ME 646 Lab # 6
(Version 1: April, 2017)
Aerodynamics Lab: Lift and Drag on an airfoil

Purpose: The research question in this laboratory exercise is to compare lift and drag measurements on a NACA 0012 airfoil using a force balance to the lift and drag estimated from the sum of the measured integrated pressure distribution, the estimated skin friction drag, and the estimated induced drag.

Your report should follow the format of a research paper. This will be a two-person report which you will have 2 weeks to complete starting from the completion of the in-lab data acquisition. You may choose your lab partner in your section.

Part I: Airfoil Data Acquisition Tasks:

The lift and drag forces and the pressure profile on a NACA 0012 airfoil will be measured at various angles of attack and at one flow speed (setting of 3-6 on speed dial) in the UNH ME student wind tunnel. Lift and drag forces will be measured using a TecQuipment AFA2 single component lift and drag balance (see attached manual). The pressure profile will be determined from pressure taps in the span-wise center of the airfoil that are connected to a manometer referenced to atmospheric pressure.

The airfoil model (chord = 150 mm, span = 300 mm, see Fig. 1) is equipped with pressure taps on the top and bottom surfaces (see Table 1) to provide a measurement of the pressure profile. A manometer using water as the working fluid will be used to measure the pressure from these pressure taps. Pressure profiles will be measured for angles of attack of 0, 9, and 18 degrees only. The mean wind speed in the tunnel will be estimated using a Pitot-static tube connected to a manometer.

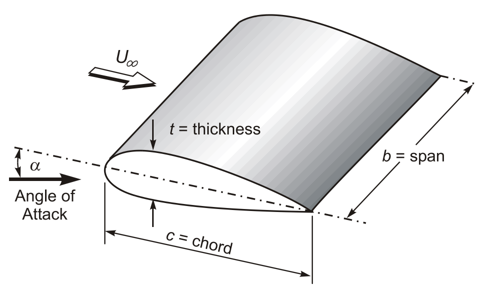

Figure 1. Airfoil geometry

Tasks:

1. Record temperature and barometric pressure using the weather station in the lab.
2. Take pictures of the experimental setup. Shared pictures are fine.

<u>Lift measurements</u>

1. Make sure the balance assembly is fitted for lift measurements (load cell on top of balance assembly).
2. Switch on the power to the AFA2 force balance.
3. Loosen model clamp and adjust protractor reading to 0 degrees (Fig. 2), then retighten model clamp.
4. Zero the load cell.
5. Turn on wind tunnel and slowly increase speed controller to a speed setting between 3-7.
6. Wait 5 minutes for the flow to reach steady state.
7. Adjust the protractor to read zero when the indicated lift is as close to zero as possible.
8. From tubes 1 and 2 on the manometer, record static and stagnation pressure, respectively, measured by the Pitot-static tube (Fig. 3).
8. As done in task 3, adjust the angle of attack to -9 degrees and record the lift force.
9. Repeat step 8 for increasing angles of attack in 3 degree increments until an angle of attack of 21 degrees. (Remember to record the pressure profile on the airfoil at angles of attack of 0, 9 and 18 degrees, as described below.)
10. Record the pressure profile using the manometer on the airfoil at angles of attack of 0, 9, and 18 degrees. (Note tubes 3-12 correspond to pressure taps 1-10 on top of airfoil and tubes 13-22 correspond to pressure taps 11-20 on bottom of airfoil.)
11. Once an angle of attack of 21 degrees is reached, adjust the angle of attack to 0 degrees and record the lift force.
12. Press stop on wind tunnel controller (do not adjust dial speed controller). Wait 2 minutes and record the “zero” reading of lift.

<u>Drag measurements</u>

1. Rotate balance assembly for drag measurements (load cell on right center of balance assembly).
2. Loosen model clamp and adjust protractor reading to 90 degrees (which corresponds to 0 degrees angle of attack since the balance was rotated 90 degrees to measure drag), then retighten model clamp.
3. Zero the load cell.
4. Press start on wind tunnel controller (the speed dial should still be at the setting used for the lift measurements). Wait 2 minutes for the flow to reach steady state.
6. From tubes 1 and 2 on the manometer, record static and stagnation pressure, respectively, measured by the Pitot-static tube (Fig. 3).
7. Adjust the angle of attack to -9 degrees and record the drag force.
9. Repeat step 7 for increasing angles of attack in 3 degree increments until an angle of attack of 21 degrees.
10. Once an angle of attack of 21 degrees is reached, adjust the angle of attack to 0 degrees and record the drag force.
12. Press stop on wind tunnel controller. Wait 2 minutes and record the “zero” reading of drag.

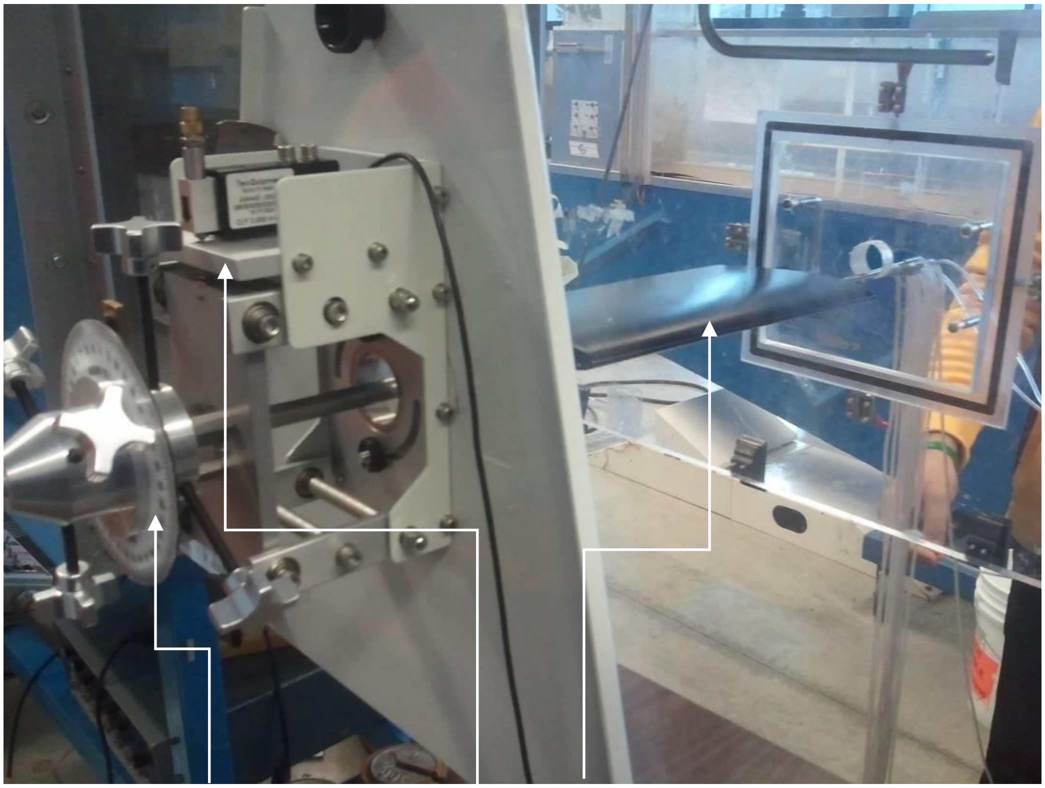

Figure 2. Protractor, model clamp, load cell, and airfoil

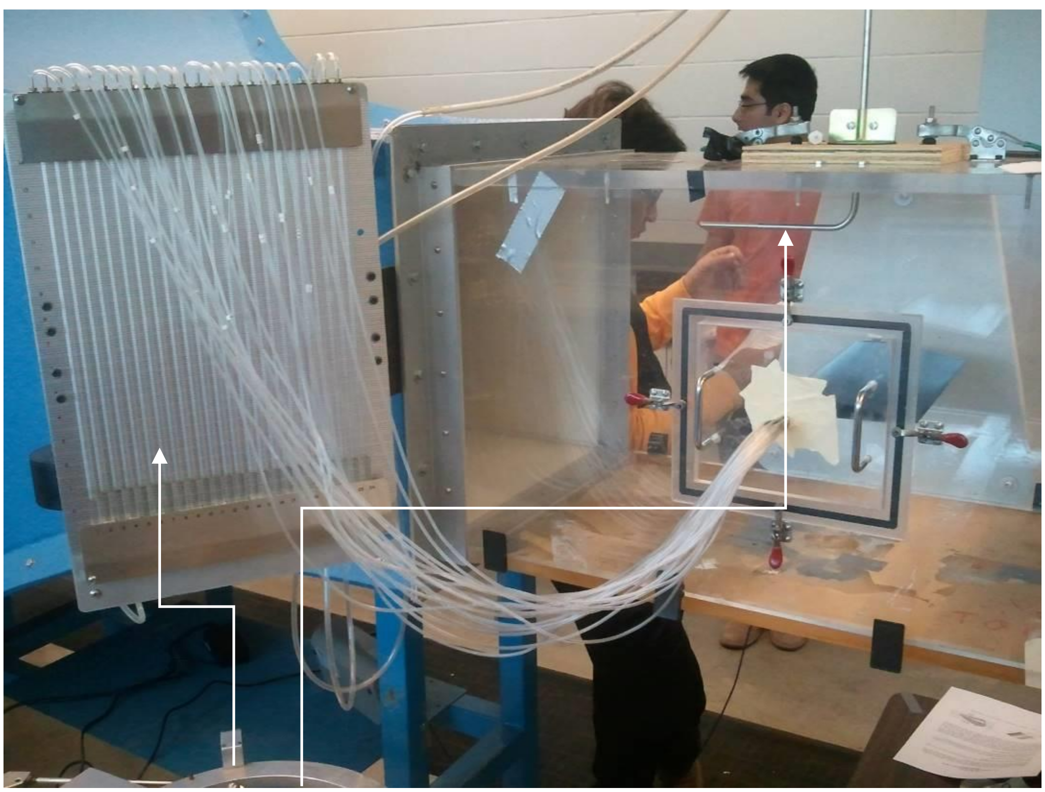

Figure 3 – Manometer and Pitot tube

Data Reduction (to be done after lab & included in report). ***<u>Your grade will be based on the inclusion of these pieces of information:</u>***

1. Compute the density of air in the wind tunnel using the ideal gas law, room temperature, and the barometric pressure in Durham.
2. Convert height readings on the manometer to pressure.
3. Compute the mean wind speed in the tunnel from the pressure measurements recorded with the Pitot-static tube.
4. Compute and tabulate the lift (C_L) and drag (C_D) coefficients at the various angles of attack. Observe the angle at which C_L changes sign (i.e., the transition between negative and positive lift). For a symmetric airfoil such as the one used in this lab, physics dictates this angle should be zero degrees. If it is non-zero correct the angle of attack accordingly, such that zero lift corresponds to zero degrees.
5. Plot C_L and C_D on the same graph as a function of angle of attack (the corrected angle of attack if it needed to be corrected).
6. Plot the ratio C_L/C_D as a function of angle of attack.
7. Estimate the lift and form drag force from the pressure profile measurements at 0, 9 and 18 degrees.
    a. Compute the forces using gage pressure (having a large number corresponding to absolute pressure on every port is not useful).
    b. Assume the gage pressure at the trailing edge of the airfoil is equal to the pressure of the last pressure port on that side of the airfoil.
    c. Assume that the pressure at the leading edge is the stagnation pressure as measured by the Pitot-static tube. The leading edge will rotate with angle of attack and you can correct for this rotation if you wish or just ignore it saying it is a small effect
    d. Use the NACA 0012 profile provided in the lecture PowerPoint that can also be found at https://en.wikipedia.org/wiki/NACA_airfoil . You need the x position of the pressure taps that are provided in the table at the end of this document.
8. Model the airfoil as a flat plate and estimate the skin friction (although, not entirely correct here we will assume that the skin friction is independent of angle of attack). Use Equation 9.34 from your Fluid Dynamics text to find the information to make this estimate. This is likely to be an overestimate based on the calculated Reynolds number.
9. Estimate and tabulate the induced drag as a function of angle of attack. You are given formulas for induced drag in your book and in the PowerPoint presentation.
10. Estimate and tabulate the form drag as a function of angle of attack using the results of 7a.
11. On the same graph, plot the estimated skin friction drag force, the estimated induced drag force, the estimated form drag force, and the drag force measured using the force balance all as a function of angle of attack. Add the estimated skin friction drag force, the estimated induced drag force, and the estimated form drag force and compare this sum to the drag force measured using the force balance. Also, summarize these data in a table for the three angles of attack including a column for the percent difference between the force balance measurement and the estimated drag force.
12. At maximum lift, estimate the uncertainty in C_L estimated from the force balance using the truncated Taylor series approach to account for propagation of errors. Assume the uncertainty in L is 0.01 N, the uncertainty in the manometer readings is 0.05 in H_20, the uncertainty in the planform area is 0.25 mm^2, and the uncertainty in air density is 0.05 kg/m^3.

Report format:

The report is to be written in the format of a scientific paper to a general, technically oriented audience. It should have the following sections:

1. Abstract: Should state the main goal in 1-2 sentences, the main approach in 1-2 sentences, and the main findings in 1-2 sentences. It should be less than 200 words.
2. Introduction: Should state the research question and describe the overall approach. It is appropriate to provide formulas describing the overall approach. It should end with a summary of the remaining report format.
3. Experimental Methods: Should describe the entire experimental setup NOT IN CHRONOLOGICAL ORDER. Should describe any data reduction and should include statements of the resolution and/or accuracy of all measurements.
4. Results and Discussion: Should present the results in an order that provides the information to answer the research question(s). Should discuss errors and deviation from expectations when appropriate.
5. Summary and Conclusions: Should summarize *only* the findings of the work described in the paper. Should not be a summary of what was done, should not summarize the work of others. Should focus on how the work provided and answer to the research question.
6. Appendix: Scientific papers do not generally have Appendix sections. However, your report can include tables, computer programs, etc.

Extra credit 10%: Assume you were designing an aircraft with similar performance as a Cessna 172 Skyhawk (http://www.risingup.com/planespecs/info/airplane292.shtml), using a NACA 0012 airfoil; estimate the optimal angle of attack for takeoff and the required wing area. Provide this part as a separate document.

Late Penalty: I will stick with the 2.5% per day for the first two days and then 10% off per day for subsequent days with a maximum late penalty of 50%. The grade will be multiplied by the late penalty as opposed to a strict 2.5% or 10% off the top.

Upper surface tapping Port#/tap #	Distance from leading edge (mm)	Angle of pressure vector relative to chord (degrees)	Lower surface tapping Port#/tap#	Distance from leading edge (mm)	Angle of pressure vector relative to chord (degrees)
3/1	0.76	139.6	13/11	1.52	-128.8
4/2	3.81	115.3	14/12	7.62	-106.7
5/3	11.43	102.3	15/13	15.24	-99.4
6/4	19.05	97.3	16/14	22.86	-95.6
7/5	38	91.3	17/15	41.15	-90.7
8/6	62	87.6	18/16	59.44	-87.9
9/7	80.77	85.9	19/17	77.73	-86.1
10/8	101.35	84.5	20/18	96.02	-84.8
11/9	121.92	83.5	21/19	114.3	-83.9
12/10	137.16	82.7	22/20	129.54	-83.1

Table 1. Locations of static pressure taps and normal vector angle relative to chord. Port 23 is open to atmosphere and is to be used as the reference port for the height change relative to atmosphere.