ENGINEERING RESEARCH JOURNAL (ERJ)

Vol. 1, No. 45 July. 2020, pp. 34-42

Journal Homepage: http://erj.bu.edu.eg

Aerodynamics Performance of Multi Gurney Flaps Configurations on Airfoil

M.A. Abdelrahman,Waleed Mohamed, Ibrahim Shahin, M.W.Al-Dosoky, M.G. Higazy

Benha University, Faculty of Engineering at Shoubra, Department of Mechanical Engineering, Cairo, Egypt.

Abstract. : This paper aims to mitigate those negative effects by adding more than one flap at different distances in the circulation region. Since installing the flap on the trailing edge of airfoil increases the lift coefficient, with a negative effect represented by flow circulation and adverse pressure gradient around the flap. The present work carried out numerically on an airfoil NACA 0012 with two dimensional CFD simulations using the commercial code ANSYS FLUENT 19 and the shear stress transport (SST) k-ω turbulence model was used to simulate the flow structure around the airfoil. Single Gurney Flap, GF, with a height of 2 % chord ,c, Dual GF with heights of 2 % c and 1.5 % c and Triple GF heights of 2% C, 1.5% C, and 1% C are studied at a different attack angle in two cases, high Reynolds numbers and low Reynolds numbers. The results showed that GF has enhanced both the lift and the lift-to-drag ratio in a range for angles of attack. The computational results are compared with a published experimental result and showed good agreement with these experimental results. The results indicate that at high Reynolds number, multi GF improves the lift to drag ratio by up to 13.43 % at the attack angles of range 2˚, to 6˚.While the rates of improvement in the case of high Reynolds number are greater than that in the case of low Reynolds number.

Keywords: Multi Gurney Flap, Lift, drag, pressure distribution, airfoil, CFD.

1. INTRODUCTION

Gurney flap (G.F) can be defined as a vertical tape, the length and location of which can be controlled according to use, it is fixed perpendicularly to the chord at trailing edge of the airfoil on the pressure side, as shown in Figure.1. It has a noticeable effect on the aerodynamics of the airfoil in producing higher lift.

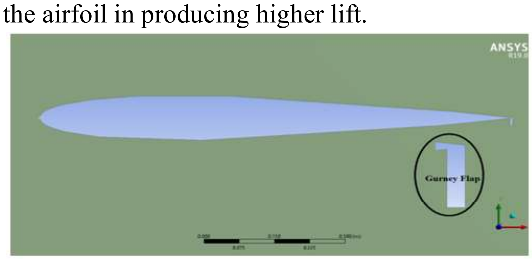


Fig 1: Schematic drawing of Gurney flap.

The principal change in the flow condition (Figure. 2), as opposed to a clean around an airfoil, consists in the formation of one vortex in front of the flap (upstream) and two counter-rotating vortices behind the flap (downstream). This phenomenon leads to the following simultaneous aerodynamic effects, which have been subject to a lot of research projects are conducted in recent 20 years, Considerable efforts are carried out to study the effects of Gurney flap on the airfoil aerodynamics many investigations are undertaken to determine the effect of various parameters of gurney flap such as height, location, and mounting angle.

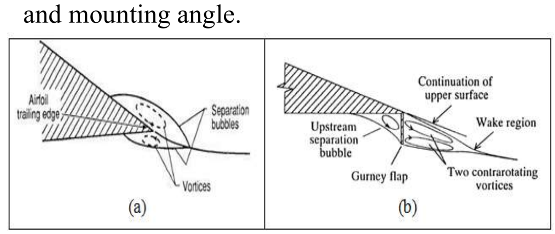


Fig 2: Basic flow field around a gurney flap as opposed to a clean airfoil Ref. [1]

Initial research of gurney flap lift enhancement is conducted by Liebeck [1] when conducted wind tunnel tests on the effect of a 1.25 % C height gurney flap about a Newman airfoil, which begotten in an increase lift and a temperate decrease in drag. Greater lifting increases can be obtained by increasing the height of the GF, However, drag increase significantly after increasing 2% C, which can effectively increase airfoil lift and aerodynamic performance. Cavanaugh et al. [2] examined the effect from G.F at a NACA 23012 airfoil on the wind tunnel tests for various flap lengths that leads to increased lift force. Neuhart et al. [3] made a water tunnel study of gurney flaps with the NACA 0012 section in Langley Water Tunnel at a Reynolds number of 8588. Visualization of the flow behind the Gurney flap is made by the hypothesis of Liebeck [1] and the separation bubbles and vortices behind the trailing edge are visualized as shown schematically in Fig 2 (b). jeffrey .et.aL [4] He also reported that waking the lower part of the Gf consisted of rotating shed swirls, which increased suction at the trailing edge on the side of the wing suction side, while the flow slowed down on the pressure side and consequently the pressure increased. Generate an increase in loading and rotation over the airfoil. Li et al. [5] also investigated the effects of Gurney flap on a NACA 0012 airfoil with experimental measurements in a wind tunnel. Magstadt et al. [6] carried out wind tunnel tests on gurney flaps mounted at the blunt trailing edge of the wind turbine blade airfoil DU97-W-300, they concluded that the lifting height can be increased when the GF is installed on the lower surface of the airfoil at the trailing edge, unlike the ones fixed to the upper surface, it reduces the lift. Jang et al. [7] also solved the Navier-Stokes equations for NACA 4412 airfoil with a gurney flap. Cory et al. [8]. It is found to cause a downward momentum of fluid in the area above the trailing edge due to a decrease in pressure in the area behind that Gurney flap .They also concluded that the small separation area resulting from the suction side of the aileron is one of its benefits. It resists the drag resulting from the Gurney flap. Henne Preston et al. [9]. The addition of a gurney flap is shown to improve airfoil performance at high lift coefficients in particular. Storms et al. [10], the Gurney flap installation also has potential in rotorcraft applications. Some potential improvements by deployable gurney flap designs on rotors are; auto relative characteristics enhancements and to improve the performance of the wind turbines. Kentfield. [11] She also examined the effect of GF of various sizes and holes on the growth and improvement of the tip vortex resulting from the aileron NACA 0012 using a particle image velocity measurement (PIV). Lee [12]. Also studied Cole et al.[13]. The average power output of 10.4% and 3.5% are found at two different wind velocity realizations. Gurney flaps appear to be one of the most appropriate devices to improve reliability and/or power output in large wind turbines. Gerontakos and Lee [14] extended the gurney flap concept to the passive control of dynamic loadings of an oscillating NACA 0012 airfoil. They found that gurney flaps are also generally applicable in terms of Cl and Cd max increment except for the undesired large increase and the promotion of dynamic stall. The pressure distribution changes such that the overall pressure gradient increases. Storms et al [15], The aft loading of the trailing edge region augments considerably such that the airflow is pushed downwards when leaving the trailing edge The overall circulation around the airfoil augments, provoking an effective increase in the maximum camber of the airfoil. Myose et al [16], the sharp edge of the Gurney flap cause separation, leading to a considerable increase in drag forces Bechert et al [17], The Kutta condition for an airfoil mentions that for an airfoil with a finite trailing edge angle, then the trailing edge acts as the rear stagnation point for the flow, Anderson [18]. In the case of Gurney flaps, the Kutta condition is shifted to a point off the surface of the airfoil, Roy Myose et al. [19,20], thereby allowing for the flow about the top surface on the airfoil to resist the destructive pressure gradient and increase the lift by postponing separation and stall of the airfoil.

Several studies Gai, S. L, and Nikolic, V. R. [21–22] further substantiated that the observed increase in the airfoil circulation, and thus the lift force, is associated with the downward turning of the flow near the trailing edge and that the optimum flap height (h) of about 2% C provided the maximum improvement in the lift force with a minor increase in the drag force. Storms and Ross et al. [23] and Carrannantoet et al. [24] Performed experimental investigations and computational simulations on a NACA632- 215 model B airfoil with gurney flaps. The found revealed that when shifted forward from the trailing edge of the airfoil the performance of the gurney flap on lift augmentation will be reduced.

Lee and Ko (2009) and Lee [25] applied the gurney flap to control a NACA 0012 airfoil. They all concluded that the gurney flap could increase the lift coefficient, where the Gurney flap increases the effective camber of the airfoil to enhance the lift performance. However, there is an inevitable drag associated with this lift enhancement. Traub et al. [26] carried out a wind tunnel study of a NACA 0015 airfoil with a jet slot located at a 2% chord of the trailing edge. The jet gurney flap with a 0.68% momentum coefficient resulted in a lift and momentum increases equivalent to a 0.75% chord gurney flap.

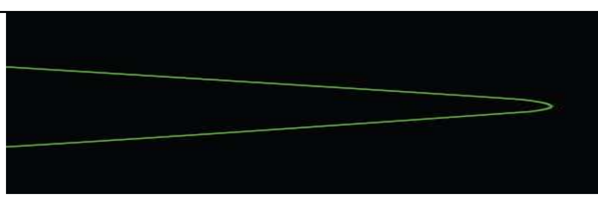
As indicated by the surveys already mentioned, Most of the researches dealt with the study of a single Gurney flap in with different thickness, height, angles and locations and highlighting its advantages, which is the increase in the lift coefficient and its evening, which is the adverse pressure gradient and flow circulations that forms at the location of GF without touching on how to reduce this phenomenon. Hence this research aims to reduce the negative effects of a single flap and mitigate the circulation flow by placing another flap in the circulation region and thus study the effect of Multi GF on the performance of NACA 0012 at different attack angles. To be the most comprehensive study, the study is conducted on two different Reynolds numbers, low Re suitable for wind turbine applications, and high Re suitable for aircraft. All Gurney Flaps studied in the present work are 5 mm wide and mounted normal to the chord line.

2. Numerical Analysis

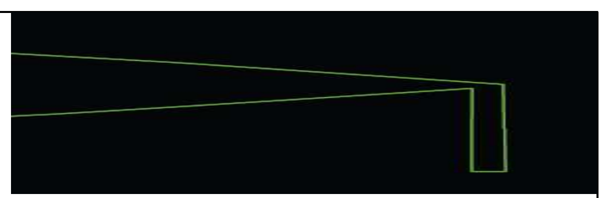
In the present study, numerical simulations using Ansys Fluent software with a 2-D k-ω SST turbulence model are carried out on NACA 0012 airfoil with a chord length of 1 meter. NACA 0012 with different configurations of gurney flap is shown in Figure 3. C-type domain and grid are created using ICEM CFD, with far-field boundaries of 25 C and 50 C is the chord length) upstream and downstream the airfoil respectively. As the study is focused on the airfoil, this, Fine mesh has been used in the layer around both airfoil and flap, while a coarse mesh has been used for the rest flow in the tunnel as shown in Figure.4.A. The illustration shows in Figure.4.B.Zoomed view of mesh near the different location gurney flap around the airfoil boundary layer by ICEM.

Regarding the boundary conditions, adiabatic and no-slip conditions are used at the wall. At the tunnel inlet, the Constant speed with variable flow direction component depending on the angle of attack. At the outlet, the pressure is set to absolute zero (Pascal).

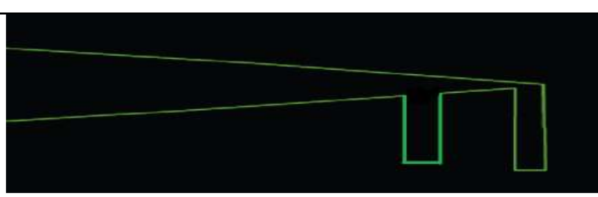
The pressure field is linked to velocity through the SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) pressure-velocity coupling algorithm. For momentum, turbulent kinetic energy, and eddies dissipation rate second-order upwind discretization scheme has been used. Turbulence intensity of 5 % is set for both inlet and outlet boundary conditions as the flow at this level of turbulence intensity is considered fully developed. The lift coefficient has been set as a goal for convergence criteria, and The Tolerance value has been set to reduce the scaled residual all flow parameters fell below the value of 10^{-5}.



(a) Without GF (clean airfoil)



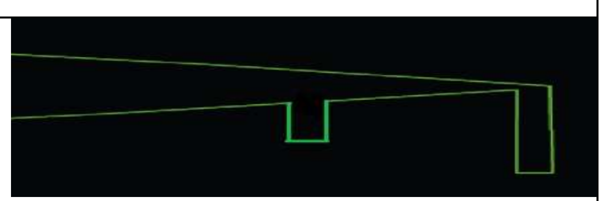
(b) Single Gf (H= 2% c & S= 0 % c)



(c) 1st DualGF Configuration

1st GF H_1= 2% & S_1 = 0% c

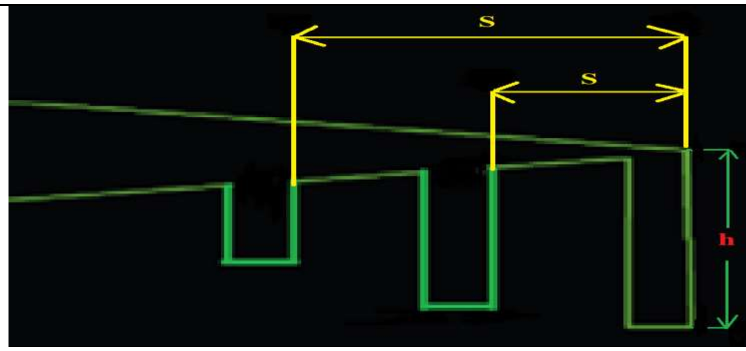
2nd GF H_2 =1.5% & S_2 =1.5% c



(d) 2nd DualGF Configuration

1st GF H_1= 2% & S_1 = 0% c

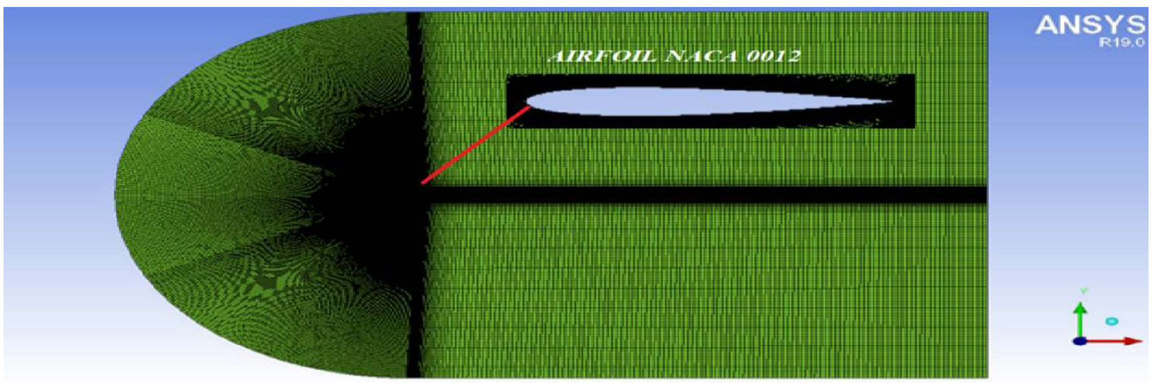
2nd GF H_2 =1% & S_2 =3% c



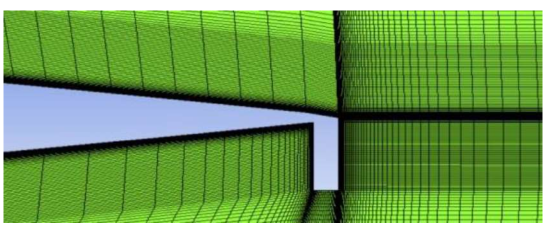
(e) Triple GF Configuration

1st GF	**2nd GF**	**3rd GF**
H_1= 2% & S_1 = 0% c	H_2 =1.5% &S_2 =1.5% c	H_3 =1% &S_3 = 3% c

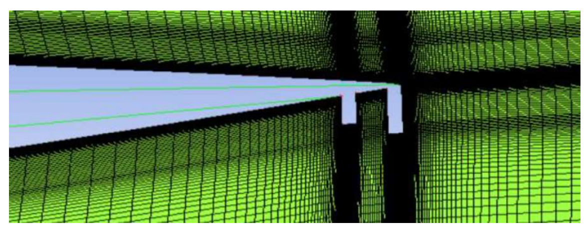
Fig 3: Trailing Edge of Airfoil with Various Gurney Flap Configurations.



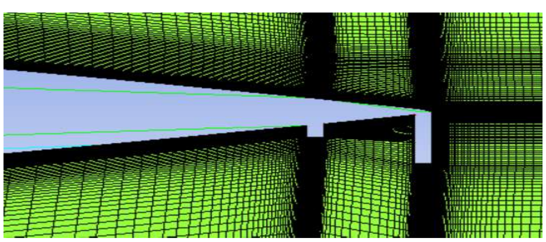
(A) Computational Domain of NACA0012 Airfoil with Gurney Flap.



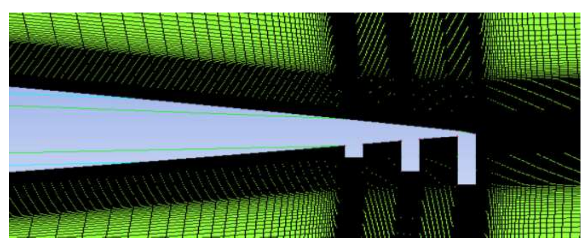
single Gf



1st case Dual GF



2nd case Dual GF



Triple GF

(b) : Zoomed view of mesh near the different location gurney flap around the airfoil.

Fig 4: Computational Domain and Zoomed view of mesh gurney flap around the airfoil boundary layer by ICEM.

3. Mesh independence

Grid independence test is done to ensure that the results did not depend on the number of elements as indicated in Table 1. This test is done for each GF configurations separately before performing the runs. The range of the dimensionless wall distance (Y plus) is less than 1 for the first grid point above the airfoil surface From Table 1, a very slight change in lift and drag coefficient is observed by increasing the cell number over 19500 from standard to fine mesh, whereas, increasing the number of elements over this value, the solution takes a long time without tangible improvement in its accuracy

Table 1: Assessment of Mesh Independence

Mesh	Cell numbers	C_l	C_d
Coarse	55000	1.0571631	0.02856436
Standard	195000	1.1059042	0.01518304
Fine	550000	1.1053976	0.01508356

4. Present Model Validation

The validation procedure examines whether the physical models used in CFD simulations proportionate with real conditions. The basic validation plan is to identify and quantify the error through the comparison of simulation results with experimental or numerical solution data. Two cases of validation test are relied on in the current study as the following:

4.1. Clean Airfoil Validation

The first validation is done on the clean NACA 0012 airfoil where both the lift and drag coefficient is compared with the published experimental results presented by ABBOTT and Doenh off [28]. Besides the comparison with XFOIL predicted results at $R_e = 10^6$ are shown in Figs 5 and 6. The results show a fair agreement between the present CFD simulation and the published results with an acceptable difference.

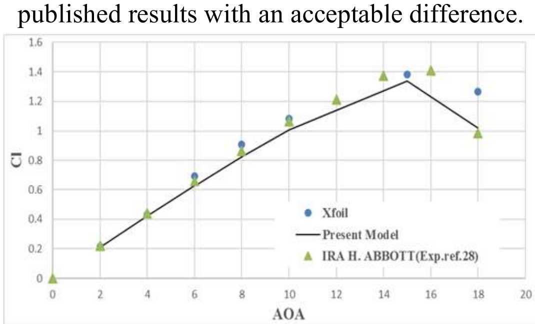


Fig 5: Comparison of Present Lift Coefficient for Clean Airfoil -NACA 0012 with experimental data [28] and XFOIL prediction at Re=10^6.

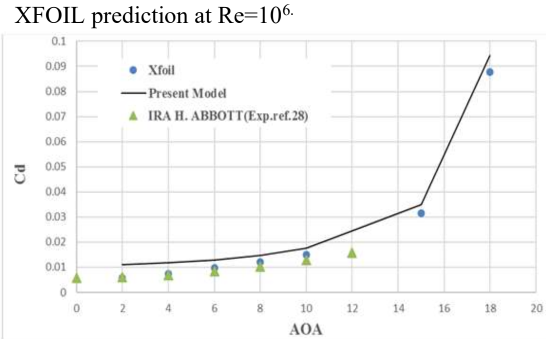


Fig 6: Comparison of Present Drag Coefficient for Clean Airfoil -NACA 0012 with experimental data [28] and XFOIL prediction at Re=10^6

4.1. Single Gurney Flap Validation

The second validation is done on the NACA 0012 airfoil with single GF (height = 2 % c and width = 5 mm) at $R_e = 10^9$.The experimental results for GF published by Wang et al, [27] are relied upon in comparing the Lift and drag coefficient calculated from the present CFD model.

The maximum deviations between the present results and the results of [27] are about 10.5 % and 13.9 % for lift and drag coefficient respectively. From Figs 7 & 8, the present CFD simulations agree pretty well with the experimental published data. As the highest deviation obtained is 12 % for the drag coefficient and 8 % for the lift coefficient, It can be considered an acceptable deviation.

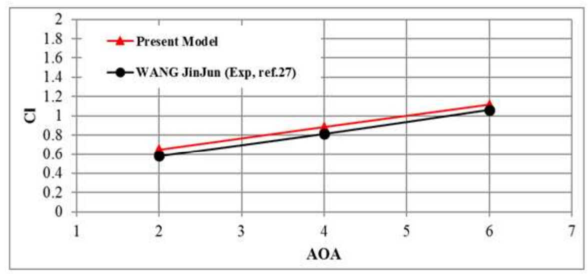


Fig 7: Comparison of Present Lift Coefficient for Single GF Airfoil with experimental data [27] at Re=10^9.

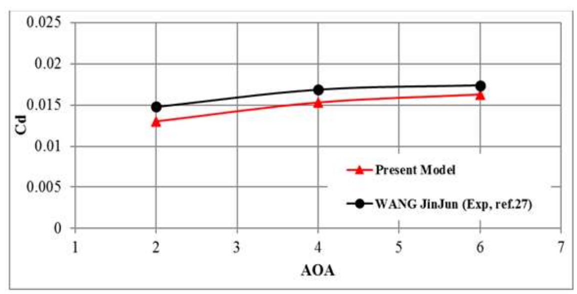


Fig 8: Comparison of Present Drag Coefficient for Single GF Airfoil with experimental data [27] at Re=10^9.

5. Results and discussion

In this section, the effect of the different GF configurations on the performance on NACA 0012 at different attack angles will be discussed for two Reynolds numbers of 10^9 which is suitable for aircraft applications and 10^6 which is suitable for wind turbine applications.

5.1. Lift to Drag Ratio at Wind Speed of 130 m/s (Re=10^9)

Most of the previous studies that are done to improve the aerodynamic performance of the airfoil are aimed not only at increasing the lift coefficient, but also to reduce the drag coefficient, and therefore the most important goal is to maximize the lift to drag ratio.

The variation of L/D ratio for the different cases of GF is obtained at different attack angles, 2˚, 4˚ and 6˚ and airspeed of 130 m/s ($Re=10^9$) as shown in Fig 9.

From Figure 9 it is clear that, the L/D ratio increases with the increase of the angle of attack. The effect of single GF appears on the small attack angles of 2˚ and 4˚, where the L/D ratio increases compared to the clean airfoil, whereas there is no significant effect at the attack angle of 6˚.

Table 2 shows the percentages of increase in L/D ratio as a result of the GF configurations compared to the clean airfoil at attack angle 2˚, 4˚ and 6˚. Single GF improves the L/D ratio with a great value at cruise angle of attack of 2° up to 89.13 %, and lower value at the attack of 2° up to 15.94 % and very low value at the attack of 6° only 1.45 %.

It can also be seen that the both of dual and triple flap configurations improve the L/D with a greater value than the single flap in all the attack angles, as the triple GF improves L/D by 92%, 31.5 % and 11.5 % at the attack angles of 2˚, 4˚ and 6˚ respectively compared to the clean airfoil and by 13.43 %, 9.9 % and 1.57% at the attack angles of 2˚, 4˚ and 6˚ respectively Compared to single GF.

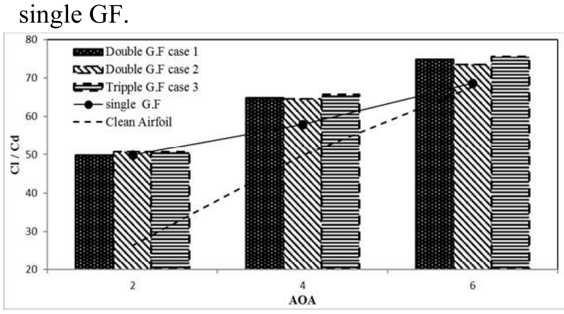


Fig 9: Lift to Drag Ratio for Airfoil -NACA 0012 with Different GF at $Re=10^9$.

Table 2: Percentage of Increase in L/D ratio for Different GF Cases Compared Clean Airfoil at $Re=10^9$.

A0A	Single GF	1st DualGF	2nd DualGF	Triple GF
2	89.13 %	88.91 %	92.30 %	92.10 %
4	15.94 %	30.02 %	29.28 %	31.51 %
6	1.45 %	10.54 %	8.63	11.49

5.2. Lift to Drag Ratio at Wind Speed of 15 m/s ($Re=10^6$)

In wind turbine applications, the turbine rated wind speed is usually around 15 m/s, so it is important to study the effect of the GF at low wind speed. Figure 10 shows the variation of L/D ratio for the GF cases at different attack angles, 2˚, 4˚ and 6˚ and wind speed of 130 m/s ($Re=10^9$).

As in the case of **$Re=10^9$**, The effect of single GF appears on the small attack angles of 2˚ and 4˚, where the L/D ratio increases compared to the clean airfoil, whereas a small significant effect at the attack angle of 6˚ as shown in Fig 10.

The positive effect of single GF appears at small attack angles, as the value of the L/D ratio improves with a great value at attack angles of 2˚ and 4˚ and with a small value at 6˚. After this angle, the effect of a single GF becomes negative, as it reduces the value of the L/D ratio for the angles greater than 6˚, This is due to large friction caused by the flap surface that leads to a large increase in the drag force and a relative decline in the lift force as shown in Fig 10.

Also from Figure 10, it can be seen that both of dual and triple flaps improve the L/D for the angles 2˚, 4˚, 6˚ and 8˚ with a large value and with a slight value for the angle of 10˚, this is due to the breaking of vortices and separation bubbles that led to a relative decrease in the drag coefficient.

By examining the percentages of increase or decrease in the L/D ratio as a result of the different flap cases compared to the clean airfoil as shown in Table 5, the following can be concluded: Single GF improves the L/D ratio in small angle with a maximum improvement of 93.6 % at an angle of 2˚ and the lowest improvement of 6.8 % at an angle of 6˚. On the other hand, both the dual and triple GF improves the L/D in the small angles of attack up to 10˚ with the maximum improvement ratio of 103 % at the angle of 2˚ in the case of 2nd DualGF and then the improvement rate decreases to down to angle 10˚ where the maximum improvement percentage reaches 1.7% in the case of a triple GF.

Figure 11 gives a comparison between the percentages of effect dual and triple flap compared to single flap, As it can be seen that the effect of both the dual and triple flaps increases with increasing the attack angles from 2˚ to 15˚. The highest improvement of the L/D ratio due to multi GF concerning single GF is achieved at an angle of 15˚ such as 51.4%, 37.8% and 22.6% in the case of 1st Dual GF, Triple GF, and 2nd Dual GF respectively.

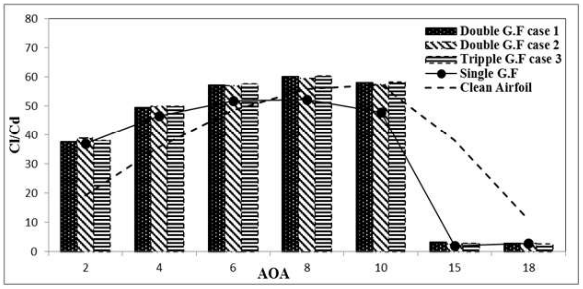


Fig 10: Lift to Drag Ratio for Airfoil -NACA 0012 with Different GF at Re=10^6.

Table 3: Percentage of Increase in L/D ratio for Different GF Cases Compared Clean Airfoil at Re=10^6.

A0A	Single GF	1st case Dual GF	2nd case Dual GF	Triple GF
2	93.6 %	97.4 %	103.2 %	99.2 %
4	29.9 %	38.1 %	39.6 %	39.1 %
6	6.8 %	18 %	17.6 %	18.7 %
8	-6.4 %	7.7 %	6.7 %	8.3 %
10	-16.6 %	1.3 %	0.1 %	1.7 %
15	-94.6 %	-91.8 %	-93.3 %	-92.5 %
18	-73.9 %	-73.5 %	-74.4 %	-75 %

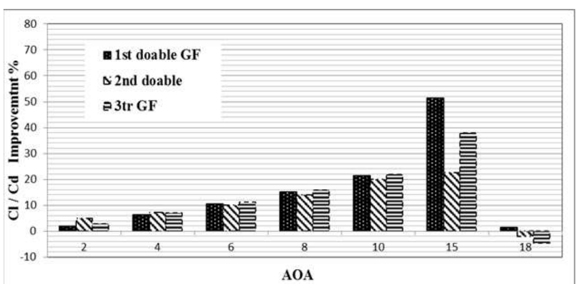


Fig 11: Lift to Drag Ratio Improvement for Multi Flap Corresponding to Single Flap at Re=10^6.

5.3. Pressure coefficient at 130 m/s (Re=10^9)

To explain what happened due to the presence of the GF at high Reynolds number of 10^9, the pressure distribution over NACA 0012 with and without GF at attack angle of 6° is shown in Fig.12. It is evident from the figure that the presence of the single Gf increased the suction with a significant value over the upper surface, which is represented by the large decrease in pressure with corresponding to clean airfoil, while we notice a slight decrease in pressure on the lower surface. The result of this is that the pressure difference over an airfoil with GF is higher than the Clean one, which leads to an increase in the lift coefficient. It also shows the presence of adverse pressure gradient at the front of the flap, due to the vortices and circulation on the lower airfoil surface upstream the flap as shown previously in Fig 1 [1].

To clarify the effect of multiple GF compared to single flap, a pressure distribution for 1st dual GF, 2nd dual GF and triple GF are compared to single flap, as shown in Figs 13 - a, b and c respectively. It is can be seen from the figures that the pressure difference between the lower and upper surfaces of the airfoil with multiple GF is greater than the difference in pressure in the case of a single flap. Also, the adverse pressure gradient and flow circulation decrease at the trailing edge of the airfoil which affected increasing the lift coefficient in the case of multiple GF than the single GF.

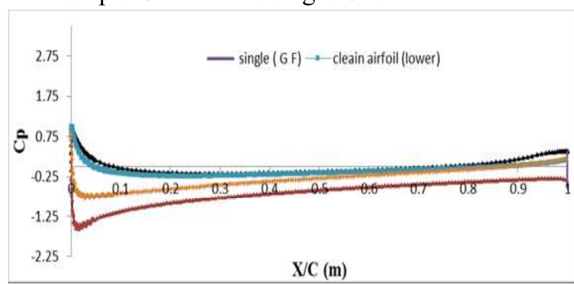
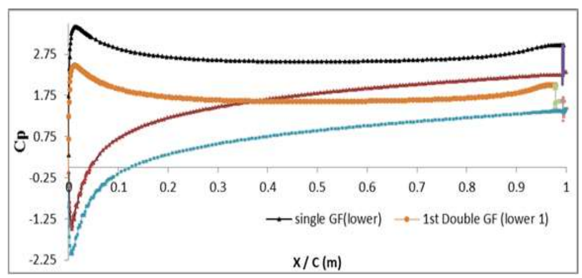
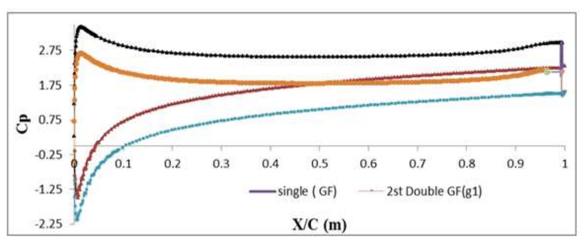


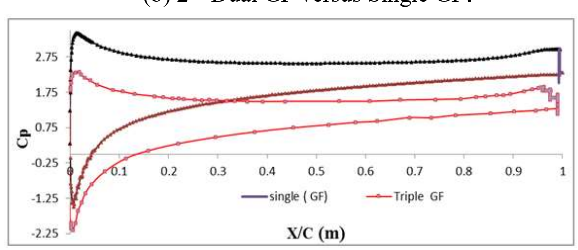
Fig 12: Pressure Distribution Over Airfoil for Single GF & Clean Airfoil at A0A= 6˚ and Re=10^9.



(a) 1st Dual GF versus Single GF.



(b) 2nd Dual GF versus Single GF.



(c) 3rd Dual GF versus Single GF

Fig 13: Pressure Distribution Over Airfoil for Multiple & Single GF at A0A= 6˚ and Re=10^9.

5.4. Pressure coefficient at 15 m/s ($Re=10^6$)

Also at low Reynolds number of 10^6, the effect of GF can be explained by comparing the pressure distribution over the airfoil in the case of the airfoil with GF configurations and the clean one. Figure 14 shows a significant pressure difference over the airfoil with a single GF than a clean airfoil, resulting in an increase in the lift coefficient. Also the presence of adverse pressure gradient and flow circulation at the flap location from the lower surface of the airfoil. Figure 15 –a, b and c, Shows the effect of multiple flaps 1st dual, 2nd dual and triple GF on a single flap in the case of low Reynolds number of 10^6 and the angle of attack 6^0, where it becomes clear that the pressure difference in the case of multiple GF is higher than that for a single flap, Which has a major reason for increasing lift coefficient in case of multi GF greater than Single flap.

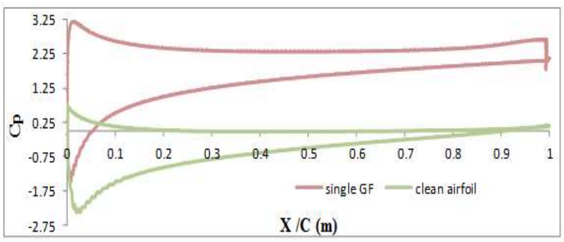
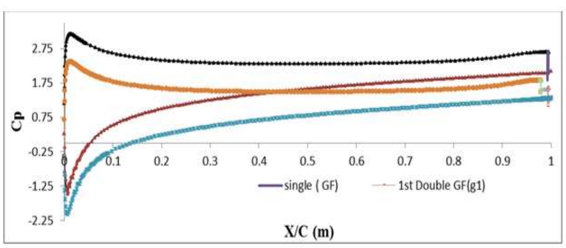
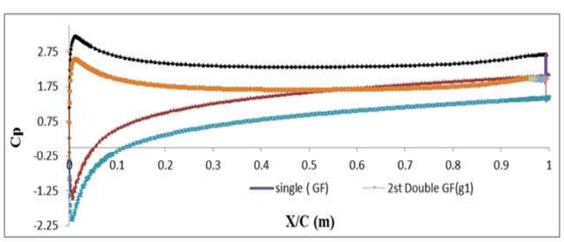


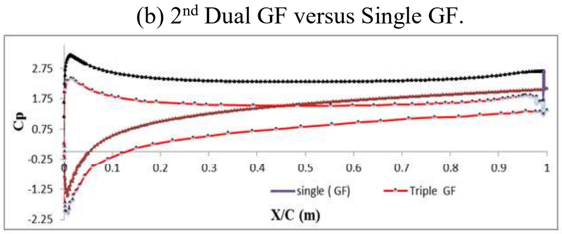
Fig 14: Pressure Distribution over Airfoil for Single GF & Clean Airfoil at A0A= 6° and $Re=10^6$.



(a) 1st Dual GF versus Single GF.



(b) 2nd Dual GF versus Single GF.



(c) 3rd Dual GF versus Single GF.

Fig 15: Pressure Distribution Over Airfoil for Multiple & Single GF at A0A= 6° and $Re=10^6$.

6. Conclusion

The validation of the CFD model with both experimental and numerical data is carried out and showing, in general, a fair agreement. The maximum deviations between the present results and the results of [27] are about 10.5 % and 13.9 % for lift coefficient and drag coefficient respectively. The effect of GF has been studied at different attack angles at two different airspeeds, high speed 130 m/s ($Re=10^9$), suitable for aircraft applications, and low speed 15 m/s ($Re=10^6$), suitable for wind turbine applications, and the following has been concluded.

First, at high Reynolds number, All GF configurations increase the L/D ratio compared to the clean airfoil at low attack angles. Where the triple flap achieved the largest increase in L/D ratio lifting rate, which is 92%, 31.5 % and 11.5 % at the attack angles of 2°, 4° and 6° respectively.

Secondly, at low Reynolds number, Single GF improves the L/D ratio in the small attack angles from 2° to 6°, whereas dual and triple flaps increase the L/D ratio up to an attack angle of 10°. Where the improvement reached 103% in the case of dual GF at attack angle of 2°, and up to 1.7% as the maximum improvement at an attack angle of 10° in the case of the triple GF.

References

[1] Liebeck, R. H., "Design of Subsonic Airfoils for High Lift,", Journal of Aircraft, Vol. 15, No. 9.pp. 547–561, 1978.

[2] Jeffrey, D., Zhang, X., and Hurst, D. W., "Aerodynamics of Gurney Flaps on a Single-Element High-Lift Wing," Journal of Aircraft, Vol. 37, No. 2, pp. 295–301, 2000.

[3] Cavanaugh, M. A., Robertson, P., Mason, W. H., "Wind Tunnel Test of Gurney Flaps and T-Strips on a NACA 23012 Wing, ". 25 th AIAA Applied aerodynamics Conference, 2007.

[4] Neuhart, D. H., Pendergraft, O. C., "A Water Tunnel Study of Gurney Flaps. NASA Technical Memorandum, 4071, 1988.

[5] Li, Y., Wang, J. Zhang, P., "Effects of Gurney Flaps on a NACA 0012 Airfoil. Flow, Turbulence and Combustion, " Vol. 68, No. 1, 27-39, 2002.

[6] P. Nikoueeyan, J. A. Strike, A. S. Magstadt, M. D. Hind, and J. W. Naughton, "Characterization of the aerodynamic

coefficients of a wind turbine airfoil with a Gurney flap for flow control applications," in 32nd AIAA Applied Aerodynamics Conference, p. 2146, Atlanta, GA, USA, 2014.

[7] Jang, C. S., Ross, J. C., Cummings, R. M., "Numerical Investigation of an Airfoil with a Gurney Flap, Aircraft Design, ". Vol. 1, No. 2, 75-88, 1998.

[8] Jang Cory S, Ross James C, Cummings Russell M. "Numerical investigation of an airfoil with a gurney flap. Aircraft Des;1(2),75e88, 1998.

[9] Henne Preston A, Robert III D Gregg. "New airfoil design concept. J Aircr;28(5),300e11, 1991.

[10] Storms, B. L., Jang, C. S., "Lift Enhancement of an Airfoil Using a Gurney Flap and Vortex Generators," Journal of Aircraft, Engineering Note, Vol. 31, No. 3, May-June, pp. 542- 547, 1994.

[11] Kentfield, J. A. C., "Theoretically and Experimentally Obtained Performances of Gurney-Flap Equipped Wind Turbines," Wind Engineering, Vol. 18, No. 2, March 1994, pp. 63-74.

[12]. Lee, T. Piv, " study of near-field tip vortex behind perforated Gurney flaps. Exp. Fluids, 50, 351–361, 2010.

[13]. Cole, J.A.; Vieira, B.A.O.; Coder, J.G.; Premi, A.; Maughmer, M.D. "Experimental Investigation into the Effect of Gurney Flaps on Various Airfoils. J. Aircr. 50, 1287–1294, 2013.

[14]. Gerontakos, P., and Lee, T., "Oscillating-Wing Loadings with Trailing-Edge Strips," Journal of Aircraft, Vol. 43, No. 2, pp. 428–436, 2006.

[15] Storms, B. L., and Jang, C. S., 1993, "Lift Enhancement of an Airfoil Using a Gurney Flap and Vortex Generators," AIAA Paper No. 1993- 0647, pp. 542-547.

[16] Myose, R., Heron, I., Papadakis, M., 1996 "Effect of Gurney flaps on a NACA 0011 airfoil," AIAA Paper No. 0059, pp.1-9, 1996.

[17] Bechert, D. W., Meyer, R., Hage, W., 2000, " Drag Reduction of Airfoils with Mini flaps. Can we learn from Dragonflies," AIAA Paper No. 2315, pp. 1-30, 2000.

[18] Anderson Jr John David. "Fundamentals of aerodynamics. Tata McGraw-Hill Education; 2010.

[19] Cole Julia A, Vieira Bernardo AO, Coder James G, Premi Amandeep, Maughmer Mark D. "Experimental investigation into the effect of gurney flaps on various airfoils". J Aircr;50 (4):1287e94, 2013.

[20] Roy Myose, Papadakis Michael, Heron Ismael. " Gurney flap experiments on airfoils, wings, and reflection plane model". J Aircr;35(2): 206e11, 1998.

[21] Gai, S. L., and Palfrey, R., " Influence of Trailing-Edge Flow Control on Airfoil Performance," Journal of Aircraft, Vol. 40, No. 2, pp. 332–337, 2003.

[22] Nikolic, V. R., "Effect of Full-Span Gurney Flap Height on Wing Wake Vortex Alleviation," Journal of Aircraft, Vol. 43, No. 5, pp. 1955–1958, 2006.

[23] Storms, B. L., and Ross, J. C., "An Experimental Study of Lift- Enhancing Tabs on a Two-Element Airfoil," Journal of Aircraft, Vol. 32, No. 5, pp. 1072–1078, 1995.

[24] Carrannanto, P. G., Storms, B. L., Ross, J. C., and Cummings, R. M., "Navier–Stokes Analysis of Lift Enhancing Tabs on Multi-Element Airfoils," AIAA Paper 94-0050, Jan. 1994. [25] Lee T, Ko LS, "PIV investigation of flow field behind perforated Gurney-type flaps. Exp Fluids 46(6):1005–1019, 2009.

[26] Traub LW, Miller A, Rediniotis O, "Comparisons of a Gurney and jet-flap for hinge-less control. J Aircr 41(2):420–423, 2004.

[27] Wang, J. J., Li, Y. C., and Choi. K. S., "Gurney Flap—Lift Enhancement, Mechanisms, and Applications," Progress in Aerospace Sciences, Vol. 44, pp. 22-47, 2008.

[28] IRA H. ABBOTT, Von Doenhoff AE. " Theory of Wing Sections. Dover Publishing, New York," 1959.