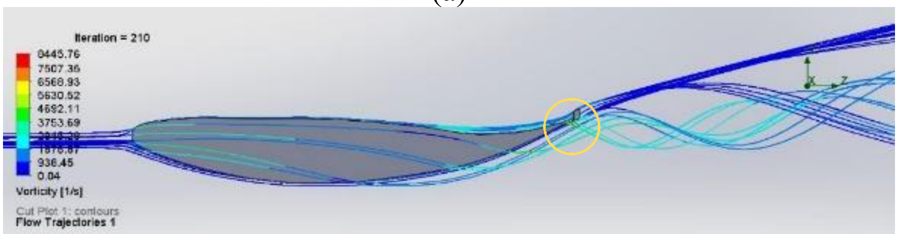
3.1.1 Air flow modeling at 250 km/h

Table 1 shows a comparison of the airflow through the rear wing at a speed of 250 km/h. Figure 7.a is the rear wing without GF, while Figure 7.b. is the rear wing with GF. The flow separation is indicated by the yellow circle in both figures.

Figure 7 shows the representation of airflow (streamline) passing through the vehicle wing at a speed of 250 km/h, with a comparison between without GF and with GF. The airflow flows more smoothly and is not disturbed much by additional devices. This causes less downforce, which affects the stability of the vehicle. On the other hand, image (b) shows the airflow passing through the wing with GF. This image shows that the airflow becomes more distorted, with a sharper deflection at the rear of the vehicle. GF creates more turbulence, which increases downforce, thus providing better stability to the vehicle, especially at high speeds. However, the side effect is increased drag force because the turbulence increases air resistance. Overall, the use of GF on a vehicle provides advantages in terms of stability (downforce), although it may slightly increase drag (Scholz, 2021).



(a)

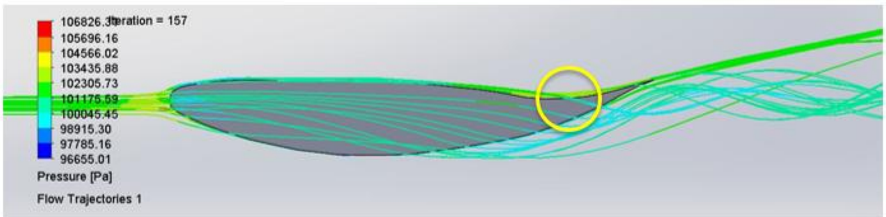


(b)

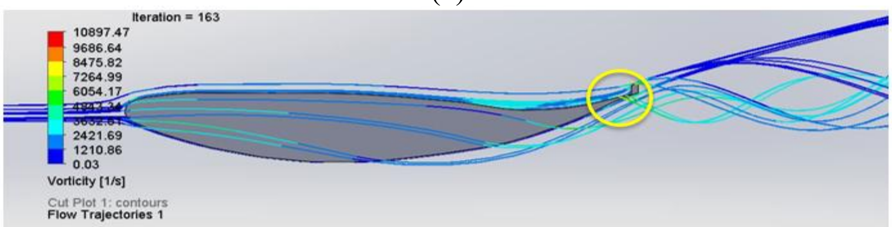
Figure 7. Streamline airflow at a speed of 250 km/h passing the rear wing (a) without GF, (b) with GF.

3.1.2 Air flow modeling at 320 km/h

Figure 8. This figure compares the airflow at 320 km/h passing over the rear wing of a vehicle with and without GF. In figure (a), without GF, the airflow appears smoother, and there is no significant disturbance at the vehicle's rear. In contrast, in figure (b), with GF, the airflow becomes more distorted and swirls around the wing, which increases downforce and vehicle stability. However, this also causes an increase in drag force. GF helps improve aerodynamic performance at high speeds.



(a)

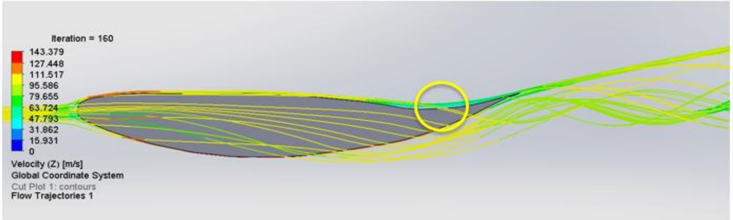


(b)

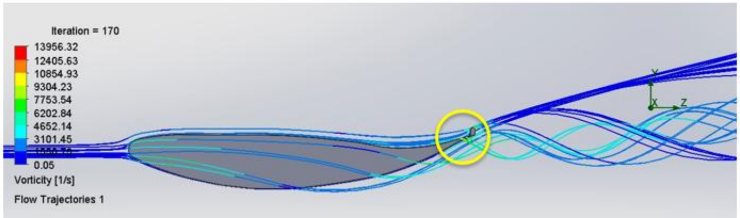
Figure 8. Air flow at a speed of 320 km/h passing over the rear wing (a) without GF, (b) with GF

3.1.3 Air flow modeling at 400 km/h

Figure 9. shows the airflow at 400 km/h passing over the rear wing of a vehicle, with a comparison without GF (figure a) and with GF (figure b). In figure (a), the airflow flows more smoothly without GF with little disturbance at the vehicle's rear. However, in figure (b), with GF, the airflow is more distorted with greater turbulence behind the vehicle, which increases downforce for better stability but also increases drag force. GF works more effectively at high speeds by providing greater control over the vehicle (Chinnappa & Srinivas G, 2023).



(a)



(b)

Figure 9. Airflow at a speed of 400 km/h passing over the rear wing (a) without GF, (b) with GF.

3.2 Discussion

3.2.1 General Phenomena that Occur with the presence of a Gurney flap

Gurney Flap (GF) generally affects the airflow past the airfoil by creating turbulence behind the wing. At low speeds (250 km/h), the airflow tends to be smoother without using GF, but with the addition of GF, the flow becomes more distorted and forms vortices that increase downforce. Better downforce and vehicle stability are obtained due to the change in airflow, which is more turbulent. However, this increase in turbulence also causes an increase in drag force. At higher speeds (320 and 400 km/h), the drag force with GF can be slightly reduced compared to without GF, indicating better aerodynamic efficiency at high speeds.

3.2.2 Effect of Increasing Speed on Downforce and Drag Force

The increase in vehicle speed significantly affects the values of downforce and drag force, both with and without GF. At a speed of 250 km/h, the use of GF substantially increases the downforce value (from -140.708 N to -199.852), but the drag force also increases (from 35.4705 N to 49.665 N). The effect of greater drag force with GF decreases with increasing speed, especially at speeds of 320 and 400 km/h, even tending to or slightly decreasing, while the downforce remains higher with the addition of GF. This happens because GF produces turbulence at high speeds, which reduces the flow resistance that flows back to the rear of the vehicle. The main benefit of adding GF is to increase vehicle stability when driving at high speeds, which is very important for racing cars, even though the consequence is that the drag force value increases at low speeds (Hu *et al.*, 2022; Nath *et al.*, 2021). Similar studies by Yoanita *et al.*, (2021) and Scholz, (2021) showed that adding GF can improve vehicle stability by increasing downforce without significantly increasing drag at high speeds.

4. Conclusion

The addition of Gurney Flap (GF) has been proven effective in improving vehicle stability by increasing downforce and slightly reducing drag force, especially at higher speeds. At a speed of 250 km/h, GF GF increases downforce by 42.03% (from -140.708 N to -199.852 N), but drag force also increases by 39.97% (from 35.4705 N to 49.665 N). At speeds of 320 and 400 km/h, GF still increases downforce (34.62% and 17.0%, respectively), while drag force shows a decrease (-7.91% and -2.31%, respectively). Although drag force increases at low speeds, GF is more beneficial at high speeds because it reduces drag force with better stability. Therefore, GF is highly recommended for vehicles that race at high speeds to obtain optimal stability without significantly reducing efficiency.

5. Authorship

All authors in this paper are major contributors. Dondi Kurniawan drafted the paper, analyzed the results, and translated, Yulia Venti Yoanita conducted the simulation and drafted the paper, Sinung Tirtha Pinindriya drafted the paper and analyzed the results, Eli Kumolosari drafted the paper, analyzed the results. Angga Darma Prabowo drafted the paper, analyzed the results.

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