Subsonic Wind Tunnel Laboratory Manual
AEROLAB SUBSONIC WIND TUNNEL
LABORATORY MANUAL

FOREWORD

Laboratory courses are widely regarded as useful and necessary parts of the curricula in science and engineering. To assist educators, AEROLAB has coordinated the design of experiments and of wind tunnel equipment so that any of several experiments can be set up within 15 minutes. Confidence and repeatability in the results is fostered by individually calibrating the airstreams and balance systems of each AEROLAB tunnel.

The eight experiments presented in this Manual are designed to challenge the student and to develop interest in the interplay of theory and experiment.

Laboratory reports place heavy demands on both the instructor and the student because of reliance on the student's written communication skills, ability to organize and capacity for sustained, productive work.

NACA (NASA) Reports are generally taken as models for student reports so we present (as Appendix I) instructions published by NACA.

"Low-Speed Wind Tunnel Testing" by Jewel B. Barlow, William H. Rae, Jr. and Alan Pope is an excellent source of information and is intended to be used as a reference for this manual - "Ref. 1."
Contents
FOREWORD .................................................................................................................. 1
AIR FLOW INSTRUMENTS ............................................................................................... 3
PRESSURE DISTRIBUTION OVER A CIRCULAR CYLINDER .................................... 6
WIND TUNNEL TESTS ON A 1/48 MODEL OF THE F-16 FALCON .............................. 7
MEASURING THE DRAG OF SIMPLE SHAPES & THE TURBULENCE OF THE AIR STREAM .......................................................................................................................... 9
CHARACTERISTIC CURVES OF A CLARK Y-14 AIRFOIL WITH A LEADING EDGE SLAT & SPLIT FLAP .............................................................................................................. 10
PRESSURE DISTRIBUTION OVER AN AIRFOIL .......................................................... 12
BOUNDARY LAYER ON A FLAT PLATE ........................................................................ 13
DRAG BY THE WAKE SURVEY METHOD ...................................................................... 15
SUPPLEMENTARY INFORMATION FOR REPORT WRITING .................................... 16
ORDINATES OF AIRFOILS ............................................................................................. 20
SECTION CHARACTERISTICS, MISCELLANEOUS AIRFOILS .................................... 21
Experiment 1
AIR FLOW INSTRUMENTS

OBJECT:  I. To measure the sensitivity of a Pitot-static tube to misalignment
II. To calibrate a cylindrical yaw probe

DISCUSSION:

I. A Pitot-static tube is widely used for measuring unknown velocities in fluids. Usually the direction of flow can be estimated within a few degrees at any point in a flow pattern and the Pitot-static tube pointed in the assumed direction. Our objective is to determine how large the discrepancy may be between assumed and actual flow directions before appreciable errors appear in the measurement.

II. The AEROLAB cylindrical yaw probe has three static pressure openings spaced at 45° intervals. The center opening indicates total pressure and is not directly used for angular measurements. The two outer holes are at 90° to each other. The static pressure read at each outer hole should be the same if the flow bisects the angle between the holes. The difference in pressure \( \Delta p \) would then be zero. If the flow does not bisect the angle, \( \Delta p \) may be expected to be a function of the angle \( \theta \) (which is defined as the angle between the flow direction and the bisector). \( \Delta p \) should be expressed non-dimensionally by dividing by the dynamic pressure \( q = \frac{1}{2} \rho V^2 \). The triangular block may not be set exactly perpendicular to the bisector of the angle formed by the outside holes giving rise to an "instrument error". In addition, the air velocity in the AEROLAB (or any other) tunnel is usually aligned a fraction of a degree from the horizontal direction. This deviation from the horizontal may be termed the "airstream error". It is clear that the instrument error is inverted when the instrument is inverted but not the airstream error. Erect and inverted runs may, therefore, be used to separate and evaluate these errors. The instrument error can be reduced to zero by re-adjusting the alignment block until the average between the erect and inverted curves passes through the origin. The reasoning underlying this procedure should be investigated by the student with the help of sketches.
PROCEDURE:

I. Insert the Pitot-static tube into one of the threaded fittings in the side of the test section so that the sensing head is in the center of the test section pointing upstream. Connect the leads to two ports on the 24-tube multi-manometer. Using an inclinometer, adjust Pitot-static tube for zero degree angle of attack. Run tunnel at 140 mph then measure and record the total pressure and static pressure at the Pitot-static tube. Adjust angle of attack plus and minus in 1° increments until reading changes dramatically. Record all results.

II. Insert yaw head in the same manner as the Pitot-static tube. Attach the two outside tubes to the 24-tube multi-manometer. Adjust yaw head angle of attack to zero using an inclinometer on the slotted side of the base. Run tunnel at 140 mph then measure and record pressure at P₁ and P₂. Adjust Angle of Attack plus and minus in 2° increments for a total of ±20°. Record all results. Insert yaw head through opening on other side of test section thereby inverting the instrument. Repeat the procedure.

DATA REDUCTION:

1. Plot the dynamic pressure read by the Pitot-static tube as a function of angle to the airstream.

2. Plot Δp/q for yaw head versus angle of attack for the erect and inverted position. Assume q is equal (in magnitude) to the depression of the test section pressure below atmospheric as shown on the LabVIEW display.

3. From the foregoing plots determine (a) the maximum angular misalignment for a Pitot-static tube to maintain the dynamic pressure reading within 1/2 percent of its value when aligned with the flow.

4. From the plots of the yaw head data determine (a) the instrument error, (b) the airstream inclination, (c) the calibration factor of the yaw head \( K = \frac{d(\Delta p)}{d\theta} \) taken near zero yaw.
ADDITIONAL ASSIGNMENTS:

1. Plot a theoretical curve for $\frac{\Delta p}{\rho}$ versus angle based on the equation for the pressure coefficient derived from perfect fluid theory for the flow around a circular cylinder.
   
   $$C_p = 1 - 4 \sin^2 \beta$$
   
   (where $\beta$ is the angle between a hole and the airstream). Compare with measured values.

2. For maximum accuracy the static, total and dynamic pressures measured by a Pitot-static tube should be corrected. Determine the correction to static, total and dynamic pressures for the AEROLAB Pitot-static tube (modified Prandtl type) using information from sources such as Ref. 1.

3. Using the corrections to $p_s$ you found in step 2, measure the true static pressure in the test section (with the Pitot-static tube) and divide by the pressure measured in the static pressure ring (used by the DAC to determine “q” and airspeed). If the ratio is appreciably different from unity assess the error in the yaw head calibration.
Experiment 2
PRESSURE DISTRIBUTION OVER A CIRCULAR CYLINDER

OBJECT: To calculate the pressure distribution resulting from the flow of an ideal fluid about a circular cylinder and to compare with the measured flow of a real fluid.

PROCEDURE:

Remove the top window of test section to install the pressure cylinder. Mount the cylinder to the yaw table inside the test section. Replace the top cover. Connect tubes 1 - 24 to tubes 1 - 24 on 24-tube multi-manometer. Run the tunnel at 60 mph. Measure and record all 24 pressures around cylinder (note – pressures are referenced to prevailing atmospheric pressure because the manometer reservoir is open to atmospheric pressure). Repeat procedure at 40 mph.

DISCUSSION:

As derived in several standard textbooks, the pressure coefficient in ideal flow theory at any angular position \( \theta \) on the surface of a circular cylinder is expressed by \( C_p = 1 - 4 \sin^2 \theta \).

The pressure coefficients resulting from the flow of air about a cylinder at 15° intervals will be measured and compared with theory. Since these real flow coefficients depend to some extent on Reynolds number it is recommended that measurements be taken at airspeeds of 40, 60, and 70 mph. Since the positions of the separation points are determining factors in the flow patterns, it is suggested that wool tufts be fastened to the cylinder near the equatorial diameter to indicate flow reversal and separation. (A wand with a single wool or thread tuft might also be used).

PLOT:

Plot the variation of Pressure Coefficient versus angular position for the ideal flow and the three real flows. Locate the position of separation points on the curves, if independently measured. Indicate the magnitude of Reynolds number for each curve.

NOTE:

The large size and drag of the model limits the top speed with the model in place to approximately 75 mph.
Experiment 3
WIND TUNNEL TESTS ON A 1/48 MODEL OF THE F-16 FALCON

OBJECT:  I. To obtain a Drag Polar of the F-16 Airplane.
II. To measure the static longitudinal and directional stability of the airplane

DISCUSSION:

Many thousands of hours of wind tunnel tests, ranging from overall performance characteristics to stability and control are conducted on a new military airplane. In a single laboratory session, the student can only touch upon such a program.

AVAILABLE DATA:

Built by General Dynamics, for the US Air Force, 32 ft. wing span, 47 ft. max. length, gross weight 22,500 lbs., in the Mach 2 class, powered by one F100 PW-100 power plant with 24,500 lb. thrust at sea level.

WIND TUNNEL CORRECTIONS:

An airplane flies in practically a limitless volume of air (except when near the ground) whereas an airplane model "flies" in a wind tunnel test section in a volume of air which is more confined. This difference gives rise to a number of corrections which are applied to wind tunnel data (Ref. 1). Many are quite small and in this experiment we will consider only the correction arising from the streamlines being forced straight by the flat walls of the wind tunnel whereas they are curved at corresponding distances from the full scale airplane, the so-called wind tunnel wall correction. The correction depends upon the shape and sweep of the wing as well as its span relative to the test section width but as an approximation we suggest the following additive corrections to angle of attack and to the drag coefficient for any given value of $C_L$:

\[ \Delta \alpha = 1.5C_L \text{ (in degrees)} \]
\[ \Delta C_D = 0.02C_L^2 \]

Another consideration in reducing the data is that the Sting Balance reads Normal Force and Axial Force which coincide with Lift and Drag at zero angle of attack and otherwise are related, as follows:

\[ L = N \cos \alpha - A \sin \alpha \]
\[ D = A \cos \alpha + N \sin \alpha \]
The balance reads moments about an axis through the center of the moment strain gage bridge (see Figure 5 of the EWT Operations Manual). The exact location of the balance moment axis can be determined by moving a weight along the calibration barrel (with the barrel horizontal) and noting the point where the moment changes sign and passes through zero (this was determined at AEROLAB prior to shipment as a reference). To be useful in the analysis of an airplane the moment axis should pass through the aerodynamic center (a.c.) of the airplane, which must be given or assumed. The moment read by the balance must consequently be adjusted by the Normal Force times the horizontal distance between the balance moment axes and the airplane a.c. and may be plus or minus depending on the geometry. (The two axes do not ordinarily coincide in a vertical direction either but this relatively short distance times the Axial Force may be neglected in this experiment).

PROCEDURE:
2. Measure Normal Force, Axial Force and Pitching Moment at 2° intervals from $\alpha = -4°$ to $\alpha = 16°$.
3. Remove the airplane model from the balance, rotate the balance 90° within its holder as described in the EWT Operations Manual, reinstall the model (upright as usual) and measure Side Force, Yawing Moment and Axial Force at angles of yaw of 0°, 5°, 10°, 15°, 20°, 25°, 30°.

PLOT:
(1) $C_D$ versus $C_{L(\text{potar})}$
(2) $C_M$ versus $\alpha$
(3) $C_N$ versus $\Psi$

ANALYSIS:
(1) What is the minimum landing speed for the model as configured?
(2) What is the thrust required for $M = 0.5$ at 20,000 ft. altitude (neglecting compressibility effects)?
(3) What is the static longitudinal stability $\frac{dC_m}{d\alpha}$ at $\alpha = 0$ ?
(4) What is the static directional stability $\frac{dC_N}{d\psi}$ at $\psi = 0$ ?

Suggestion: Conduct the test at 130 mph to cover the high drag range just beyond the stall.
Experiment 4
MEASURING THE DRAG OF SIMPLE SHAPES & THE TURBULENCE OF THE AIR STREAM

OBJECT:
I. To measure the drag of simple shapes at various Reynolds numbers.
II. To measure turbulence of the air stream of the AEROLAB Wind Tunnel.

DISCUSSION:

I. An inspection of the five AEROLAB models indicates that three may be classified as blunt shapes, with well defined separation points, and two as rounded shapes. One would expect little scale effect (variation of Drag Coefficient with Reynolds number) on the blunt shapes and considerable scale effect on the rounded shapes. Investigate at airspeeds of 60, 80, 100, 120, and 130 mph.

II. The drag coefficient of a sphere experiences a marked reduction when the flow in the boundary layer upstream of the separation point undergoes transition from laminar to turbulent flow. The Reynolds number associated with this transition is known as the critical Reynolds number. Its value is lower for high turbulence air streams and its magnitude can be related to the turbulence of the air stream. To define its magnitude more precisely the critical Reynolds number is taken at the point on the drag curve where $C_D = 0.3$.

The student should obtain the complete variation of drag coefficient with Reynolds numbers over an airspeed range from 50 mph to the top speed of the tunnel using the larger diameter sphere. (The smaller sphere is not large enough to undergo critical conditions even at the top speed of the tunnel).

The per cent turbulence may then be determined by referring to curves available from sources such as Ref. 1. The value of the critical Reynolds number may also be affected by the surface finish of the sphere. Hot wire anemometers are generally considered more accurate indicators of per cent turbulence.

ADDITIONAL EXPERIMENT:

Fabricate a ring of bare copper wire or fishing line with a diameter about ½ inch less than that of the turbulence sphere. Mount the sphere on the balance and operate the tunnel at an airspeed of 10 or 20 mph below the critical Reynolds number. Note the drag of the sphere. Then fasten the ring on the sphere (with an adhesive or tape) and repeat. The drag should be reduced with the ring in place. Explain the seeming paradox where adding roughness decreases drag.
Experiment 5:  
CHARACTERISTIC CURVES OF A CLARK Y-14 AIRFOIL WITH A LEADING EDGE SLAT & SPLIT FLAP

OBJECT: To measure the Lift, Drag and Pitching Moment of a Clark Y-l4 airfoil alone, with slat and with flap.

DISCUSSION:

The Clark Y-l4 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.

It is recommended that tests be conducted at a dynamic pressure corresponding to about 120 mph (about 20% below top speed) to allow for the additional power required for the model in a high-drag attitude.

The student should review the DISCUSSION of Experiment 3 regarding tunnel wall corrections, relations between Lift, Drag, Normal Force and Axial Force and the transfer of Pitching Moment to parallel axes.

The tunnel wall corrections for this test may be approximated by the following additive connections:

\[ \Delta \alpha = 1.7C_l \]
\[ \Delta C_D = 0.03C_L^2 \]

In correcting the results to infinite aspect ratio, assume elliptic lift distribution even though this condition is only an approximation, especially for the flap-deflected runs.

PROCEDURE:

1. Start out with slat and flap retracted (in the airfoil-alone configuration).

2. Set angle of attack reading to zero with the chord line horizontal as determined by inclinometer.


4. Starting at an angle of attack of \(-4^\circ\) with the wind on, take readings of Normal Force, Axial Force and Pitching Moment at 2° intervals to 4° beyond the stall.

5. Deploy the slat to about 3/16 inch slot and repeat items (3) and (4).
6. Deploy the flap and set at 45° to the chord line. Repeat (3) and (4).

DATA REDUCTION:

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.

2. Correct for tunnel wall effect and Aspect Ratio. Calculate Reynolds number.

3. Plot $C_L$, $C_D$, and $C_M$ versus $\alpha$ for (a) the wing alone (b) wing with slot and (c) wing with slot and flap.

4. Compare the measured results with NACA curves (available online) and discuss any differences. Estimate the possible combined reading error in balance and dynamic pressure measurements.

ADDITIONAL ASSIGNMENTS:

1. Measure influence of slat gap in increasing the maximum lift coefficient.

2. Measure influence of flap angle on the maximum lift coefficient.

3. Does the increase of lift coefficient of (1) plus the increase of (2) equal the increase due to both optimum slat and flap settings?
Experiment 6
PRESSURE DISTRIBUTION OVER AN AIRFOIL

OBJECT: To measure the pressure distribution over a Clark Y-14 Airfoil at various angles of attack.

DISCUSSION:
An airfoil develops Lift at a positive angle of attack through generally lower pressures above the wing and higher below with respect to the pressure of the approaching air. The overall pressure distribution can be measured with small tubes embedded in the wing leading to a suitable pressure transducer.

The AEROLAB model is equipped with 18 pressure openings. The openings are located 0, 7.5, 10, 20, 30, 40, 50, 60 and 70% chord on both upper and lower surfaces and there is an additional opening at 80% chord on the upper surface.

PROCEDURE:
1. Install the pressure wing vertically in the wind tunnel and connect the pressure tubes, in order, to the 24-tube multi-manometer. Dividing the pressure measured at any point on the airfoil by \( q \) (as seen on the LabVIEW display) provides the pressure coefficient at that point, \( \frac{p-p_{ref}}{q} = C_p \).

2. Operate the tunnel at an airspeed of 130 mph and make pressure measurements at angles of attack of 0° and 4° (or as assigned).

RESULTS:
1. Plot pressure coefficient to a suitable scale on the airfoil plots included in this manual (copies can be made for each student).
2. Plot pressure coefficients along the chord line and along a normal line (Ref. 1) and integrate to give Normal and Chordal Forces. (Use a planimeter, count squares on quadrulled paper, or use Simpson's rule to integrate).
3. Determine Lift and Draft coefficients from (2) and compare with results of Experiment 5.
4. Note that this method does not measure drag viscous forces.
Experiment 7
BOUNDARY LAYER ON A FLAT PLATE

OBJECT: To measure the velocity profile in the boundary layer at several longitudinal stations on a flat plate and to estimate the location of transition.

DISCUSSION:

Because of viscous dissipation the total pressure $p_t$ varies within the boundary layer, whereas the static pressure, $p$, remains closely equal to its value in the flow just outside the boundary layer. At any level in the boundary layer the dynamic pressure $q$ is equal to $p_t - p$ so by measuring $p_t$ with a total head tube (and using the constant value of $p$) $q$ and, therefore, the velocity can be determined at that level. There are various definitions of boundary layer thickness which are roughly equivalent. We suggest that the thickness be considered the distance from the plate to the point where the velocity reaches 99% of its free stream value.

The leading edge of the AEROLAB plate is curved in a parabolic manner rather than sharpened as in illustrations in many text books. The parabolic nose can be shown experimentally to increase the region of laminar flow.

PROCEDURE:

1. Total head readings are taken with a pressure probe with 10 open-ended tubes extending into the flow. Such a probe is often used for this purpose and is known as a boundary layer mouse. Fasten the mouse to the plate with the forward set of tapped holes in the plastic plate. The tubes are supported on small projections at approximately 0.018, 0.025, 0.030, 0.040, 0.060, 0.080, 0.100, 0.120, 0.160 and 0.200 inches from the plate. Connect the 10 tubes of the mouse (in order) to the pressure inlet nipples and connect the pressure from the static pressure ring of the tunnel to the transducer reference pressure connection.

2. Maintain airspeed of 20 mph and take total head readings at each of the positions defined by the tapped holes. Record the distances from the leading edge of the plate to the tube openings for each of these positions. Record the temperature of the air passing through the test section.
DATA REDUCTION:

1. Make individual plots of velocity versus height from the plate for each station and determine the boundary layer thickness, $\delta$, at each station.

2. Plot velocity profiles in dimensionless form, $\frac{V}{\delta}$ versus $\frac{\mu}{V_{\infty}}$. Calculate local Reynolds number for each station. Estimate location and Reynolds number for transition based on the plots.

3. Assuming zero pressure gradient along the plate and uniform external velocity, the shearing stress is given by the Von Karman integral momentum equation:

$$\tau_0 = \frac{d}{dx} \left[ \int_0^\delta \rho (V_{\infty}u - u^2) dy \right]$$

4. Approximate the derivative by taking the value of the integral (determined graphically) at successive stations and dividing by the distance between the stations (check units). Do this for the forward two stations and the last two stations.

Note: A low airspeed is recommended to form boundary layers of reasonable thickness in spite of the short distance from the leading edge of the plate.
Experiment 8
DRAG BY THE WAKE SURVEY METHOD

OBJECT: To measure the drag coefficient of a wing by the wake survey method.

DISCUSSION:

Application of momentum principles indicates that the drag force on an airfoil in a flow should equal 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):

\[ C_D = \frac{Y_w}{c} - \frac{1}{q_0} c \int q dy \]

Where

- \( Y_w \) = width of wake
- \( q \) = dynamic pressure in wake
- \( q_0 \) = upstream dynamic pressure

It is recommended that the wake survey be made as far from the trailing edge as possible to render static pressure effects negligible. These assumptions preclude the use in highly rotational flows such as those in the wake of an airfoil near the stall or with flaps deflected.

This method of drag measurement is often used on portions of airplane wings in flight to test special drag profiles or surface treatments.

PROCEDURE:

Install pressure wing vertically in the test section and the 18-hole total pressure rake downstream of the airfoil. Make wake measurements at \( \alpha = 0^\circ, 2^\circ \) and \( 4^\circ \), or as assigned.

COMPARE:

The values obtained with corresponding readings from balance readings on the plain airfoil with proper consideration of aspect ratios.
APPENDIX I

SUPPLEMENTARY INFORMATION FOR REPORT WRITING

The following information is quoted from the Manual for NACA Editors, NACA Washington, 1952, for your assistance in writing reports.

The SUMMARY Section:

NACA papers always begin with a summary, which is concise and accurate condensation of the entire paper. Although this section is characterized by briefness, the following items should be included: The object and scope of the work, the information obtained, and the main conclusions reached. Only essential ideas should be given and specific statements are of more value than generalities.

From the summary readers, indexers, the bibliographers should be able to obtain a fairly complete idea of the material contained in the paper. For this reason, the summary should be an independent unit; therefore, mention of equations, tables, and figures by number must be avoided, symbols must be adequately defined, and references must be identified other than by the number given in the list.

The INTRODUCTION Section:

The introduction serves as a preparation for the material to follow and relates the current work on the subject to the field. As much of the following material as is applicable should be included in any logical order:

1. The status of the problem prior to the present research
2. The purpose of the investigation precisely defined
3. The conditions under which the work was done and the procedure, if unusual
4. The scope of the present work and its connection with the general problem.
5. Recognition of similar work on the subject
6. Significance of the material treated

In addition, it may be desirable to state where and when the work was done. Such mention should occur in the introduction unless it is specifically included in a following section.

If valuable help has been received from a person not connected with the investigation, a brief courteous acknowledgment can be made at the end of the introduction; the person should be mentioned by full name and title. The organization with which the person is associated should be added after his name if the contribution was a result of his affiliation with the organization.
The DESCRIPTION OF APPARATUS Section:

For papers presenting experimental data this section is usually a brief but adequate discussion of the apparatus used, the material employed, the models tested, and the experimental setup. Unless the equipment is new or modified, suitable reference to a published description is satisfactory. Dimensions and descriptions of unmodified, permanent equipment should be kept in the present tense. Trade names of equipment or material, including aircraft and engines, may be used, if necessary, for identification and if no evaluation is presented. Trade names and designations should be carefully checked for correct form. Any sketches or photographs of the equipment, setup, and tests in progress should be referred to in this section.

The RESULTS Section:

A well-organized and objective presentation of the results should be given. Not only the results, but also the method of computation or derivation used to obtain them should be presented unless it is described in another section, for example, "Procedure." If the method is involved, one complete example may be included; however, if this example entails a lengthy computation or derivation, it may be put in an appendix and only the main steps indicated under "Results".

Tables and figures that show the results should be referred to in this section. A tabular form for the results is more useful if many readers might want to plot the results in a variety of forms; graphs are preferable in showing trends and comparisons. All statements about the results and any numerical values cited from them should agree precisely with the tables and figures.

In short papers the presentation of results may be combined with other sections, such as "Procedure" or "Discussion." The heading should be altered accordingly, for example, "Results and Discussion".

The DISCUSSION Section:

Discussion of the results, together with their analysis, to show that the conclusions are warranted is one of the most important parts of the paper. Each major conclusion should be clearly explained and comparisons should be made with results of similar work by other investigators. If the results have an immediate application, this should be pointed out in the discussion and, if possible, an example should be worked out to show the method of application. All statements should be clear to readers who are in other fields of aeronautical science and may not be so well acquainted with the subject as the author.
The APPENDICES Section:

Related material desirable as supporting evidence but not essential to the development of the paper itself - material such as derivations - may well be placed in an appendix following the concluding section. Only in rare cases are groups of tables or figures presented as an appendix.

Appendices should be referred to in the text. This is because only material related closely enough to the text to warrant mention should be appended. For reference each appendix of a group should be identified as appendix A, appendix B, and so forth, but a single appendix need not be thus identified. In addition, an appendix should be given a title (e.g. "Section Characteristics of Miscellaneous Airfoils") whenever possible. Appendices should preferably be arranged in the order of their mention in the text. This order, however, may not be feasible if it is desirable to maintain a certain logical reference to a list of symbols, which is one of a group of appendices, is either first or last.

In typed papers each appendix begins on a new page. In order to save space in printed reports, however, an appendix follows continuously after the signature. The heading is set full measure and the text is set in two columns beneath it.
DATA SHEET FOR EXPERIMENT 6

Date____________________
Test Section Airspeed____________________

Chord C = 3.50''

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See Figure 1 for wing cross section and dimensions
## ORDINATES OF AIRFOILS

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# AEROLAB SUBSONIC WIND TUNNEL LABORATORY MANUAL

## SECTION CHARACTERISTICS, MISCELLANEOUS AIRFOILS

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Abbreviations: B = Boeing; S = Sikorsky, G = Goettingen; C = Clark; N = US Navy

Refer to NACA Tech Reports 628 & 669.
Figure 1 | Clark Y14 Pressure Tap Locations