

Lab 1a

Wind Tunnel Testing Principles & Lift and Drag Coefficients on an Airfoil

OBJECTIVES

- Calibrate the RPM/wind speed relation of the wind tunnel.
- Measure the drag and lift coefficients of an airfoil as a function of the angle of attack and Reynolds number.
- Measure the RMS fluctuations of pressure
- Perform a complete uncertainty analysis on the measured drag and lift coefficients.

EQUIPMENT

<i>Name</i>	<i>Model</i>	<i>S/N</i>
Flowtek Wind Tunnel		
Pressure Transducers		
Airfoil NACA 2415		
NI DAQ Card	PCI-6024E	
Computer		

The wind tunnel flow measurement workstation consists of 8 pressure tubes connected to pressure transducers to measure pressure relative to atmospheric pressure, Flowtek wind tunnel with control panel to control air flow, and data acquisition system (DAQ NI PCI-6024E and LabView 2010 software). In this experiment, you will perform air pressure on the surface of an airfoil.

This lab was designed to be completed in 2 lab sessions. Data processing may take 1 or 2 more sessions. Data processing should be performed as data is taken, to guarantee good results.

REQUIRED READING

Read reference [1] for introduction and operation of the wind tunnel. For review in fluid mechanics see [2]. Experimental data is available for $Re = 200,000$ in [3] and for other Re in [4].

THEORY

Airfoil theory is well described in [2], chapter 8.7. The standard coordinate definitions are shown in Fig. 1.

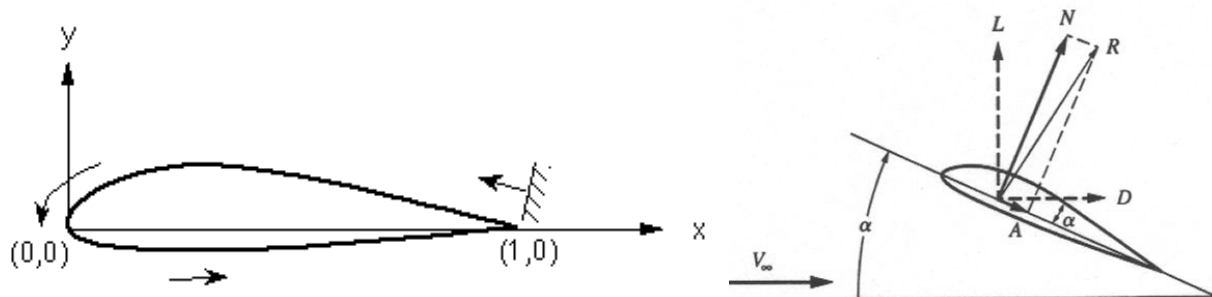


Figure 1: Coordinate definitions for an airfoil.

In this experiment the lift and drag coefficients are measured as a function of the angle of attack α and Reynolds number, defined as:

$$Re = \frac{\rho V_0 C}{\mu}$$

with C is the airfoil chord length, ρ and μ are the air density and viscosity. The lift and drag coefficients are defined as:

$$C_L = \frac{F_L(\alpha, Re)}{\frac{1}{2} \rho V_0^2 C S} \quad C_D = \frac{F_D(\alpha, Re)}{\frac{1}{2} \rho V_0^2 C S}$$

where F_L and F_D are the lift and drag forces, respectively, and S is the span. To measure the lift and drag forces we will use the pressure measured in 8 points along the airfoil upper and lower surfaces. Integration of the pressures along the surface of the foil will yield the pressure force, which is usually much larger than the viscous friction force and will thus assumed to approximate well the total force. The normal and axial forces on the foil are then computed as:

$$F_x = N = -\oint p n_x da \quad F_y = A = -\oint p n_y da$$

where $\mathbf{n} = (n_x, n_y)$ is the outward normal to the airfoil surface around the two dimensional cross section shown in Fig. 1, and da is the area differential on the surface of the airfoil. Once the normal and axial forces have been computed, the lift and drag forces are obtained from projecting the forces normal (lift) and tangential (drag) to the incoming flow direction:

$$F_d = D = F_x \cos\alpha + F_y \sin\alpha$$

$$F_L = L = -F_x \sin\alpha + F_y \cos\alpha$$

The Excel worksheet AirfoilLiftDrag.xlsx performs this integration and reports the drag and lift coefficients. The worksheets completes the following tasks:

- a) Interpolates and extrapolates the pressures measured on the pressure taps to cover all the airfoil surface
- b) Computes the normal
- c) Computes the axial and normal forces on each foil segment per unit span
- d) Sums all foil segments to obtain the net axial and normal forces per unit span
- e) Projects into the flow direction to obtain the drag and lift forces
- f) Normalizes to obtain the drag and lift coefficients

Explore the worksheet to make sure you understand all steps needed to obtain the drag and lift coefficients and how these are implemented.

PRE-LAB QUESTIONS

- a) The static and dynamic pressures on a Pitot tube are 1000 Pa and 1050 Pa, respectively. Compute the velocity if the working fluid is (1) air and (2) water. What the dynamic pressure in water would have been if the velocity was the same as that of air?
- b) What is the stall angle of an airfoil? How is it related to the Reynolds number?
- c) An airplane uses the NACA0015 airfoil 3m in chord and flies with an angle of attack of 5 degrees. For a speed of 50 m/s, what is the wingspan to maintain flight if the weight of the plane is 60,000 kg? Note: You will need to find an outside reference for lift data on the NACA0015 airfoil.
- d) Describe important elementary errors to consider when estimating the uncertainty of the experimentally obtained lift coefficient.

PROCEDURE

1. Write detailed explanation of how the different components of the experiment work. Be sure to include information about:
 - How can you control the fan of the tunnel?
 - What DAQ channel does each of the pressure taps connect to?
 - Describe in detailed how to mount the rake with pressure tube.
2. A LabView program (lab1a.vi) will be used to control the measurement of this experiment using the DAQ. The LabView VI is available on the course website under the Lab 1a section of the Laboratories page. After opening the VI, you should be able to find the device PCI-6009 by clicking Measurement & Automation under tools in LabView and then expanding the Devices and Interfaces list.

By pressing “Ctrl + e” you can switch between the front panel view and the block diagram view. Explore the program to understand its functionalities before conducting the experiment.

Note: The data saved in the specified file will be overwritten if the file name is not changed for each run of the program. Also, click the “stop” button on the front panel to stop the program instead of “abort execution” in the menu bar.

In the front panel, 0 to 7 denotes the corresponding channel measurement (i.e. 0 is channel 0 measurement, 1 is channel 1 measurement, etc.). The “Original measurement” (V0 to V7) provide the voltages measured by the transducers, with instant and mean values. “Pressure” (Pressure 0 to Pressure 7) show the pressure in Pascals (Pa) relative to atmospheric pressure.

- a. Copy the downloaded folder containing the LabView VIs a place of your preference such that you can play around with it without modifying the original. Use the copy for the entire experiment.
- b. Test the program. Change the user input options if necessary in the front panel, such as the file name and path where your data is to be saved.

- c. The “Measure” button takes a single point sample of all the pressure and velocity and records the data into the file that you specified in step 2-ii. The “Read_Counter” will tell you how many times the data is recorded. Note that the data will be recorded at the time when you release the mouse, i.e., click and hold the mouse will NOT take any data.
- d. Look over the wind tunnel control panel (of the wind tunnel station). The “Control Power” key turns on the power to the control panel. The “Fan Enable” button starts the tunnel fan, while the E-Stop button stops it. On the back of the control panel box, there is a switch that controls the method in which the motor RPMs are adjusted. If the switch is toggled up, the RPMs are adjusted using the Fan Speed dial on the panel. If the switch is toggled down, the RPMs are adjusted using the “Motor RPM Controller” on the front panel of LabView software. **For the whole experiment, the RPMs will be adjusted using the computer.**

You can control the RPM of the fan either by hit/sliding the controller, or increment/decrement or enter the exact percentage of the RPM (0 – 100) in the controller’s window. The controller of the fan is connected to channel ao0 of the DAQ.

- e. Look over the pressure transducers in the back of the instrumentation box on the wind tunnel. A total of 8 pressure tubes can be traced to pressure transducers located behind the tunnel. These eight transducers are connected to the computer and correspond to the eight pressure and velocity measurement on the front panel of the program.
- f. Install the **Pitot tube** into the wind tunnel (if it is not already installed), this will allow the velocity of the wind tunnel to be computed and monitored.
- g. **Important: Make sure there are no loose objects inside the tunnel before start-up.**

Turn on the wind tunnel by turning the key from Lock to Run. **Do not press “Fan Enable” yet.** Run the LabView program. Notice the indicator “Initializing” in the bottom left corner saying “Wait” with the red button. Wait until the button turns green and the indicator says “Ready” before continuing (it takes one minute). During this time, the program is initializing all the pressures to zero. **This measurement initialization is very important. Be sure to perform this at the beginning of each run of the program.** Once the indicator turns green, then press the “Fan Enable” button on the wind tunnel control panel. Notice the changes that take place on the screen. Slowly increase the RPMs by sliding up the Motor RPM slider in small increments and then releasing the mouse button (or by other ways to change the RPM in step 2-iv). **Note: Do not make sudden and large increases in the RPMs.**

- h. For each of RPM level, wait for the air flow to reach steady state (monitor it from readings of the Dwyer Mark II Manometer). Record several data point in your log book at the steady state of each RPM (e.g. 10%, 20%, 30% ...100% FSO) by reading the value of *INCHES OF WATER* on the manometer.
- i. Set the RPM back to 0 (**without sudden changes**) and turn off the wind tunnel by pressing the E-Stop button on the wind tunnel control panel. The E-Stop button will always shut off the motor.
- j. Stop the LabView program and the wind tunnel.

Now you should be able to perform a calibration of the wind tunnel FSO and its air velocity.

3. Calibration of pressure transducers

- a. You will perform a full up-scale and down-scale calibration on each pressure transducer.
- b. Turn on the wind and run the LabView program. Perform the measurement initialization as in step 2-vi. Wait until the indicator turns green and says “Ready”.
- c. Detach pressure tap 0’s hose from the wind tunnel instrumentation box **while holding the connector to avoid breaking the connector**, connect it to the laboratory standard pressure calibrator. Turn the calibrator on by pressing “kPa”.
- d. Press the button on the side of the pump to release any pressurized air.
- e. Turn the dial on the pump to create a vacuum within the pump. There is no need to pump the hand pump. **Do not exceed -0.6kPa.**
- f. Record the value of the corresponding pressure **and voltage** measurement in LabView. Denote this value as $\Delta P_{\text{measured}}$, and the value on the calibrator as $\Delta P_{\text{standard}}$. They are measurements of the pressure difference between the static pressure and the ambient pressure from LabView program and the lab standard.
- g. Plot the results of the output voltage as a function of lab standard pressure.
- h. Repeat for the other seven transducers.
- i. Check pressure equations in the LabView program to ensure they match with your calibration data.

4. Lift and drag of an airfoil.

- a. You will need to measure the performance curve of the NACA2415 airfoil for 2 different Reynolds numbers of your choice, make sure to choose Reynolds numbers that fall within the capacity of the wind tunnel. To measure the performance of the airfoil you will sweep the angle of attack from -30 to 30 (ex. -30, -20, -15, -10, -8, -6, -4, -2, 0, 2, ... 30) and compute the lift and drag of the airfoil section using the provided excel sheet. Make sure to measure the pressure tap locations on the airfoil and correctly enter them into the excel sheet. See reference [4] for sample plots and discussion.

- b. Find the stall angle for 3 additional Reynolds numbers different from 4.a.

REFERENCES

- [1] GDJ Inc, “FLOTEK 360 Wind Tunnel Instructions and Operations Manual”,
http://www.engineering.uiowa.edu/~expeng/equipment/Flotek360_Wind_Tunnel_Instruction.pdf (1998).
- [2] Frank M. White, *Fluid Mechanics*, McGraw Hill (2010)
- [3] M. S. Genc and Unver Kaynak, “Control of Laminar Separation Bubble over NACA2415 Airfoil at Low Re Transitional Flow Using Blowing/Suction,” 13th Int. Conf. on Aerospace Sciences and Aviation Technology, Cairo, Egypt (2009)
- [4] M. Selig, C. Lyon, P. Giguere, C. Ninham and J. Guglielmo, “Summary of Low-Speed Airfoil Data,” Dept. of Aeronautical and Astronautical Engineering, The University of Illinois at Urbana-Champaign (1996)