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Research Paper Engineering

Analysis of Drag for an Aircraft Wing Model with and without Winglet

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ABSTRACT

This work describes the aerodynamic characteristic for aircraft wing model with and without winglet. Rectangular wing and this aerofoil has been used to compare the result with previous research using winglet. The model of the rectangular wing with winglet has been fabricated using polystyrene before design using CATIA software and finally fabricated in wood. The experimental analysis for the aerodynamic characteristic for rectangular wing without winglet, wing with horizontal winglet and wing with 60 degree inclination winglet for Reynolds number 1.66×105, 2.08×105 and 2.50×105 have been carried out in open loop low speed wind tunnel at the Aerodynamics laboratory in Bhagwant university,Ajmer. The experimental result shows 25-30 % reduction in drag coefficient and 10- 20 % increase in lift coefficient by using winglet for angle of attack of 8 degree.

Keywords : Aerofoil, Wind tunnel, Winglet, Drag Coefficient

I. INTRODUCTION

One main obstacles limiting the performance of aircraft is the drag that the aircraft produces. This drag stems out from the vortices shed by an aircraft's wings, which causes the local relative wind downward (an effect known as downward) and generated a component of the local lift force in the direction of the free stream called induced drag. The strength of this induced drag is proportional to the spacing and radii of these vortices. By designing wings which force the vortices farther apart and at the same time create vortices with large core radii, one may significantly reduce the amount of the drag the aircraft induces. Airplanes which experience less drag require less power and therefore less fuel to fly an arbitrary distance, thus making flight, commercial and otherwise, more efficient and less costly. Vortices at the wing tip can cause crash in aircraft. This is when a big aircraft goes in front of a small aircraft; this big aircraft which has larger vortices can cause the small aircraft to loose control and crash. In airport to minimize the separation rule, an aircraft of a lower wake vortex category must not be allowed to take off less than two minutes behind an aircraft of a higher wake vortex category.

METHODOLOGY

A. Wind tunnel, Instrumentation and model details.

The aircraft model's wing with two sets of bird feather like winglet has been designed and fabricated using wood for aerodynamic characteristic analysis in subsonic wind tunnel at Aerodynamic Laboratory, University Putra Malaysia. The NACA 653-218 airfoil has been used for the structure of wing, winglet and adapter. The winglet design is shown in Fig. 1.

The aircraft wing model has a span of 0.66 m and a chord of 0.121 m as shown in Fig. 2.

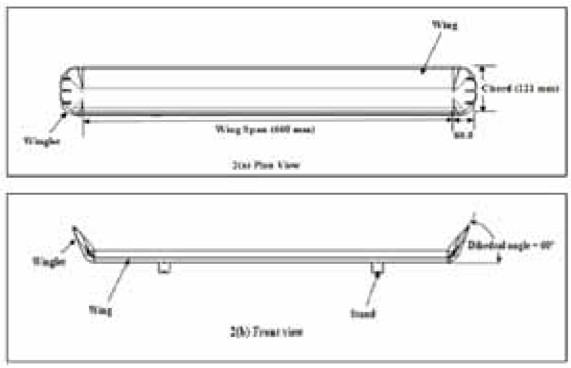


Fig.2. Rectangular Wing with Winglet using Adapter

B. Theoretical Models

Lift Coefficient and Drag coefficient are defined as [19-20]

$$C_L = \frac{L}{\frac{1}{2}\rho_\infty V_\infty^{\ 2} S}$$

$$C_D = \frac{D}{\frac{1}{2}\rho_\infty V_\infty^{\ 2} S}$$

ρ∞ is the air density in kg/m3, V∞ is the free stream velocity

in m/s , c is the chord length in m and S is the reference area in m2.

Using equation of state of perfect gas the air density kg/m3 is defined as

$$\rho_\infty = \frac{p}{RT}$$

Where, p is the absolute pressure in N/m2, T is the temperature in K, and R is the gas constant of air in Nm/(kg) (K).

Reynolds number based on the chord length is defined as

Re = (ρ∞ v∞ c)/μ

Where, v∞ is the free stream velocity in m/s; μ∞ is the dynamic viscosity in kg/(m)(s) and c is the chord length in m.

The air viscosity , μ∞ is determined using Sutherland's equation describe below

Where, T is the temperature in K.

C. Experimental Procedure
Experiments were conducted in the Aerodynamics Laboratory Faculty of Engineering (University Putra Malaysia) with subsonic wind tunnel of 1 m ×1 m rectangular test section and 2.5 m long. The wind tunnel could be operated at a maximum air speed of 50 m/s and the turntable had a capacity for setting an angle of attack of 14 degree. The ambient pressure, temperature and humidity were recorded using barometer, thermometer, and hygrometer respectively for the evaluation of air density in the laboratory environment. Fig. 3 shows a photograph of the aircraft wing model with winglet, which is mounted horizontally in the test section of the wind tunnel.

Fig.3. Schematic diagram of the wing with winglet

The tests were carried out with free-stream velocity of 21.36 m/s, 26.76 m/s, and 32.15 m/s respectively with and without winglet of different configurations. The coefficient of lift (Table I) and coefficient of drag (Table II) were obtained from the experimental results as per the procedure explained in [16-17]. The simulations on the parameters were conducted at Reynolds numbers 1.7×105, 2.1×105, and 2.5×105 respectively by using the MATLAB.

D. Calibration of External Balance
Calibration of the six-component balance has been done to check the calibration matrix data provided by the manufacturer. Fig. 4 shows a photograph of the calibration rig used for the validation of calibration matrix, which is mounted on the upper platform of the balance in place of model. The relationship between signal readings, Li and the loads, Fi applied on the calibration rig are given by the following matrix equation, the detailed procedure of calibration using Matlab software is explained elsewhere [17-18].

{Li} = [Kij]{Fi}

Where, [Kij] is the coefficient matrix, {Li} is the signal matrix,

Lift Coefficient Data

Winglet Configuration	Reynolds Number 105	Lift coefficient CL		
		Initial angle of attack 0o	Stall angle of attack 8o	Final angle of attack 14o
Without winglet	1.6	0.227	0.803	0.665
	2.0	0.255	0.786	0.588
	2.4	0.307	0.879	0.734
Configuration 1 (0o angle)	1.6	0.403	0.848	0.570
	2.0	0.431	0.913	0.720
	2.4	0.412	0.970	0.757
Configuration 2 (60o angle)	1.6	0.443	0.994	0.781
	2.0	0.457	0.957	0.751
	2.4	0.482	0.991	0.829

Table II

Drag Coefficient Data

Winglet Configuration	Reynolds Number 105	Drag coefficient CD		
		Initial angle of attack 0o	Stall angle of attack 8o	Final angle of attack 14o
Without winglet	1.6	0.087	0.155	0.257
	2.0	0.084	0.151	0.288
	2.4	0.066	0.135	0.217
Configuration 1 (0o angle)	1.6	0.060	0.101	0.191
	2.0	0.053	0.092	0.162
	2.4	0.051	0.083	0.129
Configuration 2 (60o angle)	1.6	0.077	0.119	0.194
	2.0	0.065	0.105	0.162
	2.4	0.053	0.140	0.160

The calibration matrix is obtained by finding the inverse of Kij, coefficient matrix and it compares well with the calibration matrix data supplied by the manufacturer with six component external balance.

E. Speed Calibration
The airflow velocity was controlled by the RPM controller of the wind tunnel. For the different Hz settings at the RPM controller the flow velocities in wind tunnel test section were recorded using six-component external balance software. The validity of the digital manometer was confirmed by comparing the dynamic pressure measured through the digital manometer and through the tube manometer used along with the pitot tube mounted in the test section. The experimental error using the external balance was nearly 6% [16, 21]. The flow velocity readings of the external balance are corrected through the following calibration equation obtained through the data shown in Fig.5,

y =1.0796x −0.2336 (7)

Where x denotes external balance software velocity (m/s) and y denotes digital manometer velocity (m/s).

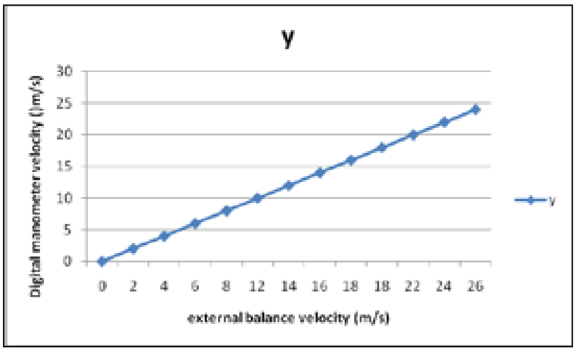


Fig.4. Flow velocity calibration for external balance

Using the equation (7), the actual value of free stream air velocity would be 21.36 m/s for corresponding 20 m/s of air velocity from six-component external balance software.

III. RESULTS AND DISCUSSIONS

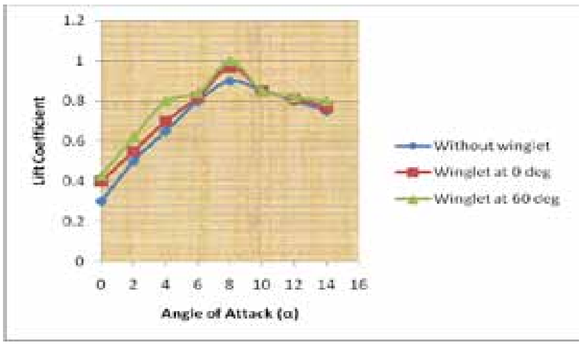
A. Test Conditions

The aircraft model tests with different configuration of winglets and without winglet were carried out at Reynolds numbers 1.7×105, 2.1×105, and 2.5×105. The measured values for the lift force, and drag force for the various configurations were given in Ref. [16-17] and coefficient of lift and coefficient of drag were calculated as per the procedures explained.

B. Coefficient of Lift

The coefficient of lift versus angle of attack for the aircraft wing model with and without winglet studied in the present investigation are shown in Fig. 7 for the maximum Reynolds number of 2.5105. From the figure it is observed that the lift increases with increase in angle of attack to a maximum value and thereby decreases with further increase in angle of attack

Fig.5. Lift Coefficients for the Wing Model



B. Coefficient of Drag

The drag coefficients of the aircraft wing model under test for all Reynolds numbers are shown in Fig. 8. From the graph, it is observed that the drag coefficient for the aircraft wing model measured under all the configurations under this study shows an increasing trend with angle of attack for a Reynolds number 0.25x106. The drag increases slowly with increase in angle of attack to a certain value and then it increases rapidly with further increase in angle of attack. The rapid increase in drag coefficient, which occurs at higher values of angle of attack, is probably due to the increasing region of separated flow over the wing surface, which creates a large pressure drag. From the figure it is observed that the values of the minimum drag coefficients are 0.067, 0.053, and 0.052 respectively for different configurations for the maximum Reynolds number of 2.5x105 which occur at zero angle of attack. In particular the measured drag values against the angle of attack are minimum for the winglet of configuration 1 and 2 over the values of the range of angle of attack considered under this study. To establish the superiority of the winglet at 0 degree over the winglet at 60 degree more detailed experiments are required.

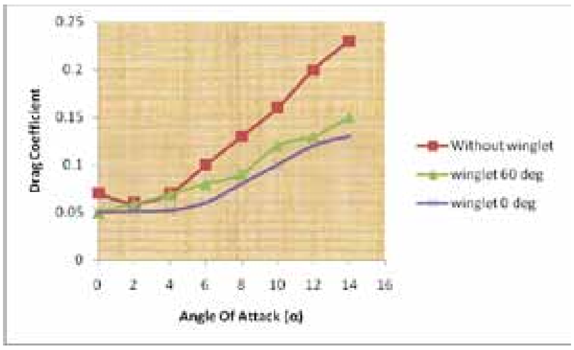


Fig.6. Drag Coefficients for the Wing model of an aircraft

D. Lift/Drag ratio Characteristics

The lift/drag ratio is the outcome of the observations made in the two preceding sections. It is observed from the Fig. 9 that the lift/drag ratio for all the configurations considered increases with an angle of attack to its maximum value and thereby it decreases with further increase in angle of attack for a Reynolds number 2.5x105.

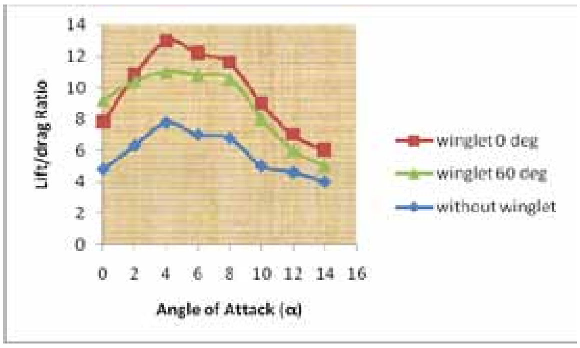


Fig.7. Lift/Drag ratio for the Wing model of an aircraft

CONCLUSION

The conclusions drawn from this investigation.is that the drag coefficient and lift coefficient graph it is clearly shown that using winglet will increase lift force and reduce drag force.This winglet design is capable to reduce induced drag force and convert wing tip vortices to additional thrust which will save cost by reducing the usage of fuel, noise level reduction and increase the efficiency of the aircraft engine. The experiment result shows 25-30 % reduction in drag coefficient and 10-20 % increase in lift coefficient by using winglet for angle of attack of 8 degree

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