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Energization of Boundary Layer Over Wing Surface By Vortex Generators

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Abstract— The issue taken into consideration is sudden increase in drag over an aircraft wing due to three dimensional flow, tip vortices and flow separation. When flow separates its displacement thickness increases sharply this modifies the outside potential flow and pressure field. The pressure field modification results in an increase in pressure drag, and if severe enough will also result in loss of lift and stall. This study presents computational analysis results of a prototype wing with and without vortex generators of two different shapes located at leading and trailing edges of a linear wing. Here both wind tunnel testing and computational fluid dynamic analysis is carried out. The effect of the vortex generators are studied in four different cases. Nine sets of rectangular shaped vortex generators inclined at 15 degree were placed in the leading edge and trailing edge of the wing, nine sets of ogive shaped vortex generators inclined 15 degree were placed in the leading edge and trailing edge of the wing, are the cases analyzed. The studies also focus on prevention of downstream flow separation and improve overall performance by reducing drag. Both analytical and experimental results are compared where it shows that the pressure over the upper surface increases, so that the boundary layer is reenergized and attached with the body surface thus reducing the drag.

Keywords — ANSYS, CATIA, Ogive Vortex Generators

I. INTRODUCTION

A vortex generator is an aerodynamic device, consisting of a small vane usually attached to a lifting surface or a rotor blade of a wind turbine. The angle of the vortex generator causes the air to swirl creating a vortex behind it. This effect allows the airflow to remain attached to the surface even at points where the flow without a vortex would separate from the surface.

Vortex generator creates a vortex, when the airfoil is in motion relative to the air, which, by removing some part of the slow moving boundary layer in contact with the airfoil surface. It delays the local flow separation and aerodynamic stalling, thereby improving the effectiveness of wings and control surfaces, such as flaps, elevators, ailerons and rudders.

A. Operation of Vortex Generator

VGs are typically as tall as the local boundary layer, and run span wise lines usually near the thickest part of the wing .Vortex generators are positioned obliquely so that they have an angle of attack with respect to the local airflow in order to create a tip vortex which draws energetic, rapidly moving outside air into slow moving boundary layer in contact with the surface. A turbulent boundary layer is less likely to separate than a laminar one, and is therefore desirable to ensure effectiveness of trailing edge control surface.

As air normally flows over the wing of an aircraft, the air sticks to the surface of the wing. This adherence to the wing's surface produces lift. If the air flow loses its adherence and separates from the wing, aircraft performance can suffer in the form of increased drag, loss of lift and higher fuel consumption. Vortex generators are used to control this flow detachment by producing vortices. The vortex generators sweep away uncontrolled airflow separation over the airplane's wing with the benefit of reduced drag and increased lift, i.e., less engine power needed to produce the same lift.

Types

There are many types of vortex generators, as listed below

1. Gothic vortex generator
2. Rectangular vortex generator
3. Parabolic vortex generator
4. Triangular vortex generator
5. Ogive vortex generator

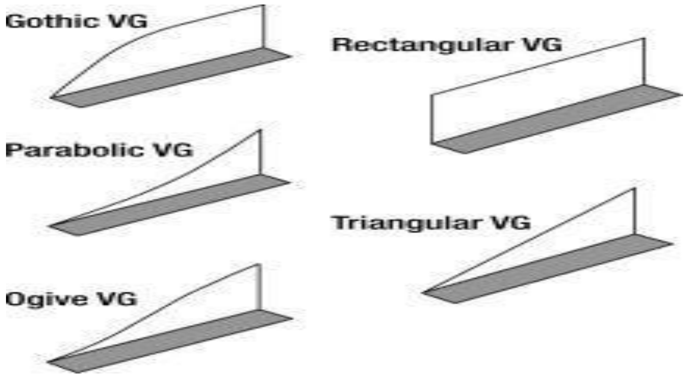

Fig 1:Types of Vortex Generators

II. LITERATURE REVIEW

[1] H. A. Alawadhi, A. G. Alex, and Y. H. Kim. [1]: The vortex generator energizes the boundary layer and encourages the flow to remain attached to the flap, allowing for a greater range flap deflection. A wind tunnel experiment was developed and conducted to substantiate the computational analysis in a real world scenario.

[2] Mathieu Gruber, Phillip F. Joseph [2]: Focuses on the effect of saw tooth serrated edges on steady and unsteady aerodynamics around airfoil. The results obtained were not satisfactory, that is there were no significant changes in drag co-efficient due to the introduction of serrations.

[3] B. Raghava Rao, Rangineni Sahitya [3]: Focuses on the effect of stall angle on the performance of the wing .here performance parameters include lift, drag co-efficient and pressure distribution of two dimensional subsonic stream over a symmetric airfoil at different angle of attacks and at low and high Reynolds number. So, in order to perform this experimental test was conducted in low speed wind tunnel, and the computational analysis was performed using ANSYS-15(FLUENT) software

[4] John C. Lin [4]: Focuses on boundary layer flow separation control by a passive method using low profile vortex generator. Here, the topics of discussion consist of both basic fluid dynamics and applied aerodynamic research. The fluid dynamic research includes comparative study on separation control effectiveness as well as device induced vortex characteristics and correlation. The aerodynamic research includes several applications for aircraft performance enhancement and covers a wide range of speed.

III. DESIGNING OF VORTEX GENERATORS

A. Design Pre-Requisites

1) Selection of the shape of vortex generators:

Based on the literature review the vortex generator usually used in airplanes are ogive and rectangular. Hence rectangular and combination of ogive and gothic vortex generators are used for this study.

2) Determine the length and the location of the vortex generator

The length of the vortex generator should be around 5-8% of the chord of the wing. The vortex generator should be placed just in front of the laminar to turbulent transition of the boundary layer on the wing. This transition is located at approximately 16% back on the wing chord from the leading edge. Thus place the leading edge of the vortex generator at a length equal to a value of (16% of chord) – (length of the vortex generator). This will place the vortex generator just in front of the laminar to turbulent boundary layer transition.

3) Determine the height of the vortex generator.

Vortex generators work to control the boundary layer and thus they are more effective inside the boundary layer. On larger general aviation aircrafts and airlines vortex generators typically have height 80% that of laminar boundary layer right before laminar to turbulent transition point on the wing

$$\delta = \frac{5.0 * x}{\sqrt{Re}}$$

Where,

$\boldsymbol{\delta}$- boundary layer height (mm)

x – Transition point (16% of chord) (mm)

Re- Reynolds number

Height of the vortex generator = 80% of height of boundary layer.

4) Calculate the span wise spacing of the vortex generator.

Since the number of vortex generators to be placed is 18 we divide the span wise components of the wing such that there is equal distance between each vortex generator.

Wing Span	570 mm
Wing chord	300 mm
Domain a) height b) length c) width	1000 mm 2600 mm 4000 mm
Type of vortex generators used	Rectangular, combination of ogive and gothic
Number of vortex generators	18
Length of the vortex generator	18 mm
Distance of the vortex generator from the leading edge	30 mm
Reynolds number	$5*10^5$
Height of the boundary layer	2.12 mm
Height of the vortex generator	3mm
Span wise spacing of the vortex generator	30mm each
Angle at which vortex generators are placed	15˚
Thickness of the vortex generator	1mm

Table 1: Vortex Generator Specifications

IV. METHODOLOGY

A. Objective and Purpose:

The main objective of this project is diminishing drag by delaying the formation of boundary layer separation thereby increasing lift. Our prototype produces more lift when compared to the results of the other lift enhancing devices like serrations. Our model also delays the formation of boundary layer around the aerofoil thereby increasing the aerodynamic characteristics. The model is analysed using CFD tools.

B. Modelling:

As earlier said the basic wing dimensions and aerofoil coordinates are obtained through reference papers. Then with these co-ordinates we design a 3d wing using CATIA V5.

Steps involved in CATIA modelling:

The very first step in CATIA is

1. File → New → Part design → Geometry OK.
2. Open Excel Sheet → Copy the coordinates → Run the excel sheet → End the process.
3. After the coordinates of NACA 0024 Are created then Line → Spline → Curves Curve by points Join all the coordinates

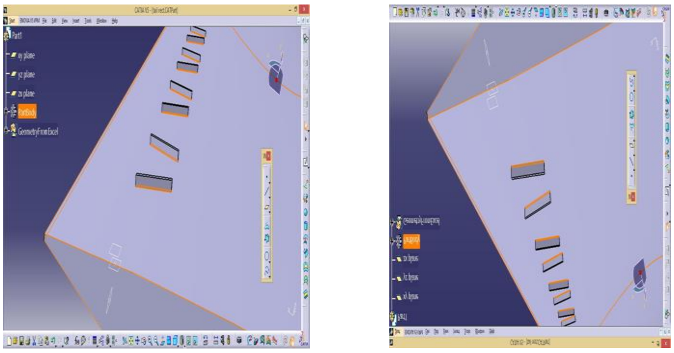

Fig 2: Rectangular Vortex Generators at Trailing and Leading Edge

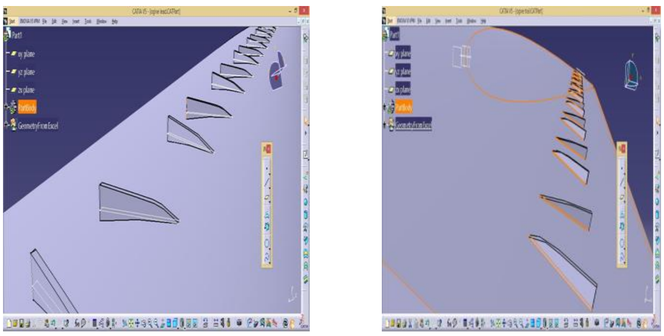

Fig 3: Ogive Vortex Generators at Leading and Trailing Edge

C. Meshing

In meshing the following steps are also followed

1) Geometry → location → Centroid of two points → Mesh → Global mesh set up.
2) Mesh parameters → Inlet → 2 → Outlet → 2 Wall → 4 → wing → 2 → compute mesh.
3) Axis → Z → angle → 5˚ → Centroid.
4) Compute Mesh → type → Tetrahedron Mixed → Method → Robust.
5) Curve Mesh Parameters → Max Mesh size 0.5.

After the meshing, the model is imported to ANSYS FLUENT for analysis.

D. Analysis

As mentioned earlier the ANSYS 14.5 solves the case in three basic steps. In the pre-processor stage the boundary conditions are applied for each section. The boundary conditions , meshing and the convergence criteria is re checked and then its sent to the solver, where in the case is solved for specified number of iterations. After the case is solved it is saved in .res file and then post processed for obtaining the result.

1) File → load results → select the prototype saved in .res file → ok
2) File → load state → select the file in .cst format ok.
3) Double click on contour 1 for pressure plot vary the maximum and minimum pressure values to obtain an accurate profile → file → save picture in PNG format → ok
4) Double click on contour 2 for velocity plot vary the maximum and minimum velocity value file → save picture as → ok.
5) Double click on stream line for pressure stream line file → save picture as → ok.
6) Double click on vector → file → save picture as → ok.
7) File → export → to polyline → select pressure → velocity → x → y → z → ok save in .bsl format → ok.
8) In excel sheet → plot graphs of the above parameters with respect to X Y and Z coordinates ok.

The results are taken for two angles of attacks

1) 0˚ and
2) 5˚ AOA

The result files are analysed for pressure and velocity criteria.

V. RESULTS AND DISCUSSIONS

A. Computational Analysis Results

- Plain Wing with No Vortex Generators

Computational fluid analysis is performed on a plain wing to study the flow properties over a wing and understand the flow pattern and theory of flow separation. And these computations are compared with a symmetric airfoil having vortex generators placed at the trailing edge.

Pressure Plot:

At 5◦ angle of attack

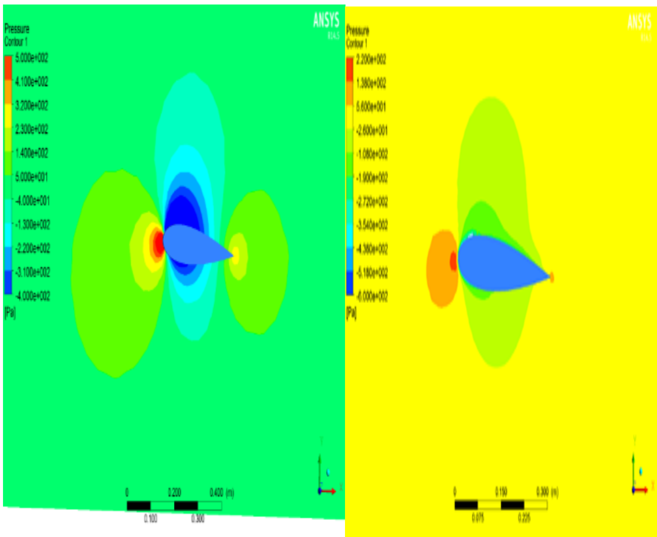

Fig 3: Pressure Countour and Streamline Pressure

At 0◦ angle of attack

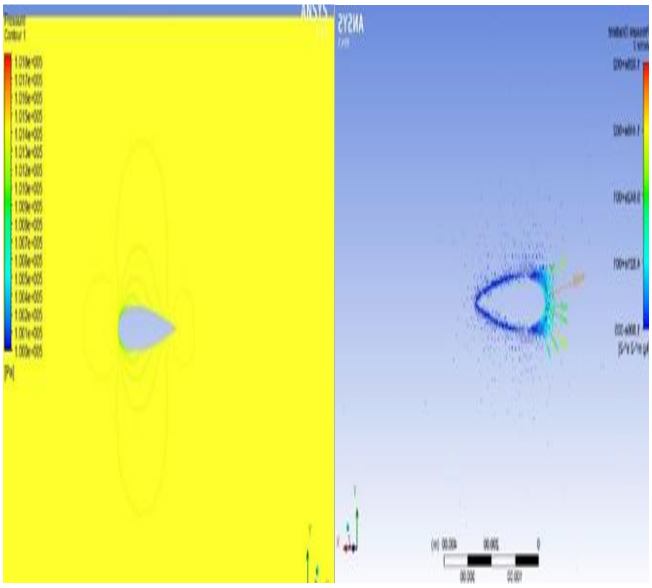

Fig 4: Pressure Contour and Pressure Gradient

Velocity plot:

At zero angle at attack

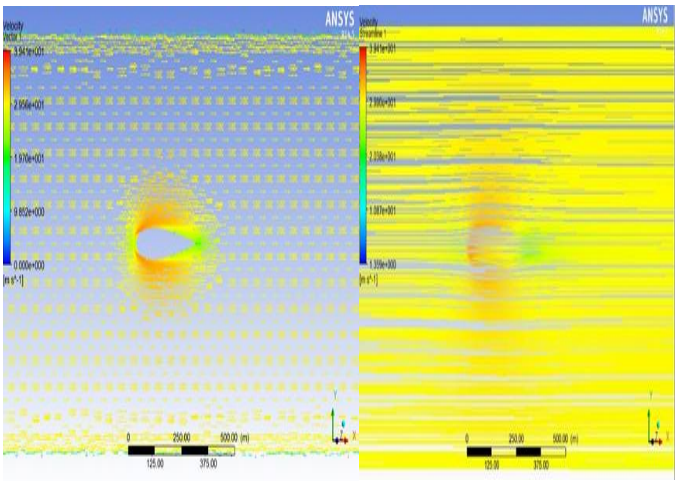

Fig 5: Velocity Contour and Velocity Streamline.

At 5° angle of Attack

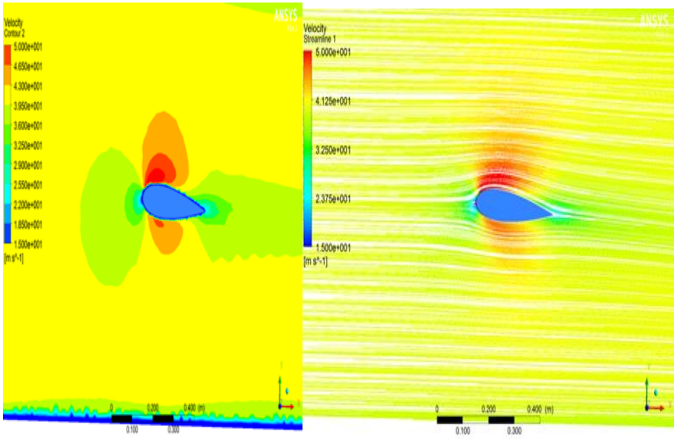

Fig 6: Velocity Contour and Velocity Streamline.

Plain wing with rectangular vortex generators at leading edge
Pressure plot:
At zero angle of attack.

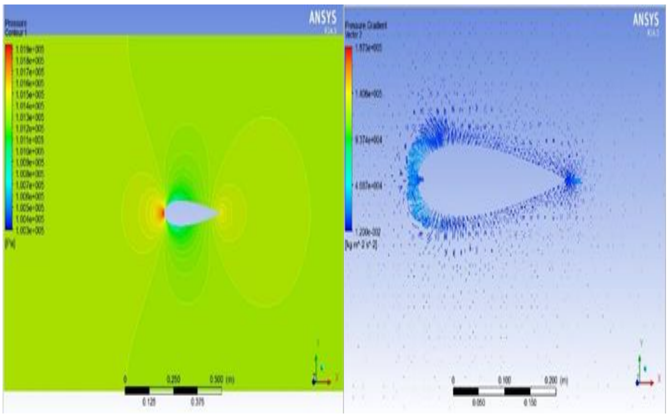

Fig 7: Pressure Contour and Pressure Gradient

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At 5˚ angle of attack.

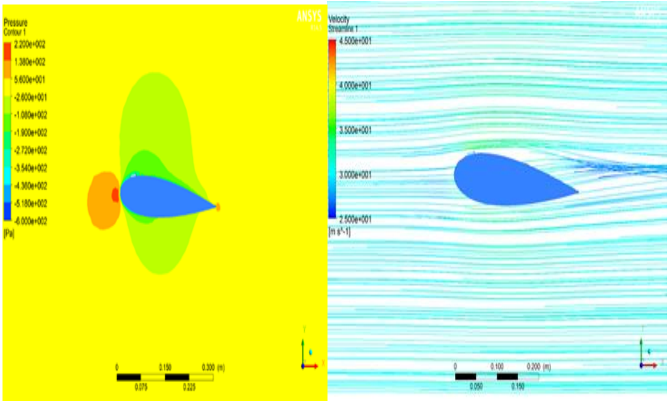

Fig 8: Pressure Contour and Pressure Gradient

Velocity plot:

At 5˚ angle of attack.

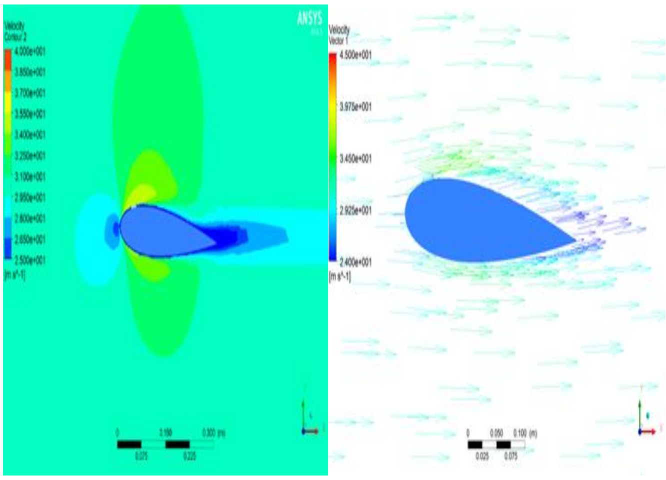

Fig 9: Velocity Contour and Velocity Streamline.

At 0˚ angle of attack

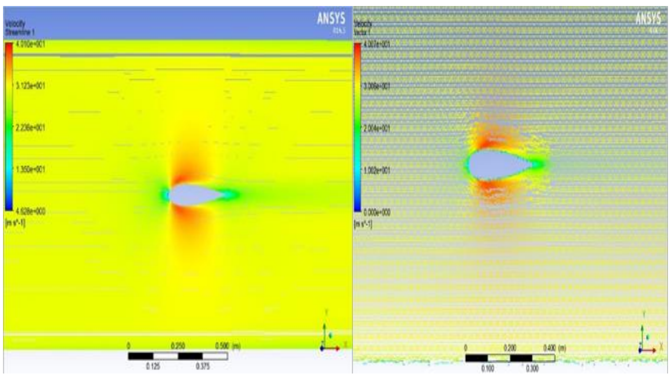

Fig 10: Velocity Contour and Velocity Streamline.

Plain wing with rectangular vortex generators at leading edge

Pressure plot and Velocity plot:

At zero angle of attack.

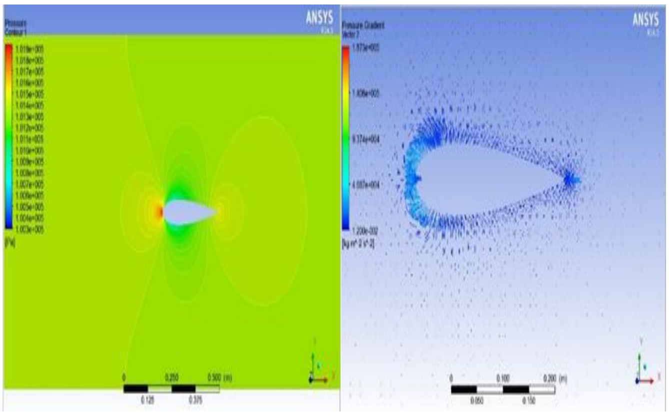

Fig 11: Pressure Contour and Pressure Gradient

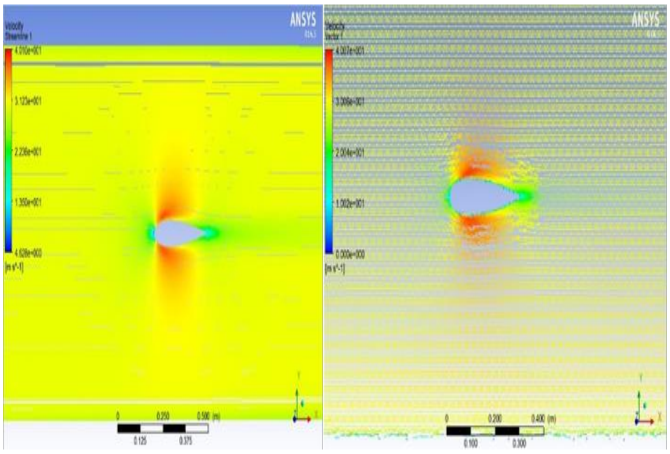

Fig 12: Velocity Contour and Velocity Streamline.

Plain wing with Rectangular vortex generator at trailing edge

Pressure plot and Velocity plot

At zero angle of attack

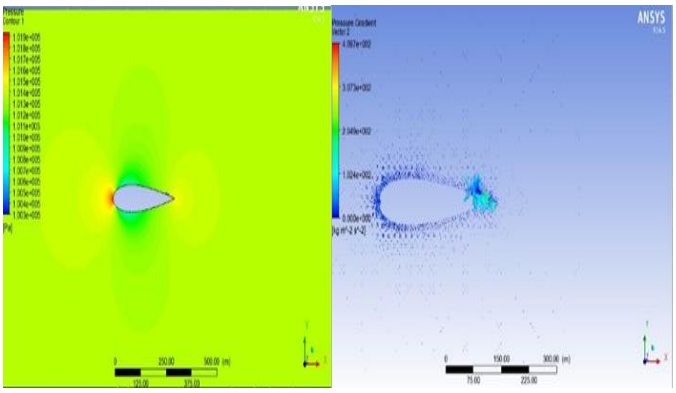

Fig 13: Pressure Contour and Pressure Gradient

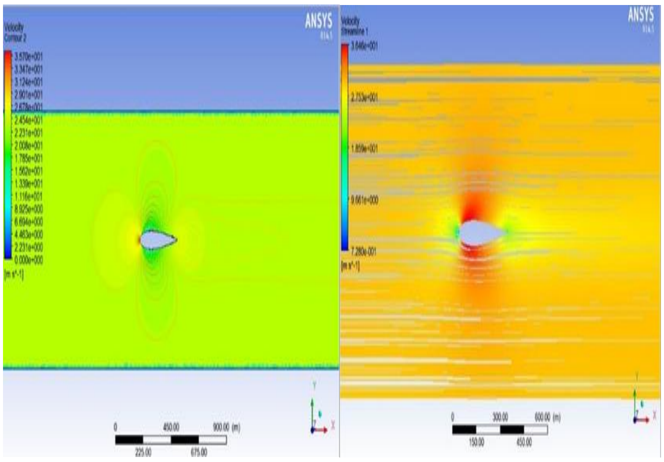

Fig 14: Velocity Contour and Velocity Streamline

Plain wing with Ogive Vortex Generator placed at the leading edge

Pressure plot and Velocity plot

At 0˚Angle of attack

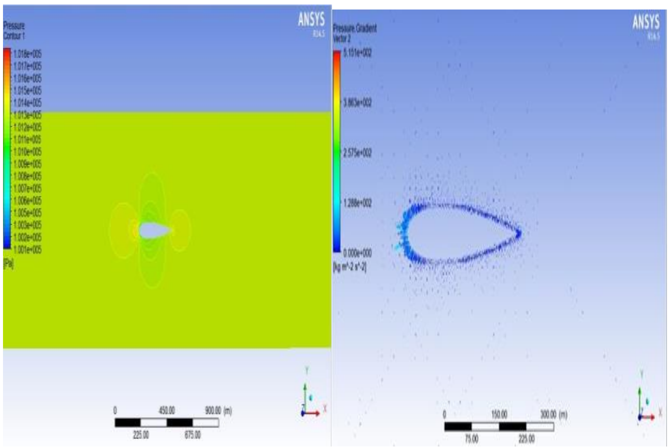

Fig 15: Pressure Contour and Pressure Gradient

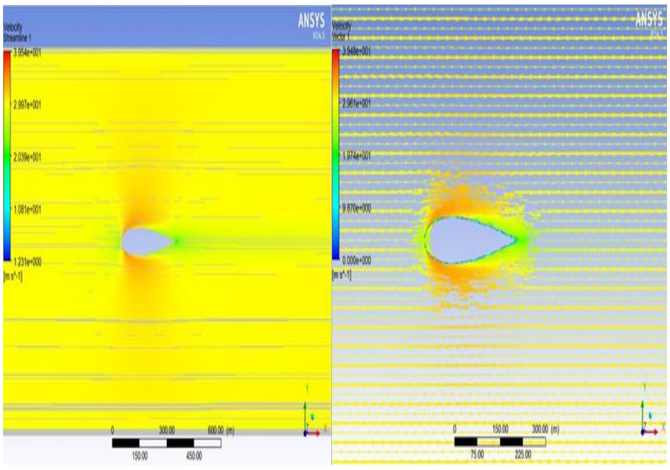

Fig 16: Velocity Contour and Velocity Streamline

Plain wing with Ogive vortex generator placed at the trailing edge:

Pressure plot and Velocity plot:

For 0˚AOA

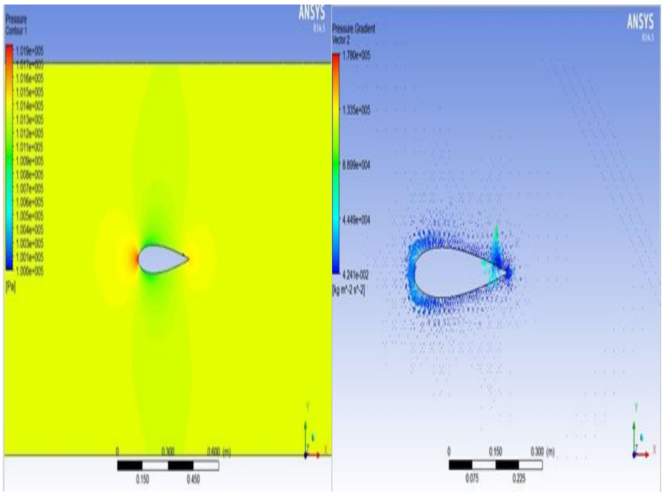

Fig 17: Pressure Contour and Pressure Gradient

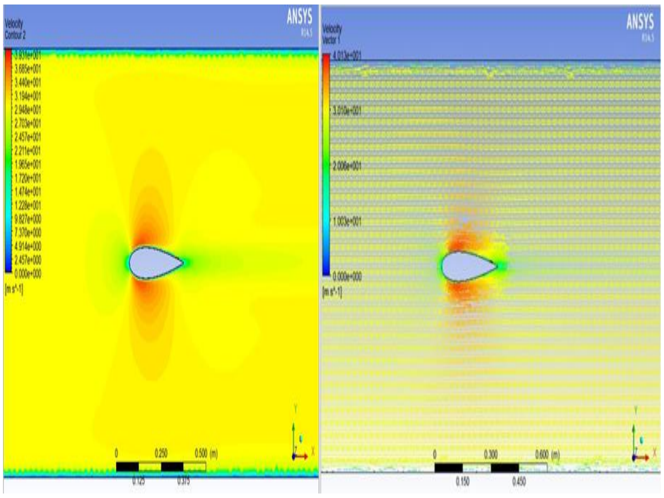

Fig 18: Velocity Contour and Velocity Streamline

B. *Comparison*

- The velocity in the upper surface for the plane wing is more when compared to the wing with ogive vortex generator placed at the trailing edge. The flow separations takes place when there is an increase in velocity, because of which the flow separates from the body and the value of lift will be reduced, increasing the drag and hence increase in Reynolds number.
- In case of ogive vortex generator since the velocity is reduced, the flow is much more attached to the body resulting in the increment of lift.
- Whenever there is more velocity in the upper surface the pressure will be very less leading to the increase in the pressure difference but in case of ogive vortex

generator the velocity on the upper surface is less when compared to the plane wing with no vortex generator.

- This results in increase in pressure and decrease in the pressure difference. In this view there is a loss in lift, which can be compensated with the attached flow over the body.

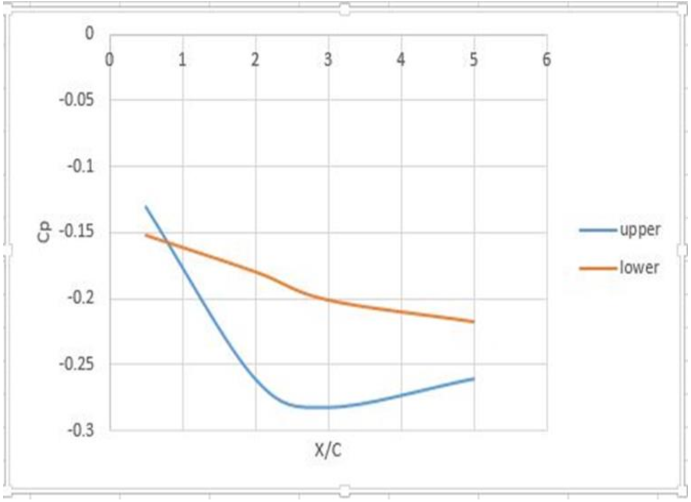

Fig 19: Pressure Variation in a Plain Wing

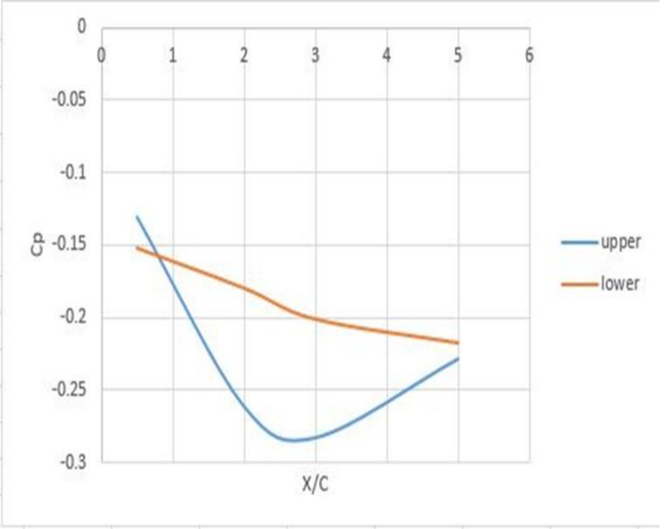

Fig 20: Pressure Variation in a Plain Wing with Ogive Vortex Generators

VI. CONCLUSION

Vortex generators are valuable aerodynamic devices which can be used by aircraft designers to enhance airplanes flying qualities. Judicious use of vortex generators results in optimum aerodynamic characteristics over a wide range of flight conditions. Example from cruise flight to high load factor and /or high angle of attack manoeuvres into heavy buffet.

The use of these devices have resulted the following i.e., reduce in overall aerodynamic drag, rear-end airflow separation. This results in increase of fuel efficiency, lower take-off distance, lower approach speed, gentle stall characteristics.

Vortex generators alleviate boundary layer separation, and in instances provide overall aerodynamic benefits, however their potential and efficiency varies considerably in practical applications.

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