Proceedings of the
International Conference on Mechanical Engineering 2009
(ICME2009) 26- 28 December 2009, Dhaka, Bangladesh

ICME09-FM-10

INDUCED DRAG REDUCTION FOR MODERN AIRCRAFT WITHOUT INCREASING THE SPAN OF THE WING BY USING WINGLET

Mohammad Mashud, Md. Hasan Ali, Abdullah-Al-Nahian and S. M. S. Selim

Department of Mechanical Engineering
Khulna University of Engineering & Technology, Khulna

ABSTRACT

This paper describes the potential of winglets for the reduction of induced drag without increasing the span of the aircraft. For this experiment a model aircraft has been constructed by aluminum-alloy whose wings profile is NACA 4315. There are three different types (rectangular, triangular and circular) of winglet are constructed for experiment. Aerodynamic characteristics for the model aircraft wing with rectangular, triangular and circular winglets and without winglet have been studied using a subsonic wind tunnel of 36cm×36cm rectangular test section. Drag measurements are carried out using an external balance. Tests are carried out on the aircraft model with and without winglet at the Reynolds numbers 0.16×10^6, 0.18×10^6, 0.20×10^6, 0.23×10^6 and 0.25×10^6. The experimental results show that the drag decreases by 26.4% - 30.9% as compared to the aircraft model with and without winglet for the maximum Reynolds number considered in the present study.

Keywords: Induced Drag, Wing, Winglet, Aircraft and Aerodynamics.

1. INTRODUCTION

The wings are the most important lift-producing part of the aircraft. Wings vary in design depending upon the aircraft type and its purpose. Most airplanes are designed so that the outer tips of the wings are higher than where the wings are attached to the fuselage. This upward angle is called the dihedral and helps to keep the airplane from rolling unexpectedly during flight. Wings also carry the fuel for the airplane.

Wingtip devices are usually intended to improve the efficiency of fixed-wing aircraft. There are several types of devices, and though they function in different manners, the intended aerodynamic effect is to modify the aircraft's wake in some beneficial manner. Wingtip devices can also improve aircraft handling characteristics. From a marketing standpoint, they are also valued for their aesthetic appeal.

Such devices increase the effective aspect ratio of a wing, with less added wingspan. An extension of span would lower lift-induced drag, but would increase parasitic drag, and would require boosting the strength and weight of the wing. At some point there is no net benefit from further increased span. There may also be operational considerations that limit the allowable wingspan.

The wingtip devices increase the lift generated at the wingtip, and reduce the lift-induced drag caused by wingtip vortices, improving lift-to-drag ratio. This increases fuel efficiency in powered aircraft, and cross-country speed in gliders, in both cases increasing range. US Air Force studies indicate that a given improvement in fuel efficiency correlates directly with the causal increase in L/D ratio.

A winglet is a near vertical extension of the wing tips. The upward angle (or cant) of the winglet, its inward angle (or toe), as well as its size and shape are critical for correct performance, and unique in each application. The vortex which rotates around from below the wing strikes the cambered surface of the winglet, generating a force that angles inward and slightly forward, analogous to a sailboat sailing close hauled. The winglet converts some of the otherwise wasted energy in the wing tip vortex to an apparent thrust. This small contribution can be very worthwhile, provided the benefit offsets the cost of installing and maintaining the winglets during the aircraft's lifetime. Another potential benefit of winglets is that they reduce the strength of wingtip vortices, which trail behind the plane. When other aircraft pass through these vortices, the turbulent air can cause loss of control, possibly resulting in an accident.

Aerodynamic characteristics for the aircraft model with and without winglet having wing with NACA 4315 has been presented in this paper. The study on the enhanced performance of the aircraft models is also given by incorporating different shaped winglets.

2. MODEL CONSTRUCTION

The cambered airfoil sections of all NACA families considered herein are obtained by combining a mean line and a thickness distribution. The necessary geometric data and some theoretical aerodynamic data for the mean lines and thickness distributions obtained from the supplementary figures by the methods described for each family of airfoils. The process for combining a mean line and a thickness distribution to obtain the desired cambered airfoil section is shown in figure below.

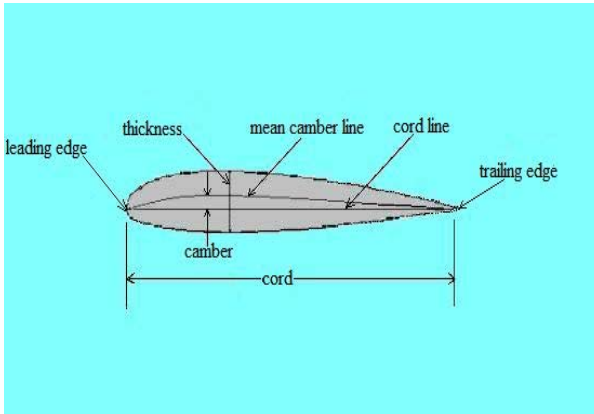

Fig 1. A typical airfoil

The cross sectional shape obtained by the intersection of the wing with the perpendicular plane is called an airfoil. The major design feature of an airfoil is the mean cambered line, which is the locus of points halfway between the upper and lower surfaces as measured perpendicular to the mean cambered line itself. The most forward and rearward points of the mean cambered line are the leading and trailing edges respectively. The straight line connecting the leading and trailing edges is the chord line of the airfoil and the precise distance from the leading to the trailing edge measured along the chord line is simply designated the chord of the airfoil, given by the symbol C. The camber is the maximum distance between the mean camber line and the chord line, measured perpendicular to the chord line. The camber, the shape of the mean camber line and to a lesser extent, the thickness distribution of the airfoil essentially controls the lift and moment characteristics of the airfoil. If X_u and Y_u represent respectively the abscissa and ordinate of a typical point of the upper surface of the airfoil and y_t is the ordinate of the symmetrical thickness distribution at chord wise position X_1, the upper surface coordinates are given by the flowing relations:

$$X_u = x - y_t \sin\theta$$
$$Y_u = Y_c + y_t \cos\theta$$

The corresponding expressions for the lower surface co ordinates are

$$X_1 = x + Y_t \cos\theta$$
$$Y_1 = Y_c - Y_t \cos\theta$$

As is θ very small, $\sin\theta=0$, $\cos\theta=1$

$X_u = x$ $\qquad$ $Y_u = y_c + y_t$ s

$X_1 = x$ $\qquad$ $Y_1 = y_c - y_t$

The center for the leading edge radius is found by drawing a line through the end of the chord at the leading edge with the slope equal to the slope of the mean line at that point and laying off a distance from the leading edge along this line equal to the leading edge radius. This method of construction causes the cambered airfoils to project slightly forward of the leading edge point. Because the slope at the leading edge is theoretically infinite for the mean lines having a theoretically finite load at the leading edge, the slope of the radius through the end of the chord

For such mean lines is usually taken as the slope of the mean line at x /c = 0. 005. This procedure is justified by the manner in which the slope increases to the theoretically infinite value as x/c are reached. Large values of the slope are thus limited to values of x/c very close to 0 and may be neglected in practical airfoil design.

We have made software for the profile generation by using some basic equations of airfoil. They are as follows:

From leading edge to maximum wing thickness

$$Y_c/c = f/c\,(1/X^2)\,[2x_1 (X/C) - (X/C)^2]$$

Valid for $0 \le X/C \le X_1$

From maximum wing thickness to trailing edge

$$Y_c/c = f/c\,\{1/(1-X_1)^2\}[(1-2X_1) + 2X_1 (x/c) - (x/c)^2]$$

Valid for $x_1 \le x/c \le 1$

Maximum wing thickness

$$Y_t = 5t\,(0.2969\sqrt{x} - 0.126\,x - 0.3516x^2 + 0.2843\,x^3 - 0.1015\,x^4)$$

Where, f = maximum camber

X_1 = distance from leading edge to maximum wing thickness

C = chord of the airfoil

t = maximum wing thickness

Y_c = vertical distance between mean camber line and chord line.

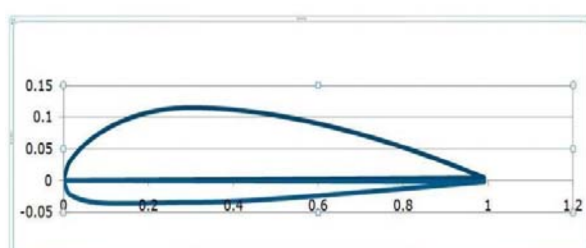

Fig 2. NACA 4315 Airfoil (Designed)

By applying Computer C ++ Programming Language the regular surface profile of the NACA 4315 model was made. The thickness and chord length of the model is 15 cm and span is 10 cm respectively. Thus the chord length

based Reynolds number relevant at low flight speeds, which are a concern for the exploration of wing formation mechanism, is estimate to be about 10^5. The chord length of the model was determined to have Reynolds number of the same order. The span length of the model, relative to the chord length is one of the important design parameters. Obviously, it should be made as large as possible so that the weight of the model can be reduced. To ensure the aerodynamic characteristics of an airfoil, it is important that the trailing edge of the model have a sharp edge form.
After construction of the wing now it is time to construct the winglet. Three shapes of winglet are used for this experiment. The shapes are rectangular, triangular and half circular. The winglet is attached with the wing at the tip. Now the model is ready for testing.

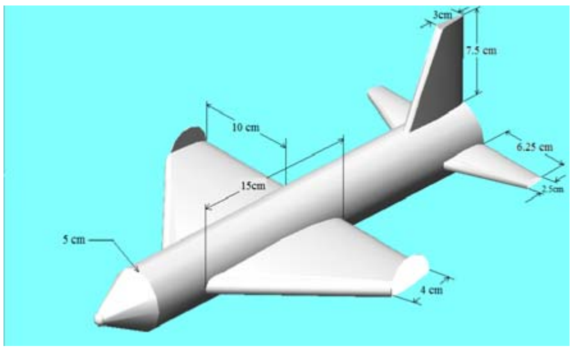

Fig 3. Designed Aircraft model

3. EXPERIMENAL SET-UP AND PROCEDURE

The experiments were conducted using wind tunnel. Figure: 2 shows a schematic of the experimental set up. A small sized model is appropriate to examine the aerodynamic characteristics for the experiments. If we desire to examine the aerodynamic characteristics of a large model, a large scale wind tunnel facility is necessary for testing or the inflatable wing must be drastically scaled down to match the usual wind tunnel size violating the Reynolds number analogy requirements.

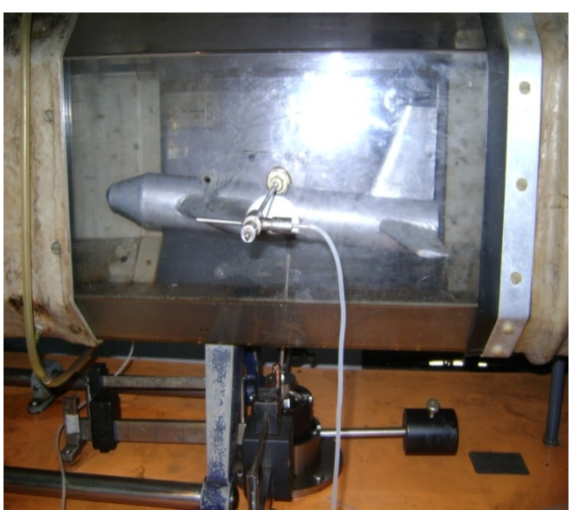

Fig 4. Experimental Setup (Actual investigation)

Furthermore, it would be difficult to support the inflatable wing a desirable attitude in these wind tunnel experiments. Since the vertical part of the aerodynamic force produces the lifting force necessary to suspend the load. We are mainly interested in the aerodynamic characteristics of each model. The model was placed in the testing section of the wind tunnel. Then the testing procedure is started of measuring the drag and lift of the constructed model from the wind tunnel scale.

For the complete testing the constructed model, subsonic wind tunnel and pressure measuring instrument were used as required apparatus. At the first step of the experimental procedure the constructed model aircraft with NACA 4315 along with winglets was placed inside the testing section of the wind tunnel. Three shaped winglets were used and those were half circular, triangular and rectangular. The half circular winglets were attached to the wing of the model aircraft at the wing tip. At the vertical position of the winglet which means 0° angle of the winglet the testing section was closed to start the measurement. For different velocities of the wind tunnel the lift and the drag forces were measured from the scale and pressure was also measured. After this the winglet angle was changed to 5° and then the lift and drag forces were measured along with pressure from the relative scales for different velocities. Next the winglets were changed. Then triangular and rectangular shaped winglets were attached one after another to measure the necessary data as the same way of half circular shaped winglets. The velocity of the wind tunnel was controlled by a regulator attached with the wind tunnel.

When the measurement of data had been complete then the calculation process was started. From the measured pressure the stream velocity was calculated by using the mathematical relation. Lift to Drag ratio was calculated by using the measured lift and drag forces.

$$\textit{Reynolds number},\ R_e = \frac{\rho v l}{\mu}$$

Here,

ρ = Density of free stream or air

v = Velocity of free stream or air

l = Model length

μ = Dynamic viscosity

To calculate the Reynolds number at first we have to measure the velocity of the free stream of air .To measure the velocity the pressure is measured by a inclined manometer which pressure tube is connected into the wind tunnel.

Now,

$$\text{Velocity of free stream or air},\ v = \sqrt{2gh}$$

Here,

g = Acceleration due to gravity

h − Pressure in the air stream

Again,

Pressure in the air stream, $h = \dfrac{\Delta p}{\gamma}$

Here,
Δp = Difference of pressure
γ = Specific weight

4. RESULTS AND DISCUSSION

Wind tunnel measurements using the constructed aircraft model without winglet and with winglet of different configurations were done. The coefficient of lift and the coefficient of drag have been calculated from the experimental results. Also various graphs have been drawn to examine the measured and calculated data nature.

The lift and drag depends on several factors, the most important of which are:

1) Airstream velocity
2) Plan form area S (ft^2)
3) Profile shape of the airfoil
4) Viscosity of the air
5) Angle of attack (degrees)
6) Angle of winglet (considering the initial position perpendicular with wing)

The first two factors determine the dynamic pressure *q* of the airstream. Factors 4, 5, and 6 influence the amount of drag that an airfoil will develop at a certain angle of attack. It is convenient to express the lift and drag forces in terms of non-dimensional co-efficient that are functions of angle of attack. These are called the *co-efficient of lift* (C_L) and the *coefficient of drag* (C_D).

Co-efficient of lift, $C_L = \dfrac{2F_L}{L^2 \rho v^2}$

Co-efficient of drag, $C_D = \dfrac{2F_D}{L^2 \rho v^2}$

Coefficient of lift can be said to be “the ratio between the lift pressure and the dynamic pressure”. It is a measure of the effectiveness of airfoil to produce lift. Values of coefficient of lift have been obtained from experimental data. The importance of angle of attack in determining wings performance cannot be overemphasized. An airfoil has its maximum climb angle at a certain angle of attack, will achieve maximum rate of climb at another angle of attack, and will get maximum range at still another angle of attack. All airfoil i.e. aircraft performance depends on angle of attack. The lift characteristic is also depends upon or affected by thickness and location of maximum thickness, camber and other factors.

Increasing the thickness which results in lower static pressure and more lift. Our designed NACA 4315 models of airfoils have a maximum camber of 4% c, located at the 30%c position. Our designed NACA 4315 airfoils are 15%c thick. So this have much higher value of coefficient of lift and the stall is also higher. The drag increases 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 0.065, 0.052, 0.050, 0.049, and 0.047 respectively of different configurations for the maximum Reynolds number of 0.23 $\times 10^6$ which occur at zero angle of attack. In particular the measured drag against the angle of attack is minimum for the triangular winglet of configuration 1 and 2 over the values of the range of angle of attack considered under this study.

The measured drag values for the aircraft model with rectangular winglet of configuration 2 are also practically same as triangular winglet compared to the circular winglet. Other details of drag coefficients are given in Table 1.From this investigation it is observed that at the maximum Reynolds number of 0.23 $\times 10^6$ triangular winglet of configuration 1 and 2 (Figure 5) provides the significant decreases in drag ranging from 18% to 26.4%, giving an edge over other configurations. Decisively it can be said that the triangular winglet of configuration 2 (Winglets inclination at 5°) has the better performance giving about 26.4% - 30.9% deceases in drag as compared to other configurations.

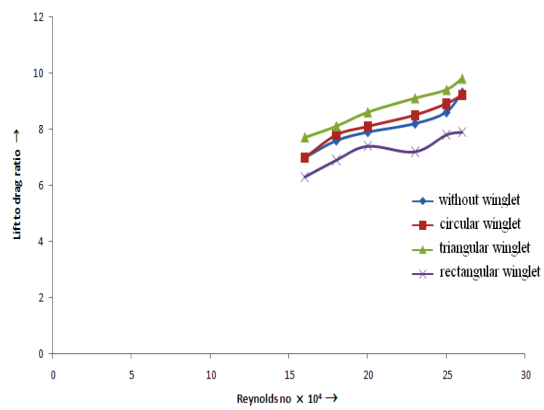

Fig 5. Lift to drag ratio Vs Reynolds no.

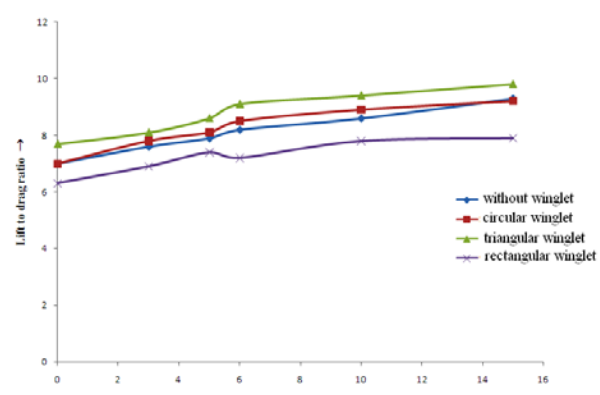

Fig 6. Lift to drag ratio Vs Winglet angle

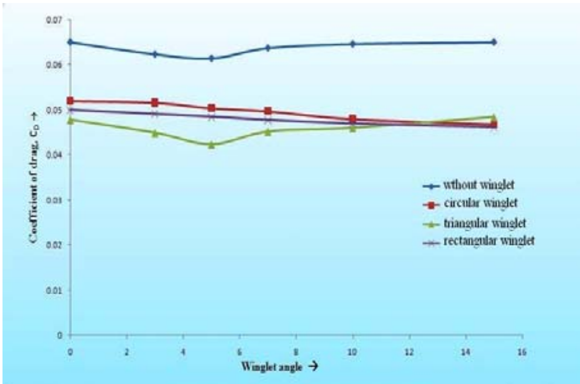

Fig 7. Coefficient of drag vs. winglet angle

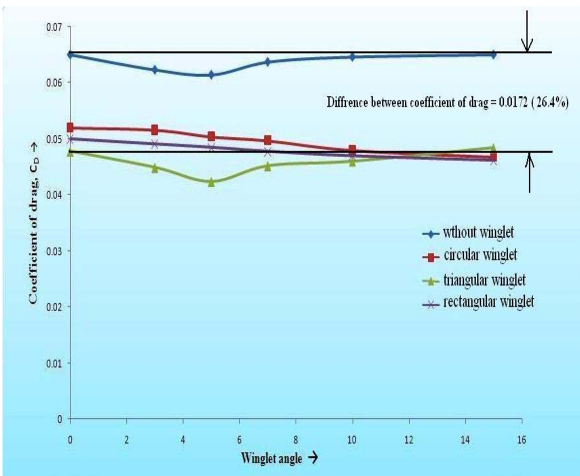

Fig 8. Variation of C_D with winglet angle

Winglets have the potential to give the following benefits:

- Reduced climb thrust. A winglet equipped aircraft can typically take a 3% derate over the non-winglet equivalent aircraft. This can extend engine life and reduce maintenance costs.
- Reduced cruise thrust. Cruise fuel flow is reduced by up to 6% giving savings in fuel costs and increasing range.
- Improved cruise performance. Winglets can allow aircraft to reach higher levels sooner.
- Good looks. Winglets bring a modern look and feel to aircraft, and improve customers' perceptions of the airline.

5. CONCLUSION

Following are the conclusions drawn from this investigation,

Aerodynamic characteristics for the aircraft model with and without winglet having NACA wing section no. 4315 have been presented.

Triangular winglet at 5° inclination has the better performance giving about 30.9% decreases in drag as compared to other configurations for the maximum Reynolds number considered in the present study.

So we have to suggest the triangular shape of winglet for the maximum lift and minimum drag among the other shapes

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7. MAILING ADDRESS

Mohammad Mashud
Department of Mechanical Engineering
Khulna University of Engineering & Technology, Khulna
E-mail: mdmashud@yahoo.com