INVESTIGATION ON AERODYNAMIC PERFORMANCE OF SYMMETRIC WINGS WITH SERRATIONS

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Abstract : The current study investigates the numerical simulations of symmetrical infinite wing of NACA 0012 with modified trailing edges. The trailing edge serrations have been provided to study the aerodynamic performances. The objective is to understand the effects of changes in aerodynamic coefficients with the saw tooth trailing edge serrations. The detailed mathematical investigations have been carried out using CFD technique for various angles of attack (0º to 20º). Spalart-Allmaras turbulence model with standard wall function is considered to solve the turbulent parameters. Current study has been focused on visualising the changes in flow behaviour and vortex mechanism at various Reynolds numbers (30 m/s, 93.7 m/s) and modified NACA wings and also computing the performance characteristics numerically and observing the changes in performance characteristics with the base wing. The application of serrations to the trailing edge results in control of vortex shedding and changes in performance characteristics of the modified wing.

IndexTerms **- Symmetric Airfoils, Trailing edge serrations, Aerodynamic Performance, CFD, Vortex shedding** .

I. INTRODUCTION

Numerous components of aircraft are responsible for generation of noise, it is one of the major issues that have its greatest effects in the areas of health, sleep disturbance, annoyance and many more potential effects. Severe noise is produced in aircraft engines; however other airframe components are also responsible for generation of noise in aircraft. Trailing edge noise of airfoil is one of the major noise effects in aircraft wings; reduction of noise generated by the trailing edge is of more concern. However, earlier studies have been focused on reducing trailing edge noise of aircraft wing but less attention was specified towards observing aerodynamic performance of aircraft wings on the account of reducing aircraft wing noise. The present study relates generally to the aerodynamic field and more specifically a structure which gives better aerodynamic lift and reduction in drag with sharp trailing edges by reducing noise.

The shape of the trailing edge in case of airfoils mainly affects the lift as well as drag characteristics in wings. Considering in viscid theory, the shape of camber located near to the trailing edge and the shape of trailing edge shows the total lift produced.

Typically, surface of aircraft wing is moderately blunt or sharp trailing edges from which the shedding of wake takes place. The distribution, direction of wake turbulence separation, strength, vorticity and the wake beginning location are the sources of reduced lift and increased drag, which is highly undesirable.

The pressure of air below the aircraft wing is high compared to that of pressure above the wing leading to movement of air from bottom surface to upper surface, this span-wise movement of air causes spillage of air at the tips of wings which is northing but vortices causing increased drag and noise.

The trailing edge noise of airfoil is self generated noise and is mainly because of the turbulence which convects over the airfoil surface, and is carried by the hydrodynamic pressure fluctuations. When these fluctuations move over the airfoil solid surface and on reaching the sharp trailing edge interacting with the free stream behind the airfoil a sudden impedance jump is felt. This causes them to diffract and scatter into acoustic pressure waves.

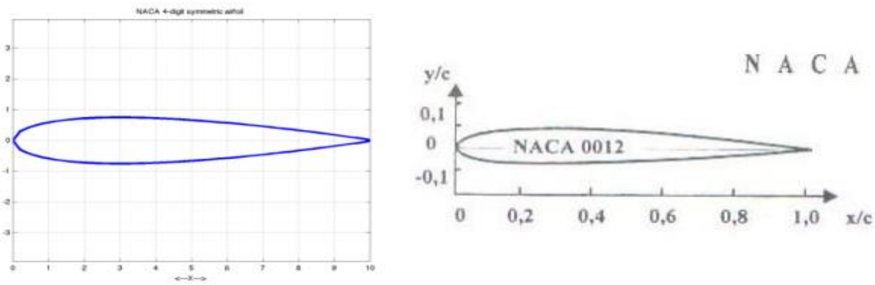


Fig 1 Symmetric airfoil

When the upper and lower surfaces of airfoil are identical, then the airfoils are termed to be symmetrical airfoils. There is no centre of pressure travel in case of symmetrical airfoils. The centre of pressure travel is almost constant providing best aerodynamic characteristics for various speeds and angles of attack. They produce zero lift at zero angle of attack. Symmetrical airfoils creates lift usually lesser than that of lift produced by the cambered airfoils. Stall characteristics of symmetrical airfoils is undesirable than non symmetrical airfoils. For the present study NACA (National Advisory of Committee) 0012 symmetric airfoil is considered having zero camber and maximum thickness of 12% in percentage of chord.

J. Nedic et al. [1] investigation on vortex shedding and aerodynamic behavior of NACA0012 wing section with truncated and serrated trailing ends was carried out experimentally. Truncated trailing ends leads to increment in coefficients of both lift and drag, which results in decrease in overall lift to drag ratio in comparison with NACA0012 base wing section. It can also be noticed with multi-scale patterns of serrations with decreased chevron angle or sharper chevrons to the trailing ends of NACA0012 wing section leads to decrease in energy of vortex shedding and improvement in aerodynamic performance of wings.

Catalano et al. [2] effect of adding serrations to the trailing edge of NACA0012 airfoils in order to reduce self noise have been studied experimentally. It mainly focused on three types of serrations namely, triangular, wishbone and trapezoidal type. All of these types individually contribute in reduction of noise for frequencies up to 5 kHz. Among all three types of serrations wishbone trailing edge found to be more efficient. For aerodynamic analysis, NACA0012 wing model with 92 pressure tapings is used, where trailing edge boundary layer is measured with the help of hot wire annometer.

H.A. Alawadhi et al. [3] NACA 0012 base wing modified by incorporating trailing edge serrations have been studied computationally. The serration effects were examined from -90deg to +90deg at 10deg intervals. The obtained results showed that if the deflection of serrations with respect to chord of wing is larger than it induces vorticity with stronger magnitude, but the vortex strength decays faster compared with the smaller defections. It has also shown that as the serration deflection angle varies the velocity profile downstream of wing also varies.

Xiao Liu et al. [4], acoustic and aerodynamic performance of serrated trailing edges of airfoils have been studied experimentally. This research paper was mainly focused on the use of different types of serrations in order to control trailing edge noise. A symmetric NACA0012 and cambered NACA 65(12)-10 airfoils are chosen to understand the aerodynamic effects of different serrations to the trailing edges of airfoils. The aerodynamic characteristics (lift and drag) were measured for wide range of angles of attack and wind speeds.

Alexandros [5], numerical and experimental research on passive flow control methods to reduce airfoil self noise is studied. The research is related to various applications of airfoils that encounter non turbulent smooth inflow where trailing edge is considered as dominant source of noise.

II. TRAILING EDGE MODIFICATION WITH SERRATIONS

Aircraft wings are the surfaces which contribute to the maximum amount of total lift generated in an aircraft. There are various design factors which affect the amount of lift produced , one of the major design factor include the shape of an airfoil trailing edges. Most of the birds and aquatic animals show modifications in their trailing edges i.e. presence of serrated geometry along the trailing edges of wings. Understanding these serrations to wings plays a major impact in the view of aerodynamics and acoustics performances of aircrafts. Modification of wings refers to changing the trailing edge geometry of wings in order to obtain better acoustic performance of wings, while improving acoustic performance by modification of wings will also leads to the changes in aerodynamic characteristics of wings. One of the major way to alter the noise generated in wings is by the application of serrations to the wings. The word serration refers to sharp cutting edge; modified wings produce vortices on the wing surface higher than the baseline. The boundary layer is reenergized by these vortices (eddies) thereby carrying momentum flow higher near the wall.

In the current investigation modification of wings with tailing edge serrations are given to airfoils by changing thickness, depth between serrations and the shape of serrations, having a great impact on flow field which in turn depends strongly on angle of attack and Reynolds number.

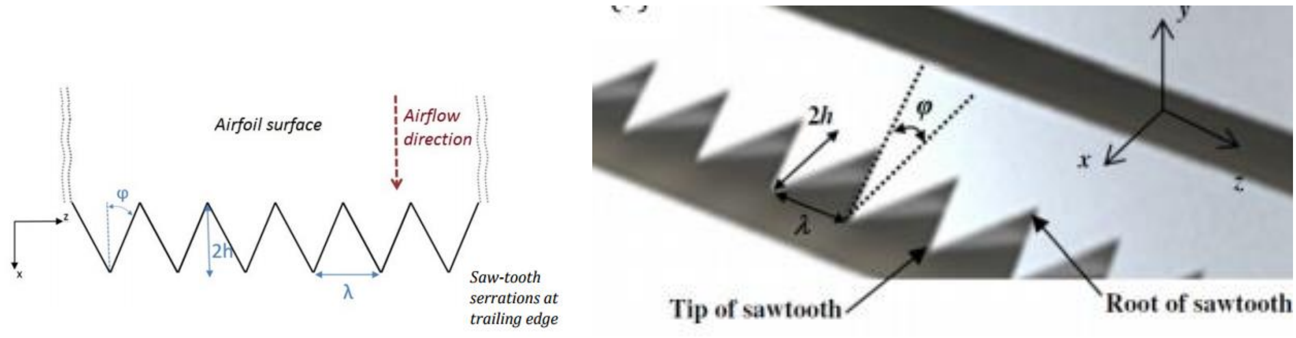


Fig 2 Schematic representation of typical trailing edge serrations

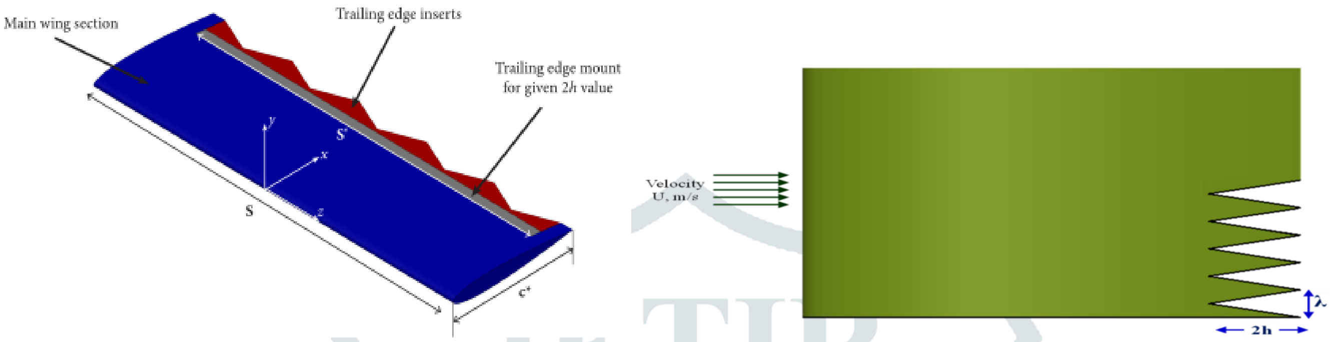


Fig 3 Saw tooth serrations at the trailing edge of infinite wing

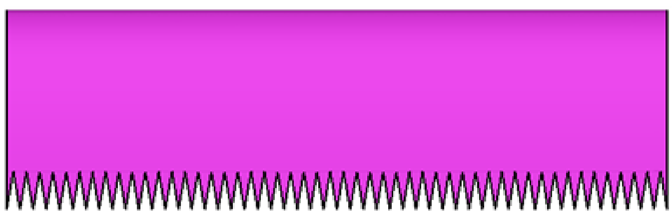
III NACA0012- Saw tooth serrations to the tips of NACA0012 infinite wing

Figure 3 shows the models of infinite wings with base wing and three different configurations case 1 complete serrations are given to trailing edge of base wings with 2h>λ , case 2 complete serrations are given to trailing edge of base wings with 2h=λ and case 3 tip serrations are given to trailing edge of base wings. These serrations were modeled by truncating trailing edge portion of base models according to specifications.

3.1 Grid Generation

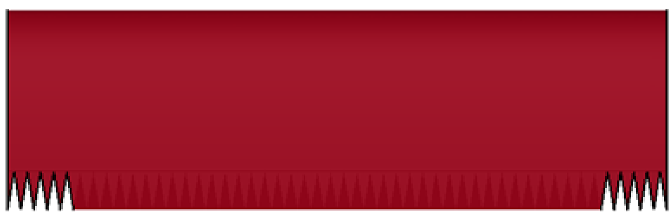
In the present study, to carry out the meshing process Altair Hypermesh pre-processing tool is used. Unstructured tetrahedral volume elements were used for the NACA 0012 infinite wing with and without serrations. The tetrahedral elements have been generated to capture the fluid region and the mesh count is almost 1.8 million. The 2D quality parameters for aspect ratio have kept below 10 and skewness is below 60. The 3D volume skewness for tetrahedral elements kept below 0.91. Boundary layer mesh has been created to capture the flow gradients near to airfoil surface as shown in fig. The non-dimensional distance between the wing surface and first grid layer (Y^+) maintained around 1.

Base Wing



Case 1 (2h>λ)

Case 2 (2h=λ)



Case 3 tips of NACA0012 infinite wing(2h>λ)

Fig 4 Modeling of base wing and design modification cases

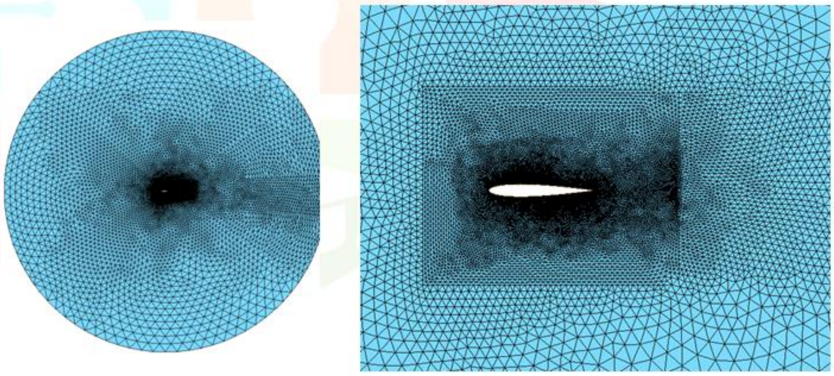


Fig 5 Discrete representation of computational domain and zoomed view near to the wing

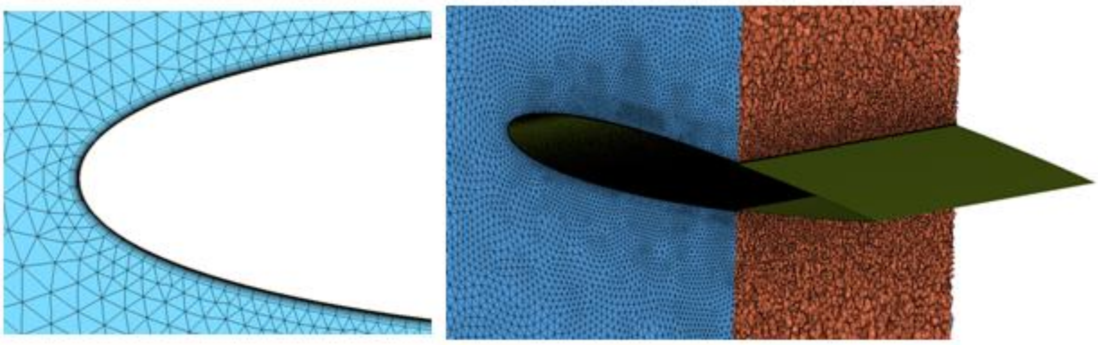


Fig 6 Grid generation at the surface of the wing with boundary layers

IV. RESULTS AND DISCUSSION

Three dimensional flow simulations have been carried out using Fluent to solve steady state RANS Navier-stokes equations with velocity inlet and pressure outlet and noslip boundary conditions, Spalart –Allamaras turbulence model at Reynolds number $3.2x10^5$, to account for flow turbulence to obtain the aerodynamic coefficients of NACA0012 infinite wing with different serration profiles at various angles of attack. The lift and drag coefficients are computed through numerical integration of the friction force and pressure force acting along and normal to the surface respectively.

4.1 Validation of Numerical Simulation with Experimental Result

To validate the computational methodology's accuracy aerodynamic characteristics of base wing NACA0012 were compared with experimental data Xiao et al [4].

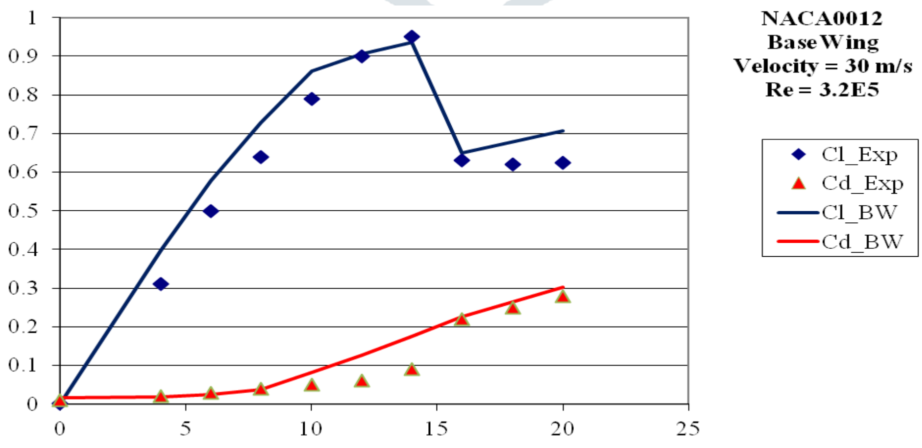


Fig 7 Correlation of NACA0012 simulated data with experimental data for the free stream velocity of 30 m/s.

Figure 7 shows the comparison of lift and drag coefficients obtained from the current computation with the experimental data. The correlation level with the experimental data found closer for the free stream velocity of 30 m/s. This correlation level helps to modify the design during conceptual design phase. Region of stall can be noticed around 14 to 16 degrees angles of attack where maximum Cl is found to be 0.9352. At higher angles of attack there is increase in both lift and drag leading to lower lift to drag ratio (L/D).

4.2 Comparison of trailing edge modifications of NACA0012 infinite wing for the speed of 30 m/s

The three design modifications have been done for the NACA0012 infinite wing to study the effect on aerodynamic performances. The free stream flow conditions for the design modification simulations are kept same as that of base wing where the validation is already done. The trailing edge serration simulations are discussed below.

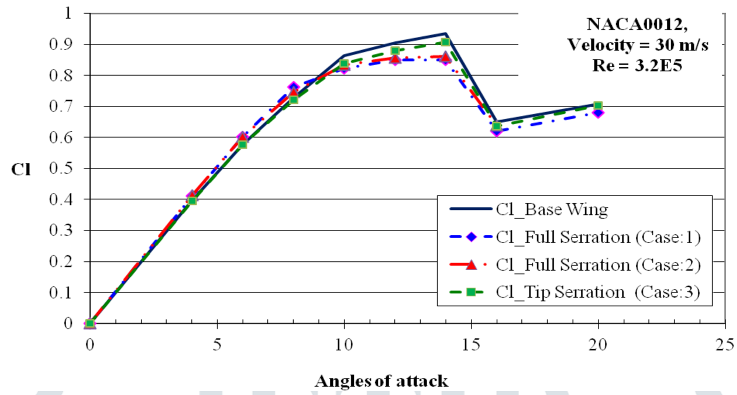


Fig 8 Comparison of C_l values for NACA0012 Base wing with different trailing edge serration profiles at V=30m/s

Figure 8 shows the comparisson coefficient of lift for base wing with different trailing edge serration profiles, it can be seen that C_l values of NACA0012 base wing at V=30m/s is found to be higher than wings with diffrent serration profiles in pre stall region.

The presence of serrations leads to increased local vortices at the trailing edge and changes in pressure. At each serrations a pair of local vortices distributes that leads to reduced noise and changes in aerodynamic coefficients. However in the pre stall region between 0 to 8 degree angles of attack serration profiles gives better C_l values than base wing. Also the presence of serrations only at the tips of trailing edge leads to formation of pair of local vortices only at tips, this helps in reducing noise giving better aerodynamic performance without altering base wing structure much. Among three serration profiles , $C_{l\ max}$ of trailing edge tip serration is found to be near to C_{lmax} of base wing. (C_{lmax} of case 1<C_{lmax} of case 2<C_{lmax} of case 3<C_{lmax} of base wing).

From figure 9 it can be seen that drag coefficient of NACA0012 infinite wing with different trailing edge serration profiles are compared with base wing at V=30m/s , C_d increases with increasing angles of attack , however drastic increase in C_d can be seen in post stall region . Among three serration profiles trailing edge tip serration is found to be more effective in reducing C_d.

($C_{d\ max}$ of case 1>$C_{d\ max}$ of case 2>$C_{d\ max}$ of case 3>$C_{d\ max}$ of base wing)

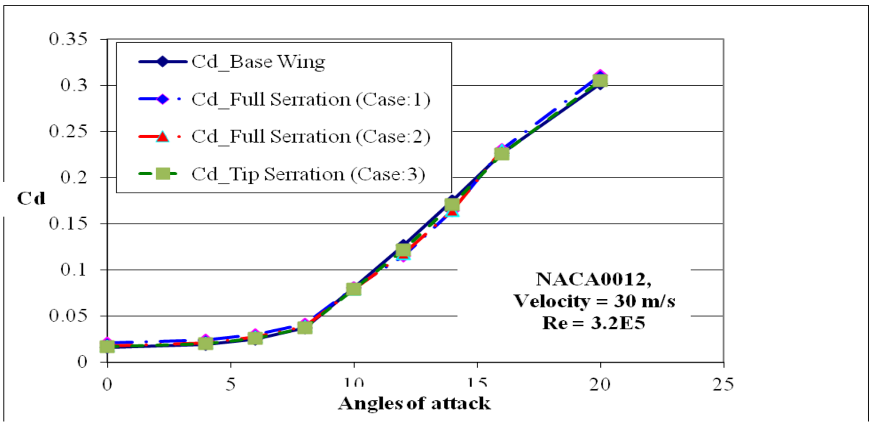


Fig 9 Comparison of C_d values for NACA0012 infinite wing with different trailing edge serration profiles and base wing at V=30m/s

From figure 10, it can be seen that at lower angles of attack L/D is found to be more effective, and decreases as angle of attack is increased , maximum L/D at V=30m/s can be obtained around 6 degree angle of attack and gradually decreases as angle of attack is increased.

$(L/D)_{max}$ of case 1<$(L/D)_{max}$ of case 2<$(L/D)_{max}$ of case 3<$(L/D)_{max}$ of base wing

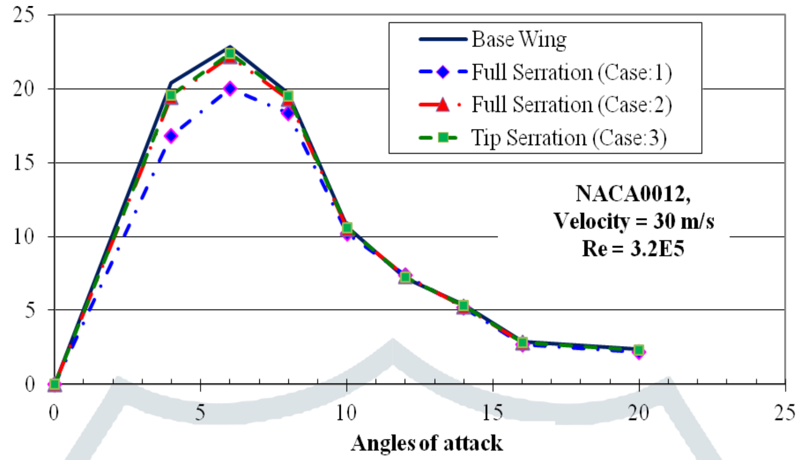


Fig 10 Comparison of L/D for NACA0012 base wing with different serration profiles and base wing at V=30m/s

V CONCLUSION

The aerodynamic performance of NACA0012 infinite wing model with serrations in the trailing edge has been studied through computational simulations. The results are as follows

1. The aerodynamic coefficients for the base NACA0012 infinite wing are validated with the experimental results taken from [Ref 4]. It was found that when numerical results are compared with experimental data, the coefficient of lift increases as angle of attack increases, the attained numerical data follows the same trend as experimental results but are slightly over predicted and the coefficient of drag also increases with increase in angle of attack and the simulated values matches well with experimental data till angle of attack 8. Further as there is increase in angle of attack the values of C_d slightly over predicted till angle of attack 20.
2. Region of stall can be noticed around 14 to 16 degrees angles of attack where maximum C_l is found to be 0.9352. At higher angles of attack there is increase in both lift and drag leading to lower lift to drag ratio (L/D).
3. For Case 1 the obtained coefficient of lift and drag values are compared with the base wing, it can be predicted from the results giving complete serrations to the trailing edge does not alter lift curve much, however lift values are found to be higher at lower angles of attack but decreases as angle of attack is increased and stall region occurs in the range of 14 to 16 degrees where maximum C_l is found to be 0.8488 which is 8.4% lower than base wing.
4. The obtained aerodynamic coefficients for case 2 at velocity 30 m/s are compared with base wing , it can be predicted from results that coefficient of lift increases as angle of attack increased till stall region. Stall region can be noticed in the range of 14 to 16 degree where increase in drag can be noticed after stall. Before stall the maximum lift coefficient is found to be 0.86227 which is 7.2% lower compared to base wing.
5. Aerodynamic coefficients for case 3 are compared with base wing, it can be predicted from obtained values that coefficient of lift is higher at lower angles of attack and decreases after stall. Stall region ranges between 14 to 16 degrees and maximum C_l is found to be 0.905969 which is 2.9% lower than base wing.

From the above analysis it is concluded that the serrations on the trailing edge may improve the aerodynamic performance within pre-stall condition. There is 8% improvement in lift coefficient for the serration model when compared with base wing model at pre-stall condition.

FUTURE WORKS

The main focus of current study was given attention towards aerodynamic behavior of trailing edge serrations to symmetric NACA 0012 infinite wing. However, following are the few topics that we can focus in future work:

- Cambered NACA series infinite wings
- Acoustic characteristics of NACA series for both symmetric and unsymmetric infinite wing with saw tooth trailing edge tip serrations
- From earlier researches we found that by giving leading edge serrations to wings leads to change in coefficient of lift vs. angle of attack curve and stall properties , and current study reveals that with trailing edge serrations coefficient of lift vs angle of attack curve does not vary much as compared to base wing. Hence future studies can be focused on effect of both leading edge and trailing edge serrations on acoustic as well aerodynamic behavior of infinite wings.

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