ANALYSIS OF WINGTIP VORTEX AND MITIGATION BY USING WINGLETS

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Abstract: *Airplanes have played a crucial role in the industrial and commercial development. Therefore it is necessary to have an efficient system for transit through air. The most important component of an airplane is its wing. The aerofoil shape of the wing facilitates the creation of the lift and because of this, it actually flies. Therefore in the design of a wing, it is to be taken into consideration that it has minimal losses. One such loss of lift is due to the vortices produced at the wing tips on the wings. Wingtip vortices are circular patterns of rotating air left behind a wing as it generates lift. The wingtip vortex has been in existence since the beginning of flight. It has been an ever-increasing problem as the weight of each succeeding generation of aircraft has increased. In addition to the large drag associated with the lift-induced vortex, the vortex system of the large jumbo-jet aircraft of today has become a major problem to the air traffic controller in the terminal area as well as an unseen hazard to smaller aircraft during cruise flight. This is a result of not only the strength of the vortex but also the persistent nature of its flow. To fully comprehend the nature of lift induced wingtip vortex, the lift produced by a wing of an airplane should be closely examined. In this paper CFD is used in ANSYS to simulate the effects of such vortex on a scaled wing model of an airplane, and also simulates the effect of a vortex reducing device on the generation of lift and the vortex. The results can be useful in designing a better device for the reduction of wingtip vortices.*

Keywords: **Winglets , Trailing Vortex ,Angle of Attack**

1. Introduction

Wingtip vortices are circular patterns of rotating air left behind a wing as it generates lift. One wingtip vortex trails from the tip of each wing. Wingtip vortices are sometimes named trailing or lift-induced vortices because they also occur at points other than at the wing tips. Indeed, vorticity is trailed at any point on the wing where the lift varies span-wise (a fact described and quantified by the lifting-line theory); it eventually rolls up into large vortices near the wingtip, at the edge of flap devices, or at other abrupt changes in wing platform.

Wingtip vortices are associated with induced drag, the imparting of downwash, and are a fundamental consequence of three-dimensional lift generation. Careful selection of wing geometry (in particular, aspect ratio), as well as of cruise conditions, are design and operational methods to minimize induced drag. Wingtip vortices form the primary component of wake turbulence. Depending on ambient atmospheric humidity as well as the geometry and wing loading of aircraft, water may condense or freeze in the core of the vortices, making the vortices visible.

When a wing generates aerodynamic lift the air on the top surface has lower pressure relative to the bottom surface. Air flows from below the wing and out around the tip to the top of the wing in a circular fashion as shown in fig . An emergent circulatory flow pattern named vortex is observed, featuring a low-pressure core.

The trailing vortex is a continuation of the wing-bound vortex inherent to the lift generation. If viewed from the tail of the airplane, looking forward in the direction of flight, there is one wingtip vortex trailing from the left hand wing and circulating clockwise, and another one trailing from the right-hand wing and circulating anti-clockwise. The result is a region of downwash behind the aircraft, between the two vortices. The two wingtip vortices do not merge because they are circulating in opposite directions. They dissipate slowly and linger in the atmosphere long after the airplane has passed. They are a hazard to other aircraft, known as wake turbulence.

1.1 Vortex Affecting Aircraft

The pressure imbalance that produces lift creates a problem at the wing tips. The higher-pressure air below a wing spills up over the wing tip into the area of lower pressure air above. The wing's forward motion spins this upward spill of air into a long spiral, like a small tornado, that trails off the wing tip. These wing tip vortices create a form of pressure drag called vortex drag. Vortices reduce the air pressure along the entire rear edge of the wing, which increases the pressure drag on the airplane. The energy required to produce a vortex comes at the expense of the forward motion of the airplane. Tilting the airplane's wings upward makes the vortices stronger and increases vortex drag. Vortices are especially strong during takeoff and landing, when an airplane is flying slowly with its wings tilted upward.

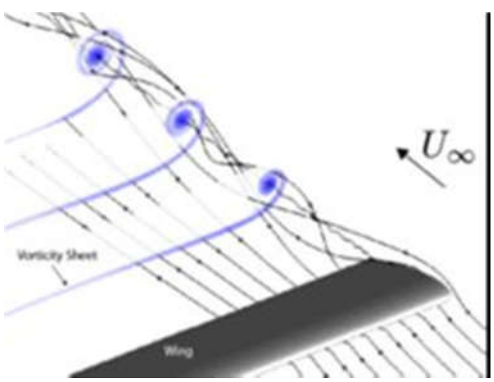

Fig.1 : Generation of trailing vortices

1.2 Wake Turbulence

Wake turbulence is turbulence that forms behind an aircraft as it passes through the air. This turbulence includes various components, the most important of which are wingtip vortices and jetwash. Jetwash refers simply to the rapidly moving gases expelled from a jet engine; it is extremely turbulent, but of short duration. Wingtip vortices, on the other hand, are much more stable and can remain in the air for up to three minutes after the passage of an aircraft. Wingtip vortices occur when a wing is generating lift. Air from below the wing is drawn around the wingtip into the region above the wing by the lower pressure above the wing, causing a vortex to trail from each wingtip. Wake turbulence exists in the vortex flow behind the wing. The strength of wingtip vortices is determined primarily by the weight and airspeed of the aircraft. Wingtip vortices make up the primary and most dangerous component of wake turbulence.

Fig.2 : Wake Turbulence

1.3 Winglets

The term "winglet" was previously used to describe an additional lifting surface on an aircraft, e.g., a short section between wheels on fixed undercarriage. The upward angle of the winglet, its inward or outward angle (or toe), as well as its size and shape are critical for correct performance and are unique in each application. The wingtip 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 wingtip vortex to an apparent thrust. This small contribution can be worthwhile over the aircraft's lifetime, provided the benefit offsets the cost of installing and maintaining the winglets. Another potential benefit of winglets is that they reduce the intensity of wingtip vortices, which trail behind the plane and pose a hazard to other aircraft. Minimum spacing requirements between aircraft operations at airports is largely dictated by these factors. Aircraft are classified by weight because the vortex strength grows with the aircraft lift coefficient, and thus, the associated turbulence is greatest at low speed and high weight. Winglets and wingtip fences also increase efficiency by reducing vortex interference with laminar airflow near the tips of the wing, by 'moving' the confluence of low-pressure (over wing) and high-pressure (underwing) air away from the surface of the wing. Wingtip vortices create turbulence, originating at the leading edge of the wingtip and propagating backwards and inboard. This turbulence 'delaminates' the airflow over a small triangular section of the outboard wing, which destroys lift in that area. The fence/winglet drives the area where the vortex forms upward away from the wing surface, since the center of the resulting vortex is now at the tip of the winglet.

Fig.3: Wings with Winglet

1.4 Angle of Attack

In fluid dynamics, angle of attack is the angle between a reference line on a body (often the chord line of an airfoil) and the vector representing the relative motion between the body and the fluid through which it is moving. Angle of attack is the angle between the body's reference line and the oncoming flow. This article focuses on the most common application, the angle of attack of a wing or airfoil moving through air. In aerodynamics, angle of attack specifies the angle between the chord line of the wing of a fixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere. Since a wing can have twist, a chord line of the whole wing may not be definable, so an alternate reference line is simply defined. Often, the chord line of the root of the wing is chosen as the reference line. Another choice is to use a horizontal line on the fuselage as the reference line (and also as the longitudinal axis). Some authors do not use an arbitrary chord line, but use the zero lift axis, whereby zero angle of attack corresponds to zero coefficient of lift by definition.

2. Methodology

2.1 Model

The model used in this simulation is a scaled model of a Boeing 737-700 commercial aircraft. Models of the aircraft with and without winglets are used here. The specification of the scaled model against the specification of the original aircraft is given in table 1 below .

SPAN	28.35 m	237.4 mm
ROOT CHORD	7.32 m	100 mm
TIP CHORD	1.6 m	23 mm
DIHEDRAL ANGLE	6 ^{o}	6 ^{o}
SWEEP ANGLE	25 ^{o}	25 ^{o}

Table 1 : Wing Specifications

2.2 Modelling of Wings

The NACA airfoils are shapes of the cross section of the wing developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties. The NACA four-digit wing sections define the profile by first digit describing maximum camber as percentage of the chord, second digit describing the distance of maximum camber from the airfoil leading edge in tens of percents of the chord and last two digits describing maximum thickness of the airfoil as percent of the chord. The co-ordinates of the NACA airfoils was taken from [5]. The co-ordinates was then exported to Solid-Works to create a closed contour and was then lofted using various cross section and according to the scaled geometry to generate the wing model. The NACA profile of the scaled wing is of NACA 2415 wing.

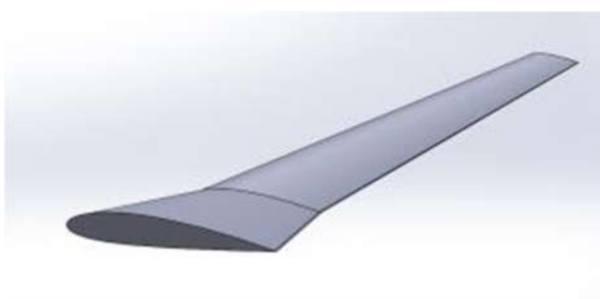

Fig.4: Wing Model

2.3 Modelling with winglets

Winglets were added to the second model with the dimensions as given in fig 5. Blended winglets of 25^{o} with the vertical were modelled with tip chord 18mm using lofting command in SolidWorks.

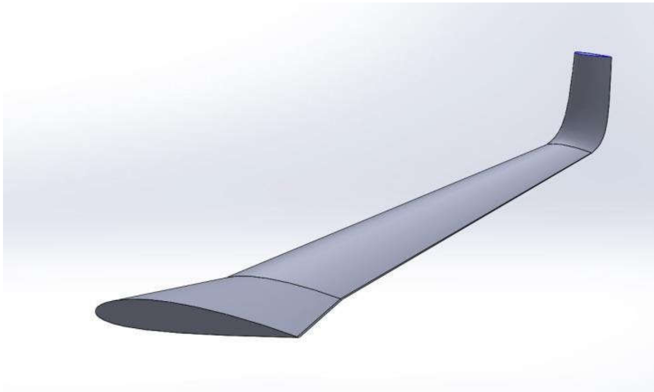

Fig.5: Wing with Winglet Model

2.4 Analysis

The analysis of the modelled wing with and without winglets were done in ANSYS Fluent software. A total of six simulation runs were done- 3 angle of attacks at 0^o, 3^o and 6^o

2.5 Meshing

Meshing was done using ANSYS software. The mesh used was unstructured grid mesh. Relevance was set to -100, and was meshed. Sizing was inserted into the meshing with a body of influence and element size set to 7mm. The total number of mesh elements is given below. The body of influence was given to refine the mesh at the region where the vortex is significant. The fluid domain are given in the figure 6 with the respective naming. The domain was named as farside, symmetry and outlet. In the setup, the growth rate of the mesh is set equal to 1.2 and the minimum size is 0.2mm.

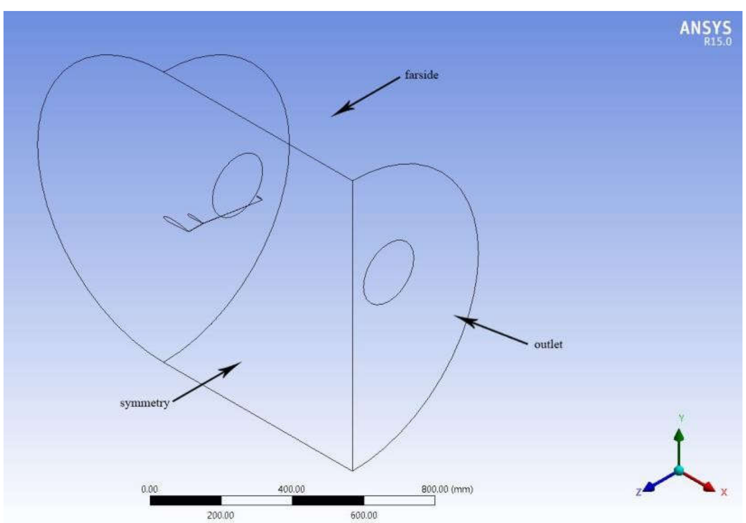

Fig.6: Domain

The Final mesh details are:

1. No. of nodes = 161704
2. No. of elements = 949385

2.6 Set up

The energy equation was turned ON in the modes tab in the setup. The turbulence model was switched to Spalart Allmaras. The Spalart–Allmaras model is a one-equation model that solves a modelled transport equation for the kinematic eddy turbulent viscosity. The Spalart–Allmaras model was designed specifically for aerospace applications involving wall-bounded flows and has been shown to give good results for boundary layers subjected to adverse pressure gradients.

The characteristics of air are given as:

1. Density of air is calculated from the ideal gas to facilitate pressure far field boundary condition
2. Specific heat = 1.00643 kJ/kgK
3. Thermal conductivity of air = 0.0242 W/mK
4. Viscosity = 1.7894e-0.5 kg/ms

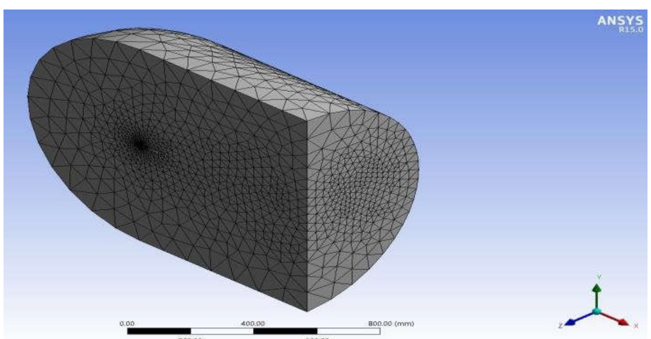

Fig. 7: Final mesh of the domain

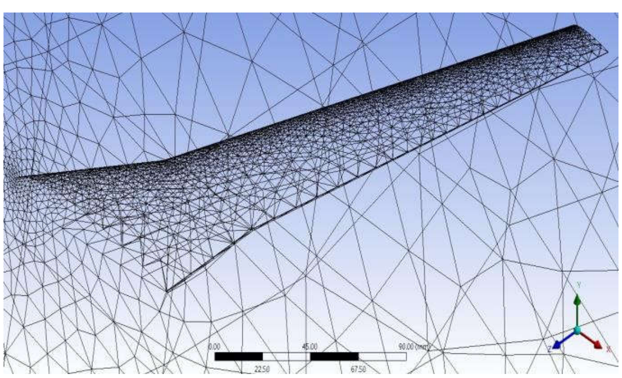

Fig. 8: Final mesh of the wings

2.7 Boundary conditions

Pressure far-field conditions are used in FLUENT to model a free-stream condition at infinity, with free-stream Mach number and static conditions being specified. The pressure far-field boundary condition is often called a characteristic boundary condition, since it uses characteristic information (Riemann invariants) to determine the flow variables at the boundaries. To effectively approximate the infinite extend condition, the boundary is kept far from the geometry. This justifies the size of the fluid domain. The settings are:

Pressure = 101325 Pa

Mach number = 0.23

Temperature = 300K

ANGLE OF ATTACK	X- COMPONENT	Y- COMPONENT
0^o	1	0
3^o	0.9986	0.0523
6^o	0.9945	0.1045

Table 2 : Flow direction

3. Results

The plots at several condition were obtained from the simulation. The pressure distribution on the wing, the core vortex region and the streamline plots at 3 angle of attacks with and without winglets were taken. It is to be noticed that there is reduction in the vortices formed at the wingtip as the winglets are attached. It can be visually verified from the given plots. The coefficient of lifts against different angle of attacks were also plotted. We can infer from that,there is a slight increase in the lift when winglets are attached to it. The coefficient of lifts values were taken from the software after steady state was attained. It can also be inferred from the result that the vortex occurs at the whole wing itself.

3.1 Core Vortex Region

The following figures shows the core vortex regions in the domain. It can also be noticed that the vortex regions are also active on the wing itself. Figure 9 shows the vortex region at 0^0 angle of attack. The vortex regions are not that significant at 0^o AOA.

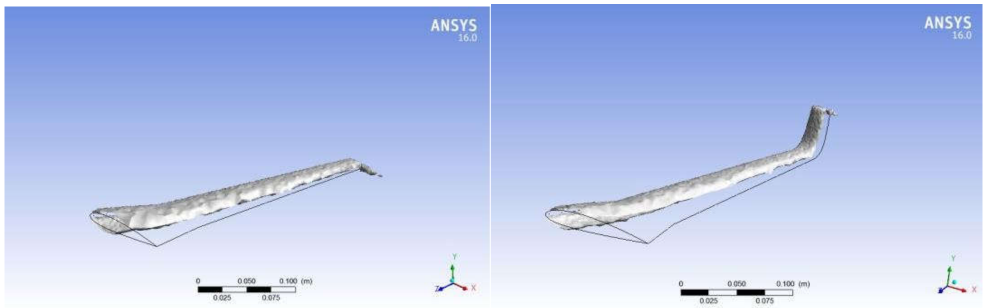

Fig. 9: Core vortex region at 0º Angle of attack with and without winglets

From figures 11 and 12, i.e., at higher angle of attacks of 3º and 6º, the vortex regions without the winglets are bigger and trailing vortices are much more visible.

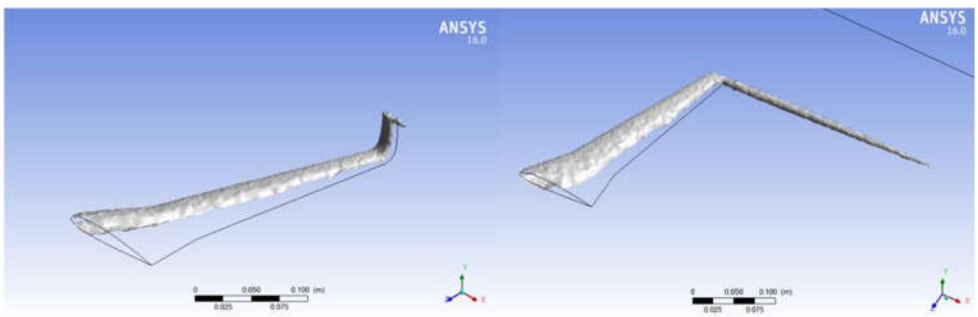

Fig.10: Core Vortex region at 3º AOA with and without winglets

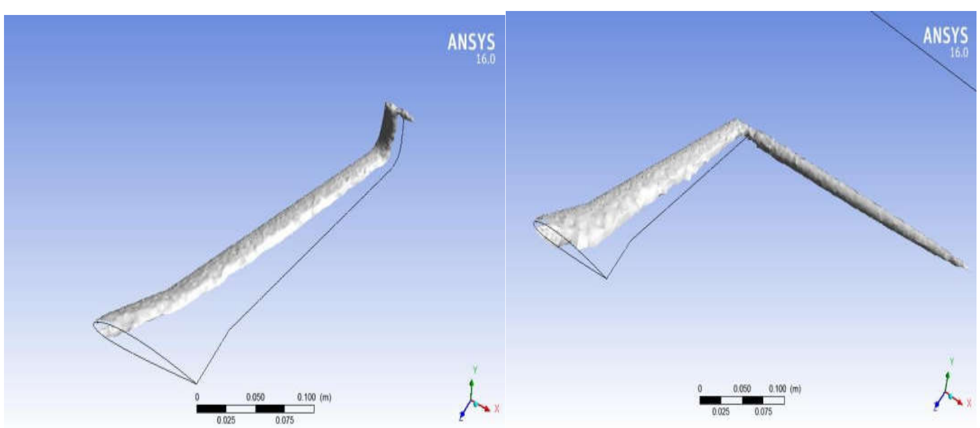

Fig. 11: Core Vortex region at 6º AOA with and without winglets

3.2 Streamlines

The following figures 12, 13 and 14 shows the streamlines of the trailing vortices with and without the winglet. Although the streamlines does not show much vortex region at 0º, there is significant visible trails at 3º and 6º

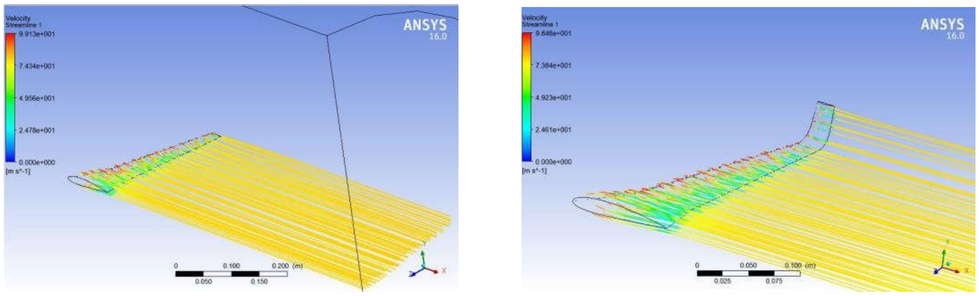

Fig.12: Velocity streamline 0º AOA

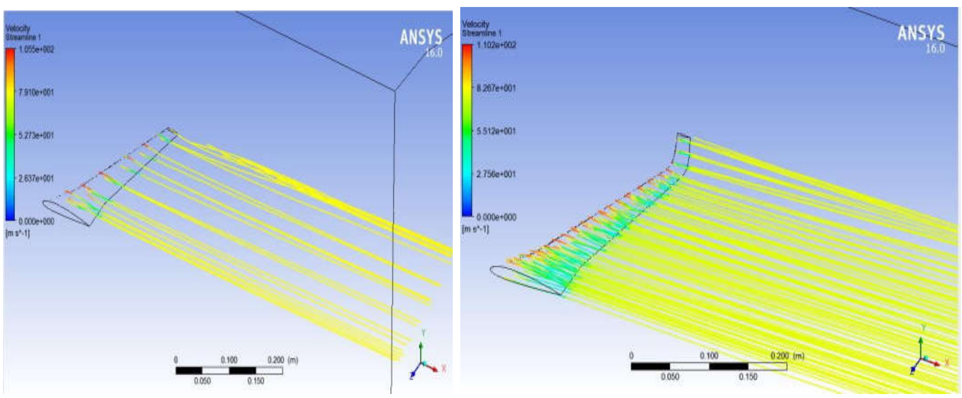

Fig.13: Velocity streamline 3º AOA

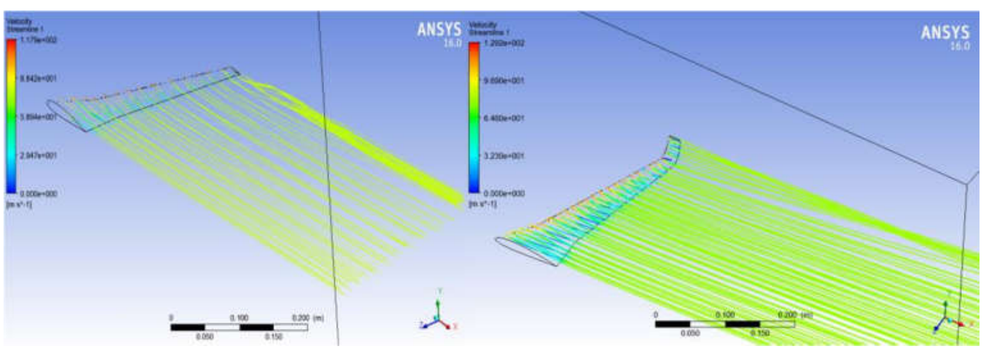

Fig.14: Velocity streamline 6º AOA

3.3 Variation of Co-efficient of Lift

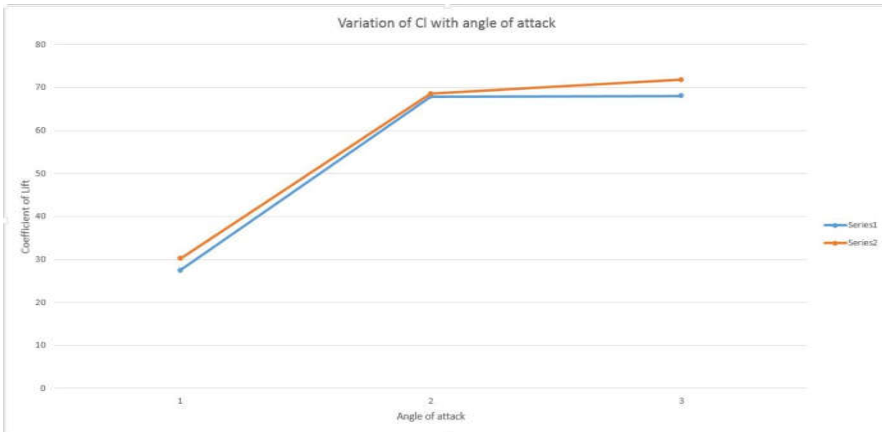

Fig.15: Coefficient of lift vs AoA, Series 1- with winglets, Series 2- without winglets

4. Conclusion

In this paper we have shown how the trailing vortices formed at the wingtips can be reduced to some extend by the use of winglets. The results have clearly shown the reduction of the trailing vortices. The induced drag created at the wingtips can be reduced placing a winglet at the wingtips which leads to the increase in L/D ratio, fuel efficiency. The wing without winglet experiences high amount of induced drag due to the boundary layer separation which leads to vortices created at tip so by attaching the winglet the boundary layer separation is delayed which causes less amount of vortices.

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