EFFECTS OF WINGLETS ON A LAMINAR AIRFOIL WING

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Summary An experimental study was performed to examine the aerodynamic performances of a rectangular, untwisted laminar airfoil wing with and without winglets. The testing was conducted in a blow-down trisonic wind tunnel by measuring the lift and drag forces acting on the model using a force balance, with the freestream Mach numbers of 0.5 to 0.8 and the Reynolds numbers in the range of $1.3x10^6$ to $2.0x10^6$.

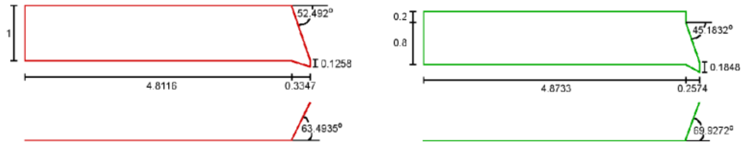
INTRODUCTION

Winglets are usually referred to the vertical extensions of wingtips used for improving aerodynamic efficiency for a range of lift and Mach number conditions by reducing the drag associated with the vortices formed around the wingtips. Over the years, though various wingtip devices have been studied and applied to aeroplanes, the search for novel and more efficient devices is still ongoing [1-5]. In this study, a wind tunnel testing was conducted to evaluate the aerodynamic performances of a baseline rectangular wing and two other configurations with winglets. They were designed by the Computational and Theoretical AeroScience Group (CTAG) in Temasek Laboratories of NUS, based on the vortex-lattice method in conjunction with an evolution algorithm for performing winglet design optimization.

EXPERIMENTAL SETUP

Experiments were conducted in an open circuit, blow-down trisonic wind tunnel in the National University of Singapore (NUS), with a test section of 4 feet by 4 feet. A six component force balance, with accuracy of 0.067% and 0.092% for normal and axial forces respectively, was used to measure the forces and moments acting on the model.
A full-span, sting mounted force model is considered in experiments, including a centre ogive cylinder body (diameter of 76.2mm) to hold the force balance and the wing, a pair of rectangular and untwisted main wing (half wing aspect ratio of 4.7, calculated assuming without the centre body), and wingtip/winglet parts to be connected to the main wing. Three configurations were tested. The parameters considered include the winglet span b_w, winglet dihedral angle φ_w, sweep angle β_w, taper ratio τ_w, and leading-edge indentation d_{LE}.
The first (Baseline) is the extension of the main wing to form a rectangular and untwisted wing with half wing aspect ratio of 5; The second (Winglet 1) has half wing aspect ratio of 5.146 with a main wing (aspect ratio of 4.81) and a winglet without indentation, and the third (Winglet 2) has half wing aspect ratio of 5.131 with a main wing (aspect ratio of 4.873) and a winglet with 20% indentation (Fig. 2). Note that all three configurations have the same projection area as the reference area to calculate the aerodynamic coefficients. All sections use a same laminar airfoil (Fig. 3) developed by the CTAG and the wing has a chord length of 82mm. The tested Mach numbers are M = 0.5, 0.6, 0.7, and 0.8, and the angles of attack range from −5° to 20°. The Reynolds numbers tested are in the range of $1.3x10^6$ to $2.0x10^6$.

Fig. 1 Wing and winglet models



	Baseline	Winglet 1	Winglet 2
Sweep angle β_w		52.5°	45.2°
Taper ratio τ_w		1.0	0.23
Dihedral angle φ_w		63.5°	70.0°
LE indent d_{LE}		0.0	0.2
Wing chord c	1.0	1.0	1.0
Main wing b_m	10	9.62	9.75
Winglet span b		0.75	0.75

Fig. 2 Parameters of wing and winglets

Fig. 3 Airfoil profile

RESULTS AND DISCUSSIONS

The performances of the baseline wing in terms of lift and drag coefficients versus angles of attack for Mach numbers of 0.5 to 0.8 are shown in Fig. 4. It can be seen clearly that the lift coefficients increase as the freestream Mach numbers increase from 0.5 to 0.7, which is consistent with the Prandtl-Glauert rule. However, when the freestream Mach number reaches 0.8, the lift drops and the drag increases rapidly, which is suspected that there is strong shock induced separation.

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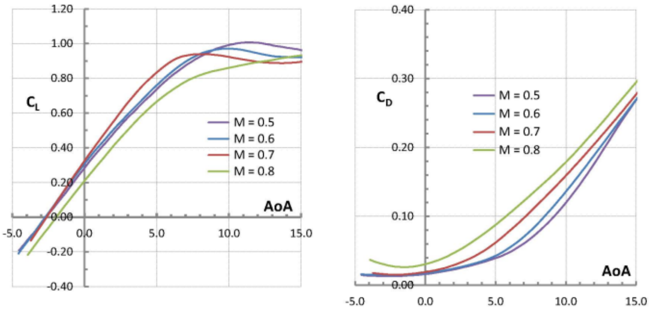

Fig. 4 Lift and drag coefficients for the baseline model.

Figure 5 shows the aerodynamic performances of the three configurations of wing/winglets at M = 0.5. Compared to the Baseline, it can be seen that the lift for both winglet configurations is increased at the same angles of attack, while the drag changes are not obvious. While if we examine the drag polar curve (Fig. 5c), it can be observed that the winglets are to increase C_D at relatively low values of C_L, and to decrease C_D at relatively high values of C_L. This means that the dominant drag component at lower lift conditions (low angles of attack) is viscous drag as the winglets increase the surface area, while the dominant drag component at high lift conditions (high angles of attack) is induced drag where the winglets reduce the induced drag more compared to viscous drag. The overall effects of winglets can be evaluated using the plots of L/D versus C_L as shown in Fig. 5d. It can be seen that there are no obvious changes in lift over drag ratio at low lift conditions (C_L less than 0.3), while the lift over drag ratio is increased for the wing with winglets at high lift conditions. Among all the three configurations, the Winglet 2 has the highest aerodynamic efficiency in terms of lift over drag ratio by about 6% at C_L of 0.5. As the Mach number increases to 0.6, while the aerodynamic behaviour has similar trend compared to that of M = 0.5, the favourable effects of winglets are reduced. As the Mach number further increases to 0.7, the lift coefficients of winglet configurations increases slightly compared to low Mach number cases as shown in Fig. 6. There are also obvious increases in the drag coefficients, giving rise to the poor aerodynamic performances, i.e. smaller lift over drag ratio for the winglet configurations compared to the baseline for most of the lift conditions. The poor performances of winglet configurations at high Mach numbers suggest that the wave drag become more dominant and there are strong interaction between the main wing and winglet part.

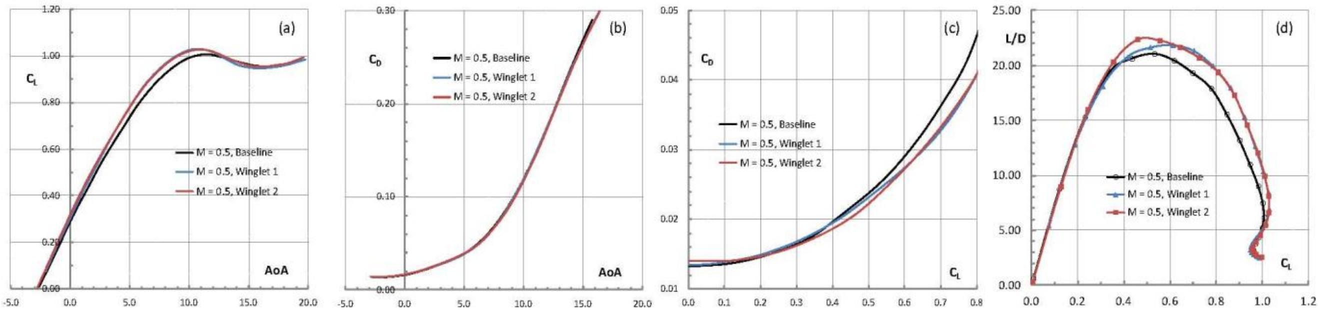

Fig. 5 Aerodynamic performances for the configurations of Baseline, Winglet 1 and Winglet 2 at M = 0.5.

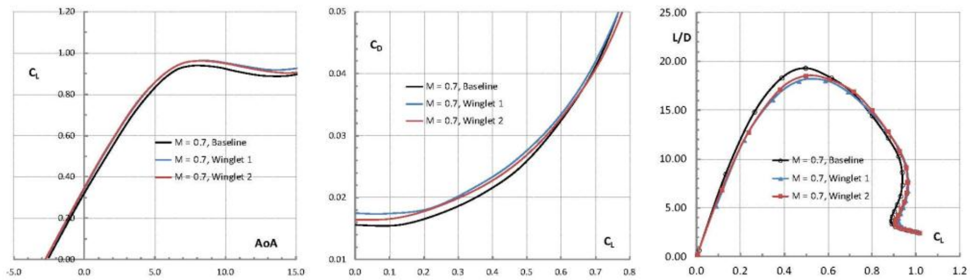

Fig. 6 Lift and drag coefficients for the baseline model.

CONCLUSIONS

The force measurements over the laminar airfoil wing with and without winglets show that at low Mach number, the overall effects of winglets are to increase C_D at relatively low values of C_L, and to decrease C_D at relatively high values of C_L. At low Mach number, the winglets have more favourable effects, i.e., improving the aerodynamic performance of wing. At high Mach number, the performance of wing with winglet is degraded, mainly due to large increases of wave drag and the interaction between the main wing and winglet. The experimental results are also in good accord with the numerical studies.

References

[1] Whitcomb, R. T.: A Design Approach and Selected Wind Tunnel Results at High Subsonic Speeds for Wing-Tip mounted Winglet. NASA TN-D-8260, 1976.

[2] Jones, R., and Lasinski, T.: Minimum Induced Drag of Wings with Winglets. NASA TM-81230, September 1980.

[3] Kroo, I.: Drag due to Lift: Concepts for Prediction and Reduction. *Annual Review of Fluid Mechanics* **33**:587-617, March 2001.

[4] ESDU 98013, Engineering Sciences Data Unit: Aerodynamic principles of winglets.

[5] Mann, A. and Elsholz, E.: Investigations in novel wing tip device design. 43rd AIAA Aerospace Sciences Meeting and Exhibit, AIAA 2005-461.