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Aerodynamic Analysis of Variable Cant Angle Winglets for Higher Mach regimes

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***Abstract*—** The performance of the aircraft is reduced due to induced drag generated at the wingtip. The vortices are generated at the wingtip in the turbulent flow. For the reduction of the vortices the small device with the positive or negative cant angle called winglet is introduced. This paper describes Computational Fluid Dynamics (CFD) analysis, performed on a trapezoidal wing prototype with a winglet of NACA 63(2)-215 airfoil section. The White comb geometry is used for the parametric values of the winglet. The objectives of the analysis were to compare the aerodynamic characteristics and to investigate the performance of winglets at cant angles -15°, 0°, 15°, 30° and 45^0 at the constant angle of attack (AOA) 0°. The entire wing works on around 0.5 Mach .The CFD simulations were performed in ANSYS fluent. 3-dimensional unstructured tetrahedral meshes were used to compute the flow around the model. The parameters like pressure, velocity are found and analyzed at different cant angles.
***Keywords*— Airfoil, Aerodynamics, Cant angle, CFD**

I. INTRODUCTION

In the field of aerodynamics, our main purpose is about the forces acting on the air molecules and the flow around the surfaces. Mach number is defined as the ratio of velocity of the object to the velocity of sound. It defines the criteria for the aircrafts relative speed and classifies the aircraft as the aircraft needs to be lighter and efficient. The important aspect is to gain lift and reduction in drag. According to the theories, pressure difference generates lift. During lift generation the problem is found at the wingtips. The higher pressure air below a wing spills up into lower pressure above creating a circular pattern called vortex. They are associated with the induced drag and are responsible for increasing drag. During the transformation of laminar to turbulent flow vortex generation is formed. So winglets are introduced at the tip points of the wing to reduce wingtip vortices. There have been various types of winglets due to emerging innovations. The flow of the air over the winglet surface changes as the shape of the winglets tends. In the real world the flow calculations need to be defined and practically they are found different but the simulation software’s helps to analyze them easily. The concept presented hereafter represents the study of the winglet at different cant angles and their effect. Keeping the parameters of the winglet like taper ratio, sweep angle, toe angle same and the variation of different canted angles the comparison of vivid parameters like temperature, pressure, and velocity is to be done.

II. LITERATURE REVIEW

By introducing a winglet device at the wingtip, for a National Aeronautics and Space Administration (NASA) test aircraft from 6% to 9% and increased the mileage by 6.5%.Various winglet shapes have been developed, such as the blended winglet, wingtip fences, split-scimitar winglets, and raked wingtips. It is obvious that more should be done to design an optimum blade characterizing winglets, therefore there are different methods for simulating the aerodynamics of a wind turbine depending on levels of intricacy and accuracy, such as the Blade Element Momentum (BEM) theory and solving the Navier-Stokes equations using Computational Fluid Dynamics

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(CFD) [1].The airfoil NACA 2213 coordinates are initially imported into CATIA from the design foil software. Then the coordinates are joined using a spline, extruded and attached with a blended winglet structure. This wing without winglet is kept at 4º, 8º, 12º angles of attack and analyzed in Ansys software using the CFX workbench. The same procedure is followed for the other wing with circular winglet and wing without winglet. By analysis the performance of the wing with winglets can be estimated[2].Dinesh M (2014) did various parametric analytical studies, from which they provide that the aircraft with variable winglet, that are, low canted winglets at low angle of attack and high canted winglets at high angle of attack gave better performance while take-off and landing. They also state that the winglet customization according to different situations will definitely be a cracking solution for efficiency in the aerospace industry [3].The optimization results demonstrated that adopting winglets can result in a 15.2-year DOC reduction of around 29 million dollars and a 3.8% reduction in fuel weight for an airplane of the Boeing 747 type [4].

III. NUMERICAL APPROACH

The important parameters required are viz Lift (L) and Drag (D) forces and so we are bound with coefficient of lift (Cl) and coefficient of drag (Cd), also angle of attack (AOA), twist angle, toe angle, cant angle, aspect ratio are required. The integro-differential equation for spanwise circulation distribution in terms of geometrical characteristics of the wing with boundary conditions at both wingtips provides the aerodynamic characteristics of the wing. Vortex Panel Method helps to find the interaction of point vertices and the total circulation of wingtip vortices [5].

Geometry

On the basis of selecting an aerofoil NACA 63(2)-215 and the parameters like sweep angle of -4^0 , ,toe angle -5^0 wing prototype (Fig. 1) was constructed using ANSYS and it was exported to ANSYS for creating a mesh and computational domain. The wing is the swept wing which has wing tip of 0.3 m and chord length of 0.5 m.

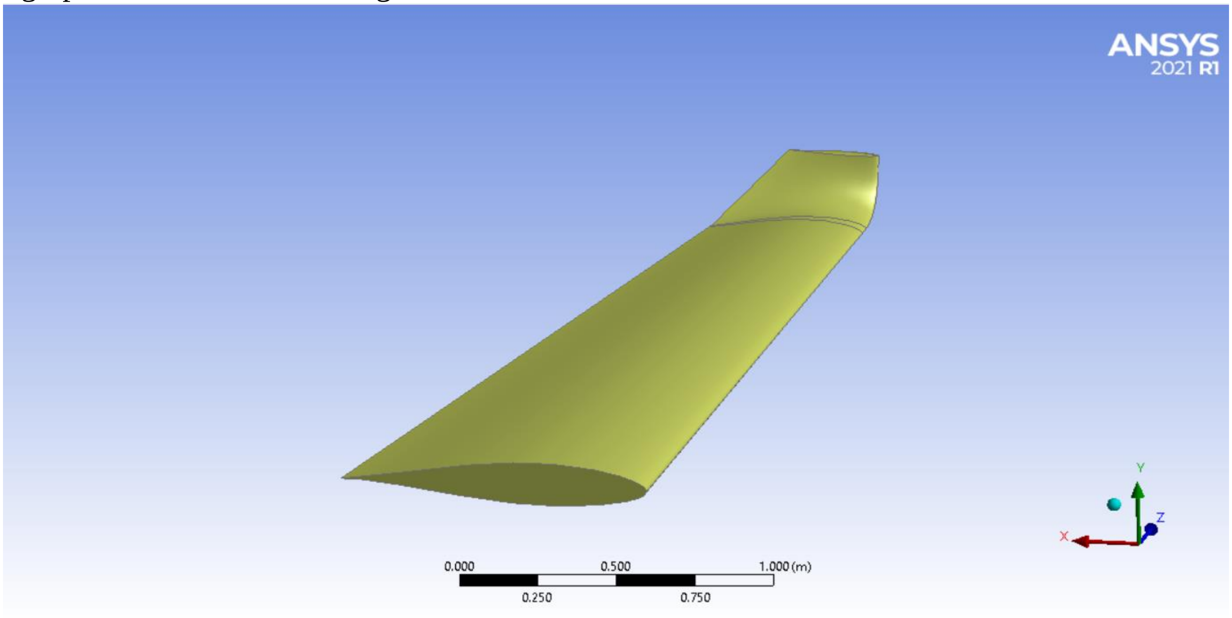

Figure. 1 Wing Geometry

Domain Generation

The rectangular part is 11m long and has a length of 5 m for the semi-circular segment. The 1m chord length airfoil is positioned in the domain so that its trailing edge is near the centre of the diameter of the domain's semi-circular area and that its chord-line corresponds with the domain's symmetry line. Consideration of about 0.5% of turbulence intensity for the inlet boundary is done as it is supposed to be lower comparatively to outflow.

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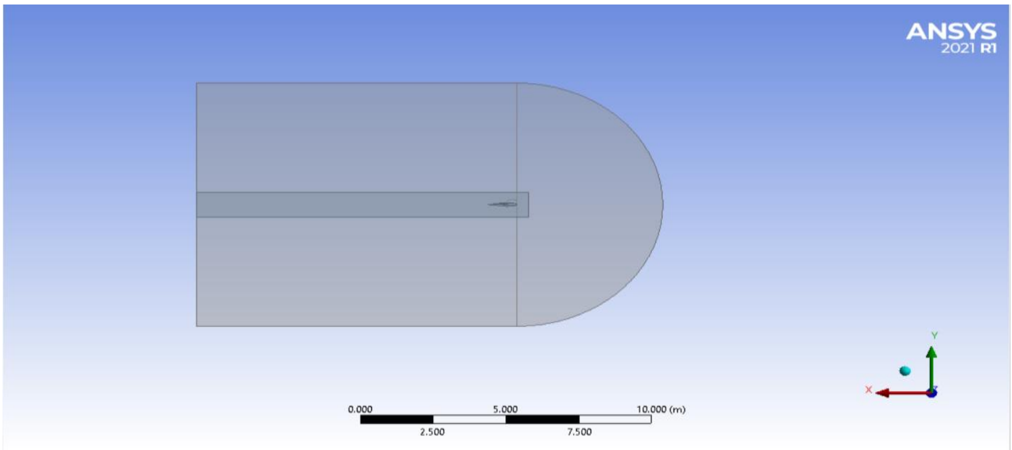

Figure. 2 Dimension and Boundary condition of computational domain

Meshing

The meshes for every winglet of cant angle were done using ANSYS Meshing component. A grid structured mesh was created, and the result is depicted in the figure below. It was determined that the mesh quality was ideal having nodes 147878 and cells 63562383.

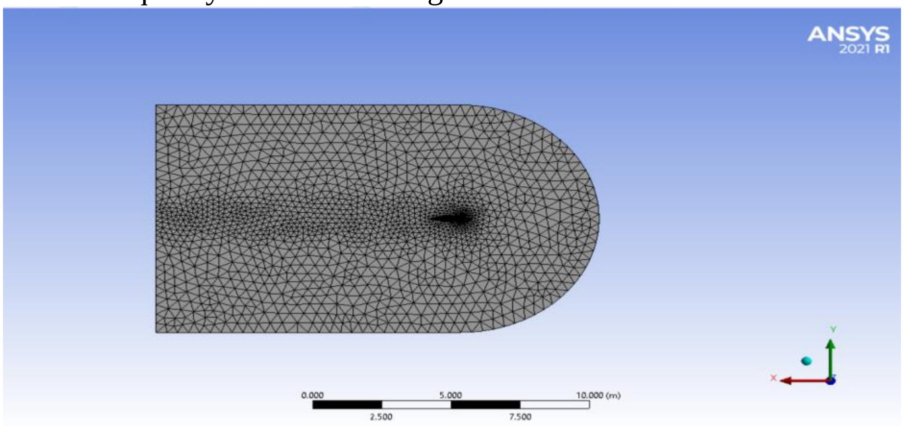

Figure. 3 Unstructured tetrahedral Mesh

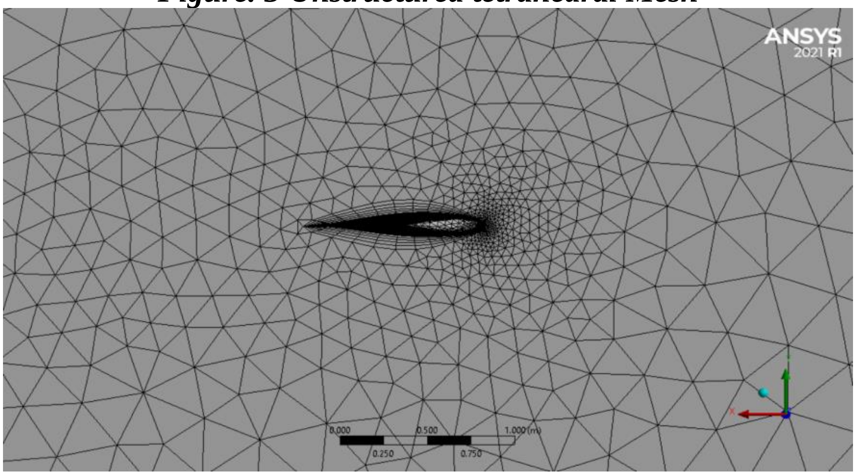

Figure. 4 Body of influence, Sizing Function centered on airfoil

Area	1 m^2
Density	0.4135 kg/m^3

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Enthalpy	0 J/kg
Length	1 m
Pressure	0 Pa
Temperature	300 K
Velocity	160 m/s
Viscosity	1.458e-05 kg/(m-s)

Table 2. Solver Conditions

RESULTS AND DISCUSSION

Pressure contours

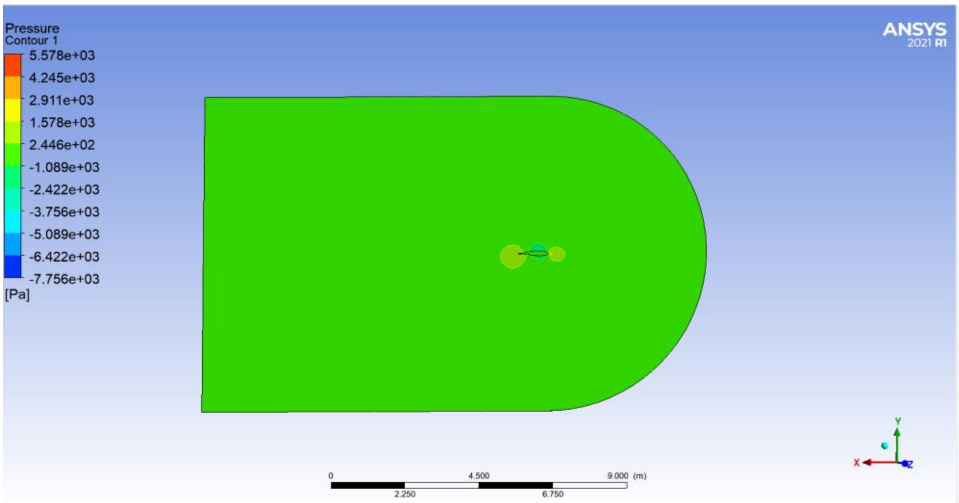

Figure. 5 Pressure distribution contour diagram of NACA 63(2)-215

Velocity contours

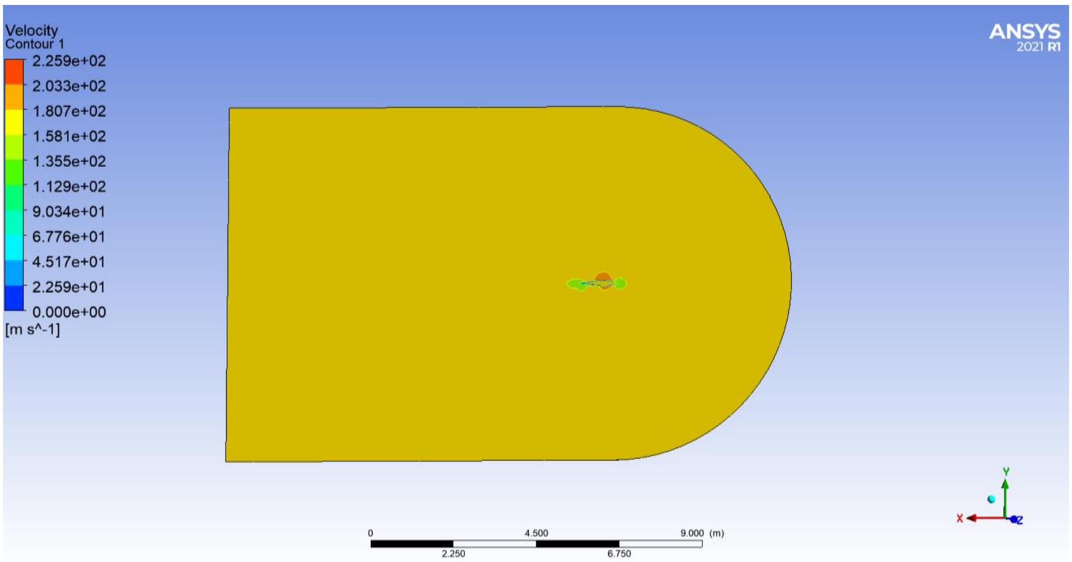

Figure. 6 Velocity distribution contour diagram of NACA 63(2)-215

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Cant Angle	Lift	Drag	Cl	CD	L/D
-15^0	2695.6059	117.74856	0.47889796	0.020919062	22.8928991
0^0	1623.1131	76.778548	0.28836023	0.013640381	21.1401901
15^0	881.63174	126.80684	0.15662959	0.022528344	6.95255666
30^0	1199.4422	444.71758	0.2130914	0.079007969	2.69708744
45^0	1396.1259	85.831898	0.24803398	0.015248787	16.2658165

Table. 1 Lift, Drag and their coefficients at various Cant angles

CONCLUSION

According to analysis at -15^o cant angle, we obtained the highest L/D ratio, which indicates highest efficiency, low fuel consumption and reduction in drag, thus greater reduction in vortices. The pressure variations shows decrease from negative to 0 cant value and again increment till same positive value. The velocity variation shows highest value at -15^o cant angle and gradual variation as it approaches positive canted angles. Analysis proved that we get maximum lift coefficient and reduction in the slope of the lift curve, as we approach high cant angle values. The decreasing drag indeed shows the pressure is uniform as the loses in pressure due to connection between winglet and wing decrease with increase in cant angle.

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