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Effect of Winglets on the Lift and Drag Characteristics of Model Airplane

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Abstract

In order to understand the effect of winglets on the lift and drag of an airplane; and to determine the critical angle of lift and drag this investigation was undertaken. Three airplanes with same plane length to wing span were produced using Accura SI 40 epoxy resin. Two of the airplane models were fitted with winglets at the end of their wings at an angle of 30 and 60 degrees to the wing plane. The airplane performance characteristics (viz. the lift and drag) were measured in a wind tunnel as a function of the air speed, the angle of attack and the angle of the winglet. The air speeds were in the range 60 – 215 kmph and the angle of attack was in the range 0 – 15 ^{o} (both in ascending and descending positions).The results suggest that the lift and drag force increased with an increase in the airplane speed. The results also suggest that except the plane with winglet attached at an angle of 60^{o}, all other planes with winglets have had better performance characteristics. The critical angle of attack for maximum lift and minimum drag for the plane without any winglets was about 7.5^{o} and 4.5^{o} respectively. The critical angle of attack for lift and drag has increased from 7.5 to 10.5^{o} with an increase in the winglet angle to the wing plane from 0 to 30^{o}. However, further increase in the winglet angle above 30^{o} to 60^{o}, had decreased the critical angle of lift and drag from 10.5 to 8.5^{o}.

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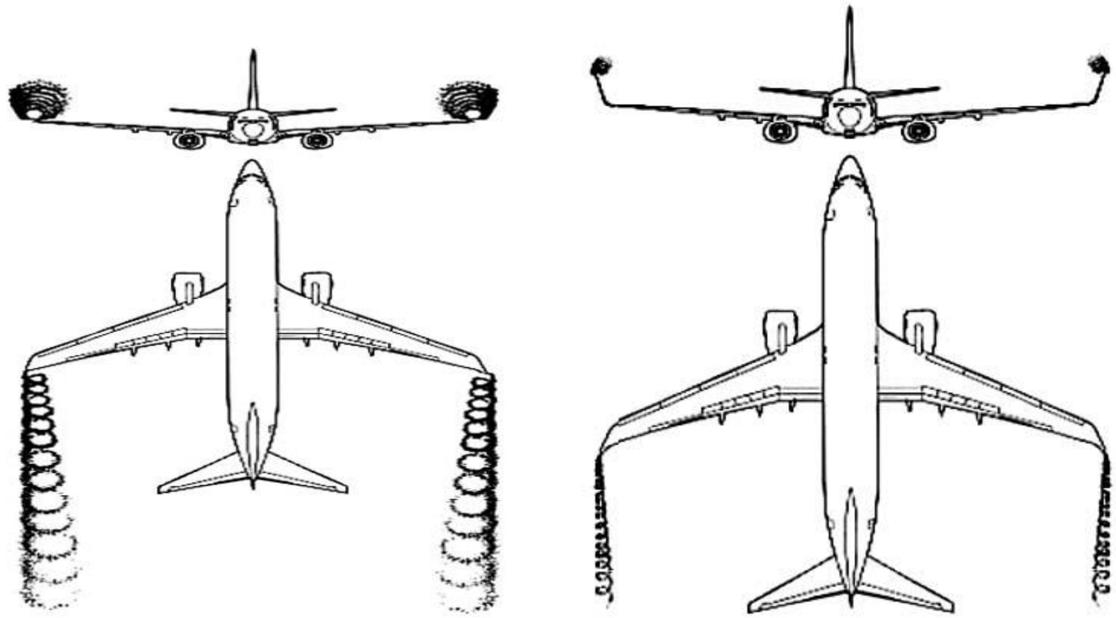
I. INTRODUCTION

When a plane moves the air molecules near the airplane are disturbed and generate aerodynamic forces [1,2]. The aerodynamic forces create a layer of air near the surface and this layer is important in determining the lift and drag of the airplane. The lift depends upon the shape size and angle of inclination and flow conditions. For lifting the wing, the airflow over the top of the wing will be at lower pressure than that of the flow under the wing. Near the tips of the wing, the air is free to move from high pressure to lower pressure region. This produces a pair of counter rotating vortices at the tip of the wings [Figure 1]. The wingtip vortices produce a down wash of air behind the wing, thus putting a drag on the forward motion of the plane. Figure 2 shows schematic representation of typical vortex formed behind the flying airplane. The location and the influence of both lift and drag changes with the angle of inclination. The position for which the lift is maximum and the drag is low is called the critical angle of lift. The lift force produces great upward thrust on the wings and the lift force increases with an increase in the wingspan. However, the larger the wingspan the higher the lead acted on the hinges and or the joining of the wings to the fuselage. One way to reduce the load on the wing is to shift the center of vortex away from the plane of the airplane. Nature has shown that such an arrangement not only improves the performance but it is also efficient way to conserve energy. Big birds often raise their feature tips of the wings. This provides them an energy efficient flight. In recent years the airplane designers implemented these natural phenomena in designing their fuel efficient airplane.



A **B**

Figure 1. Schematic diagram of the vortex formed at the (A) conventional Wingtip and (B) at the blended winglet. (Ref. 3).

Figure 2. Typical airplane in flight with the vortex formed behind the airplane. (ref. 3)

The aim of this project is to investigate the effect of the winglet angle on the lift and drag characteristics of an airplane flying under subsonic wind speeds.

II. THEORY

Dynamic Pressure:

The air molecules are in constant and random motion and they collide with each other and therefore changes in the air molecules momentum takes place. The change in the momentum is related to the gas pressure [4,5]. The pressure is the force times the surface area in a direction perpendicular to the surface. If the air is moving, the measured pressure depends upon the motion and one can define the pressure as a "dynamic pressure" as follows:

Static Pressure (P_s) + (½) ρ X (u^2) = Constant = Total Pressure (P_t) ……………. (1)

Where 'ρ' is the density of air, and 'u' is the speed At high speeds we can ignore static pressure. Therefore, the total pressure is defined as Dynamic Pressure (q) which is given as

Dynamic Pressure (q)= (½) ρ X (u^2) …………………………….…. (2)

The dynamic pressure (q) is a pressure with units $Kg/(m.s^2)$

Lift Equation:

In a controlled environment such a wind tunnel, the lift produced under a given set of conditions of velocity, density and wing surface area, can be calculated using the dynamic pressure (q), as follows.

At low speeds (< 360 kmph), the compressibility effects are negligible.

Therefore the lift force (L) is given as

Lift Force (L) $\propto$ q

Lift Force **(L** (kg/m^2)**)** = [constant] [(½) ρ X (u^2)] = (½) C_{CL} / ρ X (u^2) ………………. (3)

Where C_{CL} is the coefficient of lift and it is expressed as the ratio of lift force to the force produced by the dynamic pressure.

The total lift load ($\mathbf{T_L}$ (kg)) acting on the wing = lift force X area of the wing …………..... (4)

III. EXPERIMENTAL PROCEDURE

Airplane Models:

3 different airplanes with winglets attached at 0, 30 ^{o} and 60^o to the plane normal of the fuselage were first designed using "Rhinoceros" computer aided design and computer aided manufacturing (CAD & CAM) software. Once the model shapes were designed, the models were built using a "3D Systems" Stereo Lithography Apparatus (Model SLA 5000). The models were made out of a commercial epoxy resin called the "Accura" SI 40 resin. The epoxy models were later cured under UV light. The mechanical properties and other details of the epoxy resin are given in Table 1.The length of the airplane was 38.75 cm long. The diameter of the fuselage is about 3.35 cm, and the total wingspan is about 30 cm.

The strength of the wings of the airplanes was enhanced by reinforcing the wing structure with 0.625, 0.625 and 0.3125 cm diameter steel rods. These rods were placed inside the airplane model after the resin was cured. Figure 1 shows the airplanes as they were produced using the Stereo Lithography Apparatus.

Table 1. Typical Properties of "Accura SI 40" Epoxy Material [Ref. (6)]

Liquid Material		Post Cured Material		
Property		**Property**	**90 min UV Cure**	**90 min UV Cure + Thermal**
Appearance	**Clear Amber**	**Tensile Strength (MPa)**	**57.2 – 58.7**	**73.9 – 74.2**
Density at 25^{o}C	**1. 1 gm/cm^3**	**Elongation at Break**	**4.8 – 5.1 %**	**4.8 – 5.1 %**
		Flexural Strength (MPa)	**93.4 – 96.1**	**116 – 118**

Airplane Wings with Winglets:

As shown in Figure 2, in order to shift the plane of the airplane from the plane of the vortex formed behind, the wings of the present airplane models were augmented with winglets. Figure 3 shows model airplane without winglets (Figure 3(a), and airplanes with winglets attached to the wings at 30^o (Figure 3(B)) and 60^o (Figure 3(C)) respectively. Both the wings and winglets are solid. The overall thickness of the wing near fuselage side is about 0.9375 cm and the thickness near the wing tip near 0. 5 cm. The winglets have a constant thickness of 0.5 cm.

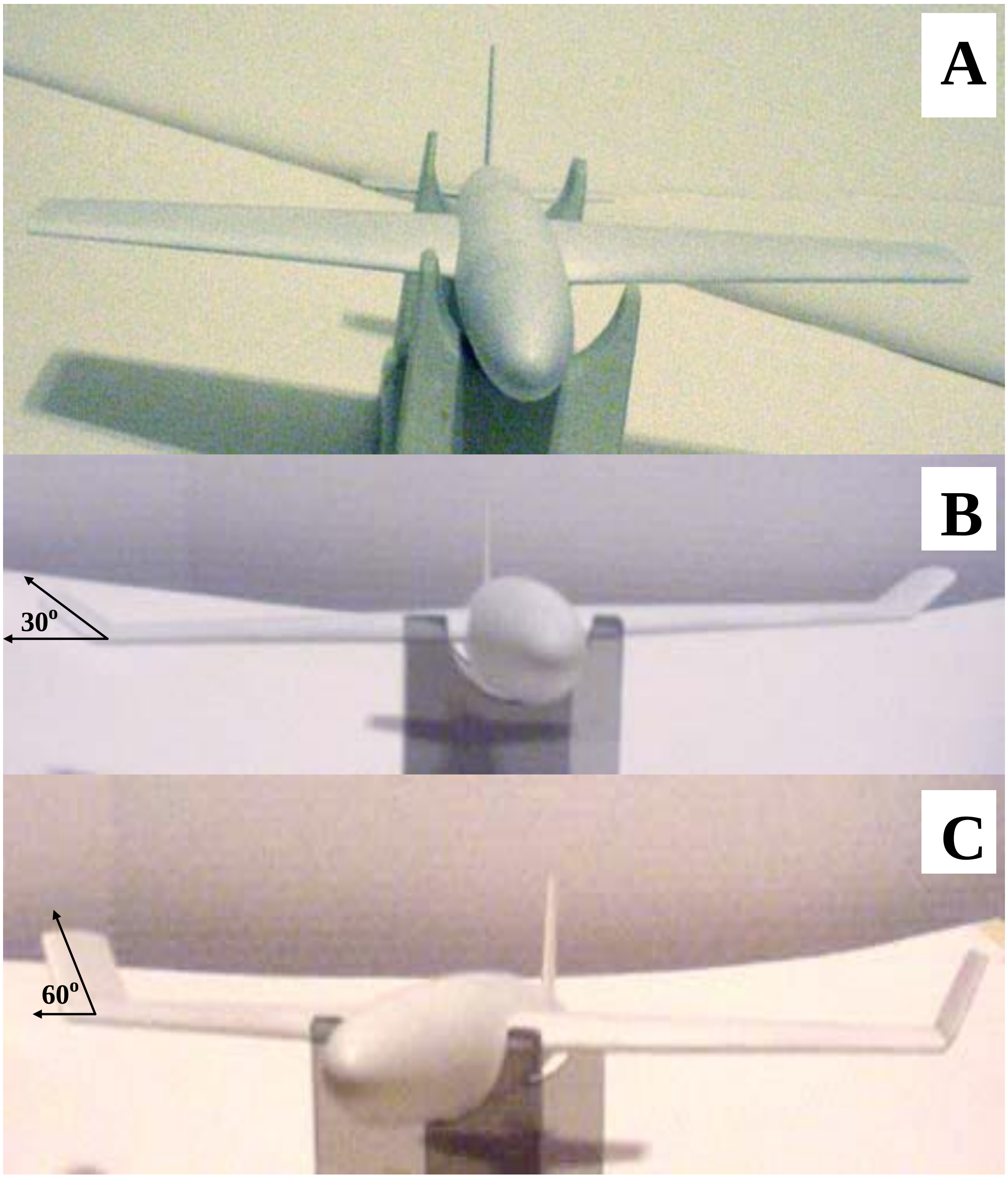


Figure 3. Typical airplane models (A) no winglets and (B, C) solid winglets attachedat 30^o and 60^o to the plane normal to the fuselage respectively.

Wind Tunnel Experiments

The important parameters that affect the stability of a flight system are the lift and the drag. Therefore in this paper only results obtained from the measurement of lift and drag on the airplane models investigated in a subsonic wind tunnel was presented. The present experiments were conducted in a horizontal wind tunnel. The positioning of the model airplane in the wing tunnel is shown in Figure 4 [(A) plane positioned parallel to the direction of air flow, (B) the airplane in ascending position and (C) in descending position respectively). The maximum air speed of the wind tunnel used in the present study is 215 kmph. The wind tunnel has the capability to move the model in any direction and the maximum tilt that can be achieved on the wind tunnel experimental test table is about 45^o. The wind tunnel experimental chamber was augmented with sensors that will monitor the lift and drag effects and send the output as an electrical current signal. In the wind tunnel, the lift and drag that is created on a model (as a result of flowing wind of different speeds) is converted as an electrical signal and the electrical signal output is recorded as a function of angle of inclination (angle of attack) and the wind speed. After the experiment is over the electrical signal output data (milli volt (mV)) is converted to determine the lift and drag as a force (Newtons). The models were clamped to the wind tunnel mounting unit with a special attachment. The wind tunnel experiments were carried out at speeds ranging from 65-215 kmph and the angle of inclination (ascending and descending) was studied in the range $0 – 15^o$.

First, the airplane models with no tilt were subjected to wind to the maximum speed of 215 kmph. At the maximum speed, the air flow was continued for about 15 minutes. After the initial treatment, the air speed was decreased and the models were brought to room air pressure. The wind tunnel was switched on and the models were subjected to airflow. Once, a specific required air speed is achieved, the airflow was kept at that speed for 5 minutes and the output current value for the lift and drag were noted. The air flow was then increased with 30 kmph increments until the maximum of 215 kmph was achieved. Then the air speed was decreased with a stepwise decrease of 30 kmph. The actual value of the lift and drag force was determined using the current (in milli amperes) versus lift or drag force plots.

The lift or drag force values were plotted as a function of air speed and the angle of attack. From those plots, the critical angle of attack for maximum lift or drag was determined.

IV. RESULTS

Airplane with no Winglets

The lift and drag characteristics of the plane was studied both during ascent and descent. The maximum angle of attack studied was + (ascent) or – (descent) 15 degrees. The lift and drag plots for the airplanes without winglets are given in Figure 4 (A) and (B) respectively. The lift force versus the angle attack plots for airplane during descent is shown in Figures 5 (A) and (B). The results suggest that during the ascent of an airplane, the lift force increases with an increase in the air speed. The lift increases with an increase in the angle of lift initially, once an optimum angle of attack is reached, any further increase in the angle of attack ahs decreased the lift force. The critical angle of attack for the airplane without winglets during ascent is around 8^o. The drag force decreased with an increase in the angle of attack initially. Once an optimum angle of attack (around 3^o), is reached the drag increased with an increase in angle of attack.

The results on the lift and drag of an airplane during descent suggest that the lift force decreases with an increase in the angle of descent initially. Above a critical angle of attack, the lift increases with an increase in the angle of attack. The critical angle of attack is around 8^o. The drag decreased with an increase in the angle of attack and above approximately 6o, the drag increases with an increase in the angle of attack

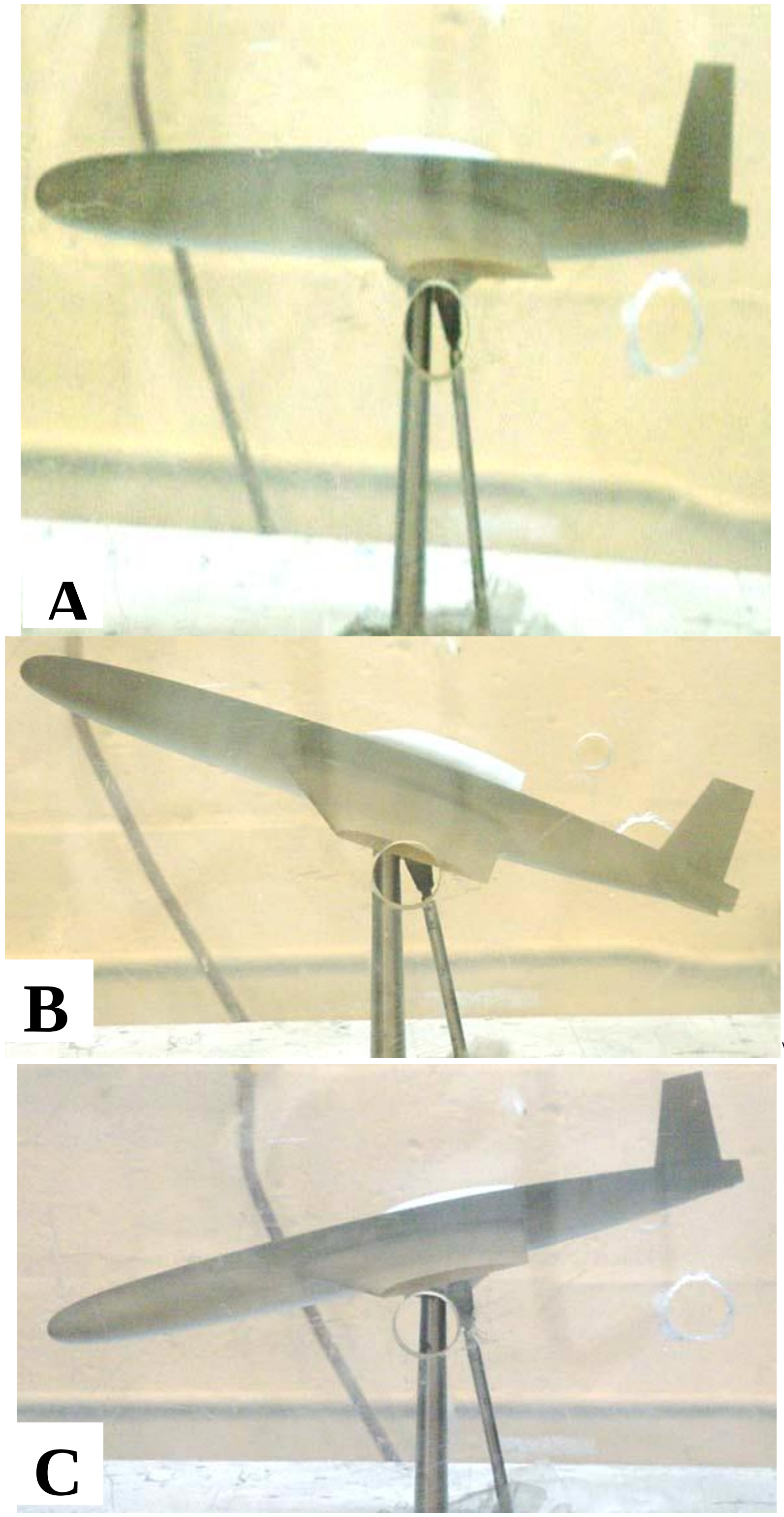
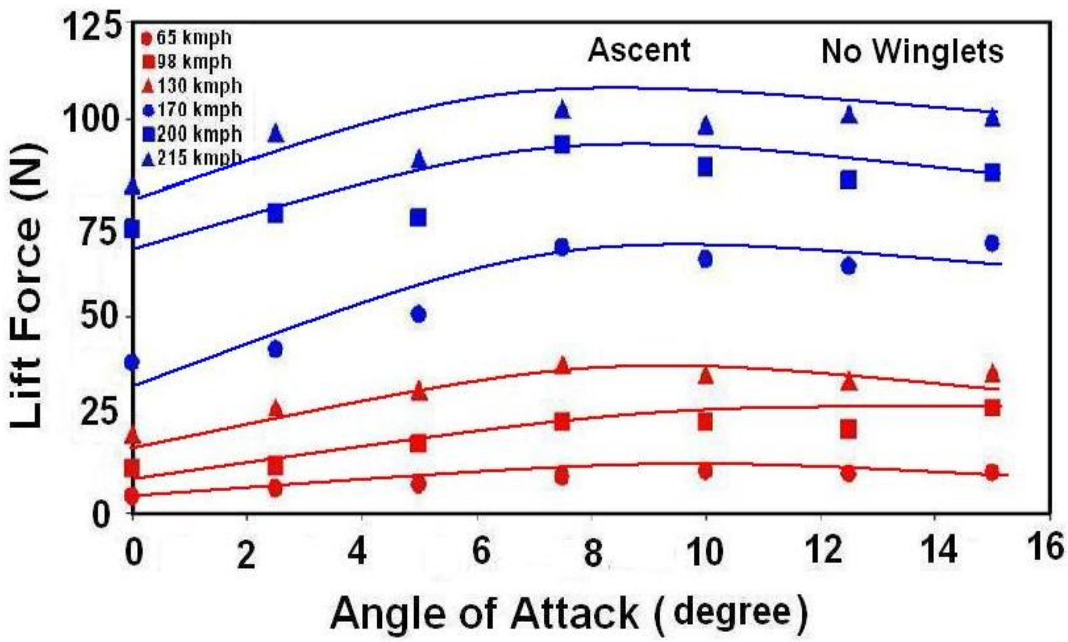


Figure 4. Model airplane with solid wings during wind tunnel experiments.
Angle of attack (A) 0^o, (B) 15^o ascending and (C) 15^o descending.

Airplane with Winglets:

The lift force versus the angle attack plots for airplane with winglets during ascent is shown in Figures 6 (A) and (B). Similarly the drag force versus the angle of attack during ascent for the same planes is shown in Figure 7 (A) and (B) respectively. The results suggest that during the ascent the lift force increases with an increase in the air speed. The lift increases with an increase in the angle of lift initially and once an optimum angle of attack is reached, any further increase in the angle of attack decreases the lift force. The critical angle of attack for the airplane with winglets at 30^o and 60^o angles (during ascent) is around $10.5\,^o$. and 8^o respectively.



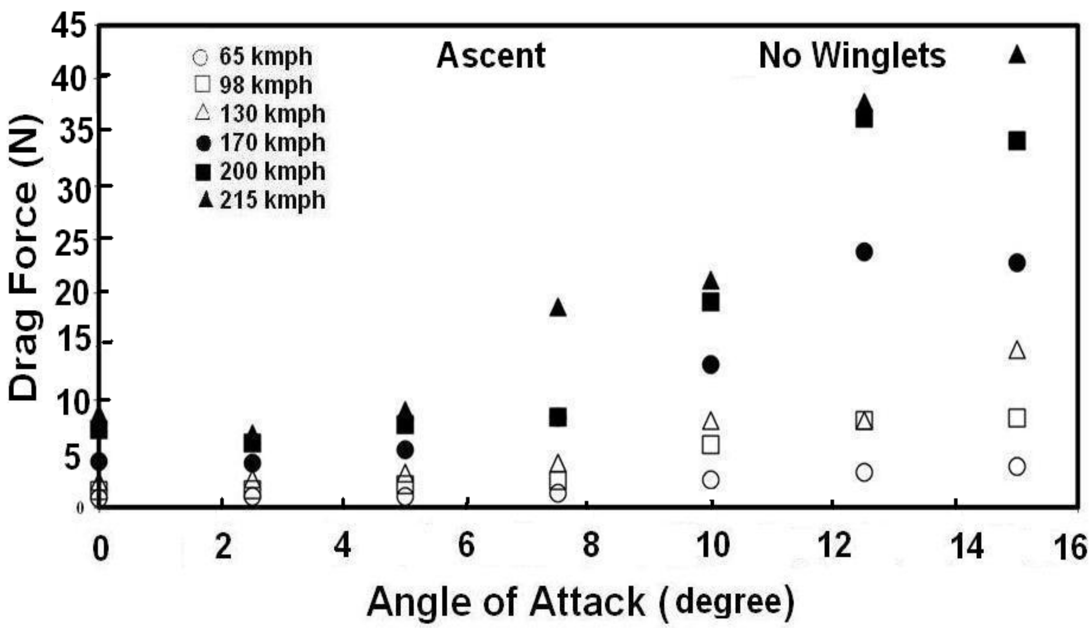


Figure 4. The (A) lift force or (B) drag force versus angle of attack of an airplane without winglets during ascent.

The drag versus angle of attack results (Figures 7 (A) and (B)) suggests that the drag force decreased with an increase in the angle of attack initially. Once an optimum angle of attack (around 4.5^o for airplane with winglets at 30^o and ~ 3^o for airplane with winglets at 60^o), is reached the drag increased with an increase in angle of attack. Although the results are not presented here, the critical angle of attack for drag during descent was found to be 4^o and 5.5^o for airplane with winglets at 30 ^{o} and 60^o angle respectively.

In order to establish the effect of winglets on the critical angle of attack for maximum lift and/or minimum drag, the angle of attack corresponding to the maximum lift force or drag force values that were determined experimentally were tabulated as a function of air speed. The critical angle was then plotted as a function of winglet angle. Figures 8 (A) and (B) show plots on the critical angle of attack for maximum lift, and minimum drag versus the airplane winglet angle, and at different air speeds. The results suggest that as the airplane winglet angle increases from 0 ^{o} and 30^o the critical angle of lift increases from ~ 7.5^o to ~10.5^o. Further increase in the winglet angle from 30 ^{o} to 60^o angle decreases the critical angle of lift from ~10.5^o to ~ 8.5 ^{o}. The results on the drag versus the angle of winglets indicate that as the angle of winglets increased from 0 ^{o} to 60^o, the critical angle of drag increased from ~ 4 ^{o} to ~ 6^o angle

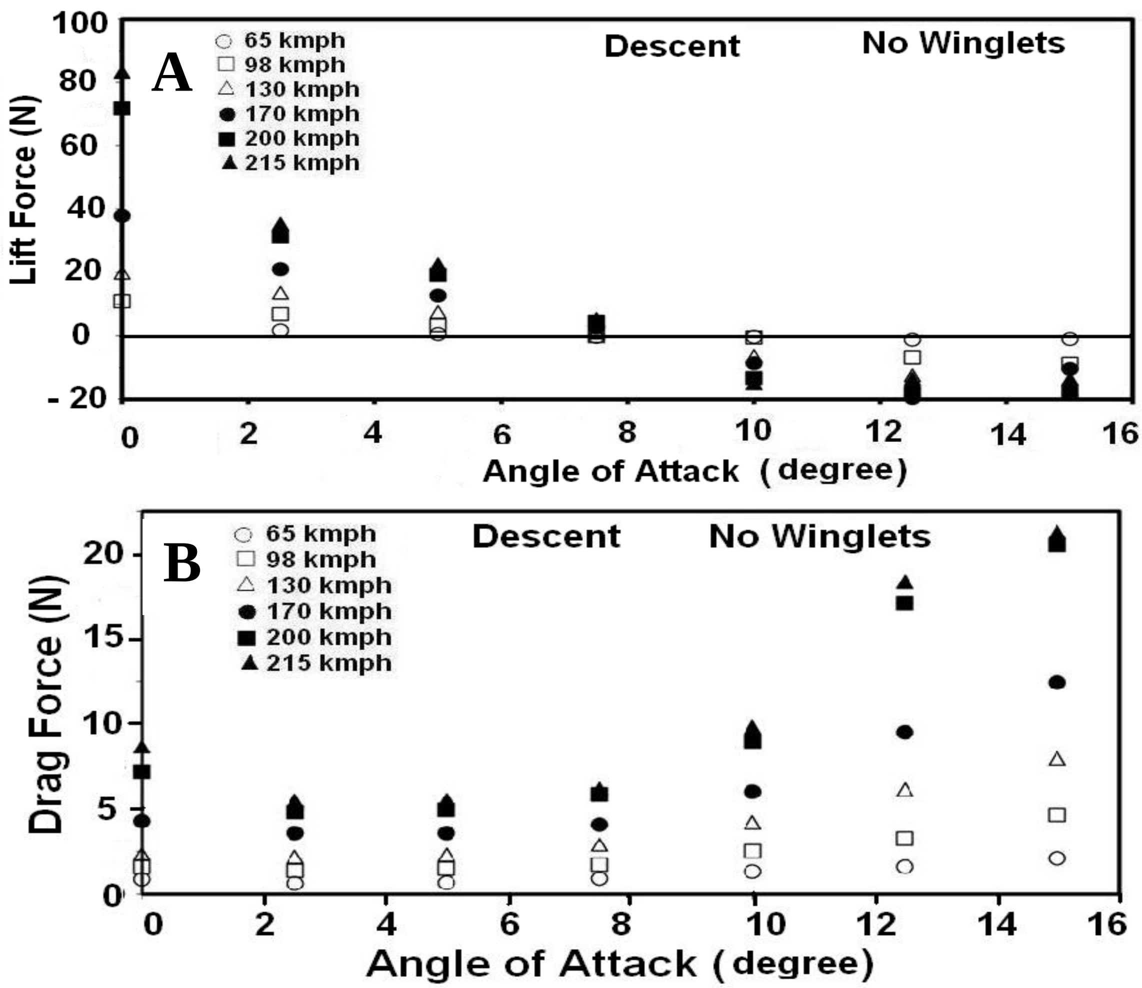


Figure 5. The (A) lift force or (B) drag force versus angle of attack of an airplane without winglets during descent.

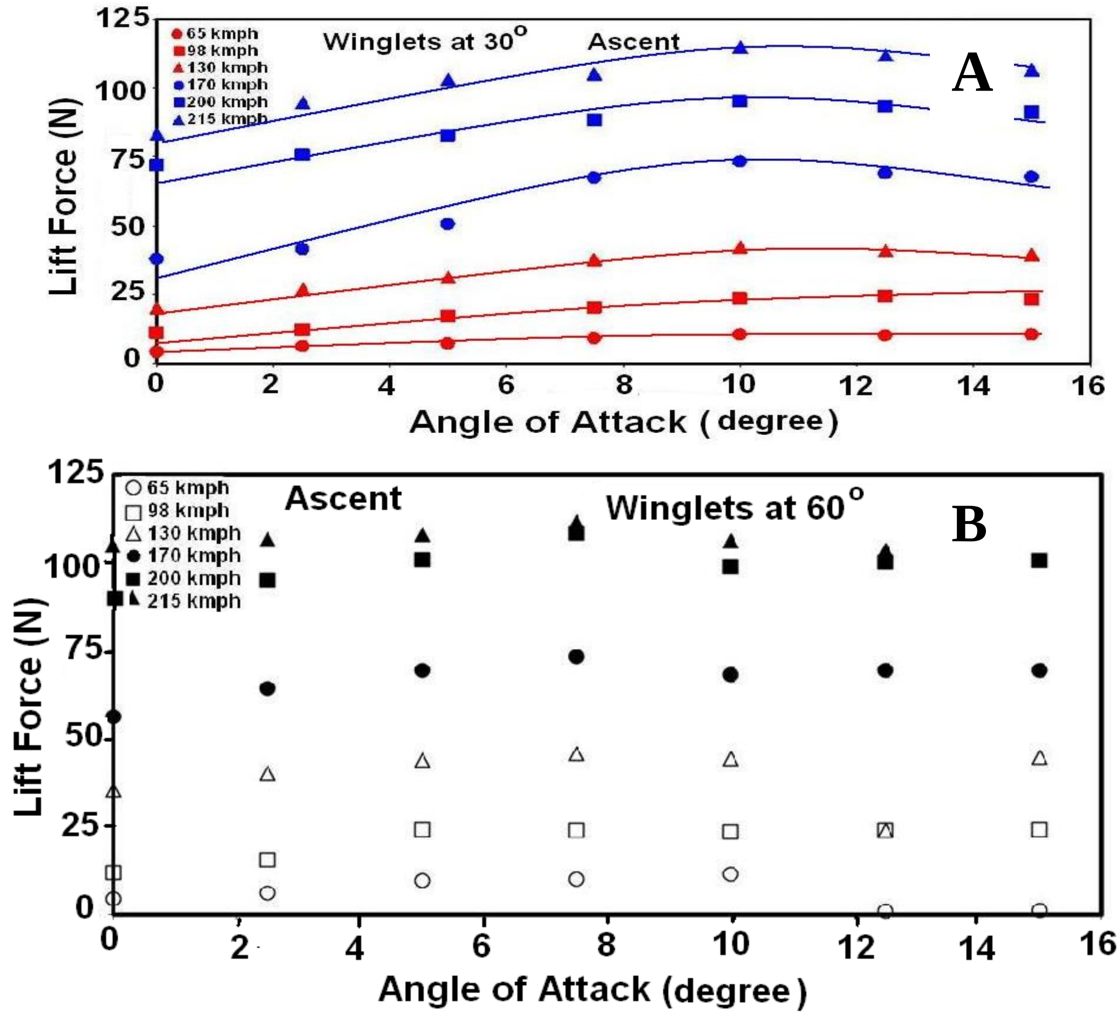


Figure 6. The lift force versus angle of attack of an airplane with winglets during ascent. Winglet angle (A) 30° and (B) 60°.

VII. DISCUSSION

The present results clearly indicate that the when the airplane is augmented with winglets, the lift force increases. In addition, the results also conclude that critical angle of attack for lift increases by about 40%. For a real airline performance, such an increase in both the lift force and also the angle of attack of lift will have significant savings on the fuel consumption. This increase in critical angle of attack and the lift force is due to is due to the fact that the wing lets will deflect the vortex away from the plane of the airplane [Figure 1].

The results on the critical angle of lift and lift force also suggest that the reduction in the drag on the airplane is dependent on the winglet angle. Above an optimum winglet angle, the winglets will not improve the performance of the airplane. The limitation of the present study is that only 3 winglet positions were investigated. Based on the three angles, it can be inferred that the optimum winglet angle is 30°. More detailed investigation with different winglet positions is needed to determine the critical anglr of lift and drag. It is possible that the critical angle of lift may be between 0° and 30° or 30° and 60°.

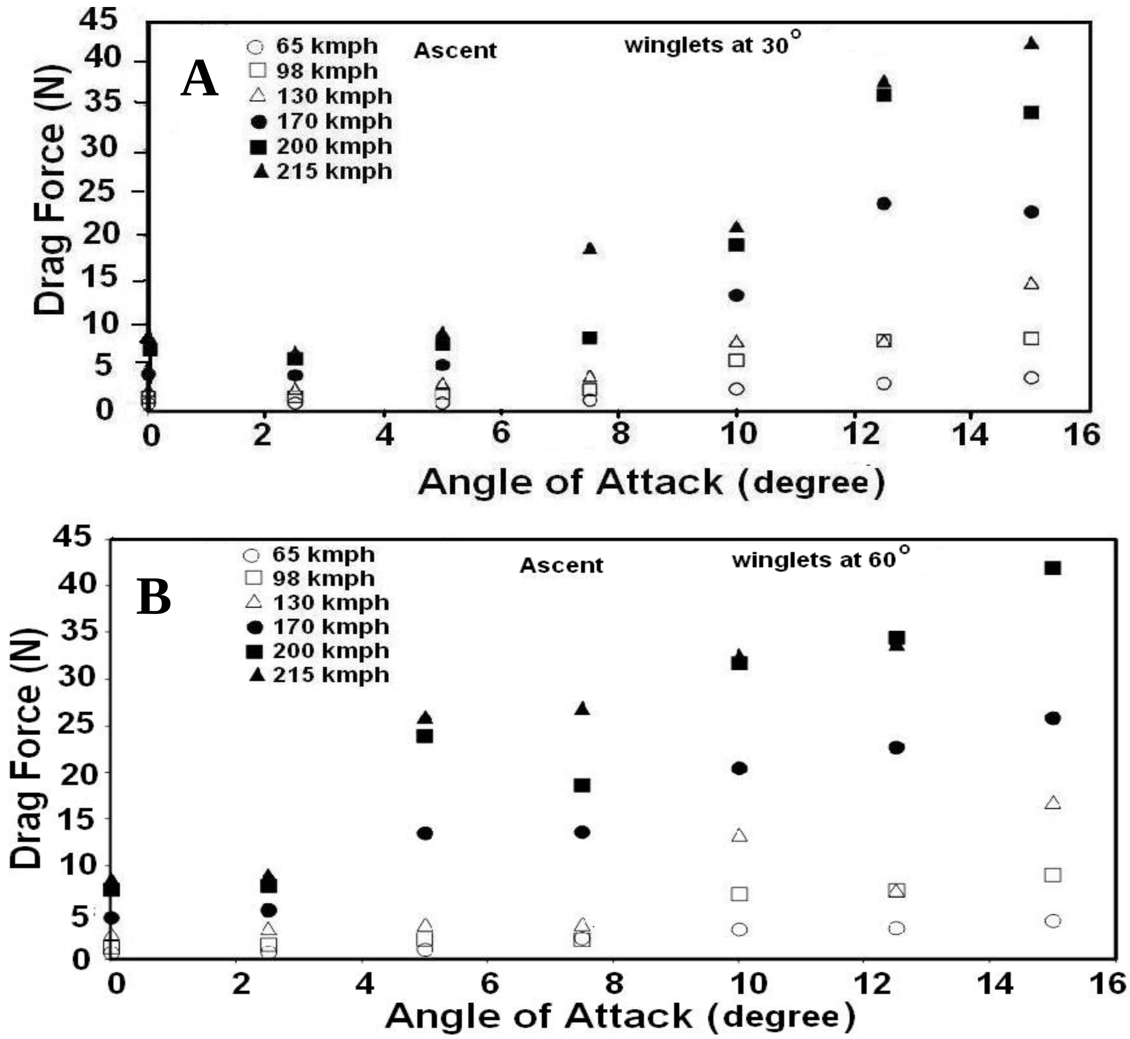


Figure 7. The drag versus angle of attack of a airplane with winglets during ascent. Winglet angle (A) 30^o and (B) 60^o.

VIII. CONCLUSION

From the present investigation, it can be concluded that the winglets will affect both the lift and drag characteristics of the airplane. The critical angle of lift can be achieved when the airplanes are supplemented with winglets at 30^o angle. The airplane with winglets at 60^o have better control because of improved drag characteristics.

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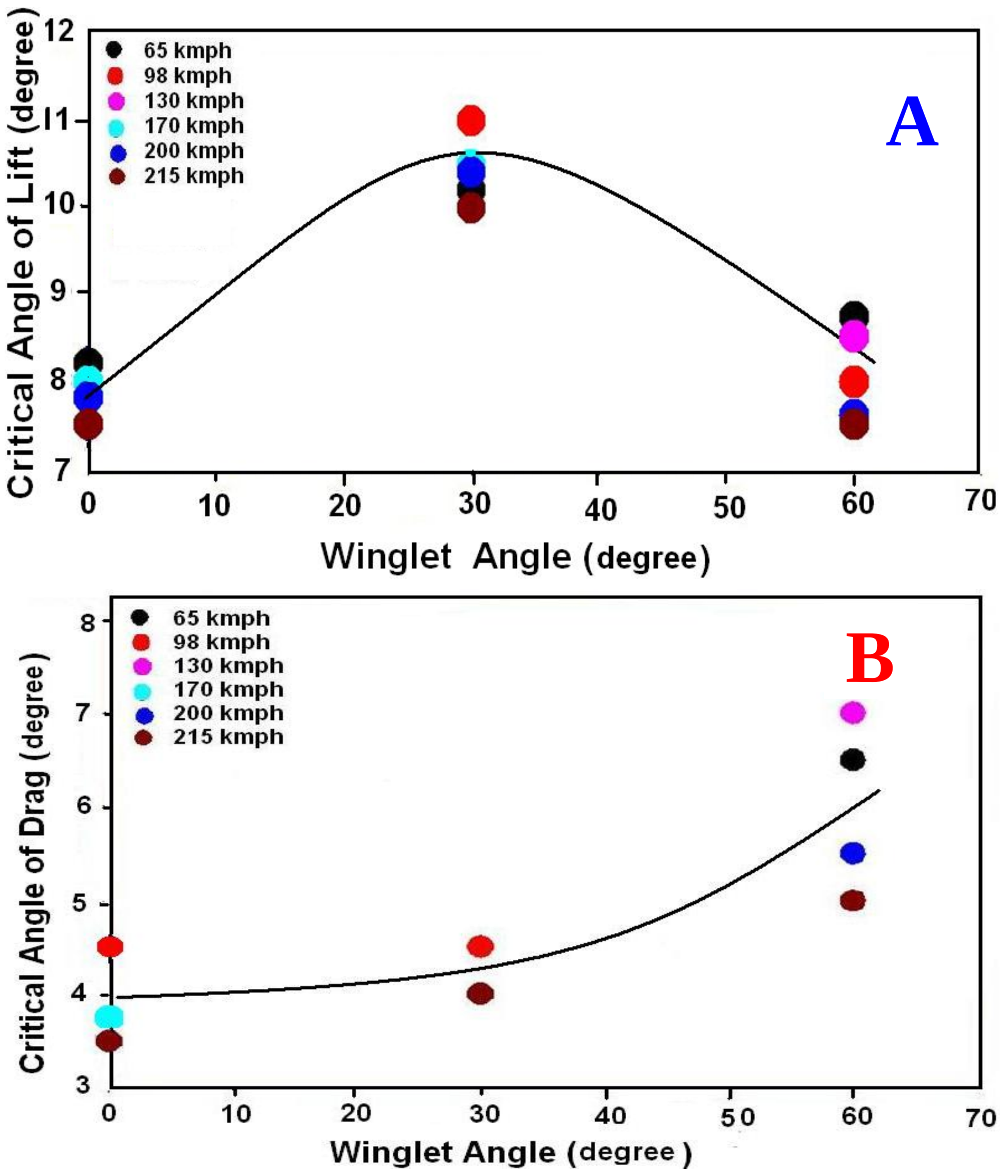

Figure 8. The critical angle of attack of (A) lift and (B) Drag versus the winglet angle of an airplane during its ascent.

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