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Engineering Notes

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Preliminary Parametric Study of Gurney-Flap Dependencies

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Introduction

THE Gurney flap[1,2] is typically a small plate, which is attached at or near the trailing edge of an airfoil on the pressure side. The flap has been shown to be a highly effective small-scale (typically 0.5–1.5% of the chord) modification that can achieve significant lift and pitching-moment generation.[1,2] The Gurney functions by essentially increasing the downward deflection of the trailing-edge flow, facilitated through the formation of a series of counter-rotating vortices similar to that of a von Kármán vortex street. A subsequent effect is an apparent violation of the trailing-edge Kutta condition; experimental data show that finite loading is carried to the trailing edge. The Gurney flap increases the effective chord and camber of the airfoil, so by augmenting circulation. Liebeck[3] suggested a flow pattern where a "virtual" cusped trailing edge is formed downstream of the Gurney from the shear layers merging downstream of the flap. The final pressure recovery would then occur off-surface, which is analogous to violation of the Kutta condition.

Experimental and computational studies exploring the effect of Gurney flaps have been undertaken covering effects of flap height,[4] angle,[5] effects on multi-element airfoils,[2] etc. In this Note, the database is increased through evaluation of the effects of flap porosity, inclination, and spacing from the surface. It would also be useful for experimental design and conceptual understanding to have correlations that relate Gurney-flap geometric parameters to performance. Consequently, such correlations are developed.

Experimental Details

The wing model had a rectangular planform and a NACA 0015 profile. The wing used endplates to reduce three-dimensional effects. The span between the plates was 0.26 m with a chord c of 0.425 m. Trip strips were located at 5% of the chord on both the upper and lower leading-edge surfaces. The leading edge and aft section of the wing were rapid prototyped from acrylonitrile butadiene styrene plastic. The wing was used in prior tests of trailing-edge circulation control and consequently had a blunt trailing edge.

Tests were undertaken at a freestream velocity of 20 m/s, yielding a Reynolds number of 0.57×10^6. The experiments were undertaken in Texas A&M University's 3 by 4 ft closed-loop wind tunnel. The freestream velocity was measured using a FlowKinetics™ LLC FKT 1DP1A-SV flow analysis system. This instrument calculates the air velocity using a pitot static tube (differential pressure measurement); however, the instrument also directly measures atmospheric pressure, temperature, and relative humidity (using a detachable probe) and uses these measurements to calculate air density including effects of water vapor. Thus, the calculated velocity needs no corrections for atmospheric effects. The 1DP1A-SV's real-time standard deviation function was also used to estimate the temporal fluctuation in the freestream velocity. The data indicated an uncertainty interval of ± 0.12 m/s (within a 99.7% probability) at the test freestream velocity. The instrument can also be configured as part of an acquisition system and be read directly into a PC using a serial port connection. Velocity error is less then 0.8%.

Tunnel turbulence intensity has been measured (using a hot-wire anemometer system) at less then 0.5% assuming isotropic turbulence. Data acquisition was facilitated using a three-component Pyramidal balance. Conditioned and amplified balance output voltages were read 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 use for these experiments, the Pyramidal balance was recalibrated. Subsequent balance verification through application of pure and combined loads suggests errors less than 0.6% for lift, drag, and pitching moment. Wind-tunnel corrections for solid and wake blockage were applied using the methodology described in Ref. 6.

Results

Preliminary data are presented covering the effect of Gurney-flap height, inclination angle, porosity, and distance (gap) from the surface. If no indication of inclination angle is given, then the flap was set perpendicular to the surface. Figure 1 presents a multi-element data summary for variation of Gurney-flap height h, porosity, and inclination β. The porosity was 22% based on open to closed space. The inclined flap was set at $\beta = 45$ deg. As the length of the flap h was constant for a given h/c, the inclined flap's projected height was 71% of the uninclined flap. The data show that the lift coefficient increases with flap height and decreases with flap inclination and porosity. Similar effects are observed for moment augmentation (see middle inset figure). The data of Li et al.[5] also indicated a systematic lift coefficient reduction with Gurney-flap inclination (evaluated angles were 45, 60, and 90 deg). Gai and Palfrey[7] evaluated the effects of a solid and triangularly serrated Gurney flap on a NACA 0012 profile. The flap was set perpendicular to the surface. Their data show that lift augmentation was lessened with the serrated flap compared to the solid; however, analysis was not presented showing if there was any correlation of the percentage of area removed (compared to the solid flap) to reduced lift augmentation.

It would be reasonable that a functional relationship expressing the dependency of the Gurney flap on key geometric parameters (e.g., height, porosity, inclination) should reduce Gurney-flap data to a constant (within the experimental uncertainty) for a particular angle of attack. A relationship describing these dependencies was found empirically to be of the form

$$\mathrm{SLAR} = (C_{\mathrm{LGurney}} - C_{\mathrm{LBasic}}) \Bigg/ \left[\frac{h}{c} \times \cos(\beta) \times \left(1 - \frac{\%\mathrm{porosity}}{100\%}\right)\right] \tag{1}$$

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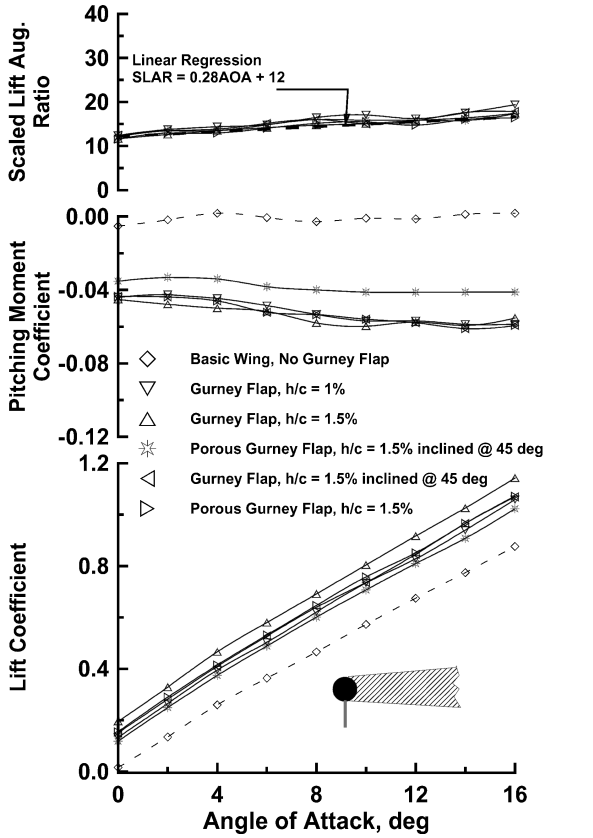

Fig. 1 Effect of Gurney-flap geometric parameters on measured aerodynamic coefficients.

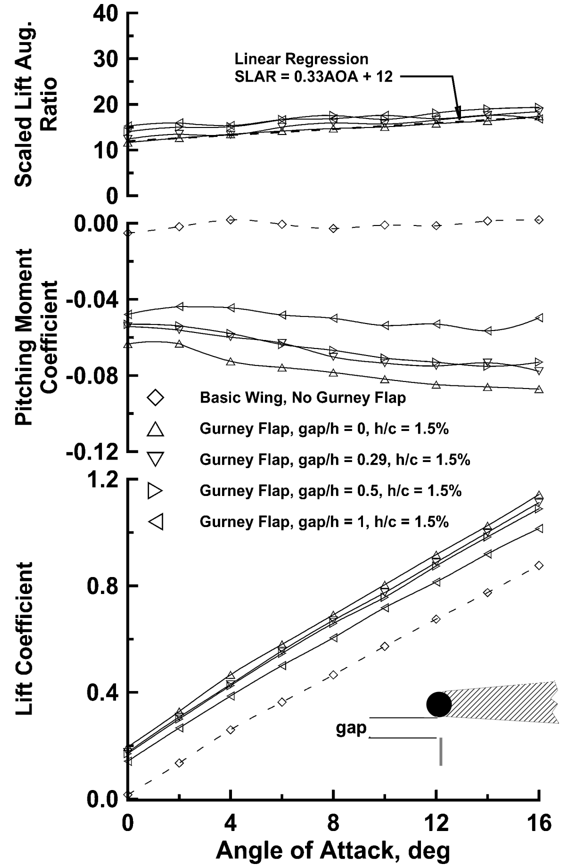

Fig. 2 Effect of Gurney-flap gap on measured aerodynamic coefficients.

where SLAR is the scaled lift augmentation ratio. The relationship expressed in Eq. (1) is presented in the top element of Fig. 1. The data clearly show significant collapse, supporting the form of Eq. (1). Note that validation of the functional form of Eq. (1) is preliminary due to the limited size of the data set. It is surprising that porosity should scale linearly, considering the mechanism of lift augmentation by a Gurney flap. Within the Gurney height range, lift variation with this parameter h is linear. Lift augmentation also appears to scale linearly with the projected height of the flap normal to the pressure surface.

Figure 2 shows the effect of a gap between the flap and the pressure surface. It is interesting that up until gap/$h = 0.5$, the presence of the gap appears to have only a small effect on the measured lift coefficient. This might be because the gap exceeds the boundary-layer thickness (for gap/$h = 1$), thus altering the shedding mechanism from the trailing edge. Although the collapse is not as satisfactory as that of Eq. (1), see top insert in Fig. 2, an empirical SLAR for gap was found of the form:

$$\mathrm{SLAR}(\alpha) = \left\{ (C_{\mathrm{LGurney}} - C_{\mathrm{LBasic}}) \Big/ \left[\frac{h}{c} \times \cos(\beta) \times \left(1 - \frac{\%\mathrm{porosity}}{100\%}\right)\right]\right\} \left(1 + \frac{\mathrm{gap}}{h \times \cos(\beta)}\right) \tag{2}$$

Figures 1 and 2 do suggest a moderate angle-of-attack dependency of the SLAR; hence, the inclusion of a function SLAR(α), reflecting the dependency. Thus, the lift coefficient dependency (for the evaluated geometric parameters) of the Gurney flap can be expressed as

$$C_{\mathrm{LGurney}} = \left[\mathrm{SLAR}(\alpha) \times \frac{h}{c} \times \cos(\beta) \times \left(1 - \frac{\%\mathrm{porosity}}{100\%}\right)\right] \Big/ \left(1 + \frac{\mathrm{gap}}{h \times \cos(\beta)}\right) + C_{\mathrm{LBasic}} \tag{3}$$

The results in Figs. 1 and 2 show that although the SLAR does appear to have a dependency on angle of attack it appears to be consistent for all of the data sets. Regression analysis yields for the data in Figs. 1 and 2 respectively:

$$\mathrm{SLAR}(\alpha) = 0.28\alpha + 12 \text{ (data from Fig. 1, } \alpha \text{ in deg)} \tag{4}$$

$$\mathrm{SLAR}(\alpha) = 0.33\alpha + 12 \text{ (data from Fig. 2, } \alpha \text{ in deg)} \tag{5}$$

Using Eqs. (4) or (5) in conjunction with Eq. (3) allows estimation of the effects of a Gurney flap including angle-of-attack dependency. Note that Eqs. (4) and (5) should be used cautiously as their dependence on Reynolds number is uncertain.

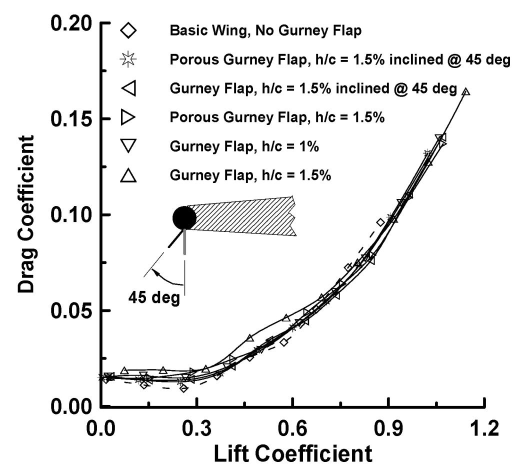

Fig. 3 Effect of Gurney-flap geometric parameters on the measured drag coefficient.

Effects of Gurney-flap height, inclination, and porosity on the measured drag coefficient are presented in Fig. 3. As seen in other studies, lift augmentation of the Gurney coupled with its moderate

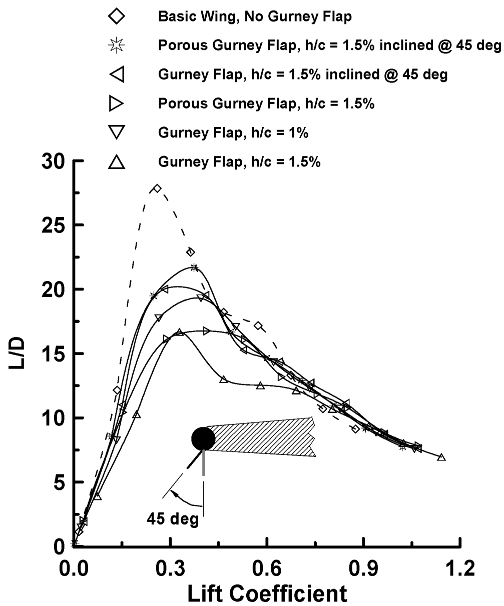

Fig. 4 Effect of Gurney-flap geometric parameters on the measured L/D ratio.

zero-lift drag penalty result in lower drag than the clean profile at higher lift coefficients. However, the zero-lift drag penalty of the Gurney flap does attenuate performance compared to the clean configuration at low lift coefficients. This characteristic is clarified in Fig. 4, where lift/drag (L/D) is presented as a function of lift coefficient. Li et al.,[5] recorded similar results. Note that the solid flap inclined at 45 deg records higher L/D values than the uninclined flap due to the larger zero-lift drag penalty. An interesting result is also in evidence when comparing the efficiency of the 1.5% inclined flap at 45 deg to the 1% Gurney flap (uninclined). These two flap geometries have similar projected heights perpendicular to the surface and similar lifting performance (see Fig. 1). However, as shown in Fig. 4, the inclined flap configuration records higher L/D values. Figure 3 shows that this behavior is caused by the lessened drag penalty associated with inclining the flap (even though the projected height is the same). The preliminary data suggest that performance of a Gurney flap can be increased through flap inclination, as lift augmentation scales with projected flap height, but the zero-lift drag penalty reduces for a given projected flap height as the flap is inclined.

Conclusions

A preliminary wind-tunnel investigation was undertaken to examine the dependence of a Gurney flap on various geometric descriptive parameters such as height, inclination angle, porosity, and gap. Through correlation parameters, the data suggest that the lift augmentation of a Gurney flap varies linearly with flap height, porosity, and the projected height of the flap normal to the surface. The data also suggest that although lift augmentation scales with projected flap height, the zero-lift drag penalty can be lessened through inclining the flap for a given projected flap height. The small data set analyzed necessitates an expanded study to validate the dependencies indicated.

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References

[1] Jeffrey, D., Zhang, X., and Hurst, D. W., "Aerodynamics of Gurney Flaps on a Single-Element High-Lift Wing," *Journal of Aircraft*, Vol. 37, No. 2, 2000, pp. 295–301.

[2] Papadakis, M., Myose, R. Y., Heron, I., and Johnson, B. L., "An Experimental Investigation of Gurney Flaps on a GA(W)-2 Airfoil with 25% Slotted Flap," AIAA Paper 96-2437, 1996.

[3] Liebeck, R. H., "Design of Subsonic Airfoils for High Lift," *Journal of Aircraft*, Vol. 15, No. 9, 1978, pp. 547–561.

[4] Bloy, A. W., and Durrant, M. T., "Aerodynamic Characteristics of an Aerofoil with Small Trailing Edge Flaps," *Wind Engineering*, Vol. 19, No. 3, 1995, pp. 167–172.

[5] Li, Y., Wang, J., and Zhang, P., "Influences of Mounting Angles and Locations on the Effects of Gurney Flaps," *Journal of Aircraft*, Vol. 40, No. 3, 2003, pp. 494–498.

[6] Rae, W., and Pope, A., *Low-Speed Wind Tunnel Testing*, Wiley, New York, 1984, pp. 344–401.

[7] Gai, S. L., and Palfrey, R., "Influences of Trailing-Edge Flow Control on Airfoil Performance," *Journal of Aircraft*, Vol. 40, No. 2, 2003, pp. 332–337.