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Experimental and Numerical Analysis over the Truncated Airfoil with Slotted Flap Configuration

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Abstract

Objectives: The objective of this work is to investigate the flow over the truncated NACA2414 airfoil with slotted flap configuration. Investigation is carried using wind tunnel and commercial CFD tools with the consequences of the variation of speed, angle of attack of control surface and effective angle of attack. **Methods/Statistical Analysis:** Wind tunnel tests are performed on a reduced scale model (3:10) in wind tunnel at Manipal University. Experimentally determined static pressure distribution data at equal interval stations, placed over the wing are used to generate pressure data. The results obtained are used in turn as a benchmark to validate the CFD simulations. **Findings**: Findings clearly states that the blunt trailing edge has high drag coefficient. Although off set cavity and cavity has proven to be the ideal modification for trailing edge shape in a plane wing from the study. It can be concluded that the same is not true when such modifications are applied to slotted flap configuration. **Application/Improvements:** Further studies can be carried out with the alternative designs and a rigorous research can contribute in efficient designs in high lift devices.

Keywords: High-lift Devices, Numerical Analysis, Slotted Flaps, Truncated Airfoil, Wind Tunnel

1. Introduction

Optimization of the aircraft performance has been the motivation behind the ever-expanding aircraft industry. Slightest of the design improvements has the potential to boost the performance of the aircrafts in the long run. The Slotted flaps design has been used to increase the lift coefficient of the primary wing to a considerable extent. Any geometrical variation in the trailing edge of an airfoil implies a considerable change in lift and drag characteristics of the airfoil[1]. This change in the lift characteristics are the byproducts of eddies formed at the end of the trailing edge of the airfoil. The shape and nature of these eddies depends on the several factors like the shape of the airfoil, Reynolds number and angle of the incidence of the airfoil. Different shapes for the trailing edges are considered to study the effectiveness of the designs.

Rapid increases in the computational power of the modern-day computers have assisted researchers across the world to resort to the ComputationalApproaches to

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simulate the required environment to study the problem. Computational fluid dynamics is extensively used in aerodynamics and it has been proven to be a reliable source for predicting the flow intricacy. In the context of this study, several other studies carried out by independent researchers have proven that offset cavity exhibits 50% lesser drag compared to splitter plate and cavity configurations. Similarly,trailing edge modificationslike splitter plate method, Trailing edge wedge method, ventilated cavity method and M-shaped serration has a wing configuration has been to know the most favorable shape for the drag reduction[2].

2. Methodology

Due to the experimental constraints of the wind tunnel, Experiments were carried out on a 3:10 scaled model witha chord length of 30 cm. The Computational analyses were carried out at the true lengths and the experimental model was manufactured by the use of CNC machine.

The placement of ribs was taken by considering the structural factors of wing as shown in Figure 1. The experimental analysis was carried by pressure tapping methods. A total of 14 pressure taps have been arranged symmetrically in order to calculate pressure coefficient at a speed of 30m/s.

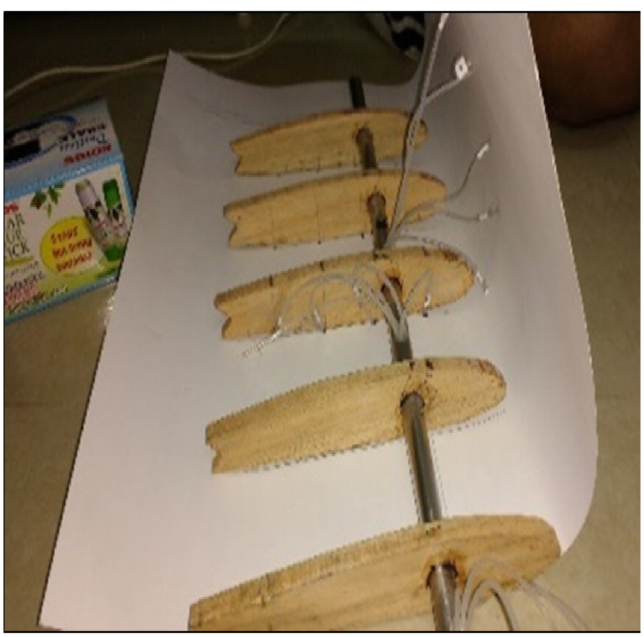

Figure 1. Depicts the wing skeletal body with the placement of the ribs along the span of the wing.

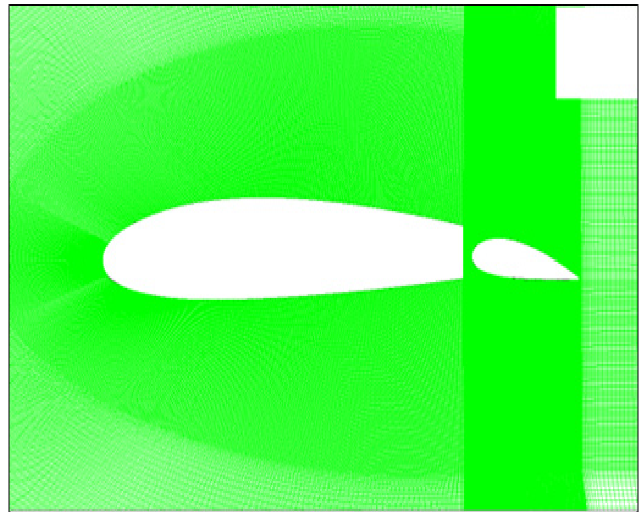

Figure 2. Meshed model.

The airfoils have been modeled in ICEM. Sections of the NACA 2414 airfoil has been selected as the base wing. The model is scaled to 25 percent of the one meter chord and 0.02 gap is given in between the main and flap as shown in Figure 2. Domain has been modeled to be 10 times larger than the chord of the airfoil. Control surfaces are primarily used to during the take-off and the landing phases of the flight. A final angle of 12 degrees has been obtained through an incremental angle of attack of 4 degrees for the iteration.

Multi body computational analyses have been one of the most difficult problems due to the requirement of higher mesh resolution at the interface. The gap between the main wing and the control surface tend to complicate the flow structure. The first element height was chosen to be 1.2E-04. Analysis had been carried out at a Reynolds number of 2.1E6. Spalart-Allmaras model is a one equation model specifically designed for the application involving wall bounded flows and boundary layers with steep pressure gradients. Advantage of Spalart-Allmaras not only increases the accuracy of the solution[3], but also has an advantage of y+ insensitivity towards wall treatment. K-Epsilon and K-Omega have also been considered for the study and a grid independence study has been carried out and the results are as follows

3. Results

In the current section results are presented for the different sections of trailing edge modifications of NACA 2412. The test results are compared with experimental tests which were carried at MIT-MU using the sub-sonic research tunnel facility.

In the current paper two trailing edge modifications are made as shown in the Figure 3 and 4 length of the chord trailing edge was selected based the theory developed[1,2]. To obtain the effective results the trailing edge was varied different angle of attack in range between 0 to 12 degree experimentally and numerically using 43 lakh nodes computationally effective results using ANSYS Fluent which is detailed in Table 1.

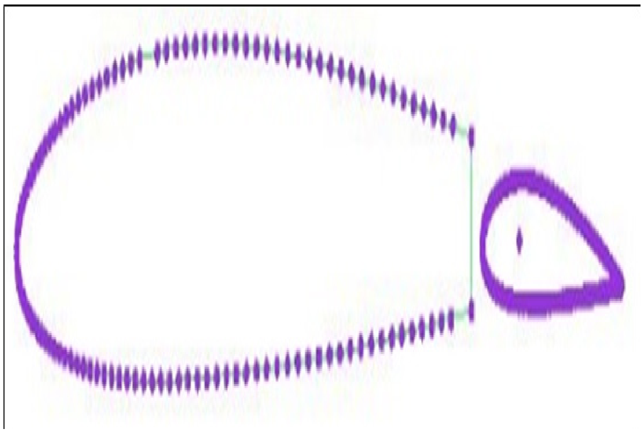

Figure 3. NACA 2414 airfoil with blunt shaped trailing edge.

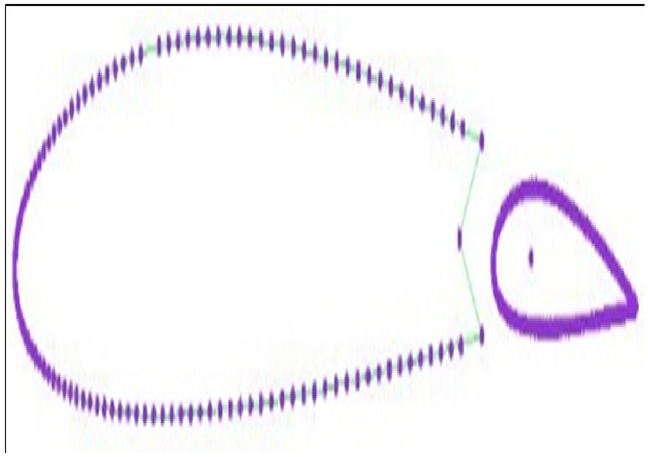

Figure 4. NACA 2414 airfoil with cavity shaped trailing.

3.1 Validation of Results

To validate the results efficiently and present effectively both experimental and numerical analysis were carried for the eight cases of the trailing edge modifications with different angle of attack. Results presented in the Figure 5-14 shows the points are nearly matched with numerical results on a scale of unit chord length.

Applying the methodology the results are presented in figures which shows that the main wing and the attached trailing edge wing with main wing or fixed wing trialing modification i.e., cavity and blunt. The discussion will start with blunt edge and followed by the cavity with the gap between main wing and secondary wing are fixed.

Table 1. Grid analysis (dual blunt with 12-degree control surface deflection)

Nodes	Co-efficient of Lift	Co-efficient of Drag	Co-efficient of Moment
1.1 Million	0.50860	0.02225	0.24147
2.9 Million	0.49437	0.022082	0.23619
4.3 Million	0.49498	0.022048	0.2349

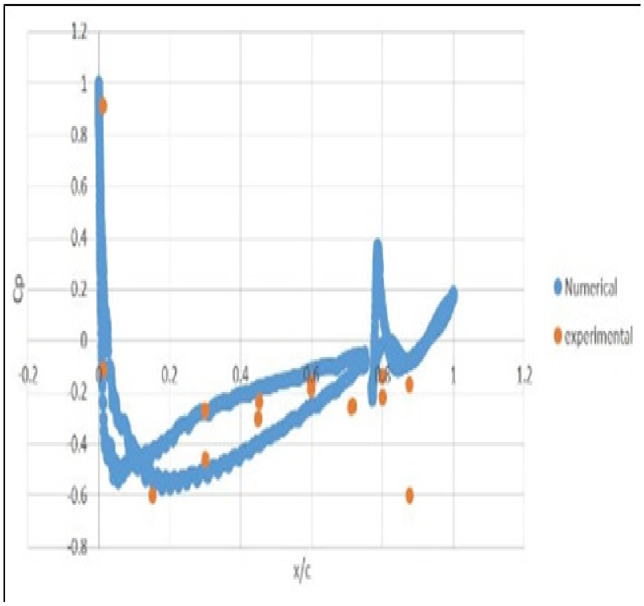

Figure 5. Cavity control surface at 0 degree with free stream 0 degree.

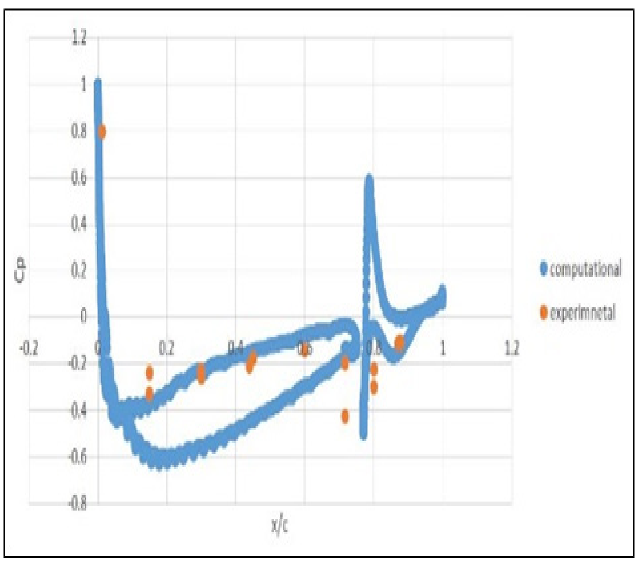

Figure 6. Cavity control surface at 4 degree with free stream 0 degree.

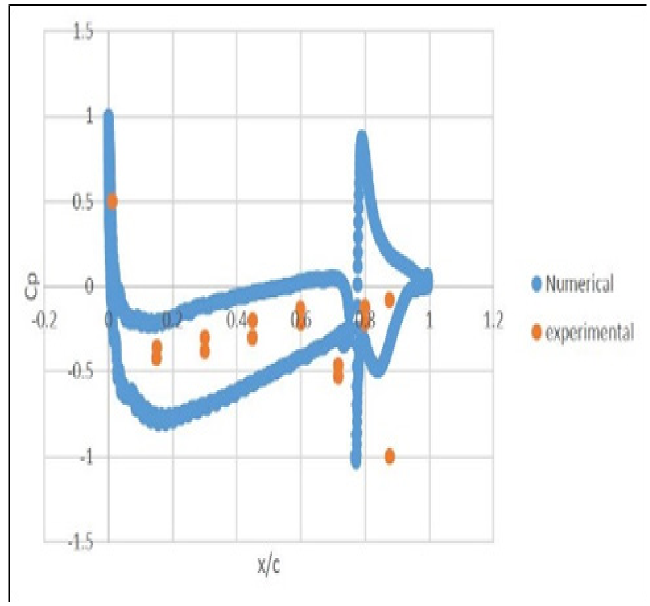

Figure 8. Cavity control surface at 12 degree with free stream 0 degree.

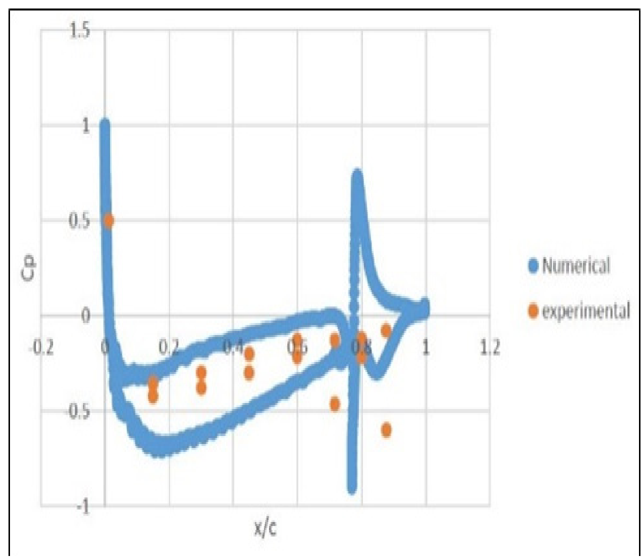

Figure 7. Cavity control surface at 8 degree with free stream 0 degree.

In case of cavity section the results of pressure coefficient at the leading edge of the airfoil reached maximum pressure for all the cases which shows that the maximum pressure or stagnation pressure is raised on the leading edge. As the results with trailing edge deflections the variation of pressure coefficient in that is of primary interest, in investigating the airfoil to reduce drag over the airfoil section, this is of interest for many years[4,5]. The deflection

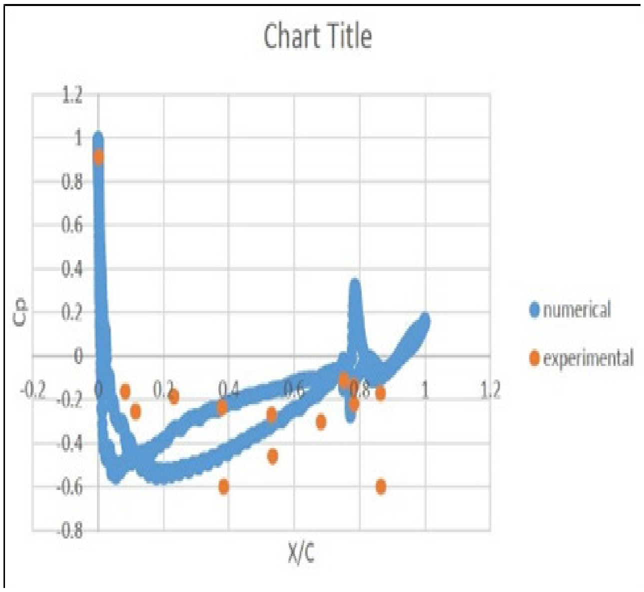

Figure 9. Blunt control surface at 0 degree with free stream 0 degree.

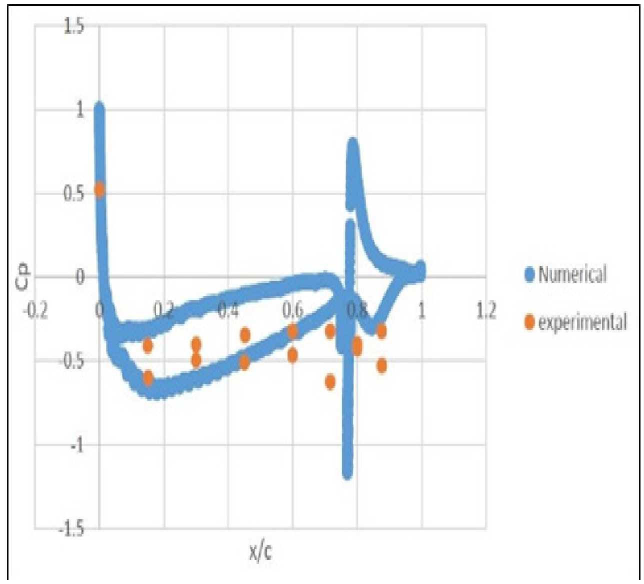

Figure 11. Blunt control surface at 8 degree with free stream 0 degree.

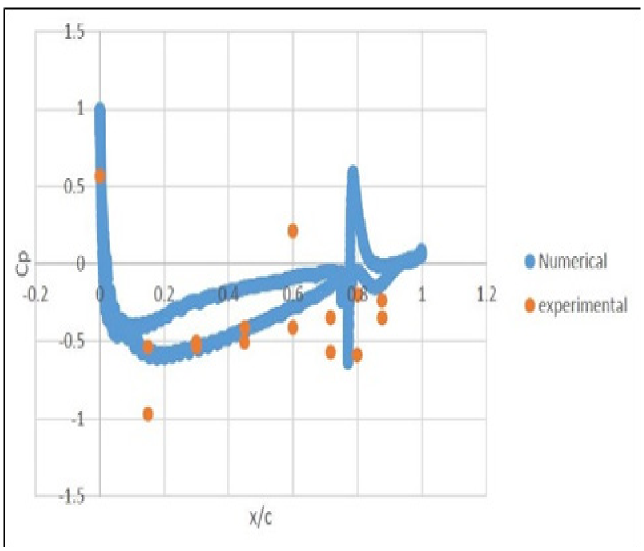

Figure 10. Blunt control surface at 4 degree with free stream 0 degree.

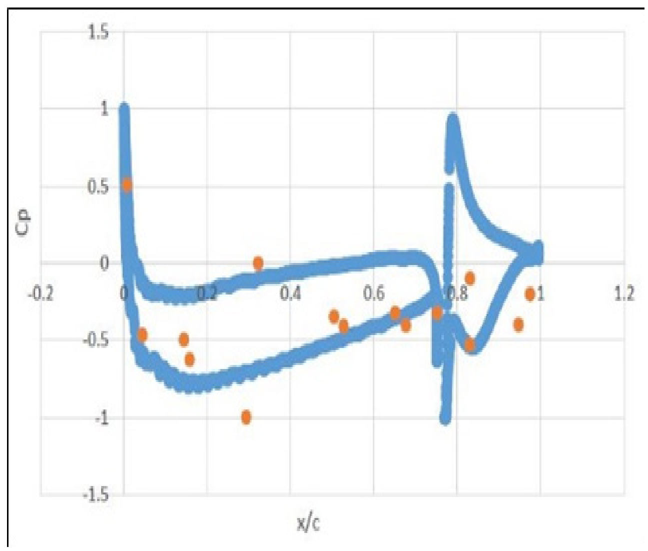

Figure 12. Blunt control surfaceat 12 degree with free stream 0 degree.

of trailing edge variation has increased with increase in pressure over the secondary airfoil section from which it clearly states the increment in pressure results in increased lift contribution which is discussed in preceding sections regarding the lift and drag variation. The pressure distribution over the primary and secondary section closely matches with experimental data, except one point where the suction pressure has increased with secondary wing angle of attack this is due to the reason that flow induced

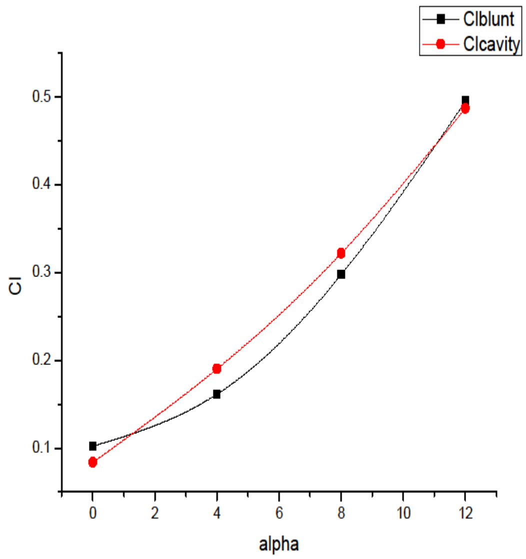

Figure 13. Lift plots of blunt and cavity shaped trailing edged aerofoil in slotted flap configuration.

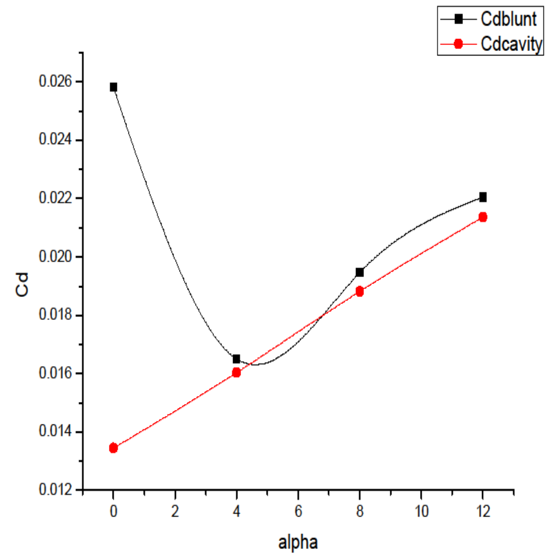

Figure 14. Drag plots of blunt and cavity shaped trailing edged aerofoil in slotted flap configuration.

vortices effect was not clearly captured in the experimental analysis.

Blunt trialing edge airfoils are also of interest in the current study which has high drag compared to the other case because the low pressure in the wake acting on the trailing edge. Figure 9-12 it clearly shows that the numerical results matches closely with experimental results but the pressure variation at the gap has induced vortex flows which increased the drag force comparatively. Results clearly states that there are two stagnation points one over each section.

4. Conclusion

Results obtained from the wind tunnel results justifies the accuracy of the turbulence model used in the computational analyses. From the above experimental and numerical results, it can be understood that the slightest of the variation in the geometrical variation would bring significant changes. The trailing edge modification of main wing is depicted. It shows that the blunt has low lift coefficient compared to the cavity although initially at zero angle of attack it increased. With increment in trailing edge angle of attack the lift has increased till 11 degree with increment in further angle result has varied by the flow induced vortices which has influenced the cavity section resulting in the low lift coefficient. It clearly states that the blunt trailing edge has high drag at low angle of attack, which has reached to minimal point at angle of 4 degree in further increment the coefficient of drag has increased. Comparatively the case of cavity of low drag at even zero angle of attack the variation of drag has increased with angle. This results we can state that clearly states that the blunt trailing edge has high drag coefficient. Although off set cavity and cavity has proven to be the ideal modification for trailing edge shape in a plane wing from the study[1]. It can be concluded that the same is not true when such modifications are applied to slotted flap configuration.

5. Acknowledgements

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