Wind Tunnel Testing Laboratory

ARO 4351L – 01

**A wood on a machine

Description automatically generated**

**Aerodynamics of NACA 0012 Airfoil**

**Experiment 2**

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#### List of Symbols and Notation

AoA = Angle of attack

Cl = Lift coefficient

Cd = Drag coefficient

Cm = Moment coefficient

M = Mach Number

= Specific Heat Ratio

p = Static Pressure

p1 = Total Pressure

= *Ambient Pressure*

= Mach Angle or Viscosity

*Laminar Boundary Layer thickness*

*Turbulent Boundary Layer thickness*

= *Freestream Velocity*

*h or Z =* Height

Density

g = Gravity

*Rex = Reynolds Number located at x*

x = Distance

P-S = Pitot Static

AeroFMS or FMS = Force Measurement System

NACA = National Advisory Committee for Aeronautics

ft = Feet

sec = Seconds

LSWT = Low Speed Wind Tunnel

SSWT = Supersonic Wind Tunnel

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#### **Summary**

The aerodynamic characteristics of a NACA 0012 airfoil was collected in the Cal Poly Pomona Low-Speed Wind Tunnel on the 12th of February 2024 in building 13, room 1229. A total of five test sets were run in this experiment, in increments of 20 feet per second. The airfoil ran through a range of velocities starting at 100 ft/s to 200 ft/s while sweeping through angle of attacks between -4 to 16 degrees. Pressure taps along the airfoil generate the pressure data which is then recorded in FMS. With this data we can evaluate additional aerodynamic characteristics including the pressure coefficient, normal force, chord force, and ultimately the lift and drag. The acquired experimental data was used to generate plots for Cl vs. AoA, Cd vs. AoA, Cm vs. AoA and compared to published data sets for the NACA 0012 wing section. Thorough analysis of the lift and drag of the airfoil through an AoA sweep at different velocities provides us foundational reference between theory and the real world.

# Test Objective and Theoretical Basis

# Test Objectives

The objective of this test is to:

1. Measure the airfoil coefficient of pressure distribution vs. The angle of attack (AoA)

2. Calculate the airfoil section lift, drag forces, and corresponding coefficients.

3. Compare and validate these corresponding coefficients to previous experiments as well as to verified NASA data.

# Theoretical Basis

NACA 0012 is one of the most widely used airfoils in the aerospace industry due to its high lift to drag ratio. Its upper and lower surface are symmetrical meaning that when it is subjected to fluid flow at 0 AoA, the velocity profile on either surface is identical. Since the velocities are identical, we can also assume that the pressure distribution across both surfaces is also identical. To generate lift or downforce, however, there must be pressure difference between the upper surface and lower surface of the airfoil. This is accomplished by angling our airfoil and subsequently increasing the velocity on one surface and decreasing it on the opposite surface. This is attributable to Bernoulli’s principle which states that an increase in speed on the surface will decrease the fluid’s potential and vice versa on the opposing surface. Ultimately, this means that there will be a decrease in pressure on one surface and an increase on the other. For our experiment, we will also assume the air stream is inviscid and the density remains constant through the test section.

The airfoil used in the experiment is NACA 0012 and consists of 32 pressure taps. These sensors collect the pressures acting along the top and bottom of the airfoil and correlate this data with transducers to produce the pressure on the model (Equation 1). Equation 2 then provides us with the pressure coefficient where we can reduce to Equation 3 for our calculations.

|  |  |  |
| --- | --- | --- |
|  |  | Equation (1) |
|  |  | Equation (2) |
|  | = , where Pref = Ps |  |
|  | Therefore,  = | Equation (3) |

After collecting the pressure coefficients for the top and bottom airfoil we can calculate the normal force coefficient (Equation 4) and chord force coefficient (Equation 5) acting on the airfoil. With these coefficients we can calculate the lift and drag coefficients acting on our airfoil using Equation 6 and Equation 7, respectively.

|  |  |  |
| --- | --- | --- |
|  |  | Equation (4) |
|  |  | Equation (5) |
|  |  | Equation (6) |
|  |  | Equation (7) |

NACA 0012 has been thoroughly investigated through many wind tunnels since its conception. To validate our findings, we will compare our calculated aerodynamic forces and coefficients with verified sources from previous experiments, the most prominent coming from NASA.

# Test Procedure

The team will perform a single run at specified velocity on the NACA 0012 airfoil and will conduct an AoA sweep as indicated in Table (2). Data from FMS will be recorded and used for calculations and analysis.

Table 2.1: Run/Team Schedule

|  |  |  |  |
| --- | --- | --- | --- |
| Run | Team | Velocity (ft/s) | AoA (deg) |
| 1 | 1 | 100 | -4 to 16 |
| 2 | 2 | 140 | -4 to 16 |
| 3 | 3 | 160 | -4 to 16 |
| 4 | 4 | 180 | -4 to 16 |
| 5 | 5 | 200 | -4 to 16 |

# LSWT Description and Equipment

Cal Poly Pomona’s Low Speed Wind Tunnel will have a NACA 0012 airfoil inserted into the test section and mounted on a variable actuator allowing the airfoil to pivot along its chordwise axis. The airfoil will have 32 pressure taps spread along the top and bottom. The airfoil will also have two sets of tufts (Figure 1) running along the spans leading and trailing edge. Pressure taps running chordwise is also depicted in Figure 1 just above the tufts. The airfoil will be swept through a variety of AoA’s using FMS (Figure 2)

A group of orange braided objects on a wooden surface

Description automatically generated

Figure 2.1: Tufts attached to leading and trailing edge

A computer monitor with a keyboard and a speaker

Description automatically generated

Figure 2.2: FMS Data Acquisition System

# Data and Error Analysis

# FMS Pressure Data Calculations

Lift, drag, and pitching moment are the forces observed in this experiment. In order to begin our analysis, we will first compute the coefficient of pressure, Cp.

|  |  |  |
| --- | --- | --- |
|  | = | Equation (3) |

Here is the change in pressure reading and q is the dynamic pressure.

|  |  |
| --- | --- |
|  | = *Pn – Pref* |

The AeroFMS system reads a reference pressure, *Pref* and a pressure per node, *Pn*. The difference calculated is divided by the dynamic pressure will give the *Cp*.

Once the *Cp* per node is calculated, we can compare the upper (*CPU*) and lower (*CPL*) nodes to calculate as follows:

Coefficient of Normal force, *CN*

|  |  |  |
| --- | --- | --- |
|  |  | Equation (4) |

Coefficient of Lift, *CL*

|  |  |  |
| --- | --- | --- |
|  |  | Equation (6) |

Coefficient of Drag, *CD*

|  |  |  |
| --- | --- | --- |
|  |  | Equation (7) |

Coefficient of Chord force, *CC*

|  |  |  |
| --- | --- | --- |
|  |  | Equation (5) |

Coefficient of Pitching moment, *CM*

|  |  |  |
| --- | --- | --- |
|  |  | Equation (8) |

We will define the chord as *C*, and the length along the chord as . From the AeroFMS system, we can determine the length, or horizontal point (*x*) at which the chord force is applied.

# Data Correction

Due to the deterioration of the pressure taps, some of the readings will be inaccurate and will cause gaps in the calculations and plots. To combat this, we will interpolate the data as follows.

where *Pi* denotes the pressure interpolated and *x* is the position along the airfoil.

By using the data points above and below the inaccuracy, we can remove that pressure value and interpolate a more accurate value.

# Data Plots

In Figure 3.1, it plots pressure against the percentage distance along the chord, with an inverse y-axis. As observed, a 100 angle of attack creates a pressure imbalance above and below the airfoil. Starting above the leading edge to trailing edge, negative pressure readings are recorded that converge to -0.05 psi. Below from leading edge to trailing edge, we observed up until the mean aerodynamic center (1/4 of the chord), the airfoil experiences a positive increase in pressure. Further passed the mean aerodynamic center, the airstream flow is separating as seen by the pressure readings.

A graph of a pressure

Description automatically generated

Figure 3.1: 10˚ AOA Pressure vs x/c

In Figure 3.2, it plots the coefficient of pressure against percentage distance along chord.

A graph of a number of objects

Description automatically generated with medium confidence

Figure 3.2: 10˚ AOA Cp vs X/c

In Figure 3.3, it plots the height distance of the pressure taps along the chord against coefficient of pressure.

A graph of a graph

Description automatically generated

Figure 3.3: 10˚ AOA Cp vs y/c

In Figure 3.4, it plots the coefficient of lift against angle of attack. Compared to the NACA 0012 *CL* vs. AoA, the results are nearly identical. As the angle of attack increase, lift increases up until the critical angle of attack where stall can be observed.

A graph with a line

Description automatically generated

Figure 3.4: CL vs AOA

In Figure 3.5, as the angle of attack increases, the horizontal chord force increases due to a larger cross-sectional area within the test section. The plot below shows the drag increasing until the critical angle of attack and exhibits the stall phenomenon again.

A graph with a line

Description automatically generated

Figure 3.5: CD vs AOA

Table 3.1: Experiment Lift and Drag Coefficients vs. Published Data

A table with numbers and symbols

Description automatically generated

In Table 3.1, the experimental and published force coefficients (R = .70 x 10^6) from NASA of the NACA 0012 Airfoil Section are presented alongside each other for each angle of attack to determine the validity and accuracy of the experiment. The Reynolds number calculated for the test run was calculated at R = 0.8 x 10^6.

# Data Interpretation

As conducted in this experiment, a model NACA 0012 airfoil demonstrated changes of pressure, lift, and drag compared to other studies. The symmetry of the airfoil results in no lift and minimum drag at zero degrees angle of attack, as represented by *CL* and *CD* respectively. As the angle of attack reaches the critical point, the positive generation of lift decreases and flow separates. Above the airfoil, negative pressures were recorded and shown to be most effective until the mean aerodynamic center.

When comparing the experiment values to that of the published data, we can conclude that the lift and drag datasets had very little discrepancies. However, it was noted that at the angle of attack of zero degrees, the lift coefficient differed by 1,600 percent in comparison to its theoretical value which indicates a slight oversight during the experiment. Theoretically, given that the airfoil is symmetric, the coefficient of lift should be ideally zero because its shape does not induce a pressure difference between the upper and lower surfaces at this angle of attack. Regardless of this inconsistency, the experimental team found that the other experimental coefficients of lift and drag were in an adequate range of the published dataset. Thus, the team concluded that the group was successful in gaging the force coefficients for each respective angle of attack.

# Conclusions and Recommendations

In conclusion, the NACA 0012 remains effective for generating lift. However, if lift generation is required at critical angles of attack, this airfoil may not produce the desired dynamics. The experimental team concluded that they were successful in gaging the force coefficients at each angle of attack of the NACA 0012 airfoil. The pressure difference between the upper and lower surfaces begin to converge as we move along the chord length to the trailing edge. The flow deceleration on the upper surface and acceleration on the lower surface can explain the converging pressure difference between the two. There were minor discrepancies in certain datapoints when comparing the experimental values to that of published data. The team concluded that the accuracy of the results was factored by the team’s overall attention to detail during the experiment. The team suggested that the angle of attack was most likely not exactly zero when the data was recorded which could explain the discrepancies between the two values. Nonetheless, the experimental team completed their objectives of measuring the airfoil pressure distribution coefficients versus the angle of attack of the NACA 0012 airfoil, calculating the lift and drag forces of the airfoil in addition to relevant force coefficients. Lastly, the experimental group decided that their results were accurate given that the calculated force coefficients were in sufficient range of that of published data by NASA. As for future experiments, the team noted that it is important to remain attentive when adjusting certain variables of interest and ensure that they are recording the correct data. The lack of caution in data recording most likely resulted in the discrepancies found in the calculations of the experiment.

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