Numerical Analysis of Aerodynamics Performance of Winglets with different Cant Angle

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ABSTRACT

A winglet is attached at the edge of the wings, it enhances the performance of the aircraft and reduces the induced drag in the form of wingtip vortices. The winglet is a upstraight or different cant angle at the tips of each wing and its leading edge was tubercle and triangle shape configuration. In this paper, 3-D winglet analysis was carried out on a tapered wing of NACA0012 airfoil. The numerical study was conducted to investigate the effect of applying different shapes on the leading edge of blended winglet configurations on the performance of the wing of an aircraft at different velocities are 20m/s, 30m/s and 50 m/s and different angles of attack of 0°,5°,15°,20° and 25°. The span of the tapered wing configuration was 250 mm analyzed with two different leading edge shape configurations varying in sizes and shapes of the leading edge. The primary goal of the analysis is to evaluate the aerodynamic properties of various winglet configurations and to investigate the performance of the two winglet forms modelled at the given cant angle (90° and 120°). The Ansys Fluent solver used the Finite Volume Approach to do the computational simulations. The Spalart Allmaras solver was used to simulate low subsonic flow and varied angles of attack. The various parameters were investigated in the simulation such as CL, CD, and CP. Also, the flow separation region is discussed with contours plots in the research work.

Keywords: *Winglets, Tubercle, Trangle leading edge, CFD, Tapered Wing, Wing*

1. INTRODUCTION

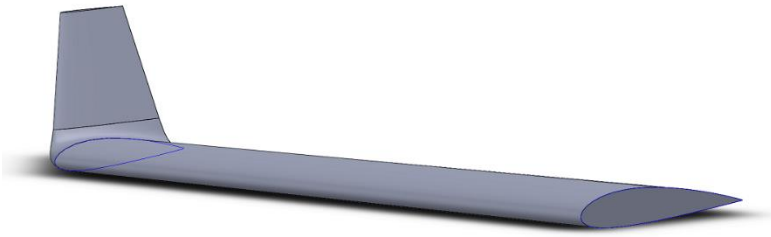
All aeroplanes don't have flat and smooth wings, some are designed with a curved end and the end of the wing is known as winglets. Winglets are vertically curved tips on aeroplane planes, which enhance an aircraft's fuel efficiency and cruising range. Engineers have noticed that adding this curved surface provides a solution from the vortex formation at the tip of the wing and consumes less fuel. Flow over the plane's wings generates lift which is not affected by the winglets and leads to lower the drag and increase the lift generation. Sardiwal et al [1] carried out the numerical and experimental investigation of a straight rectangular wing with a winglet with different cant angle. The aerodynamics performance of the rectangular NACA65218 airfoil cross section wing with different 0° ,45° and 60° wings has been investigated experimentally and numerically. It is observed that aerodynamic characteristics of lift Coefficient (CL), coefficient of drag(CD) and ratio of Lift to Drag(L/D) were evaluated and also it is observed that very good coefficient of lift v/s angle of attack plot and higher L/D ratio compared with baseline wing for elliptical and semi elliptical winglet. Beechook et al [2] and Azlin et al [6] performed CFD investigation of aerodynamics performance of variable angle winglets to improve the performance of aircraft. It is observed that coefficient of lift, drag and L/D does provide the optimum performance at particular angle of attack for different phases of flights. Rabbi et al [3] conducted the experimental investigation of induced drag reduction of a wing in an airplane with and without slotted winglets. The swept back wing with NACA0012 airfoil is considered for the testing with different cant angle sich 30° ,60° and 70° degree and it is found that drag coefficient reduced to 20-25 % and lift coefficient increased to 10 -20 % by slotted winglet configurations.

Johansen et al [4] numerically investigated the different winglets configuration on wind turbine blades with low freestream velocity of 8 m/s. The various parameters have been analysed such as cant angle, sweeping of winglet, mechanical power, thrust and winglet height characterised and discussed. Seshaiah et al [5] winglet has been simulated for different cant angles (35,65 and 90 deg) using CFD software Anysis. It is found that aerodynamics performance of winglets fluctuating on both higher and lower angle of attack changes. Panagiotou et al [7] simulation has been carried out to optimization of winglet to be used for Medium-altitude –Long- Endurance (MALE) Unmanned aerial Vehicle (UAV), RANS and Spalart – Allmaras turbulence model used for winglet used in the aircraft under various conditions optimize the design such as loitering, distinguish the lift and drag coefficient, L/D ratio and stalling characteristic and bending moment characteristics and flow over the aircraft has been investigated numerically. It is observed the optimized winglet shape gives better aerodynamics performance of aircrafts and increases the flight times to 10%. Balaji et al [8] numerically investigated the leading-edge tubercle airfoil to characterize the aerodynamic behaviour of

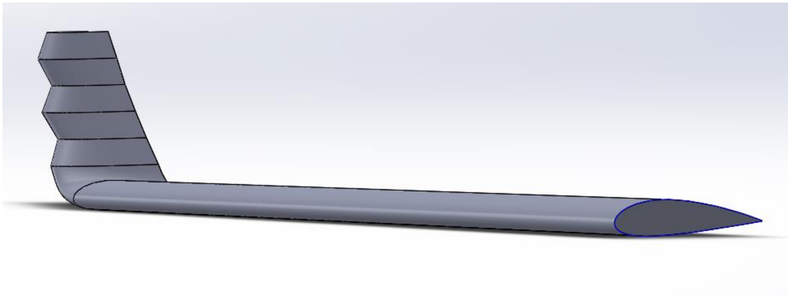
NACA2412 airfoil at a very low Reynolds number. It is found that nearer to the leading edge has more pressure variations for all freestream conditions due to tubercle effect.

Maughmer et al [9] investigated the winglet performance by theoretical methods such as panel methods considered with relaxed wake modeling. The induced drag has been estimated for both level and turning flight conditions. These values have been utilized for design of winglets to enhance the aircraft performance in different conditions as span-limited and span unlimited and also for powered aircraft under various categories. Balaji et al [10] experimentally investigated the pressure variation over the NACA5520 airfoil with tapered wing. It is studied that distribution of pressure accross the tapered wing was calculated at various freestream conditions and various angles of attack. Prieto et al [11] numerical investigated the vertical take-off and landing drone wing attached with a winglet. The aerodynamics characteristics such coefficient of lift and drag and bending moment has been studied to reduce the error value for various conditions using Open form.

Schumacher [12] the main objective of the work is to increase the aerodynamic performance of the cessna 172 wing by reducing the induced drag. It is observed that optimizing the span of the wing, reducing the parasite drag and better configuration of winglets which lead to reduce the induced drag are parameter influencing the aerodynamics performance of cessna 172 wing. Tjahjana et al [13] investigating the aerodynamics performance of the wing body used in micro-UAV with blended winglet configurations. Simulation is being carried out for six different wing designs with various parameters as taper ratio 0.3,0.4 and 0.5, with and without winglet and cant angle of the winglet are 50,60 and 70 deg using shear stress transport turbulence model and RANS. It found that lift forces increase upto 9.84% while reducing the vortex in the wingtip by 17% which was compared to baseline. Kaygan et al [14] simulation carried out for adaptable winglets to enhance the controllability and aerodynamics performance of UAV. It is observed that results provided by the adaptable winglets were good agreement with small aircraft control and performance. Hasan et al [15] numerical investigation of aerodynamics performance of EPPLER 420 airfoil wing with 45° and 90° cant winglets and rectangular and triangular vortex generator has been inserted near to the leading of the wing. It is observed that maximum lift and lower drag force on a 45° cant angle winglet fitted in the wing and also aerodynamic performance improved with different modification of triangular and rectangular vortex generators at various angles of attack.



a. Baseline blended wing with winglet



b. Tapered wing with serrated leading-edge winglet

Fig. 1 Schematic diagram of different leading-edge winglet attached in wings

The main aim of this study is to numerically investigate the aerodynamics performance of tapered wing with serrated winglet compared with baseline blended winglet as shown in Fig.1 (a &b). The serrated tips are arranged uniformly at leading edge of the winglet. The bbaseline blended winglet and serrated winglets are arranged in two different configurations of cant angle such as 90° and 120°. A symmetric aerofoil was considered as NACA 0012. The simulation is carried out using Ansys Fluent on the tapered wing geometrical dimensions as span of 250 mm, chord of 100mm at root and 80 mm at tip of the wing. The winglet is bent at 20% from tip of the wing on total span. The wing is simulated with various freestream velocities (30 m/s, 40 m/s and 50 m/s) and different cant angles. The material used for the wing surface including the winglet was 7075 T6 aluminium alloy.

2. METHODOLOGY

The computational analysis is carried out in the NACA0012 symmetrical profiled tapered wing with plane winglet and serrated winglet. The tapered wing with winglet model was designed and drawn using CATIA V5 and mesh was generated by Ansys Fluent. The unstructured grid was generated on the 3D tapered wind with winglet model using ANSYS Fluent. The boundary conditions used for the simulations that includes inlet for pressure, velocity outlet and pressure far field condition out of model and model considered as wall. The model has 85,524 elements and 88,326 nodes generated over the tapered wing with winglet. The simulation carried out using pressure-based solver and SST [k-ω] turbulence model is used for numerical analysis. The numerical analysis has been performed over the model with low speed such as 20 m/s, 30 m/s and 50 m/s to study the base aerodynamics performance of baseline blended wing and blended winglet with serrated leading edge with tapered wing with different cant angle 90° and 120° and various angle of attack (0°, 5°, 10°, 15°,20°,25°). The CFD domain and blended winglet configurations as shown in Fig. 2 and Fig 3.

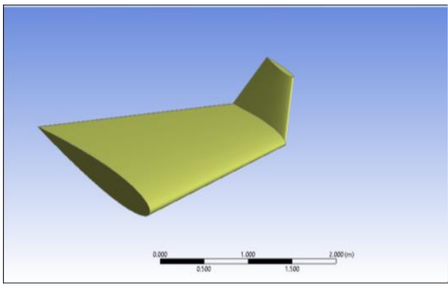


Fig.2 3D geometry of Wing with Winglets

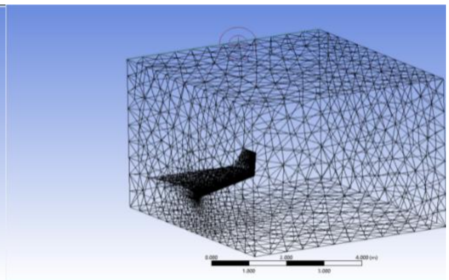


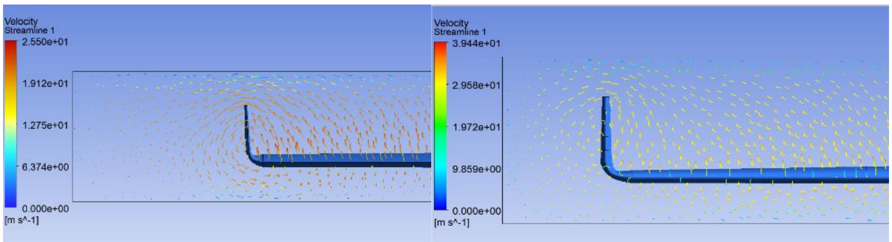
Fig.3 Meshing over the wing with winglets

3. DISCUSSION OF TEST RESULTS

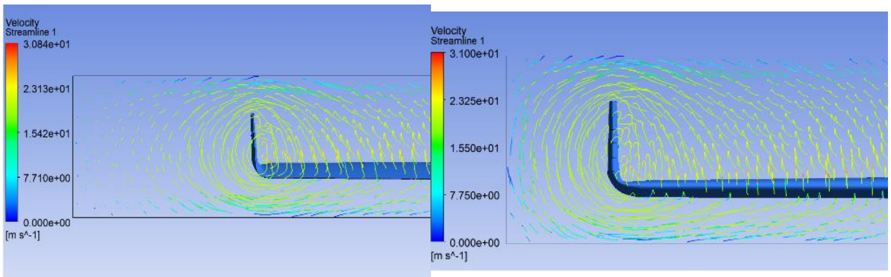
3.1 Variations of velocity vector over wing with winglet at cant angle of 90° and 120°

The numerical simulation has been carried out for the NACA0012 airfoils with tapered wings with winglets at different orientations of cant angle (90° and 120°). There are two different winglet leading edge profiles such as plane and serrated considered for this investigation for different angle of attack of the wing and various freestream conditions (20 m/s, 30 m/s and 50 m/s). All the cases have been simulated numerically using Ansys Fluent and estimated the lift coefficient, coefficient of Drag and their ratio (C_L/C_D) and graphs are plotted against different angle of attack. The flow alterations over the wing is represented only for freestream velocity conditions of 50 m/s with both cant angles as shown in Fig.4 (a-f) and Fig 5 (a-fl). This velocity vector representation has given the insight of flow behaviour over the winglet for different cant angles and good agreement with changes of lift and drag coefficient as seen in the plots. It is observed that comparison of baseline blended winglet and serrated winglet with 90 cant angle presented in the Fig 4 (a-f). The flow circulation around the wing has uniform distribution compared with tip of wing and winglet. The circulation of flow field around the serrated winglet at right varies gradually and has more variation seen for all angle of attack especially at angle of 25°.

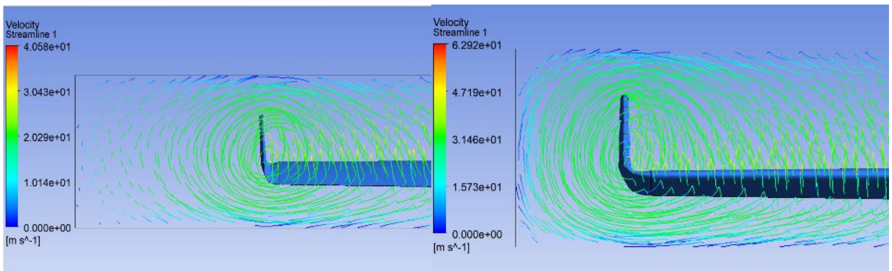
Baseline Blended winglet cant angle of 90° | Serrated winglet cant angle of 90°



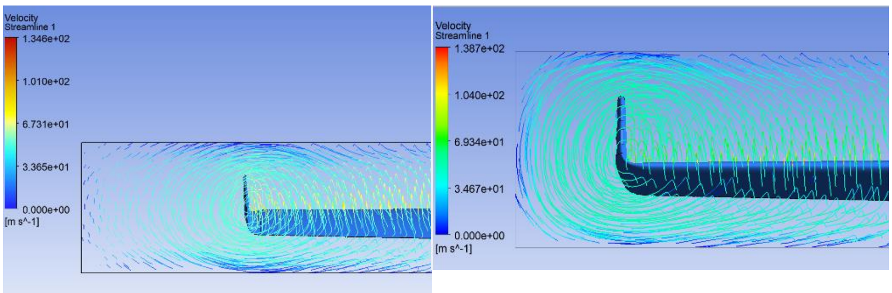
a. 0° AOA



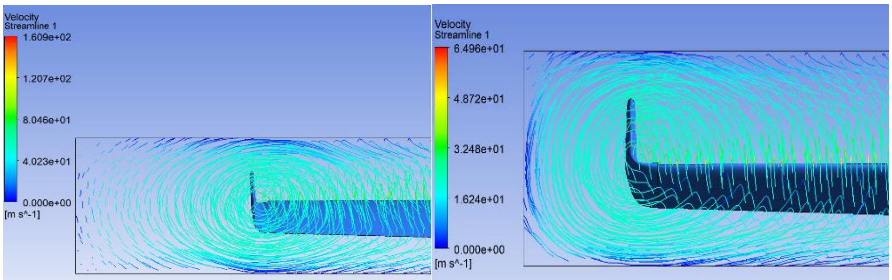
b. 5°AOA



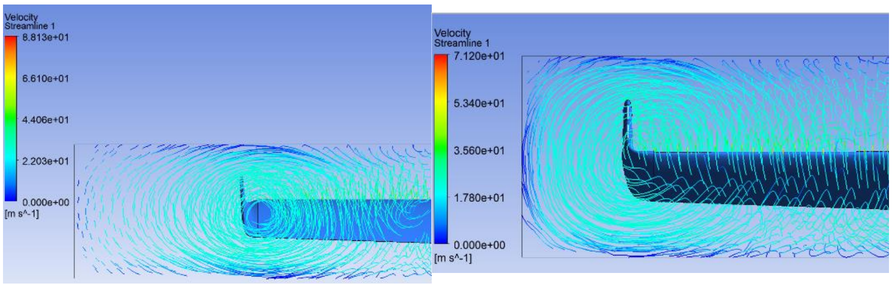
c. 10° AOA



d. 15° AOA



e. 20° AOA

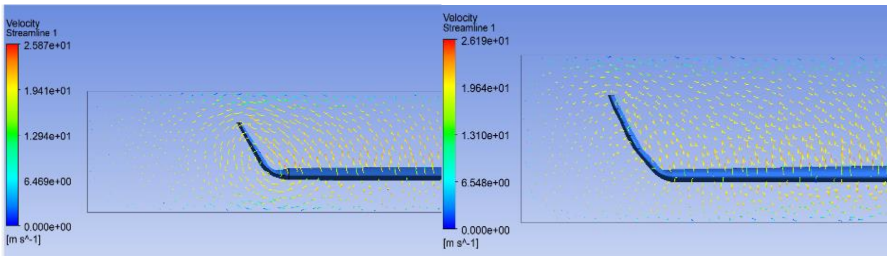


f. 25° AOA

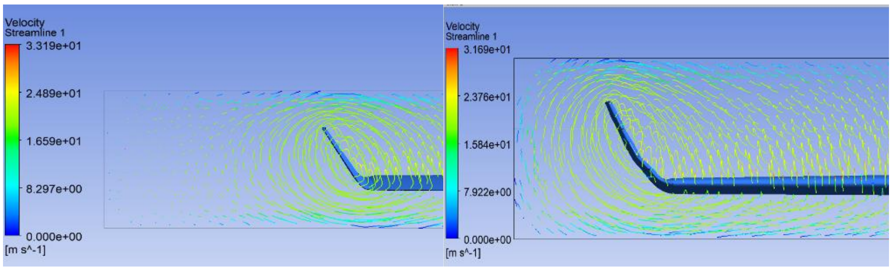
Fig. 4 Velocity vector of baseline blended and serrated winglet at 50/s and cant angle of 90°

The flow field over the baseline blended winglet at cant angle of 120° compared with serrated winglet with 120° cant angle represented by velocity vector shown in Fig.5 (a-f). It is observed that flow circulation around the baseline winglet uniformly distributed for all the angles of attack and at higher angle, lead to generation of induced drag.

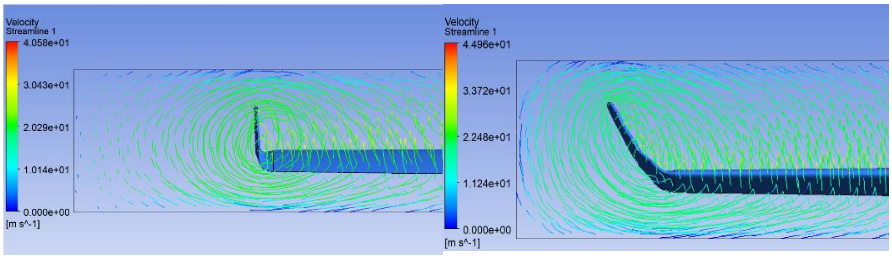
Baseline Blended winglet cant angle of 120°	Serrated winglet cant angle of 120°



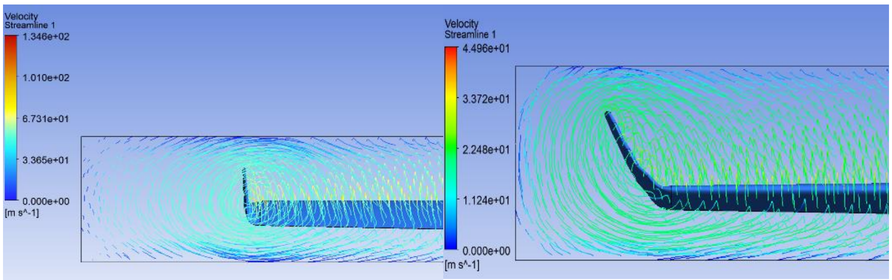
a. 0° AOA



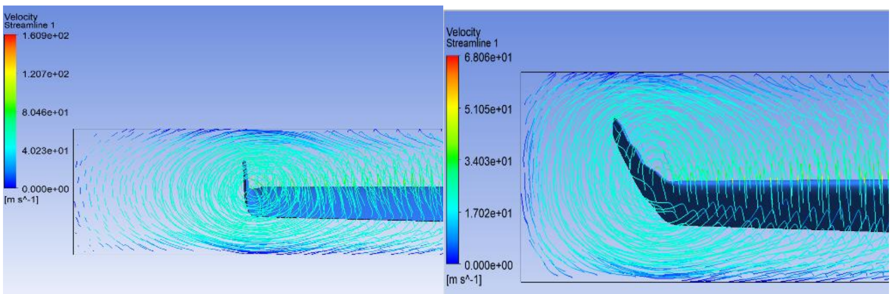
b. 5° AOA



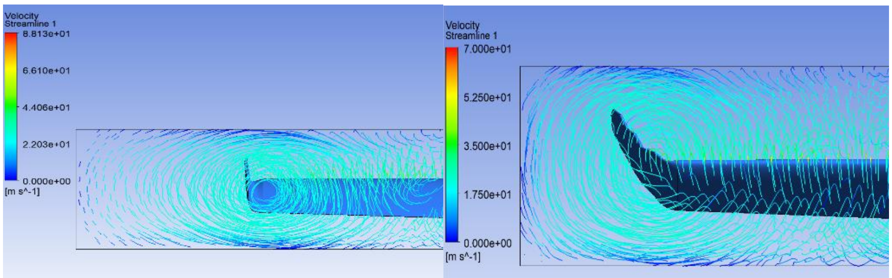
c. 10° AOA



d. 15° AOA



e. 20° AOA



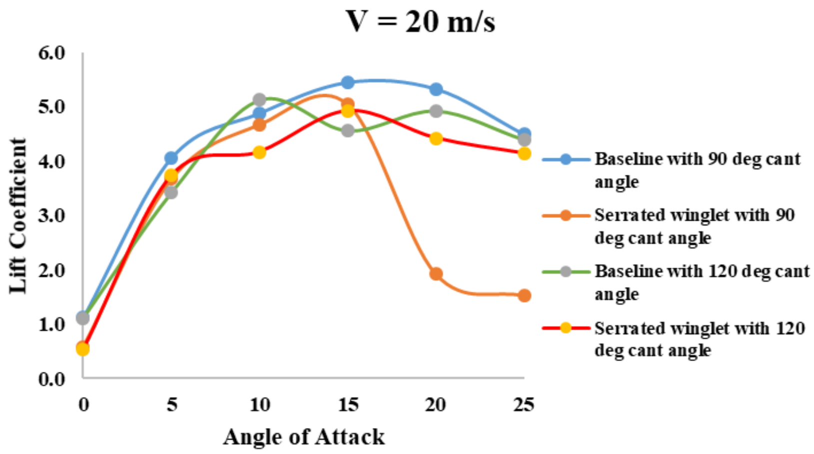
f. 25° AOA

Fig. 5 Velocity vector of baseline blended and serrated winglet at 50/s and cant angle of 120°

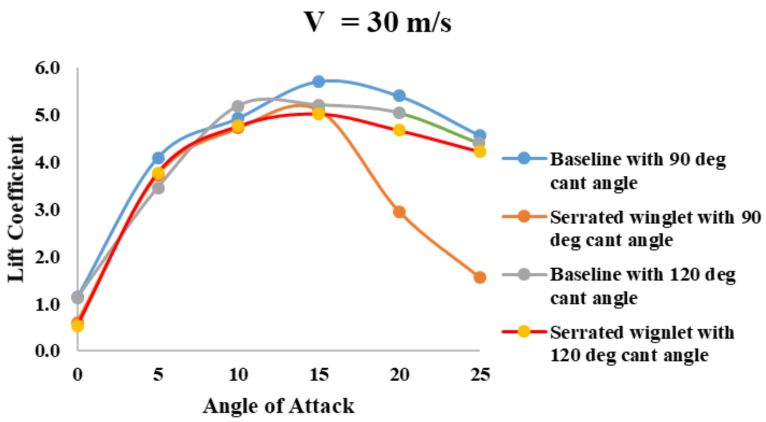
Further it is observed that the circulation appeared in two different places in the wing due to the serrated profile and trailing tip vortex of the flow occurring at higher angle of attack of 25° as shown in Fig 5 (f).

3.2 Variations of Lift coefficient of wing with winglet at cant angle of 90° and 120°

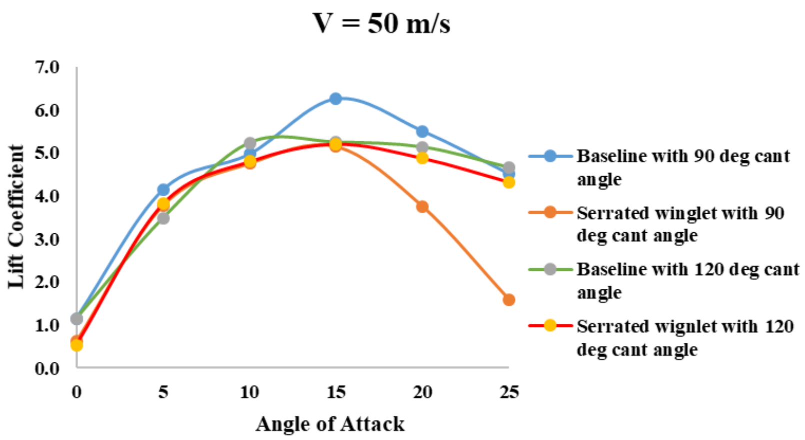
In Fig. 6 [a-c] shown the coefficient of lift varies with respect to various angles of attack for different cant angles. The aerodynamics performance of the NACA0012 airfoil profile wings has been simulated with various freestream such as 20 m/s, 30 m/s and 50 m/s and different angles of attack varies from 0°-25° with step of 5° using ANSYS Fluent. It is observed that wings with blended winglet and serrated winglet trends show increasing coefficient of lift alongside angle of attack increases and attain the stall angles at 15° for all the models. The maximum lift coefficient observed such as 4.9,5.02 and 5.3 for baseline blended winglets with 90° cant angle for all the freestream conditions as compared with other models as clearly depicted in the Fig.6 [a-c]. whilst it is found that drastic drop of lift coefficient seen in the serrated winglet of 120° cant angle after the stall occurs at 15° due to influence of induced drag generation on the winglet.



a. Coefficient lift vs AOA for 20 m/s



b. Coefficient lift vs AOA for 30 m/s

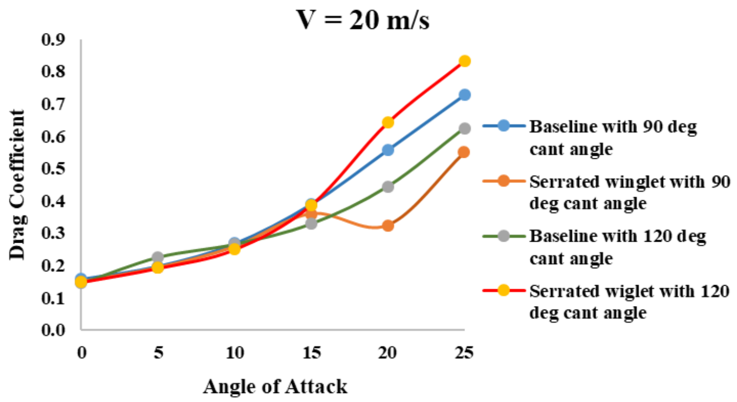


c. Coefficient lift vs AOA for 50 m/s

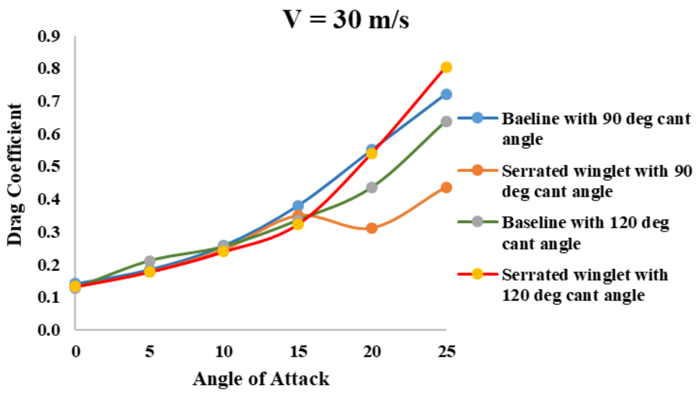
Fig 6 Coefficient of Lift Vs AOA for different cant angle

3.2 Variations of drag coefficient of wing with winglet at cant angle of 90° and 120°

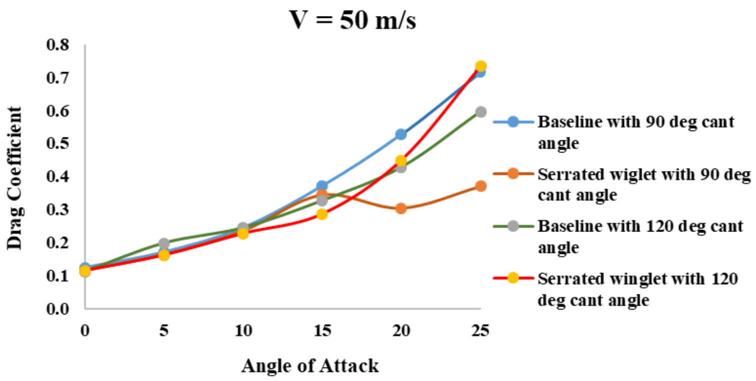
In Fig. 7 [a-c] shown the coefficient of drag varies with respect to various angles of attack for different cant angles. The NACA0012 airfoil profile wings has been simulated with various freestream conditions such as 20 m/s, 30 m/s and 50 m/s and different angles of attack varies from 0°-25° with step of 5° for investigate the aerodynamics performances using ANSYS Fluent. It is observed that a wing with serrated winglet at 90 and 120 cant angle trends shows increasing drag coefficient with increase in angle of attack. The maximum drag coefficient observed such as 0.831, 0.804 and 0.7322 for serrated winglets at 120 cant angle all freestream velocity conditions. Whistm, the minimum drag coefficient observed such as 0.32, 0.31 and 0.303 for serrated winglets at 120 cant angle all freestream velocity conditions as shown in Fig 7 [a-c]. further the drag coefficient of baseline blended winglet has been compared with serrated winglet which was dominated by the induced drag produced at the tip of the winglet as plotted in Fig 7 [a-c].



a. Coefficient drag vs AOA for 20 m/s



b. Coefficient drag vs AOA for 30 m/s

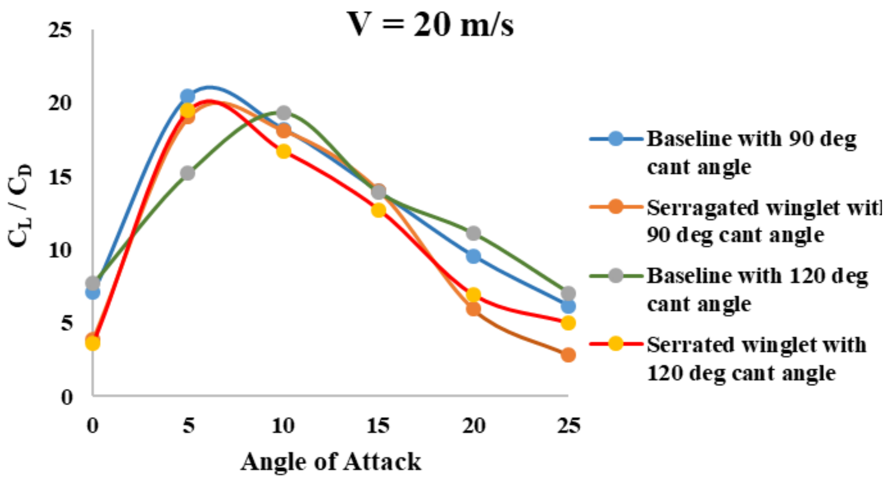


c. Coefficient drag vs AOA for 50 m/s

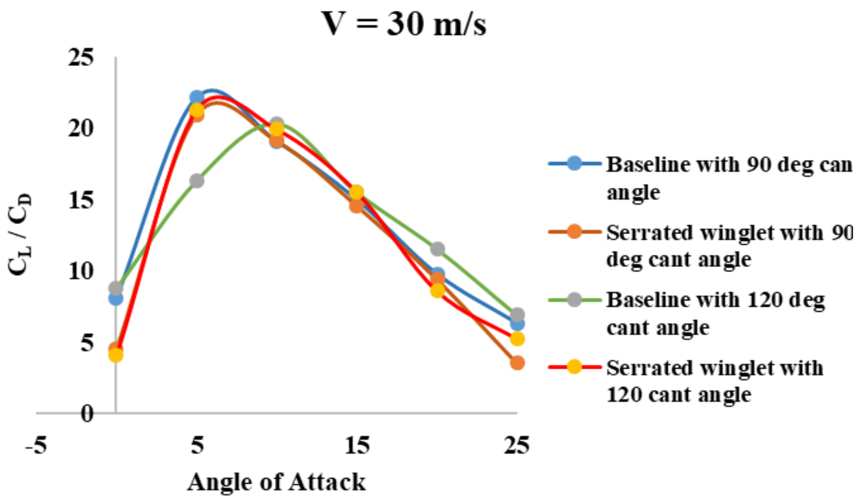
Fig 7 Coefficient of dragVs AOA for different cant angle

3.2 Variations of lift and drag coefficient of wing with winglet at cant angle of 90° and 120°

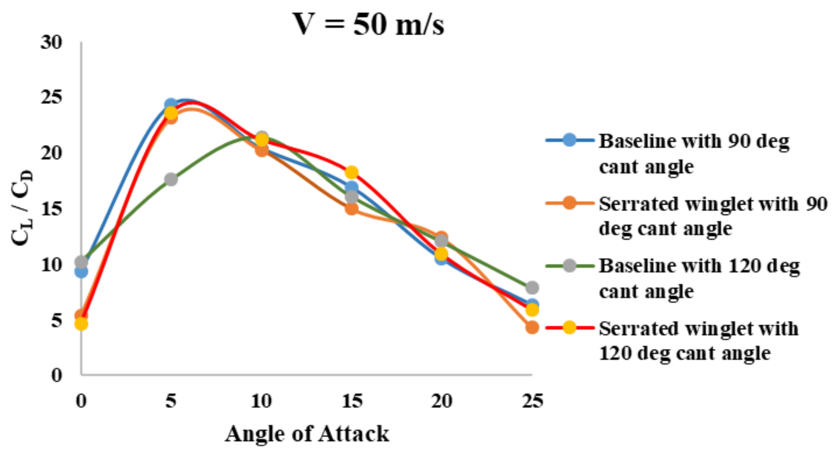
In Fig. 8 [a-c] shows as the coefficient of lift and drag ratio varies with respect to various angles of attack for different cant angles. The numerical investigation has been carried out for NACA0012 airfoil profile wings with various freestream velocities such as 20 m/s, 30 m/s and 50 m/s and different angle of attack varies from 0°- 25° with step of 5° using ANSYS Fluent to investigate the aerodynamics performances. It is observed that C_L/C_D ratios initially vary up to a certain angle of 5 degree in the all-freestream velocities afterwards and tend to decrease for further increasing angle of attack as seen in Fig 8 [a-c]. The baseline blended winglet with 90° cant angle and serrated winglet at 120° cant have the dramatic deviation at angle of attack of 5° as noticed in the numerical analysis. Further increasing the angle of attack the C_L/C_D ratios drastically decreased to a lower ratio at angle of attack of 25° due to induced drag dominating the flows over the wing especially at winglet.



a. C_L/C_D ratio for 20 m/s



b. C_L/C_D ratio for 30 m/s



c. C_L/C_D ratio for 50 m/s

Fig 8 C_L/C_D Vs AOA for different cant angle

4. CONCLUSION

The main aim of the simulation is to investigate the aircraft wing which has NACA0012 airfoil profiled tapered wing configuration attached with a serrated winglet and blended winglet using ANSYS Fluent. The simulation has been carried out for different cant angle [90° and 120°] and Angle of attack [0°,5°,10°,15°,20° and 25°] at different freestream velocities 20 m/s,30 m/s and 50 m/s. The following observation has been made on CFD analysis results.

- The flow distribution for the baseline blended wing with winglet and serrated winglet at different cant angles. Angle of attack and freestream velocity has been characterised and plotted in Fig. The induced drag at winglet
- It is found that the lift coefficient of serrated winglet at 120° cant angle performs better than 90° cant angle gives value of lift coefficients such as 4.9,5.02 and 5.3 as shown in Fig.6 [a-c]. Whilst its maximum lift coefficient corresponding to stall value occurs at 15°.
- It has been discovered that as the AoA and freestream velocity rise, so does the drag coefficient.
- The maximum drag coefficient observed on serrated winglet at 120°deg cant angle compared with 90° and baseline blended winglet. The minimum drag values observed at higher angle of attack by serrated winglet at 90° cant angle values are 0.32, 0.31 and 0.303 as shown in Fig.7 [a-c] which is compared to baseline blended winglet configurations.
- It is seen that the C_L/C_D ratio increases with increasing the freestream velocity and at 5° AOA and further increasing the value tends to decrease at a very low C_L/C_D ratio at 25° AOA as seen in Fig.8 [a-c].

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