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A study on performance of surface modified NACA 2412 airfoil at various Reynolds number and angle of attacks

In the present investigation, aerodynamic performance study of NACA 2412 airfoil with surface modifications for the enhanced optimized aerodynamic characteristics is carried out.

Three airfoils were built by introducing the cut at different locations. The present work is a computational analysis of the effect of inward cut on the lower surface of airfoil at 25%, 50%, and 75% chord length. The study parameters include flow separation (or stall), lift, drag, and angle of attack. The model is developed in Ansys design modeler and meshed in ICEMCFD. All three meshed models are simulated at 0º, 40º, 80º, 120º and 16º angle of attacks (AoA) at 60000 and 100000 (1 lakh) Reynolds number.

The post processing revealed that, the increase in AoA resulted in increase in lift co-efficient (C_L) for all three airfoils at both Reynolds number. The lift coefficient started increasing as the position of cut moved towards the trailing edge. The flow started separating after 12º AoA. It was found that, the airfoil with inward cut at 75% of chord length resulted in attaining highest lift co-efficient when compared to other two airfoils.

Keywords: NACA, airfoil, angle of attack, Reynolds number.

1.0 Introduction

Airfoils are the main lift producing devices in an aircraft. The airfoil generates lift by creating a pressure difference over its surface. Angle of attack (AoA) also plays a vital role in generating lift. Change in AoA results in variation of performance of airfoil [1]. Due to the shape of airfoil, the air passes over both the surface at different velocities and pressures. This pressure difference causes the airfoil to lift in its vertical direction [2].

Hence, the lift generated by airfoil purely depends on the shape of the airfoil's surface. As the airfoil's geometrical surface changes, the lift generated by the airfoil also changes. This research focuses on understanding the phenomenon of how an airfoil behaves when its surface is modified. Hence a computational research is carried out on surface modified airfoil at different AoA and at different Reynolds number.

A research done by Alan A [3] on surface modified airfoil resulted in a phenomenal understanding of behaviour of NACA 2412 airfoil when its surface is modified to a fish kind model. The researcher carried out a computational study on behaviour of NACA 2412 airfoil when modified to a Wahoo fish, sword fish and tarpon fish shape. The results concluded by indicating that, the aerodynamic performance of tarpon fish shape airfoil is higher than NACA 2412 airfoil.

A study on development of spoiler on the surface of the NACA 2412 airfoil was done by Scott Douglas Lindsay, Paul Walsh [4] to understand the aerodynamic performance. It is found from post processing of the result that, at high AoA, deployment of spoilers results in increase of lift and drag, but at low AoA, the lift decreases and the drag increases.

Shivam Saxena and Rahul Kumar [5] worked on understanding the aerodynamic performance of NACA 2412 airfoil at different Reynolds number and AoA. It was concluded by saying that, at thick surface of airfoil, static pressure remains constant and at the lower ends of airfoil, the dynamic pressure remains constant.

Computational fluid dynamics approach was used to enhance the lift generation process during high lift take off condition for an MAV NACA 2412 wing by Arvind Prabhakar and Ayush Ohri [6]. The results showed, at high take off condition, double slotted flap extended to 40 degrees is the ideal position. At this configuration of slots, the stall angle raised from 20 degree to 54 degree.

A research on effect of air flow over NACA 2412 airfoil at high Reynolds number was carried out by Shivananda Sarkar

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and Shaheen Beg Mughal [7]. 5 degree AoA was found to be an optimum angle which results in maximum lift to drag ratio and the stall angle was at 15 degree. As the air flows over the airfoil, the temperature of the air also plays a vital role in aerodynamic performance of that airfoil.

A research on understanding the characteristic effect of temperature on NACA 2412 airfoil was done by Yogesh Thawrani and Ajith Kumar [8]. Richardson number (RI) at 0 degree AoA is directly proportional to the lift co-efficient and the increase in temperature leads to earlier flow separation states the conclusion.

An unconditional work was done on surface modification of the airfoil by adding a vortex generator and a dimple on the airfoil to increase the aerodynamic performance by Sonia Chalia and Manish Kumar Bharati [9]. The concluding remarks states that, the introduction of vortex generator leads to increase in fuel consumption.

2.0 Methedology

2.1 Geometric Modelling

The coordinates of NACA 2412 airfoil were obtained from airfoil tools. Ansys design modeler is used to model the airfoil. There were three surface modified airfoils generated from NACA 2412 airfoil. A 90 degree inward cut of 2mm is introduced on the lower surface of the airfoil at 25%, 50% and 75% of chord length as shown in Figs.1, 2 and 3.

2.2 Meshing

The model has to be meshed before it is simulated using Ansys Fluent. ICEMCFD is used to mesh the domain. An unstructured grid is created across the domain. There are 165116 cells created across the airfoil. The orthogonal quality is 0.574, whereas values close to 0 signifies the low quality.

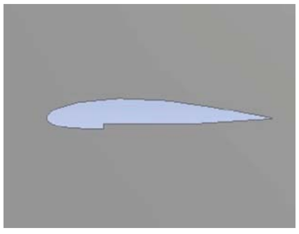

Fig.1: Geometric modelling of airfoil with inward cut at 25% of chord length

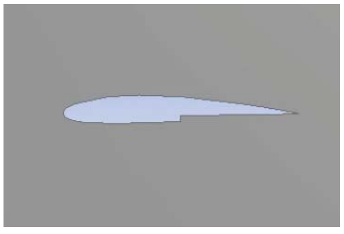

Fig.2: Geometric modelling of airfoil with inward cut at 50% of chord length

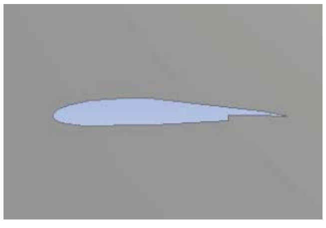

Fig.3: Geometric modelling of airfoil with inward cut at 75% of chord length

Fig.4: Unstructured mesh across the airfoil

The orthogonal skew is 0.343, whereas the value near to 1 is low quality. The meshed model is shown in Fig.4.

2.3 Simulation

The simulation on the meshed model was done using Ansys Fluent. The simulation was carried out at 60000 and 100000 Reynolds number at 0^o, 4^o, 8^o, 12^o and 16^o AoA on airfoil which has cut at 25%, 50% and 75% on the lower surface along chord length. The convergence of the solution was decided when Cl reached a constant value and the continuity equation was satisfied. The graph of converged solutions is shown in Figs.5 and 6.

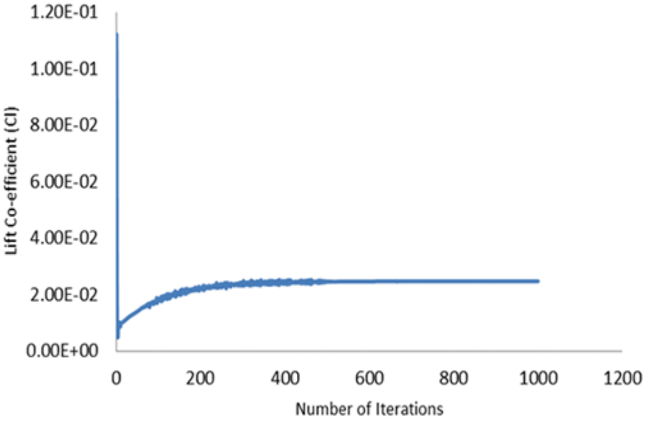

Fig.5: Convergence criteria w.r.t lift co-efficient

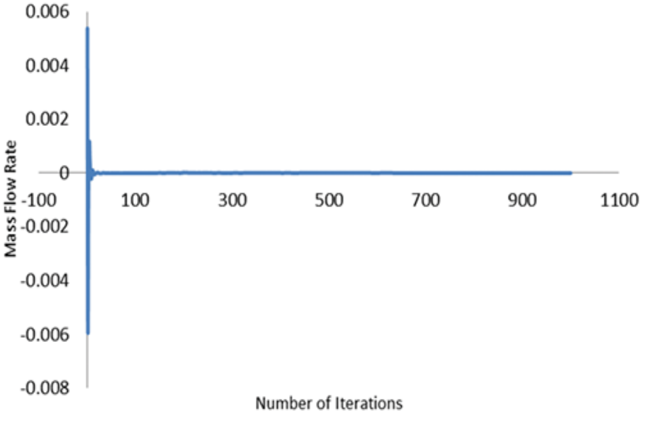

Fig.6. Convergence criteria w.r.t mass flow rate

2.4 Boundary condition

Table 1: Boundary Condition

Model	SST K-ω turbulence model
Fluid	Ideal gas
Flow condition	Steady state
Inlet	Velocity inlet
Outflow	Pressure outlet
Symmetry	Symmetry
Fairfield	Wall
Top and bottom wall	Wall (free slip)
Solver	Ansys fluent

3.0 Results

3.1 Test Case 1– Position of cut at 25% of chord length, Re=60000

Fig.7: Static pressure

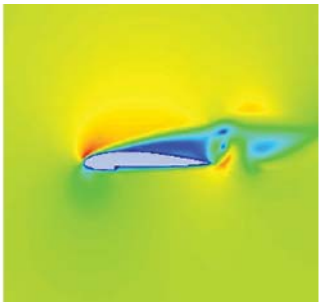

Fig.8: Velocity contours contours at 0^{o} AoA at 16^{0} AoA

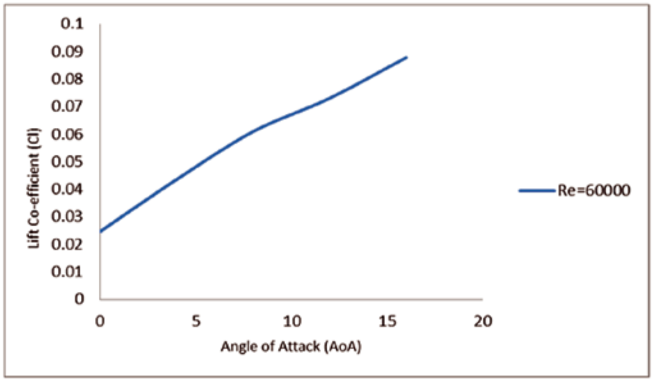

Fig.9: CL vs. AoA graph at 60000 Reynolds number

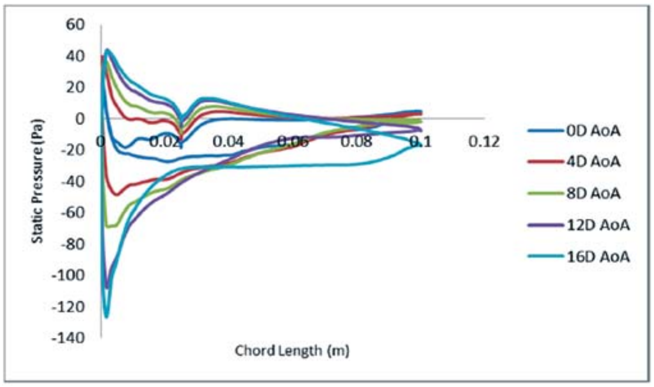

Fig.10: Static pressure vs. chord length graph at varies AoA

3.2 Test Case 2– Position of cut at 25% of chord length, Re=100000

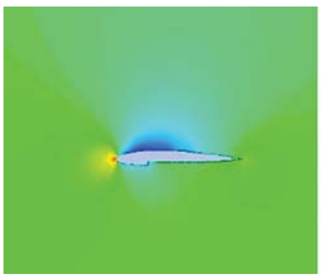

Fig.11: Static pressure contours at 0^{o} AoA

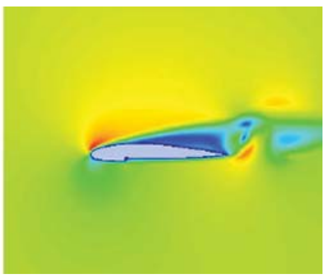

Fig.12: Velocity contours at 16^{o} AoA

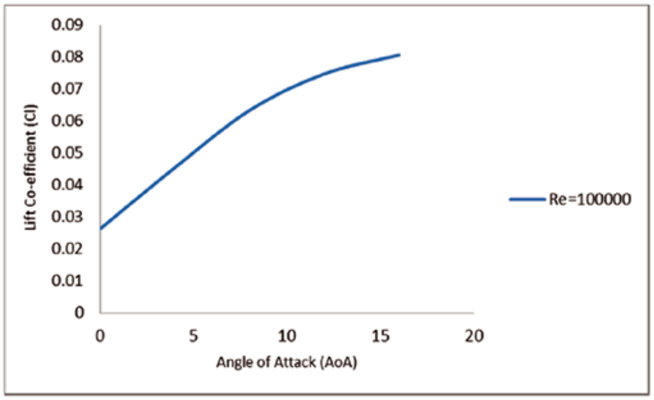

Fig.13: CL vs. AoA graph at 100000 Reynolds number

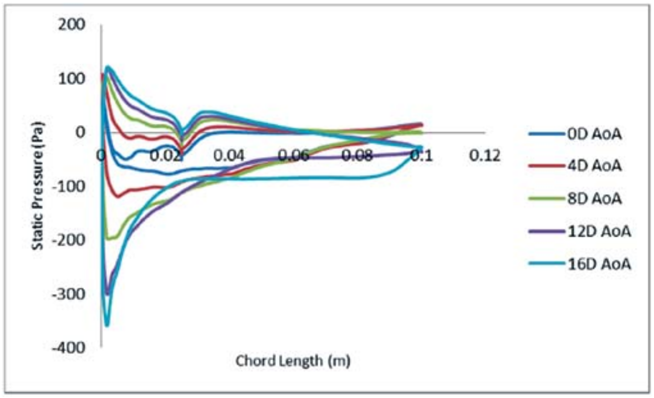

Fig.14: Static pressure vs. chord length graph at varies AoA

The simulation was carried out at 0, 4, 8, 12 and 16 degree AoA at 60000 Reynolds number. The Fig.10. is static pressure vs. chord length at various angle of attack. As angle of attack increases lift coefficient of an airfoil increases. In accordance with Bernoulli's principle, the airflow velocity increases along the airfoil, the pressure along the airfoil decreases, as the increase in angle of attack will increase the separation between airfoil's upper and lower sections increases. The dip of static pressure on the upper line at 25% chord length indicates the cut on the airfoil, the flow on the lower surface of the airfoil reaches the 25% of chord length indicates sudden increased velocity and decreases static pressure at cut region. The area inside the curve is increased with increase in angle of attack. The steep rise in pressure at 16 degree angle of attack signifies stall of an airfoil.

The simulation was carried out at 0, 4, 8, 12 and 16 degree AoA at 100000 Reynolds number. The Fig.14. is static pressure vs chord length at various angle of attack. It can be seen that, the area inside the curve in graph has increased when compared to 60000 Reynold's number test case.

This increase in area signifies the increase in lift. Both 60000 Reynold's number test case and 100000 Reynold's number test case shows a dip in pressure on upper line of the curve.

Maximum lift coefficient is 0.0916 at 16 degree angle of attack and 10000 Reynold's number but in 60000 Reynold's number test case maximum lift coefficient at 16 degree angle of attack is 0.878.

3.3 Test Case 3 – Position of cut at 50% of chord length, Re=60000

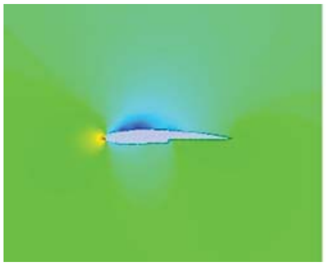

Fig.15: Static pressure contours at 0° AoA

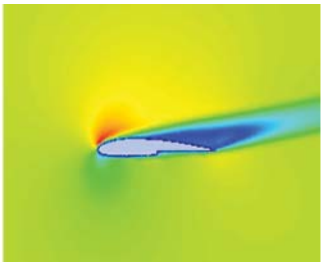

Fig.16: Velocity contours at 16° AoA

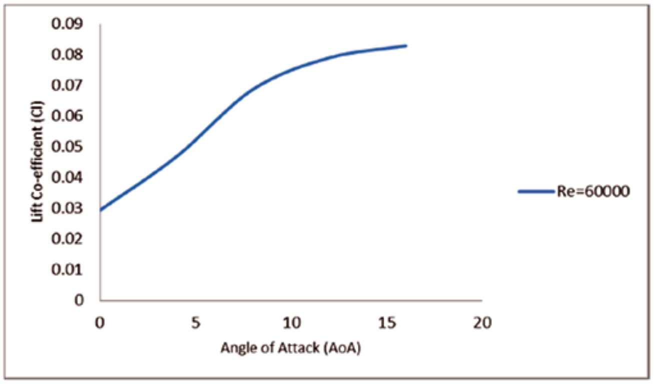

Fig.17. CL vs. AoA graph at 60000 Reynolds number

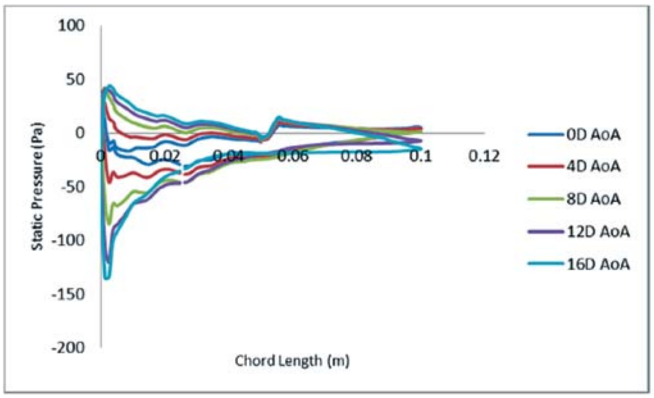

Fig.18. Static pressure vs. chord length graph at varies AoA

The simulation was carried out at 0,4,8,12 and 16 degree AoA at 60000 Reynolds number. The Fig.18 is static pressure vs chord length at various angle of attack. The lift coefficient at 0° AoA is 0.0272 in this case, but it was 0.0246 in previous test. As the cut on the lower surface of the airfoil is shifted from 25% to 50% of chord length, the coefficient of lift increased. The lift coefficient was 0.0878 in test case 1 whereas in this case the lift coefficient is 0.0829 at 16° AoA. This shows that, the airfoil which has cut at its 50% of chord length stall earlier than the airfoil which has cut at its 25% of chord length. It can be signified that the area inside the curve is higher in this case than in the 25% cut. This is due to the increase in lift. The rise in pressure at 50% of chord length shown in Fig.18. Indicates the pressure on the lower surface is increased due to the cut, leading to the excess amount of lift.

3.4 Test Case 4 – Position of cut at 50% of chord length, Re=100000

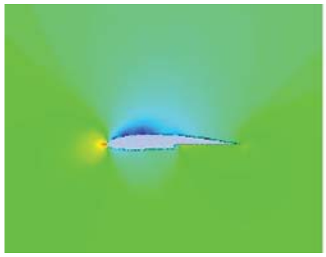

Fig.19. Static pressure contours at 0° AoA

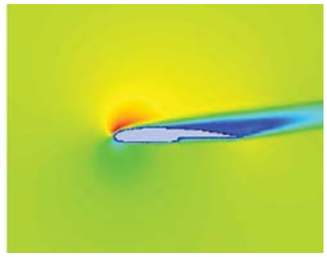

Fig.20. Velocity contours at 16° AoA

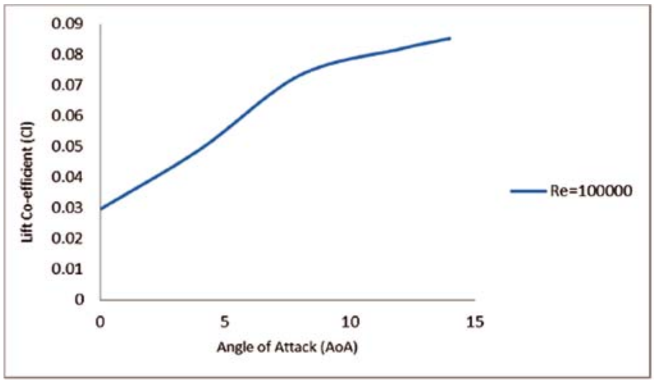

Fig.21: CL vs. AoA graph at 100000 Reynolds number

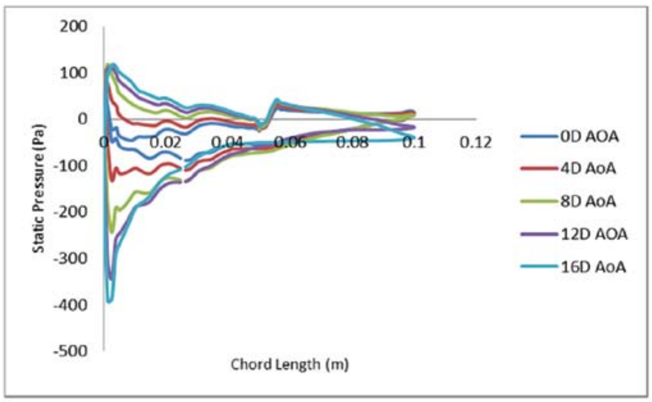

Fig.22: Static pressure vs. Chord length graph at varies AoA

The simulation was carried out at 0, 4, 8, 12 and 16 degree AoA at 100000 Reynolds number. The Fig.22 is static pressure vs. chord length at various angle of attack. The post processing of results signified that, the lift coefficient increased as the Reynolds number and AoA is increased

The flow separation was found at 16degree AoA. The airfoil stalls in this test case earlier when compared to other test cases. The increase in lift is signified by increase in area of static pressure curve as shown in Fig.30. The slight raise in pressure in Fig.22, signifies the cut on the airfoil. The steep increase in pressure on the lower line of graph indicates the flow separation on the airfoil's upper surface.

3.5 Test Case 5 – Position of cut at 75% of chord length, Re=60000

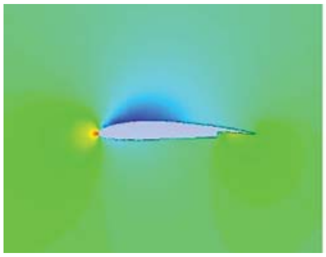

Fig.23: Static pressure contours at 0º AoA

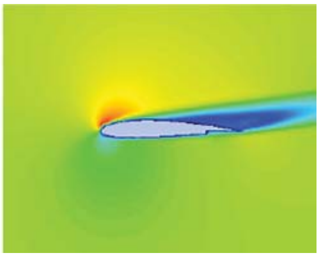

Fig.24: Velocity contours at 16º AoA

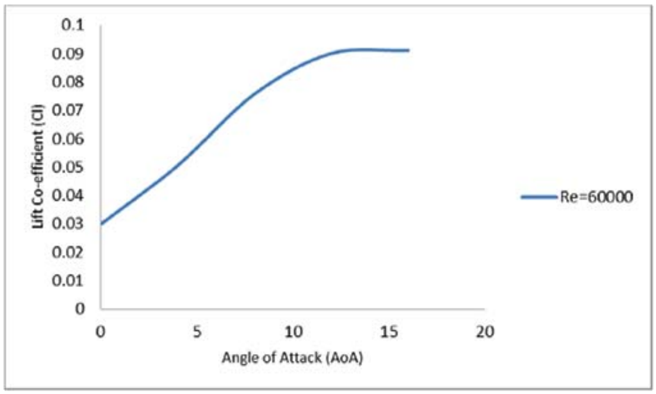

Fig.25: CL vs. AoA graph at 60000 reynolds number

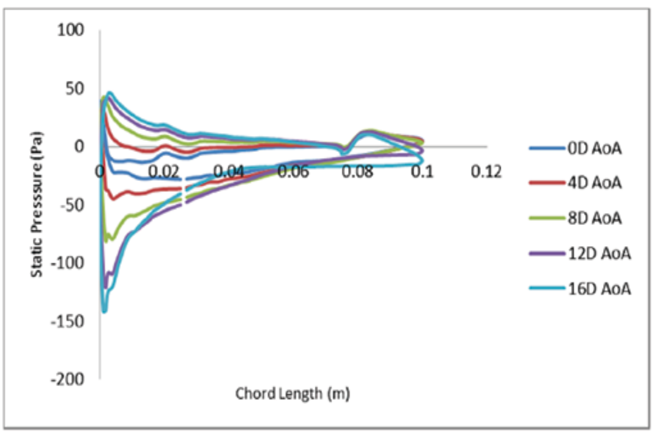

Fig.26: Static pressure vs. chord length graph at varies AoA

3.6 Test Case 6 – Position of cut at 75% of chord length, Re=100000

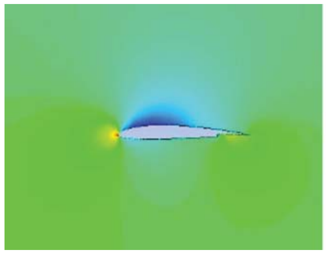

Fig.27: Static pressure contours at 0º AoA

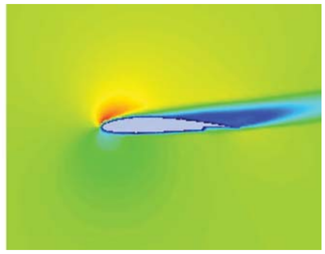

Fig.28: Velocity contours at 16º AoA

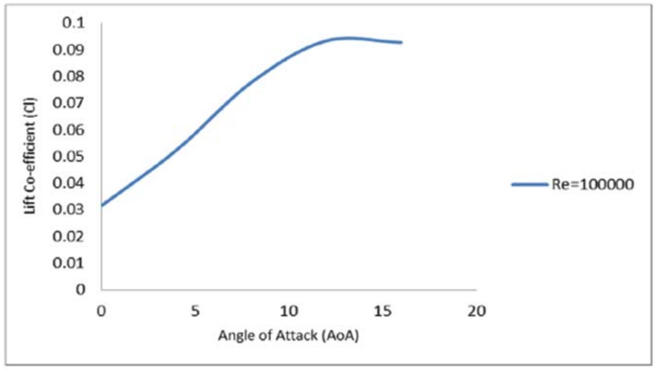

Fig.29: CL vs. AoA graph at 100000 reynolds number

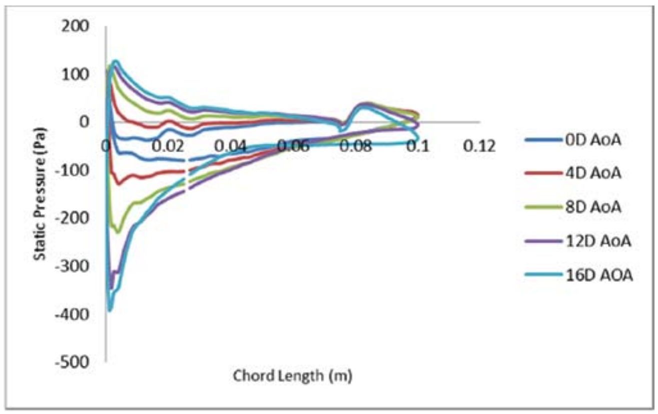

Fig.30: Static pressure vs. chord length graph at varies AoA

The simulation was carried out at 0, 4, 8, 12 and 16 degree AoA for 75% of cut at 60000 Reynolds number. The Fig.26 is static pressure vs chord length at various angle of attack. As the AoA is increased, the lift coefficient also increased.

The lift coefficient of the airfoil is 0.0299 in this test case, whereas in previous test case it was 0.0294. But the increment in lift coefficient from 12 degree AoA to 16 degree AoA is minimum in this test case. it produces higher lift when compared to airfoil which has 50% cut on its chord length.

This rise in pressure at 75% chord length in Fig.26 indicates the presence of cut on the lower surface of the airfoil. This raise in pressure on the lower surface creates an extra pressure difference due to which an excess amount of lift is generated.

The simulation was carried out at 0, 4, 8, 12 and 16 degree AoA for 75% of cut at 100000 Reynolds number. The Fig.30. is static pressure vs. chord length at various angle of attack. The lift coefficient is highest when compared to all the previous test cases.

The lift coefficient is 0.0315 which is highest of all. The highest lift coefficient is 0.0933 at 12º AoA in test case. The lift co-efficient decreased as the AoA is raised to 16º. The air flow gets separated from the airfoil at 16º AoA.

The increase in area of the static pressure curve signifies the increment of lift coefficient. Due to the increase of Reynolds number from 60000 to100000, the raise in static pressure at the position of the cut is higher, which leads to the higher lift generation. But the airfoil stalls earlier at 100000 Reynolds number than 60000 Reynolds number. The airfoil in this test case has achieved the maximum lift coefficient.

3.7 Results of lift coefficient at various AoA and position of cut on chord line

The graph in Fig.31 shows the variation of lift coefficient at 60000 Reynolds number with change in position of cut at different AoA. Fig.31 reveals a significant results obtained from all test cases. The graph indicates that, the lift coefficient increases as the position of cut is changed from 25% to 75% through 50% at various AoA. Lift coefficient increases as the AoA increases. It can be seen from graph that, the amount of increment in lift from 12º AoA to 16º AoA is decreased due to the separation of flow. The same phenomenon occurs as the Reynolds number is increased from 60000 to 100000.

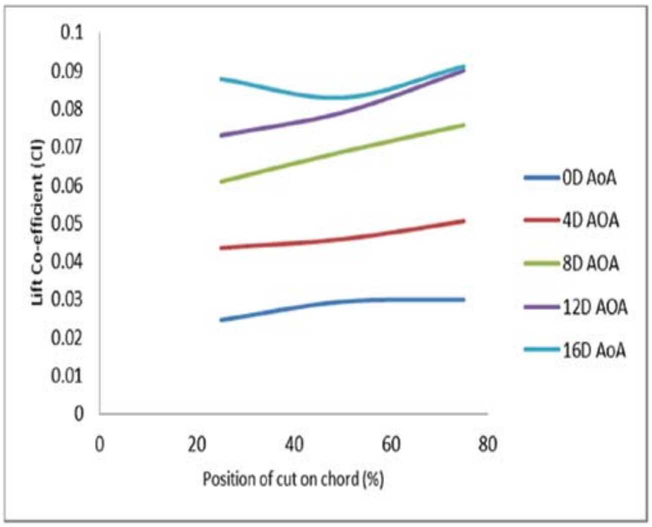

Fig.31: Position of cut on chord vs. lift co-efficient at various AoA

4.0 Conclusions

The surface modified NACA 2412 airfoil was analysed using computational method. The simulation was done on three airfoils which have an inward cut on its lower surface at 25%, 50% and 75% of chord length. All three airfoils were analysed at 60000 and 100000 Reynolds number at 0º, 4º, 8º, 12º and 16º AoA. The post processing of the results revealed that, increase in AoA will result in increment of lift coefficient. The change in cut from 25% to 75% through 50% resulted in increment of lift coefficient.

The difference in increment of lift coefficient at two Reynolds number is higher for the airfoil which has cut at its 50% of chord length. Due to the presence of cut at 25% of chord length which is near the leading edge of the airfoil, the pressure decreases due to the acceleration of flow and resulting in loss of lift. Airfoil which has cut at 75% of chord length has resulted in maximum lift coefficient when compared to other airfoils. The flow separation is found in between 12º and 16º AoA for all three airfoils. Airfoil with cut at 75% on its chord length stalls earlier than any other airfoils. Hence, it can be concluded from the results that, the surface modified NACA 2412 airfoil which has cut at 75% of its chord length yields highest lift coefficient at all the AoA operating at 100000 Reynolds number.

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