UNCLASSIFIED

AD NUMBER:	AD0053360
LIMITATION CHANGES	
TO: Approved for public release; distribution is unlimited.	
FROM: Distribution authorized to US Government Agencies and their contractors; Administrative and Operational Use; 7 Oct 1954. Other requests shall be referred to the Office of Naval Research, Arlington, VA 22217.	
AUTHORITY	
ONR ltr dtd 13 Sep 1977	

THIS PAGE IS UNCLASSIFIED

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

UNCLASSIFIED

AD 53360

Armed Services Technical Information Agency

Reproduced by

CLASSIFICATION CHANGED TO UNCLASSIFIED

BY AUTHORITY OF ASTIA RECLASS. List No. 89

Date 10 Aug 1956 Signed Richard L. Reedy

OFFICE SECURITY ADVISOR

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

UNCLASSIFIED

NOTICE: THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 and 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

EXPERIMENTAL TECHNIQUES FOR ANALYZING THE TURBULENT BOUNDARY LAYER

By
JOSEPH J. CORNISH III

Conducted For

OFFICE OF NAVAL RESEARCH

Under

CONTRACT Nonr 978(01)

By

THE AEROPHYSICS DEPARTMENT

Of

MISSISSIPPI STATE COLLEGE

Research Report No. 8 October 7, 1954

Table of Contents

List of Figures

Symbols

c - airfoil chord (5 feet)

C_f - skin friction coefficient

h - total head within the boundary layer

H - boundary layer shape parameter

p - surface static pressure

q - dynamic pressure

R_y - Reynolds number based on local velocity and height y above the surface

u - velocity within the boundary layer

U - local velocity outside the boundary layer

u^* - friction velocity

u', v' - turbulence fluctuation velocities

δ_f - flap deflection angle

δ^* - displacement thickness

ν - kinematic viscosity of air

ρ - density of air

θ - momentum thickness

τ - surface shearing stress

subscripts

i - initial conditions

o - surface conditions

l - local conditions

y - distance perpendicular to surface

Abstract

In this report some of the methods for analyzing the turbulent boundary layer are applied to experimental data measured in full scale flight test. The values of turbulent surface shear coefficient, C_f, were obtained using several experimental techniques and theoretical methods.

The measured boundary layer growth was very much in excess of the growth predicted by Ross' treatment of the momentum equation. The values of trubulent shear measured by Clauser's method were in good agreement with values found by Preston's method. However, the Squire and Young formula used with experimentally determined values of momentum thickness and velocity yielded values of surface shear considerably higher than either of the experimental methods. The values of surface shear obtained from the von Karman momentum equation showed erratic scatter and, in general, increasing trends toward separation.

Introduction

The ability to compute the growth of the boundary layer on a surface and to predict its subsequent separation from the surface is of primary importance to the design aerodynamicist. The von Karman momentum equation (Ref. 1), written as

$$\frac{d\theta}{dx} = \frac{C_f}{2} - (H+2)\frac{\theta}{U}\frac{dU}{dx} \qquad (1)$$

has been used with success to predict the behavior of laminar boundary layers, (Refs. 2, 3). Furthermore, Clauser (Ref. 4) has found agreement between this equation and experiment for "equilibrium" turbulent boundary layers. In general, however, Equation (1) shows considerable disagreement with experimental data in the case of turbulent boundary layers particularly near separation,(Refs. 5 6). The cause of this disagreement has been attributed, by some, to the fact that Equation (1) neglects the stresses due to the turbulent motion in the boundary layer.

In view of these discrepancies, there have been revisions made to Equation (1) by Bidwell (Ref. 7), Goldschmied (Ref. 6), van Le (Ref. 8), Ross (Refs. 9, 10, 11) and others. These revisions consist, for the most part, of the inclusion of stresses due to the turbulence in the boundary layer.

Ross (Ref. 9) has written the revised momentum equation as

$$\frac{d\theta}{dx} = \frac{C_f}{2} + (H+2)\frac{\theta}{\rho U^2}\frac{dp}{dx} + \frac{1}{U^2}\int_0^\delta \frac{\partial}{\partial x}\left(\overline{u'^2} - \overline{v'^2}\right)dy \qquad (2)$$

where the last term in Equation (2) is due to the anisotropy of the turbulence. This last term has been estimated by Ross who shows that

Equation (2) may be written

$$\frac{d\theta}{dx} \approx \frac{c_f}{2} - \left[(H+2)(\theta/U)(dU/dx)\right] + \left[C\,\theta\,(dH/dx)\right] \quad (3)$$

Ross further suggests that Equation (3) may explain why Clauser (Ref. 4) obtained good agreement between Equation (1) and "equilibrium" boundary layers since in Clauser's work the changes in H were relatively small.

Methods of predicting boundary-layer growth have also been offered by Rotta, (Ref. 12), Kalichman (Ref. 13) and others. In general these methods are based on the von Karman momentum equation or some other treatment of Prandtl's original boundary layer equations.

Since all of the methods of predicting turbulent boundary layer growth require some knowledge of the surface shear, the problem is further complicated by the lack of a simple accurate experimental method for the determination of turbulent surface shear. Many techniques have been proposed for the measurement of shear in turbulent flow but most of these methods, although accurate, are too complex or delicate to be easily used outside the laboratory. The hot-wire anemometer has been developed to yield very accurate data (Refs. 5 and 14) and it is used almost exclusively in laboratory measurements of turbulence properties. Other developments for shear measurement include heat transfer elements (Ref. 15) and free floating elements (Ref. 16) which measure the shear directly. Also Stanton (Ref. 17) devised a method for determining shear from the properties of the laminar sub-layer. All of the above methods require rather complicated apparatus and for the most part are suitable only under favorable conditions.

Ludwieg and Tillman (Ref. 19) have found that turbulent boundary layer profiles may be plotted non-dimensionally to form a universal curve which is independent of pressure gradient. And using this universal curve as a basis, Clauser (Ref. 4) has presented a method for the determination of the turbulent surface shear from the mean velocity distribution in the boundary layer. Goldschmied (Ref. 18) also suggested a very similar method. Both of these methods exploit the existence of a region of similarity near the wall in turbulent boundary layers. Preston also has developed a technique for measuring turbulent shear based on this region of similarity, (Ref. 20). Although Clauser's method and Goldschmied's method require a plot of the mean velocity profile, Preston accomplishes the same result with a single pitot tube.

CONFIDENTIAL

Apparatus and Methods

The test vehicle for these tests was a modified Schweizer TG-3 sailplane (Figure 1). The measurements were made on the left wing panel in a test strip located some three feet outboard of the fuselage. The airfoil in the test section is the NACA 4416 with a chord of five feet, (Figure 2). The surface of the wing is smooth, the plywood leading edge being filled with spot putty and wet-sanded. There are several breaks evident in the contour, one at 35% chord where the fabric covering joins the plywood leading edge, another at 47.5% chord where the riblets end, and one at 62.5% where there is a partition built inside the wing. The airfoil has a 25% chord plain unslotted flap which is perforated for suction.

The airplane flight velocity was measured with a balanced pitot-static system and a sensitive Kollsman airspeed indicator. The static pressure was measured with a static sonde or "bomb" which trailed some 25 feet below the aircraft. The pitot pressure was measured with a Kiel type total head tube.

The velocity distributions were obtained from "pressure tapes" which could be adjusted to measure the static pressure at any chordwise position. These pressures in conjunction with the readings from a total head tube of the Kiel type mounted in the free stream enabled the local velocity distribution to be calculated.

The velocity distributions on the upper surface of the test section, measured at airspeeds of 40, 42, 45, and 50 miles per hour, are shown in Figure 6. In all cases breaks are seen to occur at approximately 47.5 and 75%. It is thought that these breaks in the velocity distributions were caused by the surface irregularities mentioned previously and shown

CONFIDENTIAL

in Figure 2. The velocity distributions were measured once at the beginning of the test schedule and once during the tests. The repeatability of measurement is indicated by the double set of data points shown.

The point of transition from laminar flow to turbulent flow in the boundary layer was determined by the use of an aural stethoscope such as described in Ref. 21. A plot of transition position versus airspeed is shown in Figure 5. The location of transition in the boundary layer as detected with the stethoscope was checked periodically during the test schedule. Transition was said to have occurred when bursts of turbulence could be heard with the stethoscope. Later in the tests, when the surface shear was being determined by Preston's method, transition was detected with a pitot tube placed on the surface. Transition was taken to be where there was a sudden rise in the measured velocity.

The boundary layer profiles were measured with a "mouse" one inch in height consisting of nine pitot tubes and one static pressure tube, (Figure 3). The pressure from this mouse was photographically recorded from a multiple U-tube water manometer. Profiles were measured at intervals of 1.50 inches beginning at the 5.0% chord position and continuing to the 70% chord position or until the boundary layer had grown thicker than the uppermost tube on the mouse. At each of the chordwise positions, two profiles were measured at 40, 42, 45, and 50 miles per hour airspeed. A typical set of such profiles is shown in Figure 7 and the data reduced to the conventional parameters, momentum thickness, θ, displacement thickness δ^* and shape parameter $H = \delta^*/\theta$ are presented in Figure 8.

CONFIDENTIAL

In order to measure surface shear by Preston's method, it was necessary to construct a pitot tube similar to those used by Preston (Ref. 20). All of the tubes used by Preston had a ratio of inside diameter to outside diameter of 0.6 ± ½% and ranged in outside diameter from 0.02915 inches to 0.1214 inches. The tube used in the present experiment was 0.0351 inches outside diameter with a ratio of inside to outside diameter of 0.599, (Figure 4). The tube was made of stainless steel hypodermic tubing which is commercially available.

CONFIDENTIAL

CONFIDENTIAL

Discussion

In view of the mathematical difficulties encountered in theoretical treatment of turbulent boundary layers, there has been a great need for empirical information. As a result of such experimental investigation, Ludwieg and Tillman (Ref. 19) established the existence of a region of similarity near the wall in turbulent boundary layers which is independent of the pressure gradient of the free stream, (Figure 9).

Clauser (Ref. 4) has replotted the curve of Figure 9 with surface shear as a parameter and thus developed a method for the determination of turbulent surface shear coefficients. A sample profile from the present data is shown on Clauser's plot, (Figure 10). In general, the data had a slight tendency to deviate from the curves as the surface was approached. It is thought that this deviation is caused by the displacement of the effective centers of the pitot tubes in the immediate vicinity of the wall. The divergence of the data points from the upper end of the curves indicates that the upper limit of the similarity region has been reached. In practice, the data are plotted as shown and the values of surface shear coefficient are read directly. Surface shear coefficients obtained by this method are shown in Figure 11.

As mentioned previously, Goldschmied has also suggested a similar method using the Ludwieg and Tillman "universal" curve and a trial and error technique for finding surface shear, (Ref. 18).

Preston has exploited the existence of the similarity region in a somewhat different method utilizing a round pitot tube which rests on the surface. Noting that in this region the velocity is only a function of surface shear, the properties of the medium and some characteristic length, Preston has developed a universal non-dimensional

CONFIDENTIAL

relation for the surface shear stress involving the difference between the pressure measured by the pitot tube and the static pressure of the wall. Preston's curve is shown in Figure 12. This curve should be valid for other geometrically similar tubes provided the tubes lie within the region of similarity. Values of skin friction coefficient found by this method are also presented in Figure 11.

Good agreement is shown in Figure 11 between values obtained by Clauser's method and values found by Preston's method with the exception of a region between the 47% and 57% chord stations. The drop in shear in this region is thought to result from the surface irregularities previously mentioned.

Values of the surface shear computed using the momentum equation (Equation 1) are also presented in Figure 11. Skin friction coefficients computed by this method show considerable scatter and are generally in disagreement with the other methods. Some of the discrepancies may be attributed to the inaccuracies in finding the slopes of the experimental curves of the parameters involved. However, as separation is approached, the skin friction coefficients from momentum balance show a violently increasing tendency which is contrary to known physical behavior. This error is explained by Ross who maintains that as separation is approached and H begins to increase, the correction to the momentum equation (Equation 1) is of increasing importance.

It is interesting to note the agreement shown between skin friction coefficients from momentum balance and the coefficients from the other methods in the region from 25% to 35% chord at an airspeed of 40 miles per hour. Figure 8 shows that H is practically constant in this region. According to Ross (Ref. 9) the correction term in the momentum equation

(Equations 2 and 3) vanishes under these conditions and Equation 1 should hold.

As a further comparison, values of surface shear coefficient were computed from the Squire and Young relationship using experimental values of local velocity and momentum thickness. At the airspeeds above 42 miles per hour, the momentum equation yielded values so scattered that they were not included in the comparison.

Ross (Ref. 9) has presented a new solution to the momentum equation (Equation 3).

Taking

$$G = H - \left[\frac{C_f}{2}\left(\frac{\theta}{U}\right)\left(\frac{dU}{dx}\right)\right] - C\,U\left(\frac{dH}{dU}\right) \qquad (4)$$

He writes Equation 3 as

$$\frac{\theta}{\theta_i} = \left(\frac{U_i}{U}\right)^{G+2} \qquad (5)$$

Ross further found that in strong adverse pressure gradients where

$$-\left(\frac{\theta}{U}\right)\left(\frac{dU}{dx}\right) \geq \frac{C_f}{4} \qquad (6)$$

that G takes the value 2.8.

The data from the present experiment have been presented in the form suggested by Equation 5. The curve representing the data from which Ross' value of G = 2.8 was obtained is also shown. Some of the data points shown do not meet the requirements of Equation 6, which effectively states that the pressure gradient term must be predominant. However, within the limits of experimental scatter, the data appear not to depend upon Equation 6 as a criterion, all of the points showing the same trend.

Ross further states that unless two-dimensional flow is maintained Equation 5 gives results which fall apart from the curve $G = 2.8$. In order to determine the two-dimensionality of the flow in the present work, nylon tufts were attached to the wing in the test section and the motions and positions of the tufts were observed.

In no case was there excessive motion of the tufts nor did the tufts appear to indicate a cross flow within the region where the data were taken. At the lower speeds and at the rear most chordwise positions there was considerable fluttering and in some cases reversal of the tufts. However, due to the thickness of the boundary layer no data were gathered under these conditions.

The value of $G = 6.3$ determined from the present data indicates that the growth of θ in the test section is much faster than would be expected from the results of Ross' work. The high values of θ are also evident in the Squire-Young curves (Figure 11), which predict high values for the skin friction coefficients.

The boundary layer data are also presented in a form suggested by Goldschmied (Ref. 18) in Figure 14. Goldschmied has shown that in an adverse pressure gradient there exists some height in the boundary layer at which the total head is invarient with chordwise position. Above this height, the total head in the boundary layer decreases as the trailing edge is approached and below this height the total head increases as the trailing edge is approached. At the surface, the total head is equal to static pressure and increases by definition. As the total head at various heights converges, separation occurs. The present data confirm the existence of the height at which the total head is constant with chordwise position, but no effect was made to test the separation criterion. In Figure 14 it is seen that a value of total head coefficient equal to one-half of the free stream value occurred at a constant height above the wing surface. This value is the same as that obtained by Goldschmied.

Concluding Remarks

The results of the present investigation indicate good agreement between Clauser's method and Preston's method for the determination of the surface skin friction coefficient in the turbulent boundary layer. In view of simplicity of operation and data reduction, Preston's method is more attractive. However, where boundary layer profiles are to be measured, Clauser's method allows the determination of the skin friction in addition to the usual parameters.

The existence of some height above the surface at which the total head in the turbulent boundary layer has a constant value was experimentally confirmed. But due to the suction applied between the 75% and 100% chordwise stations on the airfoil the method of separation prediction suggested by Goldschmied was not examined.

The boundary layer data plotted in the manner suggested by Ross show considerable disagreement with Ross' results. Due to the possibility of three-dimensional flow in the boundary layer it is felt that further examination of the data and the theory be attempted before drawing definite conclusions.

References

1. "On Laminar and Turbulent Friction," von Karman, T., NACA TM 1092, 1946.
2. "Lecture Series 'Boundary Layer Theory', Part I - Laminar Flows," Schlichting, H., NACA TM 1217, April 1949.
3. "On the Momentum Equation in Laminar Boundary Layer Flow a New Method of Uniparametric Calculation," Thwaites, B., R. and M. No. 2587, British A.R.C. 1952.
4. "Turbulent Boundary Layers in Adverse Pressure Gradients," Clauser, F. H., Johns Hopkins University, June 1953.
5. "Investigation of Separation of the Turbulent Boundary Layer," Schubauer, G. B., and Klebanoff, P. S., NACA TN 2133, August 1950.
6. "Skin Friction of Incompressible Turbulent Boundary Layers Under Adverse Pressure Gradients," Goldschmied, F. R., NACA TN 2431, August 1951.
7. "Application of the von Karman Momentum Theorem to Turbulent Boundary Layers," Bidwell, J. M., NACA TN 2571, December 1951.
8. "The von Karman Integral Method as Applied to a Turbulent Boundary Layer," Van Le, N., Journal of the Aeronautical Sciences, Sept. 1952.
9. "An Empirical Method for Calculation of the Growth of a Turbulent Boundary Layer," Ross, Donald, and Robertson, J. M., Journal of the Aeronautical Sciences, May 1954, p. 355.
10. "Integration of the Reynolds Equations for Incompressible Turbulent Boundary Layers," Ross, Donald, Ordnance Research Laboratory Report NOrd 7958-268, May 1953.
11. "Evaluation of the Momentum Integral Equation for Turbulent Boundary Layers," Ross, Donald, Journal of the Aeronautical Sciences, July 1953.

12. "Contribution to the Calculation of Turbulent Boundary Layers," Rotta, J., David Taylor Model Basin Translation 242, Nov. 1951.

13. "A New Method for Calculating the Turbulent Boundary Layer and Determining the Separation Point," Kalichmann, L. E., Comptes Rendus Acad. Sci. USSR, Vol. 38, No. 5-6, 11-12, Feb. 1943, pp 180/185.

14. "Development of Turbulence Measuring Equipment," Kovasznay, L.S.G., NACA TN 2839, January 1953.

15. "Instrument for Measuring Wall Shearing Stress of Turbulent Boundary Layers," Ludwieg, H., NACA TM 1284, May 1950.

16. "Direct Measurements of Skin Friction," Dhawan, S., NACA TN 2567, January 1952.

17. "On the Conditions at the Boundary of a Fluid in Turbulent Motion," Stanton, T. E., Marshall, D., and Bryant, C. N., Proc. Roy. Soc. A Vol. 97, p. 413, 1920.

18. "Theory of Incompressible Turbulent Skin Friction and Prediction of Turbulent Separation," Goldschmied, F. R., Goodyear Aircraft Corp. GER-5388, May 1953.

19. "Investigations of the Wall Shearing Stress in Turbulent Boundary Layers," Ludwieg, H., and Tillman, W., NACA TM 1285, May 1950.

20. "The Determination of Turbulent Skin Friction by Means of Pitot Tubes," Preston, J. H., Fluid Motion Sub-Committee, Aeronautical Research Council, 15,758, F. M. 1883, March 1953.

21. "Boundary Layer Studies on a Sailplane," Raspet, A., Aeronautical Engineering Review, Vol. 11, No. 6, June 1952.

MODIFIED SCHWEIZER TG-3 SAILPLANE
WITH ADJUSTABLE FLAP

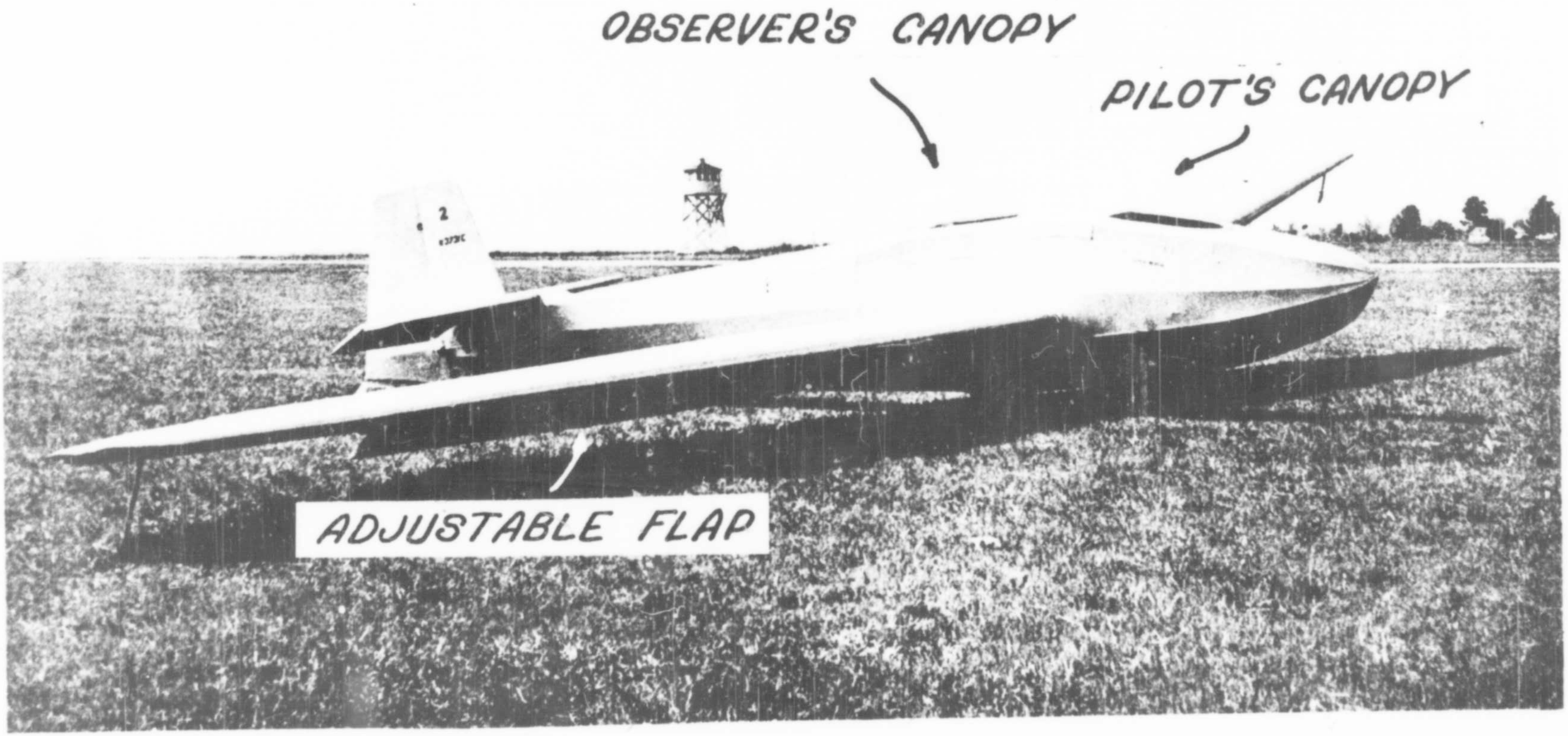
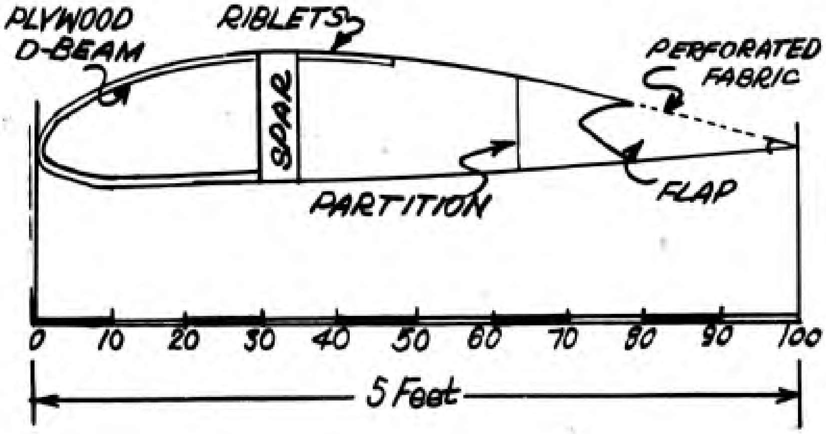


FIG. 1

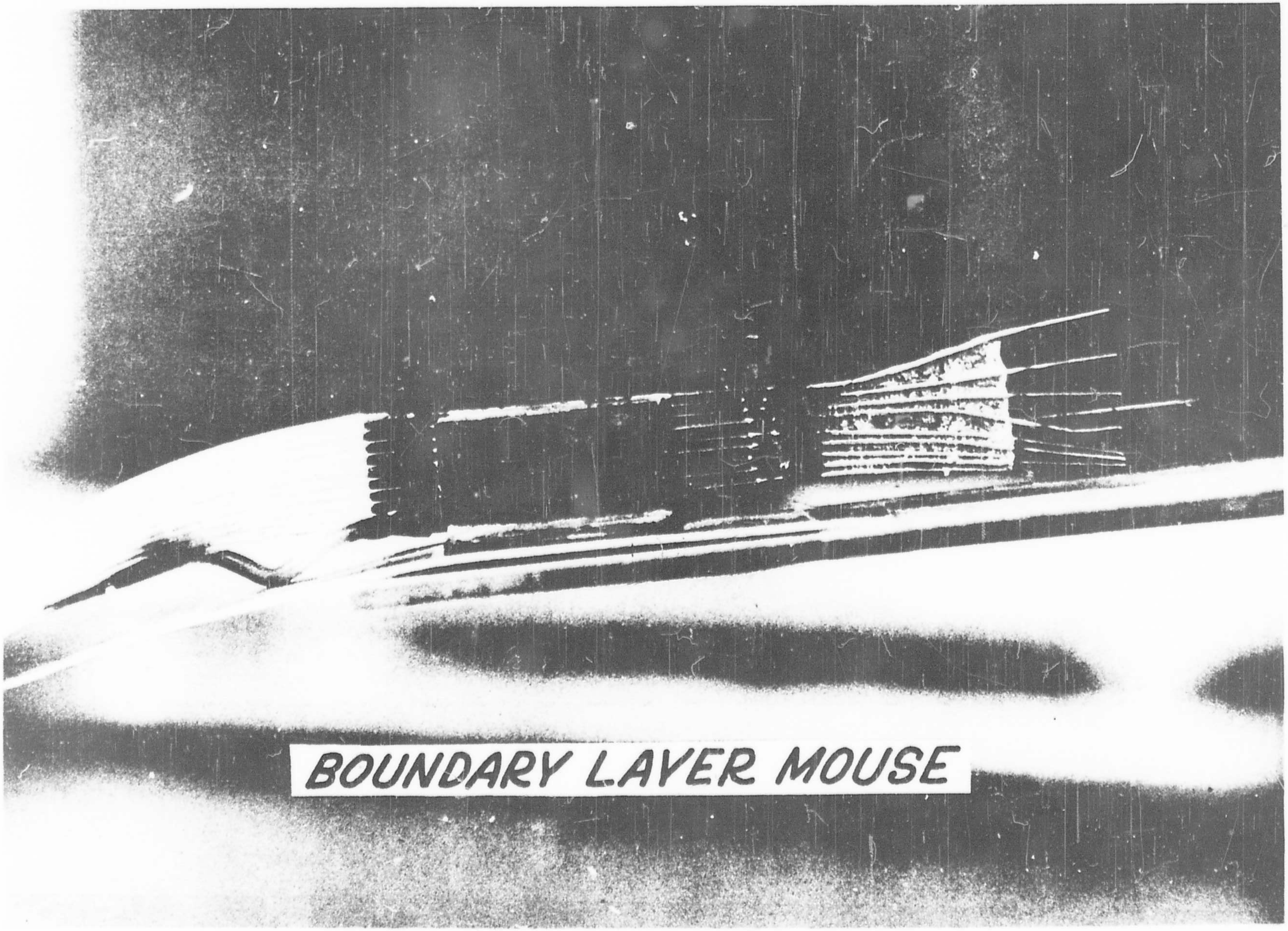
FIGURE 2

CROSS-SECTION OF NACA 4416 AIRFOIL SHOWING INTERNAL ARRANGEMENT



CHORDWISE POSITION % x/c	UPPER SURFACE	LOWER SURFACE
1.25	3.275	-1.910
2.50	4.449	-2.645
5.00	6.130	-3.490
7.50	7.380	-3.959
10	8.365	-4.248
15	9.890	-4.470
20	10.940	-4.430
25	11.660	-4.248
30	12.000	-4.000
40	12.000	-3.470
50	11.230	-2.902
60	9.930	-2.283
70	8.135	-1.655
80	5.930	-1.099
90	3.285	-6.085
95	1.785	-0.384
100	0.1707	-0.1707

FIG. 3



CONFIDENTIAL FIG. 4

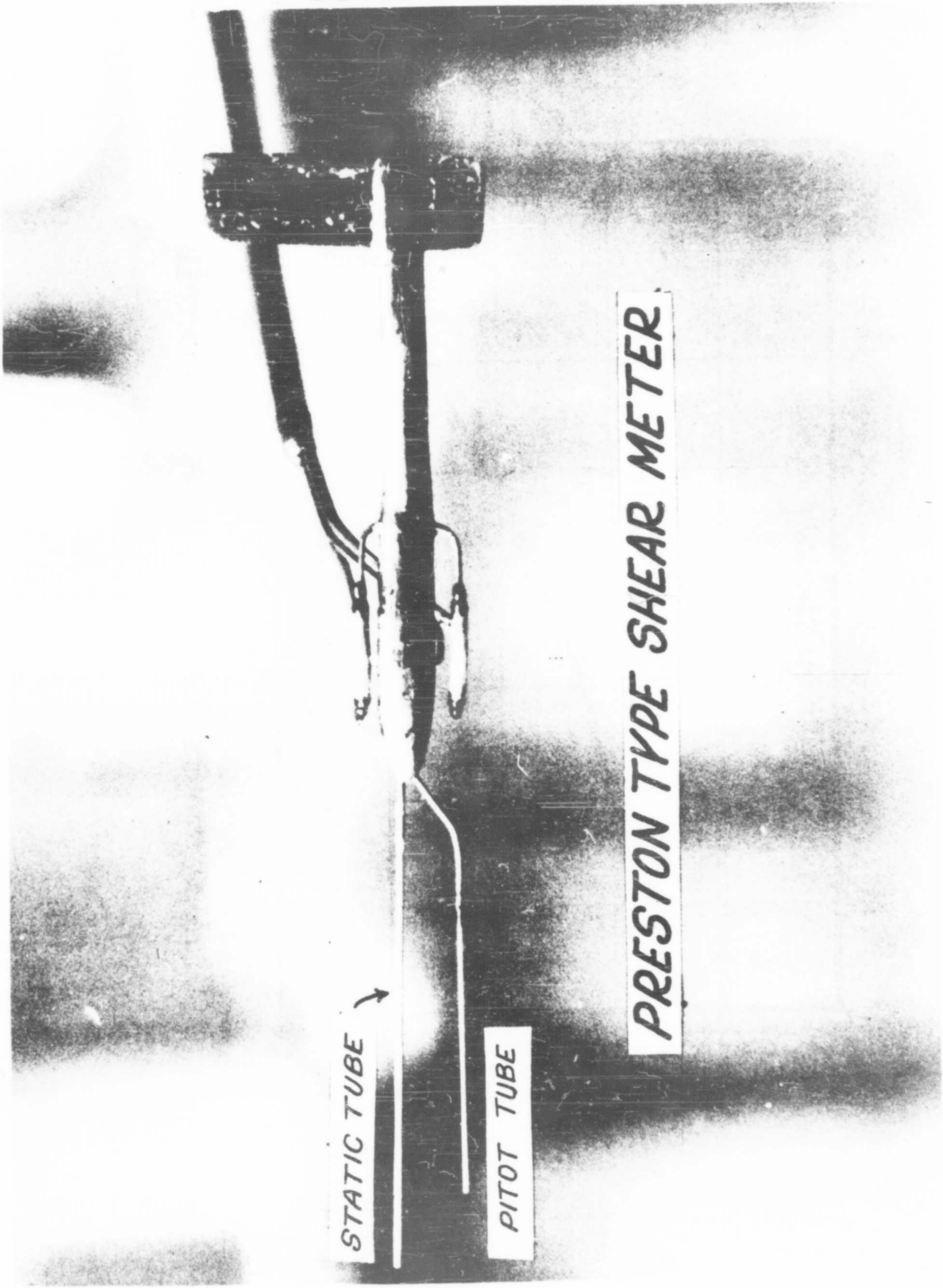

PRESTON TYPE SHEAR METER

FIGURE 5

LOCATION OF TRANSITION VERSUS AIRSPEED

$\delta_f = 0°$

FIGURE 6

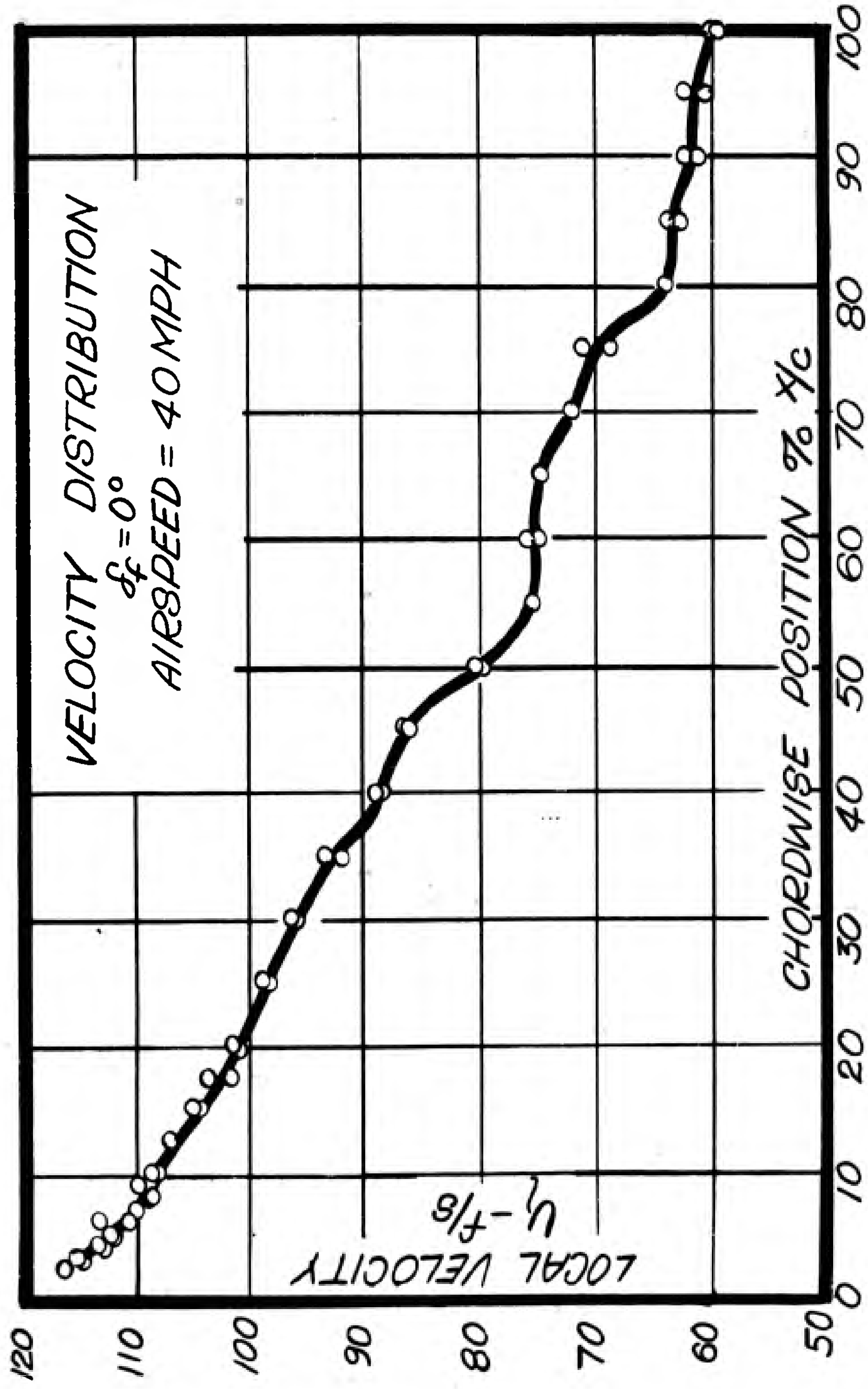

VELOCITY DISTRIBUTION
$\delta_f = 0°$
AIRSPEED = 40 MPH
CHORDWISE POSITION % x/c
LOCAL VELOCITY
U_l - f/s
0
10
20
30
40
50
60
70
80
90
100
50
60
70
80
90
100
110
120

FIGURE 6
(CONTINUED)

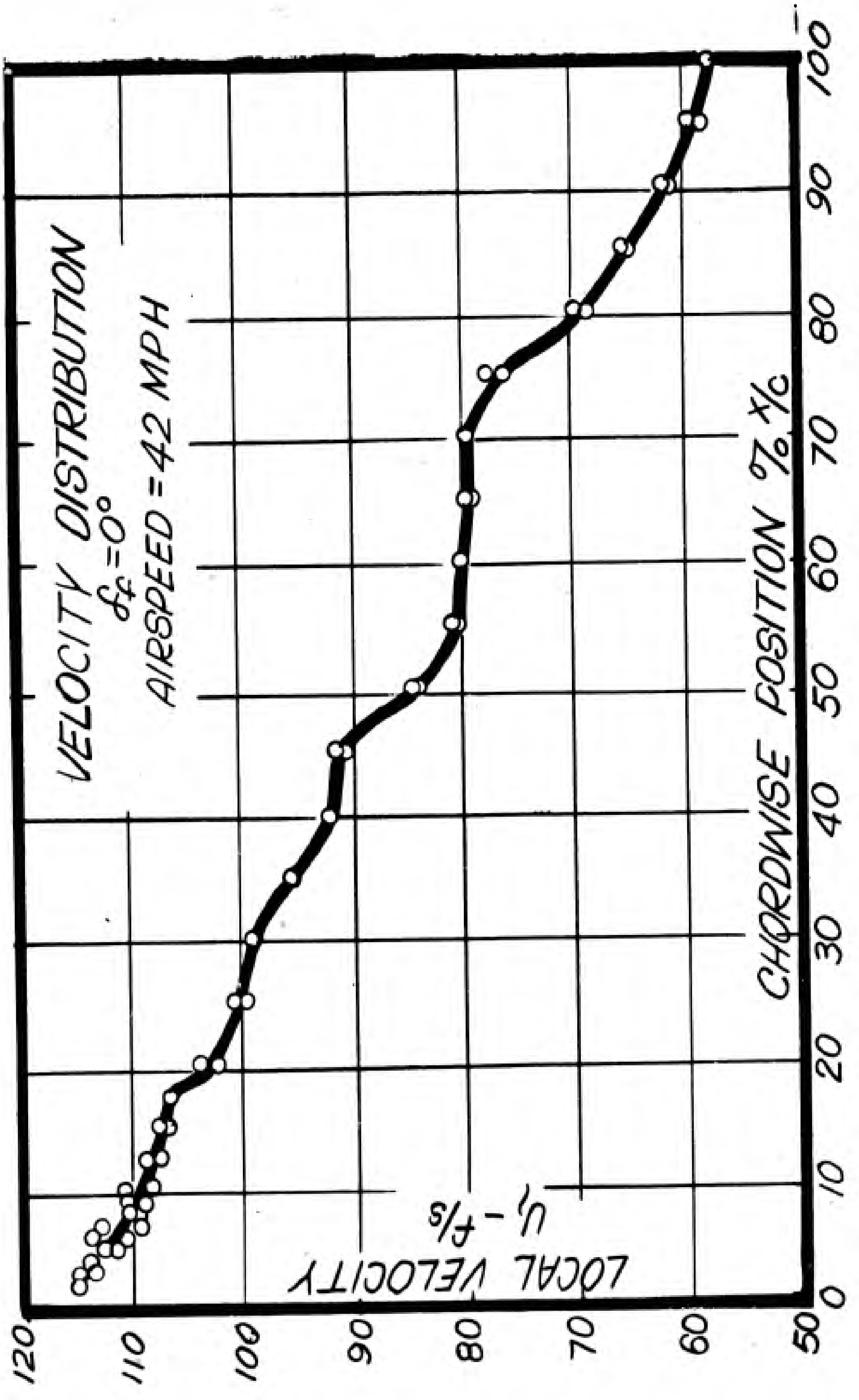


FIGURE 6
(CONTINUED)

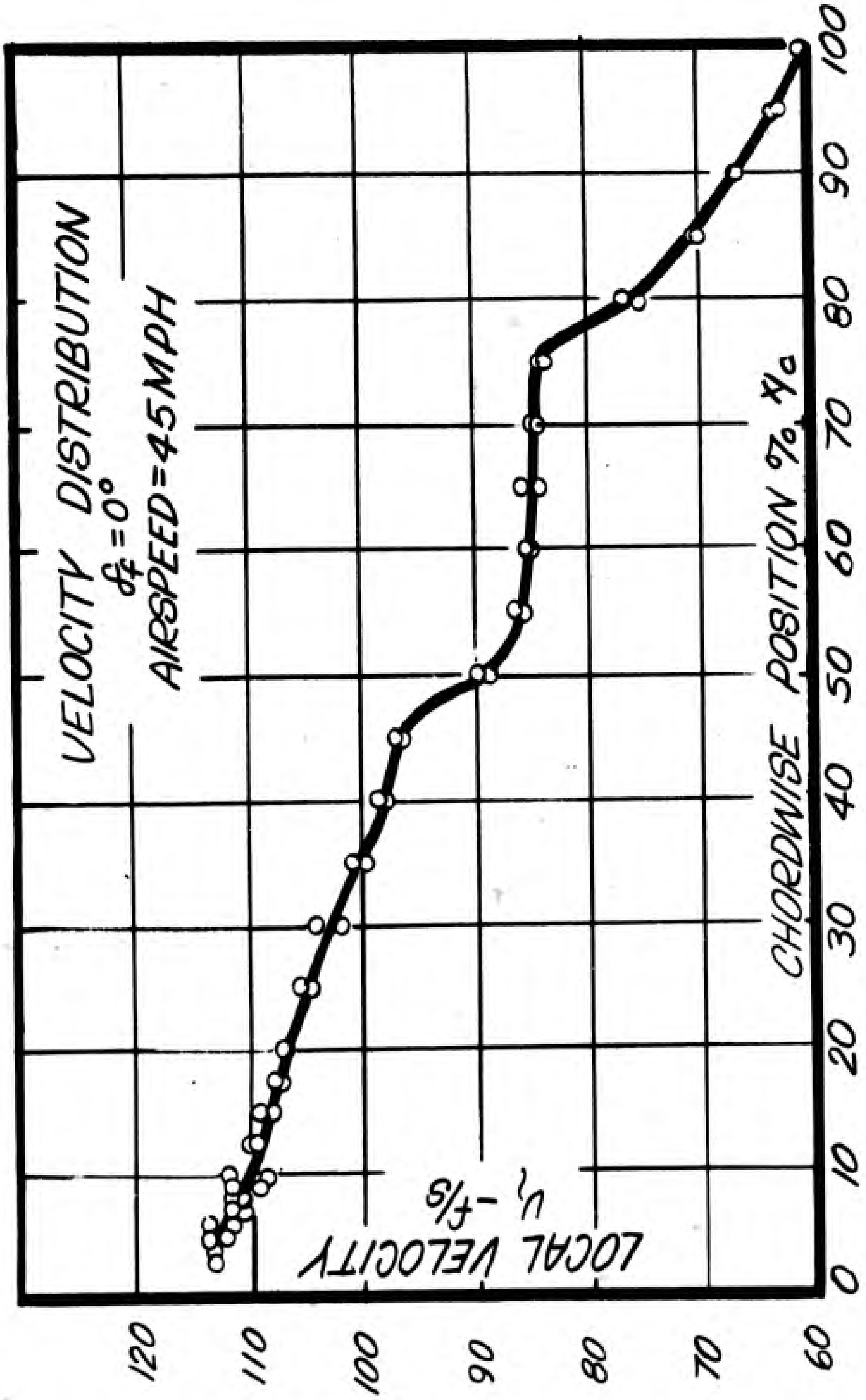
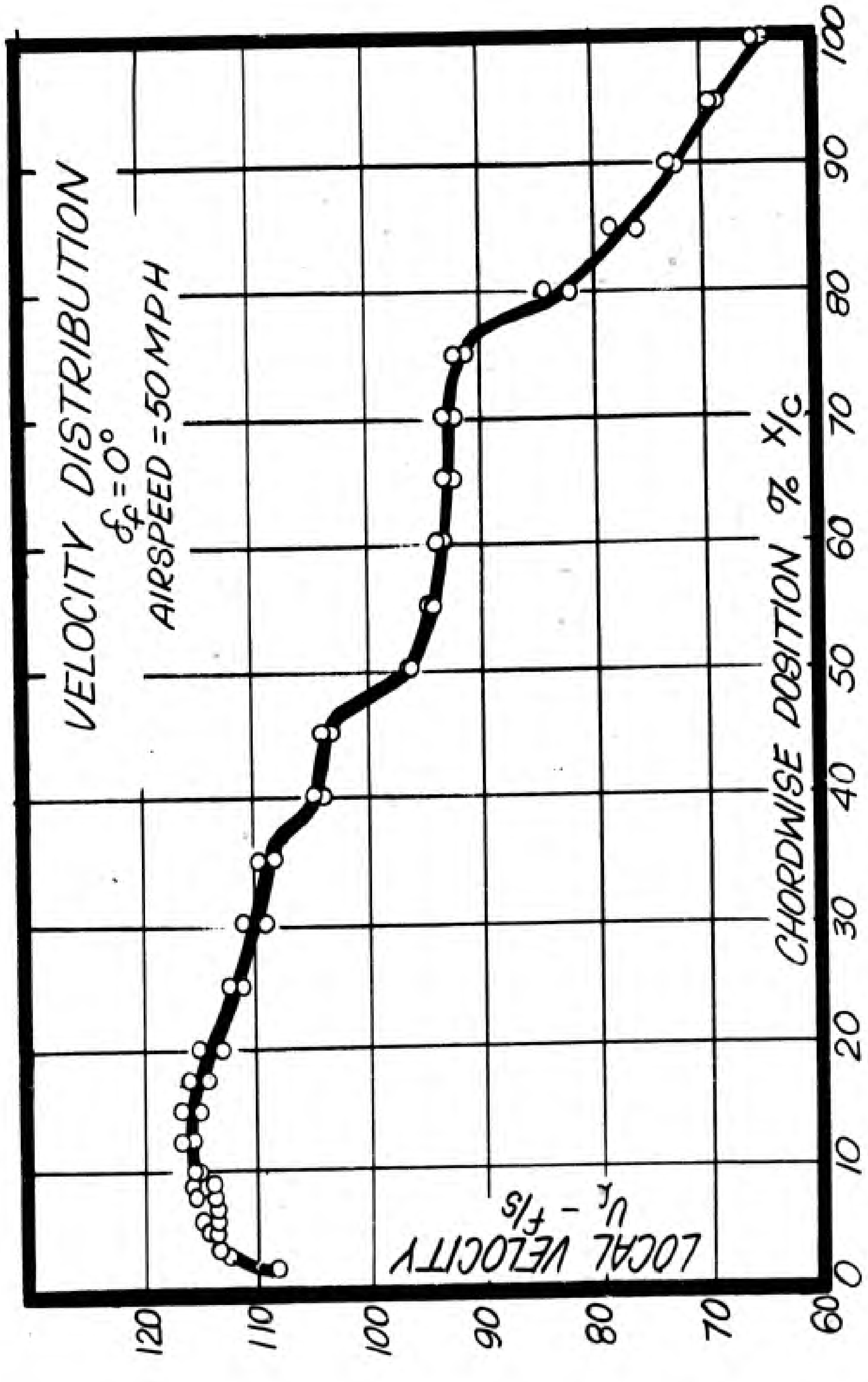


FIGURE 6
(CONTINUED)



CONFIDENTIAL

TYPICAL SET OF BOUNDARY LAYER VELOCITY PROFILES

$\delta_f = 0°$ AIRSPEED = 45 MPH

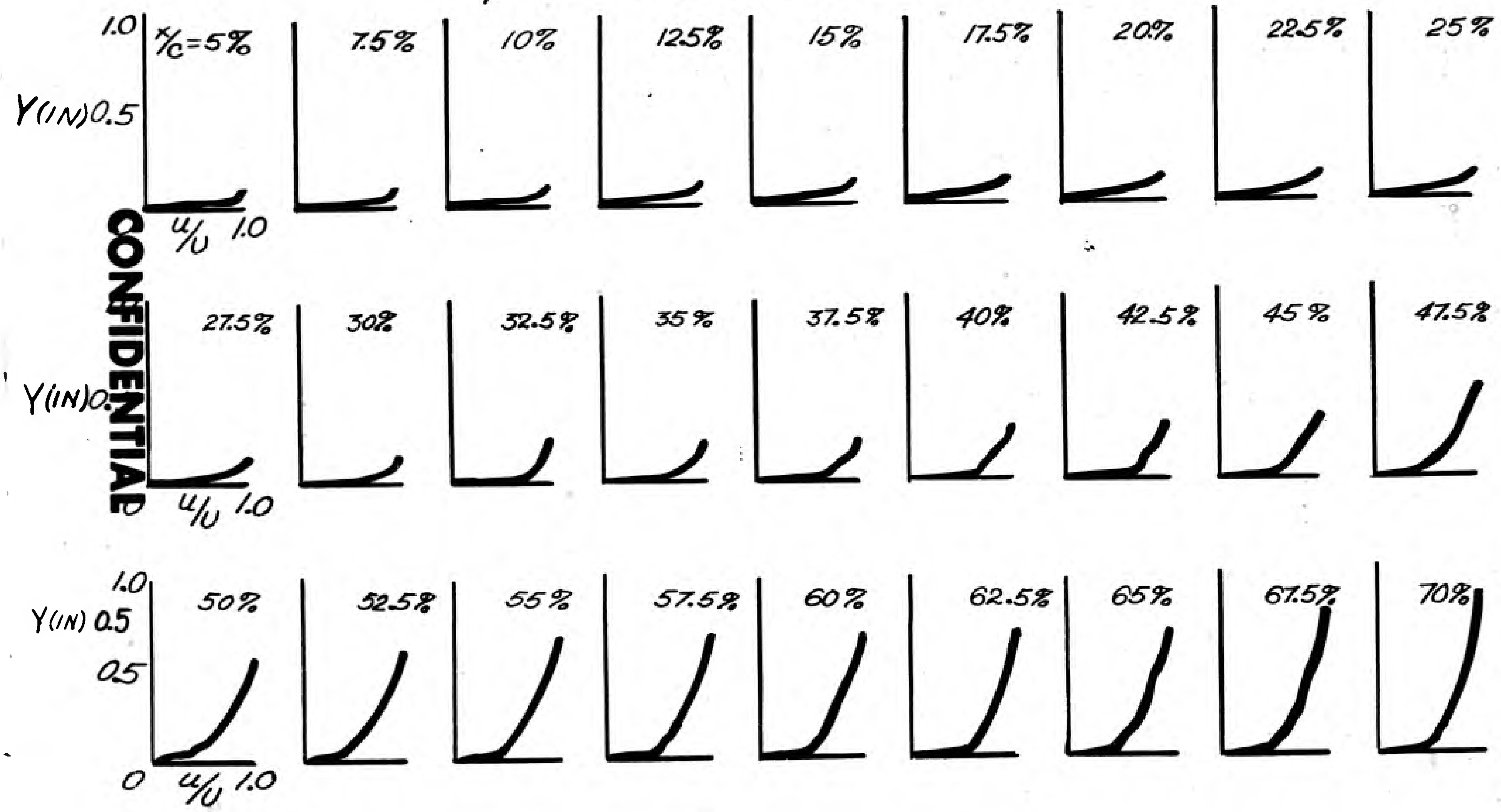


FIGURE 7

CONFIDENTIAL

FIGURE 8

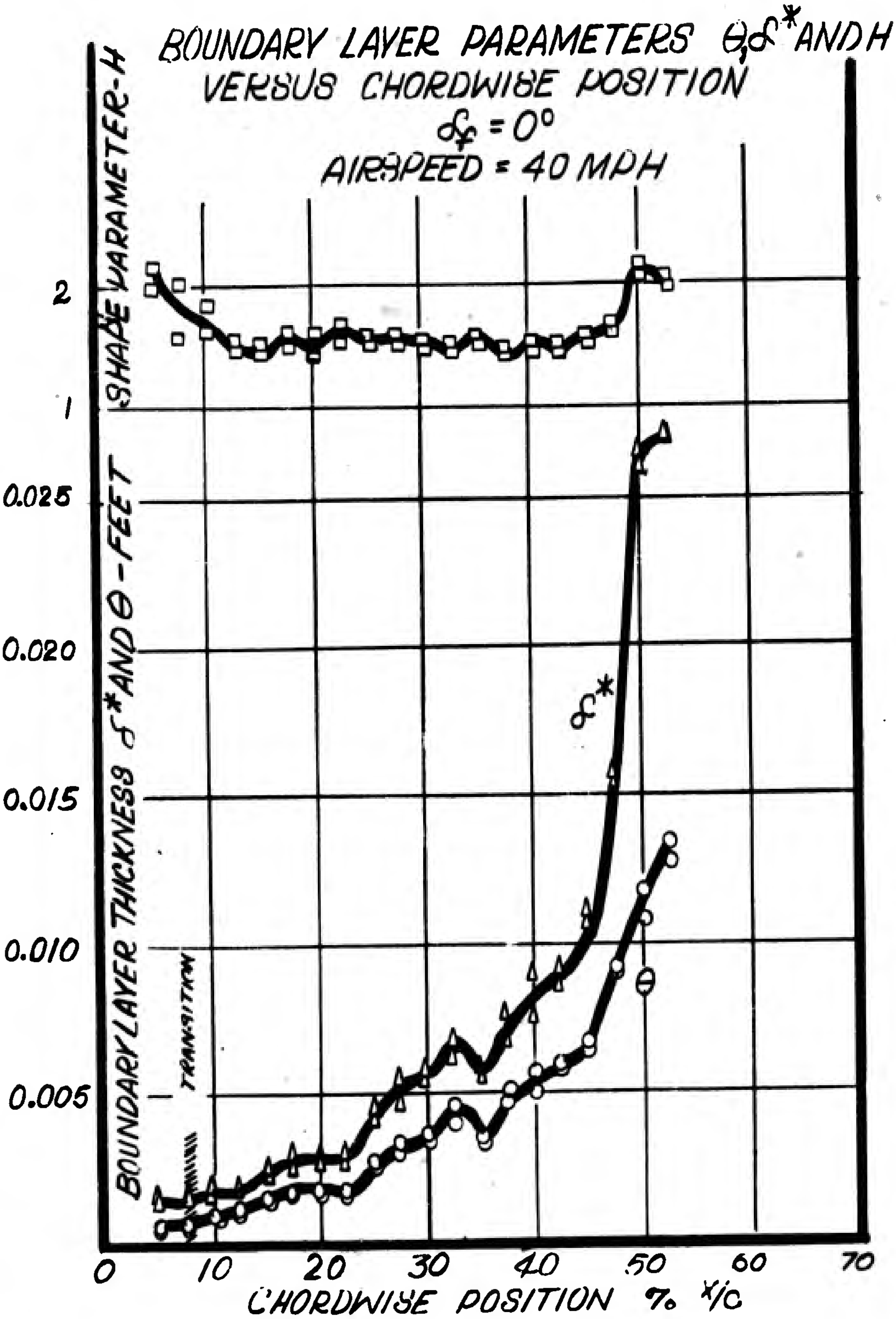

BOUNDARY LAYER PARAMETERS θ, δ* AND H
VERSUS CHORDWISE POSITION
$\delta_f = 0°$
AIRSPEED = 40 MPH
SHAPE PARAMETER-H
BOUNDARY LAYER THICKNESS δ* AND θ - FEET
2
1
0.025
0.020
0.015
0.010
0.005
TRANSITION
δ*
θ
0
10
20
30
40
50
60
70
CHORDWISE POSITION % x/c

FIGURE 8
(CONTINUED)

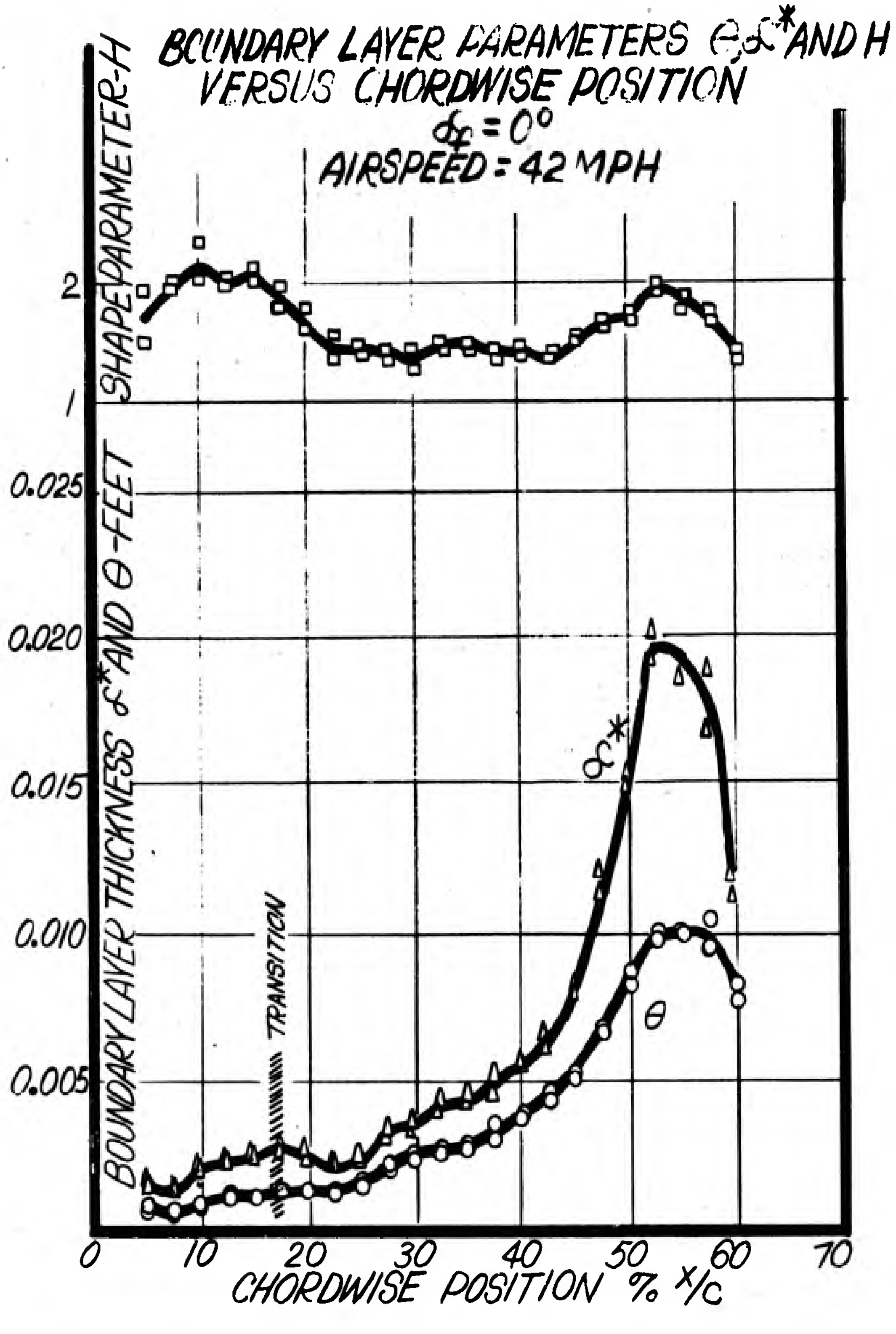
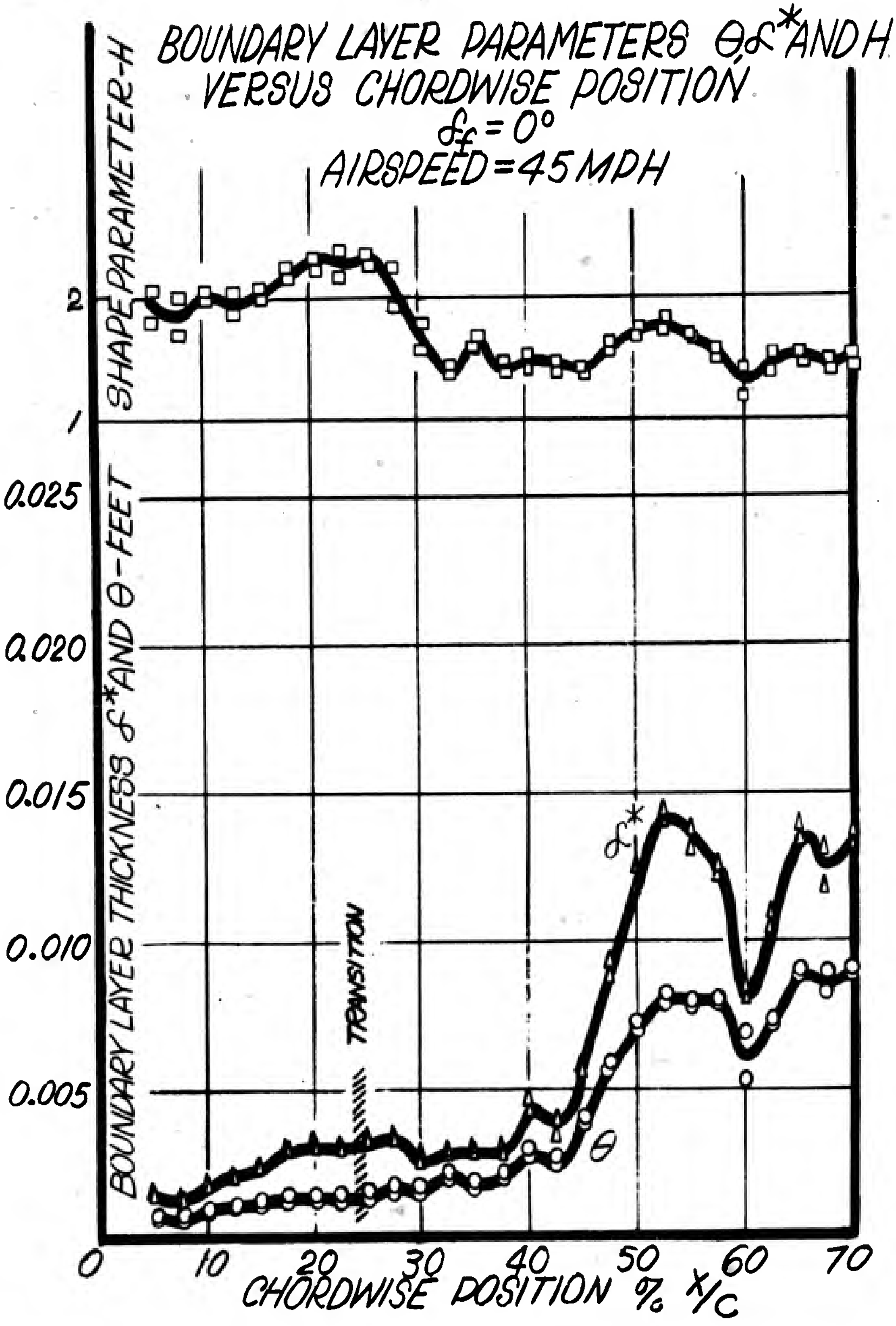


FIGURE 8
(CONTINUED)



BOUNDARY LAYER PARAMETERS θ, δ* AND H
VERSUS CHORDWISE POSITION
$\delta_f = 0°$
AIRSPEED = 45 MPH

FIGURE 8
(CONTINUED)

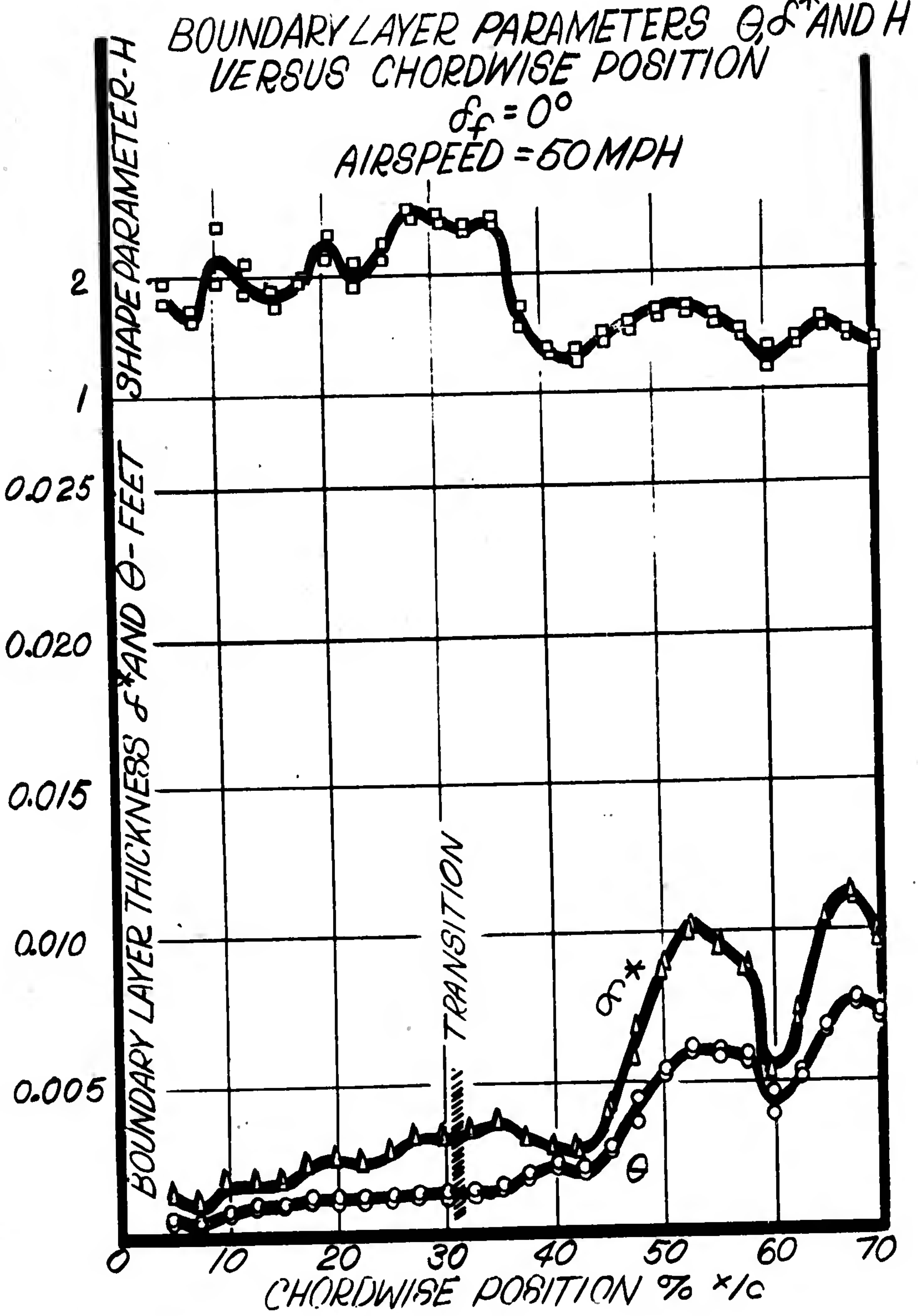
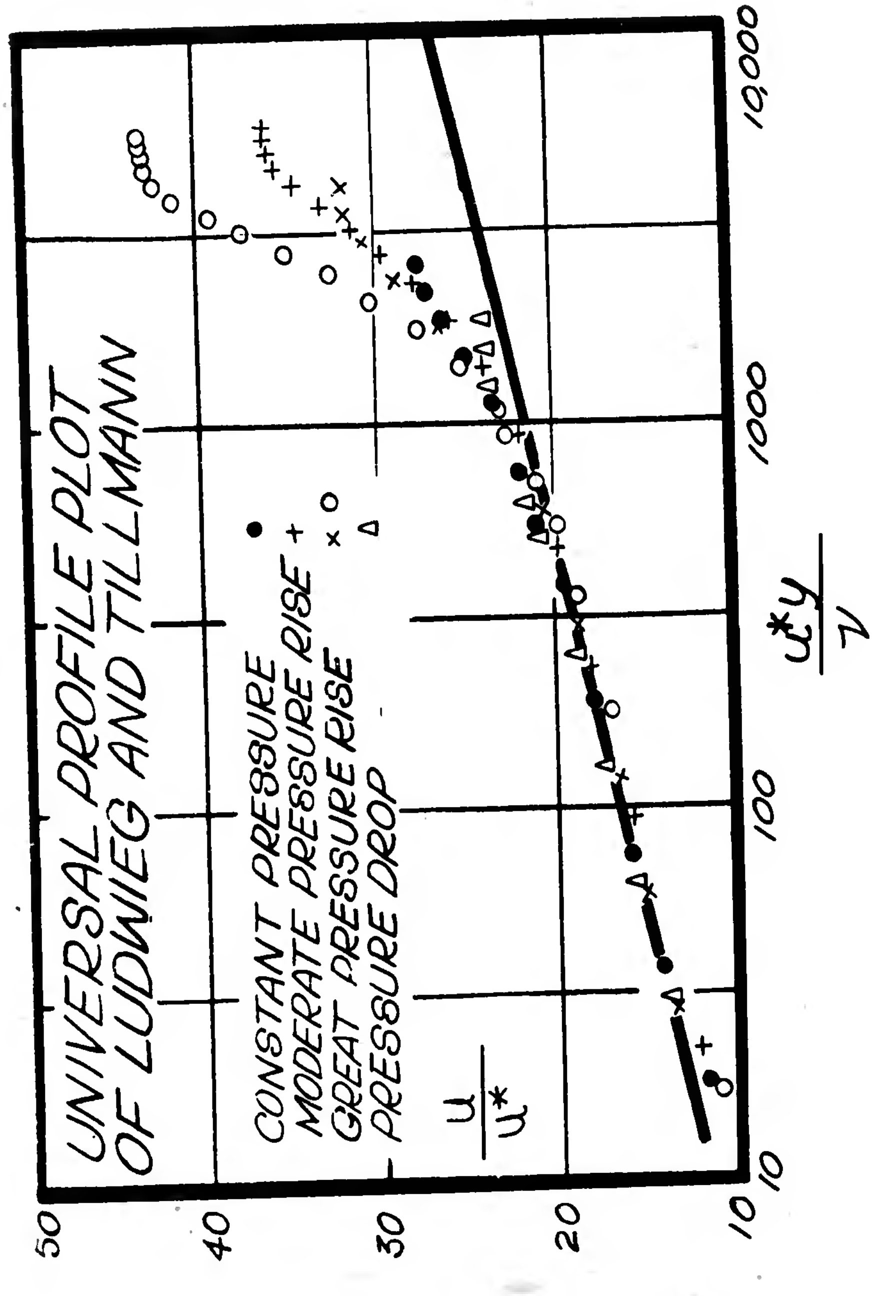


FIGURE 9



UNIVERSAL PROFILE PLOT OF LUDWIEG AND TILLMANN

FIGURE 10

CLAUSER'S CHART FOR EXPERIMENTAL DETERMINATION OF TURBULENT SKIN FRICTION

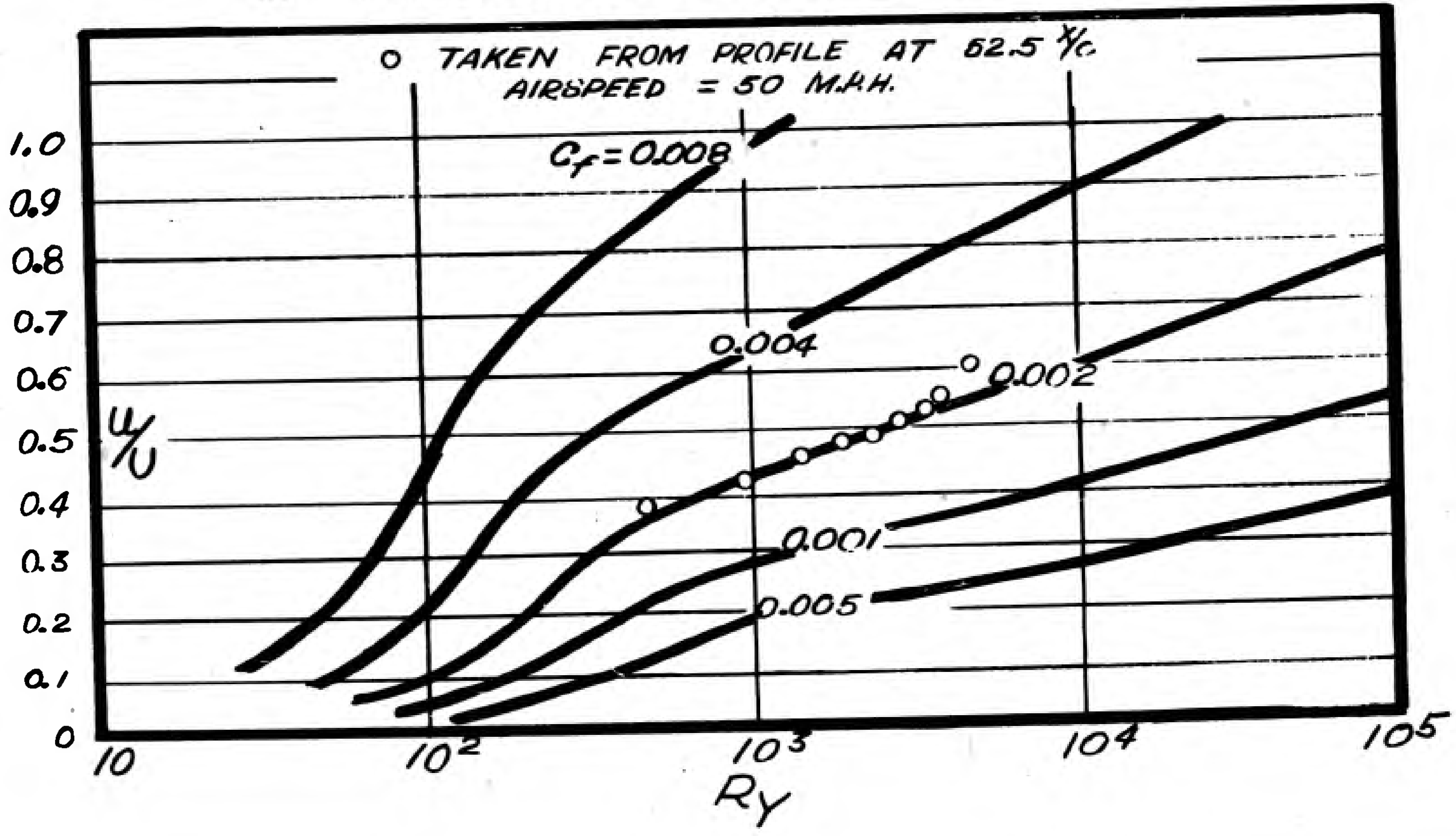


FIGURE 11

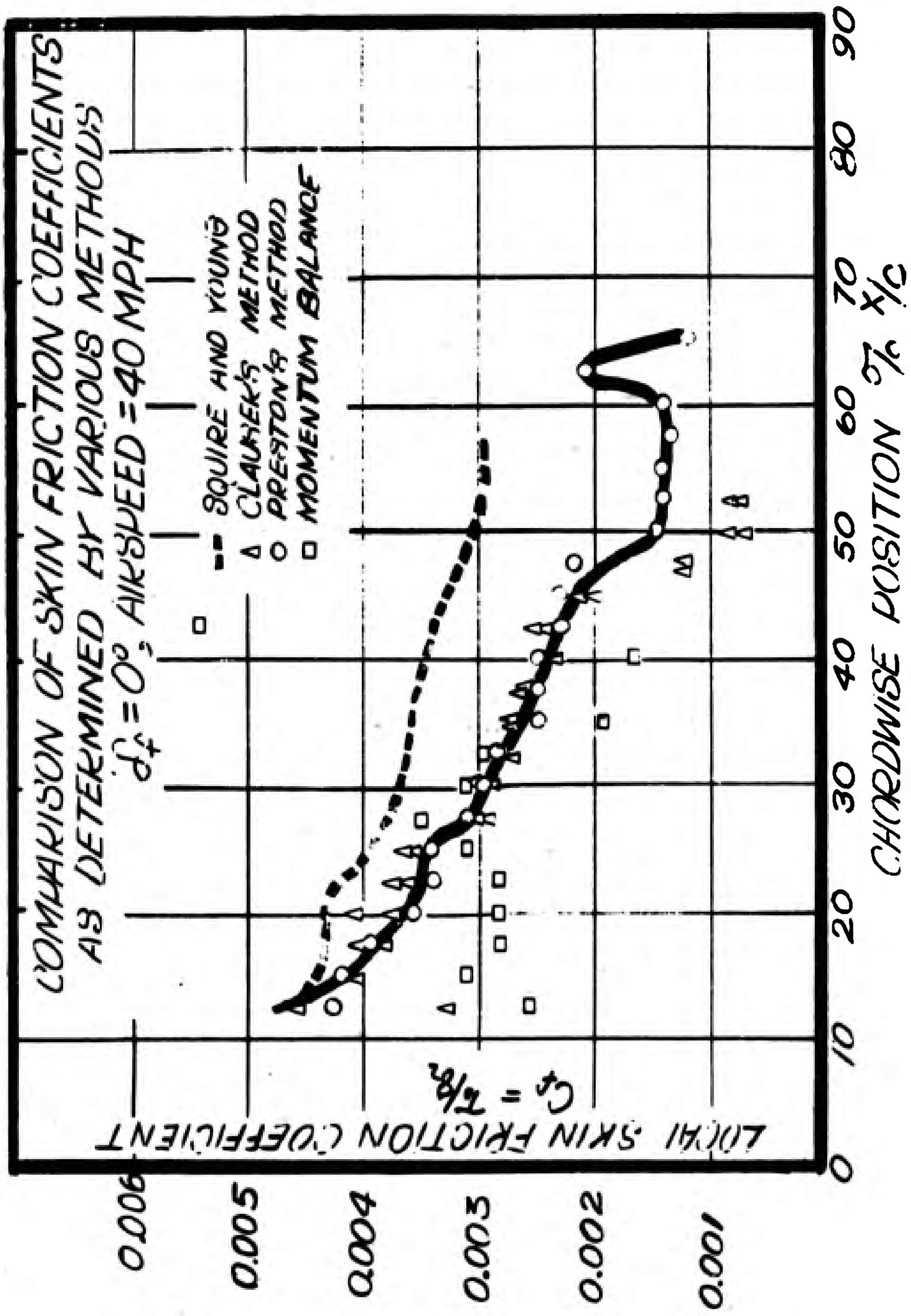
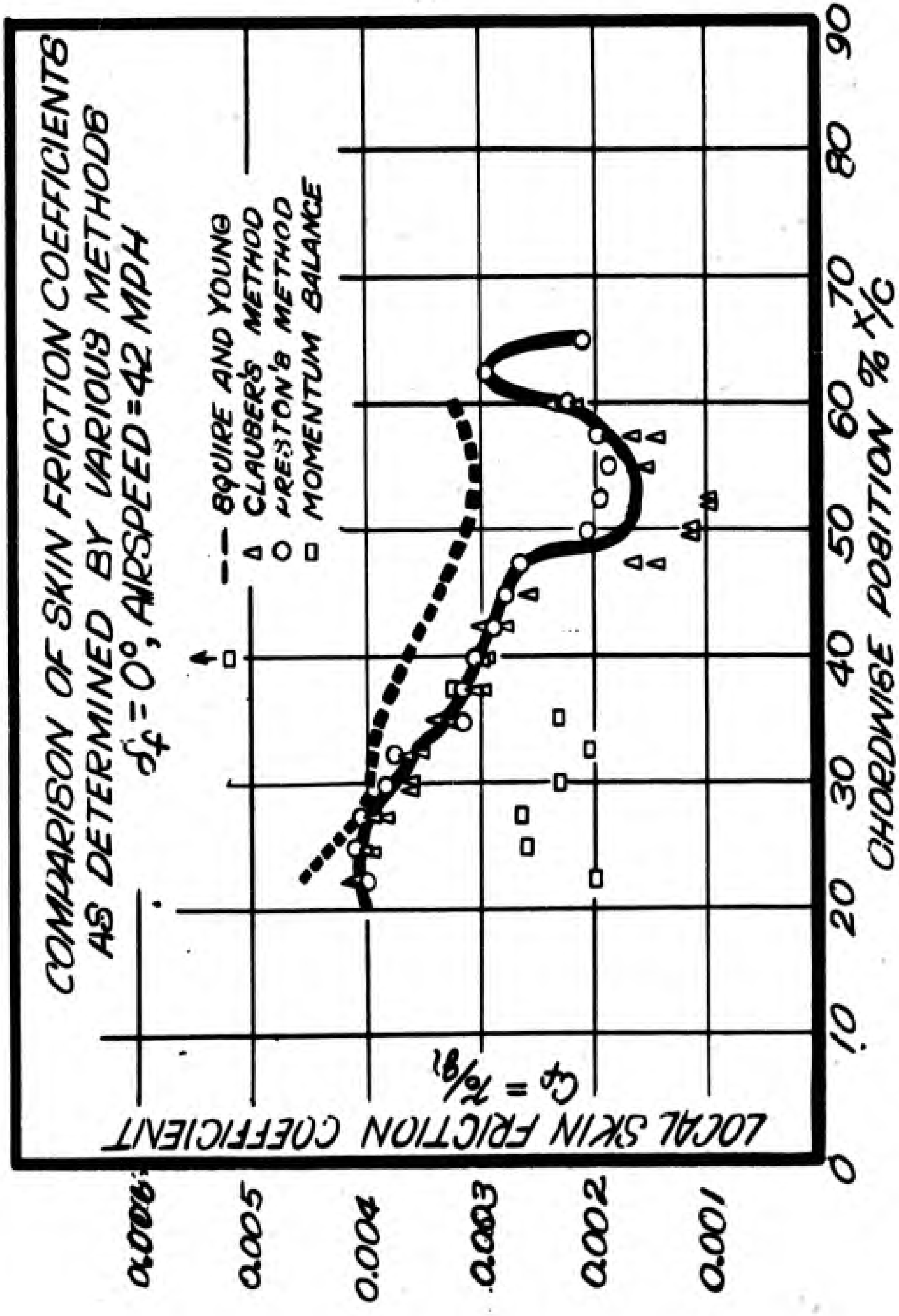
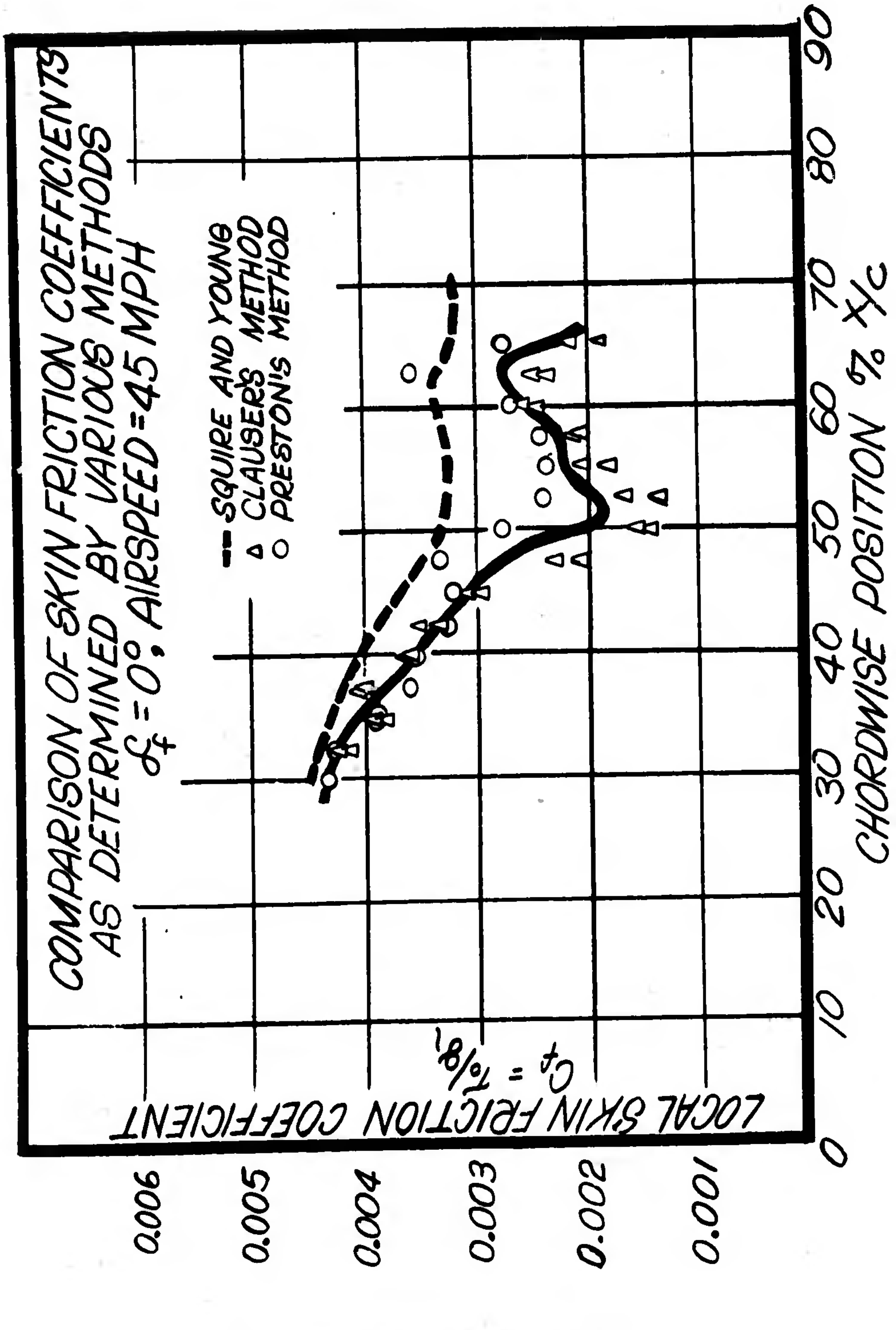

COMPARISON OF SKIN FRICTION COEFFICIENTS
AS DETERMINED BY VARIOUS METHODS
$\alpha_t = 0°$; AIRSPEED = 40 MPH
SQUIRE AND YOUNG
△ CLAUSER'S METHOD
○ PRESTON'S METHOD
□ MOMENTUM BALANCE
LOCAL SKIN FRICTION COEFFICIENT
$C_f = \tau/q$
0.006
0.005
0.004
0.003
0.002
0.001
0
10
20
30
40
50
60
70
80
90
CHORDWISE POSITION % X/C

FIGURE 11
(CONTINUED)



CONFIDENTIAL

FIGURE 11
(CONTINUED)



CONFIDENTIAL

FIGURE 11
(CONTINUED)

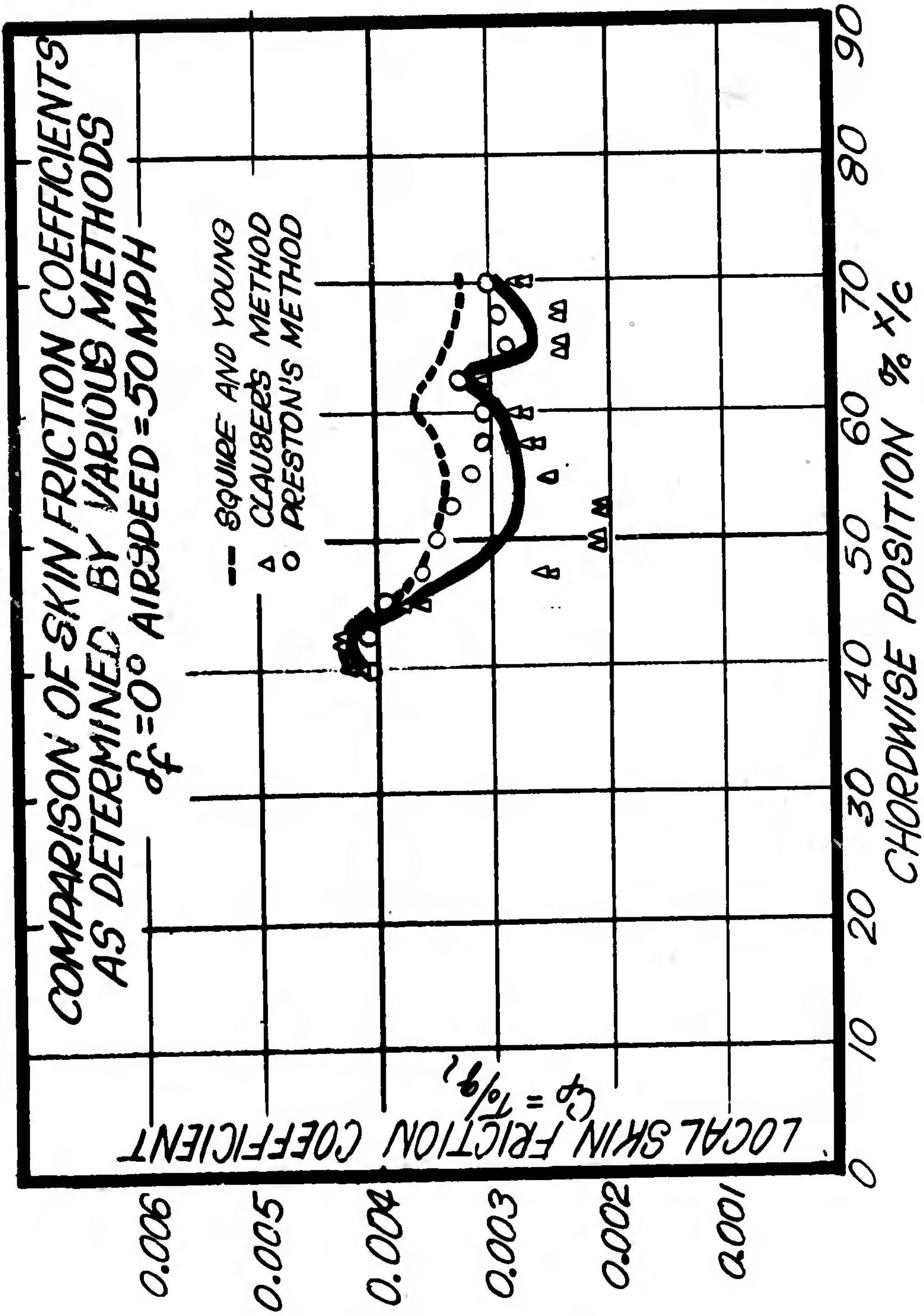
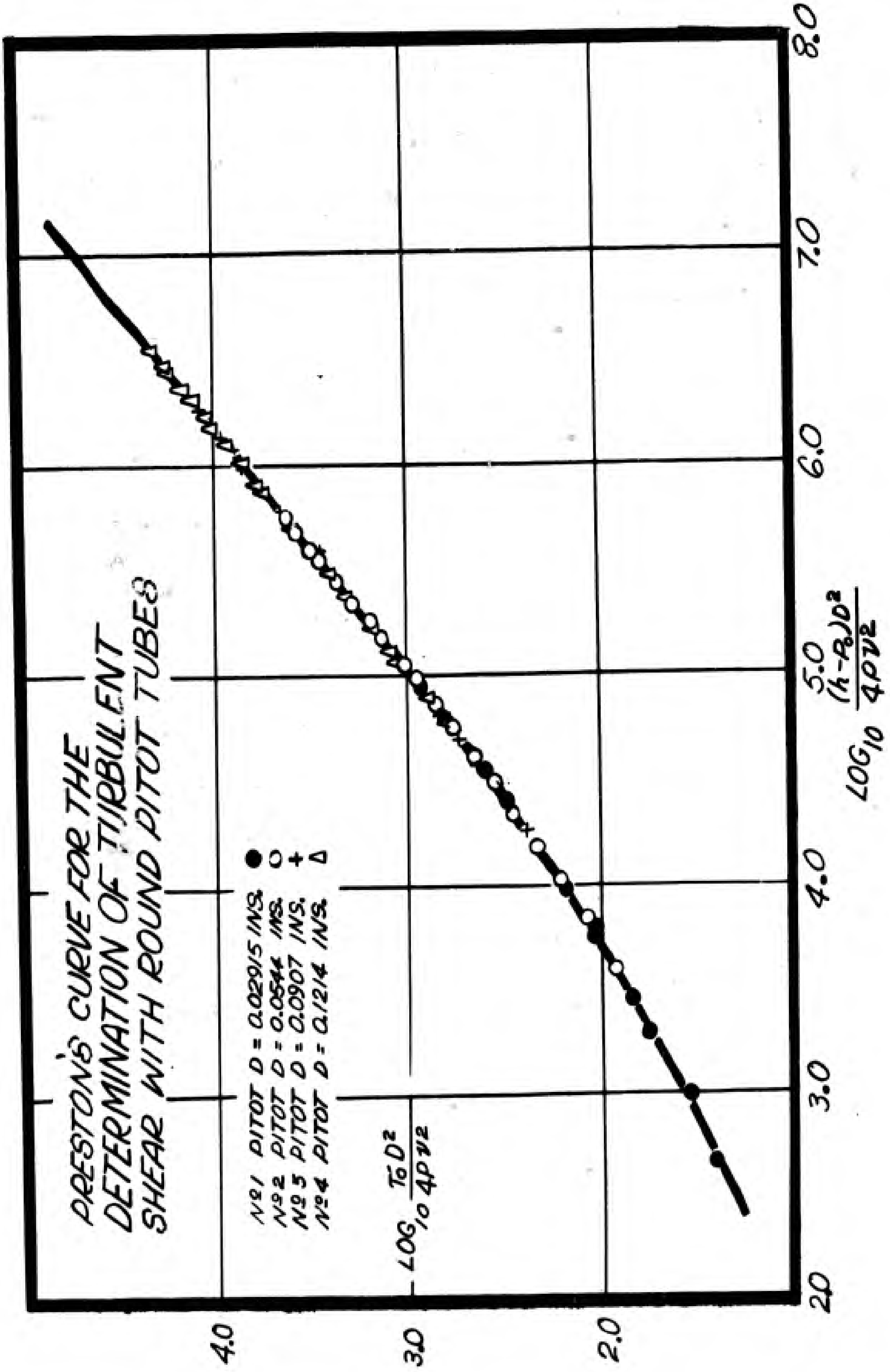
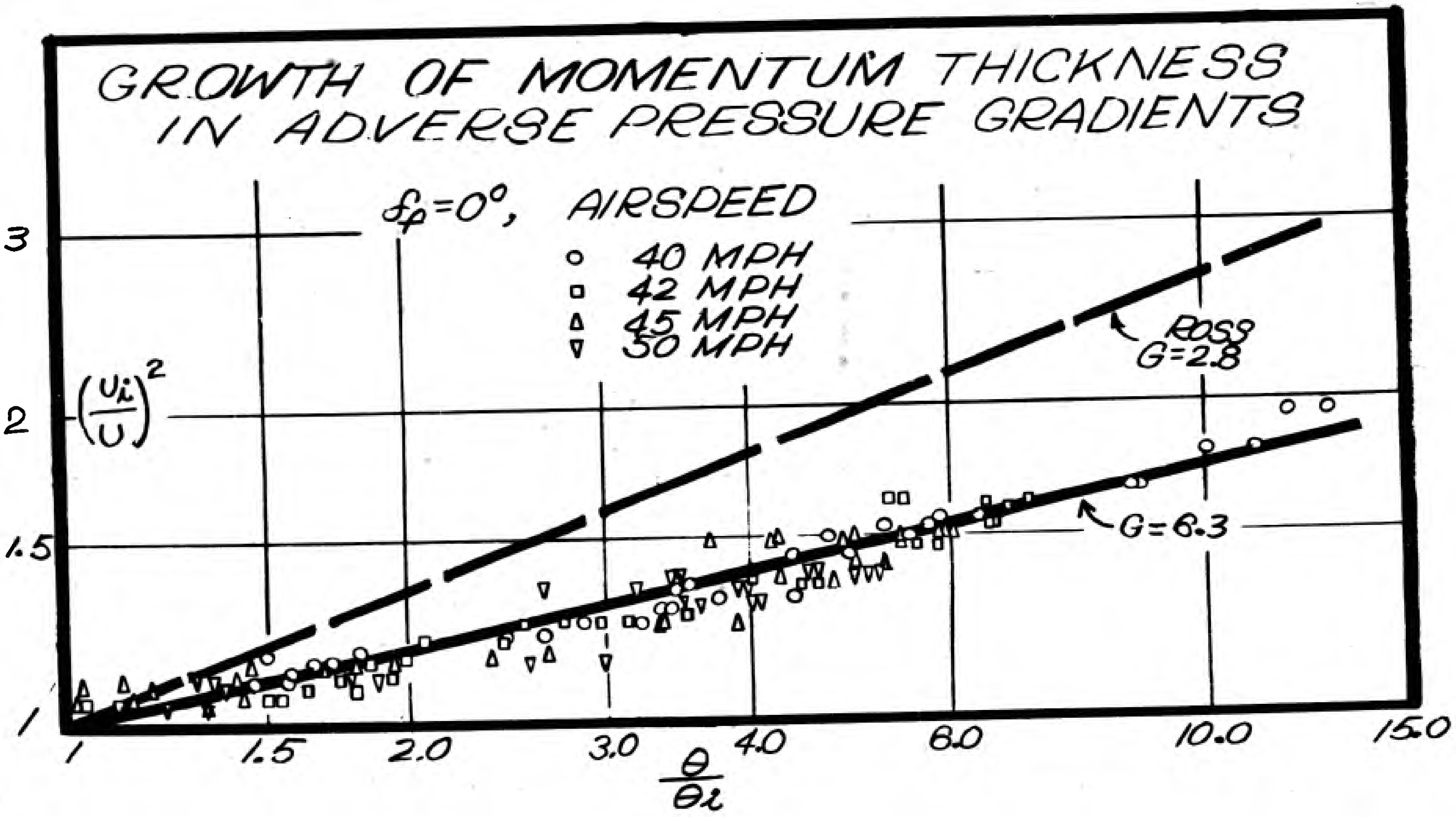


FIGURE 12


PRESTON'S CURVE FOR THE DETERMINATION OF TURBULENT SHEAR WITH ROUND PITOT TUBES
№1 PITOT D = 0.02915 INS. ●
№2 PITOT D = 0.0544 INS. ○
№5 PITOT D = 0.0907 INS. +
№4 PITOT D = 0.1214 INS. △
LOG10 τ0D²/4ρν²
LOG10 (h−p0)D²/4ρν²
2.0
3.0
4.0
5.0
6.0
7.0
8.0
2.0
3.0
4.0

CONFIDENTIAL

FIGURE 13



CONFIDENTIAL

FIGURE 14

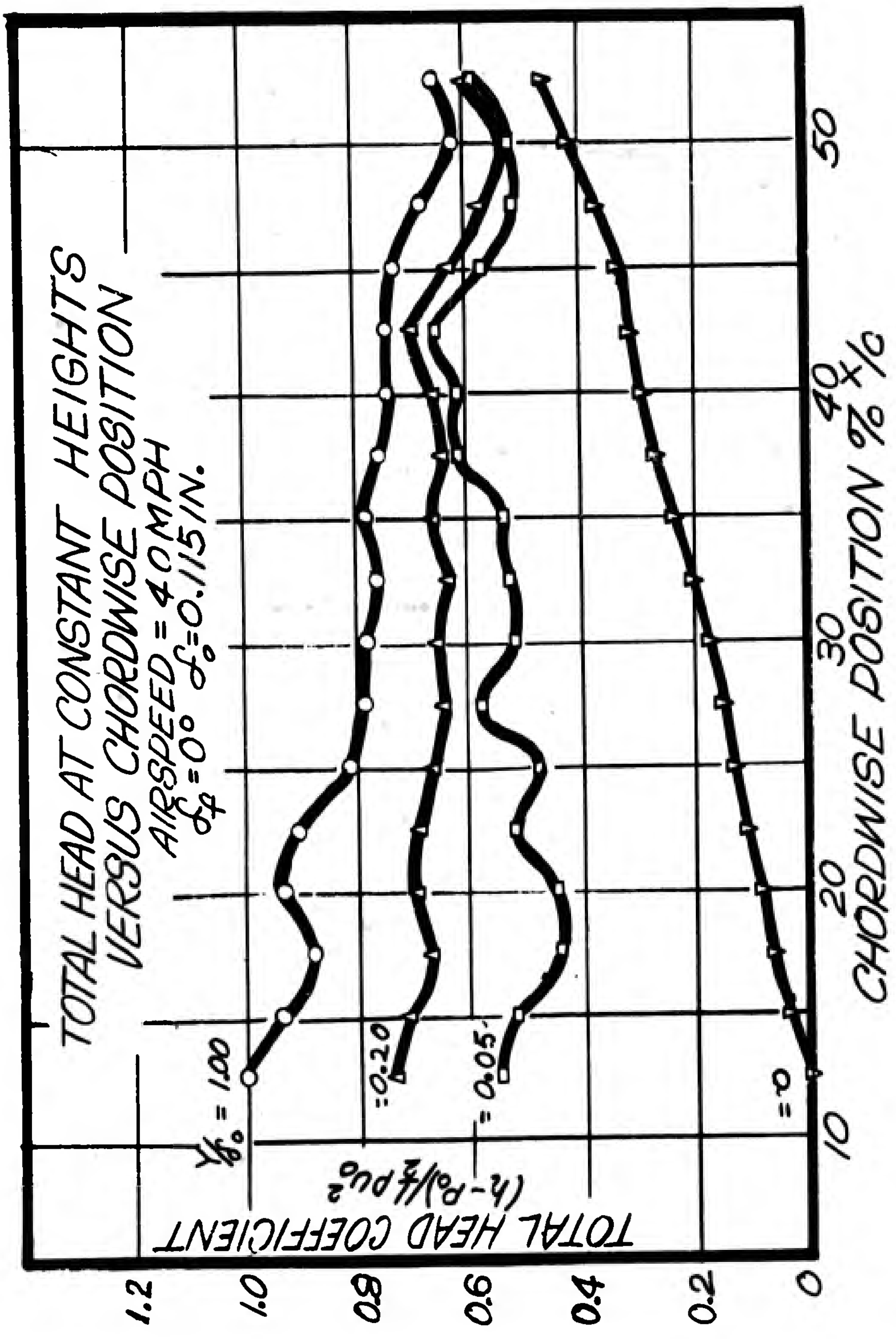

TOTAL HEAD AT CONSTANT HEIGHTS
VERSUS CHORDWISE POSITION
AIRSPEED = 40 MPH
$\delta_f = 0°$ $\delta_0 = 0.115$ IN.
$y/\delta_0 = 1.00$
$= 0.20$
$= 0.05$
$= 0$
TOTAL HEAD COEFFICIENT
$(h-P_0)/\frac{1}{2}\rho u_0^2$
1.2
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
CHORDWISE POSITION % x/c

FIGURE 14
(CONTINUED)

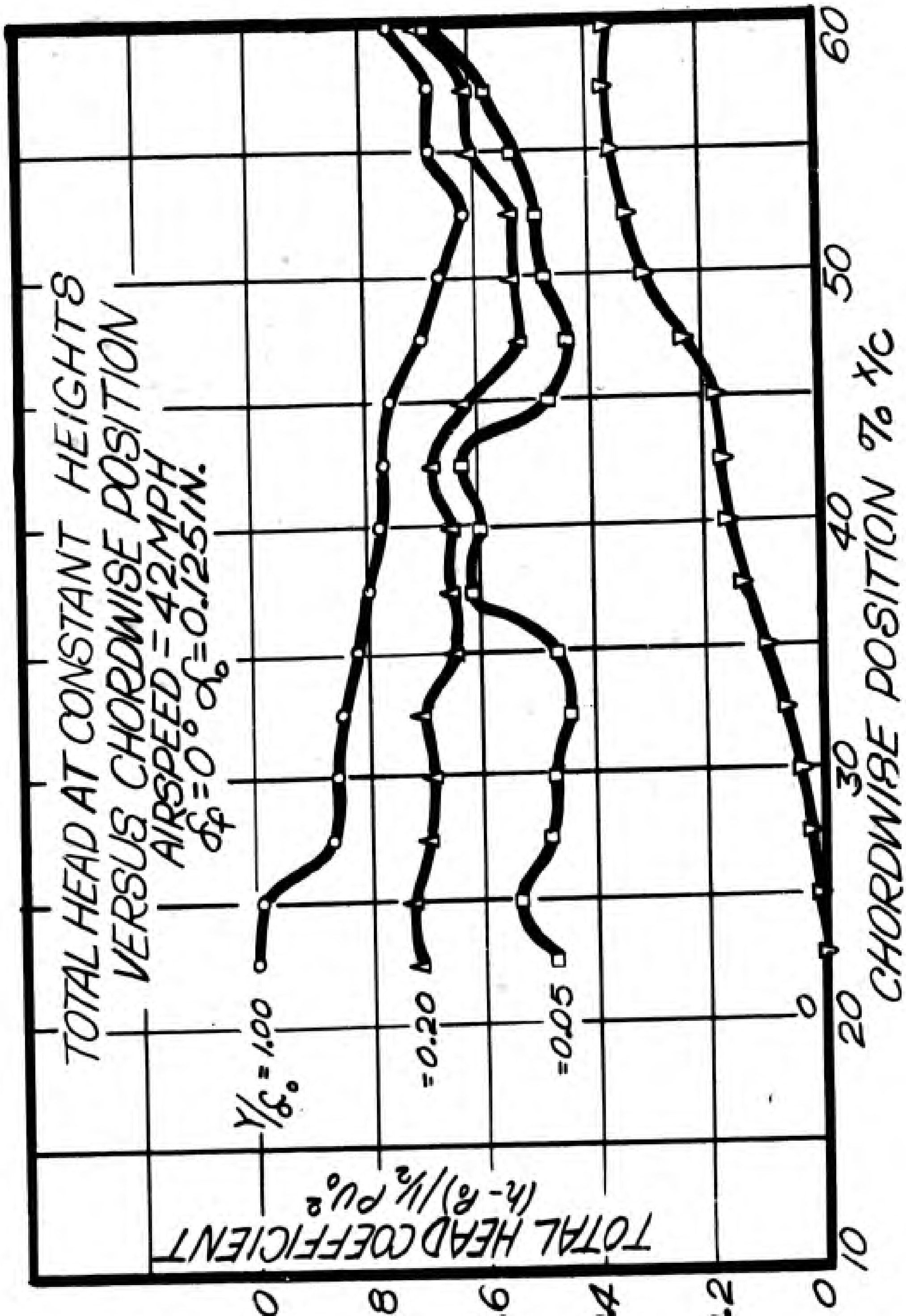


FIGURE 14
(CONTINUED)

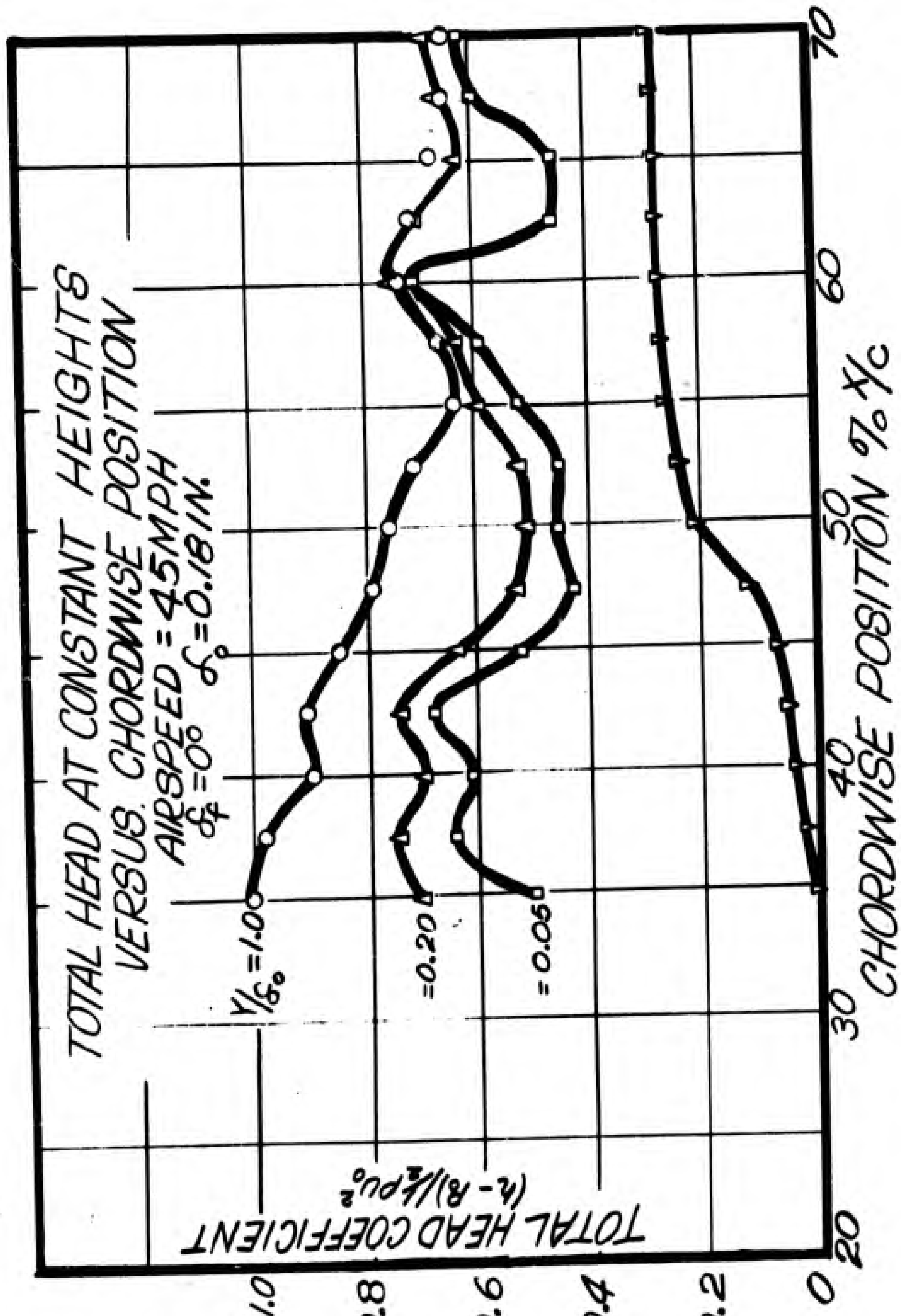
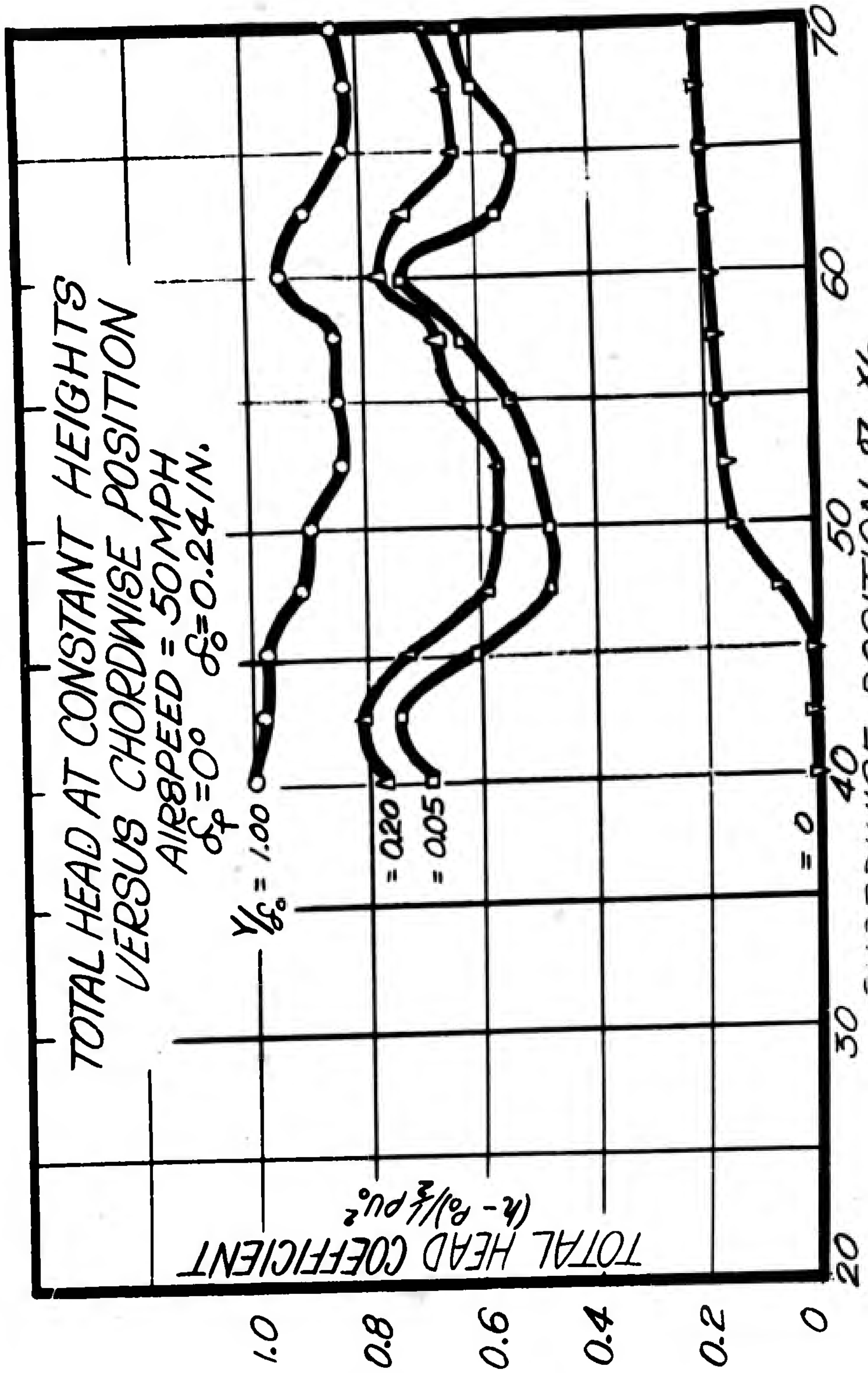


FIGURE 14
(CONTINUED)



UNCLASSIFIED

AD 53360

Armed Services Technical Information Agency

Reproduced by

CLASSIFICATION CHANGED TO UNCLASSIFIED

BY AUTHORITY OF ASTIA RECLASS. List No. 89

Date 10 Aug 1956

Signed Richard E. Reedy
OFFICE SECURITY ADVISOR

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

UNCLASSIFIED