

WIND TUNNEL EXPERIMENTAL PROCEDURE

MAE 175A

PART I

Pressure Distribution over an airfoil and Drag by the wake survey method

OBJECTIVE:

Measure the pressure distribution over a Clark Y-14 Airfoil at various angles of attack and determine the drag coefficient of the wing by the wake survey method. Data are obtained up to and beyond the stall angle, where the flow separates from the upper surface of the airfoil.

INTRODUCTION:

An airfoil develops Lift through generally lower pressures above the wing and higher below with respect to the pressure of the approaching air. In addition, the Lift force increases with higher angle of attack up to a critical angle. Beyond this critical angle the lift force decreases significantly and the wing is said to have “stalled”. The overall pressure distribution can be measured with small tubes embedded in the wing leading to a suitable pressure transducer.

The laboratory model is equipped with 18 pressure openings. The openings are located at 0, 7.5, 10, 20, 30, 40, 50, 60 and 70 percent chord on both upper and lower surfaces and there is an additional opening at 80 percent chord on the upper surface. To complete the pressure distribution you should extrapolate the last measurements on the upper and lower surfaces of the wing to a pressure coefficient of $C_p=0$ at the trailing edge of the wing.

Application of the momentum principle indicates that the drag force on an airfoil in the flow should be equal to the reduction in linear momentum of the flow (in the drag direction) provided that the measuring stations are taken where the static pressures are substantially equal. Since the flow approaching the airfoil is uniform, the drag coefficient may be written in terms of a downstream wake survey (as developed in Ref. 1):

$$C_d = \frac{Y_w}{c} - \frac{1}{q_\infty c} \int_{-\frac{Y_w}{2}}^{\frac{Y_w}{2}} q \, dy$$

where:

Y_w	=	width of wake
q	=	local dynamic pressure
q_∞	=	free stream dynamic pressure

It is recommended that the wake survey be made as far from the trailing edge as possible to render the static pressure effects negligible. Students may find that the wake field drag coefficient obtained in the stalled configuration disagrees with other drag measurements, and

they should examine the assumptions made in the momentum balance analysis in order to identify which of these assumptions are violated by the flow over a stalled airfoil.

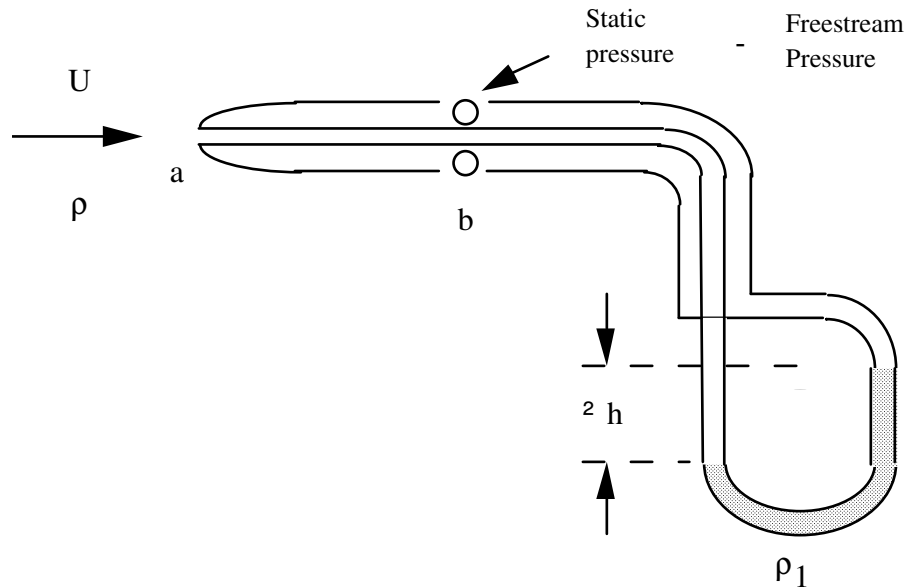
This method of drag measurement is often used on portions of airplane wings in flight to test special drag profiles or surface treatments. The pitching moment can also be obtained from the chordwise pressures by use of (Ref. 1)

$$C_{m_{LE}} = \frac{1}{c^2} \int \frac{\Delta P}{q}(x)dc$$

where: x = distance from leading edge (or other selected reference point).

PROCEDURE:

1. Using the barometer and thermometer in the laboratory determine the density of the air flowing in the wind tunnel.
2. Using the Wing Tunnel Calibration VI calibrate the wind tunnel test section by generating a plot of velocity (m/sec) versus motor frequency (0- 60 Hz) using the upstream pitot-static tube and Bernoulli's equation. Please see Wind Tunnel Laboratory Notes: week 1 for details.



Pitot Probe: Measurement of Airspeed

$$P_a + \frac{1}{2} \rho_a U_a^2 = P_b + \frac{1}{2} \rho_b U_b^2 \quad \text{where:} \quad U_a = 0 \quad \text{and} \quad U_b = U_\infty$$

$$P_a - P_b = \frac{1}{2} \rho_\infty U_\infty^2 = q_\infty \quad \text{or} \quad P_a - P_b = \rho_1 \Delta h g_e$$

and:

$$U_{\infty} = \left(\frac{2(P_a - P_b)}{\rho_{\infty}} \right)^{1/2} \quad \text{or} \quad U_{\infty} = \left(\frac{2\rho_1 \Delta h_{g_e}}{\rho_{\infty}} \right)^{1/2}$$

3. Use standard propagation of error analysis to estimate the error in U_{∞} .

$$Y = f(x_i)$$

$$\delta Y = \left[\sum_1^i \left(\frac{\partial f}{\partial x_i} \right)^2 (\delta x_i)^2 \right]^{1/2}$$

4. A pressure wing is mounted vertically in the wind tunnel. The pressure tubes (18 with locations indicated in the Appendix) from the wing are connected to the inlet nipples of the tunnel pressure transducer array sampling system. The static pressure of the test section is connected to the reference connection of the pressure transducer. The dynamic pressure of the air stream q_{∞} is measured with the Pitot probe. Dividing the pressure measured with the sampling system by q_{∞} gives the pressure coefficient at the point of the measurement:

$$C_p = \frac{P - P_{ref}}{q_{\infty}}$$

5. Operate the tunnel at airspeeds of 20, 35 and 50 m/sec and make pressure measurements on the wing at angles of attack of 0°, 4°, 8°, 12°, and 16°. Please see Wind Tunnel Laboratory Notes: week 2 for details. **Always check the zero velocity pressure measurements from the wing and pitot probe before each data set. You will need to measure and correct for any offsets in the pressure transducer at zero velocity.**

Results:

1. Plot the pressure coefficient data points (upper and lower surface) as a function of distance along the chord line of the wing and integrate to find the Normal Force coefficient C_n which is given as

$$C_n = \frac{1}{c} \int_0^c (C_{pL} - C_{pU}) dx$$

Find this normal force coefficient for all angles of attack and flow speeds.

2. Determine the Lift coefficients C_L from C_N and Plot C_L vs. α for each air-speed. Show the results on one graph for comparison purposes.

3. On a separate graph plot C_D vs. α for each air-speed. Note that this method does not measure drag viscous forces due to shear stresses and thus may under represent the total drag force on the wing. The drag force and drag coefficient measured in this experiment is the component of the normal force in the direction parallel to the free stream flow, and increases as the angle of attack increases.

4. Using the equation for the pitching moment

$$C_{m_{\text{ref}}} = \frac{1}{c^2} \int_0^c (C_{pU} - C_{pL})(x - x_{\text{ref}}) dx$$

a) Calculate the leading edge pitching moment $C_{M_{LE}}$ for the airfoil as a function of angle of attack for each velocity and present the results in a table.

b) Calculate the center of pressure for the airfoil as a function of angle of attack for each velocity and present the results in a table.

$$\frac{X_{cp}}{c} = - \frac{C_{M_{LE}}}{C_N}$$

c) Calculate the pitching moment through the quarter chord point as a function of angle of attack for each velocity and present the results in a table.

5. a). Operate the tunnel at airspeeds of 20, 35 and 50 m/sec and obtain wake pressure survey measurements in the wake of the vertically mounted pressure wing at angles of attack of 0°, 4°, 8°, 12°, and 16°. **Always check the zero velocity pressure measurements from the wing and pitot probe before each data set. You will need to measure and correct for any offsets in the pressure transducer at zero velocity..**

Note: At the smaller angle of attack values (i.e. up to about 8 degrees, the available rake can adequately cover the entire wakefield adequately. However, at a higher angle of attack, the rake may not completely cover the wake. In order to correctly measure the wakefield at these extreme values, you will need to displace the rake both above and below the airfoil. Please see the TA, Professor, or Technician for assistance for the highest angles of attack wakefield measurement setup)

b) Plot the normalized wake survey pressure distribution q/q_∞ versus distance across the wake for each angle of attack for the three different velocities.

c) Calculate the drag coefficient for the airfoil by the momentum method by integrating the wake pressure distribution for each angle of attack and the three velocities. Plot this drag coefficient versus angle of attack for each of the flow velocities used in the experiment, and compare this result to the drag force computed in part 3 above. Make sure to comment on any differences or discrepancies in the two different drag estimates.

6. Determine the effect of Reynolds Number on lift, drag, and 1/4 cord pitching moment coefficients. (Plot the lift and pitching moment coefficient from the pressure wing measurements, and the drag coefficient from the wake measurements versus Reynolds number for all available angle of attack.)

PART II

CHARACTERISTIC CURVES OF A CLARK Y-14 AIRFOIL

OBJECTIVE:

Measure the Lift, Drag and Pitching Moment of a Clark Y-14 airfoil.

DISCUSSION:

The Clark Y-14 airfoil profile is unusual in that its lower surface is straight and is taken as its chord line. The angle of attack can consequently be checked with an inclinometer contacting the lower surface.

The lift, drag, and pitching forces on the airfoil can be calculated from a force balance measurements of the axial force A' , normal force N' , and pitching moment P' relative to the sting support on the balance. The values of A' , N' , and P' are measured from strain gauge bridges on the force balance and are not independent. They interact because of mechanical coupling and deformation of the balance and must be corrected. To compensate for this interaction between the measured values, the following set of equations can be used to provided corrected values of axial force A , normal force N , and pitching moment P :

$$N = N'*.9504 - A'*.0082 - P'*.0161$$

$$A = N'*.0608 + A'*.5912$$

$$P = -N'*.1336 + A'*.0119 + P'*.1182$$

Using the corrected values of axial force A and normal force N the lift and drag can be calculated from the relations:

$$\text{Lift} = N \cos \alpha - A \sin \alpha$$

$$\text{Drag} = A \cos \alpha + N \sin \alpha$$

For conversion to lift, drag, and pitching moment coefficients the wing has a span width $b = 9.8125$ " and a chord length of $c = 2.452$ ".

PROCEDURE:

1. Using the adjustment on the drag balance set the angle of attack to zero with the chord line horizontal as determined by inclinometer.
2. Check that the normal and axial force and moment output of the drag balance is zero with no airspeed and at zero angle of attack.
3. With no airspeed operate the drag balance through a range of angle of attack from -6° to 20° and record the normal and axial force and the momentum output. The weight of the wing will affect some of these measurements and will need to be included in corrected measurements.
4. Using the LabView Sting VI, operate the tunnel at airspeeds of 20, 35 and 50 m/sec. Please see Wind Tunnel Laboratory Notes: week 3 for details.
5. Starting at an angle of attack of -4° , for a given airspeed, take readings of Normal Force, Axial Force and Pitching Moment at 2° intervals to 4° beyond the stall. (The stall point is defined as 4° beyond the maximum lift.)

In each case, hold the airspeed constant as you increase the angle of attack. Allow sufficient time between each reading for conditions to reach steady state.

RESULTS:

1. Convert Normal Force and Axial Force to Lift and Drag and transfer Pitching Moment to an axis through the quarter chord point of the airfoil. (Refer to the Operating Instructions for the Sting Balance.)
2. Plot C_L , C_D and C_M versus α . Show each graph in the same manner as described in Part I. Calculate Reynolds Number for each flow speed.
3. Compare the results obtained with corresponding measurements from the airfoil pressure distribution and wake survey experiment. Discuss any differences and estimate the possible combined reading error in balance and dynamic pressure measurements.

MILESTONES FOR EXPERIMENT

Week 1:

1. Calibrate the wind-tunnel for flow speed v. tunnel inverter frequency
2. Complete airfoil pressure distribution at three flow speeds for *at least* one angle of attack. Do as many conditions as time permits.

Week 2:

BEFORE COMING TO THE LAB YOU NEED TO HAVE REDUCED YOUR FIRST WEEKS DATA TO A WIND TUNNEL FLOW SPEED V. FAN ROTATION RATE CALIBRATION CURVE.

Week 2 Experiments:

Finish the pressure distribution measurements for all combinations of angle-of-attack and flow speed.

Perform the wake-field flow survey.

Week 3:

BEFORE COMING TO THE LAB YOU NEED TO HAVE REDUCED YOUR SECOND WEEKS DATA SET DOWN TO THE FOLLOWING:

Find the normal force coefficient for the upper and lower surfaces of the airfoil for all combinations of angle-of-attach and flow speed.

Determine the lift coefficients from the normal force coefficients and plot v. angle of attack for all required flow speeds. Also plot the drag coefficient v. angle of attack for all available conditions.

Using the equation for calculating the pitching moment, calculate the leading edge pitching moment $C_{M LE}$ for the airfoil as a function of angle of attack for each velocity and present the results in a table.

Calculate the center of pressure for the airfoil as a function of angle of attach for each velocity and present the results in a table.

Calculate the pitching moment through the quarter chord point as a function of angle of attack for each velocity and present the results in a table.

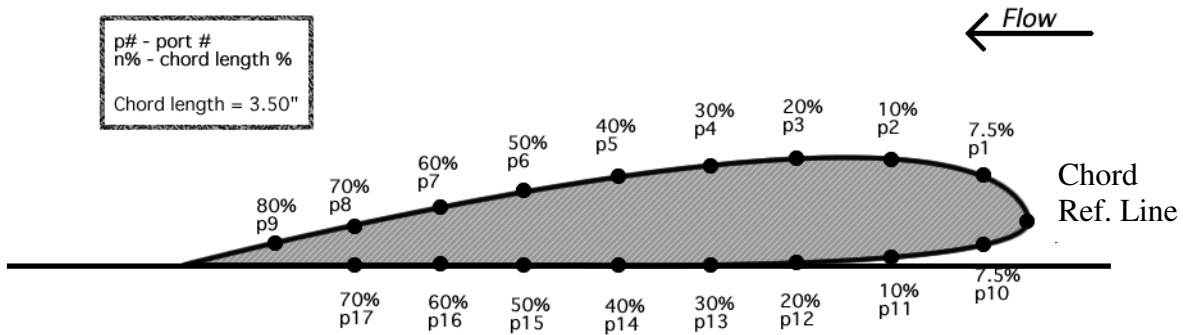
Using the downstream wake survey data, find the drag coefficient from the wake field dynamic pressure survey data v. angle of attack for each flow velocity. Compare this result with that obtained from the normal force coefficient approach and comment on any discrepancies or results that seem unusual or non-physical.

Week 3 Experiments:

Carry out the lift, drag, and pitching moment coefficient measurements using the sting assembly as discussed in Part II above.

APPENDIX

The geometry of the airfoil used for pressure measurements is shown below. Relative chord-wise (i.e. horizontal) locations relative to the leading edge of the airfoil are also shown in the figure.

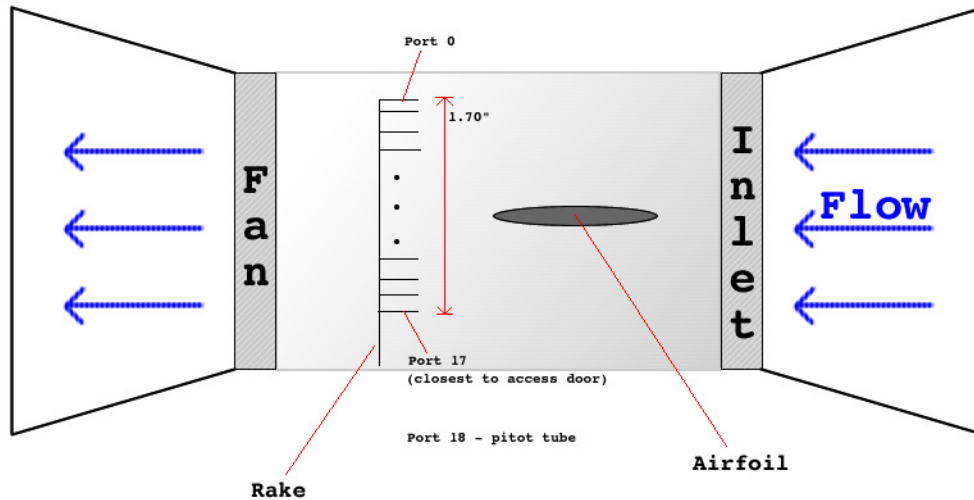


The table below gives the relative vertical displacement of each pressure port, measured from the chord reference line shown above. These displacements are given as a percentage of the chord width.

Ordinates of CY-14 Airfoil Pressure Measurements

<u>Station</u>	<u>Upper</u>	<u>Lower</u>
0.0	4.19	4.19
1.25	6.52	2.31
2.5	7.78	1.76
5.0	9.45	1.11
7.5	10.59	0.73
10.	11.48	0.50
15.	12.79	0.18
20.	13.60	0.04
30.	14.00	0.0
40.	13.64	0.0
50.	12.58	0.0
60.	10.95	0.0
70.	8.80	0.0
80.	6.25	0.0
90.	3.35	0.0
95.	1.78	0.0
100.	0.14	0.0

The Rake Probe Geometry is as follows:



Pressure port locations for wing and for rake probes:

- Rotary valve one measures pressures on wing:
 - ports 0-9 top side of wing
 - ports 10-17 bottom side of wing

Note: These pressure measurements have already subtracted off the reference static pressure (measured by the pitot-static tube) and are reported in inches of water, and thus already represent the local static pressure relative to the tunnel test-section static pressure (Δp).

- valve #2 measures pressures on the rake.
 - ports 0-17 Rake
 - Port 18 pitot stagnation

Note: These pressure measurements have already subtracted off the reference static pressure (measured by the pitot-static tube) and are reported in inches of water, and thus represent the local dynamic pressure.

When finding the pressure coefficient distribution on the airfoil, $C_p(x)$, and the momentum deficit using the rake array, students should use the freestream dynamic pressure recorded at the same time as these pressure distributions. This dynamic pressure is recorded by the *WindTunnelPressureDistribution_and_RakeSurvey.VI* during your experiment. This pressure was measured at the pitot-static tube, and was recorded by two separate pressure transducers, and is labeled “ATM” and “STAG” in the ASCII text file written by the LabViews VI. Either measurement can be used, or students may average the two values together. If you compare these dynamic pressure values with what you found during the wind tunnel calibration, you will note a modest (10% or so) discrepancy. Any idea where this comes from (the calibration is more accurate than this deviation and thus cannot explain the difference in dynamic pressure).

A drawing of the sting balance geometry is given:

Reference point (CC)

c - Balance center (Marked on wing section)

Airfoil Span (overall length of airfoil) = $9.8125 \pm 0.0625''$

Chord = $2.452 \pm 0.001''$

$1/4$ Chord

$3/4$ Chord

Socket and set screw

$D = 3.49 \pm 0.02''$

$2.98 \pm 0.010''$

N

P

Transfer of Moments: To obtain moment about the ref. point (P) from the measured pitching moment about bal. center (P_m) and normal force (N)

$$P_m = N(C+D-A) = N^*C + N(D-A)$$

$$= P + N(D-A)$$

therefore, $P = N^*C = P_m - N(D-A)$

NOTES : Location of balance center dimension A is determined during calibration where P_m reads zero when normal force is applied at this location. Value of A may vary slightly for each individual balance.

For other airfoils you may measure D by the distance between the Reference Point on your airfoil and the end of the sting sleeve.

Aerolab	Transfer of Moments	
1.2° Educational Balance		Supplied by

REFERENCES:

1. Rae, William H. Jr., Pope, Alan, "Low-Speed Wind Tunnel Testing," John Wiley & Sons, 1984.
2. Anderson, John D., "Fundamentals of Aerodynamics," McGraw-Hill, 1991.