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A CFD ANALYSIS ON THE EFFECTS OF GEOMETRY OF GURNEY FLAP ON AERODYNAMICS OF NACA0012 AIRFOIL

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ABSTRACT

A two-dimensional CFD analysis is performed to investigate the effects of geometry and size of gurney flap on the aerodynamic characteristics of NACA0012 airfoil. Computational results are validated with the available experimental results. Rectangular and triangular gurney flaps of various width and heights are analyzed which have shown improvement of lift to drag ratio. Comparison between rectangular and triangular flaps indicates that the performance of gurney flap depends on effective flap area rather than its shape.

Keywords: Gurney Flap, CFD Analysis, NACA0012 Airfoil.

1. INTRODUCTION

The high-lift systems have been studied for many years since these systems play a major role in economic success of an aircraft. An effective high-lift system allows lower take off and landing speed, greater payload capacity of given wing and longer range for a given gross weight. High-lift systems used in modern aircrafts are quite complex. So a simple high-lift system is necessary for lower manufacturing and maintenance cost. Such a simple high-lift system is gurney flap.

Gurney flap is a short strip located at the trailing edge of the wings and fitted perpendicular to the chord line. It was first used by Dan Gurney which resulted increase in downward aerodynamics which assisted race car during turning. Liebeck [1] tested a 1.25% chord Gurney flap on a Newman airfoil and found that the lift coefficient was increased with a small decrease in the drag coefficient. Liebeck hypothesized that the Gurney flap effectively changed the flow-field in the region of the trailing edge by introducing two contra rotating vortices aft of the flap, which altered the Kutta condition and circulation in the region. It was also noticed, however, that increasing the flap size above 2% of the wing chord length noticeably increased the drag, even though there was a continuing increase in downward force.

A water tunnel study of several Gurney flap configurations was performed on a NACA 0012 wing by Neuhart and Pendergraft [2]. Flow visualization results showed that Liebeck's hypothesized flowfield caused by the Gurney flap was generally correct, and that the effect of the Gurney flap was to increase the local camber of the trailing edge. This hypothesis was strengthened by the results of Sewall et al. [3], whose wind tunnel tests studied the effects of increasing the local trailing edge camber of the EA-6B wing.

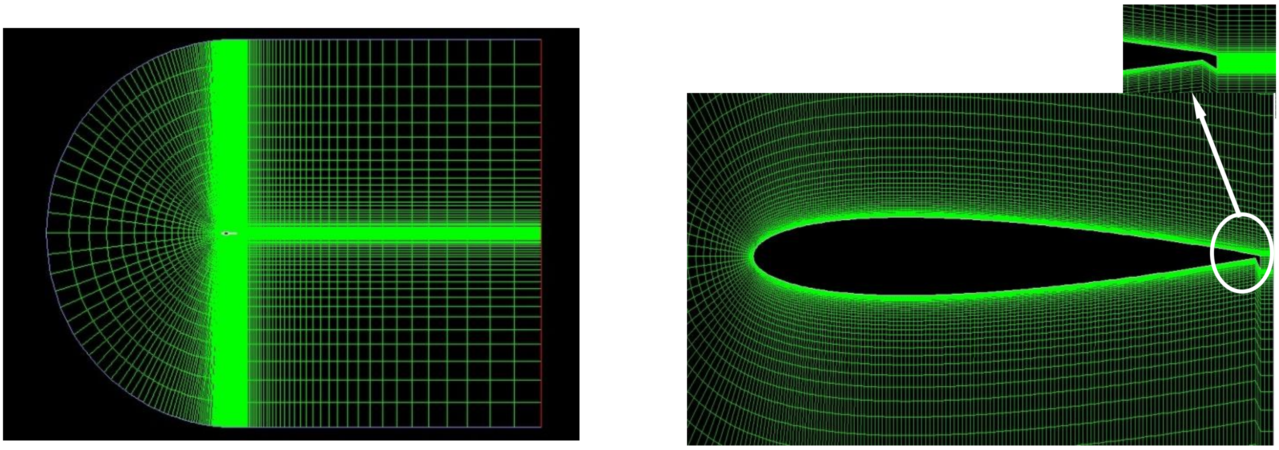
Myose et al. [4] conducted low speed wind tunnel tests on NACA 0011 airfoil with Gurney flap heights ranging from 1% to 4% of the chord. They noticed that Gurney flap increases the upper surface suction and lower surface pressure thereby resulting in lift increment. They also reported increase in nose-down pitching moment due to Gurney flap.

The present work contains mainly CFD analysis of NACA0012 with triangular and rectangular gurney flaps to determine the aerodynamic characteristics. Computations were performed on baseline NACA0012, with and without rectangular gurney flap, which were compared with available experimental data obtained in wind tunnel test by Wang and Zhang [5]. Subsequent computations were performed to determine the effect of various sizes of triangular gurney flap on the lift and drag coefficient of the same airfoil. The performance of triangular and rectangular flap was compared and analyzed.

2. CFD ANALYSIS

Two dimensional mesh of NACA0012 was created and different mesh styles and sizes were attempted before the final mesh was selected. The final mesh is shown in figure 1. The NACA0012 airfoil used in the simulation had a chord length of 1m. All data was obtained at steady conditions at chord Reynolds number 2.1×10^6.

In CFD analysis, there are many turbulence models available. In the present study, k-ε and Spalart-Allmaras (S-A) models were used to determine which model is successful in modeling the flow of interest. S-A model was used because of its high correlation with experimental data. Second order upwind discretization was used for all equations solved. The SIMPLE scheme



(a) Computational domain (b) Grids around the NACA0012 airfoil with Gurney flap

Fig 1. Computational domain and NACA0012 airfoil with Gurney flap

(a) Lift coefficient versus angle of attack (b) Drag coefficient versus angle of attack

Fig 2. Comparison of computational and experimental data [5] for base line NACA0012

(a) Lift coefficient versus angle of attack (b) Drag coefficient versus angle of attack

Fig 3. Comparison of computational and experimental data [5] for NACA0012 with 1%*c* rectangular Gurney flap

was used to resolve the pressure-velocity coupling. The total number of grids is around 35000. The first grid point above the airfoil surface is such that the value of $y+$ is of the order of 5.

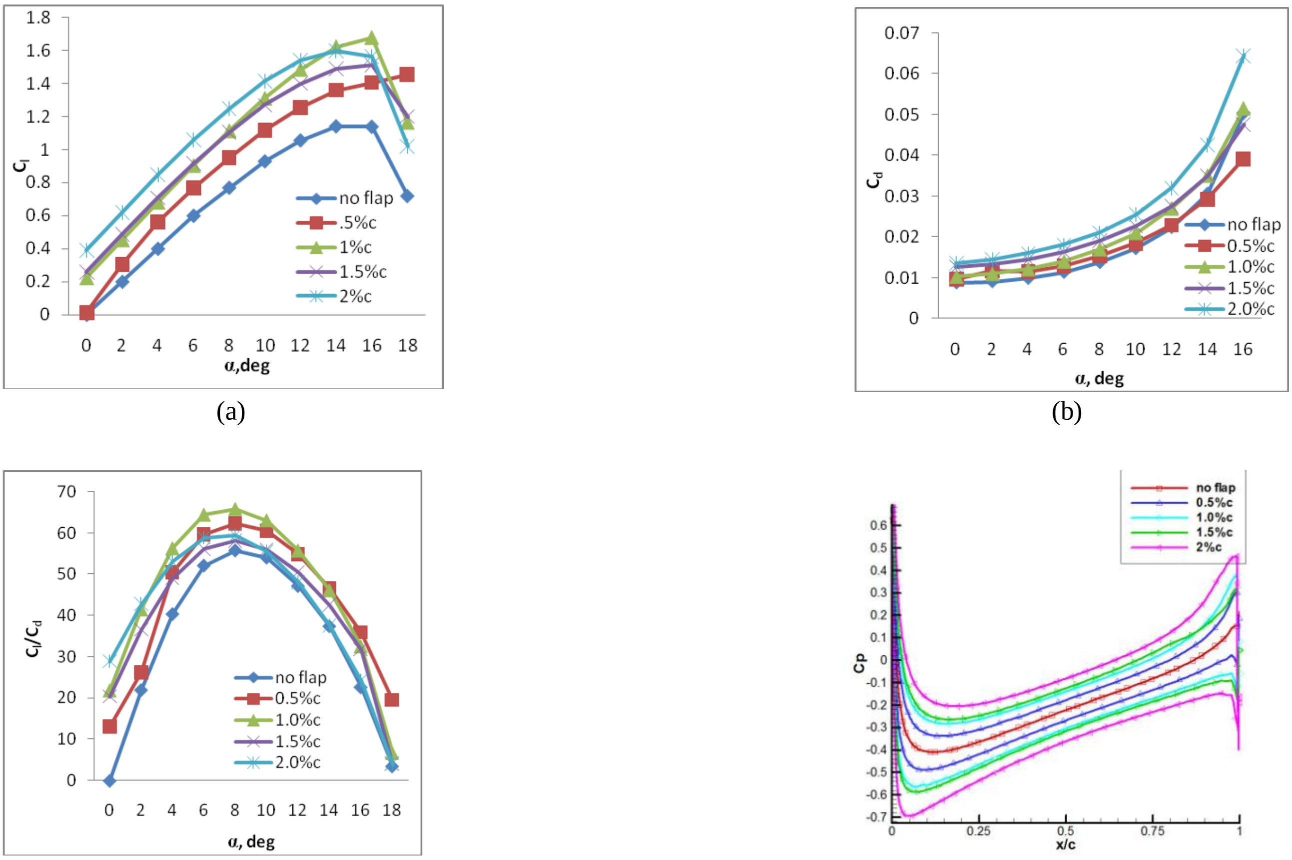
Rectangular flap of sizes 1% and 2% of chord length, *c* were chosen in order to make comparison with available experimental results. The width of 0.7%*c* was used for the computation. Data were computed for angle of attack, α from 0° to 18° with an interval of 2°.

For triangular flap the width was varied from 0.1%*c* to 10%*c* and flap height was varied from 0.5%*c* to 2%*c* with an interval of 0.5°, for angle of attack 0° to 18°.

3. RESULTS AND DISCUSSION

3.1 Validation

Computations were performed for a NACA0012 airfoil and the comparison of lift and drag co-efficient with experimental data [5] is shown in figure 2. The lift co-efficient comparable with the available experimental data within 10% error up to α =14°. The percentage of error increases with angle of attack. This may be due to unsteady flow behavior at higher angle of attack and particularly beyond the stall where computations assume the flow to be steady. While this is the stall angle of attack for NACA0012, in the computational result the maximum lift co-efficient occurs at α = 16°.



(a) (b)

(c) (d)

Fig 4. Aerodynamic performance of NACA0012 with and without rectangular gurney flap; (a) c_l vs. α, (b) c_d vs. α, (c) c_l / c_d vs. α and (d) c_p vs. α

The drag co-efficient also agrees well with the experimental results within 10% error. The computational results show more drag than experimental results. In computational solution, the flow is fully turbulent whereas the experimental flow-field is not fully turbulent. This may be one reason for the discrepancies.

The computational results of rectangular gurney flap of 1% are also compared with experimental results [5] and are shown in figure 3 . Under pre-stall conditions it is observed that there is good agreement of lift and drag coefficient between computational and experimental data with rectangular Gurney flap. Beyond stall the flow is becoming highly unsteady as discussed earlier.

3.2 Effect of rectangular Gurney flap

Figure 4 shows the effect of various lengths of rectangular gurney flap on lift coefficient, drag coefficient, lift-to-drag ratio and coefficient of pressure distribution in compared to NACA0012 airfoil with and without flap. Figures 4(a) and 4(b) show that with increase in gurney flap height C_l and C_d also increases. Figure 4(c) shows that for flap height 1%*c* C_l/C_d shows better results. Figure 4(d) shows an increase in upper surface suction and lower surface high pressure with increase in flap height, which results in lift increment.

3.3 Effect of triangular Gurney flap

At first triangular gurney flap was studied for various width with a fixed flap height of 1%*c* and α=0° and the value of C_l/C_d was compared. Figure 5 shows that C_l/C_d does not vary significantly from width 0.1% to 1%c. Thus in the following discussion of triangular Gurney flap, base width of 1%*c* was used.

The comparison of C_l, C_d and C_l/C_d for flap height 0.5% to 2%*c* for fixed flap width of 1%*c* is shown in Figure 6. It is seen that the value of C_l/C_d has increased with the use of triangular Gurney flap except for 2%*c*, for which the value of C_l/C_d has decreased compared to clean airfoil at higher angle of attack. When α=8°, the maximum value of C_l/C_d was obtained for flap height 1%*c*, which has shown good results at various angle of attack.

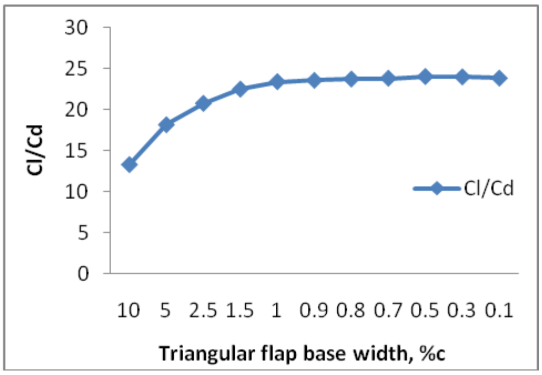
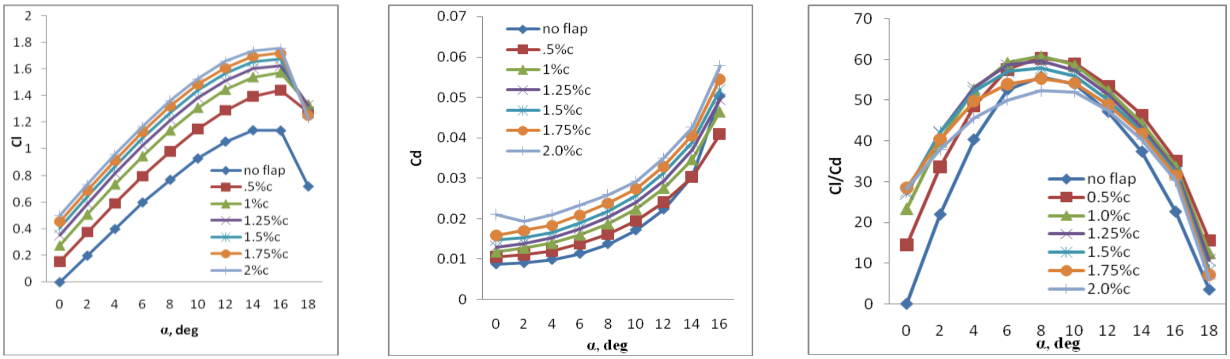
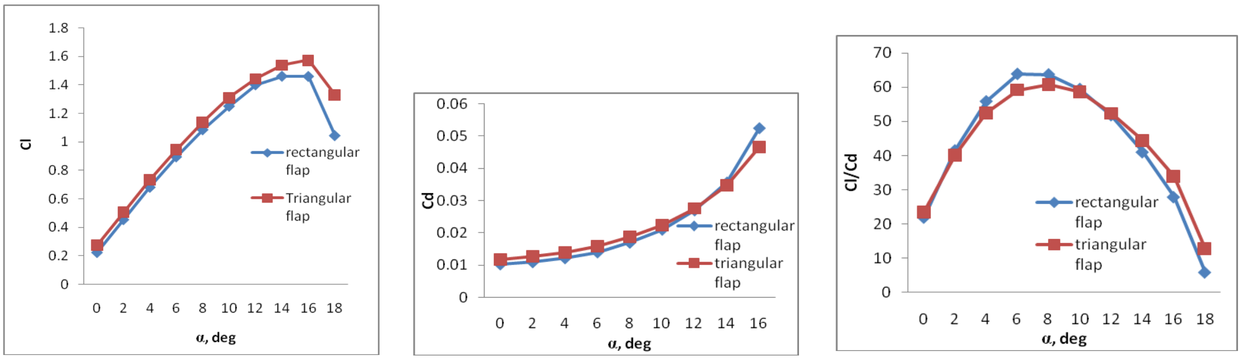


Fig 5. Variation of C_l/C_d for triangular flap with base width



(a) (b) (c)

Fig 6. Aerodynamic performance of NACA0012 with and without triangular gurney flap; (a) c_l vs. α, (b) c_d vs. α, and (c) c_l/c_d vs. α



(a) (b) (c)

Fig 7. Comparison of rectangular and triangular flaps for the same effective area; (a) c_l vs. α, (b) c_d vs. α, and (c) c_l/c_d vs. α.

3.4 Effect of Gurney flap shape

In this section the performance of rectangular and triangular gurney flap, with same effective flap area, is compared. Rectangular flap of width 0.5%*c* and triangular flap of base width 1%*c* was analyzed for same flap height of 1%*c* which gives the same effective flap area. The comparison is shown in figure 7.

The distribution of C_l, C_d and C_l/C_d are nearly identical in both cases of rectangular and triangular flaps. So shape of Gurney flap has no effect on aerodynamic performance except for α = 6° where C_l/C_d is maximum. Thus the flap area is an important consideration for Gurney flap design.

4. CONCLUSIONS

In the present CFD study, the effects of geometry and size of gurney flap on the aerodynamics performances on NACA0012 airfoil is performed. The study leads to the following conclusions:

1. A significant increase in lift is attained for both rectangular and triangular flap with some drag penalty. The value of lift-to-drag co-efficient increased for the flaps considered except for the case of 2%*c* of triangular gurney flap.
2. For both cases flap height of 1%*c* has shown better increment in lift-to drag ratio at various angles of attack.
3. Pressure distribution curves show that Gurney flap increases upper surface suction and lower surface high pressure which results in lift enhancement.
4. The comparison of rectangular and triangular Gurney flap of same effective flap area shows that lift coefficient, drag coefficient and lift-to-drag ratio remain same for both cases. So the important characteristic while designing Gurney flap is the effective flap area rather than its shape.

5. REFERENCES

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