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Drag Reduction in a Wing Model Using a Bird Feather Like Winglet

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Abstract

This work describes the aerodynamic characteristic for aircraft wing with and without bird feather like winglet. The aerofoil used to construct the whole structure is NACA . Rectangular wing and this aerofoil have been used to compare the result with previous research using winglet. The model of the rectangular wing with bird feather like winglet has been fabricated using polystyrene before design using CATIA P3 V5R13 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 Universiti Putra Malaysia. The experimental result shows 25-30 % reduction in drag coefficient and 10-20 % increase in lift coefficient by using bird feather like winglet for angle of attack of 8 degree.

Keywords: Winglet; Aerodynamic characteristics; External balance; Drag coefficient

Nomenclature

α	Angle-of-attack
D	Drag force
L	Lift force
ρ_∞	Air density
S	Reference area
V_∞	Free stream velocity
a_0	Lift slope
C_D	Drag coefficient
C_L	Lift coefficient
d	Diameter of sphere
$[K_{ij}]$	Coefficient matrix
$\{F_i\}$	Load matrix
$\{L_i\}$	Signal matrix

1. Introduction

One of the primary obstacles limiting the performance of aircraft is the drag that the aircraft produces. This drag stems 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. 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 [1]. 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. If the following aircraft does not start its take off roll from the same point as the preceding aircraft, this is increased to three minutes. One promising drag reduction device is winglet. For a number of years many investigations have been carried out to prove the possible benefits of modifying wing tip flow. Tip devices have become a popular technique to increase the aerodynamic performances of lifting wings [2-3]. The idea behind all the devices described is to diffuse the strong vortices released at the tip and optimize the span wise lift

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distribution, while maintaining the additional moments on the wing within certain limits. The design of a winglet is very complex. It requires the same aerodynamic characteristics as a wing and its chord wise position on the tip of the wing require special care to optimize its efficiency and to prevent detrimental flow interactions with the wing [4]. According to A.J. Bocci [5] winglets show greater efficiency when there is high loading near the tips of the wing and it is more efficient than a wing tip extension producing the same bending moment at the root. It enables to increase the aircraft efficiency. However, the winglet efficiency depends on the lift produced by the wing and strong aerodynamic interference can be found at the concave junction between the wing and the winglet. A group of biologists at the Technical University of Berlin has worked and demonstrated the effectiveness of multiple slotted wings or wing grid. They have shown how these features could have evolved naturally in birds through gradual increases in wing effectiveness. This theory has been emulated in an aircraft optimization algorithm developed by Kroo and Takai [6]. The new design approach "WING-GRID", developed from the observation of storks, results in revolutionary new options for aircraft wings and application to practical any aircraft can reap solid benefits [7-9]. Winglets have become a popular method of altering the trailing tip vortex system from an aircraft wing and thus improve the aircraft performance. A winglet is a device used to improve the efficiency of aircraft by lowering the lift-induced drag caused by wingtip vortices. A winglet provides an innovative method of achieving the vortex arrangement described above. The concept involves constructing wings whose tips are small extension in the form of a smaller aerofoil section placed at any angle. Because the vortices shed by the wing are strongest at the tips of the wing, the addition of the wing tip surfaces can reduce and diffuse the strength of these vortices, thus reducing the overall vortex drag of the aircraft. Two bird feather like winglets have been used with the aircraft model wing to do the experiment with the wind tunnel in Aerodynamics Laboratory of Aerospace Engineering Department, Universiti Putra Malaysia. The longitudinal aerodynamic characteristics of aircraft wing with two-winglet configurations have been the subject of this research work.

The study on the enhanced performance of the aircraft models is also given by incorporating elliptical and circular winglets. An interaction matrix method has also been presented to revalidate the calibration matrix data provided by the manufacturer of the six-component external balance. The calibration of free stream velocity and flow quality in the test section has been established and documented in the earlier published paper [10].

2. Methodology

2.1. Wind tunnel, model details and Instrumentation:

An aircraft model's wing with two sets of bird feather like winglets have been designed and fabricated using wood for testing aerodynamic characteristic in subsonic wind tunnel in Aerodynamic Laboratory, University Putra Malaysia. The NACA 653-218 airfoil has been used for the whole structure of wing, winglet and adapter. The winglet design is shown in Figure 1. The aircraft model has a span of 0.66 m and a chord of 0.121 m as shown in Figure 2. The tests were carried out with free-stream velocities of 21.36 m/s, 26.76 m/s, and 32.15 m/s respectively with and without winglet of different configurations. The ambient pressure, temperature and humidity were recorded using barometer, thermometer, and hygrometer respectively for the evaluation of air density in the laboratory environment. Figure 3 shows a photograph of the aircraft model wing with bird feather like winglet without adapter in the test section in wind tunnel.

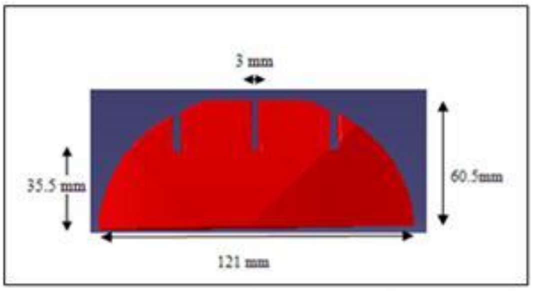

Figure 1: Geometry Characteristic of Bird Feather like Winglet from Top View.

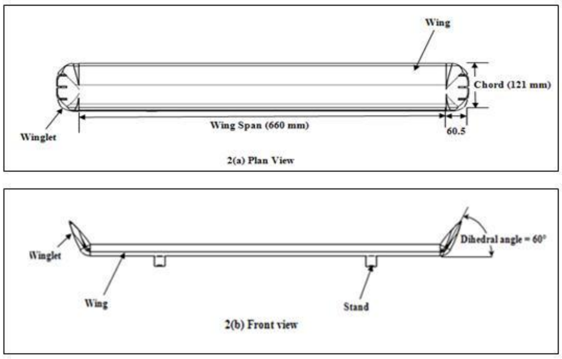

Figure 2: Rectangular Wing with Winglet Inclination using Adapter.

Figure 3: Aircraft model wing with bird feather like winglet.

Longitudinal tests were carried out at angle of attack ranging from 0 degree to 14 degree with an increment of 2 degree. During the test the pitching moment, lift and drag forces were measured using the six-component external balance and the coefficients of lift, drag and moment are obtained using the Eqs. (1-3) [11-12] given below, Coefficient of lift is defined as

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

Coefficient of drag is defined as

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

Coefficient of pitching moment is defined as

$$C_M = \frac{M}{\frac{1}{2}\rho_\infty V_\infty{}^2 Sc} \tag{3}$$

Calibration of the six-component balance has been done to re check the calibration matrix data provided by the manufacturer. 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 is explained elsewhere [13]

$$\{L_i\} = [K_{ij}]\ \{F_i\} \tag{4}$$

Where, $[K_{ij}]$ is the coefficient matrix, $\{L_i\}$ is the signal matrix, and $\{F_i\}$ is the load matrix.

3. Results and Disscussion

Wind-tunnel measurements using the aircraft model without winglet and with winglet of different configurations were carried out at Reynolds numbers 1.66x105, 2.08x105 and 2.5x105. The measured values for the lift coefficient, drag coefficient, pitching moment coefficient and lift and drag ratio for the various Reynolds number are given in Table 1 to 4 and detail calculations have been performed as per the procedure explained in [10].

Table 1: Lift Coefficient over Angle of Attack.

Winglet Configuration	Reynolds Number (10^5)	Angle of attack α: 0	4	8	12	14
Without winglet	1.66	0.228	0.594	0.804	0.725	0.666
	2.08	0.256	0.605	0.787	0.721	0.589
	2.5	0.308	0.677	0.88	0.797	0.735
Winglet in horizontal (0 degree)	1.66	0.405	0.678	0.85	0.68	0.572
	2.08	0.433	0.668	0.915	0.81	0.722
	2.5	0.414	0.725	0.972	0.83	0.759
Winglet 60 degree inclined	1.66	0.442	0.787	0.993	0.812	0.78
	2.08	0.456	0.817	0.956	0.876	0.75
	2.5	0.481	0.803	0.99	0.854	0.828

Table 2: Drag Coefficient over Angle of Attack.

Winglet Configuration	Reynolds Number (10^5)	Angle of attack α: 0	4	8	12	14
Without winglet	1.66	0.088	0.105	0.156	0.216	0.258
	2.08	0.0849	0.1029	0.152	0.236	0.289
	2.5	0.0667	0.0878	0.136	0.191	0.218
Winglet in horizontal (0 degree)	1.66	0.0616	0.065	0.103	0.175	0.193
	2.08	0.0546	0.0576	0.0936	0.145	0.164
	2.5	0.0534	0.0554	0.085	0.117	0.131
Winglet 60 degree inclined	1.66	0.076	0.0935	0.118	0.16	0.193
	2.08	0.0642	0.0907	0.104	0.152	0.171
	2.5	0.052	0.071	0.091	0.139	0.159

Table 3: Pitching Moment Coefficient over Angle of Attack.

Winglet Configuration	Reynolds Number (10^5)	Angle of attack α: 0	4	8	12	14
Without winglet	1.66	-0.086	-0.098	-0.12	-0.32	-0.373
	2.08	-0.091	-0.125	-0.197	-0.425	-0.502
	2.5	-0.113	-0.143	-0.27	-0.55	-0.643
Winglet in horizontal (0 degree)	1.66	-0.294	-0.373	-0.524	-1.075	-1.12
	2.08	-0.319	-0.404	-0.577	-0.983	-1.1
	2.5	-0.353	-0.424	-0.613	-1.045	-1.207
Winglet 60 degree inclined	1.66	-0.385	-0.486	-0.686	-1.207	-1.47
	2.08	-0.406	-0.531	-0.709	-1.103	-1.28
	2.5	-0.481	-0.549	-0.704	-1.09	-1.24

Table 4: Lift/Drag Ratio over Angle of Attack.

3.1. Drag coefficient versus angle of attack:

Figure 4 for Reynolds number 1.66 × 105 shows that without winglet the drag coefficient is higher than the winglet with 0 degree and 60 degree inclined position for all angle of attack. The drag coefficient is very high for wing without winglet for Reynolds number 2.08 × 105 compare with using winglet. Although 60 degree inclined winglet drag coefficient is little bit higher than horizontal winglet, it is more efficient to use inclined winglet because it will give more lift force. For all configurations the drag will be the highest at 14 degree because the flow separation is high at that angle. Overall from the Fig. 4, it can be concluded that by using winglet the drag force can be reduced.

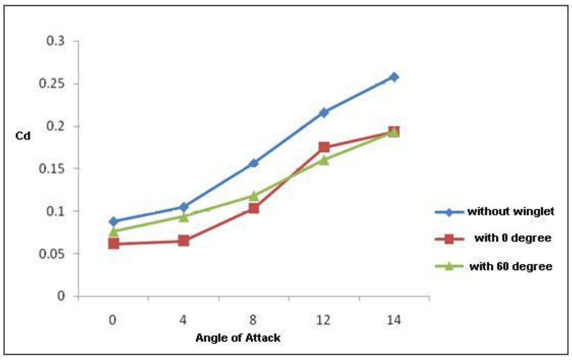

Figure 4.a: Drag coefficients for the Aircraft wing model (Reynolds number 1.66×10^5)

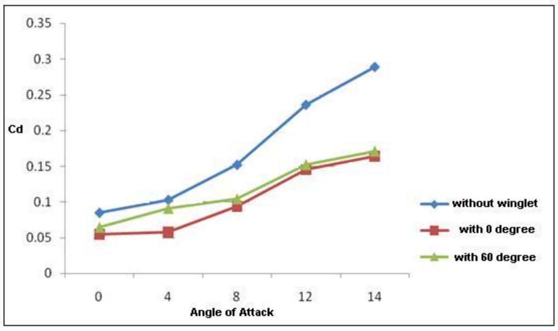

Figure 4.b: Drag coefficients for the Aircraft wing model (Reynolds number 2.08×10^5).

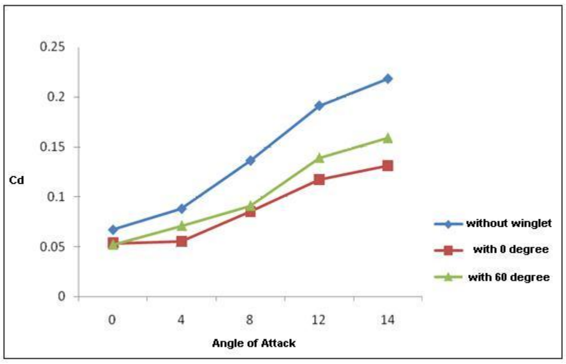

Figure 4.c: Drag coefficients for the Aircraft wing model (Reynolds number 2.50×105).

3.2. Lift coefficient versus angle of attack:

The coefficient of lift versus angle of attack for the aircraft model with and without winglet studied in the present investigation are shown in Figure 5 for different Reynolds number. For all graph, the lift increases with the addition of angle and reach maximum lift is at angle of attack of 8 degree then it is reduced with the addition of angle of attack. So it can be concluded that lift coefficient for using winglet is higher than without winglet.

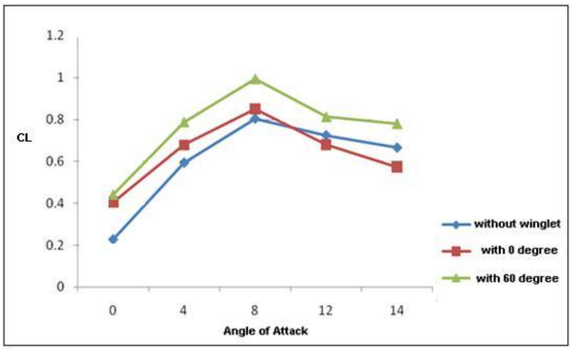

Figure 5.a: Lift coefficients for the Aircraft wing model (Reynolds number 1.66×10^5).

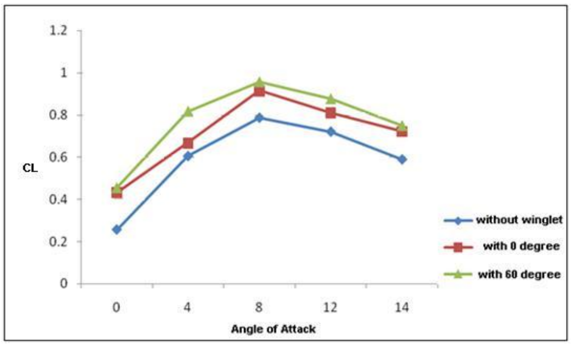

Figure 5.b: Lift coefficients for the Aircraft wing model (Reynolds number 2.08×10^5).

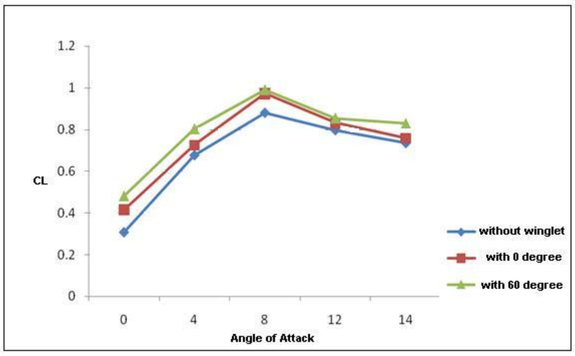

Figure 5.c: Lift coefficients for the Aircraft wing model (Reynolds number 2.50×10^5).

3.3. Pitching moment coefficient versus angle of attack:

The coefficient of pitching moment versus angle of attack for the aircraft model with and without winglet studied in the present investigation are shown in Figure 6 for different Reynolds number. Pitching moment coefficient for 60 degree inclined winglet is lowest for all three Reynolds number. The pitching moment decreases with the increase of angle of attack and finally minimum at angle of attack of 14 degree. The pitching moment coefficient decreases rapidly with the increase in angle of attack to a certain value and then it decreases more rapidly with the increase of attack. This is because the increasing of separation flow over the wing surface at that angle of attack.

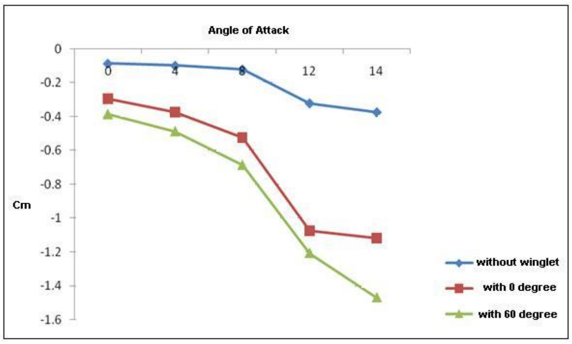

Figure 6.a: Pitching moment coefficients for the wing model (Reynolds number 1.66×10^5).

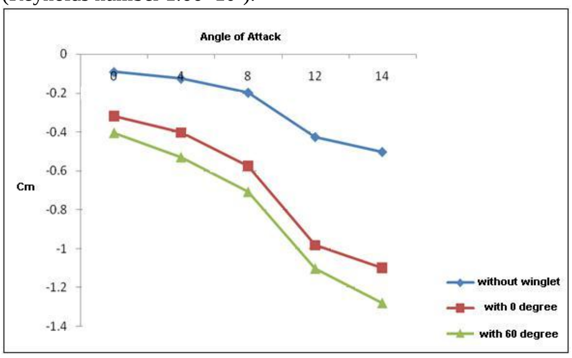

Figure 6.b: Pitching moment coefficients for the wing model (Reynolds number 2.08×10^5).

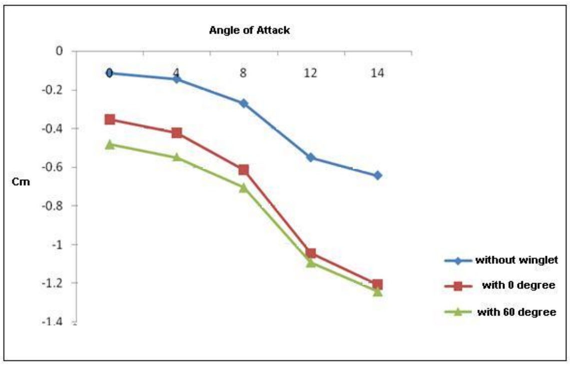

Figure 6.c: Pitching moment coefficients for the wing model (Reynolds number 2.50×10^5).

3.4. Lift/Drag aatio versus angle of attack:

The lift/drag ratio or lift/drag coefficient over angle of attack is the outcome of the study made in the previous sections. Lift/drag ratio or lift/drag coefficient over angle of attack has been shown in Figure 7 for different Reynolds number in this observation. The lift and drag ratio increases with the increase of angle of attack and reach maximum at 4 degree.

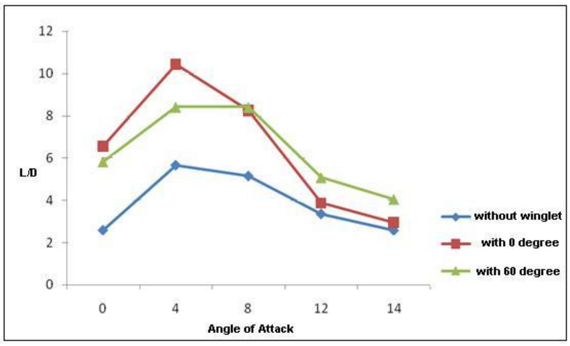

Figure 7.a: Lift/Drag ratio for the wing model (Reynolds number 1.66×10^5).

From the figure it is observed that the ratio decreases with further addition of angle of attack. The maximum value of lift / drag ratio is found as 10.43, 11.6 and 13.09 for wing with horizontal winglet at angle of attack of 4 degree. From the experimental results it can be concluded that that winglet performs better compared to without winglet.

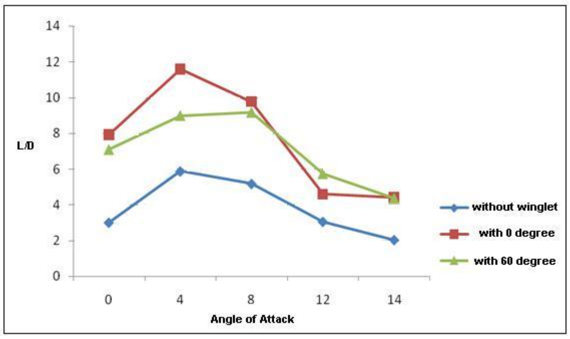

Figure 7.b: Lift/Drag ratio for the wing model (Reynolds number 2.08×10^5).

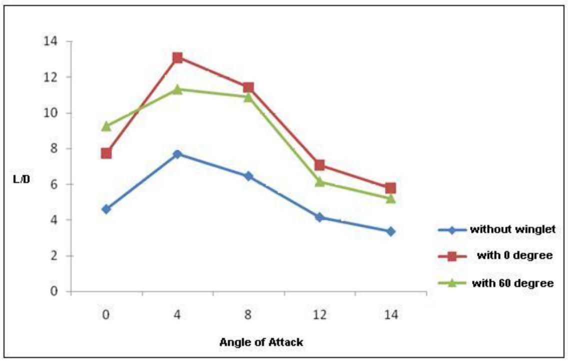

Figure 7.c: Lift/Drag ratio for the wing model (Reynolds number 2.50×10^5).

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3.5. Performance comparisons between the present and previous works:

The experimental results of the present works can be explained by comparing with the results obtained from the previous works related to the different types of winglets [13-15]. The tests at the Universiti Putra Malaysia [13] were run in three different configurations: without winglet (Configuration 0), winglets of elliptical shaped installed at 00 angle (Configuration 1), winglets of elliptical shaped installed at 600 angle (Configuration 2), winglets of circular shaped installed at 00 angle (Configuration 1), and winglets of circular shaped installed at 600 angle (Configuration 2). They investigated that at the maximum Reynolds number of 2.50×105 elliptical shaped winglet (Configuration 1 and 2) provided the largest increase of lift curve slope, ranging from 1% to 6% increases and at the same time drag decreased more for these two configurations ranging from 24.6% to 28% decrease, giving an edge over other configurations as far as L/D for the elliptical winglet of configuration 1 and 2 was considered. Tests at the Georgia Institute of Technology [14] were also run in three different configurations: without winglet (Configuration 0), winglets installed at 00 angle (Configuration 1), and winglets installed at +200, +100, 00, -100, -200 angle (Configuration 2). They showed that flat plate winglets set at zero degrees (Configuration 1) increased lift curve slope by 10% for the maximum Reynolds number of 2.90×105. They also showed that configuration 2 provided the largest increase of lift curve slope, ranging from 15% to 22% increase with the decrease of drag ranging from 15% to 20%. Compare to the previous works done by the ref. [13-14], it is observed that the present works on bird feather like winglet shows good performance with the reduction of 25-30 % drag coefficient as well as 10-20 % increase in lift coefficient by using winglet for angle of attack of 8 degree.

4. Conclusion

Following are the conclusions drawn from this investigation

- From the drag coefficient and lift coefficient graph it is clearly shown that using bird feather like 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.

5. Acknowledgment

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