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Aerodynamic Investigation of Triangular Vortex Generator over NACA 4415 Airfoil

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Abstract

This paper presents a 2-dimensional computational analysis of NACA 4415 Airfoil attached with Triangular Vortex Generator(VG) to raiseit's stalling angle. The aim of this study is to analysis the parameter such as Reynolds no. 2.18 x 105 and several angle of attack (AOA). In ansys fluent we have performed with C-H domain as enclosure specifying velocity-inlet and farfield as pressure-outlet. Airfoil is been implemented with Vortex Generator(triangular) to energize slow moving air above the airfoil by converting laminar to turbulent attached flow and to have an intact airflow over boundary surface. Structured fine meshing is done to have a better convergence and by grid independence test it is been found that lift and drag coefficient is ceased with node exceeding 150000. The computational setup consists of incompressible, steady-state, Finite –element method(FEM) using standard K-Epsilon(2-equation) with wall function as near-wall treatment. The results shows that VG(triangular) equipped on NACA 4415 airfoil is reliable to regulate the boundary layer by delaying the flow separation. This results demonstrate that VG has proficiency of achieving lesser drag and higher lift to have a substantial maneuverability at higher stalling angle. The coefficient of lift(CL) maximum value for airfoil equipped with (triangular) VG increase by 22.5% and stalling angle postpone by 20o. Overall the attached Vortex Generator(VG) on airfoil contribute an augmented lift to drag ratio.

Keywords**;** *Structured mesh, incompressible, laminar, energize turbulent flow, NACA4415.*

I. INTRODUCTION

Many lift augmentation devices has been designed and tested over the aircraft lifting surface to improvise the flow parameter. The Phenomenon called boundary layer separation seriously affect the fluid flow performance in many application such as take-off, landing maneuver of flight. The vortex generator create vortices and these vortices help in energizing the slow moving air over the airfoil downstream of VG(triangular). Boundary layer technique used here are passive because external energy contribution is not required.

1.1 VG parameter

Triangular vortex generator on Naca 4415 airfoil was used for carrying out passive flow control, on which vortex generator are fasten on airfoil before the seperation point such that they are within height of calculated thickness of boundary layer . To give rise to trailing vortices,VG(triangular) with yaw angle (ß) are placed along the span of airfoil direction. VG(triangular) are placed with yaw angle to produce counter rotating vortices.Vortex generator design should be optimised for distinct application where passive device such as vortex generator are very high,and study shows that efficiency of airfoil with VG is inversely proportional to the height of VG(within the thickness of boundary layer). Since most flight are in cruise for most of the time, passive vortex generator create large amount of drag, this high drag penalty can be reduced by replacing passive VG active VG which can be turned off during cruise to

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minimize the drag. Active vortex generator is expensive when compared to passive flow and passive vortex generator is easiest to install on wing. Vortex generator are used delay the flow separation caused due to adverse pressure gradient at low speed. Passive vortex generator of fixed shape, height, yaw angle, thickness, length effectiveness are bounded only for fixed range. In counter rotating position vortex generator are arranged along span of wing. Smaller vortex generator produces less drag when compared with conventional vortex generator which produces strong vortices which produces large drag. Studies show that to achieve the control over seperated flow vortex generator height should be kept as low as possible when compared with boundary layer (less than 0.8 times boundary layer thickness). Some studies show that for a passive vortex generator which is fixed should be placed at aclose distance. Studies show that size of region which contain turbulent boundary layer can be reduced by using a vortex generator of size equal to quarter of laminar boundary layer thickness.Height of micro vortex generator is 20% of boundary layer height. Studies have shown that strength of vortices decreases with increase in skew angle(ß).

For bump configuration , idea yaw angle was found to be 19 deg, for a single vane type vortex generator magnitude of maximum vorticity increases downstream ,this is applicable only for micro-VG of height approx 20% of boundary layer thickness, but this is not true forlarge VGof height corresponding to thickness boundary layer. Studies has been conducted on the effect of VG on roof of vehicle at different yaw angle,studies found thatdrag coefficient decreased by 89% by addition of vortex generator with 14 deg yaw angle. And with for vortex generator with yaw angle 10 deg ,20% reduction in drag was measured. for lower velocity most effective Yaw angle is 14 deg. Aerodynamic investigation of effect of triangular and rectangular vortex generator on NACA 4415 was computed both numerically and experimentally, various parameter such as spacing between vortex generator ,shape, location of vortex generator with respect to separation point. Numerical and experimental investigation show that co-efficient of lift of rectangle vortex generator is greater than triangle which shows that rectangle vortex generator is effective when compared to triangle vortex generator.

The purpose of this studies is to optimize the location of VG with respect to separation point and found out that of 10%,20%,30%,40%&50% of chord from leading edge optimum position for controlling the boundary layer and delaying the stall by moving the separation point toward the trailing edge can be best done by placing the VG from leading edge at distance of 40% C(chord length). Studies are based on behaviour of streamwise vortices from vortex generator for effectively controlling and delaying the flow separation point. This studies show that counter rotating vortices created by vortex generator move away from vortex generator in span wise direction of wing and outward in in wall –normal direction. This studies shows that to control the region of flow separation, distance between two vortex generator (spanwise spacing) is a crucial, to reduce the seperation of flow ,gap between VG is decreased to mix the vortex generated by both VG effectively.

II. PRESENT WORK

To delay the flow separation or move separation point toward the trailing edge, passive type triangular vortex generator with counter rotating configuration are used to get most effective orientation of vortex generator yaw angel are ept 10 deg to 15deg with respect to mean flow direction for conventional large vortex generator but effective angle is 18deg for micro vortex generator .Intensity of vortex increase as distance between vortex generator decrease. Passive flow control over vortex generator create a parasite drag throughout the flight from take off to landing. Generally seperation of the flow occur at higher AOA and vortex generator help in delaying the flow separation. To have more

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aerodynamic performance micro vortex generator are used which generate larger lift and lesser parasite drag in comparison to conventional VG. In this paper computational analysis of triangular VG on wing is done to improve the aerodynamic performance of NACA4415 airfoil. Computational studies were conducted on NACA4415 airfoilalong with triangular VG at various angle of attack at 21 m/s to validate the performance of triangular VG by analyzing the coefficient of drag(Cd) and lift(Cl).

Table:1.1 Vortex generator Parameter

Parameter	Triangular
e(mm)	0.25
h(mm)	5
d(mm)	5
ß(deg)	20
λ(mm)	35
l(mm)	15
X_{vg}(%c)	25.1297

The above table shows the shape and dimension of Vortex Generator were (e) determines the thickness of 0.25mm and height(h) of 5mm. Length is kept 3*h(height) of VG (l=15mm), Yaw angle(ß) is the angle relative to the freestream flow of 20o and spacing between counter-coupled(λ) VG is 35mm. The position of VG from Leading edge is at approx 25% of chord. The VG is fixed perpendicular to surface of airfoil at an skew angle(ß) of 20oand they are effective against Streamline flow.

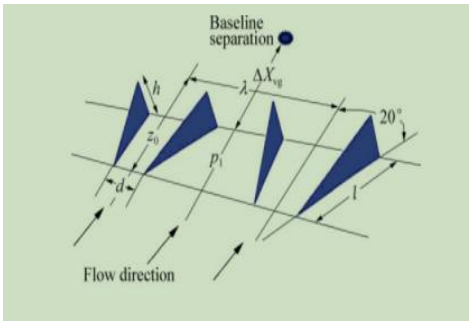
IV. AIRFOIL CHARACTERISTICS

Naca 4415 airfoil was used in many UAV in recent years by U.s army and defence organisation, it was used in aludra wing.Span of airfoil is of same length as width of encloser which is 454 mm and chord length 152mm To prevent 3-d flow effect on airfoil.Base of vortex generator has same shape as airfoil which will reduce the parasite drag.

- Maximum camber= 6.08mm
- Location of Max Camber from LE= 60.8mm
- Max Thickness= 22.8mm

Computational approach

Numerical study was carried out using ANSYS fluent 19.0 R2 with Renaulds number 2.18*105 to validate the experimental data result.Counter rotating vortex generater has been choosen since it most effective in controlling the 2-d flow separation. According to this studies vortex generator are placed such that vortex generator apex point downstream of flow. vortex generator apex pointing upstream are less effective and create more drag and lesser lift when compared with apex pointing forward.[base computational reference] location of vortex generator from baseline separation of NACA4415 airfoil is calculated by using ΔXvg =16δ for conventional.



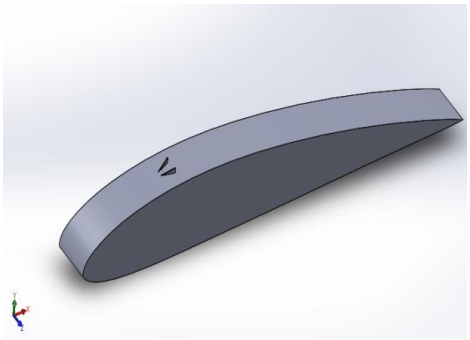


Fig1: wing with VG Fig2: 3D Solid

Setup condition in computational approach

Computational flow dynamic ANSYS fluent 19.0 R2 is used to study the flow over airfoil. Finite element technique is used convert governing equation to algebraic equation. . All the value such as density(d)=1.225kg.m-3,viscosity(υ)=1.789*10-5kg.m-1.s-1,and temperature(T)=288.16K are kept

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at sea level condition. K- epsilon turbulence model was used since it is consist of two equation.

Numerical method

For NACA4415 airfoil of chord length 0.152m C-H domain is used for creating domain around airfoil.Computational domain Upstream boundary made of C -section is at 12.5 *c from leading edge and downstream or outflow computational domain made of H-section is at 20%c from leading edge and pressure far field are positioned at 12.5*c from upper and lower surface.Reynolds number (Re) =2.18*10-5 was constant throughout the simulation and simulation was run from 0 deg AOA to stalling angle.Velocity at inlet was fixed at 21m/s to achieve the given reynoulds number.Base line seperation at stall angle(15o) for 2-D airfoil found at 0 .395*c from airfoil leading edge.

C-H type mesh are used for airfoil with vortex generator configuration.The span of the domain is 0.1662*c.As shown in given below figure domain was separated in to 6 different region.

C- type domain at the front of leading edge is best suited for fine meshing. H- section is taken further from leading edge toward the trailing edge because it create acell perpendicular to streamline flow which allow the flow to pass the airfoil wall smoothly without much deviation. All meshes surrounding the airfoil wll has been refimned in to fine cells determining the first cell thickness as per the Y+ value of 30. Where first cell thickness is in order of approx 10-4m.

2-d meshing & 3-d Meshing

In general boundary condition is choosen as no-slip wall moving at velocity equal to free stream velocity at ground. Upstream, top and bottom edge is selected as velocity inlet at a condition of free stream. Downstream edge is selected as pressure outlet and airfoil edge is selected as no- slip wall. These boundary condition are used for analysis of naca 4415 airfoil.

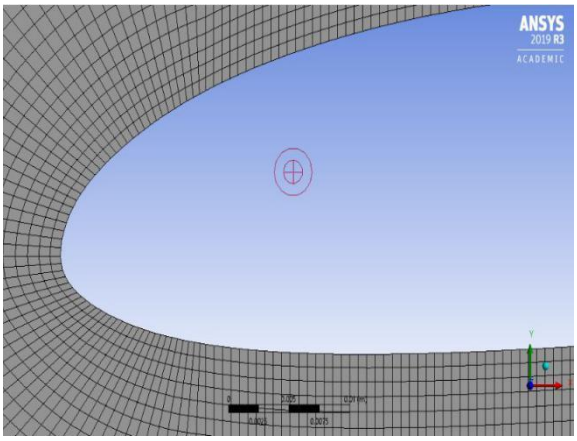


Fig3: Meshing around Airfoil

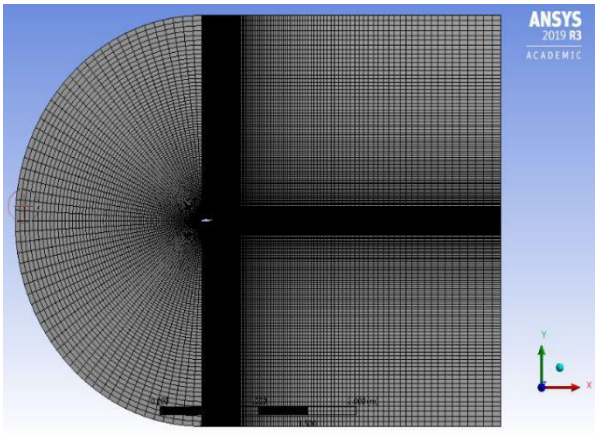


Fig4: Structured Meshing

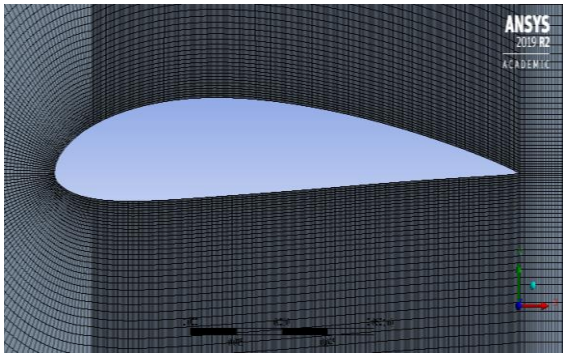


Fig5: Structured meshing around airfoil

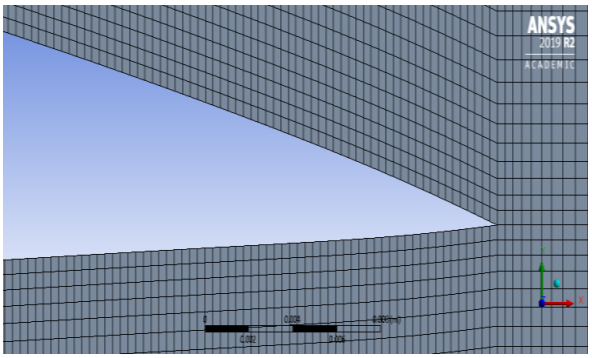


Fig6: Meshing at trailing edge

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Grid Independency:-

Grid independence(GI) test is been carried out over airfoil and Wing attached with Triangle VG.GI means calculation results change so little along with a denser or looser grid that the truncation error can be ignored in numerical simulation. For NACA 4415 Airfoil. GI is carried out with Maximum No. of Nodes= 111100 & No. of Element= 110000 were the Cl , CD value is ceased at 0.37, 0.022 respectively at 0oAOA.

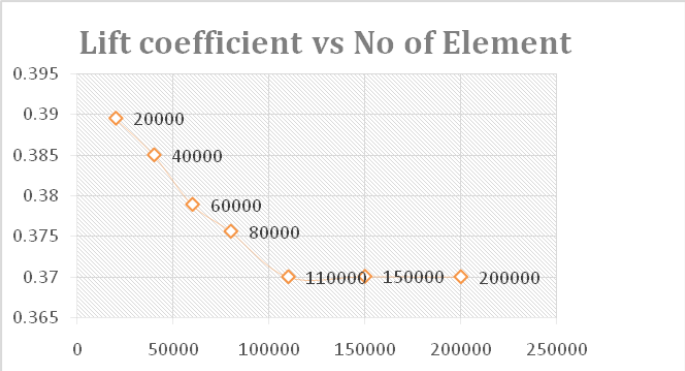


Fig7: Lift coefficient vs No of Element

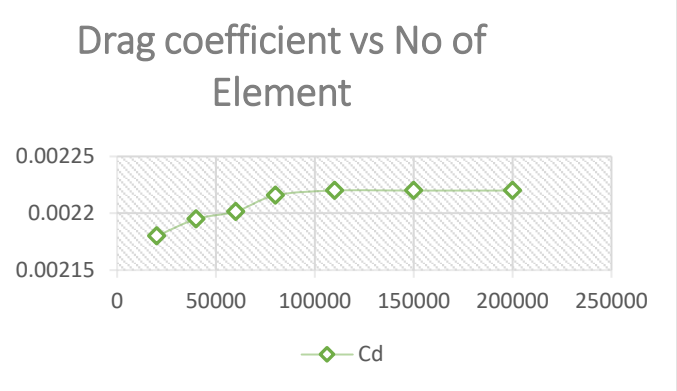


Fig8: Drag coefficient vs No of Element

Result

For normal airfoil NACA 4415 airfoil grid independence test was done and this test was also done after fixing triangular vortex generator. Both grid independent test graph are plotted with number of element on X axis and lift and drag coefficient are placed on Y axis, graph shows that initially when number of element is increased then coefficient of lift and drag both changes but after certain limit of number of element is reached ,no matter how much we increase the number of element above that value coefficient of lift and drag ceased to some particular value and remain constant.

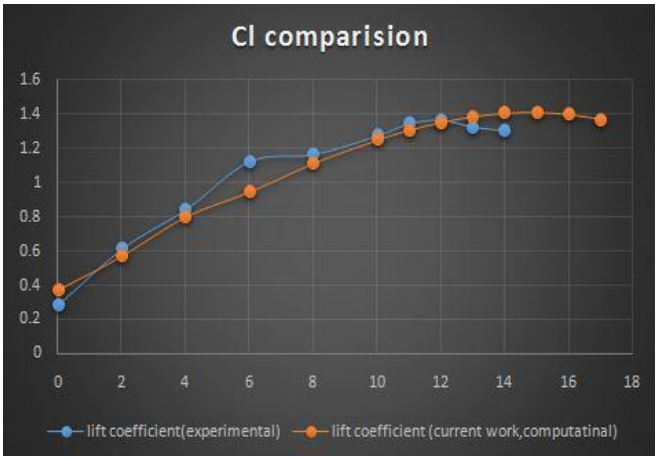


Fig9: CL vs AOA(ref01)

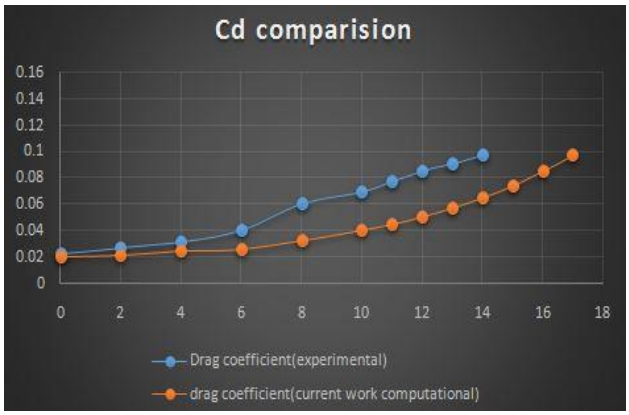


Fig10: Cd vs AOA(ref01)

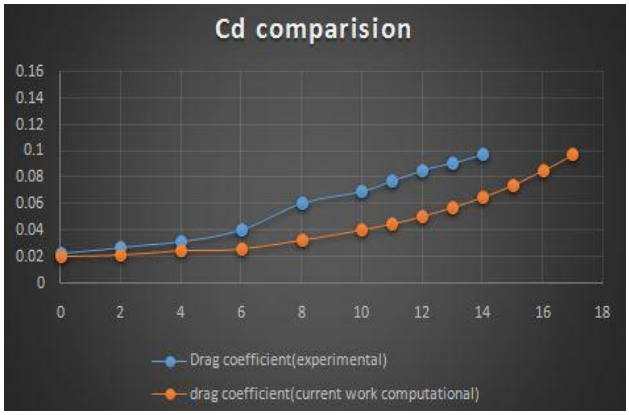


Fig11: Cl vs AOA with VG

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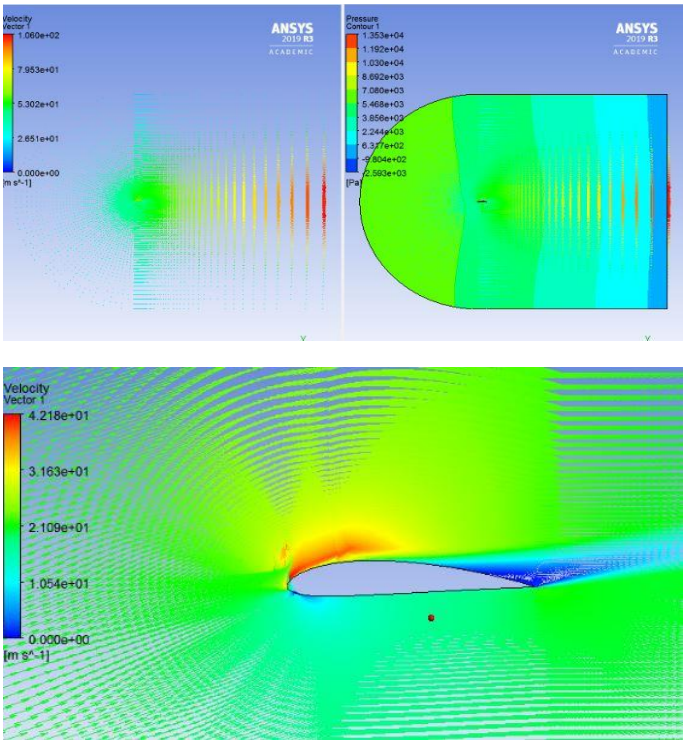


Fig12: Pressure contour and Velocity vector

CONCLUSION

The aim of this investigation is to control the boundary layer by using triangular vortex generator and placing it at appropriate distance from separation point which help in delaying the separation point further away toward trailing edge. Here study focus on computational analysis of NACA4415 airfoil and on wing with span 0.1662*c and chord length 152mm triangular vortex generator of h=5mm,l=15mm,yaw angle 20o are kept at a distance of approx 25%c from leading edge with apex pointing downstream. Computational investigation was carried out at fixed velocity V=21 m/s, which correspond to Re= 2.18*10^5, and corresponding value of density and kinematic viscosity are taken from sea level condition and of fixed chord length C=152mm. Triangular vortex generator parameter given in table [1.1] are considered. Coefffcient of lift(Cl) maximum value for triangular(VG) fittedAirfoil raise by 22.5% and stalling angle deferred by 5o(from 15o for normal airfoilto 200 for triangular VG fitted airfoil).

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