Analysis of various NACA airfoil and fabrication of wind tunnel to test the scaled-down model of an airfoil

M Krishna¹, V Thanigaivelan², J Silkson john³, A Joshua ⁴

¹,²,³,⁴Assistant Professor, Department of Mechanical Engineering, SRM Institute of Technology, Ramapuram, Chennai, India
Email: krishnam@srmist.edu.in

Abstract: Airfoil design is a major facet of aerodynamics. Various airfoils serve different flight regimes. Asymmetric aerofoils can generate lift at zero angle of attack, while a symmetric aerofoils exhibit no lift at the same case. The design of the Airfoil has a great influence in the lift provided to an aircraft and the thrust required to make the lift take place. The geometry design of the airfoil is carried through Design Modeler. The analysis work of the airfoil is carried using Ansys Fluent. The coefficient of lift and drag are calculated through constant density throughout the section.

Keywords: Airfoil, geometry design, Design Modeler.

1. Introduction
Any object with an angle of attack in a moving fluid, such as a flat plate, a building, or the deck of a bridge, will generate an aerodynamic force (called lift) perpendicular to the flow. Airfoils are more efficient lifting shapes, able to generate more lift (up to a point), and to generate lift with less drag. The design of the Airfoil has a great influence in the lift provided to an aircraft and the thrust required to make the lift take place.

Figure 1. Shape of the Airfoil and its parts

2. Lift and Drag
The amount of lift and drag provided to an aircraft from the ground can be determined by the flow of air through the aircraft. Lift provides the force to move the aircraft in an upward direction therefore it is vertical while drag is the pull effect that acts on the aircraft along the
horizontal direction. It is important for an aircraft to have greater lift coefficient with respect to that of the drag coefficient. The lift and drag can be determined by the attack of air at the leading edge of the airfoil.

![Figure 2. Lift and Drag of Airfoil](image)

3. Description of Wind tunnel
A wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects. The testing of the objects are done through the use of air as the medium that flows with the help of suction from the fan. The fan sucks the air into the wind tunnel and it is made to pass through a set of parallel placed pipes that help in making the flow streamline. The pipes make the flow of the air constant throughout the test section. The suction speed of the fan determines the flow of air.

![Figure 3. Structure of Wind tunnel](image)

4. Design of Wind tunnel:
The design of the airfoil is made through the use of Siemens NX software with respect to the fabricated airfoil that will be used for physical analysis. The fan section of the wind tunnel is designed in such a way to accommodate the space that will be taken by the fan as well as its blades during its working. The test section is made out of acrylate transparent fiber to showcase the flow of air across the fabricated airfoil.
Section 1 – Honey comb & settling chamber section
Section 2, 3 – Test section
Section 4 – Fan section
5. Calculations for Wind tunnel

To find the density of the air:

\[ \rho = \frac{P}{RT} \]

Where, 
- \( \rho \) = density of the air
- \( P \) = Pressure of the air
- \( R \) = Gas constant
- \( T \) = Temperature

Mass flow rate:

\[ Q = A_2 \sqrt{2(P_2 - P_1) \frac{\rho}{\sqrt{1 - (A_2/A_1)^2}}} \]

Where, 
- \( P_2 \) = Pressure at section 2
- \( P_1 \) = Pressure at section 1
- \( A_2 \) = Area at section 1
- \( A_2 \) = Area at section 2

Where, 
- \( R = 287.05 \) K/Kg
- \( P_a = 101.325 \) Kpa
- \( T = 32 \) C = 305 K

\[ \rho_a = \frac{(101.325 \times 10^3)/(287.05 \times 305)}{1.157 \text{ kg/m}^3} \]

It can be assumed that the flow rate of the air between the section 2 (Area) and section 3 (Area) of the wind tunnel to be constant as the velocity remains the same.

Since, \( A_2 = A_3 \)

\[ A_2 \times V_2 = A_3 \times V_3 \]

Therefore, Velocity at section 2 and section 3 will remain the same. As the velocity remain the same, the pressure will also remain same throughout the section 2 and 3.

\[ P_2 = P_3 \]

The volume will also remain the same since pressure remains same. The length of the aero foil used is of 47cm = 0.47 m. Area of the section 2 and 3 = 0.47 *h
h being the height of the section 2 and 3. It should be low to compensate the air flow throughout the section at a higher rate.

\[ \frac{A_2}{A_3} = 0.47 \times 0.3 \]
\[ A_2 = A_3 = 0.141 \text{ m}^2 \]

We know that the pressure at section 2 should be greater than that of section 1. Assume the pressure at section 2 being constant and is equal to the atmospheric pressure

\[ P_a = 101.325 \text{ Kpa} \]

The area of section 1 should be greater than the area of section 2. The flow rate (m^3/min) should remain constant between the section. Taking the area of Section 1 (A1) to be of a square cross-section of side length 62.5 cm = 0.625 m

\[ A_1 = 0.625 \times 0.625 \]
\[ A_1 = 0.3906 \text{ m}^2 \]

Assume the mass flow rate to be Q = 100 m^3/min. Using the mass flow rate formula,

\[ P_2 = 354.390 \text{ Kpa} \]

The pressure that will be present when the air reaches the far section (section 4)

Since, section 2 and section 3 remain constant

\[ P_2 = P_3 \]
\[ P_3 = 354.390 \text{ Kpa} \]
\[ A_2 = 0.141 \text{ m}^2 \]
\[ A_3 = 0.141 \text{ m}^2 \]

Using the same mass flow rate formula to find the pressure of air at section 4. Let us assume the value of A4 to be less than that of the entry section of the wind tunnel. So, the pressure drop should be low as well.

\[ P_4 > P_1 \]

Assuming the area of far section to be a square, then the dimensions being less than the dimension of the entry.

\[ A_4 = 0.6 \times 0.6 \]
\[ A_4 = 0.36 \text{ m}^2 \]

Using the mass flow rate formula,

\[ P_4 = 108046 \text{ Pa} \]
\[ P_4 = 108.460 \text{ Kpa} \]

The test section will have same pressure throughout it as the area remains the same. Since, area and pressure remain constant, the place where aero foil is kept doesn’t matter. In terms of visibility, the air foil is kept at a place so the flow of air will be visible outside.

6. Airfoil Description

An airfoil-shaped body moved through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. Some important parameters to describe an airfoil’s shape are its camber and its thickness.

The NACA four digit wing sections define the profile by:
1. 1 digit describes the max camber as % of the chord
2. 1 digit describes the distance of max camber from the airfoil leading edge in tens of % of the chord
3. 2 digits describes max thickness of the airfoil as % of the chord.

For example, an airfoil of the NACA 4-digit series such as the NACA 2415 (to be read as 2 – 4 – 15) describes an airfoil with a camber of 0.02 chord located at 0.40 chord, with 0.15 chord of maximum thickness.
7. Modelling and Simulation:
The analysis is carried out in NACA 4412, NACA 2412 airfoil sections. The geometry coordinates for the airfoil section is taken from the directory to form a spline curve. The mesh is completed on the airfoil.
The mesh is used to make named sections for the analysis of the airfoil. The semicircle being the inlet section and the plain surface at the end being outlet section. The airfoil is placed in the center which is observed through the figure that is shown below.

![Complete Mesh of NACA 4412 airfoil](image1)

**Figure 5.** Complete Mesh of NACA 4412 airfoil

![Complete Mesh of NACA 2412 airfoil](image2)

**Figure 6.** Complete Mesh of NACA 2412 airfoil

8. Lift Coefficient and Drag Coefficient for NACA4412:
The contours display the pressure and velocity with respect to the airfoil due to the flow of air through it. It can be seen that the pressure is higher in the leading edge of the airfoil and that the velocity in the upper section of the airfoil is higher with respect to the lower section of the airfoil.
The below contours display the temperature and density scale across the NACA 4412 airfoil. The point where air contacts the airfoil has the highest temperature due to the resistance provided by the airfoil to the flow of air, same goes to the trailing edge of the airfoil. Density contour is dependent of the static pressure acting in the airfoil.

\[
\begin{align*}
L &= C_l \times \frac{\rho \times V^2 \times A}{2} \\
D &= C_d \times \frac{\rho \times V^2 \times A}{2}
\end{align*}
\]

Fluent Observations for NACA4412 airfoil:

Lift Coefficient \((C_l) = 0.3949\)
Drag Coefficient \((C_d) = 0.0184\)
The velocity at the inlet was taken as 2 m/s.
Minimum Velocity = 0 m/s
Maximum Velocity = 3.471 m/s
\[
\begin{align*}
L &= 0.3949 \times 1.17669 \times (3.471)^2 \times 2.0678 \\
D &= 0.0184 \times 1.17669 \times (3.471)^2 \times 2.0678
\end{align*}
\]

Lift = 5.7829 N (Scale 0.01)

\[
D = 0.0184 \times 1.17669 \times (3.471)^2 \times 2.0678
\]
Drag = 0.265 N (Scale 0.01)

10. **Lift Coefficient and Drag Coefficient for NACA2412:**
The pressure and velocity contours with respect to the airfoil due to the flow of air is shown in the figures below. It can be seen that the pressure is higher in the leading edge of the airfoil and that the velocity in the upper section of the airfoil remains the same as that of the velocity with the lower section of the airfoil. This states that the lift and drag produced by the airfoil at 0 degree angle of attack is very small and close to zero.

![Figure 11. Static Pressure across NACA2412](image1)

![Figure 12. Velocity across NACA2412](image2)

The below contours display the density and temperature scale across the NACA 2412 airfoil. The point where air contacts the airfoil has the highest temperature due to the resistance provided by the airfoil to the flow of air, same goes to the trailing edge of the airfoil. The contours of both the density and the temperature are very similar as they are inter dependent.

![Figure 13. Density across NACA2412](image3)

![Figure 14. Temperature across NACA2412](image4)

**Fluent Observations for NACA2412 airfoil:**

- Lift Coefficient ($C_L$) = 0.0495
- Drag Coefficient ($C_D$) = 0.0551
- The velocity at the inlet is taken as 2 m/s
- Minimum Velocity = 0 m/s
Maximum Velocity = 3.471 m/s

\[ L = \frac{0.0495 \times 1.17669 \times (3.471)^2 \times 2.06215}{2} \]

Lift = 0.7235 N (Scale 0.01)

\[ D = \frac{0.0551 \times 1.17669 \times (3.471)^2 \times 2.06215}{2} \]

Drag = 0.8054 N (Scale 0.01)

The Lift and the Drag coefficient of both the NACA 4412 and NACA 2412 airfoil are used to get the Lift and Drag force that is produced by the flow of air across the airfoil in terms of newton as the entire airfoil section is scaled down to 0.01 of the original size of the model. The velocity taken is also 2 m/s as the model is scaled down to about 0.01 of its original size.

11. Conclusion
As the shape of the airfoil is considered as one of the main factors contributing to the fundamental flight of an aircraft, it is very important that the airfoil used in the design of the aircraft provides greater lift to it than drag. Since the lift and drag provided to the aero foil is heavily dependent on the amount of air that is passed through its shape, the shape of aero foil under different NACA configurations are tested for the lift coefficient and drag coefficient. Through the above calculations and observations it can be found that the NACA 4412 airfoil provides more lift as compared to the lift produce by the NACA 2412 airfoil.

The drag should be lower for better efficiency of the aircraft using the airfoil design for its wing. The drag calculated for NACA 4412 airfoil is lower than drag produced by the NACA 2412 airfoil. This explanation states that the NACA 4412 airfoil is better with respect to NACA 2412 airfoil. Through the fluent testing, the lift and drag forces across a wing of NACA type’s airfoil shape were calculated.

References
[1] S.Kandwal, Dr. S. Singh "Computational Fluid Dynamics Study of Fluid Flow and Aerodynamic Forces on an Airfoil" IJERT, Vol. 1 Issue 7, September – 2012.
[2] Nathan logsdon A procedure for numerically analyzing airfoils and Wing sections The Faculty of the Department of Mechanical & Aerospace Engineering University of Missouri – Columbia, December 2006.
[3] Mayurkumar kevadiya 2D analysis of NACA 4412 airfoil International Journal of Innovative Research in Science, Engineering and Technology, Department of Mechanical Engineering, Government College of Engineering, Valsad, Gujarat, India – May 2013
[4] Shivananda sarkar, Shaheen beg mughal CFD analysis of effect of flow over naca 2412 airfoil through the shear stress transport turbulence model International Journal of Mechanical And Production Engineering, ISSN: 2320-2092, Volume- 5, Issue-7, Jul.-2017
[5] Liyana Kharulaman, Abdul Aabid, Fharukh Ahmed Ghasi Mehaboobali, Sher Afghan Khan Research on Flows for NACA 2412 Airfoil using Computational Fluid Dynamics Method International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-9 Issue-1, October 2019
[6] Csaba Hetyei Ildikó Molnár Ferenc Szlivka Comparing different CFD software with NACA 2412 airfoil Progress in Agricultural Engineering Sciences