

# Wind Tunnel Measurements

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## Objectives

- Understand the difference between lift and drag
- Understand how the angle of attack of an airfoil changes the amount of lift (L vs.  $\alpha$ )
- Understand how lift is related to velocity (L vs. V)

## Introduction

In this experiment, we will use a wind tunnel to explore the effect of lift and drag on an airfoil. A fluid flowing past a body, in this case an airfoil has a force exerted on it. Lift is defined to be the component of this force that is perpendicular to the oncoming flow direction. The drag force is the opposite of lift, which is defined to be the component of the fluid-dynamic force parallel to the flow direction. We will explore how the angle of attack changes the amount of lift the airfoil experiences. The angle of attack ( $\alpha$ ) is the angle between flow and the chord line. The chord line is a straight line between the most forward point and most aft point of the body. We will also study the effects of velocity on lift, if the angle of attack is kept constant and velocity increased we would expect an increase in lift. We will measure the airfoil lift as a function of velocity. The drag coefficient ( $C_D$ ) and lift coefficient ( $C_L$ ) are functions of dimensionless parameters such as Reynolds number (Re), Mach number (Ma), Froude number (Fr) and relative roughness of the surface ( $\epsilon/l$ ). The lift and drag coefficients are mostly dependent on the shape of the airfoil, NACA 0012 is a symmetrical airfoil and NACA 4412 is a non-symmetrical airfoil. The shapes play a huge role on the amount of lift and drag generated and will be seen in this experiment. In order to be able to use equations (1),(2) and (3) the velocity needs to be known. This is done by using a pitot-static tube which will be able to make a pressure gradient measurement and then by using the Bernoulli's equation calculate velocity.

## Notation

V: Velocity  
 CL: Coefficient of Lift  
 CD: Coefficient of Drag  
 $\rho$ : Density  
 $A_s$ : Surface Area  
 l: Span (Airfoil Width)  
 c: Chord (Airfoil Length)  
 z: Height  
 $\gamma$ : Specific Weight

The lift is a function of dynamic pressure, surface area and lift coefficient as shown in Equation (1).

$$L = \frac{1}{2}\rho V^2 A_s C_L \quad (1)$$

The drag is a function of dynamic pressure, surface area and drag coefficient as shown in Equation (2).

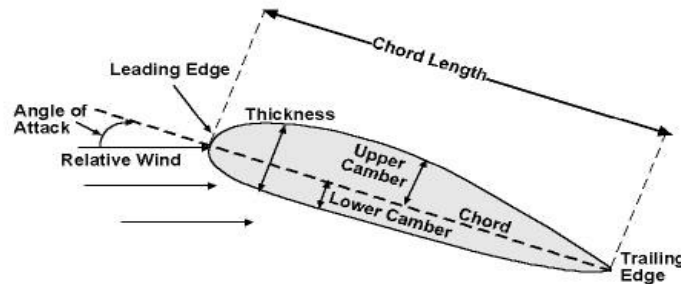
$$D = \frac{1}{2} \rho V^2 A_s C_D \quad (2)$$

Dynamic Pressure is shown in Equation (3).

$$P_d = \frac{1}{2} \rho V^2 \quad (3)$$

Surface Area ( $A_s$ ) is a function of the chord and span and is shown in Equation (4).

$$A_s = cl \quad (4)$$



**Figure 1: Airfoil Nomenclature**

Bernoulli's Equation is a function of pressure, density, velocity and specific weight and is shown in Equation (5).

$$P_1 + \frac{1}{2} \rho V_1^2 + \gamma z_1 = P_2 + \frac{1}{2} \rho V_2^2 + \gamma z_2 \quad (5)$$

Assuming if  $z_1 = z_2$ , meaning the heights are at the same level then the equation can be written as Equation (6) which then can be rearranged into Equation (7) which is the velocity along the streamline.

$$\Delta P = \frac{1}{2} \rho V^2 \quad (6)$$

$$V = \sqrt{2 \frac{\Delta P}{\rho}} \quad (7)$$

## **Equipment**

- 6" Open Circuit Wind Tunnel
- 1/3 HP, ODP, 230/460 VAC Induction Motor
- Toshiba Model VFNC1S-1004P-W Variable Frequency Controller (Motor Controller)
- NACA 0012 Airfoil
- NACA 4412 Airfoil
- Weight Set

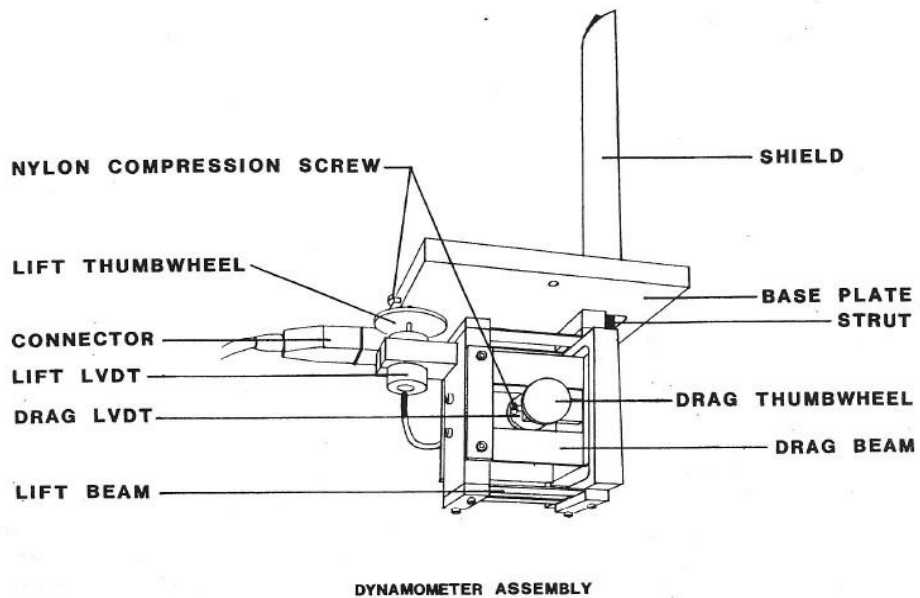


Figure 2: Dynamometer Assembly

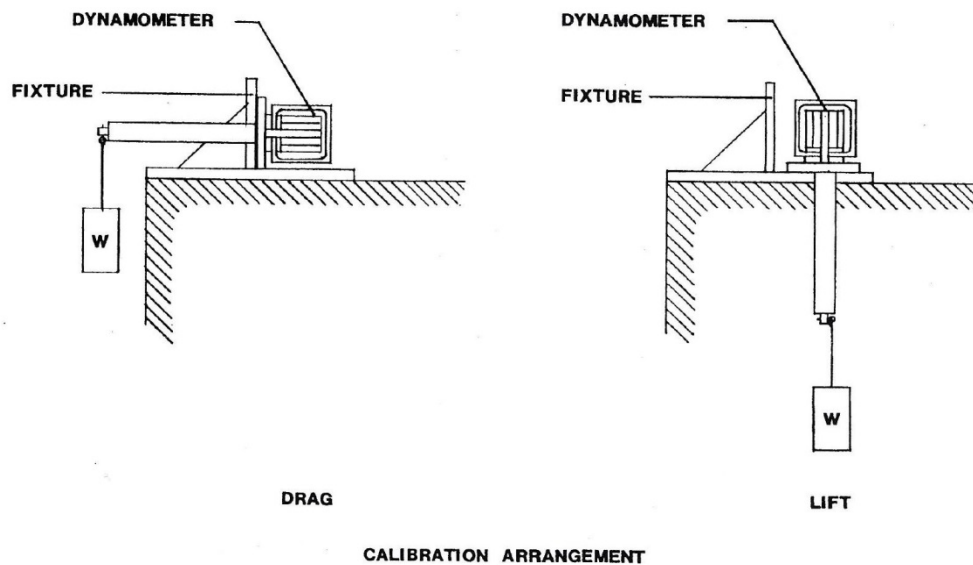


Figure 3: Calibration Setup

## Procedure

### *Dynamometer Calibration*

In order to use the Dynamometer it must be calibrated each time it is used. In order to calibrate the Dynamometer it must be calibrated for the lift and drag measurements. This is done by orientating the measuring device correctly to the calibration fixture and then hanging the

appropriate weights from the arm and comparing the meter measurements to the manufactures calibration curves.

### *Lift Component Calibration*

1. Secure the dynamometer to the calibration fixture or clamp the unit to a bench so that the strut and shroud extend beyond the edge of the bench shown in Figure (3).
2. Monitor the output from the **Lift** readout. Adjust the lift LVDT Core Thumbwheel until the voltmeter display reads **0.000**. (See Figure (2). Dynamometer Assembly)
3. Load the **LIFT** beams with known weights equal to the maximum desired operating range (MAX RATING 8lbsf).
4. Remove weights. Verify zero. If necessary adjust the LIFT thumbwheel so that the display reads **0.000**.
5. Reload the weights used in step 3. If necessary adjust the “SPAN” potentiometer. Repeat steps 3 through 5 until “ZERO” is verified.
6. With “ZERO” verified lock the potentiometer setting using the black lock tab on the side of the potentiometer on the meter display.
7. Determine the slope and intercept of the calibration curve by applying decreasing loads of known weights. Record and graphically plot the results of known weight versus digital display. Use the table below for both lift and drag calibration data.

### *Drag Component Calibration*

1. Remount the dynamometer on the calibration fixture so that the drag beams may be gravity loaded (i.e. so that the strut is horizontal) shown in Figure 3.
2. Monitor the output from the **DRAG** readout. Adjust the **DRAG** LVDT thumbwheel until the display reads **0.000**
3. Load the dynamometer with known weights equal to the maximum desired operating range (MAX RATING 5lbsf).
4. Remove weights. Verify zero. If necessary adjust the DRAG thumbwheel so that the display reads **0.000**.
5. Reload the weights used in step 3. If necessary adjust the “SPAN” potentiometer. Repeat steps 3 through 5 until “ZERO” is verified.
6. With “ZERO” verified lock the potentiometer setting.
7. Determine the slope and intercept of the calibration curve by applying decreasing loads of known weights. Record and graphically plot the results of known weight versus digital display.

**Table 1: Lift Calibration Table**

Applied Mass (g)	Meter Output (mV)

**Table 2: Drag Calibration Table**

Applied Mass (g)	Meter Output (mV)

After the dynamometer calibration has been completed it is time to conduct a few experiments. The airfoil must be attached to the dynamometer and the dynamometer must be remounted to the wind tunnel. After the dynamometer is secured to the wind tunnel, the fan will then be turned on and set to a given operation frequency which corresponds to a calibrated velocity (TBD). The fan should be allowed to run for a few seconds to ensure a steady flow of air ensuring a more constant velocity.

### **Speed Control Instructions**

The test section speed is controlled by varying the fan RPM. The wind tunnel is designed to operate in an adjustable speed range from less than 5.0 fps (1.52 m/s) to greater than 50 fps (15.24 m/s). The VFD responds to control signals from the remote keypad.

#### Operation of Motor (Remote Keypad)

1. Apply power to the inverter (flip switch to on).
2. Enter the desired frequency by using the up and down arrows or the potentiometer knob to scroll to specific frequency.
3. Press the **ENT** button once the desired frequency is achieved. The display will flash between the frequency setting and “FC” indicating that the setting has been made.
4. Press the **RUN** button. The acceleration or deceleration to the new set speed

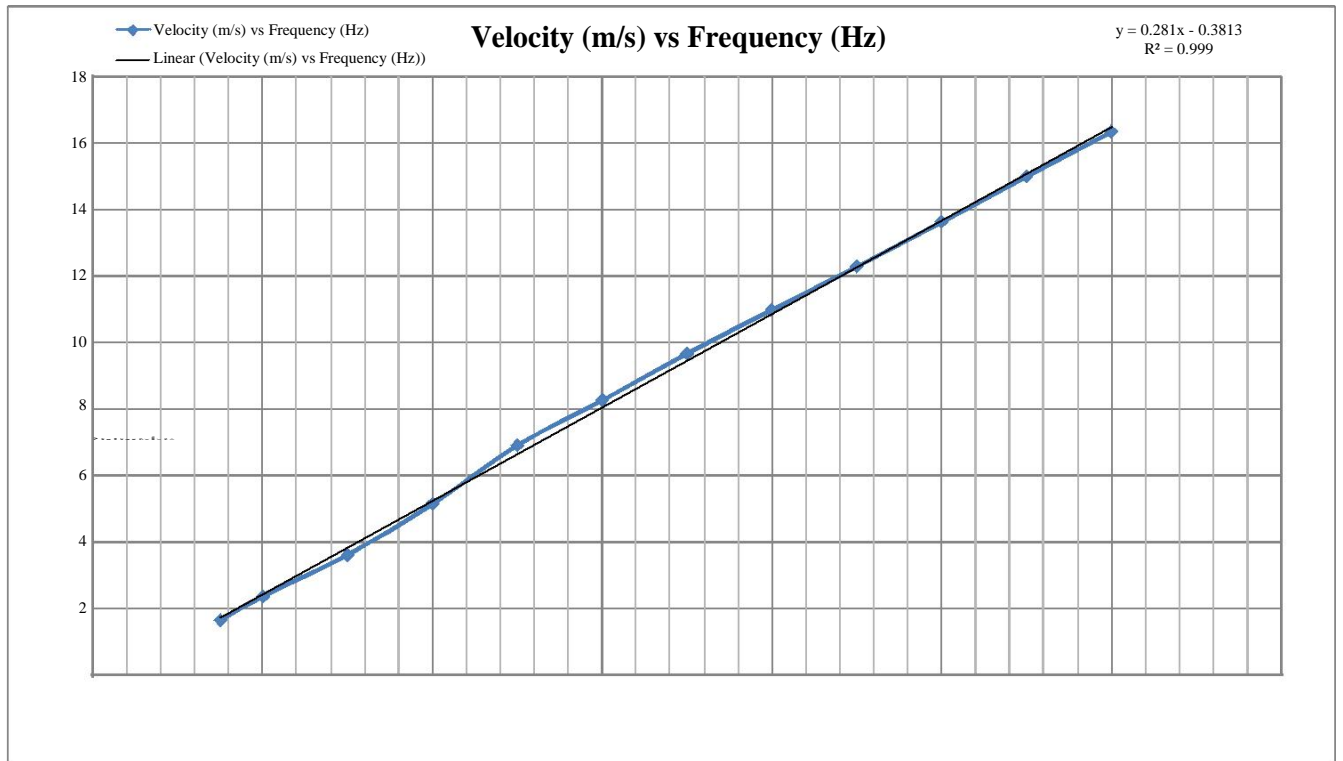
designated by “FC” will be shown on the inverters output. During operation the panel control lamp will flash.

5. Repeat steps 3-5 to change the frequency setting during operation.
6. To stop the motor drive, either enter an operation frequency of 0.0 or press the stop button.

The speed control chart Table (3) was generated by measurements of a pressure gradient using a pitot-static tube and inclined manometer. The velocity has been liner fitted against frequency Figure (4) any frequency can be selected and the corresponding velocity calculated.

**Table 3: Speed Control Chart**

<b>Speed Control Chart</b>		
<b>Frequency (Hz)</b>	<b>Velocity (ft/s)</b>	<b>Velocity (m/s)</b>
7.5	5.40	1.65
10	7.75	2.36
15	11.84	3.61
20	16.85	5.14
25	22.64	6.9
30	27.06	8.25
35	31.67	9.65
40	35.99	10.97
45	40.26	12.27
50	44.65	13.61
55	49.12	14.97
60	53.55	16.32



**Figure 4: Velocity (m/s) vs. Frequency (Hz)**

## **Experiment #1**

There will be two airfoils used in this experiment airfoil NACA 0012 and NACA 4412. The first experiment will be to change the angle of attack of the airfoil at constant velocity and record lift and drag measurements. The measurements need to be recorded to Table 4 and 5 which will be used for calculation later. The lift coefficient of an airfoil is directly related to the angle of attack. Increasing the angle of attack is associated with increasing the lift coefficient up to the maximum lift coefficient after which the coefficient decreases. The angle that produces the maximum lift is called the “critical angle of attack” or “stall angle of attack” if the angle is increased past the stall angle then a decrease in the lift coefficient will occur. The critical angle of attack is typically around  $15^\circ$  for many airfoils.

The VFD will be set at 35.0Hz for this experiment.

**Table 4: Lift, Drag vs. Angle of Attack (NACA 0012)**

<i>Angle of Attack (<math>\alpha</math>)</i>	<i>Lift (N)</i>	<i>Drag (N)</i>
0		
5		
10		
15		
20		
25		
30		
35		

**Table 5: Lift, Drag vs. Angle of Attack (NACA 4412)**

<i>Angle of Attack (<math>\alpha</math>)</i>	<i>Lift (N)</i>	<i>Drag (N)</i>
0		
5		
10		
15		
20		
25		
30		
35		



**Experiment # 2**

The second experiment will be to change the velocity while keeping the angle of attack constant. The airfoil will be kept at an angle of attack of  $10^\circ$  and velocity will be ramped from 1 m/s to 15 m/s, measurements of lift and drag will be recorded to Table 6 and Table 7.

**Table 6: Lift, Drag vs. Velocity (NACA 0012)**

<i>Velocity (m/s)</i>	<i>Frequency (Hz)</i>	<i>Lift (N)</i>	Drag (N)
1	4.9		
2	8.5		
4	15.6		
6	22.7		
8	29.8		
10	36.9		
12	44.1		
14	51.2		
16	58.3		

**Table 7: Lift, Drag vs. Velocity (NACA 4412)**

<i>Velocity (m/s)</i>	<i>Frequency (Hz)</i>	<i>Lift (N)</i>	Drag (N)
1	4.9		
2	8.5		
4	15.6		
6	22.7		
8	29.8		
10	36.9		
12	44.1		
14	51.2		
16	58.3		

**Report Outline****Title Page**

Experiment Number, Experiment Title, Class, Department, Instructor, Name, Date and Abstract.

Table of Contents

Table of Figures

List of Tables

**Introduction**

Discuss airfoils and how they are used in application; discuss how wind tunnels are used in commercial and research environments. Introduce the experiment performed.

**Experimental Setup**

Equipment used—List, describe function and how it was used in the experiment.  
Schematic or picture with appropriate labeling explaining setup.

**Procedure**

Discuss the steps you took to perform the experiment. Do not use a list. Use your own words to describe what you did and in what order. (Pretend you had to walk someone through the experiment over the phone.)

**Theory**

The theory should include how equations were derived. What kind of mechanics describe the physical phenomena you are witnessing. Explain fluid mechanics concepts like flow, Bernoulli equation, Reynolds Number, Boundary layers, etc. How are the lift and Drag coefficients calculated? How are Newtonian mechanics used in aerodynamics?

**Data**

Data Tables Completed. Table 4 and Table 5.  
Measurements of the airfoil (chord length and width)

**Results & Discussion**

*NOTE: ALWAYS show a sample calculate for EVERY calculation. Then tabulate all the results into an appropriate table. In this lab, all the plots in the results section must be plotted in terms of velocity and lift or drag force. No Hz or V (or mV) allowed! Convert the data.*

There will be a total of 4 plots generated. The two airfoils should be plotted on the same figure for comparison.

Plot 1: Lift vs Angle of Attack ( $\alpha$ ), [(NACA 0012), (NACA 4412)]

Plot 2: Drag vs Angle of Attack ( $\alpha$ ), [(NACA 0012), (NACA 4412)]

Plot 3: Lift vs Velocity at fixed Angle of Attack ( $\alpha$ ), [(NACA 0012), (NACA 4412)]

Plot 4: Drag vs Velocity at fixed Angle of Attack ( $\alpha$ ), [(NACA 0012), (NACA 4412)]

Plot 1: Discuss the difference between the two airfoils. Why does the shape play a difference in the lift coefficient? What physical phenomena is occurring to cause this difference?

Plot 2: Discuss the difference between the two airfoils. Why does the shape play a difference in the Drag coefficient? What physical phenomena is occurring to cause this difference?

Plot 3: Discuss the difference between the two airfoils. Does the plot profile follow intuition? Discuss how airfoil shape would play a critical role in airplane design.

Plot 4: Discuss the difference between the two airfoils. Does the plot profile follow intuition? Discuss how airfoil shape would play a critical role in airplane design.

**Report Questions**

1. What is the stall angle for airfoil NACA 0012 and NACA 4412? Why do you suppose the stall angles are different?

2. Why is NACA 0012 classified as a symmetric airfoil and NACA 4412 as a nonsymmetrical airfoil? How does the symmetric and non-symmetric airfoils compare in lift and drag at a fixed angle of attack?
3. Would you expect the performance of the NACA 0012 to be the same if it was flipped over? How about the NACA 4412 airfoil?
4. Why is it that an airplane can fly upside down? What must a pilot do in order for it to do so? **Bonus (+1 point)** Why is it in an open cockpit when the pilot performs a loop or vector roll he doesn't fall out?
5. What type of flow field is experienced by the airfoil in the experiment laminar or turbulent? What is turbulence? What effect does it have on an airfoil?

### **Conclusion**

Summarize what was learned in this lab

### **References**

Reference all sources used in this lab report.

### **Lab Reactions**

(This information is for the grader. It is not technically part of a technical report so include it on its own page as the last page and it does NOT count towards the report page length) – A brief explanation of what you learned in this lab. No more than half a page.