JOURNAL OF AIRCRAFT
Vol. 43, No. 5, September–October 2006

# Engineering Notes

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## Application of a Gurney Flap on a Simplified Forward-Swept Aircraft Model

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DOI: 10.2514/1.20283

### I. Introduction

THE design of lift-enhancement devices is a key problem for aircraft aerodynamics. Much attention has been paid to Gurney flaps recently due to their structural simplicity, easy manufacturing, and high efficiency in lift enhancement. Since the work done by Liebeck [1] in 1978, a number of experimental and numerical researches have been done to investigate the possibility and efficiency of a Gurney flap in enhancing the lift coefficient of airfoils [2–12]. In Liebeck's experiment [1], a Gurney flap with 1.25% chord height was installed on the trailing edge of a Newman airfoil, perpendicular to the chord line. Although Gurney flaps could increase the lift coefficient and the maximum lift coefficient, the zero-lift angle of attack and the airfoil drag were reduced. Neuhart and Pendergraf [2] conducted a flow visualization study in a water tunnel, where they found that a Gurney flap has moved the separation point downstream. It was also shown that the effectiveness of flow separation delay was improved with an increase in the flap height. Storms and Jang [3] investigated a similar problem in a wind tunnel through a pressure measurement, where it was shown that a Gurney flap with a 0.5% chord height could increase the lift coefficient of NACA 0012 airfoil despite a drag penalty. They also obtained a greater lift-to-drag ratio by the same Gurney flap. In Giguere, Dumas, and Lemay's experiments [4], it was shown that there exists an optimum Gurney flap height for the lift-to-drag performance, which can be obtained without substantially increasing the drag so long as the Gurney flap height remains within the boundary layer.

In our previous work [5–10], the efficiency and physical mechanism of lift enhancement by Gurney flaps were investigated in detail through force/pressure measurements in a wind tunnel as well as by flow visualization and (particle image velocimetry) (PIV) experiments in a water tunnel. We have studied the use of Gurney flaps on several airfoils, including ordinary symmetrical and asymmetrical airfoils, supercritical and divergent trailing-edge airfoils, and three-dimension wings (delta and double delta wings).

Received 5 October 2005; revision received 2 December 2005; accepted for publication 1 December 2005. 

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These experiments covered a wide range of Mach numbers from 0.05 to 0.7. The effect of Gurney flap parameters including their height, plan form, setup angle, location, and Reynolds number were systemically investigated in our study, which gave the following conclusions:

1) The major factor affecting the efficiency of a Gurney flap in lift enhancement is its effective windward area. In other words, Gurney flaps with an identical windward area have the same lift coefficient irrespective of their plan form shape (plate or zigzag) [8,9].

2) For Gurney flaps to have optimum lift enhancement, they should be installed on the trailing edge of the wing perpendicular to its chord line [6].

3) The mechanism of lift enhancement of a Gurney flap is proposed for flows at low free-stream speed. Karman vortex shedding from a Gurney flap changes the pressure field in the wake of the airfoil, thereby preventing flow separation near the trailing edge and enhancing suction on the upper surface of the airfoil. The Gurney flap increases the positive pressure on the bottom surface of the airfoil at the same time. Both effects result in an increase in airfoil circulation, leading to a lift enhancement [10].

4) At high speed where a shock wave exists over an airfoil, the lift-enhancement mechanism is different from that at low speed. Here, the downstream movement of the shock wave is responsible for the lift enhancement with a Gurney flap [7].

Overall, a Gurney flap is an efficient device to improve aerodynamic performance of airfoils and wings. In this paper, we report recent results of the application of a Gurney flap on a simplified forward-swept aircraft model, which was investigated in a low-speed wind tunnel. We hope that the present results will shed some light on the engineering application of a Gurney flap, particularly for aircraft wings.

### II. Experimental Model and Apparatus

The aircraft model used in this investigation was made of aluminum. It consists of four parts: a fuselage, a forward-swept wing, a canard wing, and a Gurney flap. The fuselage was modeled by a

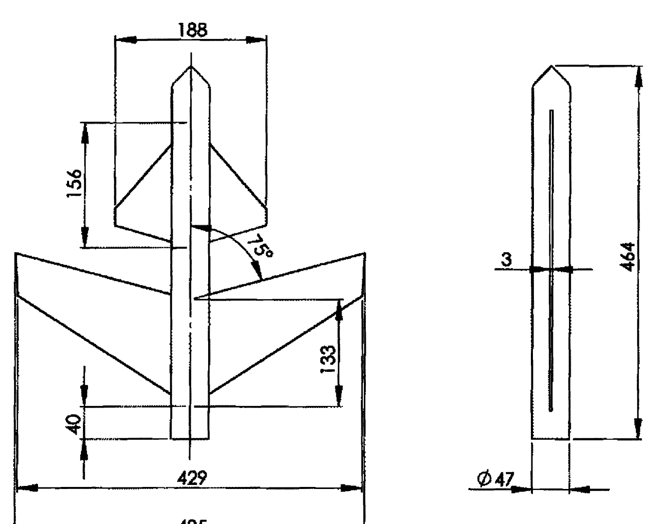



**Fig. 1 Sketch of experimental model (unit, mm).**

circular cylinder of 47 mm diameter with a head cone. A forward-swept main wing was constructed with a flat plate with 15 deg sweep angle behind a flat canard wing. A sketch of the model is shown in Fig. 1 with dimensions. The mounting angles of the forward-swept wing and the canard wing were zero. Gurney flaps were made of rectangular flat plates 1 mm thick, 200 mm long with their height ranging from 1.2 to 4.8 mm (equivalent to 1–4% average chord length), which were glued on the trailing edge of the forward-swept wing perpendicular to the wing surface.

The experiment was conducted in a low-speed closed return wind tunnel at Beijing University of Aeronautics and Astronautics (BUAA). The wind tunnel has a 2.0 m long open working section with an elliptical cross-sectional area, changing from $1.02 \times 0.76$ m at the inlet to $1.07 \times 0.81$ m at the outlet. The aerodynamic forces were measured by a six-component strain gauge balance, whose measurement uncertainty is within 5% in lift and drag forces. The model was supported in the tunnel by a sting projecting from the rear part of the model. The tunnel speed was kept at 20 m/s, where the turbulence intensity was less than 0.3%. The Reynolds number was $1.44 \times 10^5$ based on the averaged chord length of the main wing, where the angle of attack was varied from −4 to 52 deg with a step of 2 deg.

## II. Results and Discussion

### A. Effects of the Gurney Flap's Height on Lift

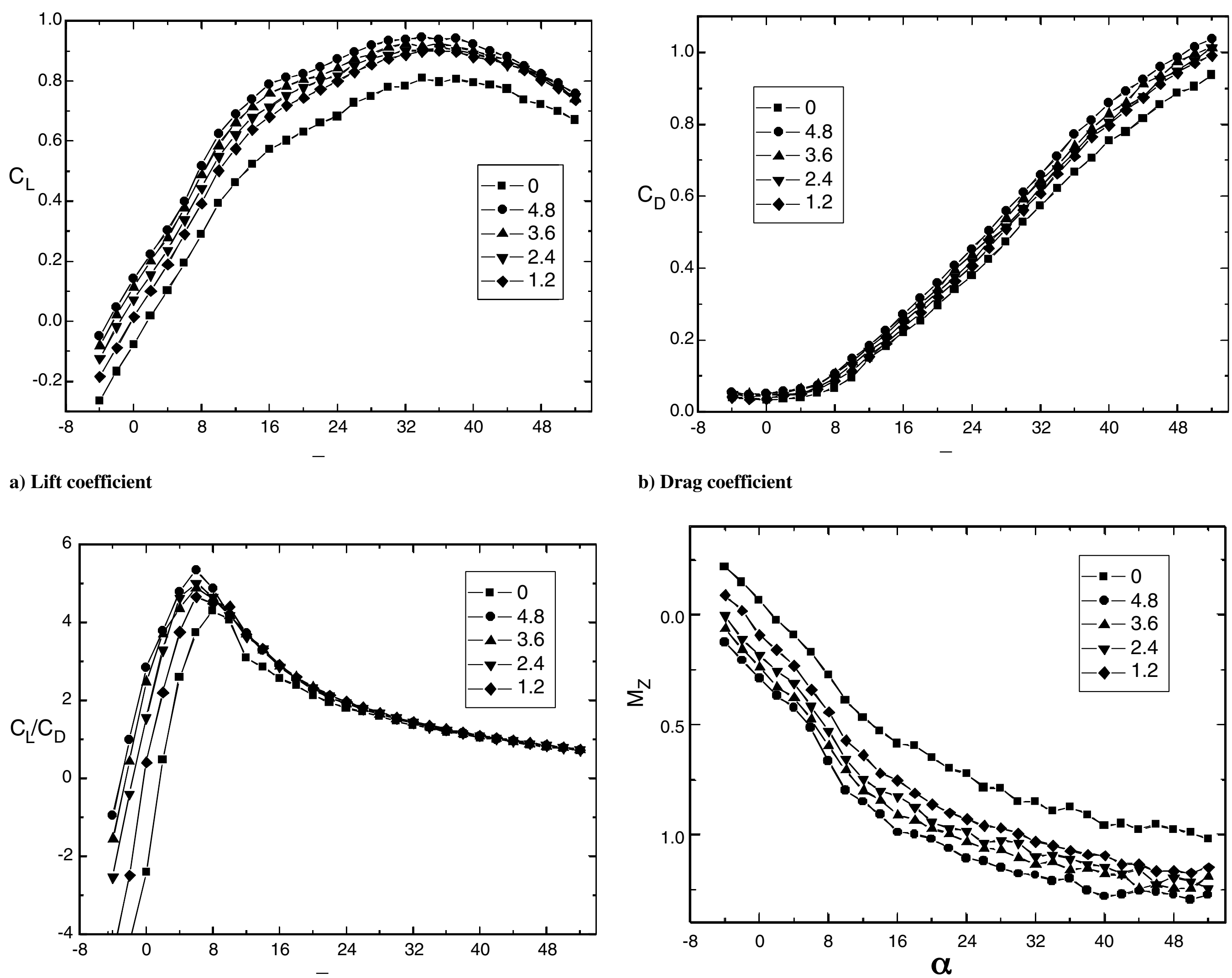
Figure 2a shows the variation of the lift coefficient versus the angle of attack $a$. It is clear that the Gurney flap can increase the lift coefficient of the model tested. It can also be seen from this figure, in general, that the lift coefficient increases with the height of a Gurney flap. When $a < 12$ deg, the slopes of the lift coefficient curves in Fig. 2a are almost the same. That is to say that a Gurney flap increases the lift coefficient without changing the slope against the angle of attack. This result is consistent with those for airfoils and wings [5,8,9,11,12].

For the aircraft model with a Gurney flap, the stall angle is about 36 deg, which is 2 deg less than the value obtained for a model without a Gurney flap. Even after the stall angle, the Gurney flap can increase the lift coefficient, whose increment seems to be constant irrespective of the Gurney flap's height and the angle of attack of the model. Generally speaking, the lift coefficient is increased with an increase in the effective windward area of the Gurney flap, which is accompanied by a small reduction of the stall angle. The maximum lift coefficient can be increased by a Gurney flap, where a flap of 4.8 mm high may result in a 16.8% increase in the maximum lift coefficient.

Let us suppose that this aircraft takes off and lands at a 10 deg angle of attack. In this case, a Gurney flap of 4.8 mm high has a maximum increase of lift coefficient of 60%. Therefore, a Gurney flap can improve the takeoff and landing performance of the aircraft significantly, which can help reduce the airport building cost.

### B. Effects of the Gurney Flap's Height on Drag

The drag coefficients vs angle of attack with and without a Gurney flap are shown in Fig. 2b. Obviously, the drag coefficient of the




a) Lift coefficient

b) Drag coefficient

c) Lift-to-drag ratio

d) Pitching moment

**Fig. 2 Effects of flat plate Gurney flaps on the aerodynamics of the forward-swept model (sweep angle = 15 deg).**

model is minimal without a Gurney flap. When the lift coefficient increases with the Gurney flap's height, the drag coefficient increases as well. The effect of the flap height on drag is similar to that on lift, that is, the higher the Gurney flap, the more drag increases.

A Gurney flap enhances the lift coefficient of a forward-swept aircraft model with a drag penalty, which is similar to the case of airfoils and wings [8,9]. This result is inevitable because a Gurney flap causes a loss of momentum. As pointed out by Giguere, Dumas, and Lemay [4], however, a Gurney flap can enhance the lift coefficient without substantially increasing the drag coefficient as long as it remains within the boundary layer.

### C. Effects of the Gurney Flap's Height on Lift-to-Drag Ratio

From the aforementioned discussion, it can be seen that a Gurney flap may increase the lift coefficient with an increase in the drag coefficient. However, an enhancement of the lift-to-drag ratio by a Gurney flap is possible at a small angle of attack, because the associated increase in the drag coefficient is relatively small. Figure 2c shows the effect of Gurney flaps on the lift-to-drag ratio at different flap heights, which indicates that the Gurney flap increases the lift-to-drag ratio of an aircraft model for $a < 28$ deg. Increments in the lift-to-drag ratio are evident when $a < 10$ deg. At $a = 6$ deg the model has a maximum lift-to-drag ratio irrespective of the flap height, which occurs at an angle of attack that is less than that without a Gurney flap by 2 deg. When $a > 28$ deg, lift-to-drag ratios are almost the same in all cases. In the present experiment, the largest increment of the maximum lift-to-drag ratio is 24.1%, which is obtained when the Gurney flap is 4.8 mm high.

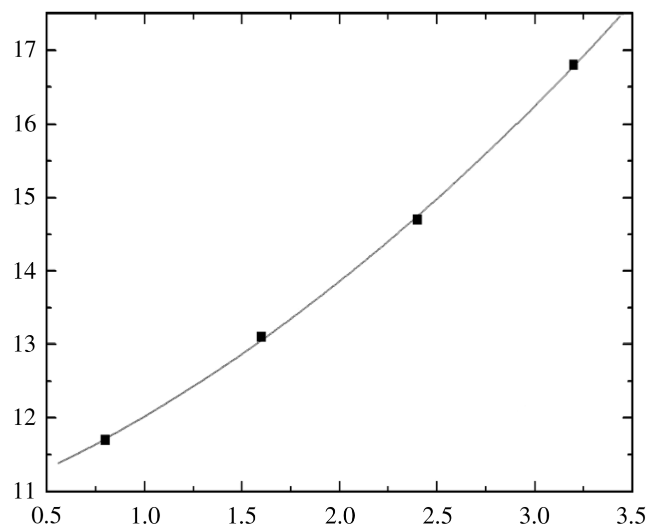



**Fig. 3 Relationship of the largest increase of the maximum lift coefficient and the ratio of the Gurney flap area to the forward-swept wing area.**

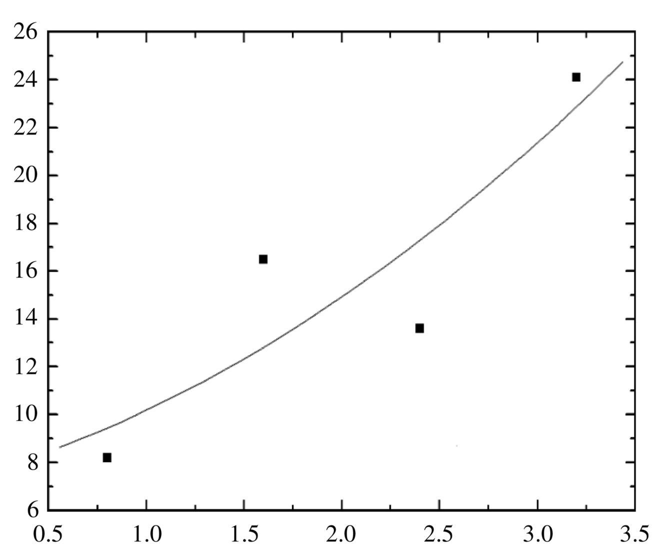



**Fig. 4 Relationship of the largest increase of lift-to-drag ratio and the ratio of the Gurney flap area to the forward-swept wing area.**

It can be clearly seen from Fig. 3 that the largest increment of the maximum lift coefficient by a Gurney flap increases with the ratio of the windward area to the main wing surface area. The largest increment of the maximum lift-to-drag ratio increases with the windward area of the Gurney flap as shown in Fig. 4. It is important to be aware that this result is different from that for airfoils and wings [5,6,10–12]. A number of researches indicated that a Gurney flap cannot increase the lift-to-drag ratio for airfoils and wings at low speed. This discrepancy can be explained as follows: in the present experiment, the drag of the main wing is a small portion of the total drag of an aircraft model, therefore the drag increase of the main wing due to a Gurney flap does not contribute much to the total drag increase. In other words, the increase in drag due to a Gurney flap is relatively a small proportion of the total drag of the model. On the other hand, the main wing contributes much to the total lift of the model, and therefore the total lift of the model is greatly increased by a Gurney flap. Therefore, our experimental result provides a promising future for the Gurney flap in aircraft applications.

### D. Effects of the Gurney Flap's Height on a Pitching Moment

Figure 2d shows the effect of the Gurney flap's height on the pitching moment of a simplified forward-swept aircraft model. It can be seen from this figure that the nose-down pitching moment increases with the Gurney flap's height, which is in accordance with the results obtained in low-speed and high-speed airfoil experiments [7,9].

## IV. Conclusions

Force measurements of a simplified forward-swept aircraft model were conducted in a low-speed wind tunnel to investigate the aerodynamic efficiency of the Gurney flap. It is concluded that all the rectangular Gurney flaps tested in the experiment can improve the aerodynamic performance of the model. Both the lift coefficient and the lift-to-drag ratio increased with the height of a Gurney flap. The largest increments of the maximum lift coefficient and that of the maximum lift-to-drag ratio are 16.8 and 24.1%, respectively. It was also found that if the angle of attack is 10 deg, a typical aircraft takeoff and landing angle, a 4.8 mm high Gurney flap can increase the lift coefficient by up to 60%. It is hoped that these results can help shorten the takeoff and landing distance of aircraft and reduce the airport construction cost.

## Acknowledgment

This project 10425207 is supported by the National Natural Science Foundation of China (NSFC).

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