Aerospace Science and Technology 55 (2016) 57–63

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Short communication

Experimental study on the effects of wing sweep on Gurney flap performance

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ARTICLE INFO

Article history:
Received 2 February 2016
Received in revised form 16 April 2016
Accepted 14 May 2016
Available online 19 May 2016

ABSTRACT

The effect of wing sweep on the aerodynamic characteristics of Gurney flaps is examined. Wind tunnel models incorporating un-tapered 2.1 aspect ratio wings with sweeps of 0, 45 and 60 deg were designed and manufactured. Flap heights of 1% and 3% of the chord were evaluated. Testing was undertaken at Reynold's numbers of 100,000 and 150,000. The overarching result was that sweep attenuates the lift modulating ability of the flap, resulting from the effects of spanwise flow and reduced base suction behind the flap. Aerodynamic parameters were found to show a strong dependence on the cosine of the leading edge sweep angle as well as the square root of the flap height.

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1. Introduction

The benefits of wing sweep are commonly associated with flight in the compressible regime as documented in the literature [1–8]. Sweep can delay the onset of drag divergence [1,2] and reduce wave drag [1,2]. As shown by Busemann [3], when considering an infinite swept wing, the impact of sweep on loading is associated with the wing leading edge normal velocity component. This velocity component is primarily responsible for the pressure distribution over the wing and is less than the freestream velocity. On swept wings, the airfoil profile is commonly defined with respect to the leading edge normal direction; thus the airfoil's thickness to chord ratio is reduced streamwise. Aft sweep causes a spanwise migration of loading; attenuating it in the wing root region and augmenting it near the tips. Consequently, a boundary layer drift towards the wing tips caused by the spanwise (transverse) pressure gradient [4] yields stall onset occurring in the tip regions. On a swept wing, stagnation does not occur along the attachment line, due to a spanwise velocity component along the line. This causes the streamlines over the swept wing to be curved in planform, initially towards the wing tip, and then bending inboard as the velocity component normal to the leading edge increases. The three dimensionality of the boundary layer over a swept wing is balanced by a pressure gradient that acts perpendicular to the external streamlines in a plane parallel to the surface. Within the boundary layer, the fluid is slowed by viscosity and consequently moves in the direction of this pressure gradient, causing a "cross-flow" [6].

Gurney flaps have received considerable attention in the literature [9–17]. They are simple lift modulation devices that consist (often $<2\%$ of the chord) of a small "L" shaped tab that is usually attached at the trailing edge pressure surface. Outwardly they function similarly to a conventional flap; shifting the zero lift angle of attack negatively, increasing the maximum lift coefficient and negative pitching moment. Their flow physics are however, different. They violate the enforcement of the Kutta condition at the trailing edge, with pressure equalization occurring in the wake. They have been observed to shed a von-Karman vortex street that induces base suction on the flap [16]. This may ease the pressure recovery demands on the upper surface boundary layer. Windward surface pressures may also increase (more positive or less negative) due to flow deceleration approaching the flap. As a result, higher $C_{L\max}$ often occurs without an α_{stall} penalty. The lift curve slope of the airfoil/wing with a Gurney flap is also seen to increase indicating an augmentation of Gurney flap efficiency with angle of attack. This occurs due to windward side boundary layer thinning [17] causing an effective increase in flap length and lessened viscous de-cambering with angle of attack [11]. Traub and Galls [14] examined the effect of leading and trailing edge Gurney flaps on a flat plate 70 deg sweep delta wing. The effect of the flap was similar to that seen on unswept wings; a negative shift in the zero lift angle of attack as well as an increase in the maximum lift coefficient. A later study by Greenwell on slender and non-slender delta wings reported similar results [15].

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http://dx.doi.org/10.1016/j.ast.2016.05.015
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Nomenclature

c	chord	h	height of the flap
C_D	drag coefficient	L	lift
C_L	lift coefficient	Λ	leading edge sweep angle
$C_{L\,\max}$	maximum lift coefficient	α	angle of attack
C_{PB}	base pressure coefficient behind Gurney flap	α_{ZL}	zero lift angle of attack
D	drag	α_{stall}	angle of attack of stall

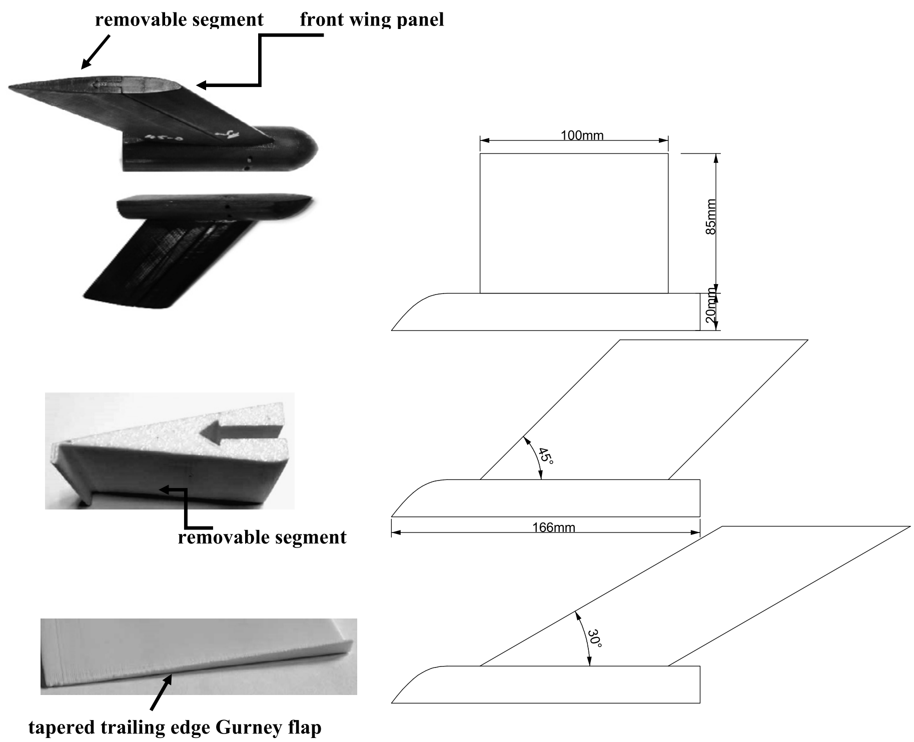

Fig. 1. Wind tunnel model panel details and sketch showing common model dimensions.

While both sweep and Gurney flaps have been studied extensively, little information is available on their combined implementation. In Refs. [9] and [12], Wang et al. describe the effect of forward sweep on Gurney flap effectiveness. Their data indicate a loss of effectiveness with sweep, with the greatest decrement at low angles of attack. This article serves to document a preliminary investigation into the effect of aft sweep on Gurney flap performance for low aspect ratio wings.

2. Equipment and procedure

Wind tunnel tests were conducted in Embry Riddle Aeronautical University's 304.8 mm by 304.8 mm low speed wind tunnel. This facility has a measured turbulence intensity of 0.2% in the velocity range spanning the wind tunnel tests. Velocity uniformity of the jet is better than 99%. Flow angularity across the jet is within 0.1 deg. A six-component JR3 load cell was used to measure the loads. A comparison of measured loads with those applied in calibration has shown accuracy within 0.015 N (corresponding to $\Delta C_L = 0.01$ for the worst case scenario, Re = 100,000). Repeated data measurements indicated an uncertainty interval (for a 99% probability) of 0.0014 and 0.0030 for C_L at low and high angles of attack respectively; values were similar for C_D. The angle-of-attack setting accuracy is within ±0.05 deg. The wind-tunnel models were designed using CATIA®, and then rapid prototyped. The models are of the reflection plane design, where the fuselage was a simple cylinder with a parabolic nose profile, see Fig. 1. The total length of the body was 166 mm, while the nose section was 29 mm. Wing AR was 2.1 for all configurations. A simple non-tapered wing planform was used. Models with a leading edge sweep of 0, 45 and 60 deg were manufactured. The airfoil profile was that of a S8036 and was defined perpendicular to the leading edge. As a result, the streamwise thickness-to-chord ratio was 16%, 11.3% and 8% for $\Lambda = 0, 45$ and 60 deg respectively. The chord of all models was 100 mm. Tests were undertaken at Re = 100,000 and 150,000. Forces were non-dimensionalized by the wing area (10,500 mm^2) extended to the root chord. Wall corrections were not applied to the data due to the comparative nature of the study.

The Gurney flaps were designed as removable trailing edge segments. Heights of 1% and 3% of the reference chord (100 mm) were used. As aft sweep migrates loading "downstream" or outboard, two flap variations were also examined. The first was a flap with linearly varying height that started at 3% of the chord at the root and diminished to 0% at the tip, see Fig. 1. The notion was to examine the effect of augmenting loading inboard. As a counter-point, a flap was also designed where the flap height increased linearly from 0% at the root to 3% of the chord at the wing tip. When attached, the junction between the segments and the main wing section was sealed with clay and smoothed over.

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