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Gurney 플랩의 공기역학적 성능

Aerodynamic Performance of Gurney Flap

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ABSTRACT

A numerical investigation was performed to determine the effect of a Gurney flap on a NACA 23012 airfoil. A Navier-Stokes code, RAMPANT, was used to calculate the flow field about airfoil. The fully turbulent results were obtained using the standard $k-\varepsilon$ two-equation turbulence model. To provide a check case for our computational method, computations were performed for NACA 4412 airfoil which compared with Wadcock's experimental data. Gurney flap sizes of 0.5, 1.0, 1.5 and 2% of the airfoil chord were studied. The numerical solutions showed the Gurney flap increased both lift and drag. These results suggested that the Gurney flap served to increase the effective camber of the airfoil. But Gurney flap provided a significant increase in lift-to-drag ratio relatively at low angle of attack and for high lift coefficient. Also, it turned out that 0.5% chord size of flap was best one among them.

키워드 : *Gurney 플랩, 익형, 양항비, 공격각, 유효캠버*
Keywords : *Gurney flap, airfoil, lift-to-drag ratio, angle of attack, effective camber*

1. Introduction

The payload and range of subsonic transports are dictated and often limited by the performance of their high-lift systems. These systems are generally quite complex, consisting of a leading edge slat and two or three trailing edge flaps. The high maintenance and weight penalty associated with such configurations have provided an impetus for the design of mechanically simpler high-lift systems with no degradation in performance. However, to maintain the high lift coefficient required for approach and landing, new technology is needed to provide lift enhancement and separation control. One candidate technology is the Gurney flap which consists of a small plate, on the order of 1-2% of the airfoil chord length($= c$) in height, located at the trailing edge perpendicular to the pressure side of airfoil as shown in Fig.1.[1] The Gurney flap was originally developed by race car driver Dan Gurney in order to increase the down force and thus the traction

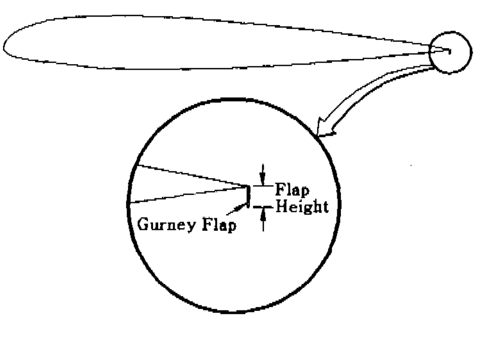

Fig.1 Gurney flap

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generated by the inverted wings used on race car.[2] It seems to be Robert Liebeck who first named the very small, low drag, flap used by Gurney "the Gurney flap".[1]

The purpose of Gurney flap is to improve the performance of the airfoil by increasing lift without introducing a commensurate increase in drag.[1] In addition, the Gurney flap is a mechanically simple high-lift system which would minimize construction and maintenance costs and therefore increase the aircraft's profitability. According to various experimental results, the height of Gurney flap is normally no greater and is usually significantly less than 2% c to which it is attached.[3]-[7] Height greater than 2% c usually result in significant increase in airfoil drag thereby seriously degrading, or negating, the sought-after improvement in airfoil performance as perceived in terms of lift-to-drag ratio.[1] So we took 0.5 to 2.0 % c as Gurney flap height for computation. The computed effect of the Gurney flap is very similar to the pressure, lift, and drag change that occur with the use of the divergent trailing edge(DTE) device reported by Henne. The modified trailing edges used in that study are very much like a Gurney flap. Henne stated that DTE acts like a Gurney flap on a high-speed airfoil.[8][9]

The objective of the present study is to provide quantitative and qualitative computational data on the effect of the Gurney flap on NACA 23012 airfoil. Computations of a baseline NACA 4412 airfoil and NACA 4412 with Gurney flap were compared with experimental results obtained by Wadcock.[1] This comparison provided a measure of the accuracy of the Navier Stokes computations. Subsequent computations were performed to determine the effect of various sizes of Gurney flaps on the lift and the drag of NACA 23012 airfoil.

2. Theoretical Background

Applying the conservation of mass and the conservation of momentum to an infinitesimal, fixed control volume of Newtonian fluid yields the Navier-Stokes equations for fluid flow. By Reynolds averaging, the following two-dimensional Reynolds-Averaged Navier-Stokes equations may be derived as :

- continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho U_j) = o$$

- momentum equation

$$\frac{\partial}{\partial t}(\rho U_i) + \rho U_j \frac{\partial U_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial U_i}{\partial x_j} - \rho \overline{u'_i u'_j}\right)$$

where

U ; average velocity, u' ; fluctuating velocity

As a CFD(Computational Fluid Dynamics) solver, we used RAMPANT code of Fluent Company which utilizes an structured/unstructured adaptive mesh Finite Volume Method(FVM). The present study assumed that the flow over the airfoil surface is completely turbulent and the standard $k-\varepsilon$ two-equations turbulence model proposed by Jones, Launder and Spalding was utilized. This turbulence model is nowadays widely used and known as a robust, economical and reasonably accurate method. The explicit time marching method to steady state is employed in this solver. The time step Δt is computed from Courant -Friedrichs-Lewy(CFL) condition.

Computations were performed for NACA 23012 airfoil with Gurney flaps whose heights from 0.5% to 2.0% chord located on the pressure side of airfoil at the trailing edge. Pressure-far-field and no-slip condition on the airfoil surface were used as boundary conditions as shown in Fig 2.

Grid was constructed using GeoMesh pre-processor. All of the computations were done with a 190×100 C-grid(Fig.2). The top and bottom far-field boundaries are located 20 c lengths from the airfoil. The upstream and downstream boundaries are also located 20 c lengths away. This spacing was deemed to be sufficient to apply free-stream conditions on the outer boundaries. This was verified for Navier-Stokes computations by varying the far-field boundary locations.[10]

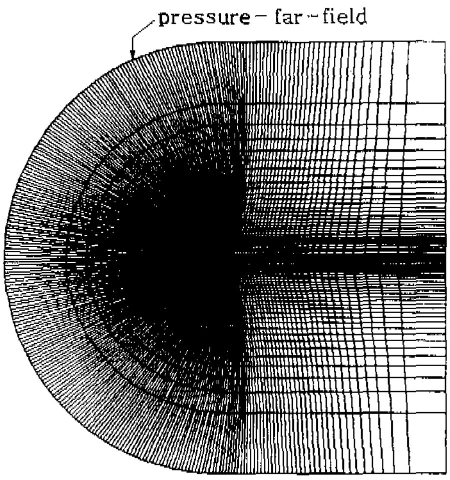

Fig.2a C-Grid used in computations

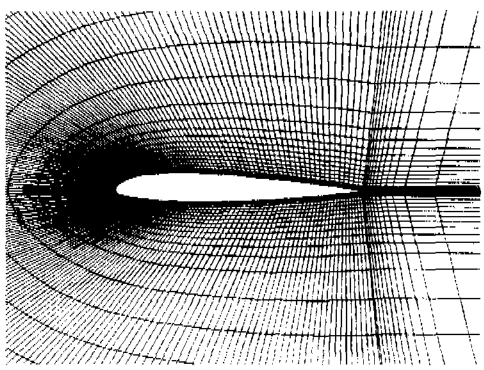

Fig.2b Closeup of grid

Clustering of points assemble near the surface of the airfoil as well as near the trailing edge, in order to accurately calculate the boundary layer and the flow physics of the Gurney flap. The first point above the surface is located 0.0002 c above the airfoil. This type of grid allowed the modeling of the various sized Gurney flaps, which are situated·perpendicular to the airfoil chordline.

3. Results and Discussion

First of all, for code validation, the Reynolds number based on chord length of 1.64 million and Mach number of 0.085 were chosen to match the baseline test conditions of the experiment by Wadcock for the clean NACA 4412 airfoil. The angle of attack tested varied from 0° up to approximately 10° .[1] Table 1 shows the comparison between computational and experimental results in terms of lift coefficient C_l, drag coefficient C_d and lift-to-drag ratio L/D for the angle of attacks α=0° and α=8° respectively. Note that there is also comparison for the airfoil with Gurney flap of 1.25% c height as well as clean airfoil. From this, it is observed that the computations agreed well with the measured data. The comparisons between the computed pressure distribution and the measured values at angle of attack 0, 8 and 16° can be seen in Fig.3, Fig.4 and Fig.5. Very good agreement is observed between experiments and Navier-Stokes computations from these figures. From this comparison, we could conclude that the computational methods used in the present study was very satisfactory. So we could proceed the computation for NACA 23012 airfoil.

Table 1 NACA 4412, $Re = 1.64 \times 10^6$

(exp ; experimental result, comp ; computational result)

		α = 0°			α = 8°		
		C_l	C_d	L/D	C_l	C_d	L/D
clean	exp	0.41	0.012	34.17	1.16	0.022	52.73
	comp	0.436	0.012	31.73	1.228	0.024	52.28
flap	exp	0.75	0.015	50.0			
1.25%c	comp	0.70	0.016	44.02			

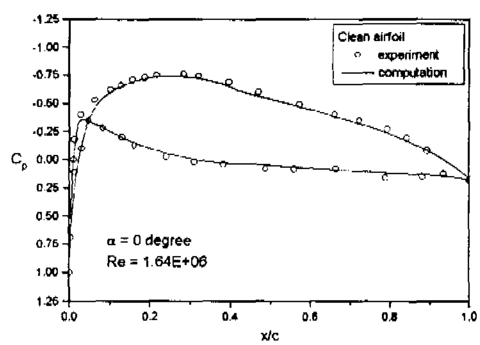

Fig.3 Pressure distributions comparison between computation and experiment I

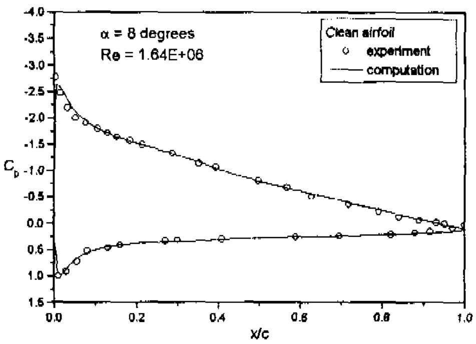

Fig.4 Pressure distributions comparison between computation and experiment II

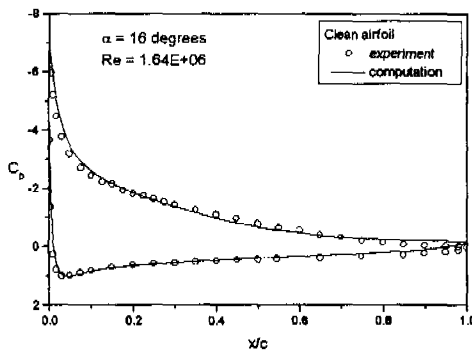

Fig.5 Pressure distributions comparison between computation and experiment III

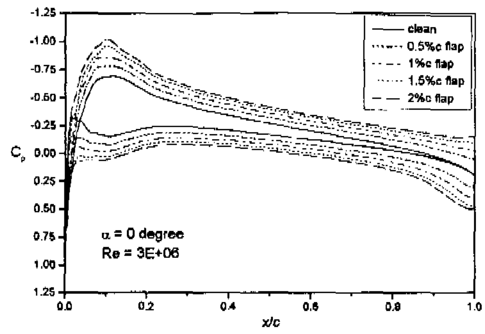

Fig.6 Pressure distributions for various Gurney flap heights I

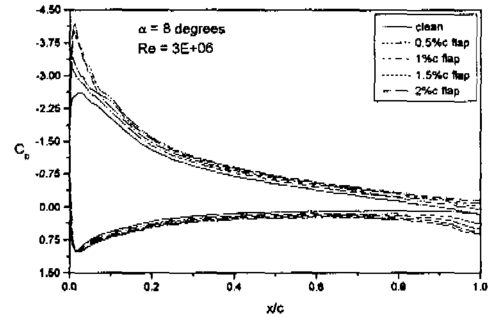

Fig.7 Pressure distributions for various Gurney flap heights II

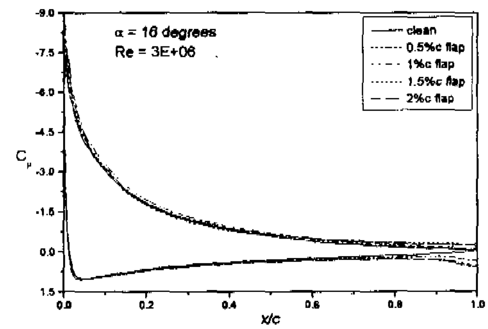

Fig.8 Pressure distributions for various Gurney flap heights III

The comparisons of pressure distribution for various Gurney flap heights including clean airfoil are presented in Fig.6, Fig.7 and Fig.8 each for α =0, 8, 16° respectively. It is found that as the Gurney flap size increases for a given angle of attack, the pressure difference between the upper surface and lower surface of the airfoil becomes larger due to a decrease in pressure on the upper surface and an increase in pressure on the lower surface. The presence of the Gurney flap considerably increases the aft loading of airfoil, but it is also noted that much of the lift increment is derived from a general increase in loading and a higher suction peak. As the Gurney flap height is increased, higher loading is noted along entire airfoil, particular at the suction peak and near the trailing edge. This leads to increased lift and increased nose-down pitching moment.

Fig.9 shows how the lift coefficient varies as the Gurney flap size changes for a given angle of attack. With the addition of a Gurney flap, the computations predict a significant lift increment that increases with flap size, although not linearly. This lift increase is accomplished by a change in the effective camber. Looking at a specific case, the increase in the lift coefficient obtained by increasing the flap size from 0%c to 0.5%c is greater than the lift coefficient increase found by changing the Gurney flap size from 1.5% *c* to 2.0% *c*. The effect of the Gurney flap is to substantially increase the maximum lift coefficient. This figure also shows that the stall angle is decreased while the zero-lift angle of attack appears to become increasingly more negative as a larger Gurney flap is utilized. These results suggest again that the effect of Gurney flap is to increase the effective camber of the airfoil.

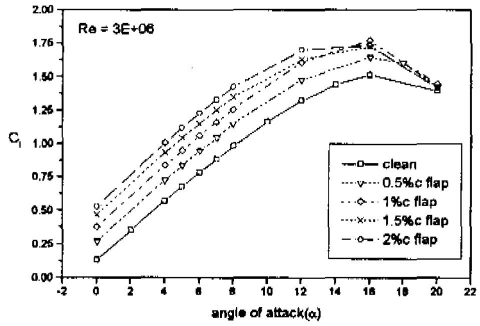

Fig.9 Lift coefficients versus angle of attack for various Gurney flap heights

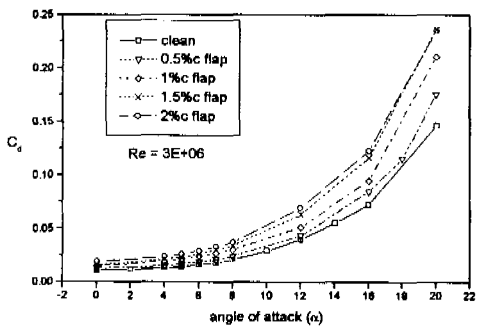

Fig.10 Drag coefficients versus angle of attack for various Gurney flap heights

The effect on C_d by using various sized Gurney flaps can be seen in Fig.10. Drag coefficient increases with the increase in flap size, and especially at high angle of attack the rate is high. The drag polar is shown in Fig.11. The addition of the flap increases C_d at low and moderate C_l (≤ 0.8). However, flap size of 0.5% *c* results in

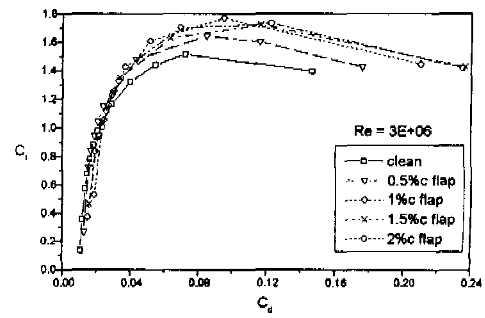

Fig.11 Drag polars for various Gurney flap heights

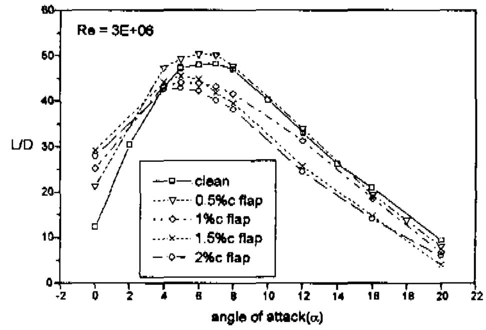

Fig.12 Lift-to-drag ratio versus angle of attack for various Gurney flap heights

a very small increase in drag. It can be seen that at lift coefficients C_l greater than 0.8 airfoils with Gurney flap have low drag coefficients than the clean airfoil. This is an evident merit of Gurney flap. But it should be noted that we can not find reduced drag overall using the Gurney flap for NACA 23012. This is the same result as that of the Storm and Jang's for NACA 4412 airfoil.[1]

Fig.12 shows the lift-to-drag ratio as a function of angle of attack. From this figures, we conclude that the Gurney flap height of 0.5% c is best one for NACA 23012 airfoil, and the other cases have benefit only for α=0~4°. Fig.13 shows the lift-to-drag ratio as a function of lift coefficient. In this figure we can see that at high lift coefficient($C_l \geq 1.1$) the airfoil with Gurney flaps have higher L/D than clean airfoil. In this figure it is also observed that the Gurney flap height of 0.5% c is best one for NACA 23012 airfoil

Fig.14 shows the relation between leading edge

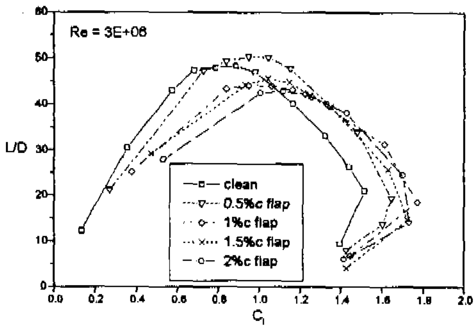

Fig.13 Lift-to-drag ratio versus lift coefficient for various Gurney flap heights

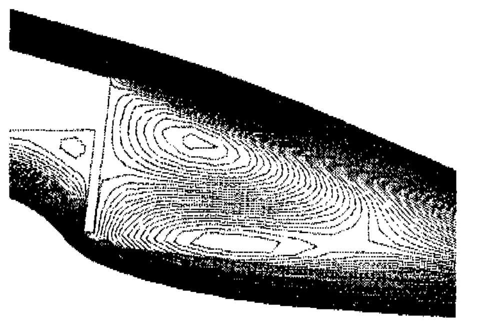

Fig.16a Streamline pattern of airfoil with 0.5% chord height Gurney flap when $\alpha = 8^\circ$

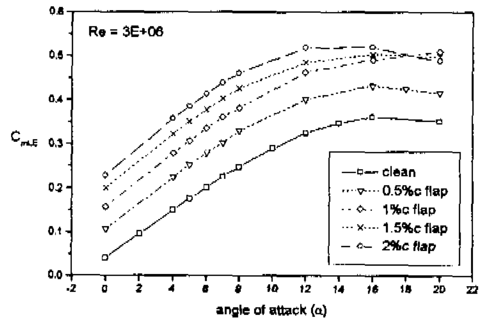

Fig.14 Leading edge pitching moment versus angle of attack for various Gurney flap heights

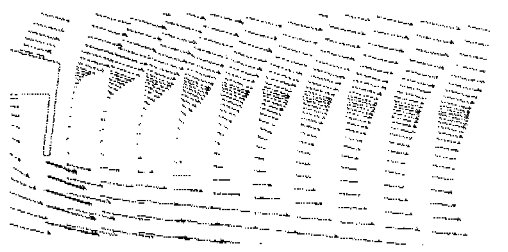

Fig.16b Velocity vector field of airfoil with 0.5% chord height Gurney flap when $\alpha = 8^\circ$

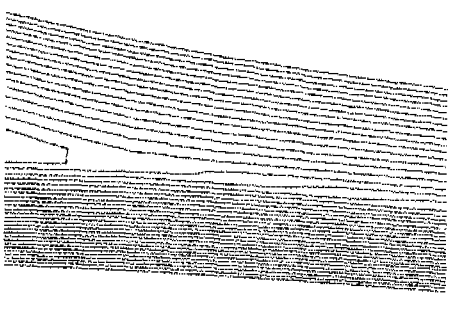

Fig.15a Streamline pattern of clean airfoil when $\alpha = 8^\circ$

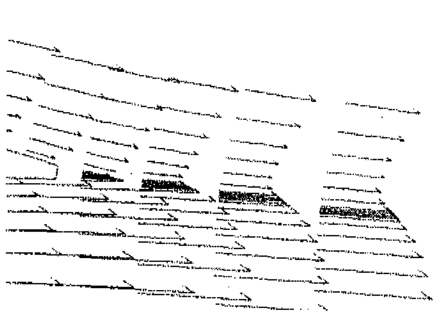

Fig.15b Velocity vector field of clean airfoil when $\alpha = 8^\circ$

moment, i.e., nose-down pitching moment coefficient and angle of attack for various heights of Gurney flap. It is found that the Gurney flap generates an additional nose-down pitching moment compared to the clean airfoil and nose-down pitching moment is increased with the Gurney flap. It results that the Gurney flap serves to increase the effective camber of the airfoil.

Fig.15a, b show the streamline pattern and the velocity vector field near the trailing edge of clean airfoil when $\alpha = 8^\circ$. The streamline pattern and the velocity vector field near the trailing edge of airfoil with Gurney flap when angle of attack is 8 ° is shown in Fig.16a, b. These figures show a separation bubble in front of flap and recirculation region consisting of two vortices of opposite sign. The appearance of this recirculation region is directly related to the increase in lift.

4. Conclusion

A computational study of the flow field for a NACA 23012 airfoil with a Gurney flap has been performed. The two-dimensional flow was calculated using the RAMPANT code with the standard $k-\varepsilon$ two-equation turbulence model. The trends observed in the benchmark computations were found to agree well with available experimental results of Wadcock. From our computational study, the following conclusions were drawn :

1) The use of the Gurney flap increases the loading along the entire length of the airfoil, particularly near the trailing edge and at the suction peak.

2) In comparison with a clean airfoil, lift coefficient and nose-down pitching moment are increased by the Gurney flaps. However, larger Gurney flaps increase lift at the expense of increasing drag.

3) From the relation between lift-to-drag ratio and angle of attack, it was found that L/D is increased only for low angle of attack by Gurney flap.

4) In fact, at higher lift coefficient the drag coefficient is lower than the clean airfoil, i.e., lift-to-drag ratio is higher than the clean airfoil.

5) For NACA 23012 airfoil, the optimum height of Gurney flap is 0.5% chord.

Because of its mechanical simplicity and significant effect on aerodynamic performance of airfoils, the Gurney flap is an intriguing device for high-lift project. Subsonic and supersonic aircrafts can greatly benefit from the use of this simple flat-plate type device.

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