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Engineering Notes

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Exploratory Investigation of Geometry Effects on Gurney Flap Performance

Lance W. Traub*
Embry-Riddle Aeronautical University, Prescott, Arizona 86301-3720
and
Gaurav Agarwal†
Texas A&M University, College Station, Texas 77843-3141

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Introduction

THE simplicity and ease of application of Gurney flaps has resulted in numerous studies to characterize their performance [1–3]. The flap itself is typically a small-scale modification consisting of a thin plate that is attached to the airfoil trailing edge on the pressure side. Its vertical height is configured to remain within the boundary layer; height to chord ratios are usually less then 1.5%. The effects of the flap are analogous to a conventional trailing edge device, that is, the angle of attack (AOA) for zero lift is shifted in the negative direction with a concomitant negative increase in the zero lift pitching moment coefficient.

In essence the flap works by violating the Kutta condition; loading is carried to the trailing edge such that the upper and lower surface pressure distributions are effectively displaced farther apart. These effects may be interpreted as equivalent to lengthening the airfoil and increasing flow turning (aft camber) near the trailing edge. In most studies [4,5] the flap increases the profile's minimum drag coefficient such the sections maximum lift-to-drag ratio (L/D max) is reduced. At higher lift coefficients the Gurney flap equipped profile may show an increase in L/D max compared to the clean wing. Jeffrey et al. [6] showed experimentally the presence of periodic separation in the form of a von Kármán vortex street propagating from the flap. As shown by von Kármán's analysis [7], the drag associated with a vortex street is reduced as the eddy spacing and the velocity of the vortex system diminishes. Recent studies [8,9] have shown a reduction in the drag penalty associated with Gurney addition by introducing irregularities into the Gurney surface consisting of notches, V-shaped cutouts, etc. Although these modifications show a lift reduction compared to a solid Gurney the associated reduction in the minimum drag coefficient yields improved L/D performance. According to Meyer et al. [9] the cutouts have the effect of producing a three-dimensional wake that diminishes the absolute instability, that is, a shedding frequency is no longer clearly discernible (the formation of the vortex street is disrupted).

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*Associate Professor, Aerospace Engineering Department.
†Graduate Student, Aerospace Engineering Department.

Any effective lift modulation device should achieve the maximum lift augmentation with as small a drag penalty as possible. If the flap is to be used for lateral or longitudinal control (the flap may be rotated into position to alter lift), lift should be maximized with respect to the projected height of the flap (as the flap height when deployed is usually fixed). Thus a modification that improves the L/D performance of the flap but reduces its lift increment may be deleterious from a control perspective. Consequently, a study has been undertaken to evaluate two Gurney flap configurations that may show a reduction in the minimum drag penalty with only a small decrement in lift compared to a solid flap. The flaps, shown in Fig. 1, have discontinuous forms, but when viewed in a streamwise direction appear solid. It is suggested that the configurations may generate streamwise vorticity that would serve to disrupt vortex street formation.

Experimental Details

An existing wing, used for flow control studies, was used to evaluate the Gurney flap configurations; see Fig. 1. The wing was rapid prototyped in acrylonitrile-butadiene-styrene (ABS) plastic and featured a NACA 0015 profile. The wing was equipped with end plates to reduce three-dimensional effects. This does not, however, imply that the flow was two dimensional due to the limited extent of the side plates. The Gurney flap designs were a solid flap, "V" wedge and segmented (shown in Fig. 1). All flaps had a height of 3.5 mm yielding a height-to-chord ratio of 1.1%. The flaps were also rapid prototyped in ABS plastic.

Geometric details of the model are a chord of 0.31 m and a span of 0.22 m. The tests were undertaken in Texas A&M University's 3 ft by 4 ft closed loop wind tunnel. A freestream velocity of 20 m/s was used yielding a Reynolds number of 0.42×10^6. Tunnel turbulence intensity has been measured at less than 0.5% assuming isotropic turbulence. Flow angularity for this facility is typically less than 0.25 deg at the test velocity. Data acquisition was facilitated using a 3-component pyramidal balance. Balance output voltages were measured using a 16-bit A/D board. A dedicated software acquisition code has been written for this facility and was used for acquisition and processing. Prior to undertaking the tests the pyramidal balance calibration was checked by applying proof loads, both singly and in combination. The measured loads suggest accuracies better then 0.6% for lift, drag, and pitching moment. All presented moments are referred to the wing's quarter chord. Wind tunnel corrections for solid and wake blockage were applied using the methodology described in [10].

Results and Discussion

Figure 2 shows a repeated data run for the base wing. In this study, the base wing is that with no Gurney flap. Effects of the different Gurney geometries on the measured lift and moment coefficient are presented in Fig. 3. Also included is a prediction for the solid Gurney flap using a relation in [11] that shows close accord with the experimental results. The data show the typical negative angle of attack and pitching moment shift associated with a flow effecter that increases aft camber. All Gurney configurations show an increase in the maximum lift coefficient. The V wedge configuration shows slightly reduced lift compared to the solid Gurney as well as a smaller (less negative) zero lift pitching moment shift. The segmented

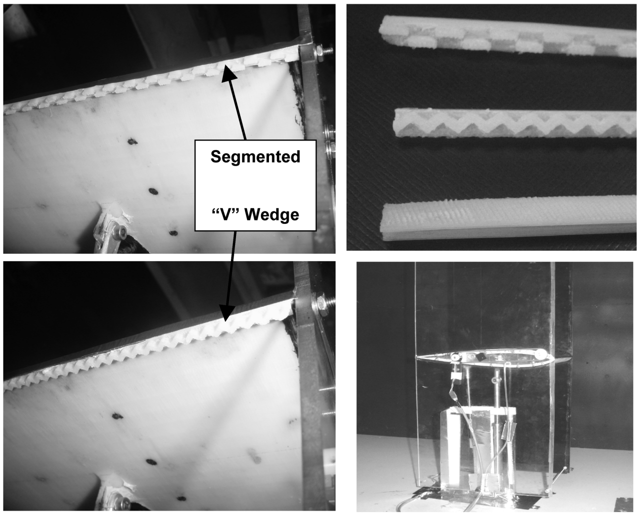

Fig. 1 Wing and Gurney flap details and installation.

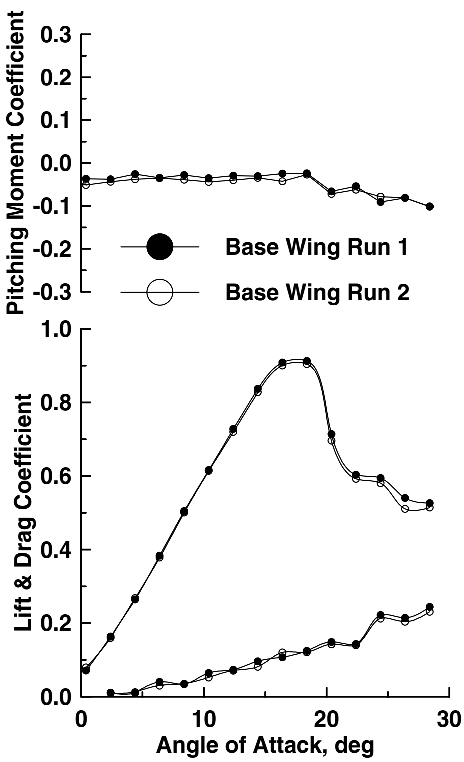

Fig. 2 Repeated data run.

Gurney, which has physical breaks in the flap surface, shows a larger loss of lift compared to the solid Gurney indicating that the porosity effectively reduces the camber effect of the flap. The effect of the flap on the nature of the stall may also be assessed from Fig. 3. The solid Gurney appears to have a more abrupt stall than the base wing, while the modified Gurneys show a more docile stall (with the segmented flap showing a higher angle of attack for maximum lift coefficient). It is also apparent that the segmented flap shows an initial "rounding" of the lift curve at approximately 12 deg, where the other flaps do not. This suggests that the wing equipped with the segmented flap shows gradual trailing edge boundary layer thickening and a slow upstream progression of the separation location, leading to a docile stall. The base suction and lack of Kutta condition enforcement associated with solid Gurney flaps would generally reduce the adversity of the upper surface pressure recovery (as recovery occurs in the wake), leading to a thinner boundary layer and an elimination of the lift curve "rollover" typical of thick aft stalling profiles. This would also

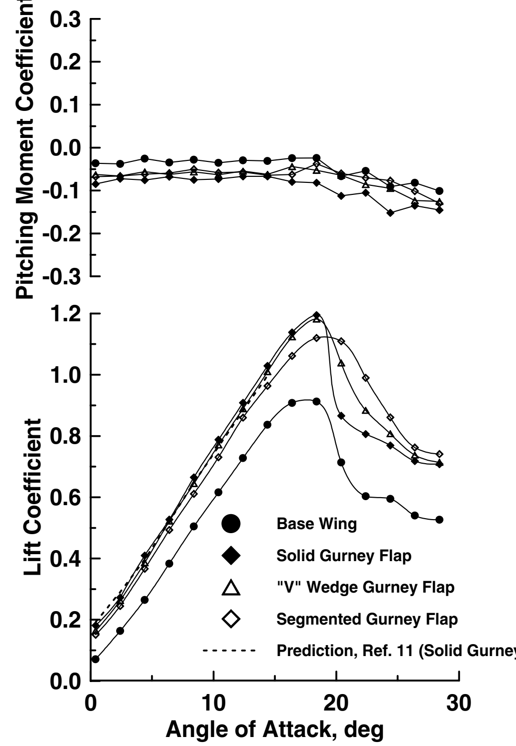

Fig. 3 Effects of Gurney flap configuration on measured lift and pitching moment coefficient.

explain the abrupt stall seen for the solid flap, as trailing edge separation would be a more rapid process.

Figure 4 shows the measured drag coefficient and L/D ratio for the Gurney flap configurations. The segmented Gurney flap shows an increase in L/D compared to the other configurations which is a manifestation of reduced drag, as shown in the upper inset plot. The

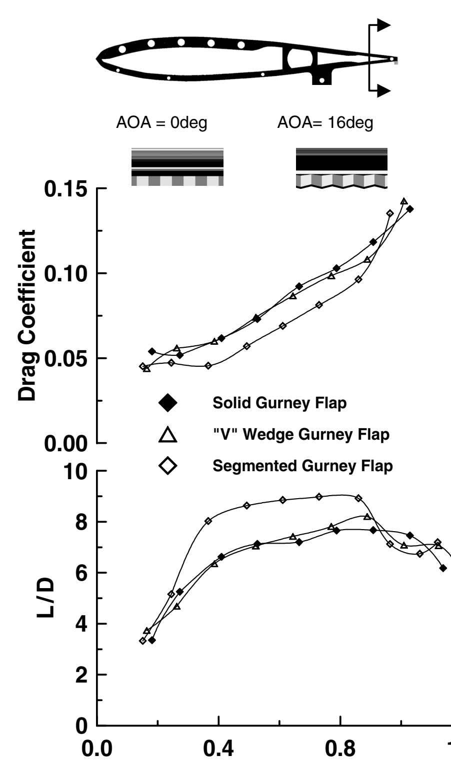

Fig. 4 Effects of Gurney flap configuration on measured L/D ratio and drag coefficient. Upper inset shows downstream view of V wedge Gurney flap at 0 (left) and 16 deg (right) angle of attack.

V wedge Gurney design shows a reduction in drag and increase in L/D compared to the solid flap only at higher loading conditions (lift coefficient > 0.6). The data in Figs. 3 and 4 show that as the AOA increases past approximately 7 deg (lift coefficient of approximately 0.6), the lift and drag of the V wedge flap reduce below the solid flap. A suggested explanation is offered by the inset CAD renderings of the V wedge at incidence shown in Fig. 4. These images are of the flap looking downstream. As may be seen, at 0 deg angle of attack, the V wedge flap appears smooth and continuous. As the angle of attack increases the lower portion of the flap shows an increasing severity serrated pattern. This pattern, that is similar to that tested in other investigations [8], naturally introduces streamwise vorticity.

The V wedge flap configuration was envisaged as a design that would generate a shear layer with streamwise vorticity (from its lower surface) that would promote breakdown of the vortex street. Because of 100% solidity, the flap should also incur only minimal lift degradation compared to a solid Gurney. The experimental results indicate that while this configuration does show only marginal lift loss compared to the solid flap, drag is not reduced significantly either, and only at higher load conditions. The segmented flap shows both lift and drag reduction, analogous to that seen in other investigations.

Conclusions

A low-speed wind tunnel investigation was undertaken to explore the effects of three Gurney flap configurations on measured lift, drag, and pitching moment coefficient. Flaps designed to reduce drag with minimal loss of lift were tested. Comparisons were made with respect to a solid Gurney flap. All the tested flaps appear solid when viewed in the streamwise direction but have an alternating pattern shape (alternating Vs and discontinuous rectangles—“segmented”) when viewed perpendicularly. The results indicate that the V pattern flap had a small effect on performance, whereas the segmented pattern reduced both lift and drag leading to an increase in lift-to-drag ratio.

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