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Effect of Stepped Leading Edge on the Aerodynamic Characteristics of NACA0012 wing

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Improving aerodynamic performance is a primary objective to improve the efficiency of aircraft with particular interest to flow control over wings. Leading edge modifications are one of the major areas of focus in flow control techniques for wings. This study aims at investigating the lift, drag characteristics and the aerodynamic efficiency of the Stepped Leading Edge airfoil and comparing its effectiveness with baseline NACA 0012 wing. It was evident from the drag characteristic curve that the stepped leading edge airfoil had a significant drag reduction of 24.78% when compared to the baseline at an angle of attack $\alpha = 20^{\circ}$. Also, the aerodynamic performance of the stepped leading edge airfoil had a higher value when compared with the baseline model at higher angles of attack. Thus, Stepped Leading Edge displays favourable drag characteristics and improved aerodynamic performance relative to baseline wing.

***Keywords*:** Stepped leading edge, Aerodynamic efficiency, Drag reduction

1. INTRODUCTION

Flow control over wings is of prime importance in order to increase aerodynamic efficiency. With improving economic framework and living conditions, air travel is in transition to become the most preferred mode of transport across the globe, primarily in developing countries. Hence, for affordable air travel, it is deemed necessary that the aerodynamics of aircrafts especially the wings are to be improved to realize a reduction in operating costs. Employing flow control techniques will result in an improvement of aerodynamic parameters such as reduction in drag or improvement lift.

Investigation of the effectiveness of various flow control techniques has been carried out in literature. These can be broadly classified into two methods based on energy requirement as active and passive flow control techniques. Passive control techniques include surface roughness, dimples etc, Surface blowing and suction, dielectric barrier discharge etc are examples of active flow control methods. These passive methods usually involve geometric modifications to the leading-edge, upper/bottom surface or trailing edge. Leading edge modification has been studied widely. The effect of small roughness distributed around the leading edge was found to delay stall whereas large roughness tends to advance stall [1]. Leading edge undulations were found to increase lift by 25% in the post-stall region [2]. The use of leading-edge trip wires resulted in a reduction of lift and the variation in diameter did not have any effect on stall angle [3]. Variable droop leading edge was found to effectively reduce the dynamic stall and improve the aerodynamic characteristics [4]. Blowing, Suction or alternate blowing and suction at leading edge is found to increase lift and delay stall [5][6]. Leading edge flaps of rectangular geometry have been found to improve the maximum lift coefficient in a delta wing, while the aerodynamic performance varies with installation angle of leading-edge flap [7]. Micro-cylinders placed upstream of leading-edge is found to increase lift coefficient and delay flow separation by altering the flow field and delaying flow separation [8].

Although there are extensive studies on leading-edge modification, the effect of step on the leading edge is less explored and further studies are needed to adjudge its effectiveness for flow control. Henceforth, the primary objective of this work is to numerically study the effectiveness of Stepped Leading Edge (LE).

2. COMPUTATIONAL DETAILS:

With a view to understanding the effect of Stepped Leading Edge as shown in Fig 1, a baseline wing model and a stepped leading-edge model were used in this study. The baseline wing of NACA 0012 cross-section with a 1 m chord length and 2.5 m span length is used. In order to have a comparable modified model, the Stepped Leading-edge model is modelled with the same planform area as that of the baseline wing. The computational test geometry (Fig 2) of dimensions $L_X \times L_Y \times L_Z = 25c \times 10c \times 5c$ in order to reduce disturbances at the boundary.

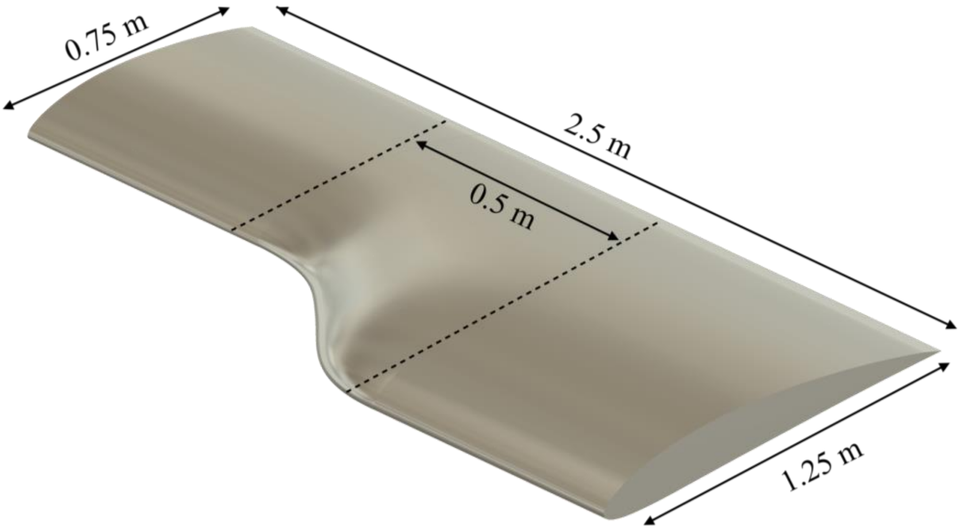

Fig 1. Geometric parameters of the Stepped Leading-edge wing.

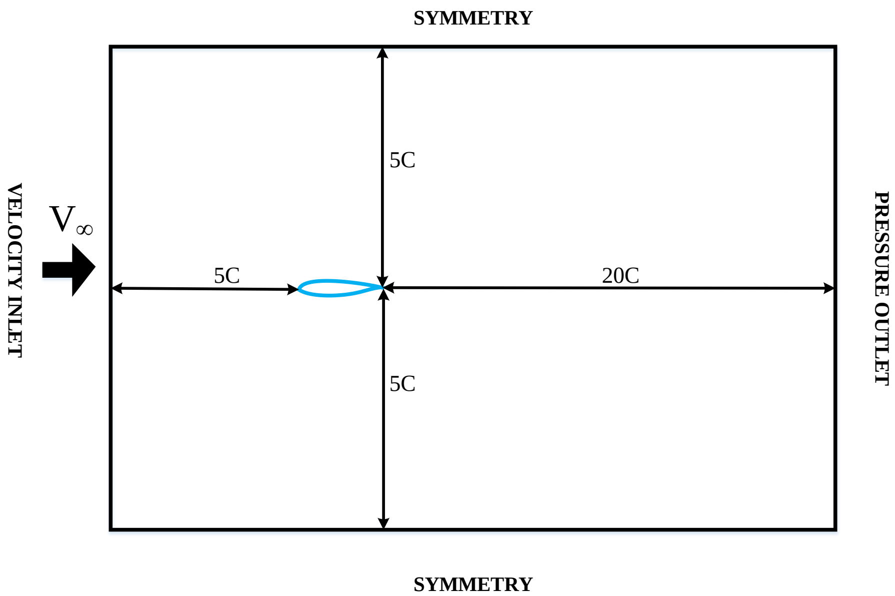

Fig 2. Computational test geometry with corresponding boundary conditions

Both the test cases are subjected to five different cases of Angles of Attack (α) ranging from α= 0 ° to 20 ° with a successive increment of 5°. The freestream velocity was set to 30 m/s corresponding to a chord-based Reynolds number of 2×10^5. The simulations were conducted using a commercial 3D steady state solver. First order and second order upwind methods have been used to solve the governing equations using the SIMPLE method. The k-ω SST turbulence model was used because of its ability to accurately predict flow separation and wall turbulence among other turbulence models. A convergence criterion of 10^{-6} was employed for all the computed quantities.

3. RESULTS AND DISCUSSION:

In order to understand the effectiveness of stepped leading edge over the baseline wing, the

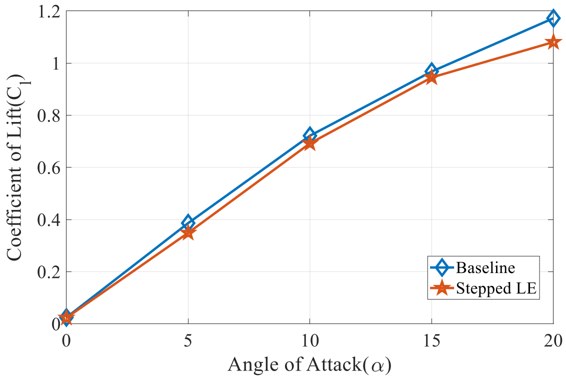

Fig.3. Variation of C_l with α

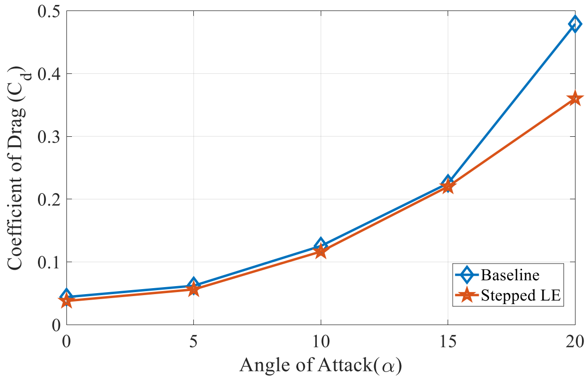

Fig.4. Variation of C_d with α

aerodynamic performance parameters such as Coefficient of Lift (C_l), Coefficient of Drag (C_d) and Lift to Drag ratio are employed. Fig.3. shows the variation of Coefficient of Lift (C_l) with respect to Angle of Attack(α). It can be seen that the C_l increases monotonically with respect to Angle of

Attack (α) for both the baseline as well as Stepped Leading Edge (LE) wing. As can be seen, the variation of C_l for both cases are minimal for the lower range of α (0 ˚ to 5 ˚). At around α= 5 ˚, the C_l value for Stepped LE exhibit a deviation of 9.66% from the Baseline C_l value. Between α = 5 ˚ to 15 ˚, the deviation of C_l curve of Stepped LE lies in the range of 2-4%. At α = 20 ˚, a large deviation of 7.79% in the C_l value is seen. Henceforth, it can be said that the Stepped LE wing exhibits relatively reduced lift characteristics in the pre-stall region.

The drag characteristics of the Stepped LE wing is plotted with Baseline wing in Fig.4.The drag characteristic curves display an increasing trend with respect to Angle of Attack(α). Over the range of Angle of Attack(α), the Stepped LE wing displays a reduced drag characteristic. The reduction in drag is almost constant in the range of α = 0 ˚ to 15 ˚ and at α = 20 ˚, a large reduction in drag of 24.78% is observed for the Stepped LE.

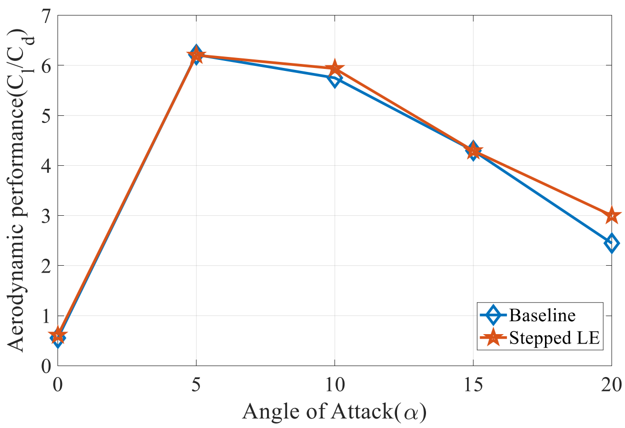

Fig.5. Aerodynamic performance of Baseline and Stepped LE wing at different Angles of Attack(α)

The aerodynamic performance also is known as Lift to Drag Ratio of baseline and Stepped LE wing are compared in Fig.5. The aerodynamic performance for baseline and Stepped LE displays an identical increasing trend until $\alpha = 5^\circ$ reaching maximum and then following a decreasing trend with deviations. The maximum aerodynamic performance achieved for both the cases is identical at a value of around 6.21 at $\alpha = 5^\circ$. At $\alpha = 10^\circ$, the Stepped LE wing shows a relatively higher aerodynamic performance of 3.24% and at $\alpha = 15^\circ$, the aerodynamic performance is identical. The Stepped LE wing outperforms the baseline wing with a 22.5% increase in aerodynamic performance.

Although the Baseline wing shows, relatively better lift characteristics, the Stepped LE wing exhibits favourable drag characteristics and larger aerodynamic performance at higher Angles of Attack (α). Hence employing this wing will reduce overall fuel consumption at the cost of a minimal reduction in lift. Thus, to arrive at an optimal design of Stepped LE, the underlying flow phenomenon has to be studied. In view of flow control effectiveness, various curvature for steps has been also planned along with experimental investigation.

CONCLUSION

Following conclusions can be made from the results and discussion section as follows:

1. There is a significant drag reduction of about 24.78% at $\alpha = 20^\circ$ when compared to the baseline model.

2. Also, it is evident that the aerodynamic efficiency of the stepped leading edge airfoil has increased over the baseline model.

Acknowledgements

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