ARTICLE IN PRESS

Chinese Journal of Aeronautics, (2016), **xxx**(xx): xxx–xxx

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Chinese Journal of Aeronautics

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Experimental study of flow field distribution over a generic cranked double delta wing

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Received 21 July 2015; revised 14 September 2015; accepted 25 December 2015

KEYWORDS

Cranked double delta wing;
Flow field;
Hot wire;
Leading edge shape;
Vortical flow

Abstract The flow fields over a generic cranked double delta wing were investigated. Pressure and velocity distributions were obtained using a Pitot tube and a hot wire anemometer. Two different leading edge shapes, namely "sharp" and "round", were applied to the wing. The wing had two sweep angles of 55° and 30°. The experiments were conducted in a closed circuit wind tunnel at velocity 20 m/s and angles of attack of 5°–20° with the step of 5°. The Reynolds number of the model was about 2×10^5 according to the root chord. A dual vortex structure was formed above the wing surface. A pressure drop occurred at the vortex core and the root mean square of the measured velocity increased at the core of the vortices, reflecting the instability of the flow in that region. The magnitude of power spectral density increased strongly in spanwise direction and had the maximum value at the vortex core. By increasing the angle of attack, the pressure drop increased and the vortices became wider; the vortices moved inboard along the wing, and away from the surface; the flow separation was initiated from the outer portion of the wing and developed to its inner part. The vortices of the wing of the sharp leading edge were stronger than those of the round one.

1. Introduction

The interest in flying wings for military and civil application has currently increased. Accordingly, questions on aerodynamics, control and structural efficiency have arisen. Flying wings are of the most efficient configurations, but have some special constraints, compared with the conventional arrangements.[1] Some advantages of this type of configurations are higher lift to drag ratio, lower drag force and weight saving.[2] Flying wings generally use delta or lambda shaped wings; hence, understanding the flow behavior of these types of wings becomes an important aspect. A nonslender wing is defined as one with a leading edge sweep angle less than or equal to 55°.[3] The flow behavior of slender delta wings has been extensively studied, whereas the interest in understanding the flow over nonslender delta wings has increased in the literature.

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Peer review under responsibility of Editorial Committee of CJA.

ELSEVIER **Production and hosting by Elsevier**

http://dx.doi.org/10.1016/j.cja.2016.08.002
1000-9361

Please cite this article in press as: Manshadi MD et al. Experimental study of flow field distribution over a generic cranked double delta wing, *Chin J Aeronaut* (2016), http://dx.doi.org/10.1016/j.cja.2016.08.002

Luckring[4] has described flow structure of a sharp edge slender delta wing. By virtue of the sharp leading edge, primary separation is forced to occur at the leading edge, and for the slender wing, this separation rolls up to form the primary leading edge vortex. The primary vortex induces significant spanwise flow on the wing upper surface, resulting in the negative suction peak. After the primary suction peak, the adverse spanwise pressure gradient induces separation of the spanwise boundary layer flow, resulting in a secondary separation and secondary vortex. The secondary vortex induces suction outboard of the primary vortex suction peak.[4] The primary vortex can have a diameter around 30% of the local semi span.[5] The primary vortex trajectory for a given sweep angle is relatively insensitive to angle of attack (AOA) α, and is essentially proportional to the wing leading edge angle.[5]

The vortical flow structure over a sharp edge nonslender delta wing differs substantially from that over a slender delta wing.[6] Computations of Gordnier and Visbal[7] for a 50° delta wing have shown a broad wake-like flow which is consistent with the experimental measurements. At upstream locations near the apex, the long and thin shear layer that emanates from the leading edge of the delta wing terminates in the formation of the primary vortex. Further downstream, a second vortex, with vorticity of the same sign of the primary vortex, emerges in the separated shear layer, outboard of the primary vortex, creating a dual vortex structure. This second vortex, which is slightly weaker and smaller than the original one, arises from the interaction of the secondary flow with the primary shear layer.

Feizian[8] has performed a flow visualization over a 60° delta wing. The observed vortical flow above the surface is shown in Fig. 1. Dual vortex structure is well identified in the experiment.

Yayla et al.[9] have studied flow structure on a nonslender lambda wing, using particle image velocimetry (PIV) technique. The study showed that increasing the angle of attack amplifies the strength of the vortices, velocity fluctuations near the surface, and turbulent kinetic energy.

Konrath et al.[10] have conducted experiments on a 53° swept lambda wing. The flow field above the wing was investigated by PIV measurements. The results showed the development of three different vortex systems, i.e., an apex vortex, a thickness-caused vortex and a leading edge vortex. A complete or fractional merging between these co-rotating vortices can be observed above the model, which occurs in dependency of the AOA.

It should also be noted that aerodynamic stability and control may be degraded by the presence of multiple interacting vortices, vortex breakdown and large-scale flow separation.[11]

Some aerodynamic investigations on cranked double delta wing layouts have started by the authors of the present work. Accordingly, several wing configurations have been considered. The present work is concentrated on a configuration which is similar to the novel wing planform of the Northrop Grumman X-47B aircraft.

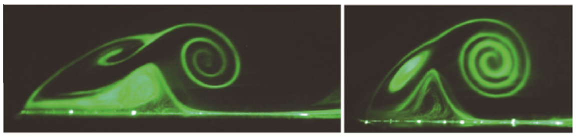
(a) α=12° (b) α=18°

Fig. 1 Formation of the dual vortex structure above a 60° delta wing.[8]

Several wind tunnel experiments have been conducted in a low speed wind tunnel with a model of the aforementioned cranked double delta wing. As the aircraft take-off and landing are performed at low speeds, the present study discusses the behavior of the flow field above the surface at low speeds. The pressure and velocity measurements were performed for two different edge shapes, namely round and sharp, in different cross planes on the upper side of the model. It should also be mentioned that the primary flow structures such as primary vortices and their subsequent breakdown are insensitive to Reynolds number for highly swept lifting surfaces such as delta wings.[5,12] The resulting data have also provided a basis for evaluating the ability of computational fluid dynamics (CFD) methods to predict the characteristics of the cranked double delta wing configuration at low Mach numbers.

2. Experimental setup

Wind tunnel models were two nonslender cranked double delta wings: one wing with a "sharp" leading edge and the other with a "round" leading edge. A planform of the model is shown in Fig. 2. The inner wing has a sweep angle of 55° and the outer 30°. The root chord c and the span of the wing are equal to 150 mm and 244 mm respectively with the thickness ratio of 6.7%. The installed model in the wind tunnel is shown in Fig. 3.

The tests were undertaken in a closed circuit wind tunnel. The dimensions of the test section of the wind tunnel were 30 cm × 40 cm. The flow quality and turbulence intensity across the test section were examined and they were good enough to perform the experiments.[13] The turbulence intensity across the tunnel working section was measured and it was obtained between 0.20% and 0.25%. In all measured cases, a free stream velocity of $V = 20$ m/s was applied, which corresponds to a Reynolds number of $Re = 2 \times 10^5$ based on the root chord of the model. The blockage ratio of the model in the test section at maximum AOA with all the measurement instruments was about 5.1%; hence the wall effects were negligible.[14]

To measure the velocity field over the wing surface, a single normal hot wire probe was used. The diameter of the wire was

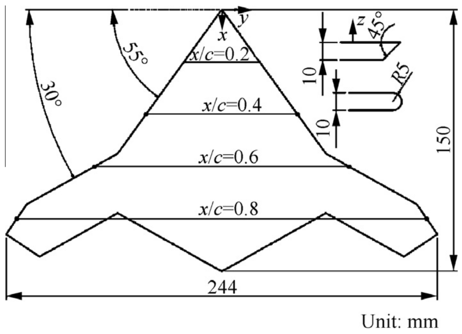

Fig. 2 Planform of model with cross plane locations of measurements.

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