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Stall delay Characteristics of Airfoil using circular ridges

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A Study on stall delay was carried out by numerical simulations on unsymmetrical NACA 2415 airfoil with the placement of a circular ridge of d/c ratio of 0.01 on the suction surface at individual chord positions operating at a Reynolds number of 2.14×10^5. The effect of the placement of the circular ridges is assessed on the basis of Lift, Drag and Pressure Coefficients. The simulations have demonstrated the ability of the circular ridges to delay the stall. The maximum lift improvement of 42.47% and was achieved at α=45°, with the circular ridge positioned at 0.4c corresponding increase in drag is 9 %. The delay in stall is achieved with the increase in the value of the drag coefficient.

***Keywords*:** stall delay, circular ridges, numerical simulations

1. Introduction

Recent advancements in the aviation industry are revolving around the potential ways of improving the performance of aircraft. The Airfoil, the cross-section of the wing, must be well designed for increased lift without introducing serious drag. However, there must be some compromise which is to be made in the existing configuration to attain increased efficiency. At stall angles, the drag dominates the lift, hence the stall point must be delayed in order to obtain better performance at higher angles of attack. Studies suggest that modifications in the present wing geometry have to be made in-order to achieve better flow characteristics. The passive flow control devices, which are relatively cheap and simple are used in many practical applications for enhanced aerodynamic performance. Riblets [1,2] which are micro-grooves aligned parallel to the free stream velocity vector on the surface show a significant viscous drag reduction of 4-8 %. The placement of longitudinal ridges not only energizes the flow but also restricts the streamwise vorticity and spanwise vortex moment[3]. A study conducted on an S809 airfoil (HAWT) using an oscillating micro cylinder placed nearby the leading edge near stall conditions increased aerodynamic efficiency by 88.21%[4]. Various other flow control devices have been studied by researchers like leading edge protuberences[5], thin burst control plate[6] and hairy flaps[7]. Similarly, the usage of Off-Surface control elements which have different decay characteristics is proven to be useful for flow control[8,9]. In this article, the delay in stall on NACA 2415 airfoil is studied numerically by introducing a circular ridge of diameter to chord ratio of 0.01 at various chord individual chord positions. The 2-D Models were constructed and the flow was simulated for the angle of attacks from 0-45° with successive increments of 5° at $R_e=2.14\times10^5$. The results are interesting and the delay in stall was achieved.

2. Numerical Methodology

The 2-D Baseline model selected for flow simulation was unsymmetrical NACA 2415 of chord 100 mm. The addition on the suction surface of the baseline model includes a circular ridge of diameter of 1% of the chord. The Circular ridges are attached individually at various chord positions on models as listed in Table 1. The angle of attack for each of the models is varied from 0°- 45° with successive increments of 5°.

Table -1 Ridge Positioning along the chord

Model	Ridge placement at
Baseline	-
A	0.1c
B	0.2c
C	0.3c
D	0.4c
E	0.5c

c- chord length

The boundary set for the far field was 10c in all non-spanwise directions. Unstructured triangular 2-D meshes were used around the models in infinite wing simulations. In order to maintain accuracy to a certain possible extent, the mesh points are clustered on the curved surfaces especially on the ridges (36 points). The free stream velocity set for the simulation was 30 m/s (V_∞) and the corresponding R_e=2.14x10^5. The applied boundary conditions as in Fig 1, can be listed as (i) Uniform upstream velocity $u=V_\infty$, $v = w = 0$. (ii) symmetry conditions are applied to the far-field boundaries for $u=V_\infty$, $v = w = 0$. (iii) No slip condition was imposed on the wall surface.

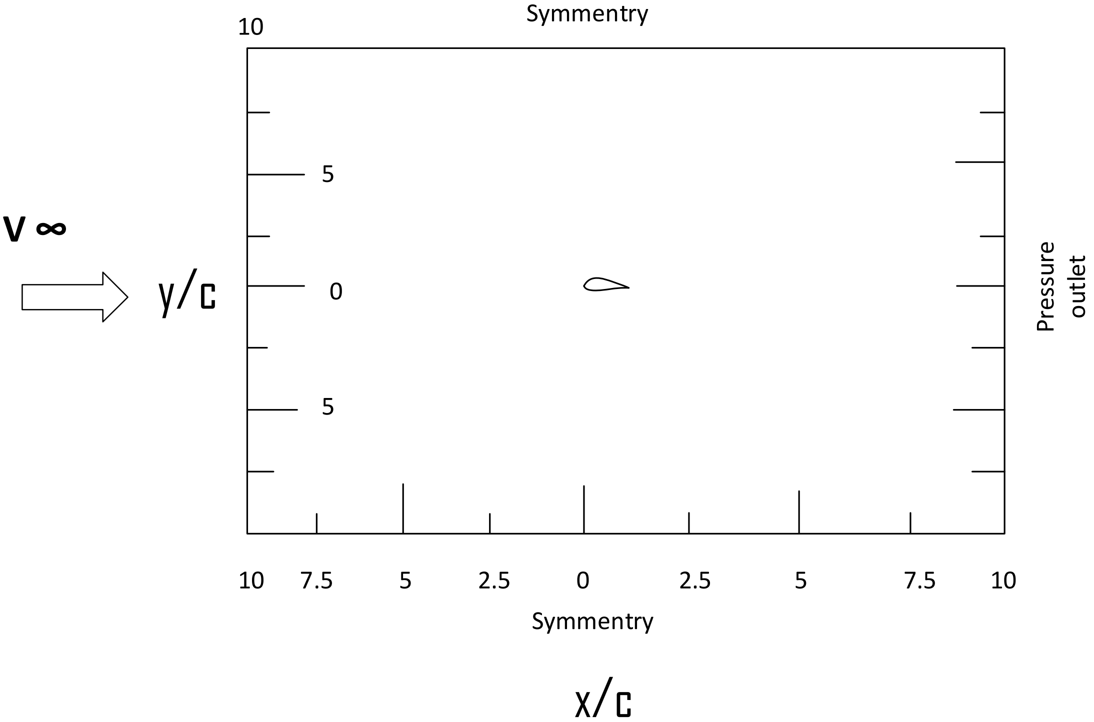

Fig 1 – Computational Domain

The flow simulation is done in commercial solver FLUENT. The steady state k-ω SST turbulence model is used to simulate the flow over the airfoil

3. Results and Discussion :

The study on the effect of the placement of the circular ridge is initially carried out based on the changes in the value of Lift and drag coefficients C_L and C_D, compared to the baseline geometry.

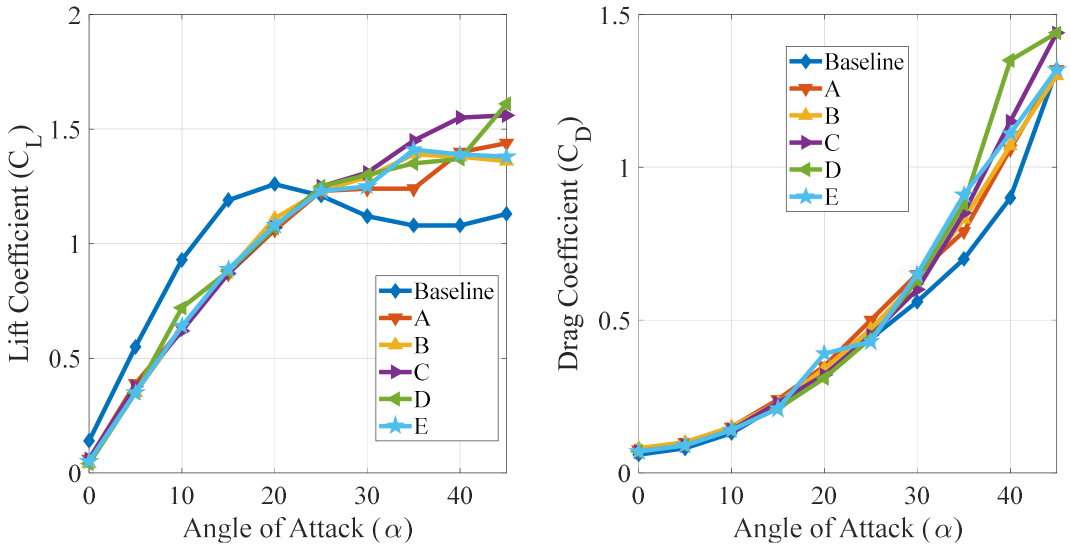

Fig 2 – C_l vs α and C_d vs α

The above figures (Fig2) depict the variation of lift and drag coefficients of the baseline and the models with the circular ridge. Initially, the increase in the value of C_l with Angle of attack is found to be linear. The Stall condition on the baseline model is observed at α=20°, as C_l has a negative slope of from α=20° to α=25°. It is also evidently seen from the steep increase in the value of C_d from α=20° to α=25°. Contrarily, the cases with the circular ridge models show that the stall has been significantly delayed and the behavior of all the models with the circular ridges is similar till α=25°. There is no appreciable change in the value of C_d for the ridged models as compared to the baseline in the pre-stall phase. Whereas in the post-stall phase, the C_l value for the ridged airfoils is better than that of the Baseline. For instance, at α=30°, the value of C_d for modified airfoils is presented in the following table.

Table - 2 C_l and C_d comparison at α=30°

Models	C_D	C_L
Baseline	0.56	1.12
A	0.65	1.24
B	0.63	1.29
C	0.60	1.31
D	0.63	1.3
E	0.65	1.25

It can be inferred from (Table 2) that there is an increase in the value of C_d in the models with ridges along with an increase in C_l compared to the baseline model. Hence it can be concluded that the stall has been delayed and more lift is obtained at the expense of increased drag.

The pressure distribution along the suction surface indicates the attachment of flow to the surface. For the baseline model, the value of C_p initially decreases due to the acceleration of the flow on the suction side. It can be inferred from the plots (Fig 3) that, when it reaches 0.4c the flow tends to get separated as the slope line is less variant. In model A, the circular ridge positioned at 0.1c on the suction surface, the flow tends to decelerate with the corresponding rise in the value of static pressure resulting in a sharp increase in the value of C_p at 0.1c

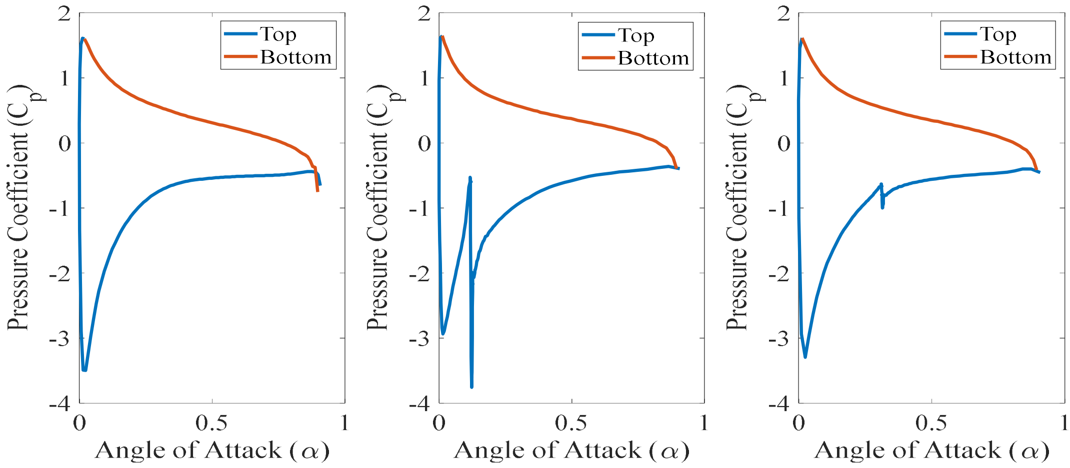

Fig 3 – C_p vs x/c plots for Baseline, Model A, Model C at α =25°

A steep drop in the value of C_p is observed at downstream of the ridge. The reattachment of the flow is observed as there is a positive slope of C_P from 0.2c. In the case of Model C, the flow on the suction surface starts accelerating initially, at 0.3c it encounters the ridge and the flow decelerates which results in an increase in the value of static pressure with a corresponding steep rise in the value of C_p. It is again seen that C_p again drops when the flow reaches downstream of the ridge and gets reattached to the surface as a positive slope in C_p is observed.

4. Conclusion

Numerical simulations were carried out on the baseline and ridged models and the following conclusions have been made

- It is evident from the C_l and C_d plots that the presence of ridge on the suction surface delays the stall on the airfoil. Flow tends to remain attached to the surface
- The Overall Lift generated is found to increase in the post-stall region compared to that of baseline. For an instance, at α=30°, the improvement in the lift for all the models with the circular ridge is presented in the following figure (Fig 4)

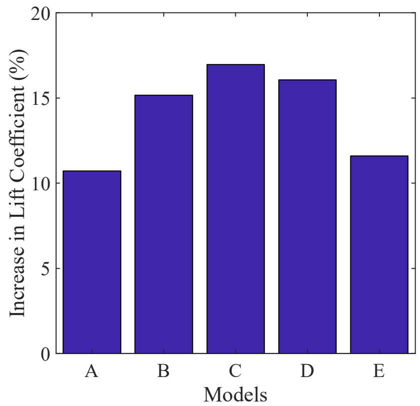

Fig 4 - Improvement in lift compared to the baseline

Acknowledgments

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