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Technical Notes

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Novel Aerodynamic Device for Wake Vortex Alleviation

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Nomenclature

AR	=	wing aspect ratio $(2a/c)$
a	=	wing half-span
a_{down}	=	spanwise length of lap
C_{l_0}	=	section lift coefficient at root
c	=	wind chord length
U_∞	=	freestream velocity
X, Y, Z	=	steamwise, spanwise, lift coordiantes in tunnel
X', Y', Z'	=	steamwise, spanwise, lift coordinates along airfoil
Y_{flap}	=	spanwise location of centroid of flap

I. Introduction

THE wake vortex hazard problem continues to be a limiting factor for increasing airport capacity. The strong and persistent wake vortices generated by aircraft during takeoff and landing can pose a serious threat to following aircraft, thus, airports are forced to adhere to strict spacing rules that severely limit the frequency with which aircraft can use their runways. Numerous attempts have been made to solve this problem, but unfortunately, no clear solution that is both practical and implementable has been found.

Aerodynamic solutions have been attempted using various devices intended to weaken or destroy the wakes of large aircraft within a relatively short amount of time. Many passive devices such as spoilers, splines, triangular flaps, and tail wings have been attempted [1–3]. Some passive techniques have been successful at weakening the wake or making the vortices more diffuse, however, none have been found that can lead to cancellation of vorticity of opposite sign, and thus, a benign wake. Active techniques that aim to excite wake instabilities that do lead to such cancellation have also been attempted. Such techniques must conserve total lift in order to be practical. Most recently, the idea of periodically oscillating the conventional flaps and ailerons to create wake perturbations that lead to instability was attempted [4]. Although the feasibility of this technique was demonstrated, relying on the ailerons for wake alleviation during takeoff and landing may significantly complicate the aircraft controls and create mechanical fatigue problems, thus, the level of practicality of this idea is unclear. In [5], the idea of using synthetic jets for separation control along the span of the wing was examined. Although significant vortex perturbations that could probably lead to instability were achieved, this technique relied upon manipulating unstable aspects of the flow, thus it may not be generally applicable.

The experiments and computations presented in [6,7] have demonstrated the feasibility of using the partial-span Gurney flap concept to perturb vortices in a way that would excite vortex instabilities and conserve lift. That study was conducted using an array of miniature trailing edge effectors (MiTEs) all along the span of a half-span model wing. A schematic of a MiTE is shown in Fig. 1. The flap pivots about a spanwise axis and the airfoil has a blunt trailing edge to accommodate it. This actuator geometry was chosen for research purposes and proof of concept, not for a practical aircraft, thus, particular characteristics of the wing and MiTEs, such as the blunt trailing edge and large number of moving parts, would not be desirable on actual aircraft. It was established in [6], however, that to significantly perturb the vortex, only 13% of the span needed to be actuated at any given time. Also, the actuated span was needed only near the tip of the wing where the loading distribution had the steepest slope. This was a rather limited task that would not require a full array of MiTEs along the entire wing and could be accomplished using a much simpler device: the spanwise actuating Gurney flap.

In this work, we examine the potential for using a spanwise actuating Gurney flap for active wake alleviation. We designed this device specifically for wake alleviation, and it is unique in that the control surface moves in the spanwise direction. One solid partial-span Gurney flap is mounted in a slot oriented in the spanwise direction on the pressure side of the wing to achieve an actuation scheme very similar to the most effective MiTE schemes from [7]. To maintain a sharp trailing edge, the slot is located upstream of the trailing edge. The flap can move inboard and outboard in the slot along the wing as required.

The question we address is whether or not this device can achieve the same types of perturbations as the MiTEs. Experiments are conducted on a prototype spanwise actuating Gurney flap to determine its effect on the vortex strength and vortex center location in the intermediate wake of a half-span model wing. The design, fabrication, and testing of this prototype are described in this Note.

II. Experimental Apparatus

A. Spanwise Actuating Gurney Flap Prototype

The prototype spanwise actuating Gurney flap is designed to fit onto an existing NACA 0012 wing with a chord length of 277 mm and a blunt trailing edge. Details regarding this wing are given in [6]. It has a half-span, $a = 619$ mm, and is equipped with a new trailing edge giving it a chord length, $c = 313$ mm, and thus, an aspect ratio, $AR = 4.0$. A row of pressure taps near the root at $Y/a = 0.081$ is used for measuring the root section lift coefficient C_{l_0}. The new trailing edge is equipped with a spanwise actuating Gurney flap approximately 32 mm ($10.2\%c$) upstream of the sharp trailing edge as shown in Fig. 1. The flap is 80 mm ($0.13a$) long in the spanwise direction and protrudes down 5.2 mm ($1.7\%c$) perpendicular to the flow. Regardless of spanwise location, the flap is always in the down position. No method for retracting or deploying the flap was considered.

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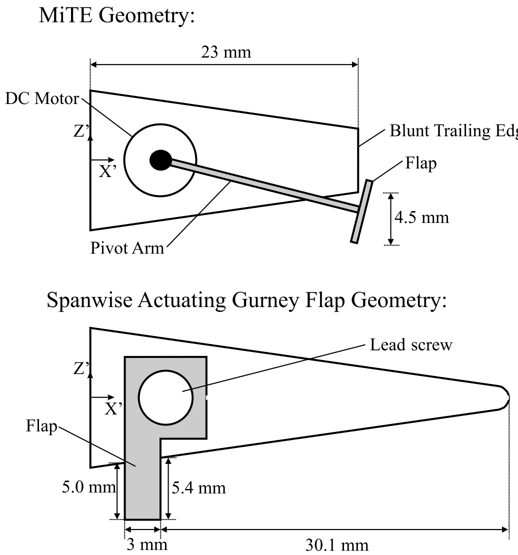

Fig. 1 A schematic of the MiTE and spanwise actuating Gurney flap geometries.

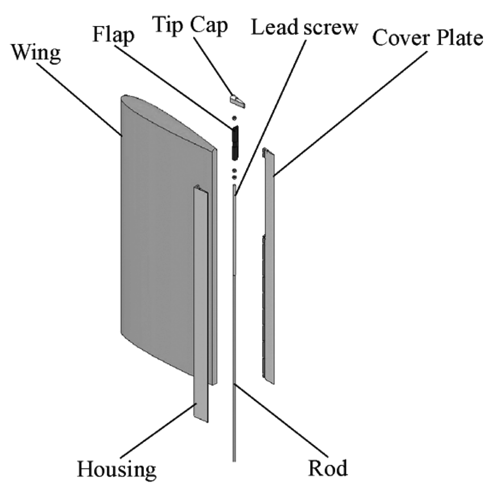

Fig. 2 An exploded CAD rendering of the wing and spanwise actuating Gurney flap.

The trailing edge assembly is composed of five major components: flap, lead screw, housing, cover plate, and tip cap. An exploded rendering of the assembly illustrating each of these components is shown in Fig. 2. The flap is machined from a block of polytetrafluoroethylene (PTFE)-filled Delrin which was chosen to minimize friction and provide high resistance to wearing. We use a 3/16 in. OD (outside diameter) multiple-start high pitch angle steel lead screw to move the flap in the spanwise direction 0.37 in. per revolution. The lead screw is mated to a smooth steel rod which extends inboard through the root of the wing, then outside of the tunnel. Only static tests are conducted, so the flap location is controlled by manually turning the rod.

The flap and lead screw are contained by the housing, cover plate, and tip cap. The housing is connected directly to the trailing edge using small bolts spaced evenly about the span of the wing. Each bolt screws into threaded inserts embedded in the wing. A slot 204 mm long in the spanwise direction is machined through the cover plate to allow the flap to protrude on the pressure side of the wing and actuate. A cover plate connects to the housing with small bolts distributed across the span to secure the flap and lead screw. Finally, the tip cap screws into the housing and cover plate at the tip of the wing. All holes are recessed and filled in with clay to maintain a smooth surface. Figure 3 shows a picture of the wing and spanwise actuating Gurney flap after final assembly mounted in the wind tunnel.

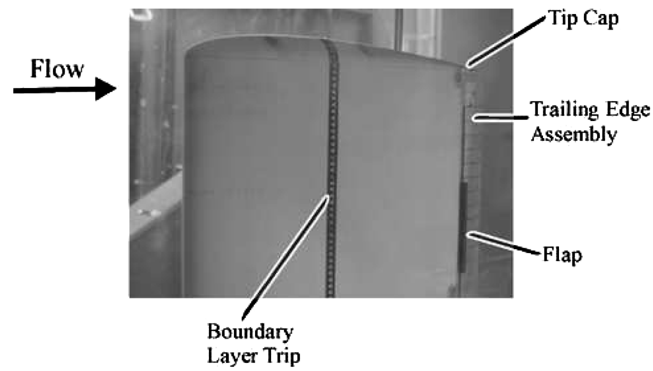

Fig. 3 The wing and spanwise actuating Gurney flap assembled and mounted in the wind tunnel.

B. Measurement Apparatus

The model is placed in the Stanford flow control wind tunnel, a low speed, closed-loop wind tunnel with a maximum velocity of 22 $\mathrm{m/s}$, excellent flow uniformity, and turbulence intensities less than 0.5%. The test section is 91 cm high, 61 cm wide, and 3.7 m long. We mount the wing directly onto the bottom wall of the tunnel.

A pressure profile near the root of the wing is used to determine the root section lift coefficient, and thus, the vortex strength. We use particle image velocimetry (PIV) to make measurements of the tangential velocities in the vortex and to locate the (Y, Z) coordinates of the vortex center at 4.66 chord lengths behind the trailing edge of the wing. The details of these measurement systems were given in [6]. The uncertainties in C_p and C_{l_0} are ± 0.01 and ± 0.005, respectively, and the uncertainty in the vortex center location is ± 0.3 mm. All of these uncertainties are verified with repeatability tests.

III. Results and Discussion

The key variable in this study is the location of the flap along the span of the wing quantified by the parameter Y_{flap}, which is the geometric centroid of the flap in the spanwise direction. We vary this parameter by turning the lead screw to move the flap to the desired spanwise location. Doing so is analogous to actuating different sets of MiTEs along the span of the wing, which was how Y_{flap} was varied in [6]. With the current prototype, Y_{flap}/a can be varied continuously from 0.654 to 0.854.

A. Wing Aerodynamic Effects

We measure the root section lift coefficient to determine how much the spanwise actuating Gurney flap affects the strength of the trailing vortex. A pressure profile at $Y/a = 0.081$ is measured for the minimum and maximum Y_{flap}/a values (0.654 and 0.854). The profile for $Y_{\mathrm{flap}}/a = 0.654$ is shown in Fig. 4. Between the minimum and maximum values, the section lift coefficient varies from 0.749 to 0.740. Thus, the change in C_{l_0} due to moving the flap across its entire range is indistinguishable from the uncertainty in the measurement. Because the vortex strength is directly related to C_{l_0}, this confirms that this device does little to change the strength of the vortex. This is expected because the flap is always far from the root and the spanwise influence of Gurney flap-type devices tends to be small [8].

B. Intermediate Wake Effects

Static PIV experiments are conducted in the intermediate wake at $X/c = 4.66$. We vary Y_{flap}/a across its entire range from 0.654 to 0.854 in increments of 0.020. The mean vortex center location from 500 PIV samples at each flap position is shown in Fig. 5. Vortex centers are located by finding the point of minimum tangential velocity. In general, the highest values of Y_{flap}/a move the vortex

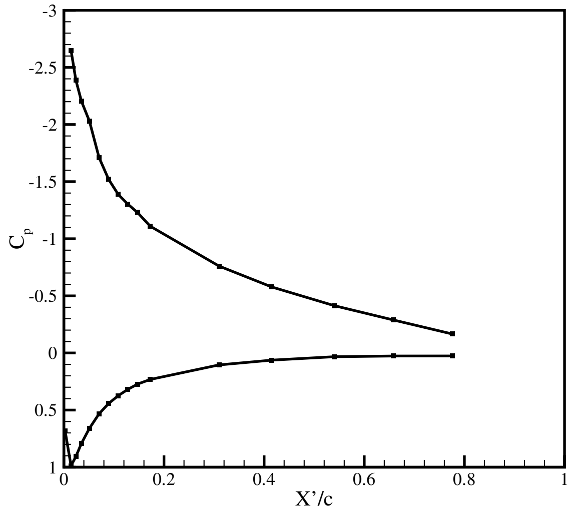

Fig. 4 The root streamwise pressure profile for the wing equipped with a spanwise actuating Gurney flap set to $Y_{\mathrm{flap}}/a = 0.654$. The uncertainty is smaller than the symbol size.

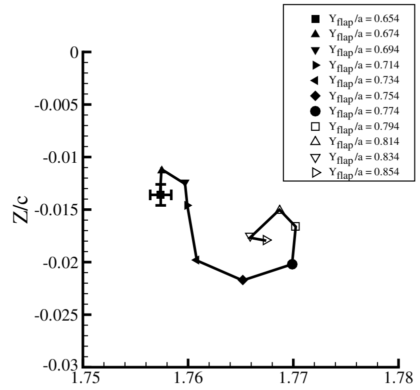

Fig. 5 Mean vortex center locations for different Y_{flap}/a values at $X/c = 4.9$. The uncertainty in both directions for all points is shown on one point.

outboard while the lowest values move the vortex inboard. At intermediate values, the vortex is displaced in the lift direction as well. Maximum displacement in the spanwise direction is $1.3\% c$, and the maximum displacement in the lift direction is $1.0\% c$. Thus, compared to MiTEs, the effect of this device is similar but smaller. The primary reason for this is likely that the flap is located upstream of the trailing edge, because this is the main difference between the two geometries. Nonetheless, it is clear that the spanwise actuating Gurney flap is capable of displacing the vortex in the manner necessary to excite vortex instability. Also, it is likely that with a larger flap, greater displacements can be achieved.

IV. Conclusions

Previous work conducted on rapidly actuated segmented Gurney flaps for wing tip vortex control has led to the development of a novel aerodynamic device specifically designed for active wake alleviation. The spanwise actuating Gurney flap constitutes a simple, practical, and implementable device capable of perturbing a trailing vortex in a manner that may excite wake instability.

Although dynamic effects were not examined here, results from other Gurney flap-type devices suggest that at the slow actuation speeds that would be necessary to excite long wavelength instabilities, the response will likely be quasi steady. More work will be required to determine the optimal shape and configuration for such a device as well as the best way to implement it on a multi-element high lift wing.

Acknowledgments

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