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Contrive and Analysis of Spiroid Winglet for Drag Contraction

Anwar Ansari[1], Antony Samuel Prabu G[2], Sudig Lal Joshi[3], Pradip Sah Teli[4]
[1, 3, 4]UG Scholar, Aeronautical Engineering Department, MVJ College of Engineering, ITPL, Channasandra, Bangalore-560067, Karnataka, India.
[2]Asst. Professor of Aeronautical Engineering Department, MVJ College of Engineering, ITPL, Channasandra, Bangalore-560067, Karnataka, India.

***Abstract:** The aim of this Project is to reduce the aircraft's drag by partial recovery of the tip vortex energy. it is obvious that the results of the wing with the spiroid winglet has overall better aerodynamic characteristics then the aerodynamics characteristics of wing model alone. The Coefficient of lift of the model is increased due to the addition the spiroid winglet and the Coefficient of drag has been reduced due to the addition the spiroid winglet. As we can observe that as the lift increases the drag also increases. And the amount of lift decreased of wing with winglet with respect to the normal wing is due to the extra profile, surface due to the addition of the winglet which increases the profile drag.*

I. INTRODUCTION

Wingtip devices are usually intended to improve the efficiency of fixed-wing aircraft. There are several types wingtip devices, and although the function in different manners, the intended effect is always to reduce the aircraft's drag by partial recovery of the tip vortex energy. Wingtip devices can also improve aircraft handling characteristics and enhance safety for following aircraft. Such devices increase the effective aspect ratio of a wing without materially increasing the 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.

In aeronautical engineering, drag reduction constitutes a challenge and there is room for improvement and innovative developments. The drag breakdown of a typical transport aircraft shows that the lift-induced drag can amount to as much as 40% of the total drag at cruise conditions and 80–90% of the total drag in take-off configuration. One way of reducing lift-induced drag is by using wingtip devices. By applying biomimetic abstraction of the principle behind a reducing lift-induced drag is by using wingtip devices. By applying biomimetic abstraction of the principle behind a bird’s wingtip feathers, we study spiroid wingtips, which look like an extended blended wingtip that bends upward by360 degrees to form a large rigid ribbon.

This is evident that aviation industry has been striving to increase efficiency and performance of aircrafts for so long in order to make fuel efficient journeys which can drastically increase profit and open doors for new routes. Winglets have known to be used on aircraft for so long to reduce lift-induced drag. Winglets are one of the most important yet simple innovation in aviation industry. These are actually extension of wings at the tip to avoid flow to move span-wise from under to the wing to the top of the surface. If this span-wise flow is not avoided then wingtip vortices are generated and they can be strong enough to reduce the aircraft lifting capabilities and these vortices also generate lift induced drag which is one of the major portion of drag.

Several winglets have been designed, tested and modified on aircrafts and they have served their purpose to quite an extent but there is always room for improvement in design features to improve aerodynamic performance. Present study deals with one of the recent winglet which is bio-inspired and is known as spiroid winglet. Spiroid winglet is one the most modern designs and also not significant work has been done on such winglets.

A. Methodology

The methods involved in the project are given as follows:-

1) Designing
2) Computational Fluid Dynamics Analysis
3) Post-processing

The geometry of the model was designed in OPEN VSP and then analysis was done in the VSP AERO. The computation results obtained was post-processed.

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First a scheme of CFD analysis that best fits our purpose must be analyzed. The first step of this procedure is to identify a CFD scheme that gives reasonably accurate results for our intended application. This is done by reproducing results of a research whose data is available for validation. For this purpose, one such paper was used to establish a working scheme for our purposes. The paper does a study on a clean wing and spiroid-tipped wing with the following parameters and same parameters were established for present research.

A study was carried out by Juel et al. titled as ‘Biometric spiroid winglets for lift and drag control’. This study included many benefits of spiroid winglets which incorporated reduction in lift-induced drag, increase in slope of 9.0 % in co-efficient of lift vs AoA curve and lift-to-drag enhancement. This research also concluded that introduction of spiroid winglets in aircrafts has few shortcomings as well. This includes increase in parasitic drag and weight of the aircraft but these factors can be compromised because benefits of introduction of spiroid winglets overcome its shortcomings.

B. Numerical Methodology

Fluid flow equation of general use in any study involving fluid as medium as discussed in this section. Continuity equation in its most basic form can be obtained by applying the principle of conservation of mass to a finite control volume fixed in space [12]. Ref to (1) is density and is volume

$$\frac{\partial \rho}{\partial t}\oiiint_{\forall} \rho d\forall + \oiint_{S} \rho \boldsymbol{V}.\boldsymbol{dS} = 0 \qquad (1)$$

Momentum equation is based on Newton’s second law which says that the rate of change of momentum of an object is equal to net force applied on that object. In equation form this can be written as follows. Ref to (2) F is force, m is mass and V is velocity.

$$F = \frac{d}{dt}(m\boldsymbol{V}) \qquad (2)$$

Momentum equations in partial differential form are given as Eq. (3), (4) & (5)

$$\frac{\partial(\rho u)}{\partial t} + \nabla.(\rho u\boldsymbol{V}) = -\frac{\partial p}{\partial x} + \rho f_x + F_{x,viscous} \qquad (3)$$

$$\frac{\partial(\rho v)}{\partial t} + \nabla.(\rho v\boldsymbol{V}) = -\frac{\partial p}{\partial y} + \rho f_y + F_{y,viscous} \qquad (4)$$

$$\frac{\partial(\rho w)}{\partial t} + \nabla.(\rho w\boldsymbol{V}) = -\frac{\partial p}{\partial z} + \rho f_z + F_{z,viscous} \qquad (5)$$

Energy equation is based on the first law of thermodynamics which states that energy can neither be created nor be destroyed , it can only change its form. Energy equation in partial differential form is given as Eq. (6)

$$\frac{\partial}{\partial t}\left[\rho\left(e + \frac{V^2}{2}\right)\right] + \nabla.\left[\rho\left(e + \frac{V^2}{2}\right)\boldsymbol{V}\right]$$

$$= \rho\dot{q} - \nabla.(p\boldsymbol{V}) + \rho(\boldsymbol{f}.\boldsymbol{V}) + \dot{Q}'_{viscous} + \dot{W}'_{viscous} \qquad (6)$$

C. Objectives

The objectives of this study are listed in detail as the followings:

1) Obtain the fundamental knowledge about spiroid winglet and its impact on aircraft aerodynamic performance.
2) Identify the optimum spiroid configuration in terms of shape, size, airfoil and sweep angle.
3) Analyze and improve the aerodynamic performance of the spiroid wing in terms of lift, drag, etc.
4) Compare the performance with a basic wing and a wing with spiroid winglet, in terms of pressure coefficients.
5) The main objective is to reduce the drag by partial recovery of wingtip vortex energy.

II. LITERATURE SURVEY

1) The first US patent on spiroid winglets was published by *Louis* et al. by the name of 'Spiroid-Tipped Wing'. It incorporated the very first spiroid wingtip design which was intended to be used for the minimization of lift induced drag and to alleviate noise effects associated with vortices that trail behind lifting objects. This basic design comprised a closed loop which initiates from wingtip at appropriate sweep and included angles to form a continuous and closed loop at the wingtip.
2) In this design it was established that the spiroid configuration should be such that for fixed wing aircraft the spiroid configuration on the right is opposite to that of left hand side. This design incorporates airfoil cross section with specified thickness, camber and twist.
3) Further organized study on spiroid winglets was published by the name of 'Parametric investigation of non-circular spiroid winglets'. This paper presented the detailed study of spiroid winglets that produced efficient aerodynamic performance results in terms of L/D and induced drag etc.
4) In this paper various simulations were carried out to check for the aerodynamic performance of each design and research was concluded by establishing the fact that FWD spiroid gave better results when compared to other types of winglets. This study also concluded that spiroid winglets are superior when compared to other two wingtip configurations in terms of vortex suppression and drag reduction.
5) In another paper by GiftonKoil et al. titled as Design and Analysis of Spiroid Winglets the fact was established that induced drag comprises 40% of the total drag in cruise phase and 80-90% of the total drag in take-off phase of flight so it's a serious threat to the performance of aircraft in both phases.
6) Study was further enhanced to compare the performance of spiroid winglets with the dual feather winglets by Vinay et al. titled as 'CFD Analysis of Spiroid Winglets and Dual Feather Winglets'. In this study potential of spiroid and dual feather winglets are taken into consideration by using biomimetic abstraction principle of a bird's wingtip feathers, study of spiroid and dual feather winglets which look like extended blended winglets .
7) Both the types of winglets were tested on Boeing 737 wing for various AoA and this study concluded that spiroid winglets show better performance than dual feather winglets in terms of stalling angle, L/D ratio etc.

A. *Existing System And Its Disadvantages*

1) Adding winglets to an existing design puts stresses on the existing spar ends that they weren't designed for. Fortunately, they're stronger than may be necessary at the ends due to various mechanical and implementation requirement, allowing some additional load. But a "full size" blended winglet should be designed in from the start to ensure sufficient strength, minimal weight and avoidance of aero-elasticity (flutter).
2) One problem in winglet addition is that they are prone to flutter. Another potential drawback to winglets is that of gate spacing at the ramp. Winglets can make for a much larger footprint at the gate.
3) This could, in turn, make 5 airplanes without winglets into 2-3 planes with winglets, depending on spacing requirements and availability. The current winglet adds to the weight at the end of the wings increases inertia (roll inertia), reducing maneuverability.

B. *Proposed System And Its Advantages*

1) The proposed system is spiroid winglet which is mostly used in STOL (Short Take Off And Landing) aircraft. They are mostly effective in Take-off. One of the best benefits of the spiroid winglet's possible ability to nearly eliminate the wingtip vortex would be in air traffic flow management at major airports.
2) As it is right now, aircraft spacing is necessary to allow for wake-vortex dissipation for the following aircraft. Aircraft with spiroid winglet would allow following aircraft to be spaced more closer in effect easing some of the congestion at major airports and improving the flow efficiency.
3) They have Improved the take-off performance and Less takeoff noise. Reduced separation distances and improved safety during take-off and landing operations due to wake vortex turbulence reduction.
4) In case of spiroid tipped wing, API has made a flight test on Gulfstream II in 1993 and they achieved more than 10% of fuel efficiency during the cruise conditions2. Raked wingtip is a unique design for Boeing B737 family and it has improved the aircraft's performance by reducing the take-off field length, improved fuel efficiency and good climb performance.

III. WINGTIP DEVICES

Wingtip devices are usually intended to improve the efficiency of fixed-wing aircraft. There are several types wingtip devices, and although the function in different manners, the intended effect is always to reduce the aircraft's drag by partial recovery of the tip vortex energy. Wingtip devices can also improve aircraft handling characteristics and enhance safety for following aircraft.

Such devices increase the effective aspect ratio of a wing without materially increasing the 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.

Some of the conventional wingtips used in the aircrafts are mentioned below

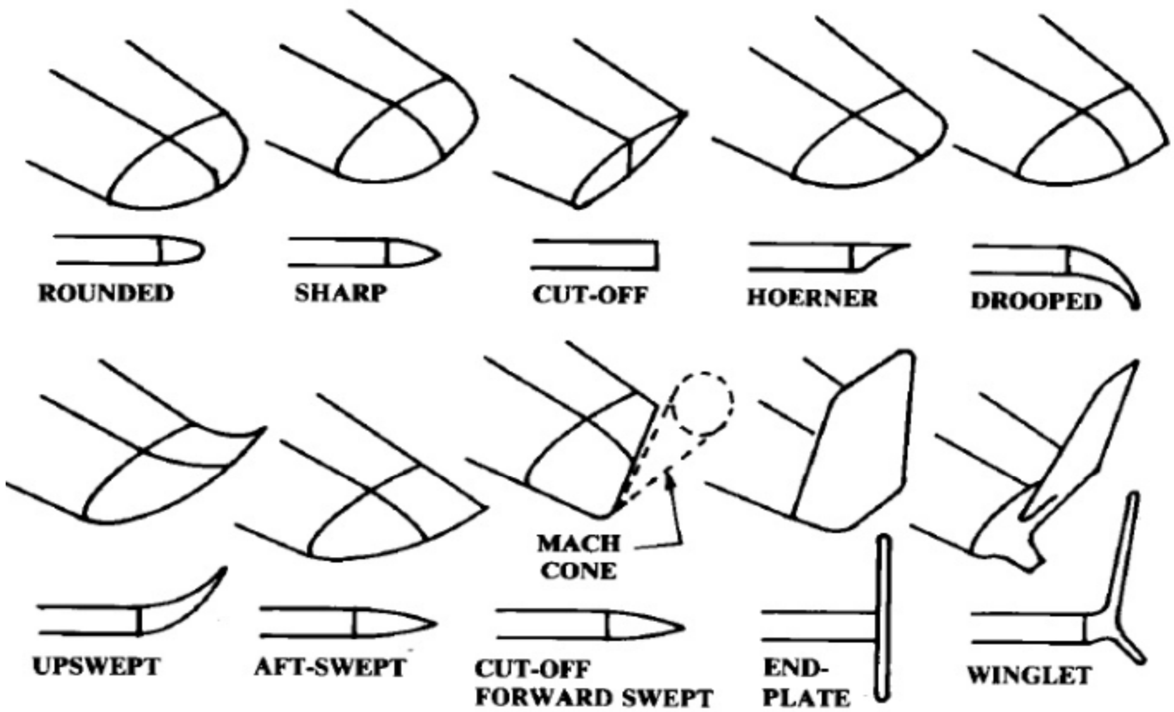

Figure 1 3.1 Conventional wingtip devices

A. Winglets

The term "winglet" was previously used to describe an additional lifting surface on an aircraft. Another potential benefit of winglets is that they reduce the strength 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 (e.g. "Light," "Heavy," etc.) because the vortex strength grows with the aircraft lift coefficient, and thus, the associated turbulence is greatest at low speed and high weight. The drag reduction permitted by winglets can also reduce the required takeoff distance.

Winglets and wing 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 (under wing) 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 de-laminates 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.

Winglets reduce wingtip vortices, the twin tornados formed by the difference between the pressure on the upper surface of an airplane's wing and that on the lower surface. High pressure on the lower surface creates a natural airflow that makes its way to the wingtip and curls upward around it. When flow around the wingtips streams out behind the airplane, a vortex is formed.

These twisters represent an energy loss and are strong enough to flip airplanes that blunder into them. Winglets produce an especially good performance boost for jets by reducing drag, and that reduction could translate into marginally higher cruise speed. But most operators take advantage of the drag reduction by throttling back to normal speed and pocketing the fuel savings.

B. Biomemetics from Bird's Wingtip Feathers to Winglets on Airplanes

In this manuscript we tackle the problem of lift-induced drag and tip vortices mitigation by looking at the analogous problem in nature. Birds' wingtip feathers with their large variety in morphology are biological examples to examine. It can be seen how the wingtip feathers of different birds are bent up and separated like the fingers of a spreading hand. This wingtip feathers slotted configuration is thought to reduce the lift-induced drag caused by wingtip vortices. Tucker showed for the first time that the presence or absence of these tip slots has a large effect on the drag of birds. He found that the drag of a Harris hawk gliding freely at equilibrium in a wind tunnel increased markedly when the tip slots were removed by clipping the primary feathers. The slots also appear to reduce drag by vertical vortex spreading, because the greater wingspan and other differences in the bird with intact tip slots did not entirely account for its lower drag.

It is worth mentioning that we do not use any winglet design or optimization criteria when designing the proposed spiroid winglet. Instead, it is built in a very heuristic way, by just splitting the wingtip with two winglets and joining them with an additional horizontal segment. In order to smoothen the transition between the wing and the spiroid winglet, a small joining section is added. Then, the spiroid winglet is attached to the clean wing and an extensive campaign of numerical simulations using the clean wing and the wing with the spiroid winglet is conducted.

At this point, it becomes clear that if, by using this simple biomimetics approach we are able to obtain some benefit in terms of lift-induced drag reduction, wingtip vortices intensity reduction and lift enhancement, the approach proves to be worthwhile and further wingtip design and optimization deserves to be carried out.

Finite span wings generate lift due to the pressure imbalance between the bottom surface (high pressure) and the top surface (low pressure). However, as a byproduct of this pressure differential, cross flow components of the velocity are generated. The higher pressure air under the wing flows around the wingtips and tries to displace the lower pressure air on the top of the wing.. These structures are referred to as wingtip vortices and very high velocities and low pressure exist at their cores.

These vortices induce a downward flow, known as the downwash and denoted by w. This downwash has the effect of tilting the free-stream velocity to produce a local relative wind, which reduces the angle of attack (α) that each wing section effectively sees; moreover, it creates a component of drag, the lift-induced drag.

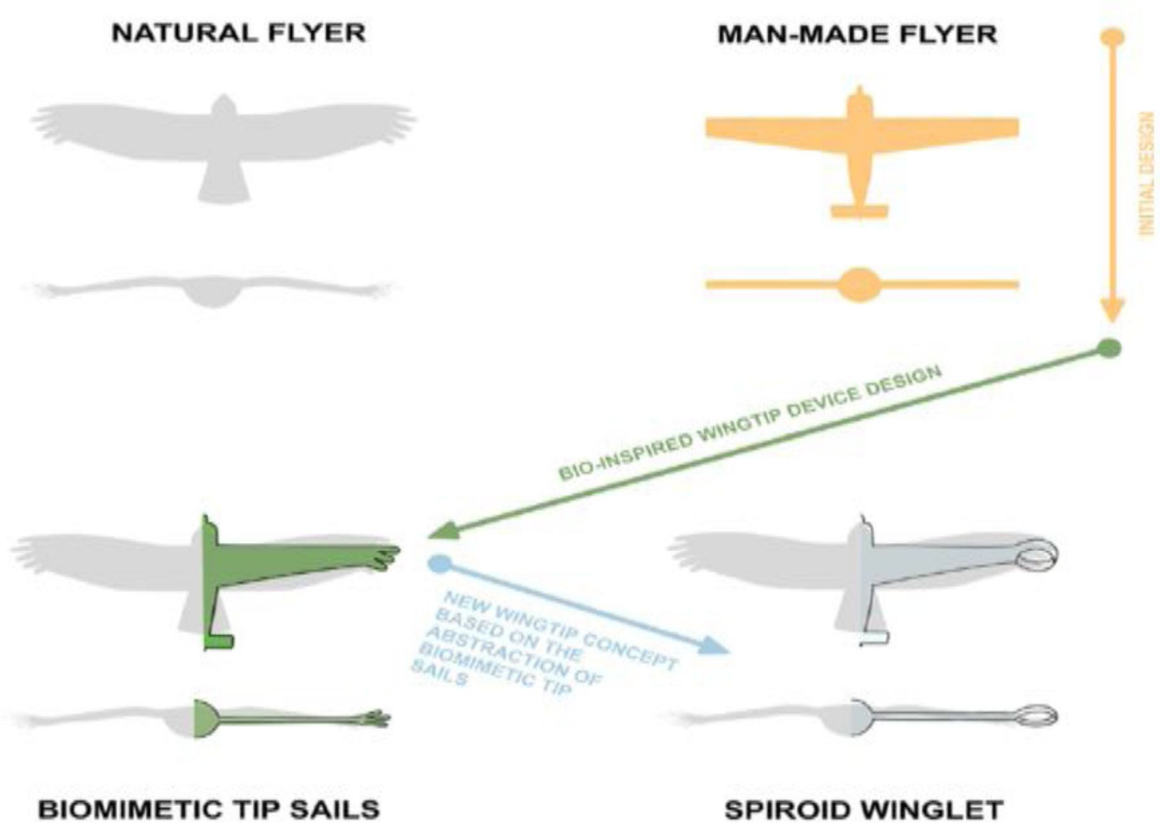

Figure 2 3.2 Winglet Design By Biomimetics Abstraction

C. Winglets and Wingtip devices

After the invention of winglet by Whitcomb, many types of winglets and tip devices were developed by aircraft designers. Some of the inventions of winglets by the respective aircraft manufacturer are discussed in the following section.

1) End plate winglet
2) Whitcomb winglet
3) Blended winglet
4) Spiroid winglet
5) Sharp-raked winglet
6) Hoerner-tip wing

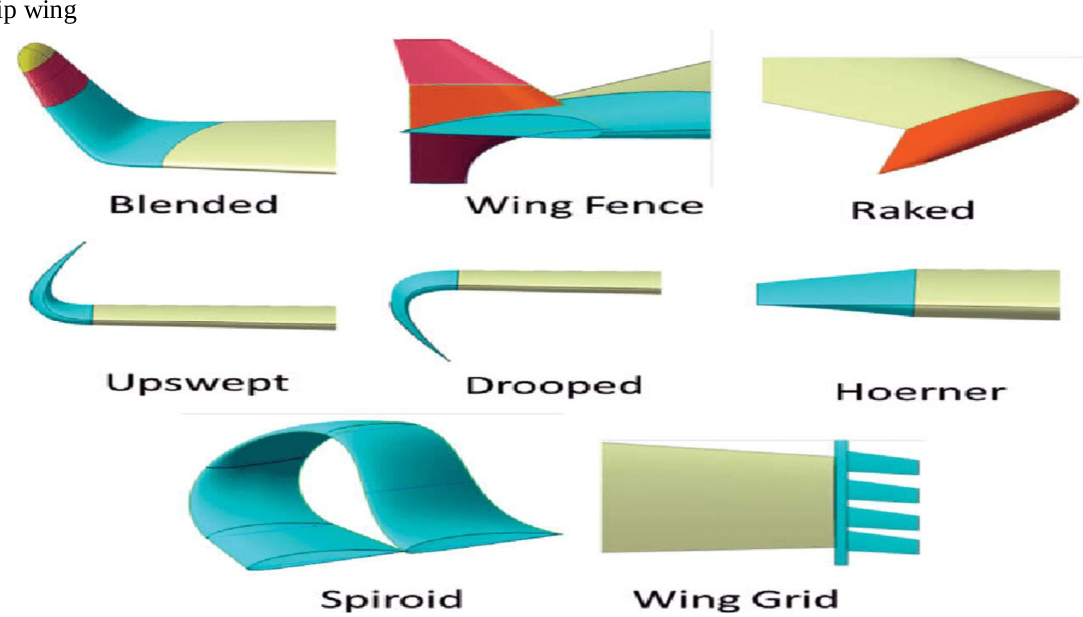

Figure 3 3.3 Types of winglet

D. Spiroid Winglet

Spiroid winglet or wingtips used to reduce the effect of wingtip vortices at tip of wing. Spiroid winglets or wingtips are functionally made to reduce vortices footprint made by wing.

Gratzer has developed the spiroid-tipped wing technology and got the patent in 1992. One end of the spiroid tip is attached with forward part of the wing tip and continues to form a spiral loop which ends at the aft portion of the wing tip.

Hence it looks oval shaped when viewed from front. Spiroid tipped wing was created to reduce the induced drag and also to reduce the noise effects associated with the tip vortices. API has made their flight test in Dassault Falcon 50 with spiroid tipped wing.

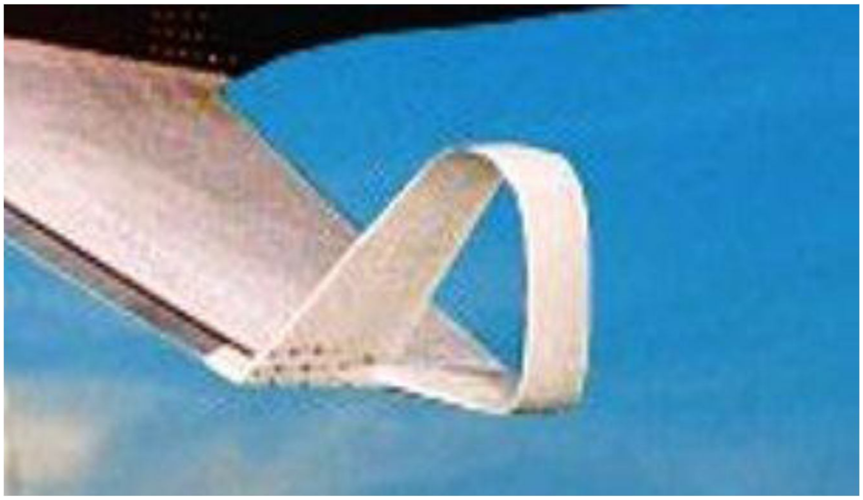

Figure 4 3.4 Spiroid winglet

E. Advantages of Winglets and Wingtip Devices

a) Ever since the winglet technology has been introduced, the advantages were being published. Dr. Whitcomb has performed an experiment with the winglet in which the winglet shows reduction in induced drag about 20%. In 1977, Heyson made an experiment to study the advantages of Whitcomb's winglet.

b) His results indicate that winglets would reduce the induced drag more than tip extension and will be at its best when it is nearly vertical. Later in 1980, R.T Jones made a research in winglets to determine its effect over the induced drag using Trefftz-plane theory and concluded that the vertical length of the winglet should be twice than the length of horizontal extension in order to have its gain over tip extension.

c) Aviation Partners Boeing announced that their APB blended winglet has saved more than 2 billion gallons of fuel in 2010. APB also added that the winglets could save 5 billion gallons of fuel by 2014 which also represents the total reduction in carbon emission. Indeed, APB blended winglet on B737 showed increased in range of about 5-7% due to overall reduction in drag.

d) In case of spiroid tipped wing, API has made a flight test on Gulfstream II in 1993 and they achieved more than 10% of fuel efficiency during the cruise conditions2. Raked wingtip is a unique design for Boeing B737 family and it has improved the aircraft's performance by reducing the take-off field length, improved fuel efficiency and good climb performance.

e) Raked wing tip could provide 2 % reduction in fuel burn which is compensated by 1.3 million of fuel saving per year and 3.9 million of carbon-dioxide emission per year3. Aviation Partners Boeing announced that their APB blended winglet has saved more than 2 billion gallons of fuel in 2010.

1) Summary

a) Reduced induced drag

b) Improved fuel efficiency

c) Increased range and more payload

d) Reduced noise effects due to vortex effects

e) Reduced the amount of carbon emissions

f) Helpful in air traffic control.

g) They have Improve take-off performance

h) Spiroid winglets save airlines lots of fuel by reducing drag

i) According to Aviation Partners, "The Spiroid eliminates concentrated wingtip vortices, which represent nearly half the induced drag generated during cruise."

j) Spiroid winglet or wingtips used to reduce the effect of wingtip vortices at tip of wing.

IV. INDUCED DRAG PHENOMENA

In Aerodynamics, the four main forces which act on aircraft during the flight are Lift, Drag, Thrust and Weight. Drag is one of the most critical phenomena amongst all and is the opposing force of aircraft's forward motion.

It could be classified briefly in to parasite drag (not due to lift) and lift induced drag. In a civil transport aircraft, frictional drag and induced drag together contributes more than 80% of the total drag as represented in figure 8 [19], but the other forms of drag could not be excluded certainly.

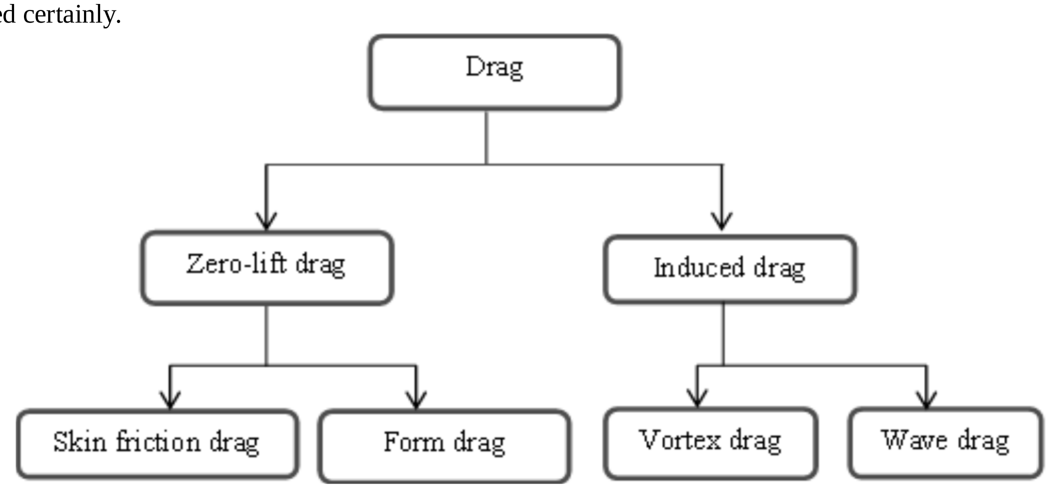

Figure 5 4.1 Different forms of Drag

Induced drag produces kinetic energy which will cause the downward motion perpendicular to the airflow. This downward force could be recognized as the lift vector and this component is regarded as the induced drag. Induced drag differs from the other forms of drag through a phenomenon of converting the dissipated kinetic energy into heat gradually. Vortex wake is a unique feature of induced drag. Induced drag differs from the other forms of drag through a phenomenon of converting the dissipated kinetic energy into heat gradually.

Vortex wake is a unique feature of induced drag. Dough Mclean has proposed the misinterpretations of the induced drag and the vortex wake produced by the wing. Normally the vortex wake is produced from the flow pattern due to the difference in velocities at upper and lower surface of an aircraft. From the figure , it is shown that the velocities at the down surface move towards the upper surface and thus it create a circular flow pattern.

This flow pattern is responsible for the vortex sheet that produced from the entire span of the wing fig.

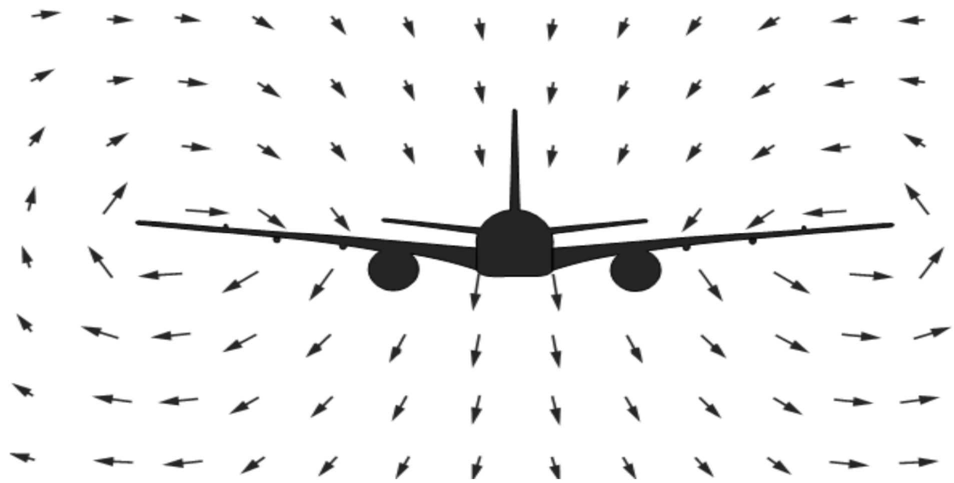

Figure 6 4.2 Flow pattern of the velocity

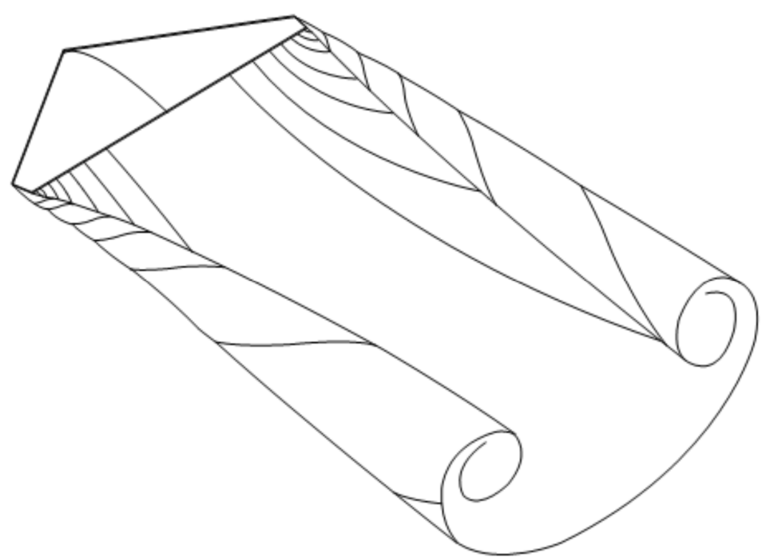

Figure 7 4.3 Vortex sheet from trailing edge

As mentioned by Doughlas, the common misunderstanding with the vortex sheet was that, the induced drag caused due to the theses vortices produced from the velocity flow pattern. Also, reducing the strength of vortex could not have a significant effect on the induced drag.

Research has been conducted to reduce the induce drag and different methods have been developed to calculate this lift induced drag . Using one of the proposed methods, induced drag for a commercial jet transport aircraft is calculated and will be discussed in upcoming section.

A. Method for Induced drag Calculation

1) Boeing aircraft's specifications are taken and the total drag of the aircraft is calculated using the following formula.

$C_D = Cd_0 + Cd_i$

$C_{D0} = C_L^2/(\pi * e * AR)$

$C_{Di} = K\, C_l^2$

$K = 1/(\pi * e * AR)$

Where,

e = Span efficiency or Ostwald's efficiency factor

AR = Aspect ratio

C_L = Lift coefficient

2) Lift-induced drag due to vortex is based on the lift coefficient of the wing, aspect ratio and the span efficiency factor.

3) The profile drag and induced drag are calculated from the above formula with the values based on the aircraft's specification table . The total drag is calculated for different altitudes and also for different velocities, starting from stall speed to cruise velocity.

4) The total drag calculated will be used for determining the additional take-off weight for the same take-off distance.

B. Wingtip vortices

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, vortices is trailed at any point on the wing where the lift varies span-wise 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 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. The main role of winglets is to reduce the induced drag formation. Winglets are small structure which plays a vital role to reduce the induced drag in aircraft. In this project, literature survey is made on various types of winglets and finalized to design and analyze the spiroid winglet.

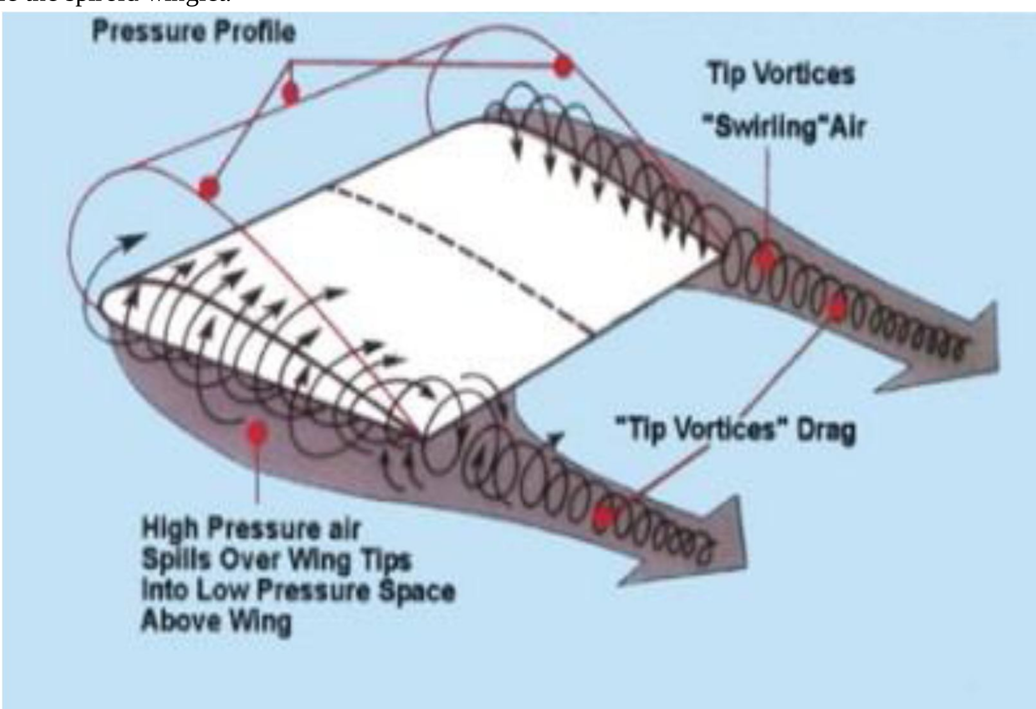

Figure 8 4.4 Wingtip vortices

V. DESIGNING AND MODELING

A. *Designing*

In order to compare the benefits of the spiroid winglet, Boeing 737 wing has been considered without the wingtips. A normal complete wing has been compared with the spiroid winglet, where the specification for both the wing remains the same. The winglet configuration is changed. Henceforth the designing configuration is very important to resolve the drawbacks of normal wing.

The designing started with the selection of the airfoil and the wing for our project. The wing and winglet model are designed using Open VSP-3.16.2 Software using the following specifications:-

1) *Design Specifications of Wing Are*

a) Wing Span:-	28.35 meters
b) Tip chord length:-	1.6 meters
c) Root chord length:-	7.32 meters
d) Sweep Angle:-	25 degrees (Sweep backward)
e) Airfoil :-	NACA 2412

For the designing of the wing with the winglet, 2 types of the spiroid winglet has been considered, they are as follows

i) Wing with Spiroid winglet 1
1. Diamond Shaped
2. All Sides NACA 2412 Airfoil
ii) Wing with Spiroid winglet 2
1. Parallelogram Shaped
2. All sides NACA 2412 Airfoil

B. *Designed View of the Normal Wing and the Spiroid Winglet*

Designed view of the wing

The complete design of the normal wing is shown in the figure below.

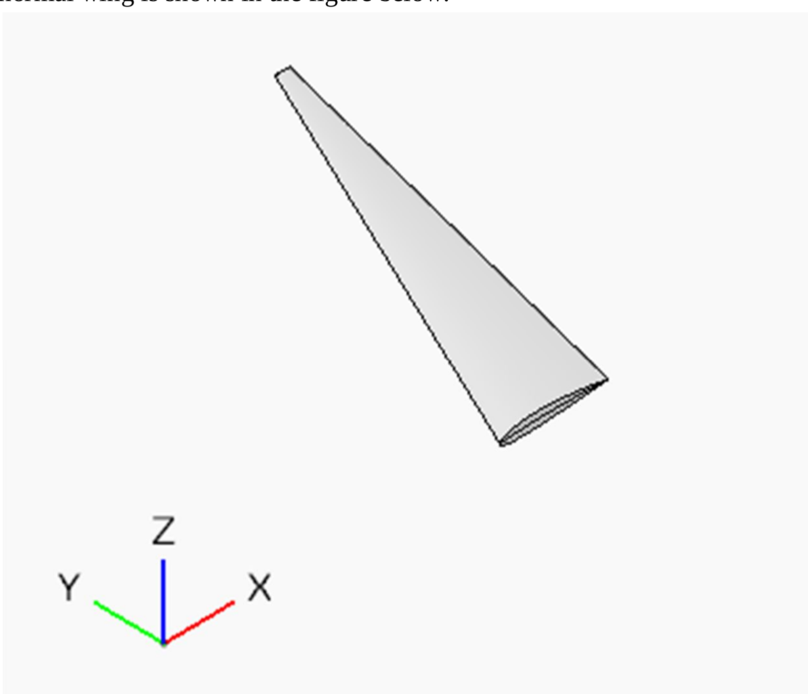

Figure 9 5.1 Design of Wing

Designed view of the wing with winglet

The complete design of the wing with spiroid winglet1 is shown in the figure below.

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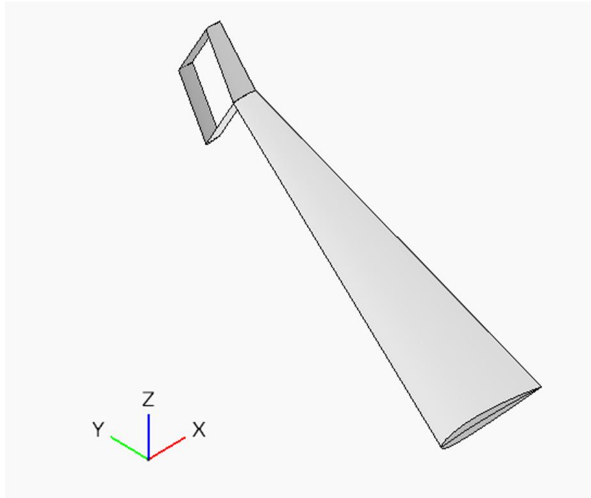

Figure 10 5.2 Design of Wing with Spiroid winglet1

The complete design of the wing with spiroid winglet1 is shown in the figure below.

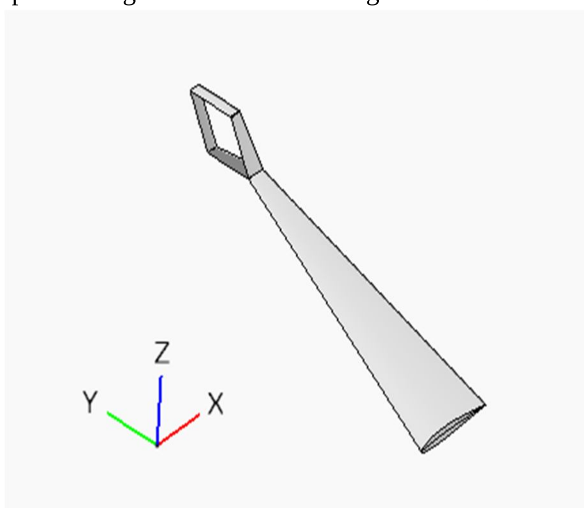

Figure 11 5.3 Design of Wing with Spiroid winglet2

B. WING LIFT EQUATION

- $L = ½ C_L \rho V^2 A$
- $C_L = \frac{2L}{\rho V^2 A}$
- $\rho = \frac{L^2}{C_L V^2 A}$
- $V = \sqrt{\frac{2L}{C_L \rho A}}$

Where,

A	lift surface area
AR	Aspect ratio
C_{Di}	induced drag coefficient
C_L	coefficient of lift
D_i	induced drag
L	lift force
V	Take off velocity
c	chord length
e	Ostwald's efficiency factor
t	maximum thickness
v	true air speed
v_e	equivalent airspeed
ρ	air density (sea level)
ρ_0	air density (altitude)

The efficiency factor for ellipse, e= 1.0
In general the efficiency factor is lesser than one.

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VI. MESHING

The Computational Fluid Dynamic mesh has been done using OPEN VSP. After Meshing has been done, the following were the results obtained during the mesh. Here the water tight design is obtained. Triangular mesh has been carried out and the number of elements for different design model of wing and the wing with spiroid winglet is determined.

The followings are the mesh parameters used for the meshing:-

MAX EDGE LENGTH	0.5
MIN EDGE LENGTH	0.1
MAX GAP	0.005
NUM CIRCLE SEGMENTS	16
GROWTH RATIO	1.3

Table I Mesh Parameters

The number of the elements for the wing model is determined to be 22892 and the meshed view of the normal wing and the spiroid winglet are shown in the figure below

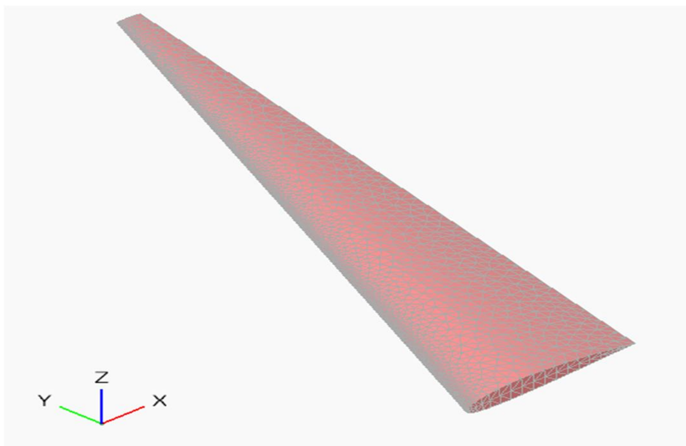

Figure 12 6.1 Mesh with normal wing

The number of the elements for the wing with winglet1 is determined to be 24852. The meshed view of the spiroid winglet1 is shown in the figure below:-

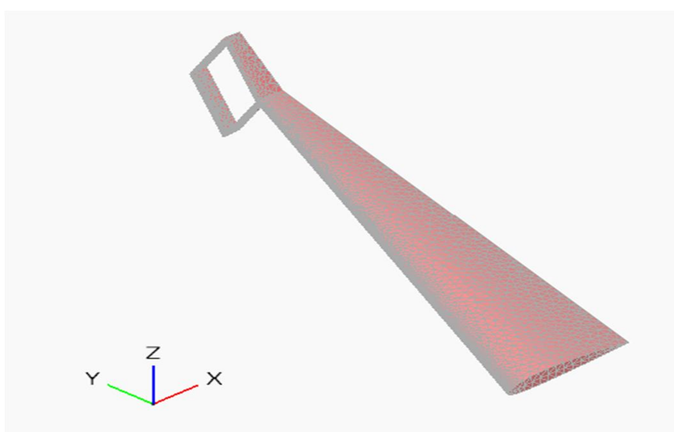

Figure 13 6.2 Mesh view of the Spiroid winglet 1

The number of the elements for the wing with winglet2 is determined to be 22892.The meshed view of the spiroid winglet1 is shown in the figure below:-

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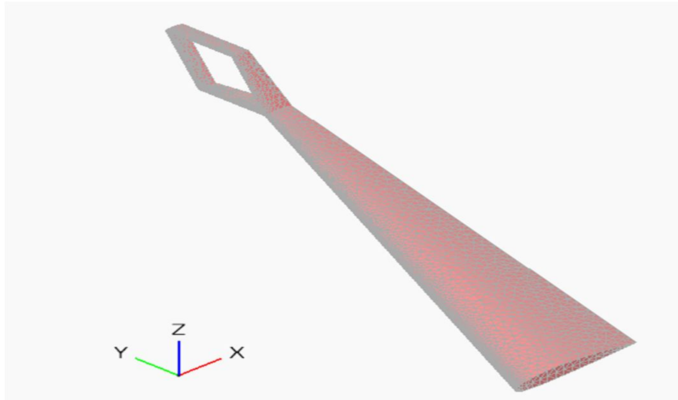

Figure 14 6.3 Mesh view of the Spiroid winglet 2

A. Boundary Conditions

The general boundary conditions for both the normal wing and both Spiroid winglets are

1) The flow of air is considered to be compressible and high subsonic region.
2) The free stream airflow has been maintained from Mach number 0.75
3) Angle of attack has been maintained at 1 degree, 5.5 degrees and 10 degrees.
4) The density of air is 1.225 kg/m^3
5) Wall is assumed to be stationary.
6) Air is considered as a working fluid.

VII. COMPUTATIONAL FLUID DYNAMICS SIMULATIONS

A. Introduction to Computational fluid Dynamics Analysis

1) Computational fluid dynamics had been done by using VSPAERO. The grid structure has been developed to be focused around the models while being less condensed on the far flow field in order to manage the computational resources and minimize the time needed for carrying out the calculations.
2) Computational fluid dynamics analysis for different values of Angle of Attack and different values of Mach number has been carried out. And coefficient of lift versus coefficient of drag has been plotted and shown below.

B. Coefficient of lift versus Coefficient of drag (C_L versus C_D)

Coefficient of lift versus Coefficient of drag for the wing model is shown below

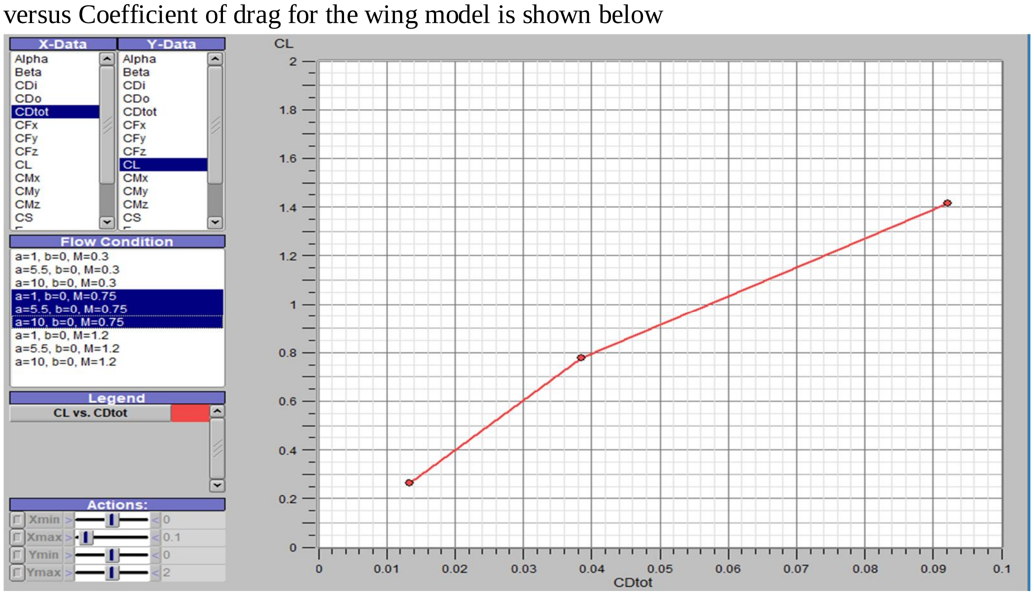

Figure 15 7.1 C_L vs C_D for the Wing at M=0.75

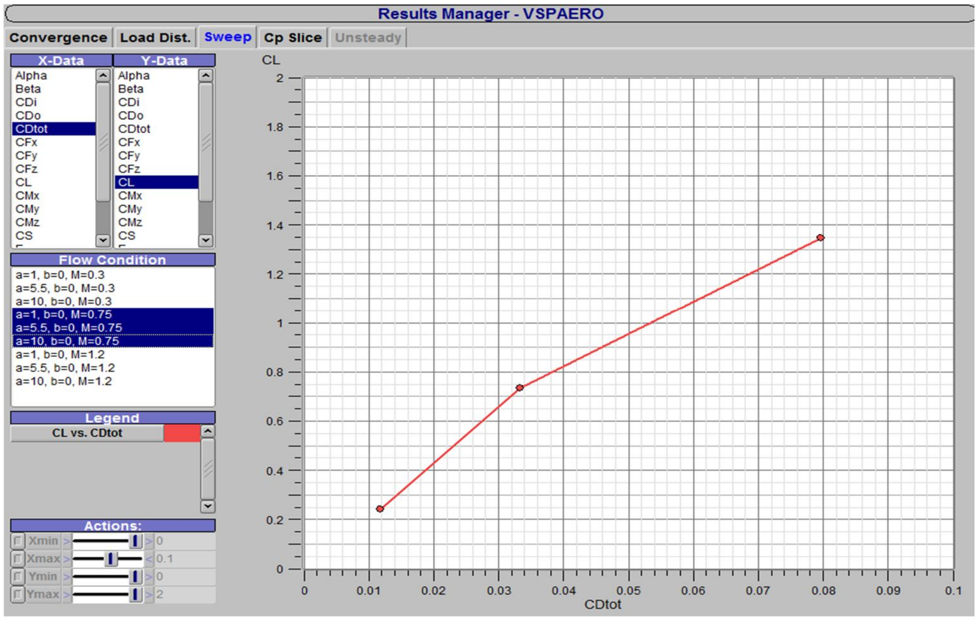

Figure 16 7.2 C_L vs C_D for the Wing with winglet1 at M=0.75

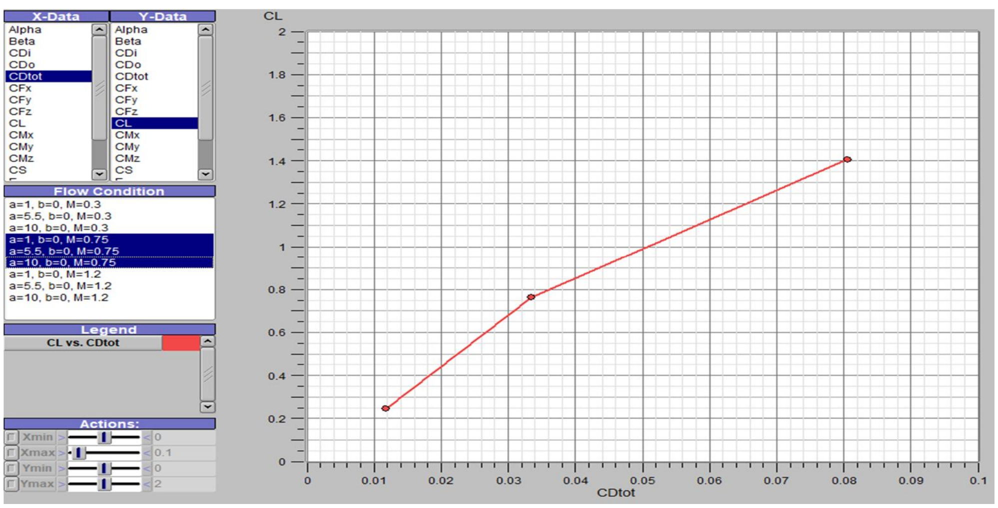

Figure 17 7.3 C_L vs C_D for the Wing with winglet2 at M=0.75

Mach number=0.75

Angle of Attack	wing		Spiroid winglet 1		Spiroid winglet 2	
	Coefficient of lift (C_L)	Coefficient of total drag (C_{Dtot})	Coefficient of lift (C_L)	Coefficient of total drag (C_{Dtot})	Coefficient of lift (C_L)	Coefficient of total drag (C_{Dtot})
1	0.26298	0.01335	0.24182	0.01173	0.2461	0.01173
5.5	0.77787	0.03855	0.73535	0.03328	0.76313	0.03345
10	1.41705	0.09254	1.34809	0.07992	1.40813	0.08102

Table II Comparison of Aerodynamic parameters - Wing model with spiroid winglets models.

C. Pressure Contours

Pressure contours are the diagrammatic representation of the variation of the pressure along the model. This contour enables others to know how the pressure is getting varied in the wing model with the change in angle of attack and the change in Mach number. The label in the pressure contour helps the reader to know the values of the pressure in accordance with the color shown in the contour.

1) The Following Are The Pressure Contours For The Wing

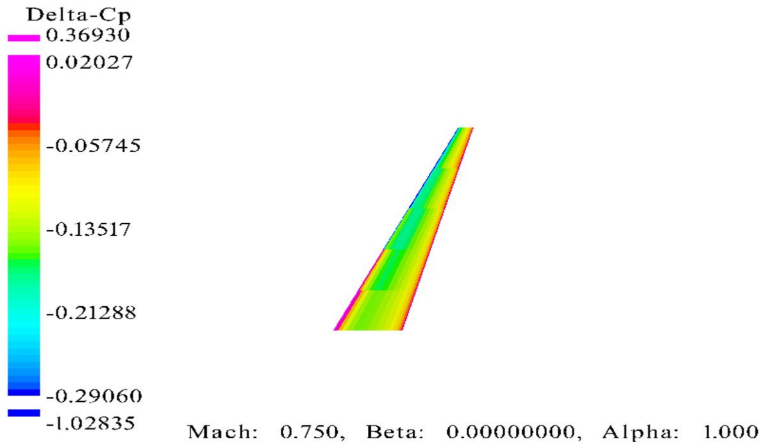

Figure 18 7.4 Pressure contour of Wing at AOA=1 and M=0.75

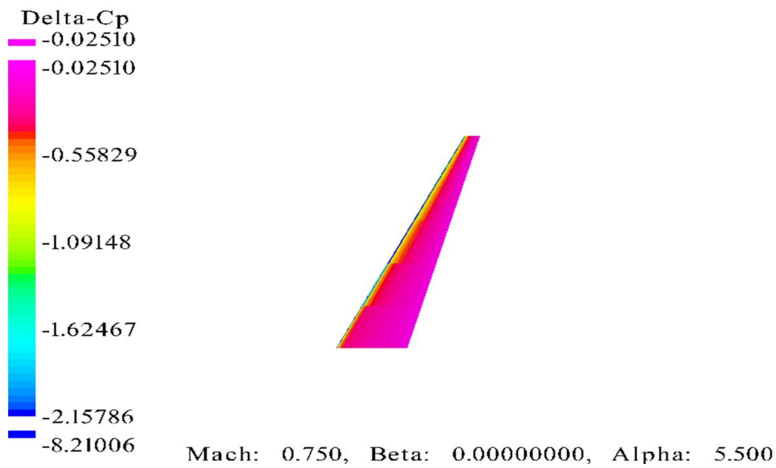

Figure 19 7.5 Pressure contour of Wing at AOA=5.5 and M=0.75

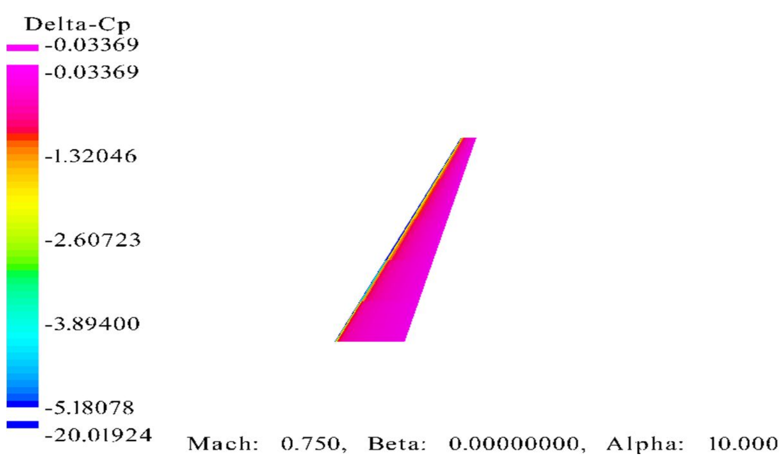

Figure 20 7.6 Pressure contour of Wing at AOA=10 and M=0.75

2) The Following Are The Pressure Contours For The Wing With The Spiroid Winglet 1

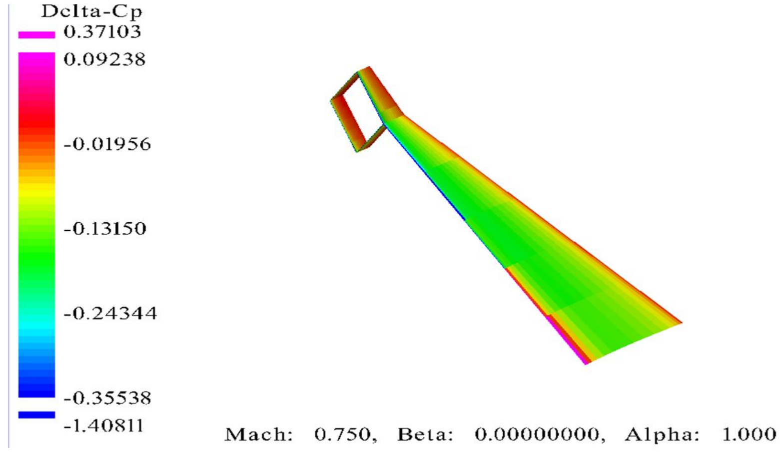

Figure 21 7.7 Pressure contour of Wing with winglet1 at AOA=1 and M=0.75

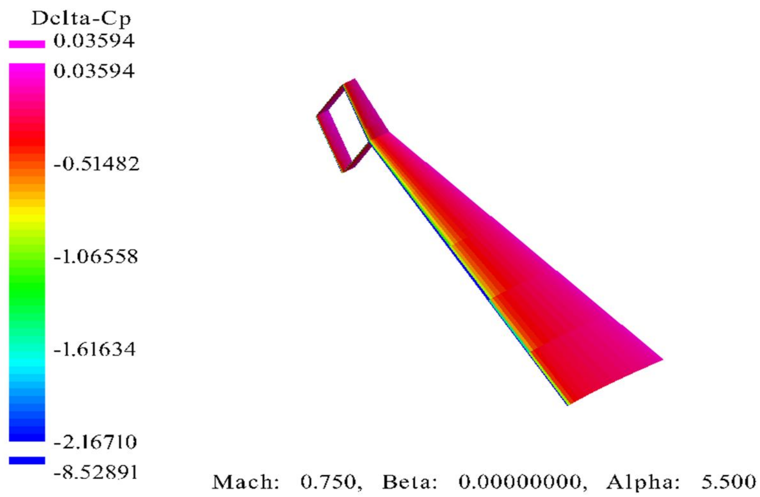

Figure 22 7.8 Pressure contour of Wing with winglet1at AOA=5.5 and M=0.75

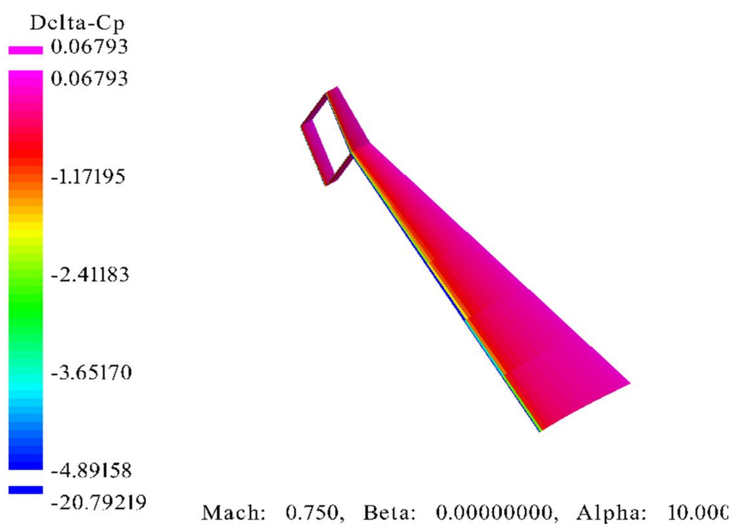

Figure 23 7.9 Pressure contour of Wing with winglet1at AOA=10 and M=0.75

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3) The Following Are The Pressure Contours For The Wing With The SpiroidWinglet2

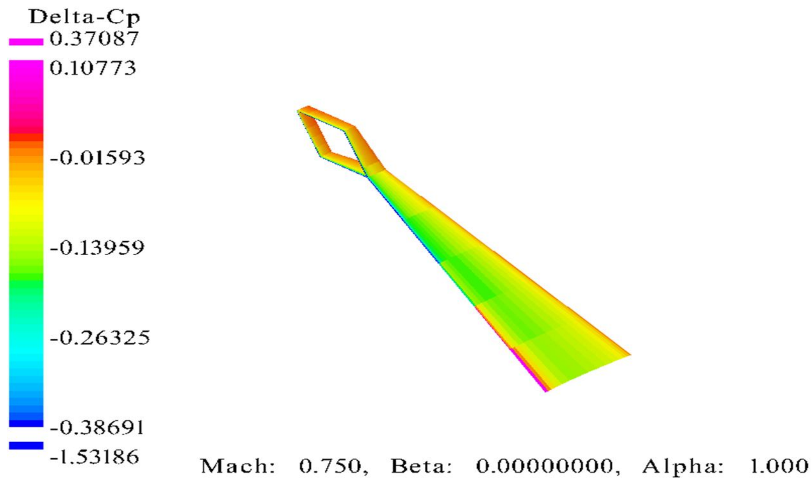

Figure 24 7.10 Pressure contour of Wing with winglet2 at AOA=1 and M=0.75

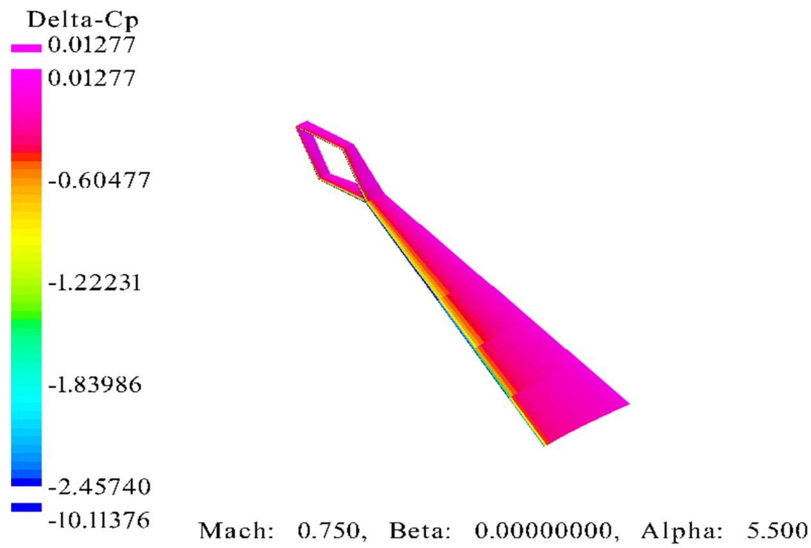

Figure 25 7.11 Pressure contour of Wing with winglet2 at AOA=5.5 and M=0.75

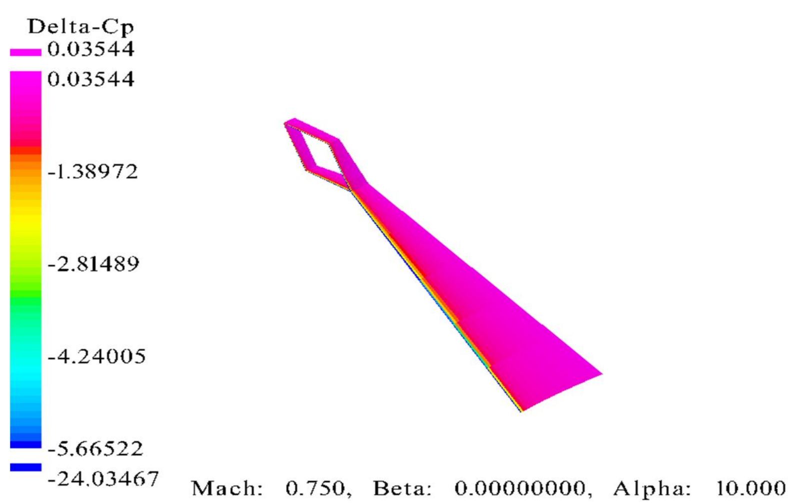

Figure 26 7.12 Pressure contour of Wing with winglet2 at AOA=10 and M=0.75

VIII. RESULTS AND DISCUSSION

Therefore, by looking towards the graphs of Coefficient of lift versus Coefficient of drag for the wing model and the wing with the winglet model, it is obvious that the results of the wing with the spiroid winglet has overall better aerodynamic characteristics then the aerodynamics characteristics of wing model alone. The Coefficient of lift of the model is increased due to the addition the spiroid winglet and the Coefficient of drag has been reduced due to the addition the spiroid winglet.

As we can observe that as the lift increases the drag also increases. And the amount of lift decreased of wing with winglet with respect to the normal wing is due to the extra profile, surface due to the addition of the winglet which increases the profile drag.

The reason behind the increment of lift and the decrement of the total drag is due to the decrement of the lift induced drag. Various shapes of winglets are being used by Boeing and Airbus. Many literatures have been overviewed and each and every type of winglets performance has been studied and selected a spiroid winglet concept in order to increase the aerodynamic performance. The comparative study on Boeing 737 with spiroid winglet and without winglet is studied in detail using software open VSP aero analysis.

A. Conclusions

This paper presented the study of spiroid winglets and a detailed research analysis which was conducted in order to choose an optimum spiroid design that produced efficient aerodynamic performance results. The parasite drag and induced drag plays a vital role in the formation of total drag which decreases the efficiency of aircraft. The spiroid winglet has liberal optimization in vortices suppression. In this project, spiroid is used in boeing 737-100 original to enhance the further improvement in lift characteristics and reduce the total drag formation.

On the basis of the table and the figure shown above, Wing with spiroid winglet2 with the following features was identified as the optimum design:

1) Parallelogram shaped
2) All sides NACA 2412 Airfoil

The comparative study on Boeing 737 with spiroid winglet and without winglet is studied in detail with different angle of attacks and different Mach numbers using VSPAERO. From the analysis it is clearly seen that the performance of the spiroid winglet is better than normal wing when compared to C_L and C_D .values at different angle of attacks. In this for reducing inducing induced drag we used spiroid winglet. If, lift to drag ratio increases the drag will reduce here in the spiroid winglet the lift to drag ratio increases than wing without winglet so the spiroid winglet reduces the vortices.

B. Future work and Scopes

Since the results presented in this work for induced drag calculation are only through basic formulas which only depend on area of the winglet, a flow analysis could be done in order to determine the lift-off performance, vorticity reduction and also to find the parasite drag associated with size of winglet. Based on the type of analysis, user interface can be created. If the analysis is to be done on Tornado, an Excel user interface should be linked with OPENVSP. Upon changing the values in excel the OPENVSP analysis model should change its geometry and the flow results should be obtained automatically from Tornado.

Similarly, for CFD method analysis, software like OPENVSP analysis with CFX should be linked with CATIA V5. So an actual drag reduction, vortex effects for the respective winglet can be calculated by varying the parameters. Optimization of the geometry for each type of winglet could be done, by targeting drag as minimizing factor. Moreover, applying a composite material to each winglet and optimizing the drag could be performed. Ribs and spars would be designed for each winglets and a finite element analysis could be performed to calculate structural integrity using FEA tools like CATIA. This work has been done with only following Knowledge Pattern approach for automation, so VB approach by making power copies of each template could be done in order to compare the efficiency of both approaches.

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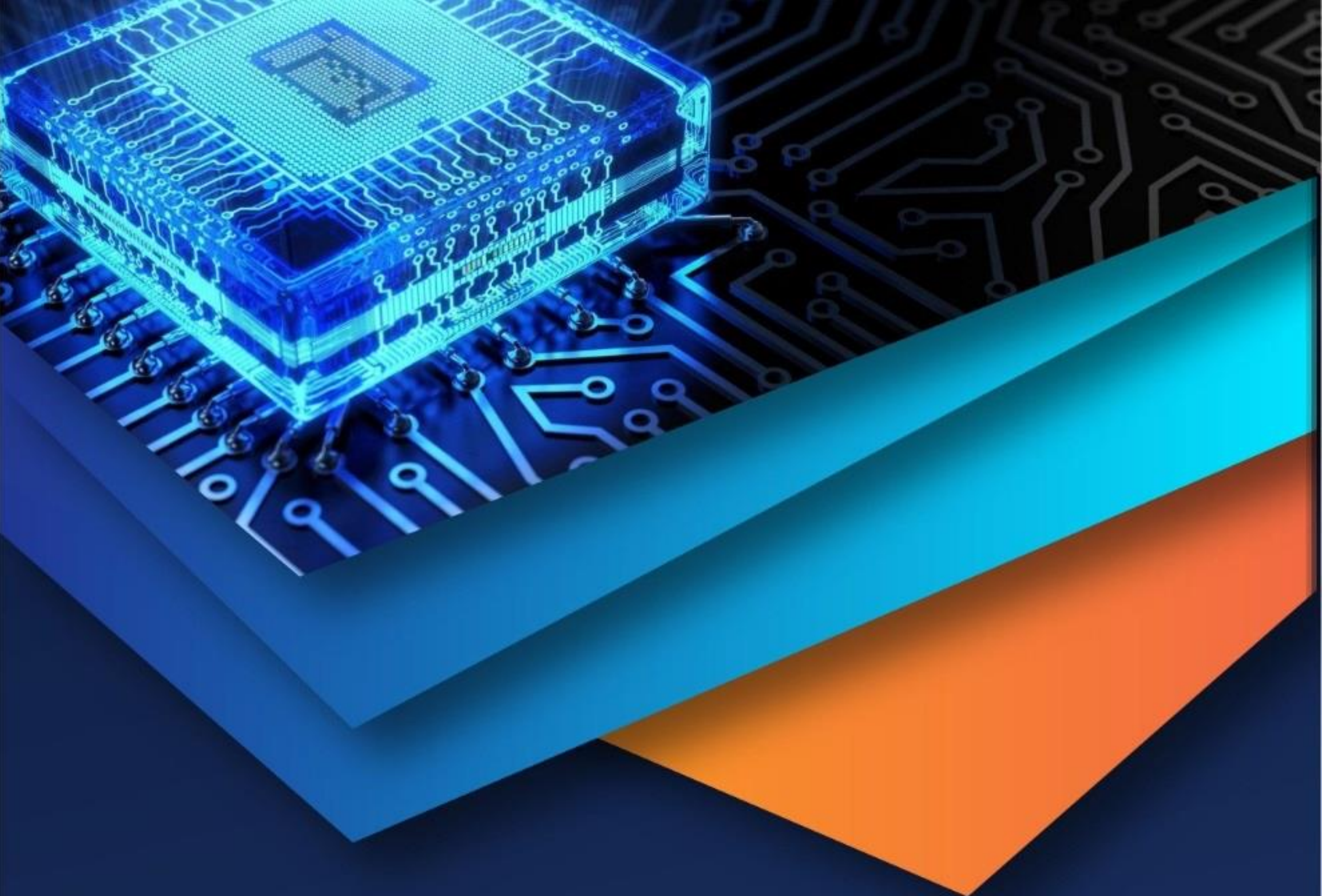

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