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Computational Analysis and Optimization of Boxwing Aircraft for Reducing Induced Drag

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Abstract: The paper describes the importance of reducing induced drag built up due to tip vortices which is caused by the lift produced by the aircraft wings. In this paper the effectiveness of boxwing is improved by reducing the induced drag on the boxwing. With this the practicality of boxwing rises to new level.The airfoil impact on the boxwing is studied and different airfoils are selected accordingly. Supercritical airfoils are analyzed and its importance is applied to boxwing as their practicality is observed. Here the effect of different supercritical airfoils when used for the front wing, aft wing and winglet according to their functionality are analyzed in the paper using sophisticated software. Then by selecting a specified commercial aircraft we can check the normal conventional wing computational results comparing the same aircraft with boxwing configuration on it. By this comparison we can determine by what percentage we would decrease the induced drag with the usage of boxwing configuration.

The following work is done to ensure that the boxwing is applied into practical aircrafts such commercial aircrafts hence we have used a commercial aircraft as the base to determine boxwing effectiveness in a commercial perspective also. With the results of this paper one can decrease the induced drag to an extent where the uses of the boxwing in commercial aircrafts will exceed that of the conventional winged aircrafts. In future, its application to military aircraft can also be deduced as supercritical airfoils are also being used in fighter jets.

Keywords: Airfoil Impact On The Boxwing.

I. INTRODUCTION

For achieving new heights in the Aircraft industry, there are many new design modification ideas being developed for this purpose.

To mitigate the various negative impacts in the environment and to improve the efficiency factors of commercial aircrafts many new designs and modifications of the wing and winglet region are carried out. One of the main upcoming type is the Boxwing configuration aircraft. Boxwing has attracted the attention of researches due to its claimed merits of induced drag. It is claimed to have a potential of improved fuel efficiency and reduced direct operating costs have been other reasons to investigate this configuration.

Induced drag accounts for approximately 40% of the Total drag during cruise flight and up to 90% during takeoff. It is an inviscid phenomenon and originates in the opposed span wise flow patterns on the upper and lower wing surface that is the result of the span wise pressure gradients of a finite wing generating lift. The theory behind the boxwing working is not a new observation but, it has been known from long time. The main reason of not being relatively unexplored is in terms of design knowledge and understanding fields. One of the main reasons of not being codified is due to the interaction between aerodynamics, structures and other aircraft characteristic function of basic geometry parameters. Much safer and best observation can be done as in contrast to conventional configurations, which are extremely well understood and have the underlying theory as well as data available, as from these data it helps us to pursue when considering a boxwing configuration.

The wing weight is a key and crucial component in understanding the strengths and weakness of any conceptual configuration, in the case of Boxwing when Theoretical and Computational observations are made it is required for the calculation purpose.

Another key area of interest is due to the availability of many design studies focused on one specific configuration or a specific combination of geometric parameters and then heavily analyzed that configuration using computationally, high fidelity tools and methodology.

A.. Induced Drag

Induced drag is low at high speeds, but at low speeds it comprises over half the total drag. Induced drag also depends on the strength of the trailing vortices and it has been proved that at a high aspect ratio wing reduces the strength of the vortices for a given lift force.

Winglets: These are small vertical airfoils which form part of the wing tip. Shaped and angled to the induced airflow, they generate a small forward force. Winglets partly block the air flowing from the bottom to top surface of the wing, reducing the tip vortex. In addition, the small vortex generated by the winglet interacts and further reduces the strength of the main wing tip vortex.

Wing tip Shape: The shape of the wing tip can affect the strength of the tip vortices, and designs such as turned down or turned up wing tips have been used to reduce induced drag.

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Energy or thrust extraction from the tip vortex and alteration of the tip boundary conditions are some other methods for reducing Induced drag.

B. .Project Background

The advantages of the Box wing configuration were known since 1920s, based on the work initially done by Ludwig Prandtl and Max Munk, where they concluded that the best way to reduce the amount of induced drag produced due to the velocity of the free vortices was to have the system involving vertical and horizontal wings.

Prandtl then built on with his 'Best Wing System' where he proposed that a multi-wing configuration with equal total lift distribution on both wings and a certain lift distribution on the vertical winglets would be the most efficient wing platform for reducing induced drag. The Boeing 757-200 has been by far the most popular 757 variant, with a total of 913 built over the course of its manufacture. The efficient turbofan engines allow take-offs from relatively high altitudes and short runways, and with a maximum range of 6300 km (3900 miles), they are well suited for both domestic and transcontinental flights. The wings are optimized to reduce drag, thereby increasing fuel efficiency.

C. .Ongoing Project

The Green Flight Challenge which started past year, is NASA's Centennial Challenges program as asked builders to create ultra-efficient aircrafts, to find new ways to use the layers of uncluttered wing design so that a better future for commercial flights is obtained.

A Rolls Royce Liberty Works Ultra Fan Engine uses advanced turbofan technology to maximize efficiency, achieving a bypass ratio nearly five times greater than that of current engines. This is ongoing boxwing design by the use of advanced lightweight composite materials.

II. LITERATURE REVIEW

1]Sahana D S, Abdul Aabid: In this literature we learnt that Boxwing configurations is an unconventional nonplanar configuration comparable to a conventional wing whose wings are connected in the tip by vertical winglets.

[2]Hugo Gagnon and David W. Zingg: this study investigates the aerodynamics trade offs of a box wing aircraft configurations using high fidelity aerodynamics optimization.

[3]Julian Schirra , William Bissonnette , and Gotz Bramesfeld: This literature we take staggered box wings where the predictions of induced drag that rely on common potential flow methods can be of limited accuracy.

[4]Adeel Khalid,Parth Kumar: In the literature we understand that the market for aircraft and aircraft transport has increased tremendously, and this has resulted in an increase in emissions, fuel consumption, and the cost. In order to reverse this increasing trend, various companies have researched methods of reducing drag in order to maximize the lift to drag ratio

[5]Ishan Roy Salam: A conceptual design analysis methodology and toolchain was developed for multidisciplinary analysis of box-wing aircraft.

[6]Timothy Chau and David W. Zingg: The box wing is an unconventional aircraft configuration that has the potential to provide dramatic savings in fuel consumption relative to the conventional cantilever wing.

[7]Stephen A. Andrews Ruben E. Perez: The literature paper details about the Box-wing aircraft designs and their potential to achieve significant reductions in fuel consumption.

[8]Sriram K. Rallabhandi, Erol Cagatay ,Dimitri N. Mavris: The literature deals with the creation and utilization of accurate drag polars is essential in the aircraft sizing and synthesis process.

[9]D.Schikantz, D.Scholz: The literature helps to detail the induced drag of box wing aircraft. The theoretical foundations of static longitudinal stability and controllability are presented and applied to the box wing aircraft. The results are interpreted and put into practice with the help of a medium range box wing aircraft based on the airbus A320.

III. METHEDOLOGY

A.. Selection Of Aircraft

For applying box wing configuration, we have selected the fuselage and empennage section of the Boeing 757-200 commercial aircraft. Total length of aircraft (including nose, fuselage and empennage) is 47.3 meters, tail height is 13.56 meters and the empty weight is 57840 kg. The wings are modified according to the requirement for the box wing configuration.

B.. Selection Of Airfoils

Airfoils are always selected depending on the airflow conditions in which they have to operate, airfoil shapes, description of the flow around the airfoils with increasing angle of attack upon reaching a critical value and the effect of roughness of airfoil surfaces at critical angle of attack.

For this purpose, we analyzed each airfoil and obtained the necessary results through XFLR Plotter.

1)KC 135 Winglet Airfoil ;-

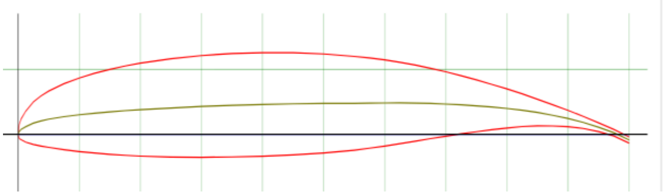

Figure 1:-KC 135 Winglet Airfoil

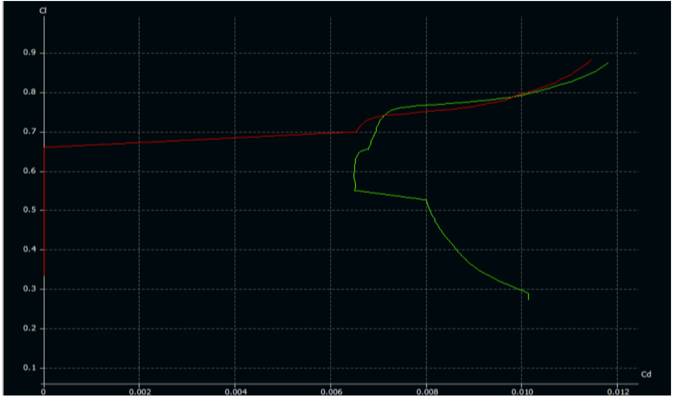

Figure 2:- $C_L$vs C_D Graph

At R_e $5*10^6$ the minimum value of C_D is 0.0065 and at R_e $6*10^6$ the minimum value of C_D is 0.

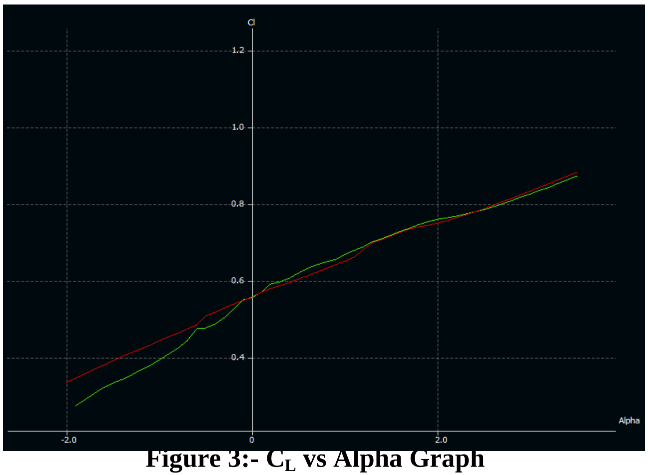

Figure 3:- C_L vs Alpha Graph

The C_L reaches a value of 0.82 and 0.83 at 3.2^0 angle of attack at R_e $5*10^6$ and R_e $6*10^6$ respectively.

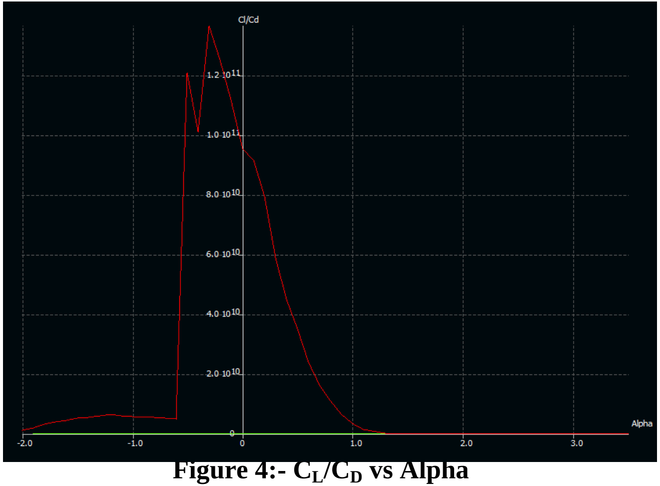

Figure 4:- C_L/C_D vs Alpha

The C_L/C_D reaches the maximum value of 0 at $5*10^6$ R_e at all angles. The C_L/C_D reaches a maximum value of $1.35*10^{11}$ at $6*10^6$ R_e at -0.3^o.

2) SC20710 Airfoil ;-

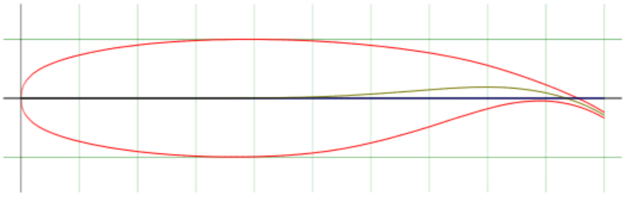

Figure 5:-SC20710 Airfoil

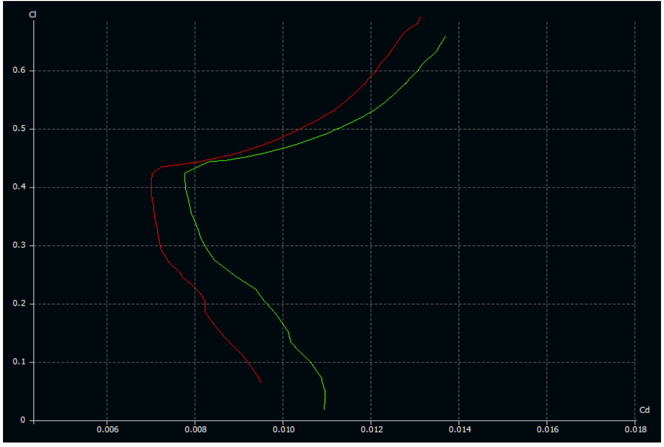

Figure 6:- $C_L$vs C_D Graph

At R_e $5*10^6$ the minimum value of C_D is 0.0078 and at R_e $6*10^6$ the minimum value of C_D is 0.007.

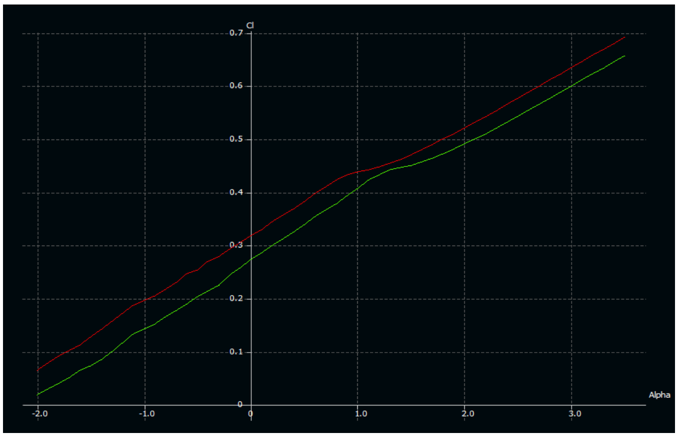

Figure 7:- C_L vs Alpha Graph

The C_L reaches a value of 0.62 and 0.66 at 3.2^0 angle of attack at R_e $5*10^6$ and R_e $6*10^6$ respectively.

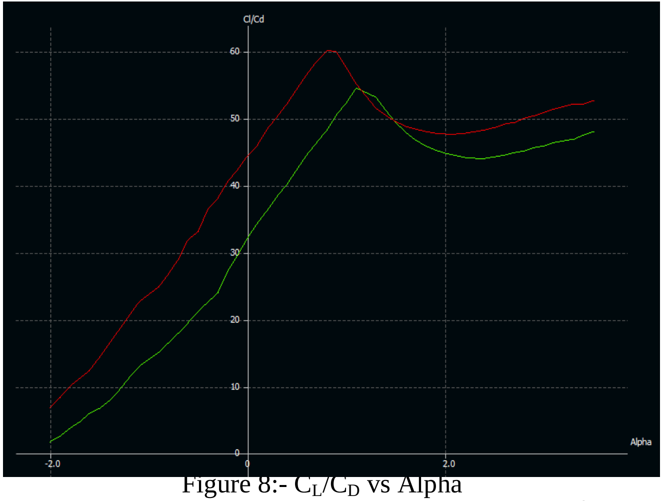

Figure 8:- C_L/C_D vs Alpha

The C_L/C_D reaches the maximum value of 53 at $5*10^6$ R_e at 1.1^o. The C_L/C_D reaches a maximum value of 61 at $6*10^6$ R_e at 0.8^o.

3)SC20714 Airfoil ;-

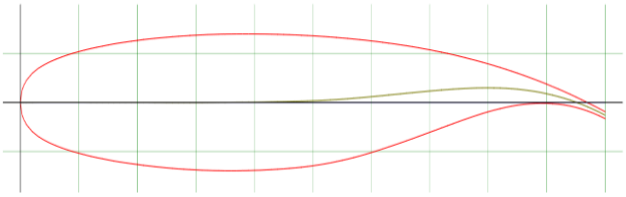

Figure 9:-:-SC20714 Airfoil

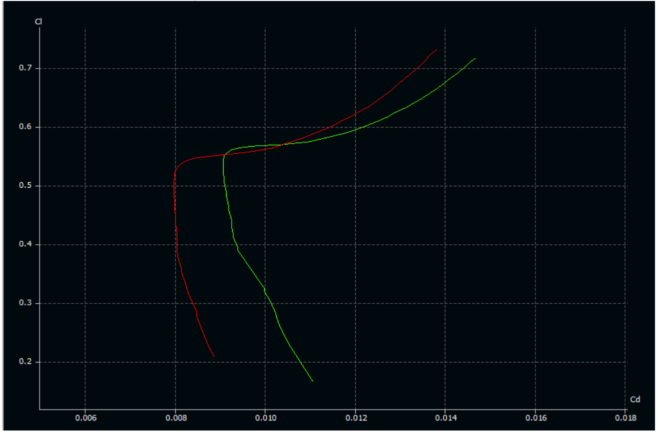

Figure 10:- $C_L$vs C_D Graph

At R_e $5*10^6$ the minimum value of C_D is 0.0091 and at R_e $6*10^6$ the minimum value of C_D is 0.008.

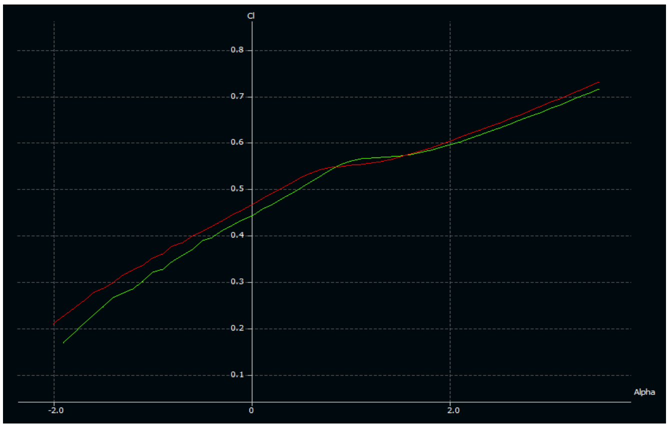

Figure 11:- C_L vs Alpha Graph

The C_L reaches a value of 0.71 and 0.72 at 3.2^0 angle of attack at R_e $5*10^6$ and R_e $6*10^6$ respectively.

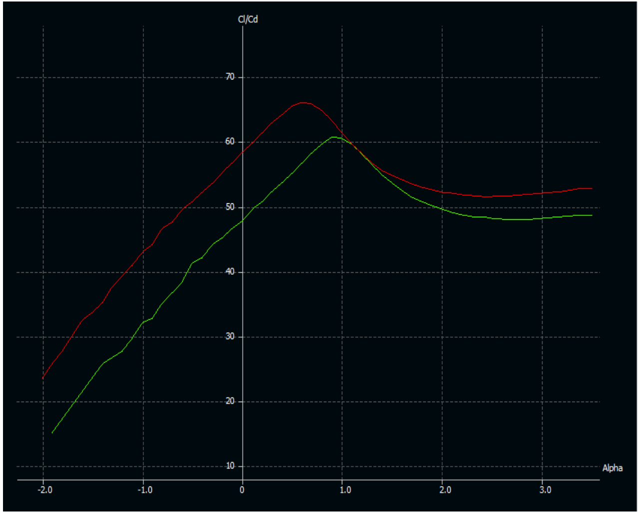

Figure 12:- C_L/C_D vs Alpha

The C_L/C_D reaches the maximum value of 61 at $5*10^6$ R_e at 0.9^o. The C_L/C_D reaches a maximum value of 66 at $6*10^6$ R_e at 0.6^o.

After obtaining all the results we decided to design an Aircraft model replicating Boeing 757-200 model with a conventional wing as first case. Then another Boeing757-200 model with Boxwing configuration where all the main wing, aft wing and winglets have different airfoils.

IV. MODELLING and ANALYSIS

A. .Normal Boeing 757-200

1) Design Of Boeing 757-200:

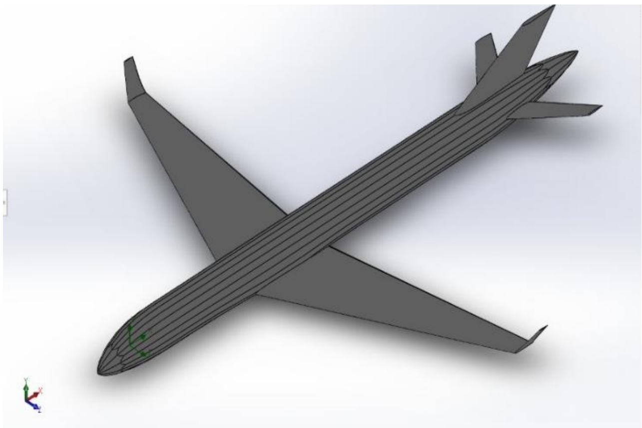

Figure 13:- Boeing757-200 model

- Data for the design of Boeing 757-200 was taken from Modern Airlines website.
- To design according to design details, we have opted Autodesk inventor 2019.
- The model has not been scaled down. Wing span of the original aircraft 38m is designed the same.
- Fuselage of aircraft was developed and modified by sheet metal sculpting process.
- From the midpoint root airfoil, we take a 19m line and insert another line from same point 25° angle for the sweep purpose.
- Then the tip airfoil is placed at these lines end point by main wing is lofted and this the developed.
- Then the wing is dihedral is kept to 5°. Based on the Boeing 757-200 design we have designed the vertical and horizontal stabilizer.

Variant	**BOEING 757-200 Dimensions**
Length	47.3 meters
Width	3.76 meters
Wing Span	38 meters with 25^0sweep
Height	13.6 meters
Root chord	8.2 meters
Tip chord	1.73 meters

2)Computational Results And Disscussion

Boundary Conditions:

PARAMETERS	**VALUES/TYPES**
Altitude	**11,000m(36089.239ft)**
Pressure	**22633 Pa**
Velocity	**250 m/s**
Temperature	**216.65 K**
Flow type	**Laminar and Turbulent**

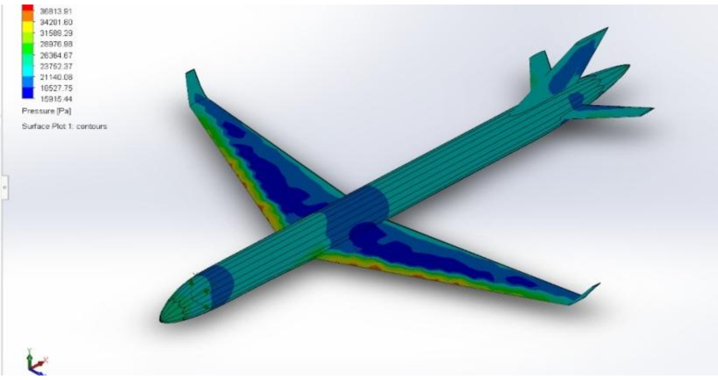

Figure14:- Pressure contour of Boeing 757-200

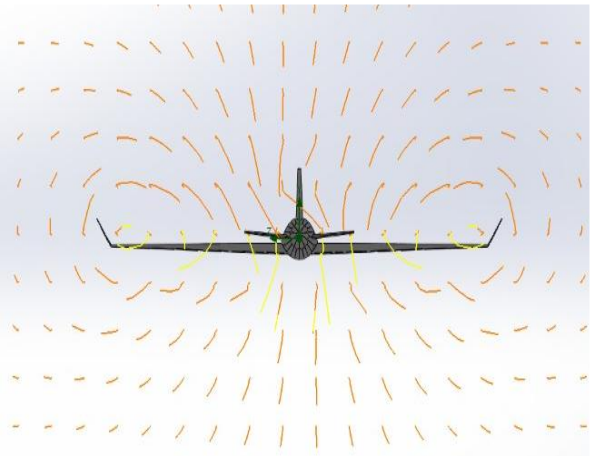

Figure 15:-Vortex formation in Boeing 757-200

3) Boeing 757-200 Calculation

Lift, l=330845.5142N

Drag, D=181633.8606N

Maximum Shear=184.375Pa

Maximum dynamic pressure=16471.96Pa

Wing area, S= (168.42+5.82)*2=348.48m

Density=0.365 at 11,000 meters altitude in air

C_L=L/(0.5*Density*Velocity^2*S)

=330845.51/(0.5*0.365*250^2*348.48)

C_L=0.083

C_D=D/(0.5*Density*Velocity^2*S)

= 181633.8602/(0.5*0.365*250^{2*}348.48)

C_D=0.045

C_{Do}= Maximum Shear/Maximum Dynamic pressure

=184.375/1647.96

C_{Do}= 0.011

C_D = C_{Do}+C_{Di}

Therefore,

C_{Di}=C_D-C_{Do}

=0.045-0.011

C_{Di}=0.033

Overall Discussion About Boeing 757-200:

In the above results we observed that Induced drag is occupies almost 73.3% of the total drag. Then we also observe the tip vortex formed at the wings is a very large region which results in the formation of high induced drag in the aircraft.

B. .Boxwing Boeing 757-200 With Different Airfoils

1)Design Of Boxwing Boeing 757-200

For this design we used different airfoils at the Main wing-SC20710, Aft wing-SC20714 and at the Winglets-KC135.

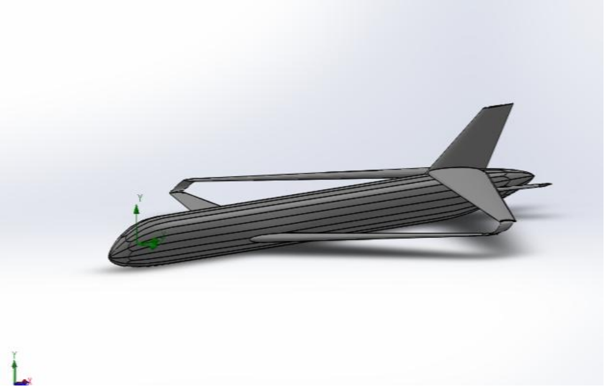

Figure 16 :-Boeing757-200 model with Boxwing

- Data for the design of Boeing 757-200 was taken from Modern Airlines website.
- To design according to design details, we have opted Autodesk inventor 2019.
- The model has not been scaled down. Wing span of the original aircraft 38m is designed the same.
- Fuselage of aircraft was developed and modified by sheet metal sculpting process.
- From the midpoint root airfoil, we take a 19m line and insert another line from same point 25° angle for the sweep purpose.
- Then the tip airfoil is placed at these lines end point by main wing is lofted and this the developed.
- Then the wing is dihedral is kept to 5°. Based on the Boeing 757-200 design we have designed the vertical and horizontal stabilizer.
- Then placing the same airfoil at the vertical stabilizer bottom, from where we would like to design Boxwing.
- From the midpoint of the airfoil we would draw a line of 19meters to winglet plane on the same plane. Then we would create another plane at 0.5 meters plane.
- Then we would loft the entire aft wing till the winglet plane and with help of revolved protrusion we join the main wing and aft wing. This takes place in the region of the 0.5 meter plane.

Variant	**BOEING757-200 WITH BOXWING**
Length	**47.3 meters**
Width	**3.76 meters**
Wing Span	**38 meters**
Height	**13.6 meters**
Main wing Root chord	**8.2 meters**
Main wing Tip chord	**1.73 meters**
Aft wing Root chord	**6.4 meters**
Aft wing Tip chord	**1.73 meters**

2)Computational Results And Discussion

Boundary Conditions:

PARAMETERS	**VALUES/TYPES**
Altitude	**11,000m(36089.239ft)**
Pressure	**22633 Pa**
Velocity	**250 m/s**
Temperature	**216.65 K**
Flow type	**Laminar and Turbulent**

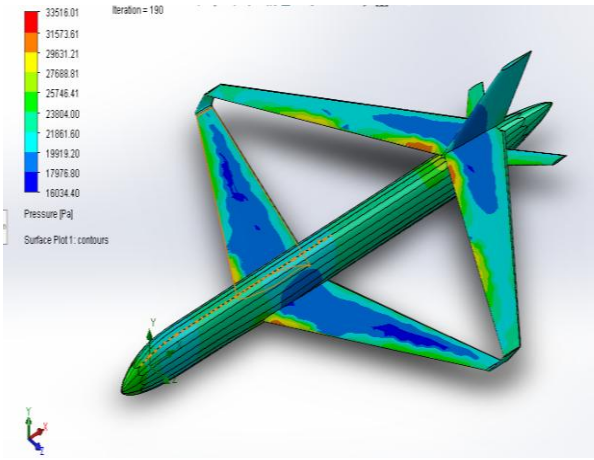

Figure 17 :-Pressure countour of Boxwing model

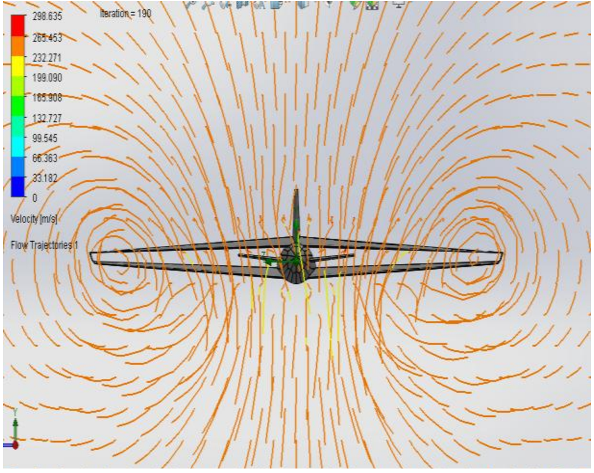

Figure 18:- Vortex formation of Boxwing model

3) Calculations

Lift, L=694889.9516N

Drag, D=146652.3556N

Maximum Shear Stress=88.95Pa

Maximum Dynamic Pressure=16977.0625 Pa

Wing area, S=661.25m

Density=0.365 at 11,000meters altitude in air

C_L=L/(0.5*Density*Velocity^2*S)

=694889.9516/(0.5*0.365*250^2*661.25)

C_L=0.092

C_D=D/(0.5*Density*Velocity^2*S)

=146652.3556/(0.5*0.365*250^2*661.25)

C_D=0.019

C_{Do}=Maximum shear stress/Maximum dynamic pressure

=88.95/16977.065

=0.0052

$C_D = C_{Do} + C_{Di}$

$C_{Di} = C_D - C_{Do}$

= 0.019-0.0052

C_{Di} = **0.0142**

V. OVEALL DISCUSSION:

In the above theoretical results we see a great amount of decrease in the total drag when compared to the conventional type wing. The tip vortex region formed at the wings is compared to that of the conventional wing which provides the main reason of decrease in the induced drag of the aircraft.

VI. ABBREVATIONS

1)C_L= Coefficient of Lift

2)C_D= Coefficient of Drag

3)C_{Di}= Coefficient of Induced Drag

4)C_{Do}= Coefficient of Zero lift Drag

VII. CONCLUSION

Thus the project shows that the Boxwing is the most effective way of reducing the induced drag developed due to vortex formation. By this we would like to conclude that Boxwing would be the future of commercial flight applications. By the results we obtained that for multi airfoil Boxwing the Coefficient of Induced drag is **0.014** and for a normal Conventional wing without Boxwing configuration the Coefficient of Induced drag is **0.033** ,so we observe there is reduce of **56.96%** of the induced drag with the utilisation of a Boxwing configuration. So our overall we conclude that bu the utilisation of boxwing we can reduce induced drag and fuel consumption. The Future scope of this project would be changing the angle of attack at the wing chord to improve the stability of the aircraft. Also by changing the winglet curvature more amount of induced drag may be reduced in the future.

ACKNOWLEDGEMENT

We express our sincere thanks to **Dr. Hareesha N G,** Professor and HOD, Department of Aeronautical Engineering, for providing the facilities required for the completion of this project work. We also express our sincere thanks to all members of the Derartment of Aeronautical Engineering, Dayananda Sagar College of Engineering for providing their valuable support for helping us complete this project.

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