

# CFD analysis of NACA 4412 Airfoil

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# 1 Mathematical Model

Reynolds-averaged Navier Stokes (RANS) equations along with  $k - \epsilon$  turbulent modeling approach has been used to study flow characteristics over the airfoil. PDEs have been solved by finite volume method (FVM). Simulation has been performed in commercially available software Ansys.

## 1.1 Airfoil NACA 4412

NACA 4412 is an asymmetric airfoil. Straight line which join leading edge (LE) and trailing edge (TE) is known as chord line. Length of chord line is 100 mm. Maximum thickness 12 mm. Maximum camber 4 mm which is located 40 mm from leading edge.

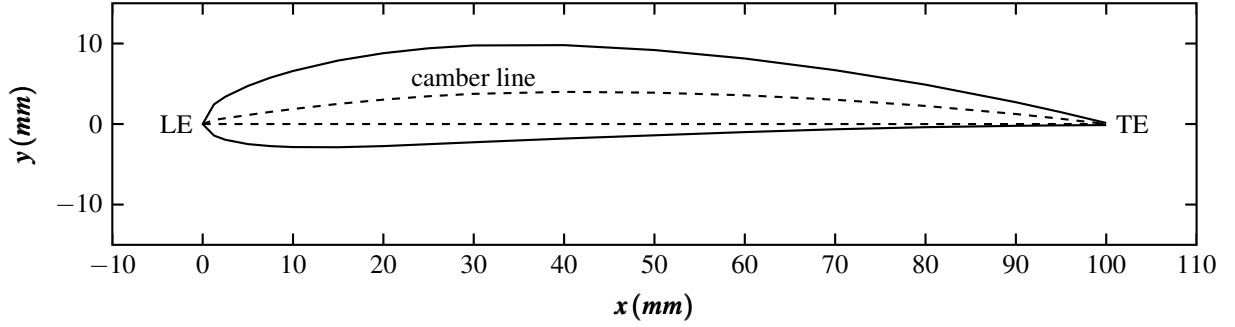


Figure 1: NACA 4412 airfoil geometry.

## 1.2 Simulation Domain

Fig. 2 shows the simulation domain. At left boundary, free stream velocity ( $V_\infty$ ) with angle of attach ( $\alpha$ ), pressure ( $P_\infty$ ) boundary condition at right and no slip condition ( $v = 0$ ) at airfoil surface have been implied. Origin is located at leading edge of the airfoil and x axis is along chord line. Density and dynamic viscosity of air are  $1.184 \text{ kg/m}^3$  and  $1.849 \times 10^{-5} \text{ kg/ms}$  respectively. Free stream velocity corresponding to Reynolds number  $3 \times 10^5$  is  $46.85 \text{ m/s}$ . Angle of attack ( $\alpha$ ) has been varied from  $-5^\circ$  to  $20^\circ$ .

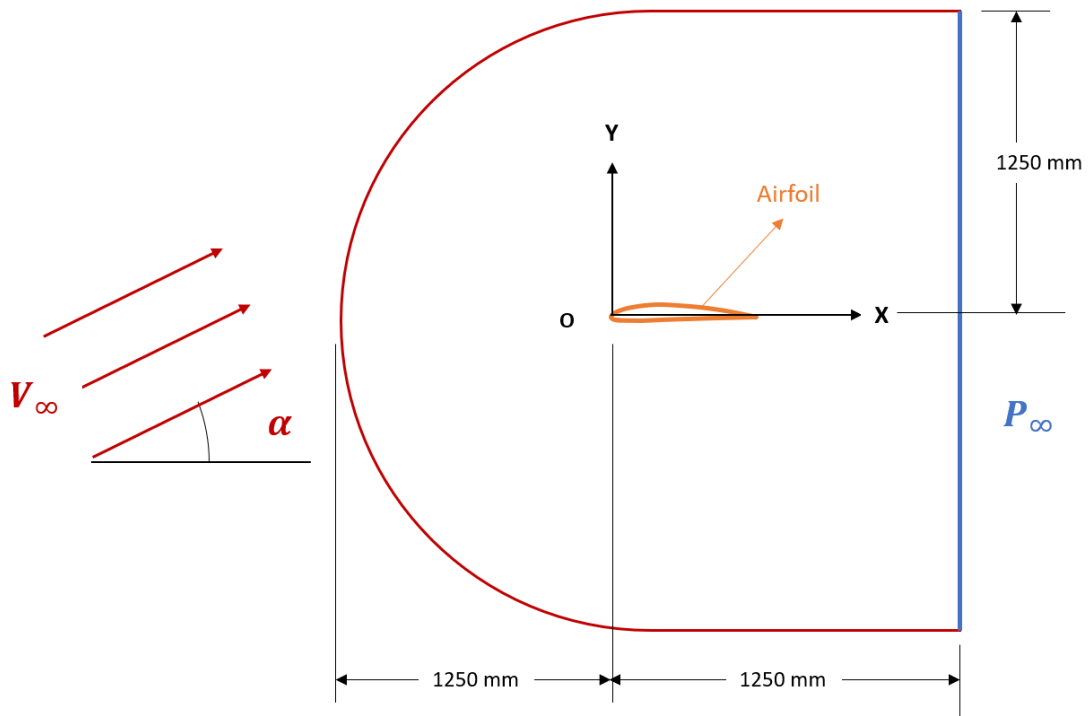


Figure 2: Schematic diagram of simulation domain with boundary conditions

### 1.3 Mesh

Mesh contains three different size of element as shown in Fig 3. Smallest element size is 1% of the chord length near the airfoil surface. Element size is 5% of the chord length within the circle of radius 3 times of chord length which center at origin. At far region from airfoil surface, smallest element size is 2.5% of chord length. Total number of element is 25498.

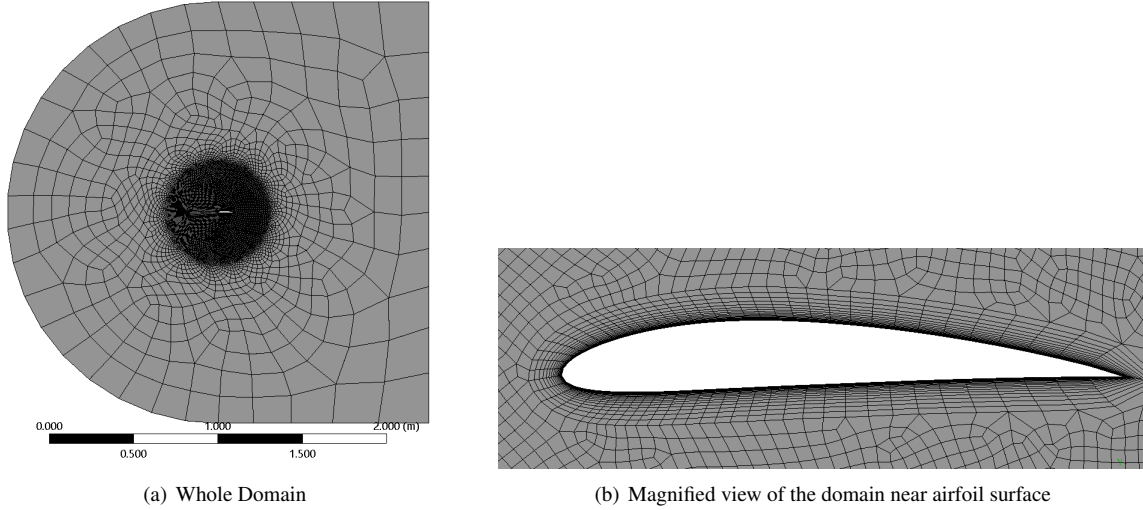
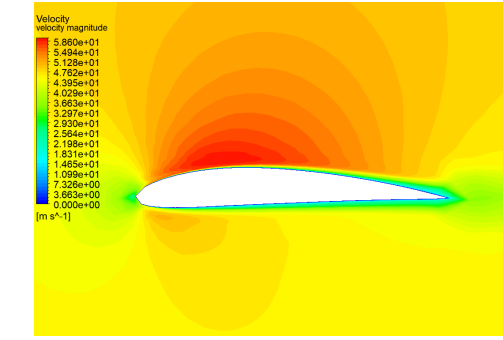


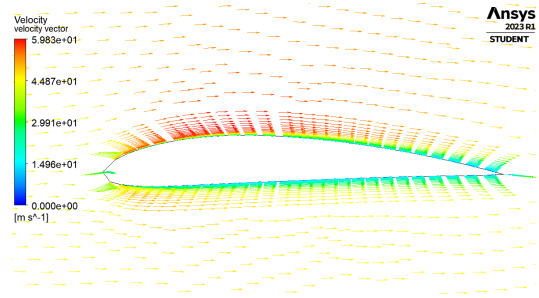
**Figure 3:** Mesh for finite volume analysis

## 2 Result and Discussion

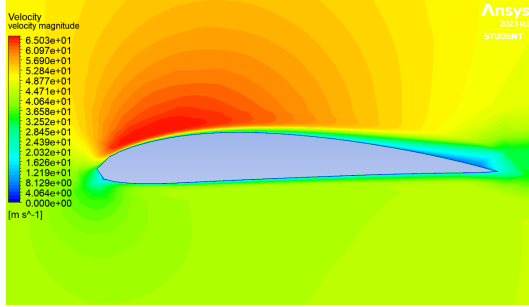
Fig. 4 shows the surrounding flow field of the airfoil at different angle of attack. Low velocity (High Pressure) occurs at bottom surface and high velocity (Low pressure) occurs at top surface of the airfoil. Thus existing pressure difference between upper and lower surface generate lift force. Very thin boundary layer develop at airfoil surface as seen in Fig. 4. It is important to note that flow separation occurs at high angle of attack as shown in Fig. 4. At  $\alpha = 0^\circ$  flow is attached to the airfoil surface. As angle of attack increase, flow become separate at trailing edge of the airfoil and air flow in reverse direction due to adverse pressure gradient at top surface of the airfoil. Flow Separation distance from LE decreases as angle of attack increases. At  $\alpha = 20^\circ$ , flow separation occurs almost at LE of the airfoil.



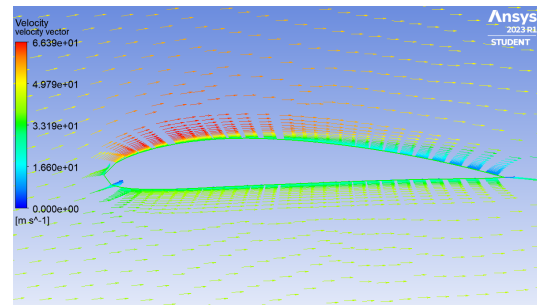
(a)  $\alpha = 0^\circ$



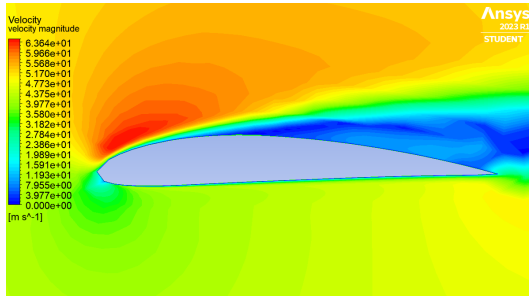
(b)  $\alpha = 0^\circ$



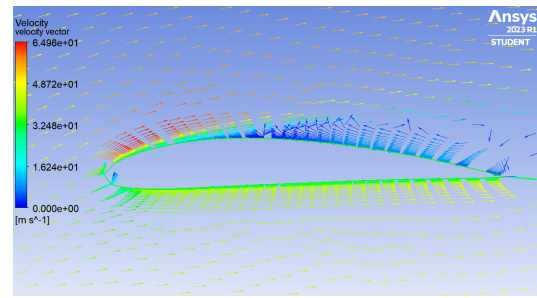
(c)  $\alpha = 5^\circ$



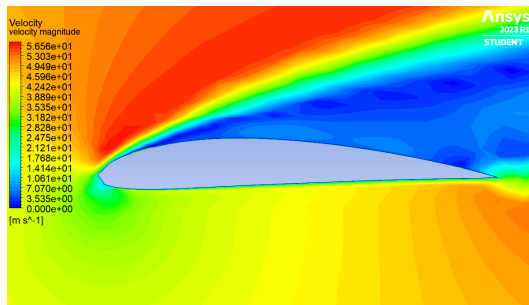
(d)  $\alpha = 5^\circ$



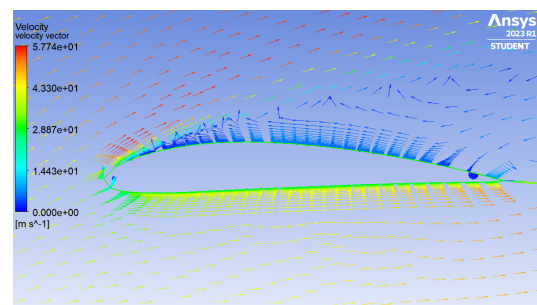
(e)  $\alpha = 10^\circ$



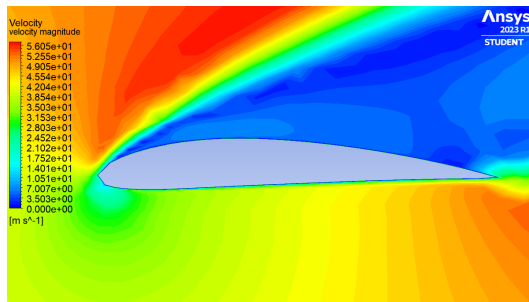
(f)  $\alpha = 10^\circ$



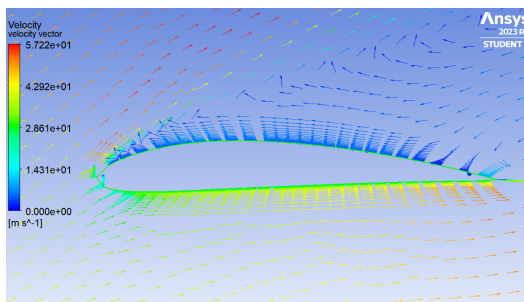
(g)  $\alpha = 15^\circ$



(h)  $\alpha = 15^\circ$



(i)  $\alpha = 20^\circ$



(j)  $\alpha = 20^\circ$

**Figure 4:** Figure depicts the flow field surrounding the airfoil. Left side figures represent velocity magnitude contour and right side figures represent velocity vector at different angle of attack.

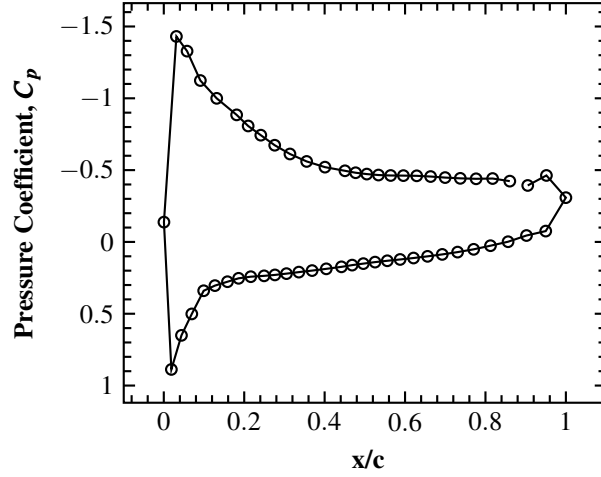


**Figure 5:** Pressure distribution over the NACA 4415 airfoil surface for AOA = 5°

Flow separation reduce lift generation capacity of the airfoil as shown in Fig. 6. Drag and lift coefficient has been defined by the following formula-

$$C_d = \frac{D}{\frac{1}{2}\rho V_\infty^2 c} \quad (1)$$

$$C_l = \frac{L}{\frac{1}{2}\rho V_\infty^2 c} \quad (2)$$

Where,  $C_d$  is drag coefficient,  $C_l$  is lift coefficient,  $L$  is lift force,  $D$  is drag force,  $\rho$  is density of air,  $V_\infty$  is free stream velocity and  $c$  is chord length.

Finite amount of lift produce at 0° angle of attack as shown in Fig. 6. This is due to asymmetric shape of the airfoil. From Fig. 6(a), lift coefficient follows linear curve upto AOA 5° which resembles with thin airfoil theory. After that, flow separation occurs and lift performance decrease with AOA as observed in Fig. 4. Drag

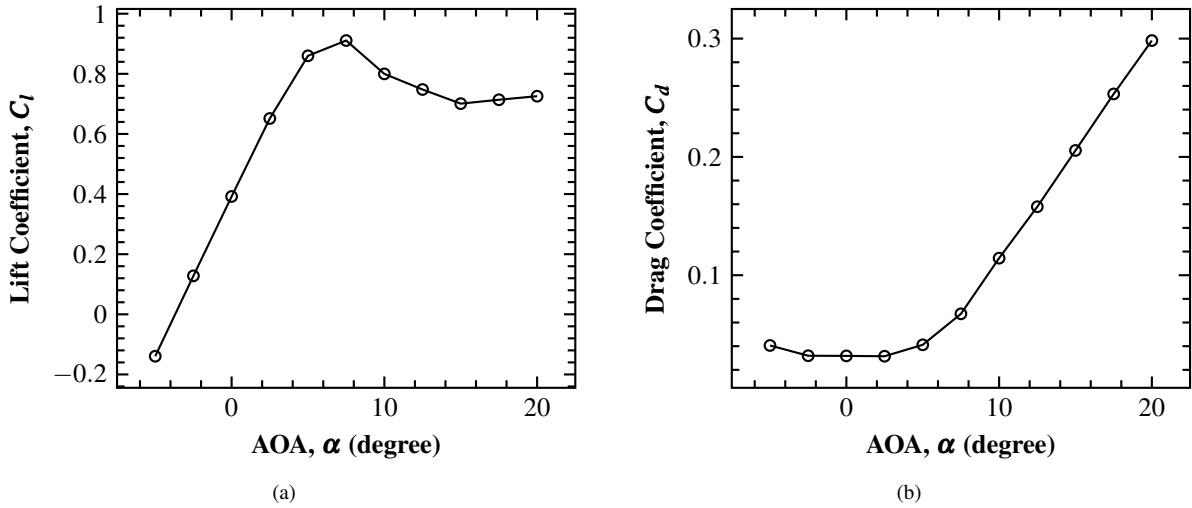


**Figure 6:** (a) Lift characteristics curve of NACA 4412 airfoil ( $Re = 3 \times 10^5$ ) (b) Drag characteristics curve of NACA 4412 airfoil ( $Re = 3 \times 10^5$ )

characteristics is opposite to lift. Drag coefficient almost constant upto 7.5° AOA. After that drag increase rapidly as shown in Fig. 6(b). Fig 7 represents the lift generation relative to drag.

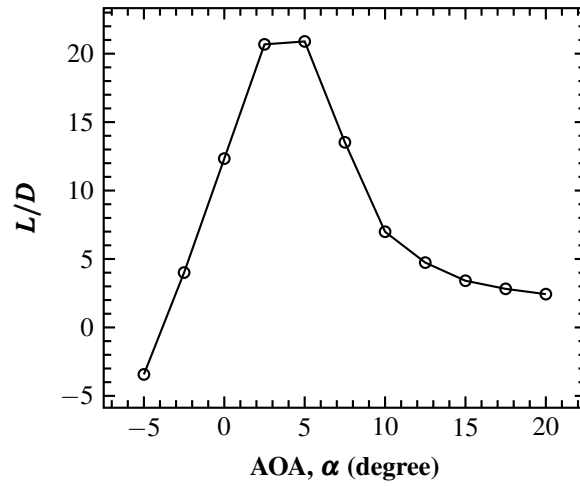


**Figure 7:** L/D characteristics curve for NACA 4415 airfoil

### 3 Conclusion

Performance of NACA 4412 airfoil has been studied using Ansys commercially available CFD software. Stall angle of NACA 4412 is  $7.5^\circ$ - $8.0^\circ$  at  $Re\ 3 \times 10^5$ . Results shows excellent resembles with thin airfoil theory upto AOA  $7.5^\circ$ . It's operating AOA range should be  $0^\circ$  to  $7^\circ$  when free stream velocity is 45 m/s.