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GURNEY FLAP INFLUENCE ON NACA 1410 AIRFOIL

Raluca BĂLAȘA[1,2], Mihaela - Luminita COSTEA[1,2], Constantin Cristian ANDREI[1,2], Mihaela BURGHIU[1,2]

[1]Politehnica University of Bucharest, 313 Splaiul Independentei, 060032 Bucharest, Romania
[2]National Institute for Aerospace Research "Elie Carafoli" – INCAS Bucharest, Romania

E-mail: balasa.raluca@incas.ro

ABSTRACT

This paper presents a study of a Gurney flap on the trailing edge of a NACA 1410 profile for different angles of attack and variable geometries. The generic model was created in Catia v5 R21 and imported for CFD simulation in ANSYS Fluent. The Gurney flap model simulation covers variables angles of attack from 00 to 100 with an inlet velocity of 51.5 m/s and Reynolds number of 3.5x106. The CFD results for lift and drag were shown for two different Gurney flap heights. Based on these CFD results for the model the lift increases with angle of attack and Gurney height until the maximum point at with the stall occurs. This point at which the maximum lift occurs varies depending of the configuration used.

Keywords: NACA 1410 profile; Gurney flap; lift; Computational Fluid Dynamics (CFD)

1. INTRODUCTION

Automotive aerodynamics studies the interaction of the fluid stream around the car to reduce drag, wind noise, unwanted lift, and other aerodynamic instability at high speeds. Some racing vehicles require a lift to improve traction and consequently cornering ability. A rear wing, an inverted airfoil, is a commonly used vehicle aerodynamic component to create downforce. Because aerodynamics rules and concepts apply to both automotive and motorsport uses, they can be applied to both. The rear wing creates tremendous downforce, although it is practically constant. To overcome this, the camber, chord, leading and trailing edge profiles must be altered. Adding a Gurney flap to the trailing edge of a rear wing with a variable angle of attack spoiler increases the amount of downforce produced [1]. On the trailing edge of a NACA 1410, a Gurney flap was attached downward and its effects were studied by altering the angles of attack inside the computational domain.

2. SYSTEM DEFINITIONS

A. *Spoiler (Rear Wing)*

A spoiler is an automotive aerodynamic device designed *to spoil* adverse air passage across the body of a vehicle. A spoiler diffuses air by increasing the volume of turbulent air flowing over it, *thereby spoiling* the laminar flow and creating a cushion for the laminar boundary layer. The shape of a spoiler is governed by its cross-section, which is an inverted airfoil that generates negative lift termed lift. At even greater speeds (air velocity 25 m/s), a race car starts to lose tractive adhesion to the track due to the large amount of lift generated beneath it due to the volume of airflow over and under the chassis. Spoilers are employed to generate greater lift in the front, in the form of front wings, and in the back of the car. This lift is required to maintain high speeds around the turns and to keep the car on the track [2].

B. *Airfoil Terminology*

Higher velocity and lower static pressure are often connected with the suction surface. The static pressure is higher on the pressure surface. The pressure gradient between these two surfaces relates to a specific airfoil's lift force.

The chord of an airfoil is a significant aspect. As a result, it outlines the following concepts:

a) The leading edge is the point in front of the airfoil with the highest curvature.
b) The trailing edge is the airfoil's point of least curvature at the back end.
c) A chord line is a straight line that connects the leading and trailing edges.

C. *NACA Airfoil*

The National Advisory Committee for Aeronautics (NACA) was a federal institution in the United States responsible for aeronautical research. The NACA four and five-digit series are the most extensively used of the several airfoils that the NACA has recognized. Although the NACA 1410 is not the most commonly utilized airfoil profile in vehicle racing, it is featured in other automotive aerodynamic applications. NACA 1410's design parameters are as follows:

a) maximum camber is 1% of the chord;
b) distance of maximum camber from the airfoil leading edge: 40% of chord;
c) maximum thickness of the airfoil: 10% of the chord.

D. Gurney Flap

A little flat tab that projects from the trailing edge of the rear wing is known as the Gurney Flap. Usually configured so that it forms a right angle with respect to the pressure surface of the airfoil. Because of this, the performance of a basic airfoil can be improved to the same level as that of a sophisticated high-performance design. In order for it to function properly, it must first raise the pressure on the pressure side and then lower it on the suction side. Moreover, it must assist the boundary layer flow in remaining attached all the way to the trailing edge [3]. Dan Gurney was the inventor of the first version of this application, which consisted of a right-angled piece of sheet metal that was fastened to the top trailing edge of the rear wing of his racing car. It was decided to put the gadget so that it pointed upwards in order to maximize lift and, thus, improve traction. After putting it to the test, he discovered that it enabled his vehicle to take corners at a greater speed while also allowing it to achieve a greater speed on the straightaways. The flap causes an increase in the camber of the airfoil, which is compatible with a decrease in the angle of attack. Moreover, the flap causes an increase in the maximum lift coefficient. Lift is increased by the Gurney flap, which does so by modifying the Kutta condition (A body with a sharp trailing edge, which is moving through a fluid, will create about itself a circulation of sufficient strength to hold the rear stagnation point at the trailing edge) [5]. A von Kármán vortex street is a recurring pattern of swirling vortices generated by the unstable fluid flow separation around blunt things. The wake behind the flap is a pair of counter-rotating vortices that are alternately shed in the street. Because of the increased pressure on the surface in front of the flap, the amount of suction on the upper surface can be decreased while maintaining the same level of lift.

3. GOVERNING EQUATIONS

Continuity Equation

According to this theory, the density, velocity, and area that go into the system must always be equal to the density, velocity, and area that go out of the system. It is consistent with the principle that mass cannot be created nor destroyed.

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2 \tag{1}$$

The Continuity Equation can be represented by equation (1).

Navier Stokes Equation

It provides an explanation of the movement of fluid substances. It is derived from the application of Newton's second law to the motion of a fluid, together with the assumption that the stresses in the fluid are the sum of a diffusing viscous term and a pressure term, which describes a viscous flow. This results in the formation of the equation. In both their full and their simplified forms, the Navier-Stokes equations are useful tools for the design of automobiles and airplanes [4].

$$\frac{\partial \mathrm{u}}{\partial \mathrm{x}} + \frac{\partial \mathrm{v}}{\partial \mathrm{y}} = 0 \tag{2}$$

In the equation developed by Navier and Stokes, the expression (2) stands for the continuity.

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right] \tag{3}$$

In the equation of Navier and Stokes, the X variable is represented by the equation (3).

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \nu\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right] \tag{4}$$

In the equation of Navier and Stokes, the Y component is represented by the equation (4).

In the field of aerodynamics, one of the most important questions to ask is whether or not there will be a change in the density of the air as it flows around a rear wing. The movement of the molecules is what keeps the air's density stable. This will be achievable only if the flow is moving at a pace that is significantly slower than the speed of sound. Because of this, it is possible to assume that the flow is an incompressible one if the velocities involved are less than the speed of sound. This is because the changes in density, temperature, and pressure that occur during the flow are minimal. Because of this, the operation of the rear wing may be described in the most precise manner by assuming that the flow around it is incompressible. As a direct consequence of this, the static pressure will decrease if the velocity increases [5].

4. MODELLING OF NACA 1410 AIRFOIL WITH GURNEY FLAP

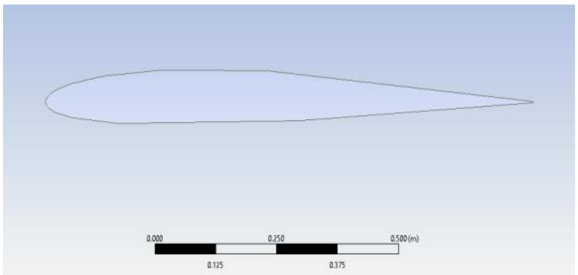
The surface parameters of the flow are simulated by CFD, in this study using three cases:

1. a NACA 1410 airfoil (Fig. 1a),
2. a 2D Gurney Flap attached airfoil model with a Gurney flap height of 2.5% of airfoil chord length (Fig. 1b) and
3. a 2D Gurney Flap attached airfoil model with a Gurney flap height of 5% of airfoil chord length (Fig. 1c).

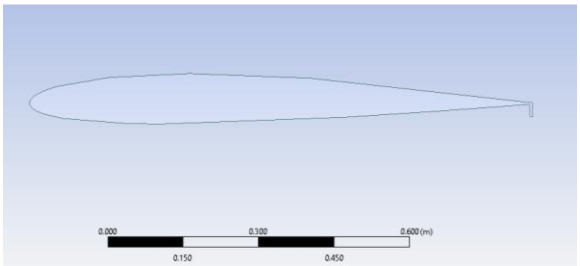
The CFD simulations for each case are accomplished in ANSYS Fluent solver.

The original meshing process resulted in numerous lines being skewed; however, as the mesh was refined, these lines were corrected, and the desired result was achieved. The rectangular blocks were created in a manner that encircled the rear wing.

Upon the completion of the creation of the necessary meshes, those meshes were then saved as mesh files in order to make them suitable for use with the solver.



a)



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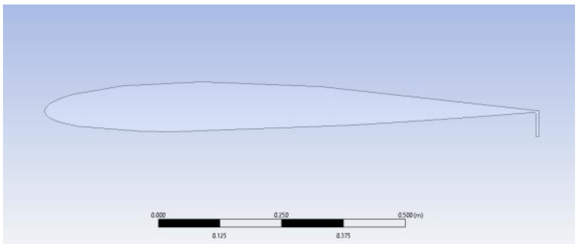


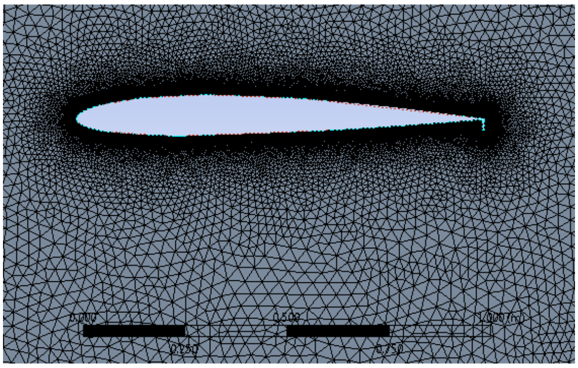
c)

Fig. 1. a) NACA 1410 airfoil; b) 2D Gurney Flap attached airfoil model with a Gurney flap height of 2.5% of airfoil chord length; c) 2D Gurney Flap attached airfoil model with a Gurney flap height of 5% of airfoil chord length

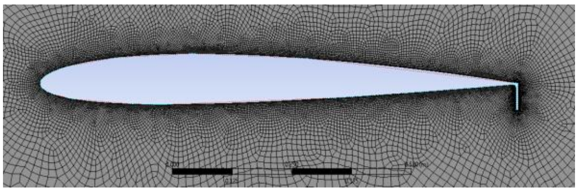
Below is a representation of the mesh for Gurney heights of 2.5% and 5%, respectively (Fig.2). It is essential to maintain the cleanliness of the finer meshes near the surface in order to achieve more accurate simulation results. Thus, an inflation with first cell height of 1.68 x 10^{-6} m and a growth rate of 1.05 for each mesh case was implemented. For the first case (2 a)) there are a number of 250000 nodes and a number of 400000 elements. In the second case (2 b)) there are 104000 nodes and 104000 elements.

The computational model is a CFD simulation of the Gurney Flap models that includes the domain along with an appropriate grid mesh for all angles of attack (AoA), ranging from 0° degrees to 18°.

The initial parameters that were evaluated for the CFD investigation of the airfoil with the Gurney flap are shown in Table 1. For instance, the solver implements the k-ω SST turbulence model in the section of the boundary layer that is placed closer to the surface.The amount of energy that is transferred by the first variable" k" is what causes the turbulence. The turbulence scale is determined by the specific dissipation, which is the second variable that is transported.



a)



b)

Fig. 2. Resulted mesh of: a) Gurney Flap attached airfoil model with a Gurney flap height of 2.5% of airfoil chord length; b) Gurney Flap attached airfoil model with a Gurney flap height of 5% of airfoil chord length

The parameter for the non-dimensional cell wall distance, sometimes known as y+, has been set to 1. Using the k-ω SST model in the inner regions of the boundary layer causes the model to be directly usable all the way down to the wall through the viscous section. This makes it possible for the model to be used as a Low-Re turbulence model without the necessity of including any additional damping functions. In addition to this, the SST formulation switches to a k-ε behavior while it is in the free stream. This allows it to circumvent the typical k-ω problem, in which the model is highly sensitive to the turbulence features of the inlet free-stream turbulence. The k-ω SST model is widely used because of its good performance even in the face of unfavorable pressure gradients and distinct flows. This is largely due to the fact that it can be easily implemented.

Table 1. Initial parameters of the models

Parameter	Value
Flow velocity	51.5 m/s
Reynolds number	3.5 x 10^6
y^+	1
Ambient temperature	300 K
Outlet pressure	0 Pa

5. RESULTS AND DISCUSSIONS

The amount of force that must be applied on the rear wing in order for the vehicle to remain lifted in the air is referred to as the lift. The lift generated in the airfoil at varying heights of Gurney and angles of attack were created.

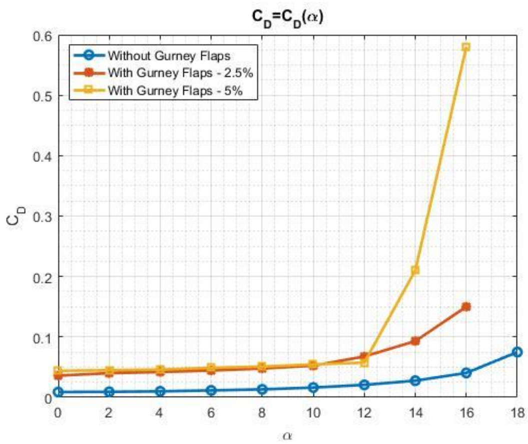


Fig. 3. Drag force for Gurney heights (Hg) and angles of attack (α)

The force that generates a force of resistance and moves in the opposite direction of the flow of air is known as drag. Because it interferes with the aerodynamics of the rear wing, its presence must be kept to an absolute minimum. Even if drag cannot be completely eradicated, it is possible to reduce its effects to some degree. The amount of drag that was produced in the rear wing was plotted for different variations of Gurney's height as well as different angles of attack as illustrated in Fig. 3.

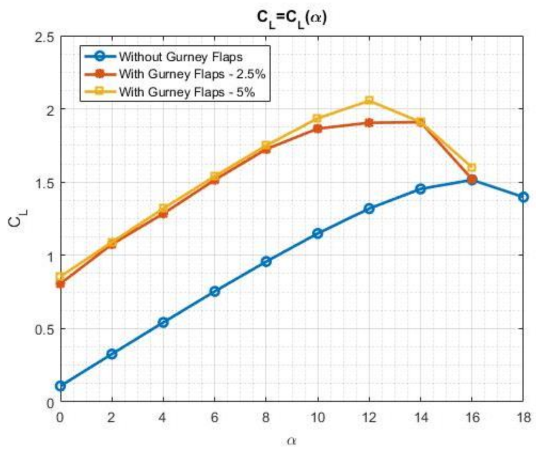
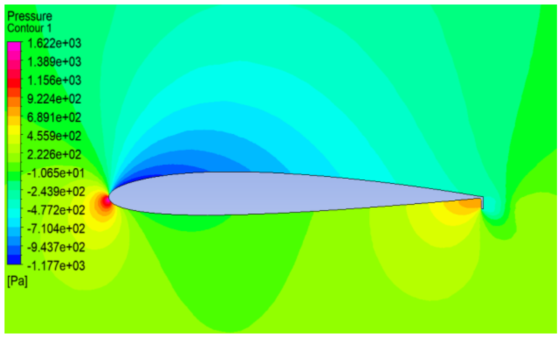


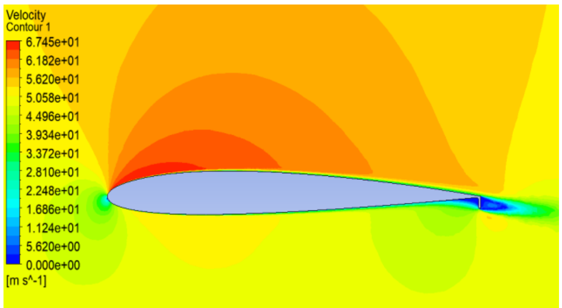
Fig. 4. Lift force generated for the various Gurney heights (Hg) for the various angles of attack (α)

A higher angle of attack implies that it's quite apparent that the flow splits off from the trailing edge, which is something that can't be ignored. Figure 4 demonstrates that the lift coefficient of the conventional airfoil is the lowest of all the cases. As a result, when compared to an airfoil with a Gurney flap at various heights, the lift coefficient of an airfoil with a Gurney flap at various heights is significantly higher than the lift coefficient of a conventional airfoil.

Figure 5 illustrates the 0° AoA NACA 1410 profile's pressure and velocity distribution with 2.5% Gurney Heights.

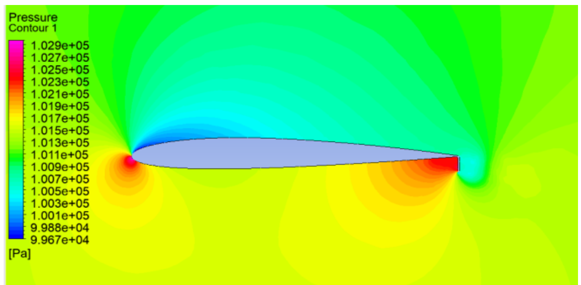


a) Pressure contour for 2.5 % Hg at 0° AoA

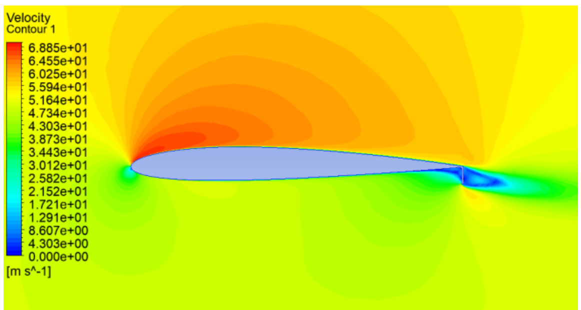


b) Velocity contour for 2.5 % Hg at 0° AoA

Fig. 5. Pressure and velocity distribution for 2.5 % Hg at 0° AoA



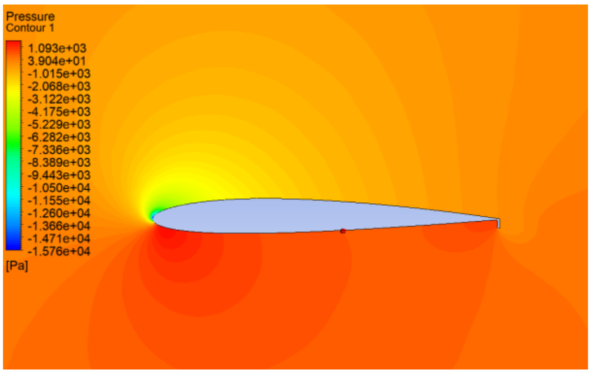
a) Pressure contour for 5% Hg at 0° AoA



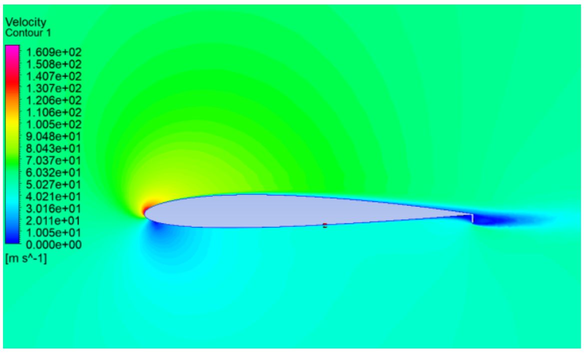
b) Velocity contour for 5 % Hg at 0° AoA

Fig. 6. Pressure and velocity distribution for 5% Hg at 0° AoA

In Figure 6, it can be seen the 0° AoA NACA 1410 profile's pressure and velocity distribution with 5% Gurney Heights.

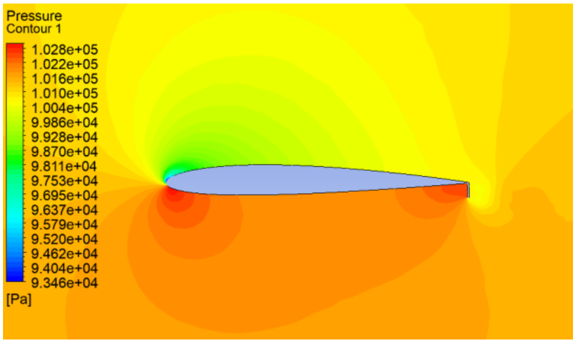


a) Pressure contour for 2.5 % Hg at 10° AoA

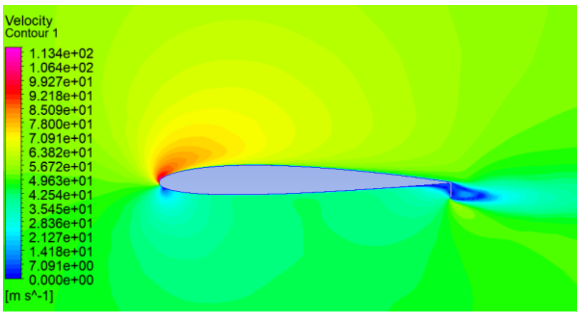


b) Velocity contour for 2.5 % Hg at 10° AoA

Fig. 7. Contours of pressure and velocity distribution for α = 10º



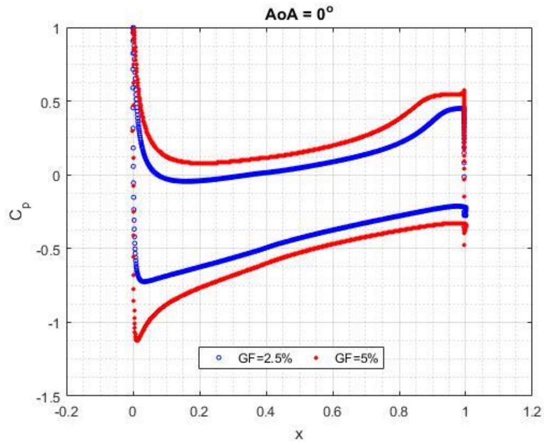
a) Pressure contour for 5 % Hg at 10° AoA



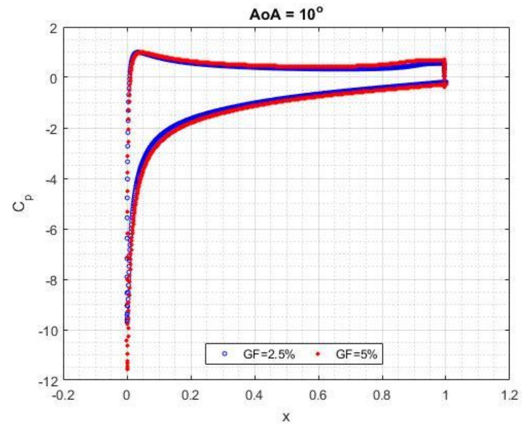
b) Velocity contour for 5 % Hg at 10° AoA

Fig. 8. Contours of pressure and velocity distribution for α = 10º

The pressure distribution at the upper surface of the airfoil expands slowly as the angle of attack increases, as inferred from the contours of the pressure coefficient in Fig. 7. It was also observed that as the angle of attack increases, the stagnation point on the upper surface moves toward the trailing edge.



a) Pressure coefficient plot for AoA=0º



b) Pressure coefficient plot for AoA=10º

Fig. 9. Pressure coefficient plot for different AoA

It is a depiction of the contours of pressure distribution from the CFD simulations, in a graphical style, from which results may be deduced with convenience, as it can be seen in Fig. 8. The pressure plot provides the value of the pressure distribution at the top surface, bottom surface, and the Gurney of the rear wing.

The graphical representations in Fig. 9 illustrate the pressure coefficient distribution for various Gurney Heights (Hg) at 0° and 10° angles of attack.

In Figure 9a, it can be seen that with the increase in the length of the Gurney Flap, the pressure coefficient difference between the inner and upper surface will also increase, which leads to a greater increase in lift. The pressure coefficient for the inner surface is represented in the two figures on the positive axis of Cp, while the pressure coefficient for the upper surface is represented on the negative axis of Cp. Also, from Fig. 9b, it can be drawn the conclusion that, with the increase of AoA, the pressure coefficient difference between inner and upper surface for 5% Hg Gurney flap tends to have the same value as in the case of 2.5% Hg Gurney flap.

4. CONCLUSIONS

The examination of flow phenomena is of considerable importance in comprehending the interactions between fluids and walls, not just in the rear wing but also throughout the entirety of the vehicle. This is mostly owing to the substantial breakthroughs in technology and different developments within the automotive sector that affect the implementation of aerodynamics. This phenomenon can be attributed to the progress that has been achieved. This study exemplifies a cost-effective innovation by showcasing a method to enhance the efficiency of a rear wing without necessitating any modifications to its design, while also minimizing expenses. The investigation of the Gurney flap can be conducted with consideration for the ground effect, since this factor has significance in its ability to modify the fluid flow characteristics surrounding the rear wing. The significance of this matter comes from its potential to advance the current research conducted within this field. Furthermore, the use of a stepped airfoil configuration can be employed in tandem with the Gurney flap to explore its effects on the overall aerodynamic performance of the rear wing.

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