Design and Analysis of Biomimetic Spiroid Winglet

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Abstract - *The winglet is a part which is placed on the end of aircraft wing. It plays an important role in improving the performance of the aircraft. The rise in cost of the aircraft made the designers and airline management find new technologies and reduce the cost. After a lot of research and study in this field, it was seen that incorporating a winglet is the best way to reduce the cost. The presence of winglet reduces the consumption of fuel by reducing the drag of the aircraft and increase the stability of the aircraft during flight. In addition, it will also give the aircraft engine longer life by reducing the load on the thrust of the engine. The aim of this project is to design and perform analysis on model of winglet. A Spiroid winglet is chosen and attached to the wing with a smooth curve instead of a sharp angle which intends to reduce the interference drag. The modelling and analysis of the spiroid winglet for various configurations will be done using the softwares CATIA and ANSYS. Air flow analysis is being carried out in the fluent module of the ANSYS workbench.*

***Key Words*: Aircraft, Winglet, Spiroid, Fuel consumption, Cost, Biomimetic.**

1.INTRODUCTION

Winglets are used to improve the efficiency of a fixed-wing aircraft. There are various types of winglets, and even though they have different functions, the effect intended is always to decrease the aircraft's drag by partial recovery of the tip vortex energy. Winglets also improve the aircraft handling characteristics and increase the safety of the aircraft. These devices increase the aspect ratio of the wing without materially increasing its wingspan. One of the ways of reducing lift-induced drag is by using winglets. By applying the principle of biomimetic abstraction from bird's wingtip feathers, we study spiroid winglets, which look like an extension of a blended wingtip that bends upward by 360 degrees to form a large rigid ribbon. It is evident that the aviation industry has been working hard to increase the efficiency and performance of the aircraft in order to make journeys which are fuel efficient and this drastically increases the profit. Winglets are known to be used on the aircraft for so long to reduce lift-induced drag.

1.1 Biomimetics

Biomimetics is a field of science in which the biological features found in nature is applied to various materials and systems which mimic the biological features. Biomaterials are any natural or synthetic material that interacts with any part of a biological system. Biomimetic designs are used in regenerative medicines, tissue engineering and drug delivery. Living organisms have evolved with well-adapted structures and materials over a long time through the process of natural selection. Biomimetics gave rise to many new technologies which was inspired by biological solutions at macro and nanoscales. Human beings have looked at nature for answers to so many problems throughout their existence. Nature has solved many engineering problems like self-healing abilities, self-assembly, hydrophobicity, environmental exposure tolerance and resistance, and harnessing solar energy.

1.2 Winglets

Winglets are used to improve the efficiency of the wings of an aircraft and reduce the vortices generated at the wingtip. The wingtip vortices are twin tornados generated due to the difference between the pressure on the upper surface and the lower surface of an aircraft's wing. High pressure present on the lower surface creates a natural airflow that makes its way to the wingtip and curls upward around it. These twisters formed represent the loss of energy and are strong enough to flip the airplanes. Winglets produce a good performance boost for jets by reducing drag, and this reduction could translate into a marginally higher cruise speed. But most operators take advantage of the drag reduction by throttling back to normal speed and therefore saving the fuel. Here, in this project we have used a spiroid winglet. The picture of a spiroid winglet is as shown in fig-1.

Fig-1: Spiroid Winglet

2. LITERATURE SURVEY

[1] Spiroid-Tipped Wing – Patent published by Louis B.Gratzer - It incorporated the very first spiroid wingtip design in its basic form, comprises a wing like lifting surface and a spiroidal tip device integrated so as to minimize the induced drag of the wing-spiroid combination.

[2] Biomimetic spiroid winglets for lift and drag control- Published by Joel E.Guerrero, Dario Maestro ,Alessandro Bottaro - This paper presented the biomimetic by abstraction from bird's wingtip feathers to wingtip feathers to winglets on airplanes.

[3] Design and Analysis of Spiroid Winglets - Published by Gifton Koil,T.Amal Seba Thomas - 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.

[4] Design and computational fluid analysis of spiroid winglet to study its effect on Aircraft Performance- Published by Ali Murtaza, Dr. Khalid Parvez, Hanzala Shahid, Yasir Mehmood - This paper presented the CFD analysis of spiroid winglet in depth of drag and lift coefficient for different AOA.

[5] Contrive and Analysis of Spiroid Winglet for Drag Contraction – Paper by Anwar Ansari, Antony Samuel Prabu, Sudig Lal Joshi, And Pradip Sah Teli - This paper presented the detailed study of reducing the aircraft's drag and increase in the aerodynamic efficiency due to addition of spiroid winglet.

[6] Design of Parametric Winglets and wingtip devices – A Conceptual Design Approach-Paper by Saravanan Rajendran - This paper presented the detailed study on procedure and formula for drag calculation different wingtip devices.

2.1 Research Gap

- Analysis for different configurations of the spiroid winglet are compared. The different configurations are – Semi-circular, Square, Parallelogram and Diamond.

2.2 Objectives

- To compare the performance of an aircraft's wing with spiroid winglet and the conclusion is drawn.
- To identify the optimum Spiroid configuration among the various shapes.
- Analyse and improve the aerodynamic performance of the spiroid wing in terms of lift, drag and aerodynamic efficiency.

3. METHODOLOGY

Our project aims to design and analyze spiroid winglet of different configurations attached to the wing of an aircraft.

Boeing 737 wing has been considered without the wingtips for study. Spiroid winglet is attached to this wing and analysis is done.

- Designing of basic wing and spiroid winglet is done.
- Assembly of winglet on basic wing.
- Analysis of spiroid winglet is done.
- Four different configurations of spiroid winglet will be taken into consideration (Square, Semi circle, Parallelogram and Rhombus).
- Air flow analysis is being carried out in the fluent module of the ANSYS workbench.
- Aerodynamic efficiency obtained from ANSYS is been compared with numerical solutions and conclusion is drawn

The different shapes of the winglet to be designed and analysed are shown in fig-2.

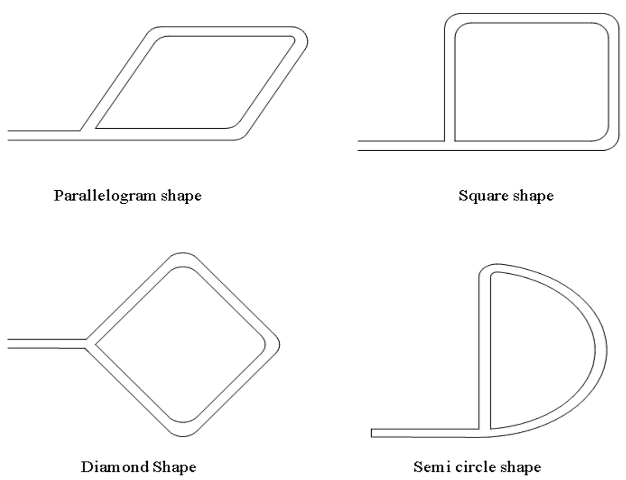


Fig-2: Different shapes of winglet to be analysed

4. DESIGN CALCULATIONS

Taking the standard values of Boeing -737(100 series).

Assumptions:

1. Wing loading of the aircraft is 433.33kg/m^2.
2. Landing and take-off are taken at mean sea level.
3. Cruise altitude is at 35000ft =10668m.

The wing parameters taken from Boeing 737-100 series are listed below:

Wing span(m) - 28.35

Area(m2)- 102.6

Aspect Ratio - 8.83

Root chord (m)- 7.32

Tip chord (m)- 1.6

Mac (m) - 3.80

Sweep Angle(o) - 25

Max velocity (m/s2) - 244.44

Cruise altitude (m) - 1066.8

Density of air at altitude (kg/m3) - 0.3802

Mach number - 0.73

Density of air at sea level (kg/m3) - 1.225

Wing loading (kg/m2) - 433.33

Kinematic viscosity(m2/s) - 1.47*10-5

4.1 Lift co-efficient (C_L)

Wing loading of Boeing -737 is considered.

$w/s = 433.33*9.81=4250.9673\ N/m^2$ (1)

At level flight, all the forces counter-balance each other

$$L = ½\ \rho_\cdot V_\cdot^2 * C_L \quad (2)$$

$$\frac{w}{s} = \frac{1}{2}\rho_\cdot V_\cdot^2 * C_L \quad (3)$$

$$C_L = \frac{2}{\rho_\cdot V_\cdot^2} * \frac{W}{S} \quad (4)$$

4.1.1 At Take-off

Let v_{max} = 250kmph=69.44m/s

Density at mean sea level ρ =1.225 kg/m^3

$$C_L = \frac{2}{\rho_\cdot V_\cdot^2} * \frac{W}{S}$$

$$C_L = \frac{2}{1.225*69.44^2} * 4250.9673$$

$$C_L = 1.4393$$

4.1.2 At Cruise

Let cruise altitude = 35000ft = 10668m

Density at that altitude ρ_0 =0.3802 kg/m^3
Let cruise speed (V_∞)=550mph= 244.44 m/s

$$C_L = \frac{2}{\rho_0 V_\infty^2} * \frac{W}{S}$$

$$C_L = \frac{2}{0.3802*244.44^2} * 4250.9673$$

$$C_L = 0.374$$

4.1.3 At Landing

Let v_{max} = 165mph=73.33m/s

Density at mean sea level ρ =1.225 kg/m^3

$$C_L = \frac{2}{\rho_\cdot V_\cdot^2} * \frac{W}{S}$$

$$C_L = \frac{2}{1.225*73.33} * 4250.9673$$

C_L = 1.2906

4.2 Drag Coefficient (C_d)

$$C_d = C_{dsf} + C_{dfd} + C_{di} \quad (5)$$

We know that $C_{di} = K*C_L^2$

So, $C_d = C_{dsf} + C_{dfd} + K*C_L^2$

$$K = \frac{1}{\pi e(AR)} \quad (6)$$

$e = \{0.47 + (1/\sqrt{AR})\}* (\cos \Lambda\ )^{0.1}$ ……….(7)

$e = \{0.47+(1/\sqrt{8.83})\}*(\cos 25)^{0.1}$

e = 0.79863

So, K = 0.04516

4.2.1 At Take-off

Reynolds' Number,

$$Re = (V * l)/\nu \quad (8)$$

$$R_e = \frac{244.44*3.8}{3.77*10^{-5}}$$

$R_e = 17.95 \times 10^6$

4.2.1.1 Skin Friction coefficient

$C_{dsf} = 0.455/(\log(Re))^{2.58} * (1+0.144M^2)^{0.65}$ (9)

$C_{dsf} = \frac{0.455}{(\log(17.95*10^6))^{2.58} * (1+0.144*0.202^2)^{0.65}}$

$C_{dsf} = 2.7293*10^{-3}$

4.2.1.2 Form Drag

$C_{dfd} = FF * C_{dsf}$ (10)

$FF = 1 + \left[\frac{(2-M^2)\cos(\Lambda)}{\sqrt{1-M^2\cos^2(\Lambda)}} * \frac{t}{c}\right] + \left[100 * \left(\frac{t}{c}\right)^4\right]$

$FF = 1 + \left[\frac{(2-0.202^2)\cos(25)}{\sqrt{1-0.202^2 cos^2(25)}} * 0.288\right] + [100 * 0.288^4]$

FF = 2.208

$C_{dfd} = 2.208*2.7923$

$C_{dfd} = 6.026*10^{-3}$

4.2.1.3 Induced Drag

$C_{di} = K*C_L^2$ (11)

$C_{di} = 0.04516*1.4393$

$C_{di} = 0.065$

$C_d = C_{dsf} + C_{dfd} + C_{di}$

$C_d = 2.7293*10^{-3} + 6.206*10^{-3} + 0.065$

$C_d = 0.0737$

4.2.2 At Cruise

Reynolds' Number,

$Re = (V * l)/\nu$

$R_e = \frac{244.44*3.8}{3.77*10^{-5}} = 24.638*10^6$

4.2.2.1 Skin Friction coefficient

$C_{dsf} = 0.455/(\log(Re))^{2.58} * (1+0.144M^2)^{0.65}$

$C_{dsf} = \frac{0.455}{(\log(24.638*10^6))^{2.58} * (1+0.144*0.7127^2)^{0.65}}$

$C_{dsf} = 2.6168*10^{-3}$

4.3.2.2 Form Drag

$C_{dfd} = FF * C_{dsf}$

$FF = 1 + \left[\frac{(2-M^2)\cos(\Lambda)}{\sqrt{1-M^2\cos^2(\Lambda)}} * \frac{t}{c}\right] + \left[100 * \left(\frac{t}{c}\right)^4\right]$

$FF = 1 + \left[\frac{(2-0.7127^2)\cos(25)}{\sqrt{1-0.7127^2 cos^2(25)}} * 0.288\right] + [100 * 0.288^4]$

FF = 2.1981

$C_{dfd} = 2.1981*2.6168*10^{-3}$

$= 5.752*10^{-3}$

4.2.2.3 Induced Drag

$C_{di} = K*C_L^2$

$C_{di} = 0.04516*0.374$

$C_{di} = 0.0169$

So,

$C_d = C_{dsf} + C_{dfd} + C_{di}$

$C_d = 2.6168*10^{-3} + 5.7526*10^{-3} + 0.0169$

$C_d = 0.02526$

4.2.3 At Landing

Reynolds' Number, $Re = (V * l)/\nu$

$R_e = \frac{73.33*3.8}{1.47*10^{-5}}$

$= 18.956*10^6$

4.2.3.1 Skin Friction coefficient

$C_{dsf} = 0.455/(\log(Re))^{2.58} * (1+0.144M^2)^{0.65}$

$C_{dsf} = \frac{0.455}{(\log(18.956*10^6))^{2.58} * (1+0.144*0.214^2)^{0.65}}$

$= 2.728*10^{-3}$

4.2.3.2 Form Drag

$C_{dfd} = FF * C_{dsf}$

$FF = 1 + \left[\frac{(2-M^2)\cos(\Lambda)}{\sqrt{1-M^2\cos^2(\Lambda)}} * \frac{t}{c}\right] + \left[100 * \left(\frac{t}{c}\right)^4\right]$

$FF = 1 + \left[\frac{(2-0.214^2)\cos(25)}{\sqrt{1-0.214^2 cos^2(25)}} * 0.288\right] + [100 * 0.288^4]$

FF = 2.207

C_{dfd} = 2.207*2.728*10^{-3}

C_{dfd} = 6.0232*10^{-3}

4.2.3.3 Induced Drag

$C_{di} = K*C_L^2$

C_{di} = 0.04516*1.2906

C_{di} =0.05828

So,

$C_d = C_{dsf} + C_{dfd} + C_{di}$

C_d = 2.589*10^{-3}+6.0232*10^{-3} +0.05828

C_d =0.06707

4.3 Aerodynamic Efficiency (AE)

AE = C_L /C_d

The co-efficient of lift, drag and the aerodynamic efficiency obtained during take-off, cruise and landing is tabulated below.

Table-1: Aerodynamic efficiency results

Condition of plane	C_L	C_d	AE
Take-off	1.4393	0.0737	19.53
Cruise	0.374	0.02526	14.8
Landing	1.2906	0.06707	19.24

5. DESIGNING OF WINGLETS

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 the normal wing. The design started with the selection of the airfoil and the wing for our project. The wing and winglet model are designed using **CATIA** software.

The wing chosen for our project is the wing of Boeing 737.

Aircraft: Boeing-737

Wing Span: 28.25m

AIRFOIL SELECTION

Root: b737a-il

Mid span: b737b-il, b737c -il

Tip: b737d-il

The wing is designed with CATIA v5 using the root and tip co-ordinates of boeing-737 aircraft and extruded using the using the wingspan.

The pad tool is used mostly to create extruded features. Wings of all the models were extruded using pad tool.

The winglets were drawn using rib tool, plane definition tool, line tool, inflation tool, rotate tool, measure tool, and scale tool.

- The wing has been designed by using the Catia v5 software
- The coordinates of the wing were imported into Catia from excel.
- Then the root and tip airfoils are connected using the multi section solid command.
- Then the winglet has been drawn by using the rib command in the wing tip.
- Then the surface is extracted from the solid by using the extract command.

The four different winglet configurations designed are given below:

5.1 Spiroid Winglet

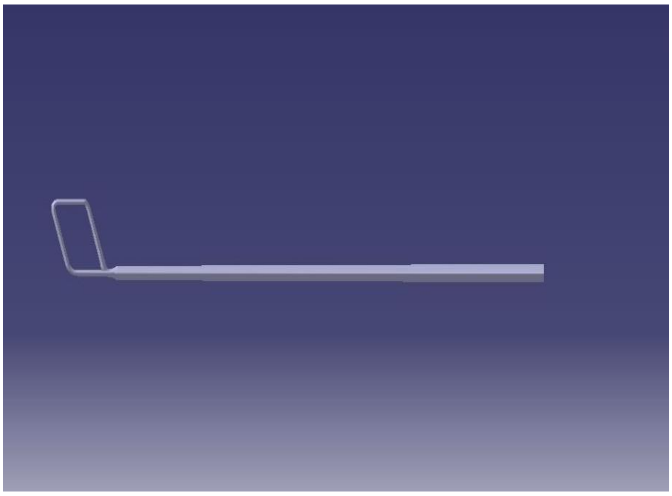


Fig-3: Spiroid Configuration

5.2 Semi-Circle Configuration

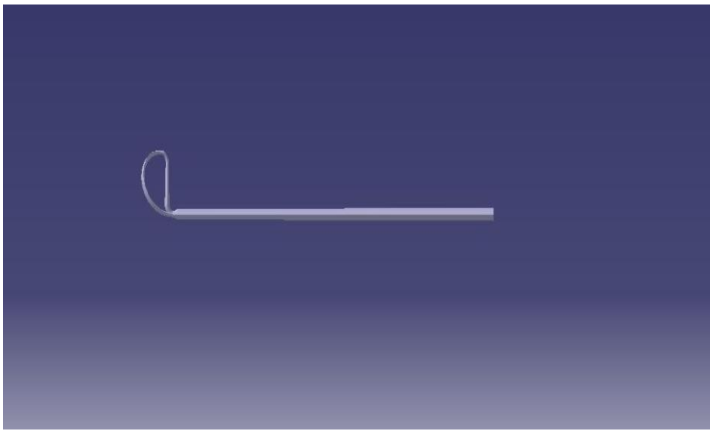


Fig-4: Semi-Circle Configuration

5.3 Square Configuration

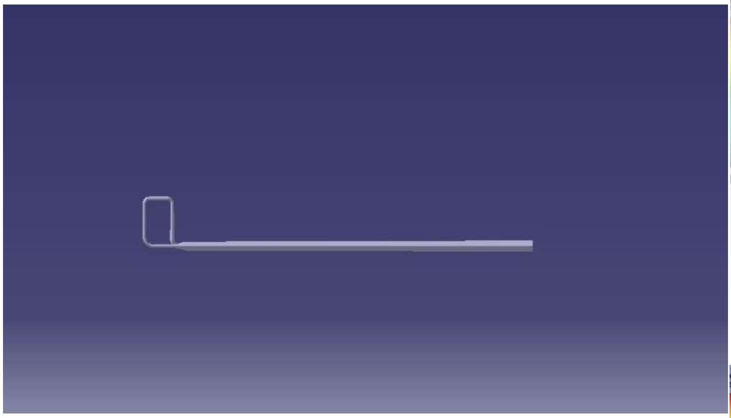


Fig-5: Square Configuration

5.4 Diamond Configuration

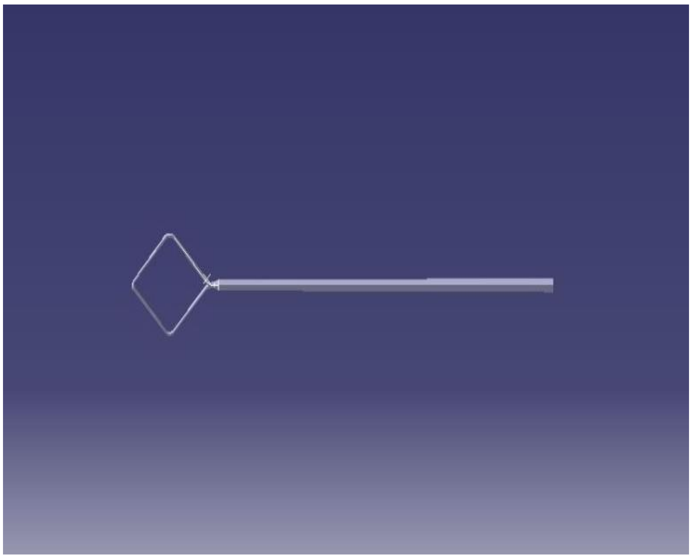


Fig-6: Diamond Configuration

6. ANALYSIS OF WINGLETS

The analysis of winglets was done using Ansys workbench and the aerodynamic efficiency was determined by finding the values of C_D and C_L.

The analysis for different configurations is shown below:

6.1 Spiroid Configuration

The solution obtained for spiroid configuration is as follows:

$C_L = 4.0960$

$C_D = 0.19008$

AE = 21.54

The analysis done for Spiroid configuration is shown in Fig-7(a) and 7(b).

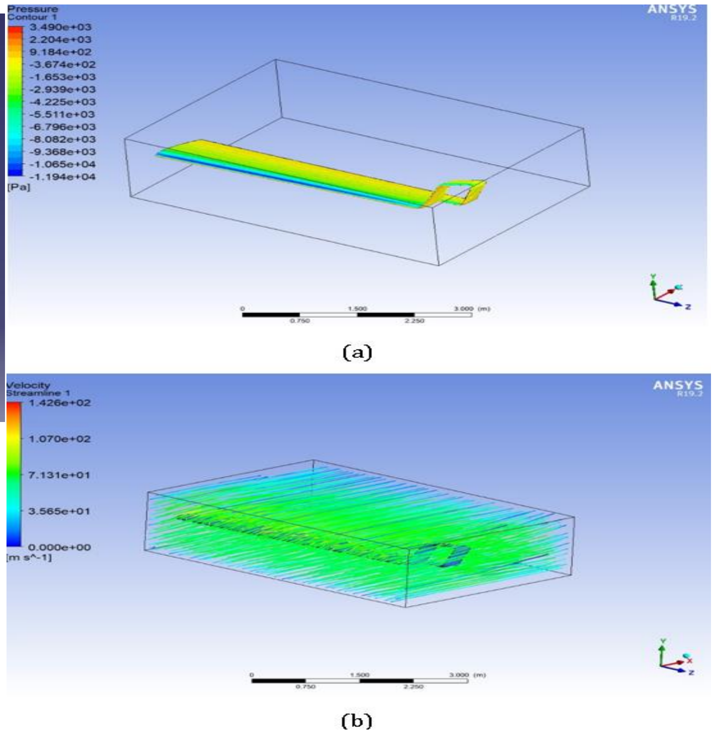


Fig-7: (a) Pressure Contour (b) Velocity Streamline

6.2 Semi-Circle Configuration

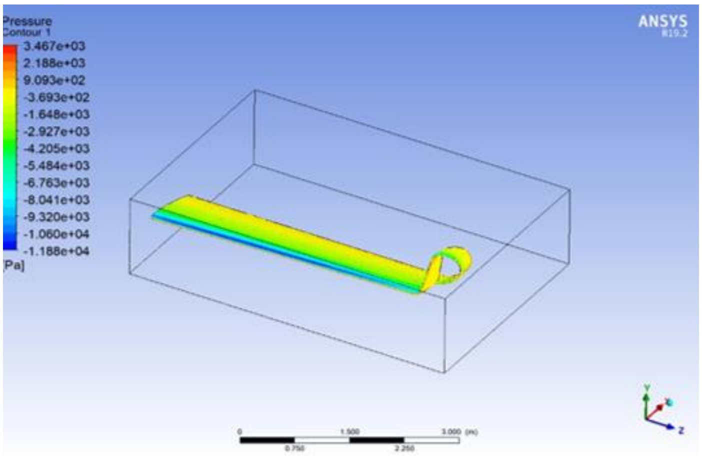
The solution obtained for semi-circle configuration is as follows:

$C_L = 3.9266$

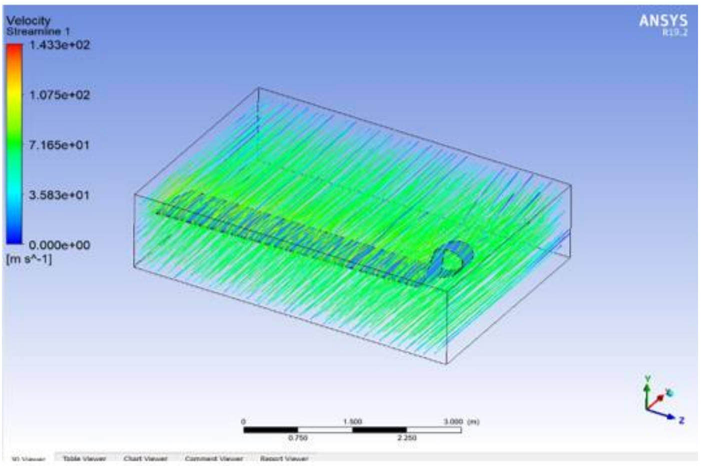
$C_D = 0.18121$

AE = 21.66

The analysis done for Semi-circle configuration is shown in Fig-8 (a) and 8(b).



(a)



(b)

Fig-8: (a) Pressure Contour (b) Velocity Streamline

6.3 Square Configuration

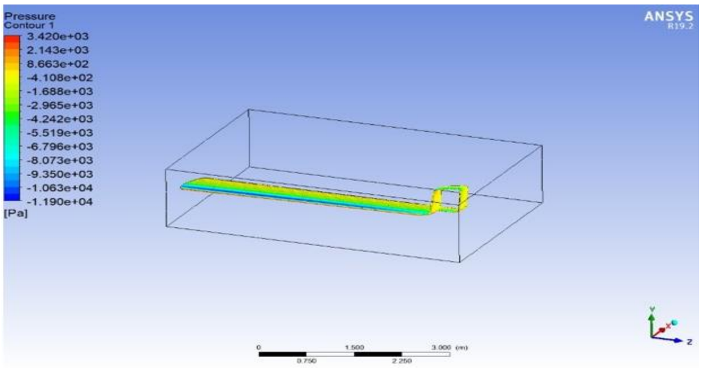
The solution obtained for square configuration is as follows:

C_L = 4.0093

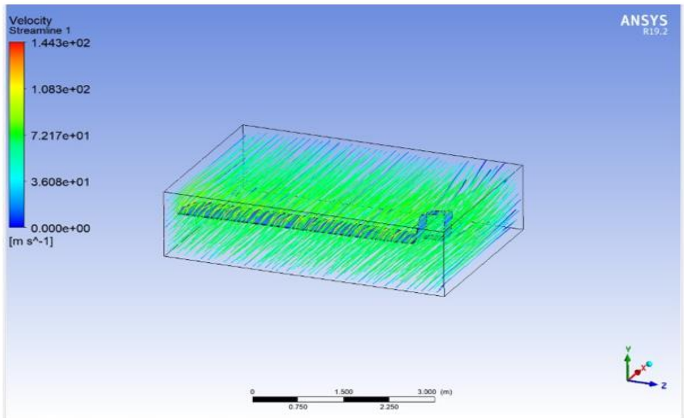
C_D = 0.19104

AE = 20.98

The analysis done for Square configuration is shown in Fig-9 (a) and 9 (b).



(a)



(b)

Fig-9: (a) Pressure Contour (b) Velocity Streamline

6.4 Diamond Configuration

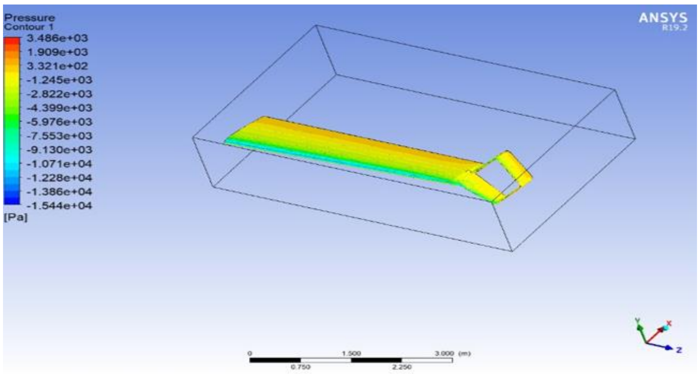
The solution obtained for diamond configuration is as follows:

C_L = 4.2847

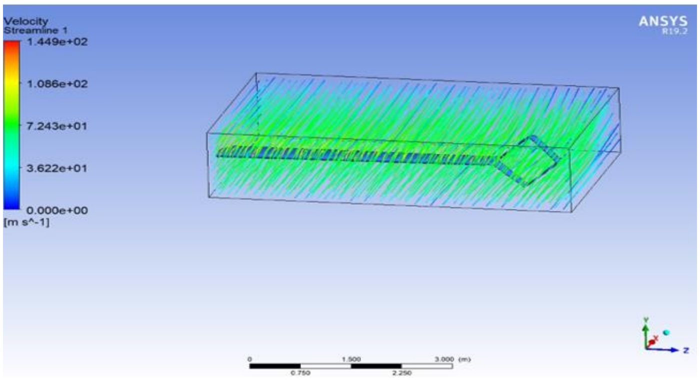
C_D = 0.20720

AE – 20.68

The analysis done for Diamond configuration is shown in Fig-10(a) and 10(b).



(a)



(b)

Fig-10: (a) Pressure Contour (b) Velocity Streamline

7. RESULTS

Therefore, by looking at the values of Coefficient of lift versus Coefficient of drag for the wing without winglet and the wing with the winglet design, it is seen that the results of the wing with the winglet have better aerodynamic characteristics than the aerodynamics characteristics of wing alone.

The comparative study on Boeing 737 with spiroid winglet and without winglet is studied in detail using software ANSYS FLUENT.

The result is tabulated as shown in Table-2.

Table-2: Aerodynamic Efficiency Results

Configurations	C_L	C_D	AE = C_L/C_D
Wing without winglet	1.4393	0.0737	19.53
Spiroid	4.0960	0.19008	21.54
Semi-circle	4.0093	0.19104	20.98
Square	3.9266	0.18121	21.66
Diamond	4.2847	0.20720	20.68

8. CONCLUSIONS

This report shows the study of spiroid winglets and research analysis which was conducted in detail in order to choose an optimum spiroid design that produced efficient aerodynamic performance results. The parasitic drag and induced drag play a vital role in the formation of total drag which decreases the efficiency of aircraft.

In this project, spiroid used in Boeing 737-100 original is used to enhance the further improvement in lift characteristics and reduce the total drag formation.

The comparative study on Boeing 737 with spiroid winglet and without winglet is studied in detail. From the analysis, it is clearly seen that the performance of the spiroid winglet is better than normal wing when compared with results obtained with respect to C_L and C_D. Thus, we can conclude that the aerodynamic efficiency is more for wings which use winglets than the wings without winglets and the best winglet out of the four is the semi-circle winglet configuration.

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