Experimental Investigations of Aerodynamic Performances of S9023 Airfoil

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Abstract: In the present work, it’s proposed to study the aerodynamic characteristics of the S9023 airfoil for the various angle of attack with different Reynolds number. With a view to extending the knowledge of the aerodynamics of pressure distribution and lifting surfaces over S9023 airfoil has been measured in a low-speed subsonic wind tunnel. Experiments were carried out by varying the angle of attack, from 0° to 15° and the Reynolds number ranges from 1.3 X 10^5 to 4.5 X 10^5. The lift coefficient and drag coefficients for S9023 airfoil are obtained by measuring the pressure distribution from the pressure ports which is situated over the airfoil surface. The aerodynamics parameters at different Reynolds number is plotted i.e. C_p vs. x/c, C_p vs. y/c, C_l vs. α, C_d vs. α and L/D vs. α. The non-dimensional aerodynamics characteristics for S9023 2D airfoil described in details for different Reynolds number.

Key Words: Pressure distribution, Wind tunnel experiment, Aerodynamic characteristics.

1. INTRODUCTION:

In this work, the wind tunnel experiments explore the effect of non-dimensional aerodynamic forces on an airfoil at different Reynolds number. An airfoil is the cross-section of a wing. Studying the aerodynamic performance of a wing is quite a tedious job since it requires more time. So, in this work considered the cross-sectional area of the wing and study its aerodynamic characteristics which invariably helps to understand the aerodynamic characteristic of the whole wing. The aerodynamic forces acting on the airfoil lift, drag, thrust and gravitational force (i.e., weight of the aircraft). [1] The shape of the airfoil makes the air molecules on the upper surface of the airfoil move faster than those at the lower surface resulting in relatively higher pressure on the lower surface than on the upper surface. This pressure difference on the upper and lower surfaces of the airfoil creates lift on the airfoil. In this paper describes how the angle of attack changes the amount of non-dimensional aerodynamic forces on the airfoil experiences. To study the effect of velocity on non-dimensional aerodynamic forces, if the AOA is kept constant and velocity increased which may lead to increase in lift and lift as a function of velocity. The non-dimensional aerodynamic forces are the function of dimensionless parameters such as Reynolds number (Re), Mach number (Ma), Froude number (Fr) and relative roughness of the surface (ε/l). [2]
METHOD TO MEASURE DRAG AND LIFT FORCE:

There is a variety of ways to measure lift. In this experiment, the lift force, \( L \), on the airfoil will be determined by integration of the measured pressure distribution over the airfoil surface. Typical pressure distribution on an airfoil and its projection on the airfoil normal are shown in figure.

A body immersed in a flowing fluid is exposed to both pressure and viscous forces. The sum of the forces that acts normal to the free-stream direction is the lift, and the sum that acts parallel to the free-stream direction is the drag. This experiment is concerned with computation of the lift on a stationary airfoil mounted in the test section of a wind tunnel. We will consider only two-dimensional airfoil where tip and root effects are neglected.

Because the velocity of the flow over the top of the airfoil is greater than the free-stream velocity, the pressure over the top is negative. This follows directly from the application of Bernoulli’s equation. Similarly the velocity along the underside of the airfoil is less than the free-stream velocity and the pressure there is positive. Hence, both the negative pressure over the top and the positive pressure along the bottom contribute to the lift. [4]

The lift force is customarily expressed as a dimensionless lift coefficient per unit span length

\[
C_l = \frac{L}{\frac{1}{2} \rho V^2 bc}
\]

Where \( L \) is lift force on the airfoil obtained by integration of the measured pressure distribution over the airfoil surface, \( b \) is the airfoil span, and \( c \) is the airfoil chord.

The purpose of this report is to present a non-dimensional aerodynamic forces and pressure distribution over an S9023 airfoil at different flight conditions. The Coefficient of lift and coefficient of drag of an airfoil is depends upon the pressure distribution and velocity distribution of an airfoil.

2. WIND TUNNEL EXPERIMENTAL SETUP:-

Figure 1 shows the wind tunnel setup, the tests will be conducted using Low-Speed Wind Tunnel. This wind tunnel has a test section area of 0.6 m x 0.6 m x 1.25 m. It is a suction type tunnel, equipped with a 3-component balance, capable of measuring lift force, drag force, and pitching moment. Hence, an
S9023 airfoil prototype model used for the tests. The detail specification of the wind tunnel as follows in Table 1.

![Wind Tunnel Image](image)

**Figure 1.** Low speed subsonic wind tunnel (Testing Equipment) is exciting in Dept. of Aeronautical Engineering, Acharya Institute of Technology, Bengaluru.

| Table 1. Wind tunnel specifications |
|------------------------------------|
| **Type of Tunnel**                 | Low speed (subsonic), Open circuit, Suction type |
| Test Section                       | 0.6 m X 0.6 m X 1.25 m cross section |
| Air Speed                          | Up to 50 meters/sec (Continuously variable) |
| Contraction Ratio                  | 11 : 1 |
| Drive                              | Axial Flow Fan driven by DC Motor with Thyristore speed controller. |
| Overall Size                       | 9 meters (L) x 2.2 meter (B) x 2.5 meters (H) (Approximately) |
| Power Requirement                  | A.C. 3 ph. 440 volts, 70 Amps Electrical supply with Neutral & Earth Connections. |
| Material of Construction           | Effuser, Diffuser (Wood) |
| Blower frames & Supporting frame   | M.S. Construction |

Experiments were carried out by varying the angle of attack, from $0^\circ$ to $15^\circ$ and the Reynolds number ranges from $1.3 \times 10^5$ to $4.5 \times 10^5$.

**Method of Measure Drag and Lift Forces**

There are many ways to measure non-dimensional aerodynamic forces. In this experiment, the lift and drag force over the airfoil measured by investigation of the measured pressure distribution over the S9023 airfoil surface. Typically pressure distribution on an airfoil and its projection on the S9023 airfoil as shown in Figure 2.
Figure 2. S9023 Airfoil Model and Geometry

A rectangular wing airfoil model having chord length 190 mm, span 580 mm used for measurement of pressure distribution over upper and lower surface. The 12 pressure tapings and small holes were drilled in a direction perpendicular to the surface of the airfoil. The pressure tapings and tap numbers on aerofoil are as shown in Figure 2.

\[ Re = \frac{\rho V c}{\mu} \]

Where \( \rho = 1.22 \text{ kg/m}^3 \), \( V = 10, 15, 20, 25 \text{ m/s} \), chord \( (c) = 190 \text{ mm} \), \( \mu = 1.78 \times 10^{-5} \)

Case – 1: \( V = 10 \text{ m/s}; Re = 130225 \)
Case – 2: \( V = 15 \text{ m/s}; Re = 195337 \)
Case – 3: \( V = 20 \text{ m/s}; Re = 260450 \)
Case – 4: \( V = 25 \text{ m/s}; Re = 325562 \)
Case – 5: \( V = 30 \text{ m/s}; Re = 390675 \)
Case – 6: \( V = 35 \text{ m/s}; Re = 455787 \)

3. RESULT AND DISCUSSIONS:-

3.1. Pressure Distribution:-

Figure 3 to 6 shows the measured surface pressure distributions around the S9023 airfoil as the angle of attack of changing from 0\(^{\circ}\) to 15\(^{\circ}\) along both the increasing and decreasing branches of the hysteresis loop. It can be seen clearly that, the surface pressure distribution for the case of \( Re = 130225 \) was found to reach its negative peak at 0\(^{\circ}\) angle of attack as compared to the other cases. Figure 4 to 6, while the surface pressure distributions on the S9023 airfoil upper surface do not change very much, the surface pressure distributions on the airfoil lower surface were found to vary significantly for the same angles of attack.
Figure 3. Pressure Distribution over S9023 airfoil for 0\(^\circ\) angle of attack

Figure 4. Pressure Distribution over S9023 airfoil for 5\(^\circ\) angle of attack
3.2. Non-dimensional Aerodynamic Forces:

Table 2 shows the non-dimensional aerodynamic force coefficients such as lift coefficient, drag coefficient and L/D ratio for all the cases for the different angle of attack at various velocity i.e. 10, 15, 20, 25, 30 and 35 m/s using wind tunnel experimental data.

| Angle of Attack | Lift Coefficient (C_l) |
|-----------------|------------------------|
|                 | Re = 130225            | Re = 195337            | Re = 260450            | Re = 325562            | Re = 390675            | Re = 455787            |
| 0               | 1.1608                 | 0.172305               | 0.39925                | 0.2873                 | 0.5033                 | 0.3846                 |
| 5               | 1.7964                 | 2.2145                 | 2.0894                 | 2.3053                 | 1.801                  | 2.5935                 |
| 10              | 2.641519               | 2.744224               | 2.547259               | 3.41212                | 2.593269               | 3.828144               |
| 15              | 3.57327                | 3.529925               | 3.269963               | 3.578925               | 3.318209               | 3.60231                |
Figure 7 shows the variation of the coefficient of lift versus angle of attack for all the cases for the different angle of attack at various velocity i.e. 10, 15, 20, 25, 30 and 35 m/s. The plot shows very clearly that, the case - 6 (Re = 455787) gives more lift as compared to the other cases. Based on the wind tunnel results, the maximum lift coefficient various from case 1 to 6 are 9.5% and the maximum drag coefficient varies from case 1 to 6 are 9.19%.

Figure 7. Lift coefficient versus angle of attack for all the cases
Figure 8 shows the variation of drag coefficient versus angle of attack for S9023 airfoil and the plot shows a very good correlation between the six cases i.e. the Reynolds number ranges from $1.3 \times 10^5$ to $4.5 \times 10^5$. The plot shows that the solution obtained from the six different cases the maximum variation of drag coefficient as 44%.

![Drag Curve](image)

**Figure 8. Drag coefficient versus AOA**

Figure 9 shows the Lift/Drag versus angle of attack for S9023 airfoil and the plot shows a very good correlation between the six cases i.e. the Reynolds number ranges from $1.3 \times 10^5$ to $4.5 \times 10^5$. The plot shows that the solution obtained from the six different cases the maximum variation of lift/drag ratio as 0.08%.

![L/D Curve](image)

**Figure 9. Drag coefficient versus AOA**
4. CONCLUSIONS FROM THE S9023 AIRFOIL STUDY IN WIND TUNNEL:--

This experiment demonstrate the non-dimensional aerodynamic forces of lift coefficient and drag coefficient those acts on an airfoil through the measured pressure distribution over the airfoil surface. As a result, the drag coefficient and lift coefficient characteristics for S9023 airfoil of varying Reynolds number and angle of attack were successfully measured. 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. The Coefficient of lift and coefficient of drag of an airfoil are depends upon the pressure distribution and velocity distribution of an airfoil.

Drag co-efficient of an airfoil depends necessarily on Reynolds’s number and geometry of the airfoil, the results shows that for higher Reynolds number the drag coefficient is more and for low Reynolds number the drag coefficient is less. The increment of Reynolds number has benefit for the airfoil aerodynamic behaviour.

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