Numerical investigation for the enhancement of the aerodynamic characteristics of NACA 0012 aerofoil by using a gurney flap

DAKKA, Sam <http://orcid.org/0000-0001-9225-761X> and AL-MAWALI, Julanda

Published version

DAKKA, Sam and AL-MAWALI, Julanda (2017). Numerical investigation for the enhancement of the aerodynamic characteristics of NACA 0012 aerofoil by using a gurney flap. International Journal of GEOMATE, 12 (34), 21-27.

NUMERICAL INVESTIGATION FOR THE ENHANCEMENT OF THE AERODYNAMIC CHARACTERISTICS OF NACA 0012 AEROFOIL BY USING A GURNEY FLAP

Julanda Al-Mawali and Sam M Dakka
Department of Engineering and Mathematics, Sheffield Hallam University, United Kingdom

ABSTRACT

Numerical investigation was carried out to determine the effect of a Gurney Flap on NACA 0012 aerofoil performance with emphasis on Unmanned Air Vehicles applications. The study examined different configurations of Gurney Flaps at high Reynolds number of $Re = 3.6 \times 10^5$ in order to determine the optimal configuration. The Gurney flap was tested at different heights, locations and mounting angles. Compared to the clean aerofoil, the study found that adding the Gurney Flap increased the maximum lift coefficient by19%, 22%, 28%, 40% and 45% for the Gurney Flap height of 1%C, 1.5%C, 2%C, 3%C and 4%C respectively, C represents the chord of the aerofoil. However, it was also found that increasing the height of the gurney beyond 2%C leads to a decrease in the overall performance of the aerofoil due to the significant increase in drag penalty. Thus, the optimal height of the Gurney flap for the NACA 0012 aerofoil was found to be 2%C as it improves the overall performance of the aerofoil by 21%. As for the location, it was found that the lifting-enhanced effect of the gurney flap decreases as it is shifted towards the leading edge. Thus the optimal location of the Gurney Flap mounting was found to be at the trailing edge or at distances smaller than 10%C. The Gurney flap was also tested at different mounting angles of -45, 90 and +45 degrees and it was found that the Gurney flap at +45 mounting angle leads to the optimal performance of the aerofoil.

Keywords: Gurney flap, Aerodynamic simulation, NACA0012 Airofoil, FLUENT

INTRODUCTION

High lift devices have a significant effect on the performance of the aircraft. Having an effective and efficient high lift system enables the aircraft to take-off and land at lower speed and it also allows the aircraft to have higher payload capacity and higher range. All high lift devices are designed to keep the drag at lowest during take-off phase in order for the aircraft to reach its cruising speed faster and to increase the drag at approaching phase so it can land at lower speed and shorter runway.

All the advantages resulting from the high lift system improve the performance of the aircraft and make the aircraft more fuel-efficient. However, high lift systems such as flaps and slats are considered to be complex devices and this is due to the behaviour of the flow around the surface of the flap where several types of flow travel over the flap's surfaces such as, the wake resulting from the wing, boundary layer as well as the flow travelling through the flaps slot and all these flows generate a circulating boundary layer over the flap's surface. This unstable flow around high lift device makes the design of the flap very difficult and also increases the cost of manufacturing and maintenance. Therefore, a simple mechanical device is required to reduce the cost of manufacturing as well as to make the aircraft more profitable.

Gurney flap is a very simple mechanical device that is able to increase the lift coefficient with low drag penalty. Gurney flap can be simply defined as a flat plate fitted vertically to the trailing edge of the wing. This kind of flap is used to change the lifting characteristics of the aerofoil.

Many researchers conducted different studies on the effect of the Gurney flap on aerofoil performance. These studies cover a wide range of applications. The outcome [1] of a comprehensive literature review indicated, optimal size of the Gurney flap is equal or slightly bigger than the thickness of the boundary layer at the trailing edge. The boundary layer thickness at the trailing edge depends mainly on the Reynolds number; however the typical thickness at the trailing edge is between 1% to 2% of the chord length. At this length, the gurney flap increased the lift generation with a slight increase in the drag penalty. This review also found that adding the Gurney Flap at the trailing edge does delay the flow separation on the suction surface of the aerofoil.

The first study on the gurney flap was carried out experimentally in 1978 [2] aimed to find to what extent the gurney flap affects the aerofoil performance. The study used a symmetric Newman aerofoil with a Gurney flap of 1.25% of chord length. The data obtained from the experiment showed that adding 1.25%c gurney flap resulted in an increase in the lift coefficient and a slight decrease in both aerofoil drag as well as the zero lift angle-of-attack. The study also tested a Newman aerofoil with larger gurney flap and it was found that Gurney flap with

2%c or larger resulted in a significant increase in the lift coefficient with a noticeable increase in the drag penalty. Another study was carried out by Wadcock [3] on NACA 4412 aerofoil tested at Reynolds number 1.64 x 10^6 in the wind tunnel. The findings of the study showed an effective increase in the total lift generated by the aerofoil with the gurney flap, moving the lift curve up by a magnitude of 0.3 for NACA 4412 with Gurney flap of 1.25%c. The addition of this Gurney flap to the trailing edge did not cause any significant increase in the drag penalty.

An experimental investigation was made on a racing car wing with Gurney flap by Katz and Largman [4]. The Gurney flap was installed at the trailing edge; the results showed that adding Gurney flap of 5% of chord length caused a high increase in the lift coefficient of about 50% compared to a clean baseline wing. However, this size of Gurney flap also caused a very significant drag penalty which in turns, decreased the lift-to-drag coefficient.

A numerical investigation [5] carried out on different sizes of Gurney flaps ranging from 0.5% to 3% chord length. These different flaps were tested on NACA 23018 aerofoil. The study concluded that increase in the size of the Gurney flap leads to an increase in the lift coefficient for the sizes tested, also, it was noticed from the obtained data that the relationship between flap size and lift-curve shift does not seem to be linear. As an example, the increase in the lift coefficient between 0% and 0.5% chord length of the Gurney flap is higher than the increase in the lift coefficient due to changing the size of the Gurney flap from 1.5% and 2% chord length [6]. Adding a Gurney flap to the trailing edge of the wing not only increase the lift, but it also has a positive effect on delaying the separation on the suction surface. Some studies concentrated on the effect of delay separation of the upper surface at certain values of angle of attack, utilising of a Gurney flap in order to control flow separation at low Reynolds number. The results showed that adding such flap has effectively eliminated the separation region. Thus, confirming the benefit of the delayed separation by a Gurney flap [7].

The Gurney flap was also found to have some effects on the boundary layer. A study was conducted [8] aimed to find a scaling for the optimal size of the Gurney flap that would result in the maximum Lift-to-Drag ratio. LA203A Aerofoil was utilized in this study at Reynolds number of $2.5\times10^{5.}$ The findings of this study indicated that the optimal size of the Gurney flap is the same as the thickness of the boundary layer at the trailing edge. Overall, for most aerofoils, the studies revealed that Gurney flap with sizes ranging between 1% to 2% of the chord length had generated the optimal lift-to-drag performance.

Increasing the Gurney flap size beyond the thickness of the boundary layer will result in a dramatic increase in the drag penalty. This was corroborated [9] by investigation Gurney flap of 5%C on NACA0012 at low Reynolds number of 2×10^5. The effect of wing seep on Gurney flap performance was investigated experimentally; the results showed sweep attenuates the Gurney flap lift enhancement [10]. Another study was focused on reduction of the drag penalty associated with Gurney flap deployment based on adjoint shape optimization of aerofoils [11].

AIM AND OBJECTIVES

The goal of this study is to conduct a thorough investigation in order to enhance the aerodynamic characteristics of a thin symmetric aerofoil NACA 0012 at low Reynolds number. This investigation includes testing this aerofoil with different configurations of the Gurney Flap. These configurations are: Different heights of the Gurney flap, different locations of the Gurney flap from the leading edge. Different deflection angles of the Gurney flap and T-strip configuration.

NUMERICAL APPROACH

The study used a Numerical method to analyse the effect of addition of Gurney flap on the behaviour of the airflow around the aerofoil. An overview of the numerical simulation will be introduced followed by mesh generation and implementation.

The aim of the study is to determine the optimal configuration for a thin symmetric NACA 0012 aerofoil. Four different configurations of the Gurney flap were tested for this investigation. These configurations are related to the height, location, mounting angle and T-strip of the Gurney Flap. These tested configurations can be seen from the table below.

Table 1 GF-Gurney Flap Configuration Tested

No	Configuration	Tested Values
1	GF Height	0%C,1%C,2%C,3%C and 4%C
2	GF Location	S=0%C,5%C,10%C and 20%C
3	GF T-strip	1%C T-strip and 2%C T-strip
4	GF Mount Angle	-45, +90 and +45 degrees

The followed procedure for the selection of the optimal configuration started with testing different heights of the Gurney flap and then analysing these data in order to select the optimal height. After selecting the optimal height, this Gurney Flap then was tested as T-strip in order to determine whether it would be more efficient than the normal configuration. The optimal Gurney height then was tested at different locations from the trailing edge to determine the optimal location for this device. After determining the optimal location, the gurney flap was then tested at different mounting angle in order to select the best angle by which the flap will improve the overall performance of the NACA0012.

Computational Fluid Dynamics (CFD) used for solving set of equations in order to model the flow-field. FLUENT 15 was utilized in order to solve set of equations called Reynolds-averaged Navier-Stokes equations (RANS). RANS equations are based on the basic physics of energy, mass and momentum conservation [12]. Two of the turbulence models were used to determine which one would give better results in modelling the flow of interest. These two models are K-ω SST and K-ε Realizable, the latter was used for the testing as it has the capability to enhance the wall treatment. The second order was also selected for the upwind discretization to solve all equations. As for the pressure-velocity coupling, the SIMPLE scheme was selected.

Enhanced wall functions with K-ε were used for the wall boundary conditions. These were applied for the aerofoil surface as well as the two walls of the wind tunnel. Inlet velocity was applied for the ‘velocity-inlet’ condition with the speed of 29 m/s. A ‘pressure-outlet’ condition was applied for the outlet pressure surface. As for the turbulence of the inflow, the turbulent intensity and turbulent viscosity ratio were specified as 5% and 10% respectively.

After creating the geometry (aerofoil), a flow domain was created around the aerofoil. C-mesh technique was used in this test, as it is a very popular technique when it comes to generating a mesh around the aerofoil. Therefore, the number of mesh elements increases as the elements goes towards the edges of the aerofoil. The triangles mesh method was used for this study as it creates a better mesh quality and more refined compared to the Quadrilateral method. Sphere of influence was also used during the mesh process as it allows us to control the size of the mesh around the aerofoil wall. Y+ value was also considered and the distance between the aerofoil wall and the first node was calculated to be 1.1 mm. this value was then used in the Inflation as the first layer thickness. As for the mesh quality, the maximum skewness of the mesh was found to be 0.54 which means that the generated mesh is high quality according to ANSYS measurements.

RESULTS AND DISCUSSION

CFD results were compared to the experimental results for the clean aerofoil The Reynolds number that was used in the computational test (Re=3×10^5) which is based on the chord length (152mm) and this can be seen from Fig. 1.

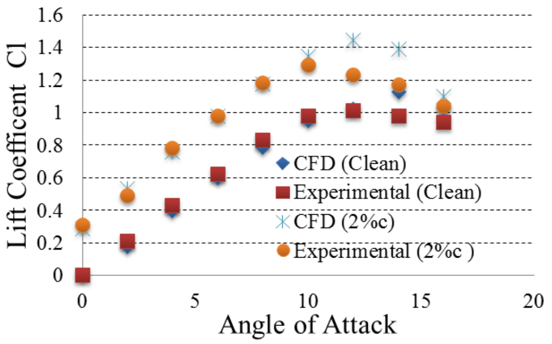

Fig.1 Computational versus experimental [13] results, for clean airofoil and 2%c Gurney Flap.

It can be seen that the CFD results agree well with the measured results up to α = 12°. It appears that beyond the stall angle of attack, the CFD data slightly over predicted the experimental data. This shows a very slight difference between the experimental and the numerical result for high angle of attack which indicates the highly refined and a good mesh method used for the numerical test. This comparison between the CFD results and the Experimental results was made to prove that the method used in the computation was satisfactory.

Figure 2 shows the lift coefficient for NACA0012 aerofoil equipped with 0%,1%,2% and 4%C at angles of attack from 0° to 16°. It can be clearly seen from the same Fig. 2 that Gurney flap effect is to increase the lift coefficient of the aerofoil. Comparison of the maximum lift coefficient of the clean NACA0012 illustrates that the maximum lift coefficient of the Gurney Flap of 1%c,2%c and 4%c is increased about 19%,28% and 45%, respectively. Adding a Gurney flap does not only have an effect on the lift coefficient but it also has a significant effect on the stall angle of the aerofoil. It can be seen from the Fig. 2 that the stall angle decreased from 14° for the clean aerofoil to 12° for the aerofoil with a Gurney flap. It also can be noticed from the Fig. 2 that the zero lift angle of attack becomes more negative as the size of the Gurney flap increases.

Therefore, increasing the size of the Gurney flap was found to increase the lift generated by the aerofoil. This significant increase in lift is mainly due to the increase in the effective camber of the aerofoil. In summary, the lift coefficient curves of Gurney flaps were shifted upwards and to the left.

However, the slope of the curves seems to remain constant. These results demonstrate that the effect of the Gurney flap is mainly to increase the effective camber of the aerofoil.

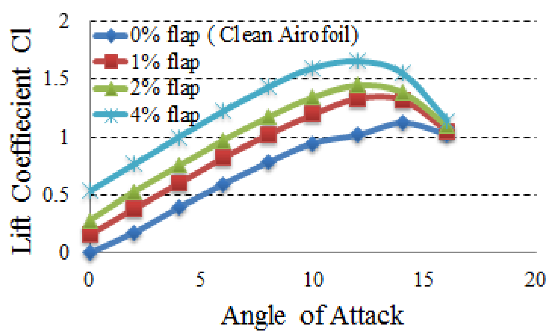

Fig. 2 Lift coefficients for different GF heights.

The effect of the Gurney flap on the drag coefficient can be seen from Fig. 3, the drag coefficient of the aerofoil increases as the height of The Gurney flap increases. As for 1%c and 2%c, compared to the clean aerofoil, the increase in the drag penalty was noticed to be very small at angle of attacks between 0° to 8° and as the angle of attack increases beyond 8° the drag penalty started to increase significantly. However, for a gurney flap above 2%, the drag penalty was noticed to be high compared to the clean aerofoil.

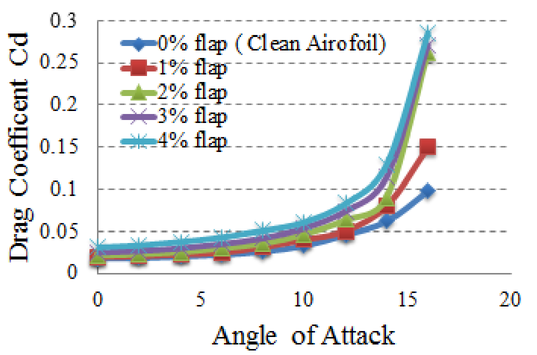

Fig. 3 Lift coefficients for different GF heights.

Figure 4 shows the lift-to-drag ratio as a function of angle of attack α. The L/D ratio increases with the increase of the angle of attack. However, this increase is not linear. As for the Gurney flap with the size of 1%C and 2%C, the lift-to-drag ratio increased up to the stall angle 14°.

It also can be noticed that the aerofoil with a Gurney flap higher than 2%c generates higher lift-to drag ratio than the clean aerofoil for the angle of attack between 0° to 6°. Beyond this angle of attack, these flaps generate less lift-to-drag ratio due to the high generation of drag. Compared to the clean aerofoil performance, the aerofoil with 1%c and 2%c seems to improve the overall performance of the aerofoil. However, the latter was selected as the optimum size as it was found to improve the performance of the NACA 0012 aerofoil by 21% which is considered to be high for the small size of the flap.

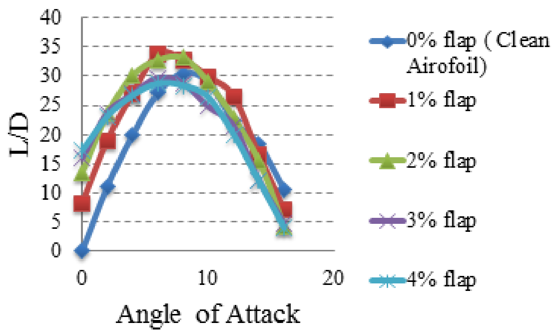

Fig. 4 Lift to Drag ratio for different GF heights.

Gurney flaps with different sizes were tested and the optimal flap that enhances the overall performance of the aerofoil was found to be 2%C. This specific aerofoil was also tested to determine whether the deflection of the gurney flap about the chord line would affect the performance of the aerofoil. The aerofoil was already tested earlier at 90 degrees and then it was tested at +45 and -45 degrees at the same boundary conditions. They were all tested at different angles of attack from 0 to 16 degrees. Fig. 5 and 6 shows the lift and drag coefficient as a function of angle of attack respectively.

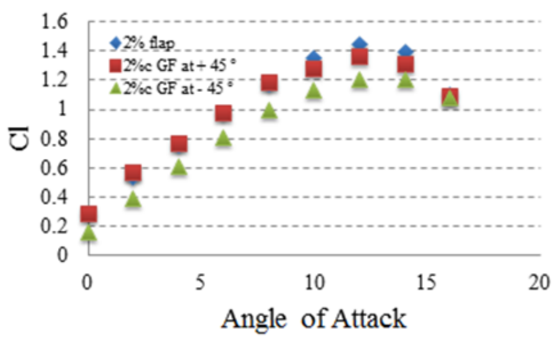

Fig. 5 Lift coefficient vs angle of attack for different deflection angle 90, +45 and -45 degrees of the Gurney flap.

From the lift coefficient plot it can be clearly seen that the Gurney flap with +45 degrees deflection generates the same lift as the flap with 90 degrees for the low to moderate angle of attacks

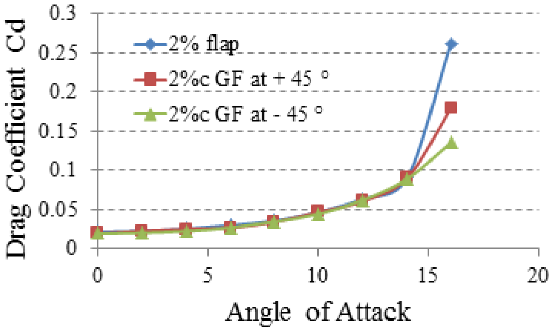

Fig. 6 Drag coefficient vs angle of attack for different deflection angle 90, +45 and -45 degrees of the Gurney flap.

As the angle of attack increases beyond 8 degrees, the former flap started to generate higher lift than the latter. As for the gurney flap with the deflection of -45, there was a significant decrease in the lift coefficient at all tested angles of attack.

As for the drag coefficient, it was noticed from Fig. 6 that deflecting the flap does not affects the drag generated by the aerofoil before the stall angle of attack. After the stall angle of attack, the flap with 90 degrees deflection generated higher drag coefficient where the aerofoil with -45 deflections generated the least drag coefficient.

The lift-to-drag ratio plot of the aerofoil with gurney flap with different deflection angles is shown in the Fig. 7 as a function of angle of attack.

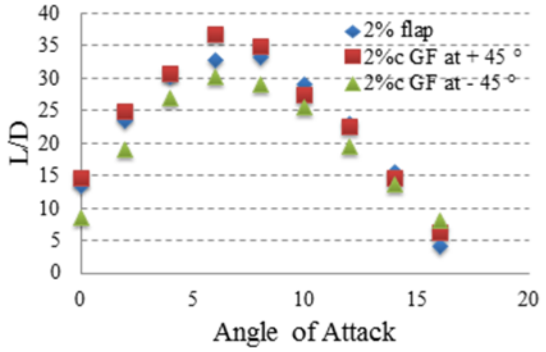

Fig. 7 Lift to Drag ratio vs angle of attack for different deflection angle 90, +45 and -45 degrees of the Gurney flap.

It can be seen that deflecting the aerofoil with -45 degrees generates the least lift-to-drag ratio. However, compared to the flap with 90 degrees deflection, the gurney flap with +45 deflections seems to enhance the performance of the aerofoil at low to moderate angle of attack. Thus, the optimum size of the aerofoil is 2%c with the deflection angle of +45.

The effect of the T-strip flap on the performance of the clean aerofoil can be seen from the Fig. 8 and 9. It can be seen that the T-strip increases the maximum lift coefficient by 8% compared to the clean aerofoil. However, it produces 6% less of maximum lift coefficient as that of normal gurney flap with the same size. It was also noticed that the T-strip flap does not produce any lift at zero angle of attack due to the flow field around the aerofoil being symmetric as the lower half of the T-strip cancels the effect of the upper half effect resulting in zero effect at zero angle of attack. From Fig. 8 the T-strip seems to produce more drag compared to clean aerofoil with normal gurney flap which in turns, makes the T-strip less efficient as it produces lower lift-to-drag ratio compared to the normal gurney flap with the same size. Thus, the T-strip does not produce better performance compared to the gurney flap with the same size for the NACA 0012 aerofoil.

The lift-to-drag ratio plot can be seen from Fig 10. It can be seen that as the location of the gurney flap shifted forward toward the leading edge, lift-to-drag ratio curve also shifted down due to the significant increase in the drag coefficient. It was also found that mounting the gurney flap between 0%c to 10%c improve the aerofoil performance beyond 10% and the lift-enhancement effects drops significantly. Overall, mounting the gurney flap at the trailing edge provides the optimum performance of the aerofoil.

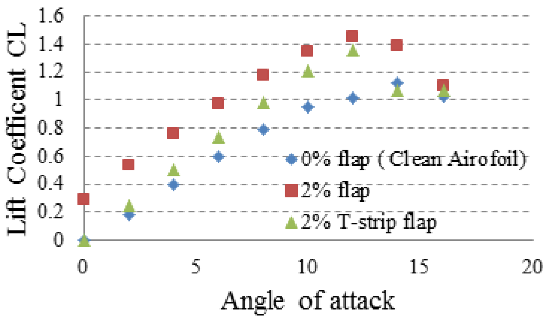

Fig. 8 Lift coefficient vs angle of attack T-strip Gurney flap shape.

CONCLUSION

Adding the Gurney flap resulted in a significant increase in the maximum lift coefficient. Compared to clean aerofoil, the maximum lift coefficient increased by 19%, 28% and 45% for the Gurney flap height of 1%c, 2%c and 4%c respectively. Optimum height for the Gurney flap was found to be 2%c. This height increased the maximum lift coefficient with small drag penalty.

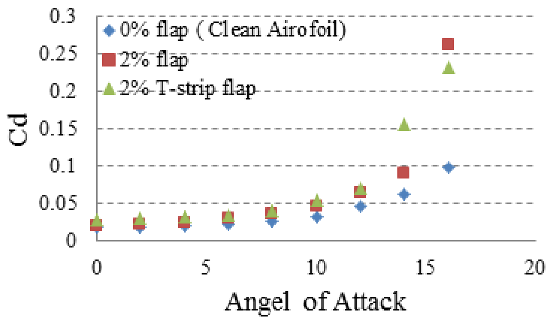

Fig. 9 Drag coefficient vs angle of attack T-strip Gurney flap shape

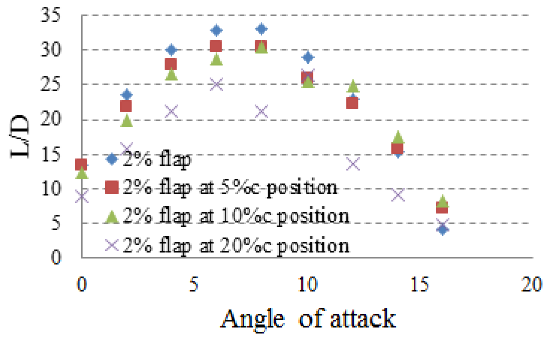

Fig. 10 Lift to drag ratio with Gurney flap mounted at different position as a percentage of the chord.

Overall, this specific height enhanced the overall performance (lift-to-drag ratio) of the clean aerofoil NACA0012 by 21%. Adding a T-strip Gurney flap of 2%c increased the drag coefficient and reduced the lift coefficient compared to the 2%c Gurney flap. As for the location of the Gurney flap, as the gurney flap shifted towards the leading edge, the lifting-enhancement effect of the flap decreased. The optimum location for the gurney flap was found to be exactly at the trailing edge. However, the performance of the gurney flap was not reduced when it is placed within 10%c distance from the trailing edge. The flap deflection of +45 degrees enhanced the overall performance of the aerofoil compared to the normal 2%c Gurney flap. Future work will be focused on innovative ways incorporating this technology into unmanned air vehicles.

ACKNOWLEGMENTS

This work is part of dissertation submitted by Julanda Al-Mawali in partial fulfillment of the degree of Bachelor of Engineering

REFRENCES

[1] Cavanaugh MA, Robertson P. and Mason WH, “Wind tunnel tests of Gurney flaps and T-strips on an NACA 23012 wing”, 2007, accessed online: http://www.dept.aoe.vt.edu/~mason/Mason_f/AIAA2007-4175.pdf

[2] Liebeck R H. "Design of subsonic airfoils for high lift". Journal of Aircraft, Vol.15, 1978 pp.547-561.

[3] Wadcock AJ, (1987) " Investigation of low-speed turbulent separated flow around airfoils" NASA-CR-177450

[4] Largman R, Katz J, " Effect of 90 degrees flap on the aerodynamic of a two element airfoil". J. Fluids Engineering, Vol. 111**,** 1989, pp.93-94

[5] Nouri M, Sayehvand H and Mekanik A, "Numerical investigation of aerodynamic characteristics of NACA 23018 airfoil with a Gurney flap", International Journal of Mechanical Engineering and Robotics Research Vol. 1 (3), Oct. 2012**,** pp.341-349.

[6] Altmann, GF, “An investigation study of Gurney flaps on a NACA0036 airfoil”. Ph.D. Thesis, Cal poly Uni. , 2011, accessed online http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1554&context=theses

[7] Salcedo S, Monge F, Palacios F, Gandia F, Rodrigues A and Barcala M, “Gurney flaps and trailing edge devices for wind turbines” in Poceedings of European wind energy conference, EWEC 2006, Athens, Greece.

[8] Giguere P, Dumas G and Lemay J, “Gurney flap Scaling for Optimum Lift-to-Drag ratio” AIAA Journal, Vol. 35, 1997, pp.1888-1890.

[9] Gai SL, Palfrey R “Influence of Trailing-Edge Flow Control on Airfoil Performance” Journal of Aircraft , Vol 40(2), 2003, pp.332-337

[10] Traub L and Chandrachekar SM, “ experimental study on the effect of wing sweep on Gurney flap performance” Aero Sci & Tech, 55, 2016, pp. 57-63

[11] Amini Y, Emdad H and Farid H, “Adjoint shape optimization of airfoils with attached gurney flap”, Aero Sci & Tech 41, 2015, pp. 216-228

[12] Temam P, NAVIER-STOKES EQUATIONS. accessed online: http://math.univ-lille1.fr/~calgaro/ENS/biblio-m2ma/T.pdf

[13] Windi IS, Faris MA and Kareem H, "Experimental and numerical investigation of the improvement of aerodynamic characteristic of NACA 0012 airfoil", IJMMME, Vol.2, 2014, pp. 11-15