Effect of the Gurney Flap on a NACA 23012 Airfoil

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A numerical investigation was performed to determine the effect of the Gurney flap on a NACA 23012 airfoil. A Navier-Stokes code, RAMPANT, was used to calculate the flow field about the airfoil. Fully-turbulent results were obtained using the standard k-ε two-equation turbulence model. The numerical solutions showed that the Gurney flap increased both lift and drag. These results suggested that the Gurney flap served to increase the effective camber of the airfoil. The Gurney flap provided a significant increase in the lift-to-drag ratio relatively at low angle of attack and for high lift coefficient. It turned out that 0.6% chord size of flap was the best. The numerical results exhibited detailed flow structures at the trailing edge and provided a possible explanation for the increased aerodynamic performance.

Key Words : Airfoil, Gurney Flap, Flap Height, Lift-to-Drag Ratio, Angle of Attack

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, and the high maintenance and weight penalty associated with them have provided an impetus for the design of mechanically simpler high-lift systems with no degradation in performance. 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 (Storms, 1994). The Gurney flap was originally developed by race car driver Dan Gurney in order to increase the down force and thus the traction generated by the inverted wings used on race cars (Myose, 1996).

The Gurney flap improves the performance of the airfoil by increasing lift without introducing a commensurate increase in drag (Storms, 1994). In addition, the Gurney flap is a mechanically simple high-lift system which would minimize construction and maintenance costs, and thus increase aircraft profitability. According to various experimental results, the height of the Gurney flap is usually significantly less than 2%c (Bloy, 1995; Jang, 1992; Kentfield, 1993; Kentfield, 1994; Neuhart, 1988; Philippe, 1997). Height greater than 2% c usually results in a significant increase in airfoil drag, thereby seriously degrading, the improvement in airfoil performance as perceived in terms of lift-to-drag ratio (Storms, 1994).

The objective of the present study is to provide quantitative and qualitative computational data on the aerodynamic performance of the Gurney flap on a NACA 23012 airfoil. NACA 23012

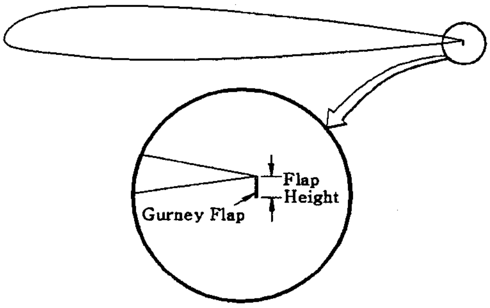

Fig. 1 Gurney flap

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airfoil was chosen because it is one of the representative conventional airfoils (Yoo, 1998). Computations of a baseline NACA 4412 airfoil and a NACA 4412 with Gurney flap were compared with experimental results obtained by Storms and Jang (1994). This comparison provided a measure of the accuracy of the Navier-Stokes computations.

2. Theoretical Background

The governing equations for this computation are the following two dimensional Reynolds-Averaged Navier-Stokes equations.

- continuity equation

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

- momentum equation

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

where

U ; average velocity, u' ; fluctuating velocity

As a CFD (Computational Fluid Dynamics) solver, RAMPANT code, which utilizes the structured/unstructured adaptive' mesh Finite Volume Method (FVM), was used. The present study assumed that the flow over the airfoil surface is completely turbulent and the standard k-ε two-equation turbulence model proposed by Jones, Launder and Spalding was utilized. This turbulence model adopts the standard wall-function and it is nowadays widely used and known as a robust, economical and reasonably accurate method. An explicit time marching method to steady state is employed in this solver.

The grid was constructed using the GeoMesh pre-processor. All the computations were done with a 190×100 C-grid as shown in Fig. 2. Pressure-far-field and no-slip condition on the airfoil surface were used as boundary conditions. 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.

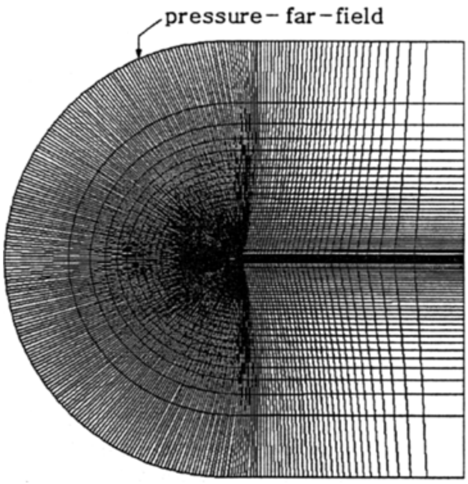

Fig. 2(a) C-Grid used in computations

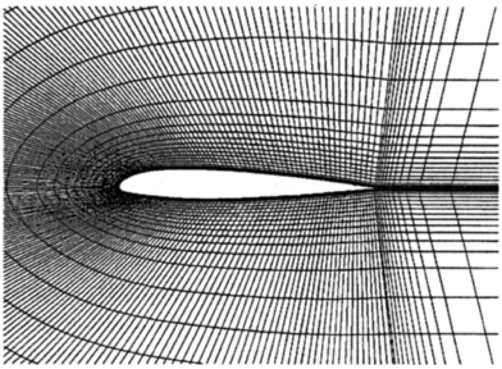

Fig. 2(b) Closeup of grid

Grid spacing is clustered near the surface of the airfoil as well as near the trailing edge, in order to accurately calculate the boundary layer and flow physics of the Gurney flap. The first point above the surface is located 0.0008 c above the airfoil which corresponds to $y^+ \approx 60$. This type of grid allowed modeling variously sized Gurney flaps.

3. Results and Discussion

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 test

Table 1 NACA 4412. $Re = 1.64 \times 10^6$ (exp : experimental result, comp: computational result)

		$\alpha=9°$			$\alpha=8°$		
		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	0.07	0.016	44.02			

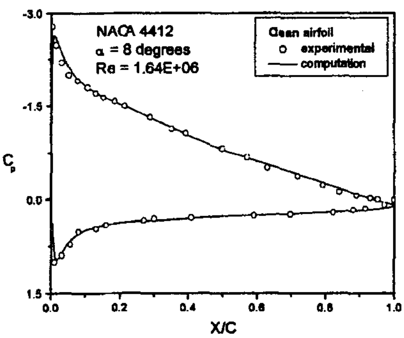

Fig. 3 Pressure distributions comparison I

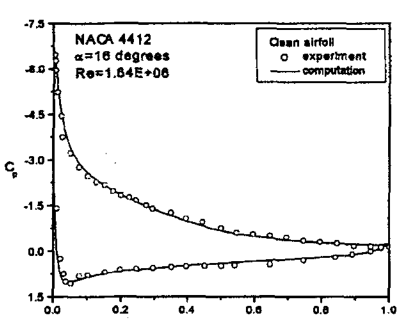

Fig. 4 Pressure distributions comparison II

conditions of the experiment for a clean NACA 4412 airfoil and another with a 1.25% c Gurney flap. 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 angles of attack $\alpha=0°$ and 8°, respectively. From this, it is observed that the computations agree well with the measured data. Comparisons between the computed pressure distribution and the measured values for NACA 4412 airfoil are shown in Figs. 3~5. Figs. 3 and 4 show the comparison for clean airfoil at angles of attack 8° and 16°. Figure 5 shows the

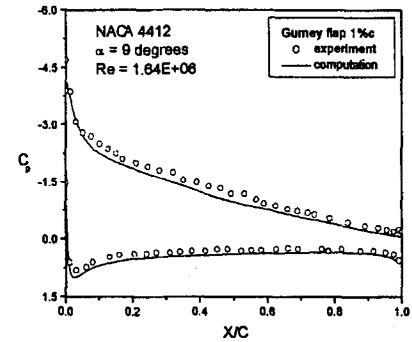

Fig. 5 Pressure distributions comparison III

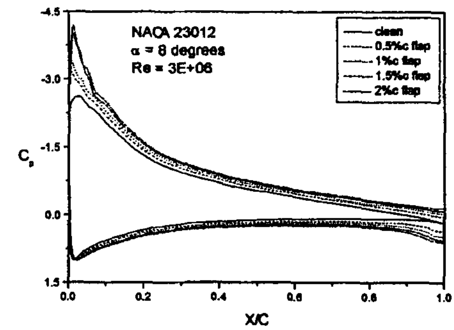

Fig. 6 Pressure distributions for various Gurney flap heights I

comparison for the flap of 1.0% c at $\alpha=9°$. Good correlation is observed between experiments and Navier-Stokes computations from these figures. From this comparison, it could well be stated that the computational method used in the present study was satisfactory. So we could proceed with the computation for a NACA 23012 airfoil. Values of 0.1 for Mach number and 3×10^6 for Reynolds number were taken. For NACA 23012 airfoil, computations were done by two steps. First, Gurney flap heights ranging from 0.5% to 2.0% chord were changed by 0.5% chord interval and their effects were studied. The best height among them was determined from the above analysis. Second, more detailed numerical calculations were made by changing the chord interval with $\pm0.1\%$ from the selected value.

Comparisons of pressure distribution for various Gurney flap heights, including a clean airfoil, are presented in Figs. 6, 7 for $\alpha=8°$, 16°. It is found that as the Gurney flap size increases for a given angle of attack, the pressure difference

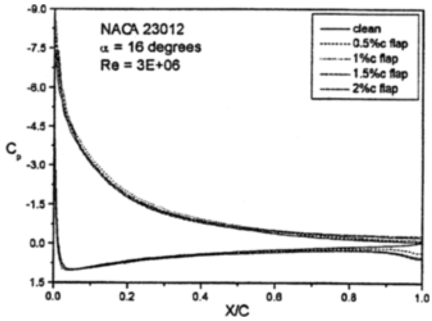

Fig. 7 Pressure distributions for various Gurney flap heights II

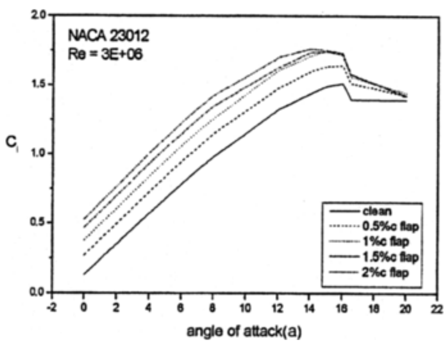

Fig. 8 Lift coefficients versus angle of attack for various Gurney flap heights

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. This leads to increased lift and increased nose-down pitching moment. But it is also noted that much of the lift increment is derived from a general increase in loading and a higher suction peak. Note the stronger adverse pressure gradient near the trailing edge on the lower surface due to the presence of the Gurney flap. Such an adverse pressure region is expected in front of the flap, and is indeed found in these figures. Liebeck has theorized that a recirculating vortex behind the flap may be associated with this adverse pressure region just upstream of the flap on the lower surface (Myose, 1996).

Figure 8 shows how the lift coefficient varies as the Gurney flap size changes for angles of attack from 0 to 20 degrees. 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 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 height from 1.5% c to 2.0% c. The effect of the Gurney flap is to substantially increase the maximum lift coefficient. Compared to the clean airfoil, the maximum lift coefficient is increased by 9% and 17%, respectively for 0.5% c and 2.0% c height Gurney flaps. Use of a 2.0% c Gurney flap decreases the angle of attack for a given lift coefficient $C_l=1.0$ by more than 4.1°. 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. In summary, the lift curves are shifted upwards and to the left with the Gurney flap, and the slopes of the lift curves generally appear unchanged. These results suggest again that the effect of Gurney flap is to increase the effective camber of the airfoil.

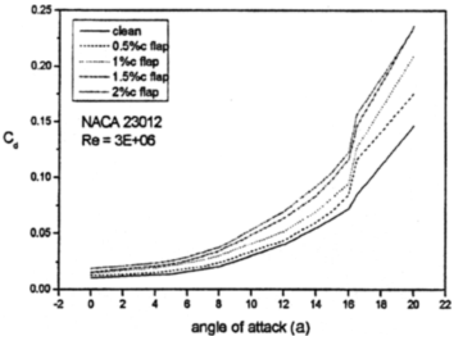

Fig. 9 Drag coefficients versus angle of attack for various Gurney flap heights

The effect on C_d can be seen in Fig. 9. Drag coefficient increases with the increase in flap size, and, especially at a high angle of attack, the rate is high. The drag polar is shown in Fig. 10. The addition of the flap increases C_d at low and moderate $C_l(\leq 0.8)$. It can be seen that at lift coefficients C_l greater than 1.2, airfoils with the Gurney flap can get the same lift coefficient with lower drag coefficients than the clean airfoil. This is an evident merit of the Gurney flap.

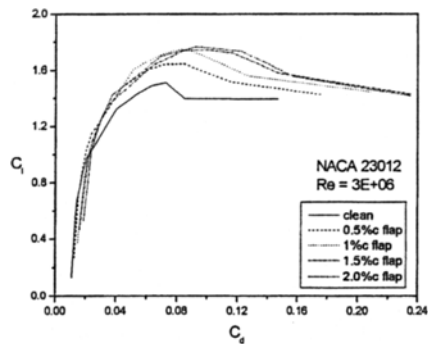

Fig. 10 Drag polars for various Gurney flap heights

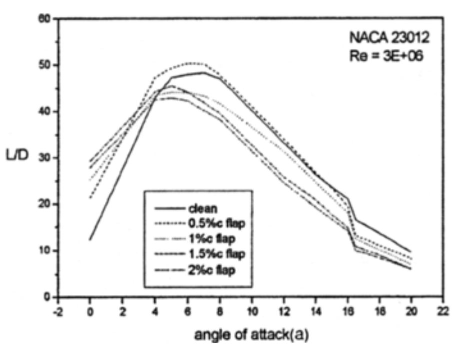

Fig. 11 Lift-to-drag ratio versus angle of attack for various Gurney flap heights

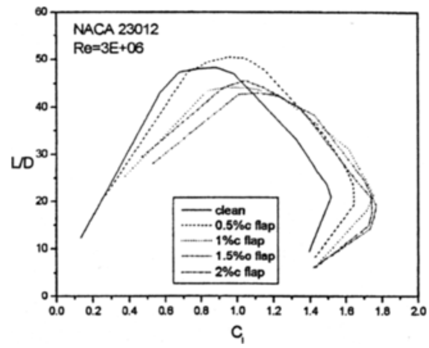

Fig. 12 Lift-to-drag ratio versus lift coefficient for various Gurney flap heights

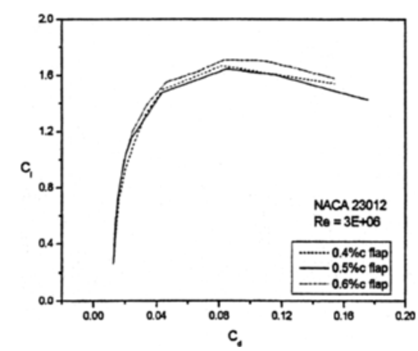

Fig. 13 Drag polars for Gurney flap heights of 0.4c, 0.5c, 0.6c

But it should be noted that we cannot find reduced drag using the Gurney flap for NACA 23012. The same trend is found in Storms and Jang's experiment (1994) for NACA 4412 airfoil. At low-to-moderate lift coefficients, there is a drag penalty associated with the Gurney flap which increases with flap height. At higher lift coefficients, however, the drag is significantly reduced. If a high lift coefficient is desired, (e. g., $C_l=1.4$), the Gurney flap can provide the same amount of lift with a smaller drag coefficient (by 0.02) compared to the clean airfoil.

Figure 11 shows the lift-to-drag ratio as a function of the angle of attack. As seen from this figure, the Gurney flap height of 0.5% c is the best, and the other heights have the advantage only for the range of $\alpha=0\sim4°$.

Figure 12 shows the lift-to-drag ratio as a function of lift coefficient. Note that the effect of flap on the maximum lift-to-drag ratio is small, but the lift coefficient for a given lift-to-drag ratio is significantly increased. Note that the maximum lift-to-drag ratio is reduced for flap heights greater than 1.0% chord. In this figure we can see that, at high lift coefficient ($C_l \geq 1.1$), the NACA 23012 airfoil with flaps have higher L/D than a clean airfoil. In this figure it is also observed that the Gurney flap height of 0.5% c is the best one among tested heights.

The above results indicate that 0.5% c Gurney flap is the best one among those tested numerically. The results for 0.4% and 0.6% cases are shown in Fig. 13 (drag polars), Fig. 14 (L/D-α), and Fig. 15 (L/D-C_l). From the above analysis, it turns out that 0.6% c Gurney flap is the best.

Fig. 16(a), (b) show the streamline pattern and the velocity vector field near the trailing edge of a clean airfoil for $\alpha=8°$. The streamline pattern and the velocity vector field near the trailing edge of a airfoil with a 0.6% c Gurney flap at the angle of attack of 8° is shown in Fig. 17 (a), (b). These figures show a separation bubble in front

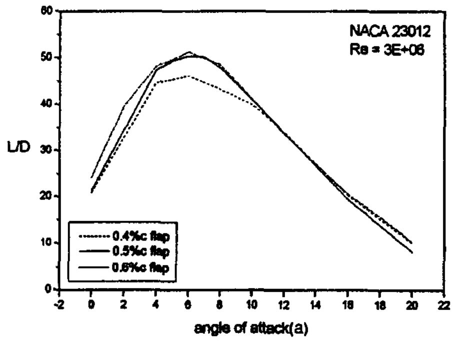

Fig. 14 Lift-to-drag ratio versus angle of attack for Gurney flap heights of 0.4c, 0.5c, 0.6c

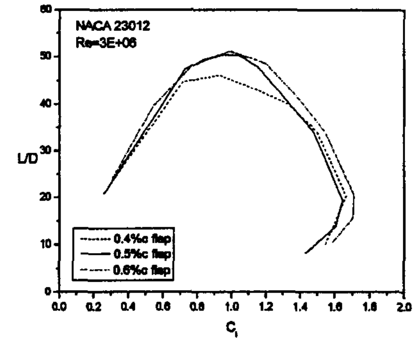

Fig. 15 Lift-to-drag ratio versus lift coefficient for Gurney flap heights of 0.4c, 0.5c, 0.6c

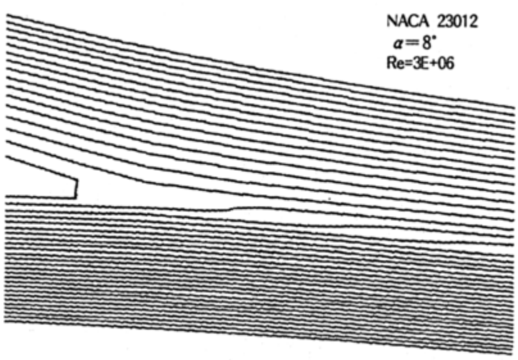

Fig. 16(a) Streamline pattern of clean airfoil

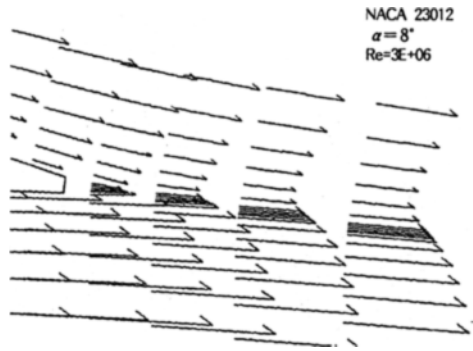

Fig. 16(b) Velocity vector field of clean airfoil

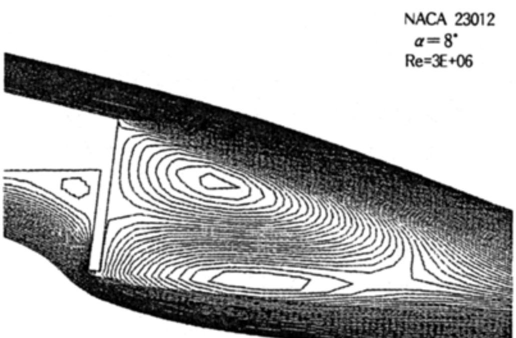

Fig. 17(a) Streamline pattern around 0.6%c height Gurney flap

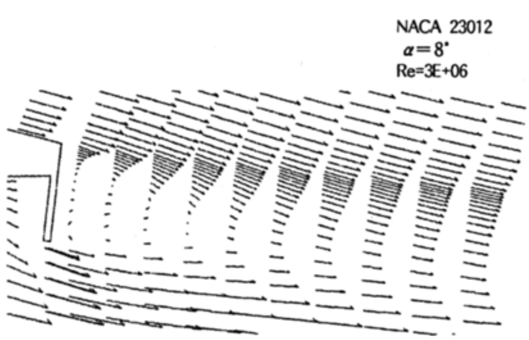

Fig. 17(b) Velocity vector field around 0.6%c height Gurney flap

of the flap and a recirculation region consisting of two opposing vortices on the back side of the flap, i. e., a counter-clockwise bubble in front of Gurney flap and a clockwise vortex on upper side and counter-clockwise vortex on lower side behind the flap. This result is consistent with the water tunnel flow visualization results of Neuhart (1988). Figs. 16(b), 17(b) show that the wake momentum deficit is deeper and wider with the Gurney flap than with the clean airfoil. This means that the drag is increased with the Gurney flap compared to the clean airfoil at the same angle of attack. These figures also show that there is a downward shift in the wake position with the Gurney flap. Such a vertical shift in the wake is presumably associated with an increase in the airfoil's circulation which is expected for an airfoil with increased camber. The appearance of this recirculation region is directly related to the increase in lift.

4. Conclusions

A computational study was performed to investigate the effects of the Gurney flap on a NACA 23012 airfoil. The two-dimensional flow was calculated using the RAMPANT code with the standard k-ε two-equation turbulence model. The trends observed in the benchmark computations were found to agree well with the available experimental results of Storms and Jang. From our computational study, the following conclusions were drawn :

- 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.
- Compared to the clean airfoil, for high lift coefficients, the same lift can be obtained at lower drag coefficients with the Gurney flap. That is, potential benefits in terms of drag may be limited to high lift coefficients.
- The effect of the Gurney flap is to substantially increase the maximum lift coefficient. Compared to the clean airfoil, the maximum lift coefficient is increased by 17% for the 2.0% c height Gurney flap.
- At higher lift coefficients, lift-to-drag ratio is higher with the Gurney flap.
- For NACA 23012 airfoil, the optimum height of Gurney flap is assumed to be around 0. 6% chord

Because of its mechanical simplicity and significant effect on aerodynamic performance of airfoils, the Gurney flap is an attractive device for high-lift project.

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