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Research Paper

EXPERIMENTAL AND CFD ANALYSIS OF AIRFOIL AT LOW REYNOLDS NUMBER

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The determination of lift and drag of airfoil from wind tunnel measurements is discussed for incompressible flow. Calculated the upper and lower surface pressure and velocity of an airfoil is essential for calculating the forces on it. The Effects of model support are neglected. No simplifying assumptions on the flow along the test section walls are made. The purpose of load measurements on the model is to make available the forces and moments so that they may be corrected for tunnel boundary and utilized in predicting the performance of the full-scale vehicle or other device at different angle of attack from 0° to 20° and at maximum velocity 15 m/s. Airfoil analysis of the airfoil at low Reynolds no. and comparing experimental results and cfd results.

Keywords: Airfoil, Angle of attack, CFD, Low reynolds no., Wind tunnel

INTRODUCTION

Lift and Drag are considered aerodynamic forces because they exist due to the movement of the aircraft through the air. The weight pulls down on the plane opposing the lift created by air flowing over the wing. Thrust is generated by the propeller and opposes drag caused by air resistance to the frontal area of the airplane. During takeoff, thrust must overcome drag and lift must overcome the weight before the airplane can become airborne. In level flight at constant speed, thrust exactly equals drag and lift exactly equals the weight or gravity force.

The purpose of load measurements on the model is to make available the forces and moments so that they may be corrected for tunnel boundary and utilized in predicting the performance of the full-scale vehicle or other device. Today, every time a new model of an airplane, automobile or railroad vehicle is introduced, the structure is designed to be lighter to attain faster running speed and less fuel consumption. It is possible to design a lighter and more efficient product by selecting lighter materials and making them thinner for use. But the safety of the product is

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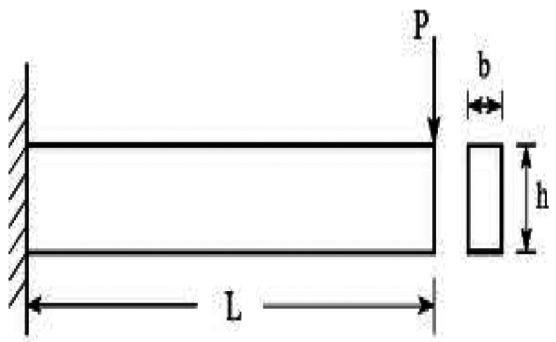
compromised unless the required strength is maintained. By the same token, if only the strength is taken into consideration, the weight of the product increases and the Economic feasibility is impaired. We are using pressure distribution method and by using strain gauge is developed Setup for the measurement of the lift and drag forces for an airfoil (Jewel, 1999).

Computational Fluid Dynamics (CFD) is one of the branch of fluid mechanics that uses numerical methods and algorithm to solve and analyze problems that involve fluid flow and heat transfer. CFD is an art of replacing the integrals or partial derivatives in the equations governing the fluid flow with discretized algebraic form, which in turn are solved to obtain numbers for the flow field in contrast to a closed form analytical solution (Anderson, 1995). Using CFD the complex flow behavior can be clearly visualized, which will be helpful to redesign and improve the efficiency of the equipment. Advances in CFD and its wide applications are proving for its stability. Hence CFD technique can be applied for analysis lift force and drag force over the testing model.

Figure 1: Cantilever Beam Load at Free End



EXPERIMENTAL SETUP

Set Up by Using Strain Gauges

The experimental setup is done by using strain gauges on the cantilever beam (Figures 1 and 2) (Khurmi, 1999).

Deflection of Beam δl is equal to

$$\delta l = \frac{wl}{3EI} \quad ...(1)$$

Moment of the inertia for rectangle

$$I = \frac{bd^3}{12} \quad ...(2)$$

Pressure Coefficient (Gordon, 1987).

At any point in the flow where the local pressure coefficient C_p is defined as

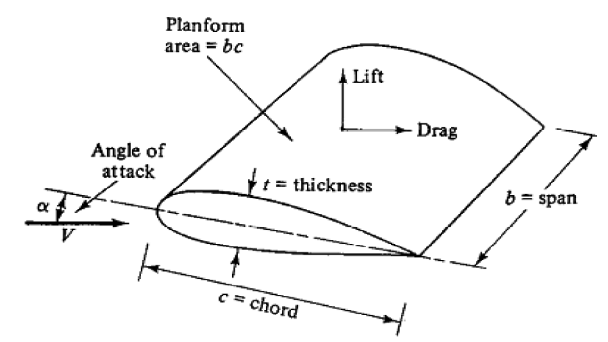
$$C_p = \frac{p - p_{atm}}{\frac{1}{2}\rho_\infty U_\infty^2} \quad ...(3)$$

Figure 2: Photograph of the Cantilever Beam With Setup

Setup by Pressure Distribution Method

The Total or Stagnation Upstream Pressure P_T as Measured by an impact probe (e.g., a Pitot tube) is the sum of the static and dynamic pressure at that point i.e.,

Figure 3: Geometric and Dynamic Parameters of Airfoils



$$P_T = P_\infty + \frac{1}{2}\rho U_\infty^2 \qquad \text{...(4)}$$

Thus, C_P may also be written in terms of the differential pressures

$$C_P = \frac{P - P_\infty}{P_T - P_\infty} \qquad \text{...(5)}$$

The presence of the airfoil in the test section will affect the test section velocity, e.g., at a 15^0 angle of attack the local velocity over the airfoil will increase to about 1.02 times the upstream. The lift force is customarily expressed as a dimensionless lift coefficient per unit span length.

Coefficient of Lift Force

$$C_L = \frac{2L}{\rho U_\infty^2 bc} \qquad \text{...(7)}$$

$$C_L = \frac{s\int (p_i - p_\infty)\sin(\theta)ds}{\frac{1}{2}\rho U_\infty^2 c} \qquad \text{...(8)}$$

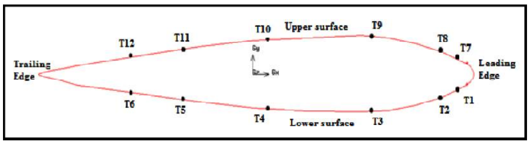
Coefficient of Drag force

$$F_D = \frac{1}{2}\rho v^2 C_D A \qquad \text{...(8)}$$

Wind Tunnel Testing of an Airfoil

A rectangular wing airfoil model having chord length 252 mm, span 227 mm and aspect ratio 0.9 used for measurement of pressure distribution over upper and lower surface. The pressure tapings were made along the chamber line with successive percentage of chord length (Schneemann *et al.*, 2010).Small holes were drilled with 1/64" drill in a direction perpendicular to the surface and up to camber line of airfoil. From bottom surface drills of 1/16" were drilled to match with the above holes. The pressure tapings and tap numbers on aerofoil are as shown in Figure 4.

Figure 4: Aerofoil and Pressure Tapings



Tygon tubes are inserted in these tap holes for measurement of gauge pressure by connecting with multi-tube manometer.

Table 1: Aerofoil Surface Coordinates

Tap Number	X/C (%)	Surface Y/C (%) Upper	Surface Y/C (%) Lower
Leading Edge	0.0	8.00	7.0
Point 1 and 7	4.0	10.80	4.0
Point 2 and 8	8.0	12.00	3.0
Point 3 and 9	24.0	14.80	0.9
Point 4 and 10	49.2	14.60	1.0
Point 5 and 11	68.8	11.20	2.3
Point 6 and 12	82.0	10.10	3.9
Trailing Edge	100.0	7.20	7.1

EXPERIMENTAL ANALYSIS

Results for the Coefficient of Pressure

- Coefficient of pressure at velocity 15 m/s at various Angle Of Attack 0 to 20 Degree.
- Results for velocity ratio V/Vinfinity for velocity at 15 m/s.

Figure 5: Coefficient of Pressure at Velocity 15 m/s at Various Angle of Attack 0 to 20 Degree

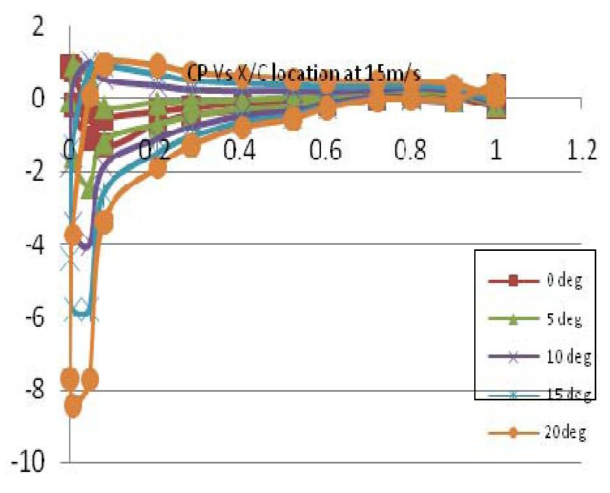


Figure 6: Coefficient of Pressure on Upper Surface at Velocity 15 m/s at Various Angle of Attack 0 to 20 Degree

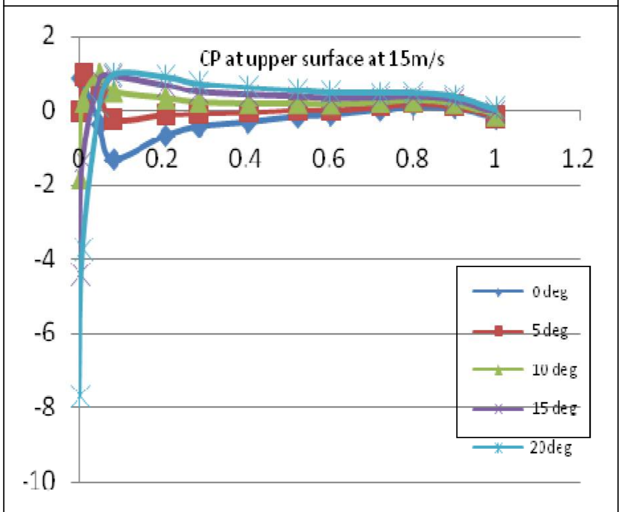


Figure 7: Coefficient of Pressure on Lower Surface at Velocity 15 m/s at Various Angle of Attack 0 to 20 Degree

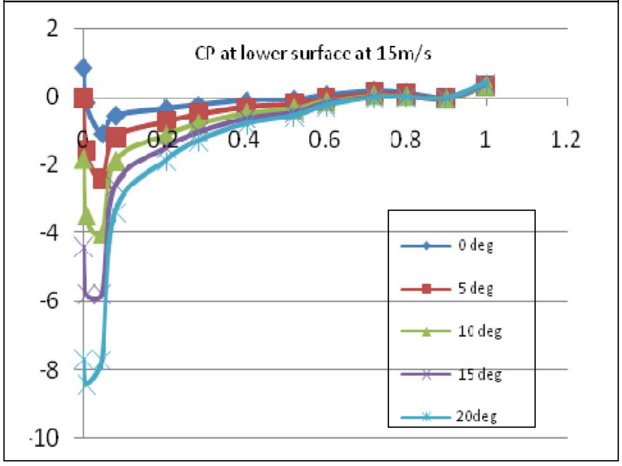


Figure 8: Velocity Ratio vs. X/C Location of an Airfoil

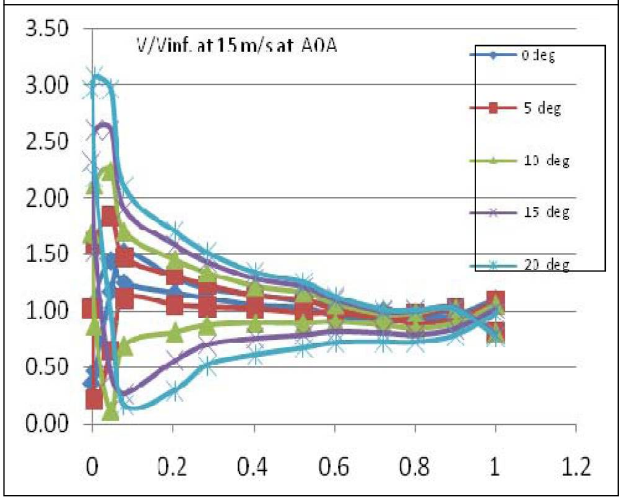


Figure 9: Shows the Velocity Ratio at Upper Surface of an Airfoil

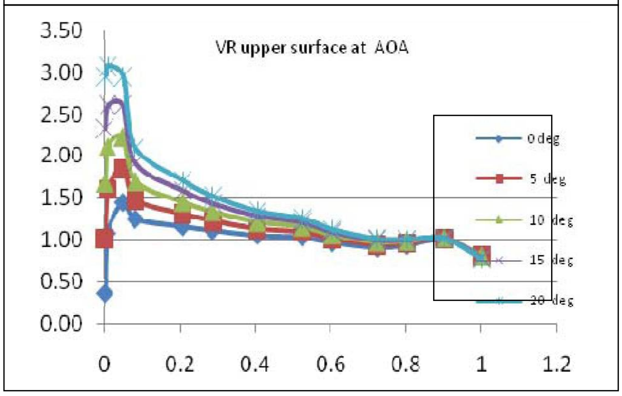


Figure 10: Shows the Velocity Ratio at Lower Surface of an Airfoil

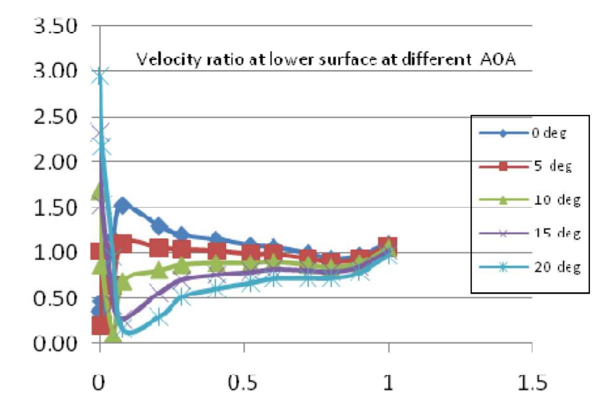
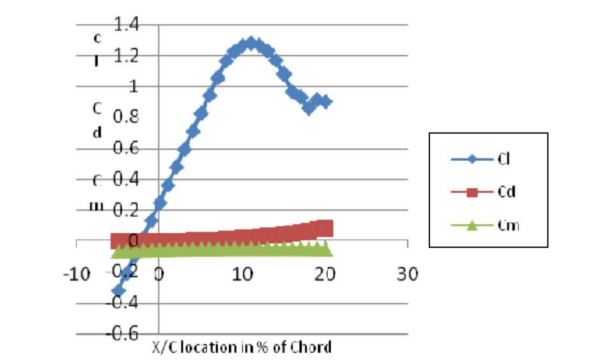


Figure 11: Shows the Coeff. of Lift, Coeff. of Drag and Coeffi. of Moment vs. X/C Location of an Airfoil



RESULTS OF CFD ANALYSIS (VIJAY KORE, 2011)

Figure 12: Shows that Pressure Distribution Over the Airfoil at Velocity 12 m/s Angle of Attack 10 Degree Contours of Static Pressure (Pascal)

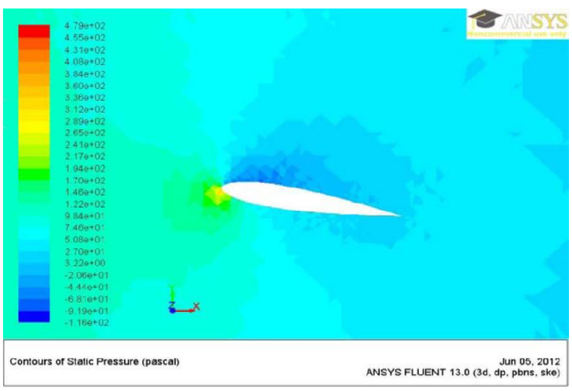


Figure 13: Shows that Pressure Distribution Over the Airfoil at Velocity 12 M/S Angle of Attack 10 Degree Contours of Dynamic Pressure (Pascal)

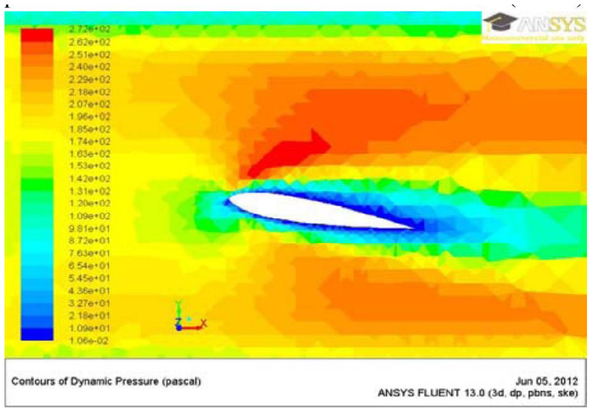


Figure 14: Shows that Pressure Distribution Over the Airfoil at Velocity 12 M/S Angle of Attack 10 Degree Contours of Total Pressure (Pascal)

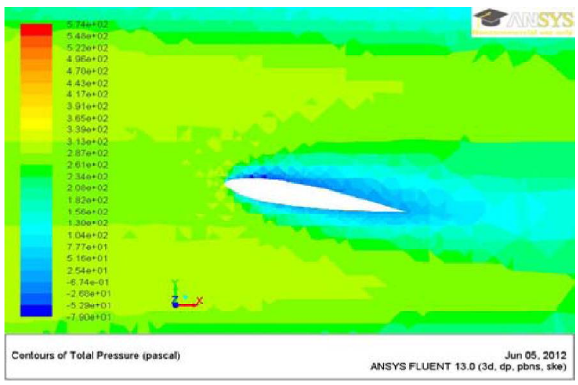


Figure 15: Shows that Velocity Distribution Over the Airfoil at Velocity 12 M/S Angle of Attack 10 Degree Contours of Velocity Magnitude (M/S)

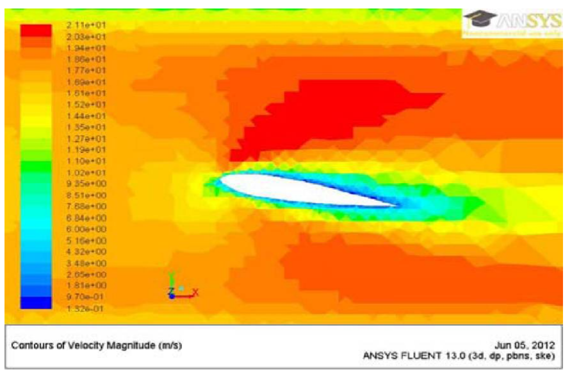


Figure 16: Shows that Contours of Pressure Coefficient Over the Airfoil at Velocity 12 M/S Angle of Attack 10 Degree

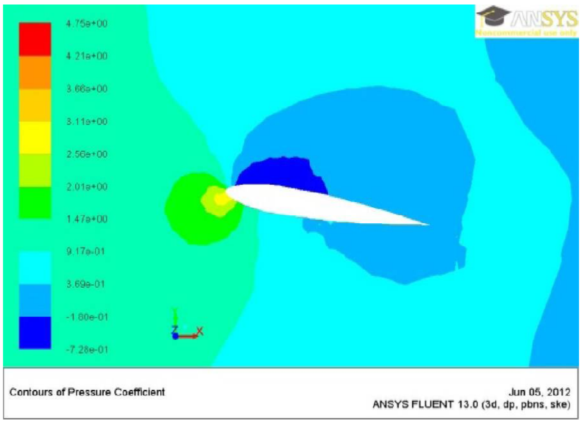
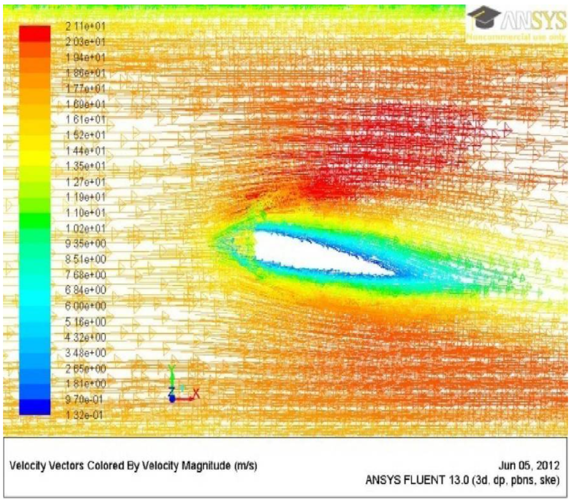


Figure 17: Shows the Velocity Vector Diagram at Velocity 12 M/S at Angle of Attack 10 Degree



CONCLUSION

The coefficient of pressure is analyzed in the upper and lower surface of the airfoil for the angle of attack varies from 0° to 10°. The results showed that the upper surface has lower negative coefficient of pressure at higher angle of attack and lower surface has lower negative coefficient of pressure at lower angle of attack.

The results demonstrate the pressure distribution over the airfoil. The pressure on the lower surface of the airfoil is greater than that of the incoming flow stream and as a result of that it effectively pushes the airfoil upward, normal to the incoming flow stream. On the other hand, the components of the pressure distribution parallel to the incoming flow stream tend to slow the velocity of the incoming flow relative to the airfoil, as do the viscous stresses.

The Coefficient of lift and coefficient of drag of an airfoil is depends upon the pressure distribution and velocity distribution of an airfoil.

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APPENDIX

Abbreviations and Acronyms	
C	Chord
b	Span
u	Velocity
C_d	Coefficient of Drag
C_l	Coefficient of Lift
C_P	Coefficient of Pressure
L	Lift
D	Drag
Re	Reynolds Number
u_∞	Free Stream Velocity
α	Angle of Attack
ρ	Density