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Semi-annual Progress Report

January 1978 - July 1978

STUDIES OF SELF STREAMLINING WIND TUNNEL

REAL AND IMAGINARY FLOWS

by

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and

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This is a semi-annual progress report, for the period January to July 1978, on work undertaken on NASA Grant NSG-7172 entitled "The Self Streamlining of the Test Section of a Transonic Wind Tunnel". The Principle Investigator is Dr. M.J. Goodyer.

C O N T E N T S

1. INTRODUCTION

During this report period the principal efforts toward extending the understanding of the flexible walled test section were directed at

(i) further testing and data analysis with the standard airfoil model in low speed wind tunnels.

(ii) completing the construction of the automated transonic test section.

Testing in the low speed flexible walled tunnel was continued in an effort to explain the reasons for data discrepancies at high angles of attack. This work was extended to include tests of the same model in the University's large 7' x 5' low speed tunnel, mainly to gather baseline wake information for comparison with measurements in the flexible walled tunnel. In addition, the flexible walled tunnel was used in a new operating mode to generate curved flow around the airfoil, allowing the extraction of purely rotary derivatives.

The transonic test section was run for the first time during this report period, although its operation is manual pending the delivery and commissioning of the computer. No significant operational troubles have been found during tests up to Mach 1.1.

This report also contains some straight-wall low speed pressure data, for walls and model, which may be of use for checking interference correction methods. The ratio model chord to test section height is unusually large.

Computer software is included. There are two complete sets: an old streamlining algorithm suitable only for low speed testing which has been used as a check on our normal predictive algorithm, plus an updated version of the Predictive algorithm with modifications designed to allow its use at compressible speeds with the new transonic test section operated in a manual mode.

A PDP 11-34 computer has been ordered for use with the transonic tunnel. The computer will have facilities for closed-loop operation.

2. WALL STREAMLINE CHECKS

Attempts have been made from time to time to account for the differences between the 0012-64 airfoil data taken in LTPT and the low speed self streamlining wind tunnel (SSWT), particularly at high angles of attack.[1,2] The method of streamlining used in the SSWT tests was the Predictive Method for Rapid Wall Adjustment[3] which has the advantage over the earlier[4] method in requiring only a small number of iterations.[1]

The question arose of whether the Predictive Method was becoming inaccurate at high angles of attack, and, therefore, an independent check has been made. The check was by means of the application to the streamlined contours of the older method[4] of analysing the wall imaginary-side static pressure distributions.

The method is applied to each wall separately, and consists of reproducing the effective contour of the wall by the envelope of the flows from a set of two dimensional sources spaced along a line parallel to the test section axis. The inclusion of an estimate of the change of wall boundary layer displacement thickness is optional. The BASIC programs for top and bottom walls are reproduced in Appendix A. This version of the method curve-fits the wall jack positions (which are unevenly spaced) to allow interpolation of the contour at regular 2.54 cm (1-inch) intervals along the whole length of test section. In addition the imaginary field is constrained to follow streamwise extensions of the walls upstream and downstream of the ends of the test section by a further 25.4 cm (10 inches). Sources (or sinks) are positioned along a straight line, each source mid-way between a pair of interpolated wall coordinates. The geometry is sketched on figure 2.1 The whole of an imaginary flowfield may be computed once a source set has been determined, in practice the pressure on the wall is computed at points mid-way between sources and then compared with the measured test section pressure to test whether or not the wall is loaded. The routines have been extensively checked against exact two-dimensional potential flow streamlines.

Computations of pressure differences across walls, that is the difference between real and imaginary pressures, were carried out for the three representative incidences of 0, 6° and 12°. The streamlined wall contours, real wall pressures and tunnel reference conditions were the input data, taken at the time of the SSWT tests 4, 7 and 13 detailed on figure 2.1 of reference 2. As a measure of wall loading, the average error in pressure coefficient Cp is presented for the twelve jack positions nearest to the model, six on each wall. Wall-induced flow errors at the model are most strongly affected by wall loading in these areas. The average errors are:-

α	0°	6°	12°
$\frac{\Sigma \lvert Cp \rvert}{12}$	0.0078	0.0178	0.0182

The implication of these levels of loadings are put into perspective when it is appreciated that a uniform error along both walls assumed extended to infinity will induce a streamwise velocity error at the model and an associated error in pressure coefficient just equal to the pressure coefficient imbalance at the walls. While the residual wall loading after streamlining is inevitably finite, it tends to be randomly distributed and, therefore, one would normally expect the wall induced errors at the model to be smaller than indicated by the pressure coefficient errors given above.

The largest wall error is at $\alpha = 12^0$, where disparity between SSWT and LTPT airfoil data is most apparent. Therefore, more was carried out at this angle of attack, continuing the streamlining process through more iterations. It was found that no significant improvement could be made in the matching of real and imaginary flows, also that the airfoil pressure distribution (which was being monitored throughout) was not affected significantly by the minor changes in wall position. It is, therefore, concluded that wall streamlining by the Predictive Method is satisfactory. Differences in the airfoil behaviour in the two wind tunnels must be accredited to some other effect perhaps to sidewall boundary layer effects or wake-wall interaction (See section 4).

The assessment of wall induced flow errors at the model has not so far been as logical as it might. We are modifying our methods along the lines developed by Kemp[8] and will present in the next progress report the assessments of blockage, angle of attack and camber which are induced at the model by the residual levels of wall loading.

One point which was apparent in the work covered by this section was a feature which has been noted before but which is quite remarkable and will stand repetition. This is that even though the tunnel user in no way pre-determines the wall shapes which are to be employed, the shapes derive from measurements solely at the walls, during the streamlining process the lower (pressure) wall sometimes takes on the unmistakable imprint of the airfoil. See the contours plotted on figure 2.2. Presumably the imprint is present on the upper wall also but is less apparent because there are fewer inflections, and because with lift the lower wall moves toward the airfoil, the upper wall away.

3. SSWT STRAIGHT WALL DATA

The effects of wall streamlining were illustrated in an earlier Progress Report[1] for example by comparing normal force coefficients measured with straight and streamlined walls. The airfoil was 0012-64 sectioned with a 13.72 cm (5.4 inch) chord, tested in the low speed SSWT having a nominal test section depth of 15.24 cm (6 inches). The force coefficients were determined from measured pressure distributions around the centerline of the 30.48 cm (12 inch) airfoil span. There were simultaneous measurements of pressure along the top and bottom wall centerlines of the test section. In the streamlined-wall cases the wall pressure distributions are used as checks on the accuracy of the streamlining. The wall pressure data taken with straight walls can be used as initial inputs to streamlining algorithms [3,4]. However, the data has more general usefulness because the ratio of airfoil chord to test section depth at 0.9 is unusually high. The straight wall interference is, therefore, higher than usual, and the main reason for presenting the data is because the airfoil and perhaps wall pressure data can be used as severe test cases in the evaluation of wall interference correction methods.

At this point a word of caution should be noted which arises from what could be regarded as a fine detail of straight wall testing of any kind. The normal practice in any wind tunnel is to diverge the test sectio walls slightly in order to compensate for the growth of wall boundary layer In advance of the tests reported in this section the walls of SSWT were adjusted to give constant velocity along the empty test section at the correct unit Reynolds number. With the model present the perturbations in boundary layer thickness on the top and bottom walls produce boundaries which are not effectively straight. The notion is discussed in reference 4 and is illustrated on figure 18 (a) to (c) of that reference. In order to produce effectively straight boundaries in the presence of the model the walls should be moved to compensate for changes in displacement thickness. This was not done. The cautionary note is raised because correction theories are based on the assumption of effectively straight boundaries.

The airfoil pressure distributions are given on figures 3.1 to 3.13 for the angle of attack range $+12^0$ to -6^0. The test Mach number was about 0.1, and the chord Reynolds number in the range 285,000 to 290,000. The force and moment coefficients quoted on each figure are derived from the integrated pressure distributions. The corresponding top and bottom wall centerline pressure distributions are shown on figures 3.14 to 3.17.

4: FURTHER LOW SPEED AERODYNAMIC WORK

There has been a continuing effort to improve the understanding of previously reported low speed aerodynamic data[1,2] obtained on a NACA 0012-64 section in SSWT. In comparison with the LTPT reference data there seem to be angle of attack errors present, small with an unstalled airfoil and large when stalled. There are of course other possible reasons for discrepancy, including inadequate streamlining although the work of section 2 above had gone some way toward removing doubts of this kind. However, it was conceivable that the walls were impressing an incorrect flow pattern on the model. While this flow pattern was not correct it was nevertheless apparently correct when judged by wall measurements alone. It was, therefore, decided to gather more information on the "free air" performance of the airfoil, specifically wake measurements, for comparison with SSWT measurements.

Wake surveys were made on the NACA 0012-64 section of 13.71 cm (5.4 inch) chord and 2.22 aspect ratio in SSWT at $\alpha = +12^0$, $+6^0$, 0^0 and -6^0 and at a chord Reynolds number of approximately 287,000. The SSWT flexible walls were set straight and also streamlined.

Tests were also carried out in the Low Speed 2.13 metre x 1.52 metre (7ft. x 5ft) Wind Tunnel (7 x 5) at Southampton University using the same model but with two 30.48 cm (1 foot) wing extensions and small end plates as shown in figure 4.10. Note that the model is mounted upside down relative to LTPT tests. This wing model of span .91 metre (3 feet) and 6.66 aspect ratio was tested through the angle of attack range 0^0 to -12^0 at the maximum sustainable Reynold's number of approximately 236,500. Positive angles of attack runs were not attempted due to poor surface contours o: one wing extension. The choice of α kept the faulty surface to the pressure side. With a test section height to chord ratio $\left(h/c \right)$ of 11.1, LSWT 7 x 5 results are assumed to be interference free. Note SSWT $^h/c \doteq 1.1$. Transition strips were fitted to the models at all times.

The velocity defect in the wake was measured with a static probe and Kiel probe of standard design. The traversing plane was 1.25 chords downstream of the model trailing edge and 2.28 cm (.9 inch) to the side of mid span. Tunnel reference pressures were taken upstream of the model in SSWT and in line with the model for 7 x 5 tests. Form drag was calculated by numerical integration of the wake's momentum defect (See pages 359 - 365 of reference 7).

SSWT tests at $\alpha = +12^0$ reveal a large wake due to flow separation. Streamlining of the walls allowed the wake to expand, possibly with earlier separation on the airfoil, until it practically filled the tunnel from floor to ceiling (See figure 4.1). The extent of the wake was surprising and may have been enhanced by sidewall separations. Interaction of wake and flexible wall boundary layers would nullify any attempts to streamline the walls downstream of the model. This discovery may account for the discrepancies in data at high angles of attack. Presumably for all points downstream of the measuring plane, in the "streamlined wall" case nowhere in the test section is there a region of potential flow. The flowfield is very roughly as sketched on figure 5(a) of reference 4.

In order for the streamlining criteria to be valid it is a requirement that the flow just outside the flexible wall boundary layer be irrotational. Therefore, the "streamlining" at the higher angles of attack may be invalid. This experience suggests that the flow at the downstream end of the test section should be monitored to test for the existence of two potential zones between the wake and walls.

SSWT tests at lower values of α show more acceptable wake profiles. For $\alpha = +6^0$ the wake occupies only 17% of the test section height at the traversing plane and experiences a small vertical displacement with streamlining (see Figure 4.2). Straight wall data for $\alpha \doteq 0^{o}$ and $\pm 6^{o}$ shows the extent of flow perturbations in SSWT (see Figure 4.3). These are considered acceptable. Note that streamlining of SSWT removes any freestream velocity error due to wake blockage which is present with straight walls, signifying the elimination of blockage interference (see Figure 4.2).

Comparisons of 7 x 5 and SSWT wake profiles for $\alpha = 12^{o}$ and 6^{o} are made in figures 4.4 - 4.5. The 7 x 5 data shows some flow velocity anomolies particularly at $\alpha = 12^{o}$, due to inherent tunnel faults. For both values of α the wake is displaced vertically by a small amount in SSWT compared with 7 x 5. For $\alpha = 6^{o}$, correction for the freestream velocity error in 7 x 5 data reduces C_{D_o} to 0.0246 improving comparison with SSWT results. Unfortunately, few conclusions can be drawn from these comparisons since α is set geometrically and also the model was a different way up in each series of tests.

Integration of wing pressures round the mid span point produced the lift coefficient data plotted in figure 4.6.LTPT and 7 x 5 data are compared, with positive and negative angle of attack data shown together due to a paucity of high negative α LTPT data. Figure 4.7 shows a comparison of LTPT and 7 x 5 model pressure distributions for $\alpha = 6^{o}$ and 12^{o}. The suction peak is the area of major difference for both α. For $\alpha = 12^{o}$ the 7 x 5 tests reveal a similar pressure distribution to SSWT results. For $\alpha = 6^{o}$, the 7 x 5 data has the appearance of a lower effective angle of attack, also the LTPT data has a very localised suction peak which is sensitive to Reynold's number (see Figure 4.8)

There are several approaches to analysing the 7 x 5 data. Firstly, consider the raw data. For $\alpha \leq 8^{o}$ there is a reduction in lift curve slope due to classical finite span effects. This is illustrated by fitting least square curves to all the available sets of C_L data in the α range $+8^o$ to -8^o. The slopes are:-

Data Source	Slope per radian
SSWT Streamlined-Wall $R_c \simeq 287,000$	4.767
LTPT $R_c \simeq 265,000$	4.916
LTPT $R_c \simeq 285,000$	4.847
LTPT $R_c \simeq 315,000$	4.625
7x5 $R_c \simeq 236,500$	4.062

The three sets of LTPT data are plotted in Figure 4.8.

A correction to the aspect ratio to account for end plates was applied to the 7 x 5 model[6] by assuming elliptical loading over the corrected model's span giving a corrected lift curve slope of 4.904 per radian. This compares favourably with the lift curve slope of 4.916 for LTPT data at the closest Reynold's number of 265,000.

Surface flow visualisation on the 7 x 5 model for $\alpha = -6^o$ and -12 is shown in Figure 4.10. At $\alpha = -6^o$ flow was uniform over the entire span on both model surfaces, but at $\alpha = -12$ the separated flow region on the suction surface had some strong three-dimensional components as could be expected with the shallow end plates. The flow pattern is symmetrica about the mid span point.

A second approach to 7 x 5 data analysis might be to correct α by matching C_L from the LTPT and 7 x 5 tests, and then to compare C_D values.

Thirdly, an effective 7 x 5 model aspect ratio could be found which eliminates any lift curve slope errors. A downwash correction could then be calculated for a finite span wing with no end plates. The effective angle of attack would yield new values of C_L for comparison. These two approaches have yet to be attempted.

Work to correct SSWT angle of attack is continuing with an investigation of wing tip loading to allow the application of a downwash correction at mid span.

Unfortunately, R_c has not been matched in all SSWT, 7 x 5 and LTPT tests. The effects of these differences are ambiguous. Variation of C_L with R_c for 7 x 5 tests at $\alpha = -12^0$ was as expected, that is a gradual increase of C_L with R_c as shown in Figure 4.9. But the C_D data shows no clear trend with R_c, similar to LTPT data. Note that in LTPT the lift reduces with increase of R_c at $\alpha = \pm 6^0$.

Force data was taken on the 7 x 5 model but this has yet to be fully analysed.

5. SIMULATION OF STEADY PITCHING

The range of flows which can be generated in a flexible walled wind tunnel has been extended by curving the test section axis in order to simulate steady pitching of the model. The bases for this type of testing were laid down by the users of the Langley Stability Tunnel[9].

The ideal test section would have these features:-

(1) be curved along its centerline

(2) contain forced vortex flow

(3) have streamlined walls to eliminate wall interference.

The Langley Stability Tunnel had 1 and 2 above; the tests in SSWT with a high blockage model (0012-64 with $^c/_h = 0.9$) had features 1 and 3. It should be noted, however, that as there was no streamlining criterion available at the time, the policy was adopted of curving streamlined wall contours which had earlier been determined in non-pitching tests. The walls may, therefore, not have been curved to proper streamlines in pitching flow.

The test section axis was arced about an axis below the airfoil quarter-chord point, with several radii of curvature to simulate various negative values of pitch rate. The jacks immediately above and below the $^c/_4$ point were not moved, therefore the test section was pulled down by varying amounts particularly near the ends. Curvature in the adapter sections (upstream of jack 1, downstream of jack 16) took up the local misalignment between the walls and the fixed contraction and diffuser.

The test section and model are sketched on the right of Figure 5.1, showing straight and curved test sections. The test data is presented in the form of the changes in the normal force and pitching moment coefficients ΔC_N and ΔC_M respectively, as functions of the measure of pitch rate $^q/U_\infty$. Data was taken at two angles of attack. Forces and moments were determined from integrated airfoil pressures. Plotted over the data are lines which show the variations of ΔC_N and ΔC_M with $^q/U_\infty$ predicted by thin airfoil theory. The agreement between theory and experiment is encouraging despite the several recognized weaknesses in the test arrangement.

6. TRANSONIC SELF-STREAMLINING WIND TUNNEL (TSWT)

6.1 FIRST RUNS

The new test section for the transonic induced flow tunnel was completed during this report period. Two photographs are included, figures 6.1 and 6.2. Figure 6.1 shows the test section region with the near sidewall partly disassembled, and an airfoil model in position. Much of the test section instrumentation is visible. Running off to the left of the figure are wiring harnesses from Scanivalve transducers, stepper motors and linear potentiometers to readout and control equipment just off the picture.

Temporarily the jacks are being motored individually. The jacks are switch-selectable and as each is selected the output of its position measuring potentiometer is displayed digitally. The initial exercising of the jacking mechanisms has shown that at the closest jack spacings sufficient wall curvature can be generated before the motors stall. Early tests with a jack prototype[1] had shown that the walls could not be damaged by a jack motor at stall torque.

Figure 6.2 is a close-up of the central region of the test section. The near sidewall sections are removed and constructional details are clearly visible. The details can be related to the drawings on figures 5.3a to 5.3d of reference 2.

The initial wind-on tests have been carried out with an empty test section, merely to explore the upper Mach number limit. For this purpose a throat was produced by the upstream jacks, and a Mach number of 1.1 reached with ease along the remaining length of the test section. Some minor leaks were revealed, through small gaps in sideplates, which were being corrected at the end of this report period

The next series of wind-on tests will be aimed at streamlining the walls with an empty test section and at various Mach numbers up to about 0.8. Present experience has shown that a continuous run time of about 3 minutes is available at M = 0.8. This time should be sufficient for fully automatic wall streamlining, wind on.

6.2 TRANSONIC SELF-STREAMLINING WIND TUNNEL CONTROL SOFTWARE

The wall setting algorithm described in previous reports[2,3] has been linked with a manual control system for TSWT. The basis of the control system is exactly that for SSWT.

An iteration process starts with the sampling of wind tunnel pressures. This data is fed manually to the control system software and analysed. The wall setting output is then used to manually reset the tunnel walls. The procedure is repeated until streamlining is achieved.

Alterations to the SSWT control software[2] included detailed changes of data input and output and the introduction of compressible flow correction terms in the wall setting algorithm. Also the TSWT control software has been generalised.

Linearised compressible flow theory yields the compressibility factor β. By scaling wind tunnel wall pressure coefficients and ordinates by the term $^1/\beta$, all flow calculations can be treated as incompressible for sub-critical Mach numbers up to about 0.8. This scaling is included in the TSWT control software, with a compressibility correction to tunnel dynamic head q. This has the form

$$\frac{q_c}{q_I} = 1 + {}^1/4\ M^2 + {}^1/40\ M^4 + \ldots$$

from isentropic flow theory.

The format of the data input now accommodates Scanivalve pressure transducer data. A check of the four pressure transducer calibrations is performed with each tunnel run.

Wall setting output is in units of volts, since the TSWT wall position is monitored by linear potentiometers. Integrated wing pressure forces are computed with each program run using subroutine LIFT which is a standard wing pressure analysis program.

The complete TSWT control software is listed in Appendix B. Its link with the TSWT scanivalve svstem and jack control system will reduce the wall streamlining time to less than the previous SSWT best of 240 minutes. During 1979 the TSWT control system loop will be closed, with further large reductions in the time to streamline. Further software development will involve the breakdown of one main program into managable subroutines. One possible configuration of the closed loop control software is as follows:

File Type	Function
Main Program	Control and sequence subroutine calls
Subroutine 1	On-line data aquisition
Subroutine 2	Data input presentation
Subroutine 3	Wall setting calculations
Subroutine 4	Residual error analysis
Subroutine 5	Wing forces calculations
Subroutine 6	Wall movement control
Subroutine 7	Data output presentation

7. PRINCIPAL CONCLUSIONS

1. Checks on the Predictive Method for Rapid Wall Adjustment have revealed that the wall streamlines selected by this method are satisfactory.

Wake surveys behind an airfoil model in near free air conditions and in SSWT are roughly the same. Imperfections in the test environment prevent a more positive claim. However, the surveys in SSWT suggest that a reason for lift data disparity may be the absence of zones of potential flow near the downstream portions of the flexible walls when the model was at a high angle of attack.

2. Measurements of purely rotary derivatives with high blockage models in a streamlined test section agree well with theory.

3. The operating mechanics and the empty-test-section aerodynamics of the new transonic flexible walled test section have proved satisfactory.

SYMBOLS

a	=	Lift curve slope
c	=	Model chord
C_c	=	Chordwise force coefficient
C_D	=	Pressure drag coefficient
C_{D_o}	=	Form drag coefficient
C_L	=	Lift coefficient
C_M	=	Pitching moment coefficient about airfoil leading edge
ΔC_M, ΔC_N	=	Change in C_M or C_N due to pitching
C_N	=	Normal force coefficient
h	=	Test section height
M	=	Freestream mach no.
q	=	Dynamic head, or rate of pitch.
R_c	=	Chord Reynold's number
U	=	Local velocity
U_∞	=	Reference velocity
x	=	chordwise position downstream of leading edge.
α	=	Angle of attack
β	=	Compressibility factor $= \sqrt{1 - M^2}$
Suffix I	=	Incompressible
C	=	Compressible

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APPENDIX A

Listing of the SSWT software WALLS 1, WALLS 2, WALL P1 and WALL P2

WALLS is used to analyse the wall adjacent to the airfoil suction surface,

WALL P for that adjacent to the pressure surface.

DATA

WALLS 1	WALL P1		
90	60		test section reference pressure (inches alcohol below ambient), ambient pressure (inches mercury), temperature °
140,150	110,120	:	sixteen jack position readings (inches) with walls curved.
170,180	140,150	:	sixteen values of boundary layer displacement thickness (inches) at wall orifices, empty tes section, correct unit Reynolds number.
200,210	170,180	:	jack positions (inches), walls straight
230,240	200,210	:	wall pressures, inches alcohol below ambient
250,260	220,230	:	wall orifice positions measured downstream (in inches) from wall leading edge. No orifices at 0.27 and 39.88.
270,280	240,250	:	wall position monitor points. 0.27 is upstream anchor point

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WALLS1

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10 COMMON D(49),S(48),C(18),W(34),M(18),X(18),Z(18),A(3)
30 PRINT "RUN 255"
40 PRINT
50 PRINT "STATION","   LMO"
90 DATA 3.16,29.97,15
100 FOR A2=1 TO 3
110 READ A(A2)
120 NEXT A2
130 DATA 0
140 DATA .155,.244,.328,.451,.538,.573,.61,.623
150 DATA .639,.592,.578,.513,.489,.378,.315,.038
160 DATA 0
170 DATA .023,.036,.044,.053,.055,.058,.061,.063,.066,.068,.071
180 DATA .073,.076,.081,.088,.097
190 DATA 0
200 DATA .096,.12,.116,.12,.155,.136,.131,.116,.132,.106
210 DATA .13,.112,.133,.108,.135,-.062
220 DATA 0
230 DATA 3.15,3.16,3.2,3.3,3.37,3.47,3.58,3.63
240 DATA 3.61,3.55,3.44,3.36,3.3,3.21,3.2,3.26
250 DATA .27,5.79,10.07,13.09,16.04,17.05,18.05,19.02,20.05,21.04
260 DATA 22.04,23.05,24.04,25.04,27.05,30.06,34.04,39.88
270 DATA 0.27,6.27,9.86,12.9,15.86,16.88,17.87,18.84,19.9,20.89,21.89
280 DATA 22.87,23.89,24.88,26.9,29.9,33.88,39.88
290 FOR A5=1 TO 34
300 READ W(A5)
310 NEXT A5
320 FOR A7=1 TO 18
330 READ C(A7)
340 C(A7)=W(A7)-C(A7)
350 NEXT A7
360 FOR A6=1 TO 18
370 IF A6=1 THEN 900
380 IF A6=18 THEN 900
390 READ M(A6)
400 NEXT A6
410 FOR A8=1 TO 18
420 READ Z(A8)
430 Z(A8)=19.991-Z(A8)
440 NEXT A8
450 FOR A9=1 TO 18
460 READ X(A9)
470 X(A9)=19.991-X(A9)
480 NEXT A9
490 D1=A(2)*.022855/(273.15+A(3))
500 FOR B1=1 TO 16
510 S=0
520 X8=Z(B1)
530 X9=Z(B1+1)
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```
540 U8=(3.28084*(M(B1)*2.54-(.1194*A(1)))/D1)^.5
550 U9=(3.28084*(M(B1+1)*2.54-(.1194*A(1)))/D1)^.5
560 B3=-12*(U9-U8)/(X9-X8)
570 U7=(U8+U9)/2
580 GO TO 1090
590 FOR I=1 TO 15
600 X1=X(I)
610 X2=X(I+1)
620 X3=X(I+2)
630 X4=X(I+3)
640 Y1=C(I)
650 Y2 C(I+1)
660 Y3 C(I+2)
670 Y4=C(I+3)
680 IF I>1 THEN 700
690 I1=19
700 GOSUB 920
710 IF I1<X3 THEN 770
720 Y=Y4+(A2*((I1-X4)^3))+(B2*(I1-X4)*(I1 X4))+(C2*(I1-X4)
730 D(20-I1)=Y
740 PRINT I1,Y
750 I1=I1-1
760 GO TO 710
770 IF I=15 THEN 840
780 NEXT I
790 D4=D(1)
800 FOR A6=1 TO 39
810 D(A6)=D(A6)-D4
820 NEXT A6
830 GO TO 860
840 IF I1=-20   IEN 790
850 GO TO 720
860 FOR A7=40 TO 49
870 D(A7)=D(39)
880 NEXT A7
882 U8=(3.28084*(A(1)*2.54-(.1194*A(1)))/D1)^.5
883 M1=5.4/12
884 M2=(U8*M1*D1*32.18*1.00000E+06)/(11.52+.034*A(3))
886 PRINT
888 PRINT "RC= ",M2
890 GO TO 1300
900 M(A6)=A(1)
910 GO TO 400
920 X5=X3-X4
930 X6=X2-X4
940 X7=X1-X4
950 Y5=Y3-Y4
960 Y6=Y2-Y4
970 Y7=Y1-Y4
980 B1 X5*X5-(X5*X5*X5)/X6
990 B3 X7*X7-(X7*X7*X7)/X6
1000 C1=X5-(X5*X5*X5)/(X6*X6)
1010 C3=X7-(X7*X7*X7)/(X6*X6)
1020 Z1=Y5-Y6*(X5*X5*X5)/(X6*X6*X6)
1030 Z3=Y7-Y6*(X7*X7*X7)/(X6*X6*X6)
1040 C2=((Z1*B3)/B1)-Z3
1050 C2=C2/(((C1*B3)/B1)-C3)
1060 B2=(Z1-(C2*C1))/B1
1070 A2=((Y5-(B2*X5*X5)-C2*X5))/(X5*X5*X5)
1080 RETURN
1090 FOR M1=3.00000E-04 TO 1 STEP 3.00000E-04
1100 M2=(U7*M1*D1*32.18*1.00000E+06)/(11.52+.034*A(3))
1110 M3=(.0179/((M2)^.25))
1120 [illegible]
```

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```
1130 A9=H5+(S12*X8-X9)/24)
1140 IF A9>M1 THEN 1160
1150 GO TO 1200
1160 IF S<0 THEN 1180
1170 GO TO 1230
1180 NEXT H1
1190 GO TO 1100
1200 S=1
1210 M1=M1-1.00000E-03
1220 GO TO 1100
1230 M =   I4-M5
1240 D9=   H1+1   -(16.0%  )
1250 S(B1 )=S( H+1)+D9
1260 NEXT  I1
1270 GO T  590
1300 CHAI  "WALLS2"
1310 END
```

WALLS2

```
10 COMMON D(49),S(48),  (18),W(34),H(18),X(18),Z(18),A(3)
20 T0=1.00000E-05
30 K=1.4
35 PRINT
40 PRINT "WALLS2"
50 PRINT
890 FOR A1=1 TO 48
900 S(A1)=(D(A1+1)-D(A1))
910 NEXT A1
920 Z9=0
930 FOR P7=1 TO 100
940 PRINT P7
950 F6=0
960 F6=0
970 FOR N=1 TO 49
980 F1=0
990 F1=F6+S(N)
1000 Y1=D(N+1)
1010 F2=Y1
1020 FOR P=1 TO 18
1030 F3=Y1/(N-P+.5)
1040 F4=ATN(F3)
1050 F5=S(P)*F4/PI
1060 F2=F2+F5
1070 NEXT P
1080 IF ((F1-F2)*(F1-F2))<.5*T0 THEN 1170
1090 F6=F1
1100 NEXT N
1110 IF P6=0 THEN 1150
1120 PRINT Z9
1130 Z9=0
1140 NEXT P7
1150 E1=0
1160 GO TO 1202
1170 P6=1
1180 Z9=Z9+1
1190 S(N)=S(N)+((F2-F1)/2)
1200 GO TO 980
```

```
1202 PRINT ",,,,,,,,,SOURCES,,,,,,,,,"
1204 PRINT "NO.";" STRENGTH"
1210 FOR N1=1 TO 48
1220 PRINT N1,S(N1)
1230 NEXT N1
1232 PRINT "     STATION   " "," "     CPI","     CPR","     I-R"
1235 Z9=2
1237 P6=Z(Z9)
1240 FOR Q=5 TO 43
1250 C7=0
1260 C8=0
1270 FOR R=1 TO 48
1280 T1=Q-R+.5
1290 T2=S(R)*T1 *T
1300 IF Q<1 THEN 1460
1310 IF Q>48 THEN 1460
1320 T3=(D(Q))^2+(T1*T1)
1330 T4=T2/T3
1340 C7=C7+T4
1350 IF Q<1 THEN 1480
1360 IF Q>48 THEN 1480
1370 T5=S(R)*(D(Q))/PI
1380 T6=T5/T3
1390 C8=C8+T6
1400 NEXT R
1410 C9=(-2*C7)-(C7*C7)-(C8*C8)
1420 IF ABS((19-Q)-P6)<.3 THEN 1860
1430 PRINT Q-19;" ";C9
1440 NEXT Q
1442 FOR R2=2 TO 17
1443 W(R2)=W(R2)+M(R2)
1446 NEXT R2
1450 GO TO 1500
1460 T3=T1*T1
1470 GO TO 1330
1480 T5=0
1490 GO TO 1380
1500 FOR R3=6 TO 13
1510 W(R3-1)=W(R3-1)+M(R3)/3
1520 W(R3+1)=W(R3+1)+M(R3)/3
1530 NEXT R3
1540 PRINT
1545 PRINT "JACK";"SET NEXT"
1550 FOR R4=2 TO 17
1552 W(R4)=1000*W(R4)
1554 W(R4)=INT(W(R4))
1556 W(R4)=W(R4)/1000
1560 PRINT R4-1,W(R4)
1570 NEXT R4
1575 PRINT  ,
1580 GO TO 1920
1860 C8=(A(1)-N(Z9))/(.953*A(1))
1870 PRINT " ";Z9-1;C9;C8;C9-C8
1872 X(Z9)=((1-C9)^.5)-((1-C8)^.5)
1875 M(Z9)=.5*(C9-C8)
1880 Z9=Z9+1
1890 IF Z9=18 THEN 1440
1900 P6=Z(Z9)
1910 GO TO 1440
```

```
1920 PRINT
1921 PRINT " "," EMO","  ERF"
1922 FOR E4=2 TO 17
1930 PRINT E4-1,C(E4),X(E4)
1940 NEXT E4
2010 END
```

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WALLP1

```
10 COMMON C(18),W(34),X(18),Z(18),A(3),D(59),S(58),M(18)
20 PRINT "RUN 255"
40 P6=0
60 DATA 3.16,29.97,15
70 FOR A2=1 TO 3
80 READ A(A2)
90 NEXT A2
100 DATA 0
110 DATA .01,.008,-.019,-.045,-.05,-.055,-.037,-.013
120 DATA .022,.021,.06,.063,.086,.11,.186,.093
130 DATA 0
140 DATA .023,.036,.044,.053,.055,.058,.061,.063,.066,.068,.071
150 DATA .073,.076,.081,.088,.097
160 DATA 0
170 DATA .085,.14,.175,.214,.226,.228,.238,.24
180 DATA .249,.224,.245,.239,.256,.247,.268,.116
190 DATA 0
200 DATA 3.16,3.16,3.1,3,2.94,2.92,2.93,2.99
210 DATA 3.05,3.12,3.17,3.15,3.13,3.16,3.17,3.24
220 DATA .27,5.99,10.07,13.09,16.04,17.05,18.05,19.02,20.05,21.04
230 DATA 22.04,23.05,24.04,25.04,27.05,30.06,34.04,39.88
240 DATA 0.27,3.27,9.86,12.9,15.86,16.88,17.87,18.84,19.9,20.89,21.89
250 DATA 22.87,23.89,24.88,26.9,29.9,33.88,39.88
260 FOR A5=1 TO 34
270 READ W(A5)
280 NEXT A5
290 FOR A7=1 TO 18
300 READ C(A7)
310 C(A7)=W(A7)-C(A7)
320 NEXT A7
330 FOR A6=1 TO 18
340 IF A6=1 THEN 870
350 IF A6=18 THEN 870
360 READ M(A6)
370 NEXT A6
380 FOR A8=1 TO 18
390 READ Z(A8)
400 Z(A8)=19.991-Z(A8)
410 NEXT A8
420 FOR A9=1 TO 18
430 READ X(A9)
```

```
440 X(A9)=19.991-X(A9)
450 NEXT A9
460 D1=A(2)*.022855/(273.15+A(3))
470 FOR B1=1 TO 14
480 S=0
490 X8=Z(B1)
500 X9=Z(B1+1)
510 U8=(3.2806*(M(B1)*2.54-(.1194*A(1)))/D1)^.5
520 U9=(3.2806*(M(B1+1)*2.54-(.1194*A(1)))/D1)^.5
530 D2=-12*(U9-U8)/(X9-X8)
540 U7=(U8+U9)/2
550 GO TO 1670
560 FOR I=1 TO 15
570 X1=X(I)
580 X2=X(I+1)
590 X3=X(I+2)
600 X4=X(I+3)
610 Y1=C(I)
620 Y2=C(I+1)
630 Y3=C(I+2)
640 Y4=C(I+3)
650 IF I>1 THEN 670
660 I1=19
670 GOSUB 1500
680 IF I1<X3 THEN 740
690 Y=Y4+(A2*((I1-X4)^3))+(B2*(I1-X4)*(I1-X4))+(C2*(I1-X4))
700 D(30-I1)=Y
715 IF Y<Z2 THEN 900
720 I1=I1-1
730 GO TO 680
740 IF I=15 THEN 810
750 NEXT I
810 IF I1=-20 THEN 830
820 GO TO 690
830 FOR A7=50 TO 59
840 D(A7)=D(49)
850 NEXT A7
860 GO TO 911
870 M(A6)=A(1)
880 GO TO 370
900 Z2=Y
910 GO TO 720
911 FOR E3=1 TO 10
913 D(E3)=D(11)
915 NEXT E3
920 PRINT
921 PRINT "STA.","END"
925 FOR Z3=1 TO 59
930 D(Z3)=D(Z3)-Z2
932 IF Z3<10 THEN 950
934 IF Z3>50 THEN 950
940 PRINT 30-Z3,D(Z3)
950 NEXT Z3
960 GO TO 1960
1500 X5=X3-X4
1510 X6=X2-X4
1520 X7=X1-X4
1530 Y5=Y3-Y4
1540 Y6=Y2-Y4
1550 Y7=Y1-Y4
```

```
1560 B1=X5*X5-(X5*X5*X5)/X6
1570 B3=X7*X7-(X7*X7*X7)/X6
1580 C1=X5-(X5*X5*X5)/(X6*X6)
1590 C3=X7-(X7*X7*X7)/(X6*X6)
1600 Z1=Y5-Y6*(X5*X5*X5)/(X6*X6*X6)
1610 Z3=Y7-Y6*(X7*X7*X7)/(X6*X6*X6)
1620 C2=((Z1*B3)/B1)-Z3
1630 C2=C2/(((C1*B3)/B1)-C3)
1640 B2=(Z1-(C2*C1))/B1
1650 A2=((Y5-(B2*X5*X5)-C2*X5))/(X5*X5*X5)
1660 RETURN
1670 FOR M1=3.00000E-04 TO 1 STEP 3.00000E-04
1680 M2=(U7*M1*D1*32.16*1.00000E+06)/(11.52+.034*A(3))
1690 M3=(.0128/((M2)^.25))
1700 S1=M3-3.4*M1*U2/U7
1710 M4=M5+(S1*((8-X)/24)
1720 IF M4>M1 THEN 1740
1730 GO TO 1780
1740 IF S=0 THEN 1760
1750 GO TO 1810
1760 NEXT M1
1770 GO TO 1680
1780 S=1
1790 M1=M1-1.00000E-05
1800 GO TO 1680
1810 M5=2*M4-M5
1820 D9=W(B1+18)-(16.8*M5)-
1830 C(B1+1)=C(B1+1)+D9
1840 NEXT B1
1850 GO TO 560
1852 Z9=C(B1+1)
1854 GO TO 1840
1860 CHAIN "WALLP2"
1870 END
```

WALLP2

```
10 COMMON C(18),W(34),X(18),Z(18),A(3),D(59),S(58),N(18)
20 T0=1.00000E-03
30 K=1.4
40 PRINT
50 PRINT "WALLP2"
60 PRINT
70 FOR A1=1 TO 58
80 S(A1)=(D(A1+1)-D(A1))
90 NEXT A1
100 U2=D(1)
110 Z9=0
120 FOR P7=1 TO 100
130 PRINT P7
140 F6=U2
150 P6=0
160 FOR N=1 TO 58
170 F1=0
180 F1=F6+S(N)
190 Y1=D(N+1)
```

```
200 F2=Y1
210 FOR P=1 TO 50
220 F3=Y1/(N-P+.5)
230 F4=ATN(F3)
240 F5=C(P)*F4/PI
250 F2=F2+F5
260 NEXT P
270 IF ((F1-F2)*(F1-F2))/ .5/10 THEN 360
280 F6=F1
290 NEXT N
300 IF P4=0 THEN 340
310 PRINT Z9
320 Z9=0
330 NEXT P7
340 L1=0
350 GO TO 400
360 P4=1
370 Z9=Z9+1
380 S(N)=S(N)+((F2-F1)*K)
390 GO TO 170
400 PRINT "........SOURCES........."
410 PRINT "NO.  ","STRENGTH"
420 FOR N1=1 TO 58
430 PRINT N1,S(N1)
440 NEXT N1
450 PRINT "     STATION"," ","     CPI","     CPR","     I-R"
460 Z9=2
470 P6=Z(Z9)
480 FOR Q=-5 TO 43
490 C7=0
500 C8=0
510 FOR R=1 TO 58
520 T1=10.5-R+Q
530 T2=S(R)*T1/PI
540 IF Q<1 THEN 710
550 T3=(D(Q))^2+(T1*T1)
560 T4=T2/T3
570 C7=C7+T4
580 IF Q<1 THEN 730
590 T5=S(R)*(D(Q))/PI
600 T6=T5/T3
610 C8=C8+T6
620 NEXT R
630 C9=(-2*C7)+(C7*C7)-(C8*C8)
640 IF ABS((19-Q)-P6)<.3 THEN 890
650 PRINT Q-19," ",C9
660 NEXT Q
670 FOR R2=2 TO 17
680 U(R2)=U(R2)+S(R2)
690 NEXT R2
700 GO TO 750
710 T3=(D(1))^2+(T1*T1)
720 GO TO 560
730 T5=S(R)*(D(1))/PI
740 GO TO 600
750 FOR R3=6 TO 13
```

```
760 W(R3-1)=W(R3-1)+M(R3)/3
770 W(R3+1)=W(R3+1)+M(R3)/3
780 NEXT R3
790 PRINT
800 PRINT "J  CK","SET NEXT"
810 FOR R4=2 TO 17
820 W(R4)=10 04W(R4)
830 W(R4)=INT(W(R4))
840 W(R4)=W(R4)/1000
850 PRINT R4-1,W(R4)
860 NEXT R4
870 PRINT
880 GO TO 970
890 C9=(A(1)-A(Z9))/(.953*A(1))
900 PRINT "   ",Z9-1,C9,C8,C9-C8
910 X(Z9)=((1-C9)^.5)-((1-C8)^.5)
920 M(Z9)=.5*(C9-C8)
930 Z9=Z9+1
940 IF Z9=18 THEN 660
950 C8=C(Z9)
960 GO TO 660
970 FOR E4=2 TO 17
980 PRINT E4-1,C(E4),X(E4)
990 NEXT E4
1000 END
```

```
      DIMENSION AA(200),BB(500),CC(700),CB(128),CN(32)
      DIMENSION T(30),[illegible](30),[illegible](30),H(30),Y(30),G(30),P(30),U(30)
      DIMENSION V(30),[illegible](30),H(30),C(30,4),Z(30),S(30),T(30),RS(30)
      DIMENSION Z(30),[illegible],[illegible]8(4),CLB(12),Q(30),XI(30),WI(30)
      [illegible] RD(49),[illegible](44),AG(44),AH(44),AJ(4))
      EQUIVALENCE ((R(2[illegible]),J(3,1))
      REAL N
      CALL TYPE('%&         UNIVERSITY OF SOUTHAMPTON')
      CALL TYPE('%        TRANSONIC SELF-STREAMLINING TEST SECTION')
      CALL TYPE('%                     WALL ANALYSIS')
      CALL TYPE('%                     ***********')
      CALL TYPE('%&                    MANUAL MODE    ')
      CALL ASKN(AA,'%&       TEST WALL DATA INPUT FILE =')
      CALL ASKN(BB,'%        TEST PRESSURE DATA INPUT FILE =')
      CALL ASKN(CC,'%        TEST DATA OUTPUT FILE =')
      CALL INPUT (AA,CB,MA)
      ASSIGN 1000 TO MA
      CALL INPUT (BB,CB,MB)
      ASSIGN 1001 TO MB
      CALL OUTPUT (CC)
      CALL INS(AA,0,0)
      CALL INS(BB,0,0)

      INPUT TEST PARAMETERS

      CALL TYPE('%&&&       TEST PARAMETERS')
      CALL ASKI(NJ,'%&       NO. OF INFO POINTS?   ')
      CALL ASKI(MT,'%       NO. OF MODEL TAPS?   ')
      CALL ASKI(NR,'%       NO. OF REF. SAMPLES?  ')
      CALL ASKR(JA,'%& [illegible] PRES. INFO - NO.? (IF NONE ANS 0)
      CALL TYPE('%%        TRANSDUCER')
      CALL TYPE('%   CALIBRATION CHECK (CM HG PORT 1)  ')
      CALL ASKR(C1,'%      CHANNEL 1 ?   ')
      CALL ASKR(Z1,'%    TRACE ZERO -  ')
      CALL ASKR(C2,'%      CHANNEL 2 ?   ')
      CALL ASKR(Z2,'%    TRACE ZERO -  ')
      CALL ASKR(C3,'%      CHANNEL 3 ?   ')
      CALL ASKR(Z3,'%    TRACE ZERO -  ')
      CALL ASKR(C4,'%      CHANNEL 4 ?   ')
      CALL ASKR(Z4,'%    TRACE ZERO -  ')
      CALL ASKR(DP,'%    MEAS. RESOLUTION (CM HG) -  ')
      CALL TYPE('%& POT CALIBRATION  (MV PER INCH)')
      CALL ASKR(CL1,'%    AVERAGE VALUE ?   ')
      NJ1 = NJ/2
C
C     READ DATA FROM INPUT FILES
C
      DO 10 J = 1,NJ1
10    CALL IN(AA,RS(J))
      DO 20 J = 1,NJ1
20    CALL IN(AA,N(J))
      N = NJ1 + A
```

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******* 'RETURN' ONLY = CONTINUE ,'CHAR''RETURN' =EXIT *******

```
      DO 30  J = 1,N
30    CALL IN(AA,A(J))
      DO 40  J = 1,M
40    CALL IN(AA,W(J))
      CALL TYPE('%%  CHECK VALUES (CM HG)')
      CALL TYPE('%CHANNEL 1              2              3              4')
      DO 42 J = 1,12
42    CALL IN(BB,CLB(J))
      DO 50 J = 1,M
      CALL IN(BB,P(J))
      P1 = P(J) - Z2
50    P(J) = CLB(4)+(CLB(5)*P1)+(CLB(6)*(P1*P1))
      DO 60 J = 1,M
      CALL IN(BB,Q(J))
      P1 = Q(J) - Z4
60    Q(J) = CLB(10)+(CLB(11)*P1)+(CLB(12)*(P1*P1))
      NR1 = NR + 4
      DO 61 L = 1,NR1
      CALL IN(BB,RD(L))
      IF (L.GT.(NR+1)) GO TO 61
      P1 = RD(L) - Z1
      RD(L) = CLB(1)+(CLB(2)*P1)+(CLB(3)*(P1*P1))
61    CONTINUE
      DO 80 J = 1,M
80    CALL IN(BB,D(J))
      CALL IN(BB,AK1)
      CALL IN(BB,AK3)
      CALL TYPE
      P1 = RD(1) + P(3
      P3 = RD(1) + Q(3,
      CALL TYPER(RD(1),P1,P2,P3)
      CALL TYPE
      CALL TYPER(C1,C2,C3,C4)
      IF (MT.EQ.0) GO TO 34
      DO 70 J = 1,MT
      CALL IN(BB,B(J))
      P1 = B(J) - Z3
70    B(J) = CLB(7)+(CLB(8)*P1)+(CLB(9)*(P1*P1))
      DO 71 J = 1,MT
71    CALL IN(BB,AG(J))
      DO 72 J = 1,MT
72    CALL IN(BB,AH(J))
      DO 73 J = 1,MT
73    CALL IN(BB,AJ(J))
      DO 74 J = 1,MT
74    CALL IN(BB,WHG(J))
34    AK2 = AK1
      AK4 = AK3
      AN1 = 0.0
      CALL TYPE('%%%      REFERENCE DATA INPUT')
      CALL TYPE('%        NO.      STATIC       MACH NO.
      R1 = RD(NR+2)-RD(NR+1)
```

******** 'RETURN' ONLY = CONTINUE ,'CHAR''RETURN' =EXIT ********

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```
      DO 81 J = 1,NR
      AD1 = AD1 + RD(J)
      R2 = RD(NR+2)-RD(J)
      R3 = 0.285714 * LOG(R1/R2)
      AM1 = 5.0*(EXP(R3)-1)
      AM2 = SQRT(AM1)
      CALL TYPE('&
      CALL TYPEI(J)
      CALL TYPER(RD(J),AM2)
81    CONTINUE
      CALL TYPE('&     TEST CONDITIONS')
      CALL TYPER(RD(NR+1),RD(NR+2),RD(NR+3))
      AS = AD1/NR
C
C     ANALYSE AIRFOIL PRESSURES
C
      CALL TYPE('&&      AIRFOIL PRES. DIST. FOR RUN')
      K = RD(NR+4)
      CALL TYPEI(K)
      CALL TYPE('&                          ===========')
      CALL ASKR(CHD,'&&        MODEL CHORD (INS.) =   ')
      CALL ASKR(AA,'&        ANGLE OF ATTACK (DEG.) =   ')
      R2 = RD(NR+2) - AS
      R3 = 0.285714*LOG(R1/R2)
      PP1 = 5.0*(EXP(R3)-1)
      AMA1 = SQRT(PP1)
      B1 = SQRT(1-PP1)
      CALL TYPE('&&              AVERAGE MACH NO. =')
      CALL TYPER(AMA1)
      R1 = R1 + DP
      R2 = R2 - DP
      R3 = 0.285714*LOG(R1/R2)
      P1 = 5.0 * (EXP(R3)-1)
      AM2 = AM1 - SQRT(P1)
      CALL TYPE('&  RESOLUTION =
      CALL TYPER(AM2)
      D1 = RD(NR+2)*8.998E-3/(273.15+RD(NR+3))
C
C   COMPRESSIBILITY CORRECTION
C
      PP2 = 1.0 + (0.25*PP1) + (.025*(PP1*PP1))
      PP3 = (AS-RD(NR+1))/PP2
      U0 = SQRT(56.65*(PP3)/D1)
      R2 = U0 * D1 * 3218E4/(11.52+0.034*RD(NR+3))
      R3 = R2 * CHD/12
      CALL TYPE('&              AVERAGE CHORD REYNOLDS NUMBER =')
      CALL TYPER(R3)
      CALL TYPE('&&&')
      MN = 1
      IF (MT.EQ.0) GO TO 36
      DO 70 J = 1,MT
      NT = (J-5)/6
```

******** 'RETURN' ONLY = CONTINUE ,'CHAR''RETURN' =EXIT ********

```
      R = NI * 6.0
      IF ((J- ).EQ.NT) MM = MM + 1
      Q1 = R( MM) - RO( R+1)
      Q2 = Q  PP2
      (J) =  -U(J))/Q
90    CONTINUE
C
C     COMPUTE THE  L     L COEFFICIENTS
C
      CALL L  T(AA,M,  ,AO,AH,AJ,UNG)
C
C     CHECK THE INPUT DATA
C
36      CALL TYPE('&&&                                  EXTERNAL VEL.')
      CALL TYPE('              WALL PRES.(CM HG)')
      CALL TY E('&        X(IN)       UPPER VEL.  LOWER VEL.')
      CALL T PE('     UPPER        LOWER')
      MM = 1
C
C     CALCULATE THE EXTERNAL VELOCITIES
C
      DO 100 I = 1,M
      NT = (I-5)/6
      NT = NT * 6
      IF((I-5).EQ.NT) MM = MM +1
      Q1 = RO(MM) - RO(MR + 1)
      Q2 = Q /PP2
      CALL TYPE('&')
      CALL TYPER(D(I),X(I),W(I),P(I ,Q(I))
      TEMP = (P(I) + Q1)/Q1
      TEMP1 = 1 - B1 + (B1*TEMP)
      TEMP = SQRT(TEMP1)-1
      U(I) = TEMP-X(I)
      E(I) = (AK3*U(I)/2)+X(I)
      TEP = (Q(I) + Q1)/Q1
      TEP1 = 1 - B1 + (B1*TEP)
      TEP = SQRT(TEP1)-1
      V(I) = W(I)-TEP
      H(I) = W(I)-(AK4*V(I)/2)
      WI(I) = (TEP+1)*(TEP+1)
      XI(I) = (TEMP+1)*(TEMP+1)
100   CONTINUE
      L = M-2
      DO 110 I = 1,L
110   Z(I) = (D(I)+D(I+1))/2
C
C     INTERPOLATE THE WALL VORTICITY AT REGULAR INTERVALS
C     AND PERFORM A NUMERICAL SUMMATION
C
      DO 175 NN = 1,2
      NC = NN-1
65    I = 0
```

******* 'RETURN' ONLY = CONTINUE ;'CHAR''RETURN' =EXIT *******

********** LISTING OF XSW3.FTP *********

```
35      DO 120 J = 1,4
        KI = I-1
        A(J) = X(I+J)
15      IF (NC.EQ.0) GO TO 25
        XB(J) = V(I+J)
        GO TO 120
25      XB(J) = U(I+J)
120     CONTINUE
        V0 = (XB(3)-XB(2))/(A(3)-A(2))
        V1 = XB(2)-V0*A(2)
        V2 = 1/(A(4)-A(1))
        V3 = (XB(4)-V0*A(4)-V1)/((A(4)-A(2))*(A(3)-A(4)))
        V4 = (XB(1)-V0*A(1)-V1)/((A(1)-A(2))*(A(3)-A(1)))
        V6 = V2*(V3-V4)
        V5 = V4-V6*A(1)
        I = I+1
        P1 = A(2) + A(3)
        C(I,1) = V1-A(2)*A(3)*V5
        C(I,2) = V0+V5*P1-V6*A(2)*A(3)
        C(I,3) = V6*P1-V5
        C(I,4) = -V6
        IF (I.LT.(M-3)) GO TO 35
        LI = M-2
        DO 130 J = 2,LI
        Z0 = Z(J)
        Z02 = Z0*Z0
        Z03 = Z02*Z0
        SS = 0
        K = M- 3
        DO 140 I = 1,K
        Y1 =D(I+1)
        C0 = C(I,1)
        C1 = C(I,2)
        C2 = C(I,3)
        C3 = C(I,4)
        Y2 = D(I+2)
        Y2SQ = Y2*Y2
        Y1SQ = Y1 * Y1
        S0 = C0+C1*Z0+C2*(Z02)+C3*(Z03)
        TEMP = ABS(Y2-Z0)/ABS(Y1-Z0)
        S1 = ALOG(TEMP)
        S2 = (C1+C2*Z0+C3*Z02)*(Y2-Y1)
        S3 = (C2+C3*Z0)*((Y2SQ)-(Y1SQ))/
        S4 = C3*((Y2SQ*Y2)-(Y1SQ*Y1))/3
        SS = SS+S0*S1+S2+S3+S4
140     CONTINUE
        IF (NC.EQ.1) GO TO 45
        R(J) = SS/6.28319
        GO TO 130
45      T(J) = SS/6.28319
130     CONTINUE
175     CONTINUE
```

******* 'RETURN' ONLY = CONTINUE ,'CHAR''RETURN' =EXIT *******

********* LISTING OF XSW3.FTP *********

```
C
C        PERFORM A NUMERICAL INTEGRATION OF WALL VORTICITY
C        TO FIND WALL MOVEMENT "Y"
C
 75      R = 0
         TT = 0
         P(1) = 0.0
         T(1) = 0.0
         CALL TYPE('&&?          OUTPUT RUN')
         K = RU(NK+4)
         CALL TYPEI(K)
         CALL TYPE('&          ************')
         CALL TYPE('&   JACK      X(IN)       UPPER VEL    LOWER VEL')
         CALL TYPE('      UP Y          LO Y')
         DO 150 I =1,NJ
         T0 = S(I)
         R0 = T(I)
         T1 = Z(I)
         I1 = I+1
         T2 = D(I1)
         T3 = S(I1)
         R3 = T(I1)
         T4 = Z(I1)
         I2 = I+2
         T5 = D(I2)
         T6 = S(I2)
         R6 = T(I2)
         T7 = Z(I2)
         FS1 = (T6-T3)/(T7-T4)
         FS2 = (R6-R3)/(T7-T4)
         T2SQ = T2*T2
         T5SQ = T5*T5
         T8 = (FS1-(T0-T3)/(T1-T4))/(T7-T1)
         T9 = FS1 - T8 * T7
         P2 = (T3-T9*T4)*(T5-T2)+T8*((T5SQ*T5)-(T2SQ*T2))/3
         TT = TT+P2+(T9-T8*T4)*((T5SQ)-(T2SQ))/2
         R8 = (FS2-(R0-R3)/(T1-T4))/(T7-T1)
         R9 = FS2 - R8 *T7
         P3 = (R3-R9*T4)*(T5-T2)+R8*((T5SQ*T5)-(T2SQ*T2))/3
         F = E(I2)
         R = R+P3+(R9-R8*T4)*((T5SQ)-(T2SQ))/2
         Y(I2) = (AK3*TT)+(AK2*AK4*R)
         B(I2) = (AK4*R)+(AK1*AK3*TT)
         E(I2) = E(I2) + ((H(I2)-W(I2)+V(I2))*AK2)
         H(I2) = H(I2)+((F-U(I2)-X(I2))*AK1)
         CALL TYPE('&  ')
         CALL TYPEI(I)
         IF(I.LT.10) CALL TYPE(' ')
         Y(I2) = A1 * Y(I2)
         B(I2) = A1 * B(I2)
         CALL TYPER(D(I2),E(I2),H(I2),Y(I2),B(I2))
 150     CONTINUE
```

******* 'RETURN' ONLY = CONTINUE ,'CHAR''RETURN' =EXIT *******

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```
C
C       CALCULATE WALL CP ERRORS
C
        EE = 0
        F = 0
        DO 160 I = 3,M-2
        W(I) = (W(I)+1)*(W(I)+1)
        X(I) = (X(I)+1)*(X(I)+1)
        EE = EE + ABS(XI(I)-X(I))
        F = F + ABS(WI(I)-W(I))
 160    CONTINUE
        EE = EE/(M-4)
        F = F/(M-4)
        CALL TYPE ('&&   UPPER CP  ERROR =')
        CALL TYPER (EE)
        CALL TYPE('        LOWER CP ERROR =')
        CALL TYPER(F)
        CALL TYPE('&         ***************************')
        CALL TYPE('              ***************************')
C
C       CONVERT "Y" INTO NEW WALL SETTINGS
C       AND OUTPUT TO A DATA FILE
C
        K = RO(NK+4) + 1
        CALL TYPE('&&   RUN')
        CALL TYPEI(K)
        CALL TYPE('    WALL SETTINGS')
        CALL TYPE('&  TOP WALL')
        CALL TYPE('&        JACK     DELTA      OLD       SET (MV)')
        DO 170 J = 1,NJ1
        RS1 = RS(J) + (Y(J+2)*CL1)
        CALL OUT (CC,RS1)
        CALL TYPE ('&         ')
        CALL TYPEI(J)
        IF (J.LT.10) CALL TYPE(' ')
        CALL TYPER(Y(J+2),RS(J))
        IS1 = RS1
 170    CALL TYPEI(IS1)
        CALL TYPE('&&   BOTTOM WALL')
        CALL TYPE('&        JACK     DELTA      OLD       SET (MV)')
        DO 180 J = 1,NJ1
        RS2 = N(J) - (G(J+2)*CL1)
        CALL OUT (CC,RS2)
        CALL TYPE('&         ')
        CALL TYPEI(J)
        IF (J.LT.10) CALL TYPE(' ')
        CALL TYPER(G(J+2),N(J))
        IS1 = RS2
 180    CALL TYPEI(IS1)
        DO 190 J = 1,M
        E(J) = 0.0
 190    CALL OUT(CC,E(J))
```

******** 'RETURN' ONLY = CONTINUE ,'CHAR''RETURN' =EXIT ********

```
*************** LISTING OF X$W3.FTP **********

        DO 200 J = 1,N
        H(J) = 0.0
200     CALL OUT(CC,H(J))
        CALL INEND(DA)
        CALL INEND(DB)
        CALL OUTEND(CC,CD)
        GO TO 55
1000    CALL TYPE('2  WALL DATA ERROR DETECTED')
1001    CALL TYPE('2      PRESSURE DATA ERROR DETECTED')
55      END

********* END OF LISTING - PRESS 'RETURN' TO EXIT ********
```

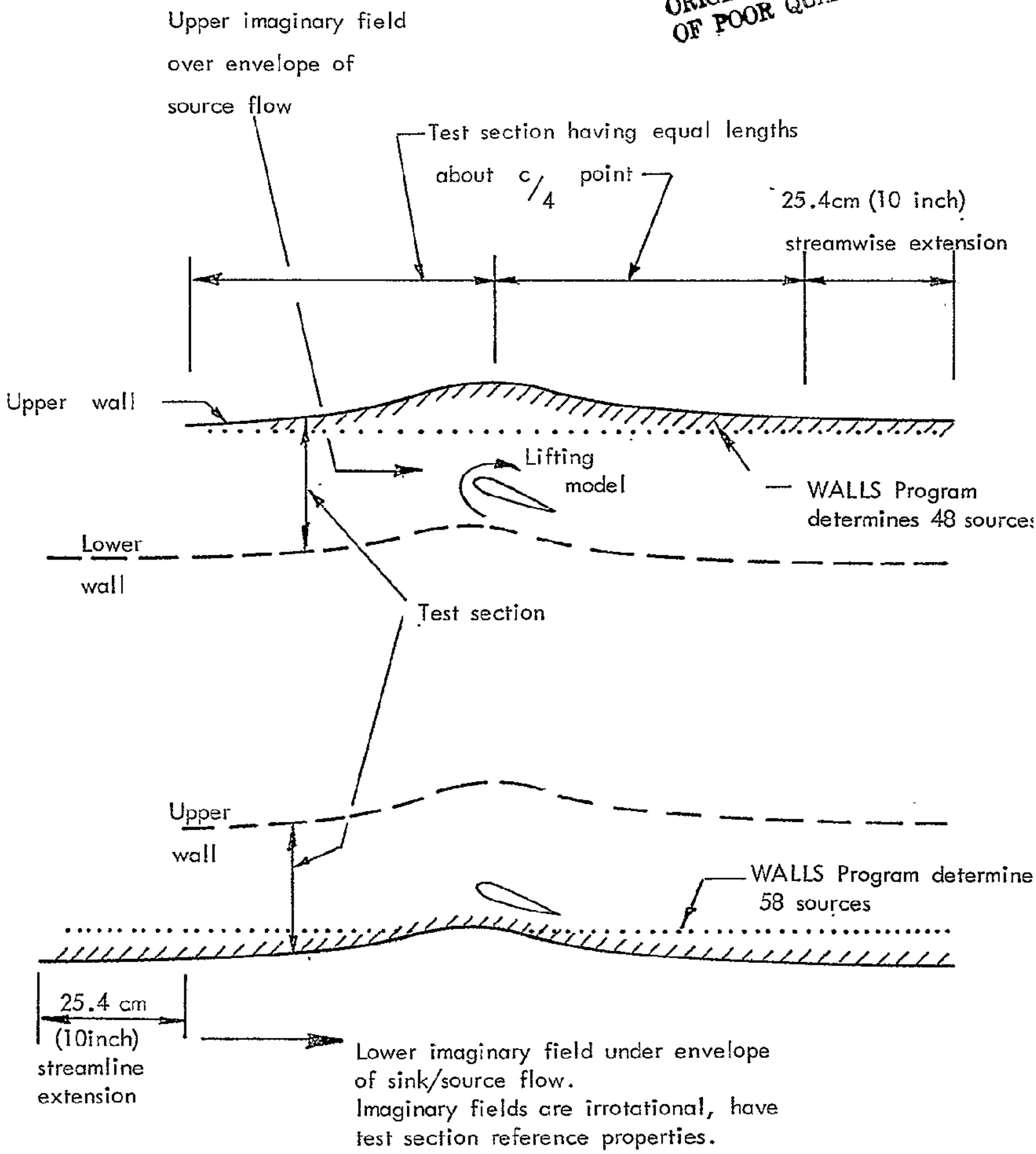

FIG. 2.1 ILLUSTRATION OF SOURCE/SINK REPRESENTATION OF TEST SECTION WALLS

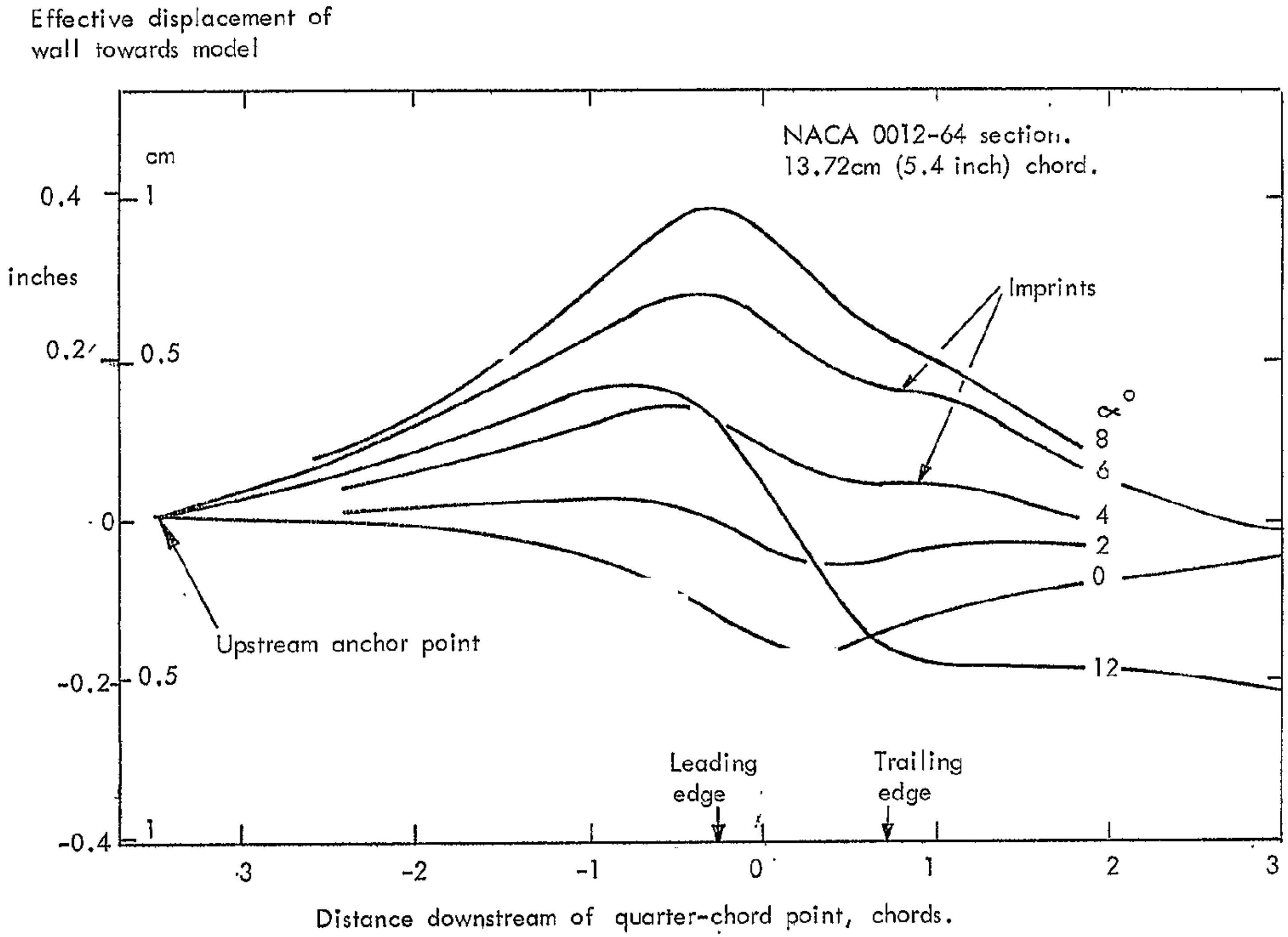

FIG. 2.2 EFFECTIVE CONTOURS OF WALL UNDER AIRFOIL MODEL AT SELECTED ANGLES OF ATTACK.

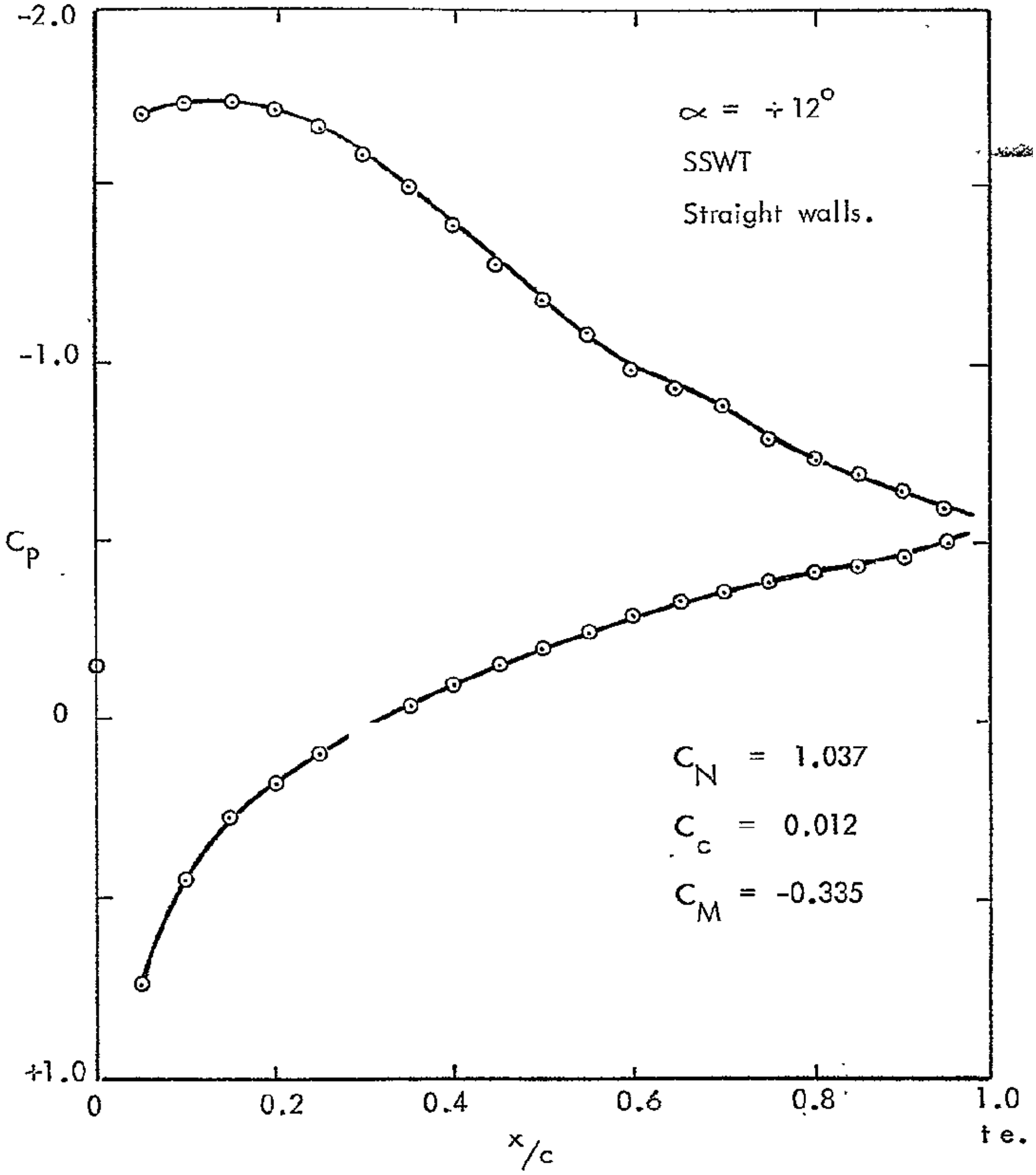

FIG. 3.1 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTIONS.

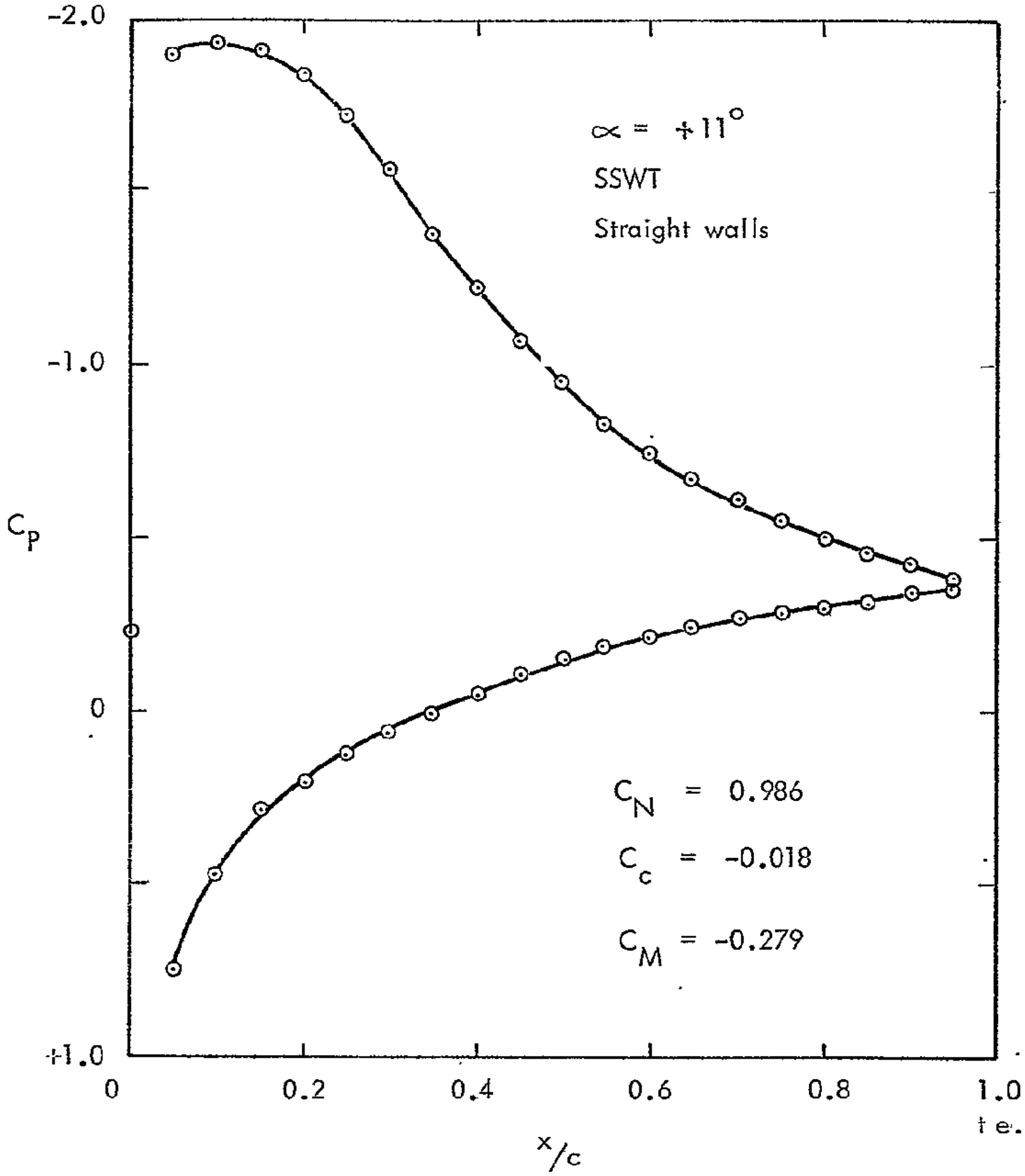

FIG. 3.2 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTIONS.

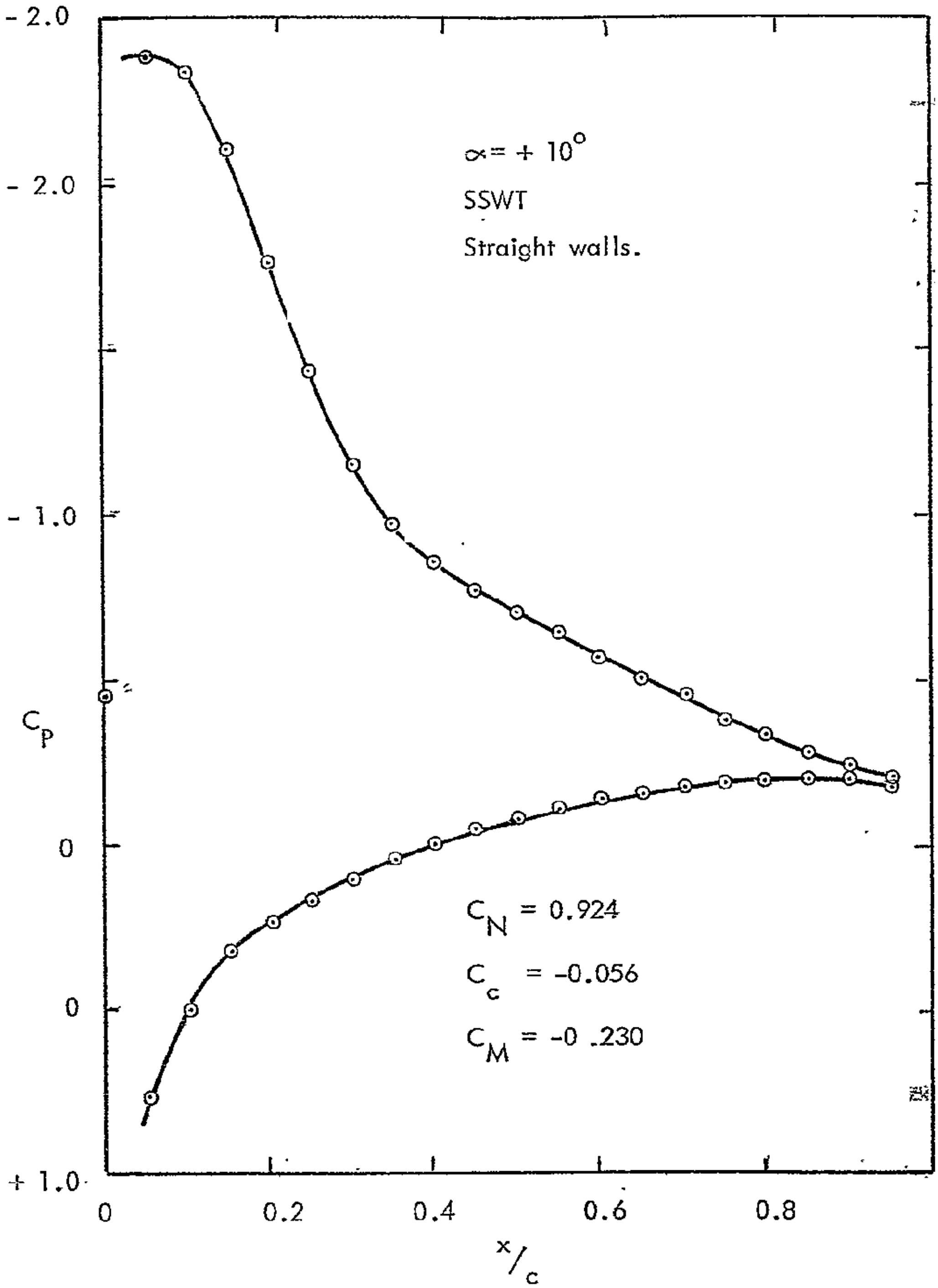

FIG. 3.3 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTIONS.

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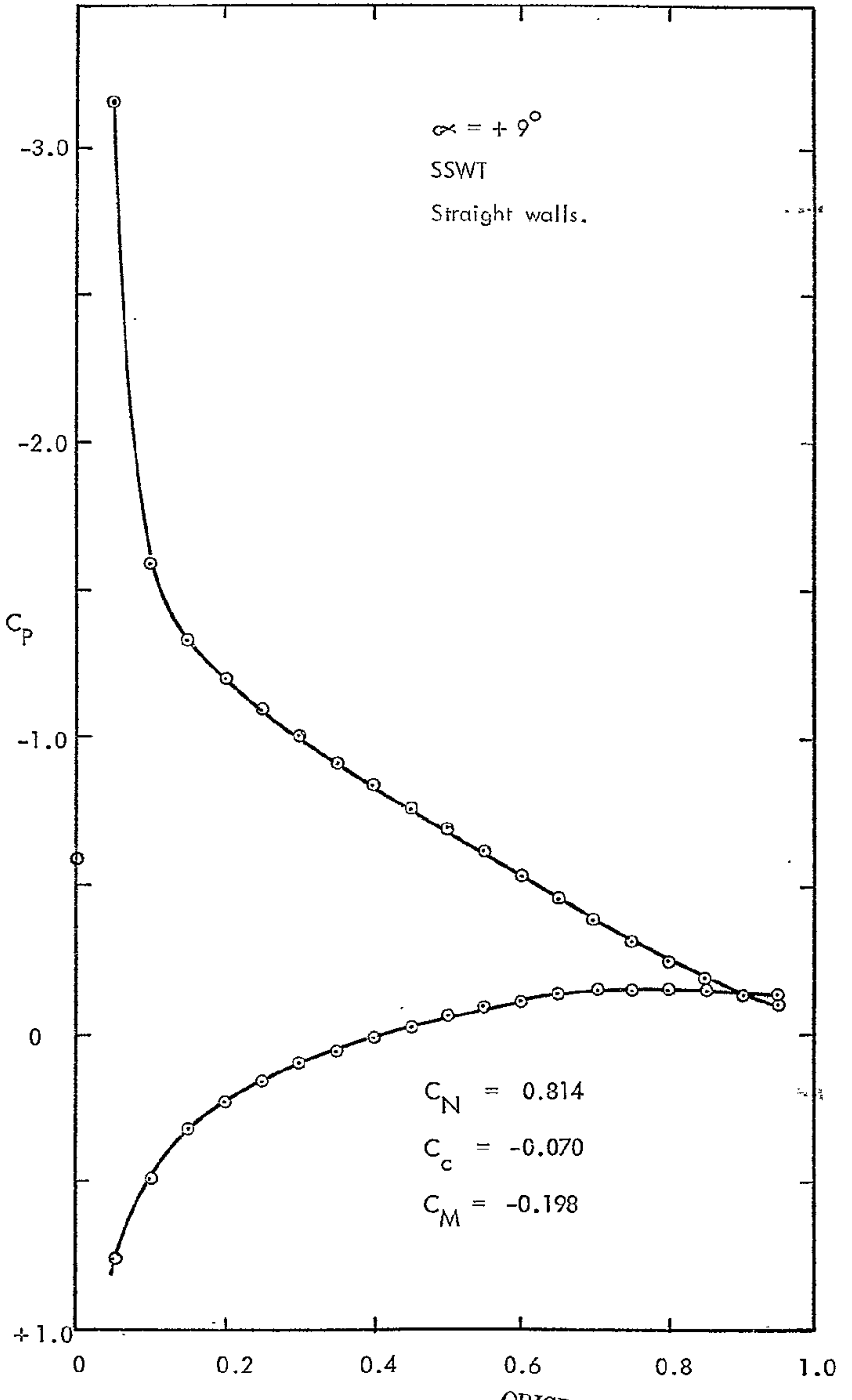


FIG. 3.4 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTIONS.

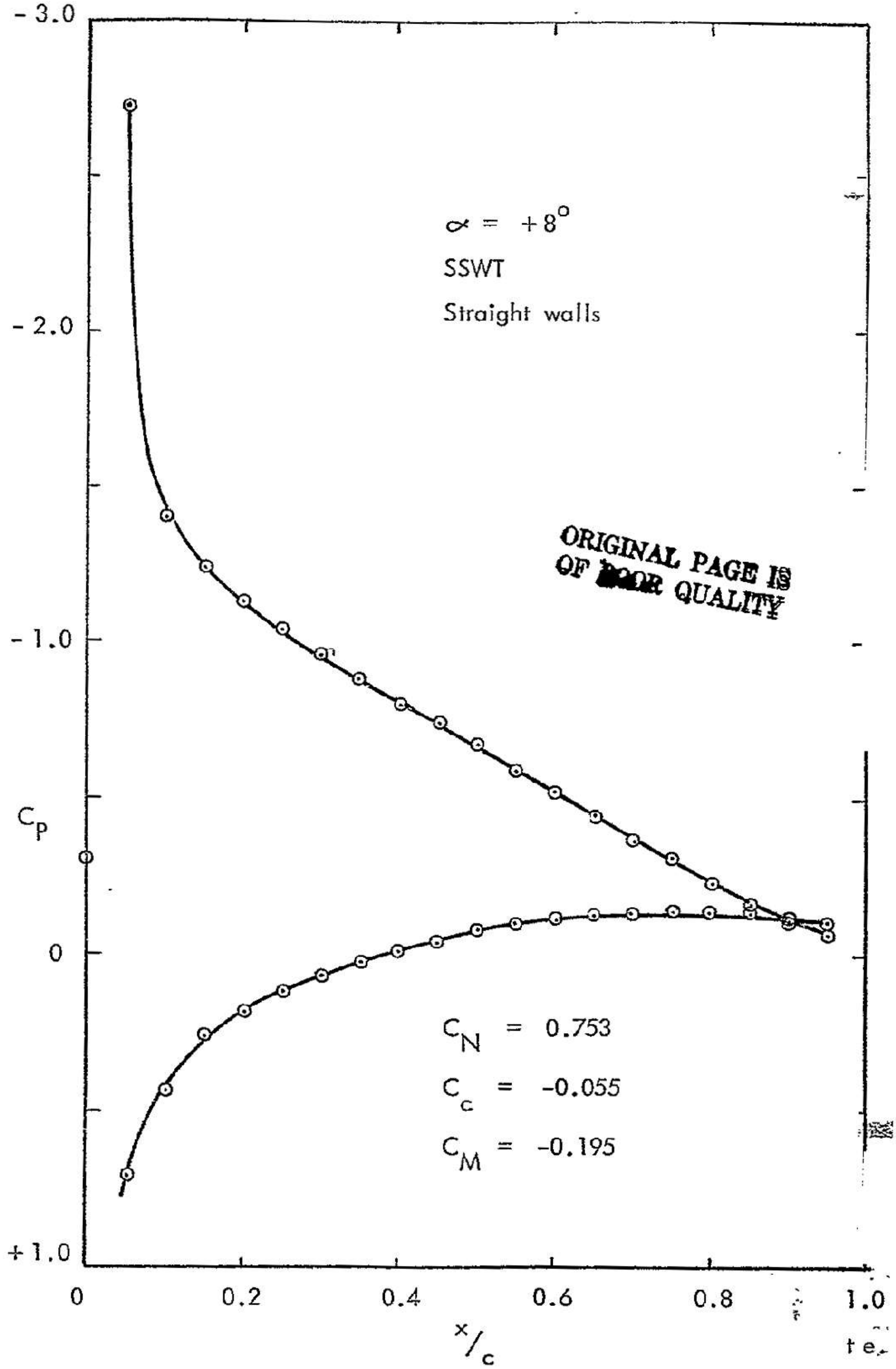


FIG. 3.5 0012-64 AIRFOIL MIDSPAN PRESSURE DISTIBUTIONS.

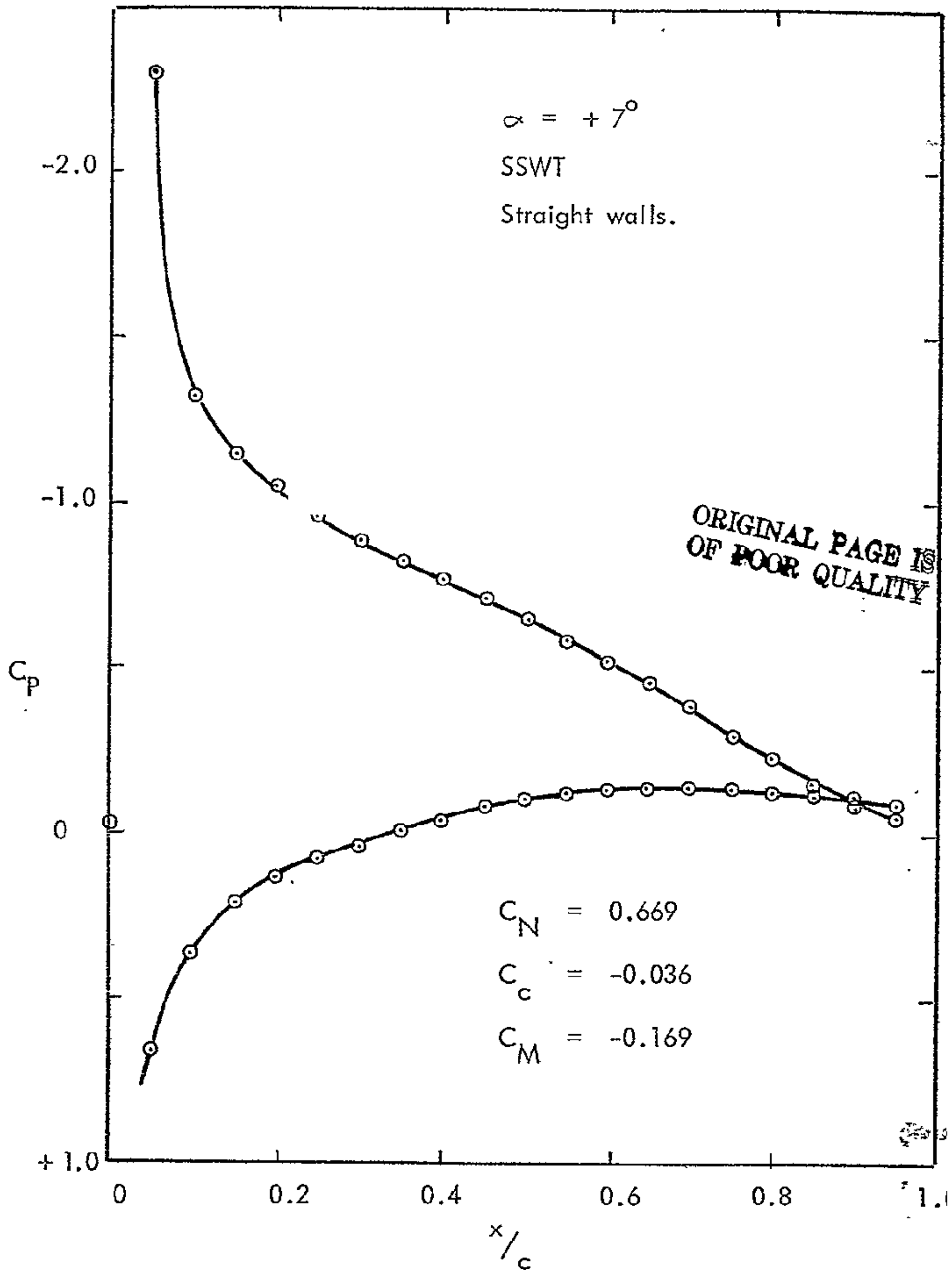


FIG. 3.6 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTIONS.

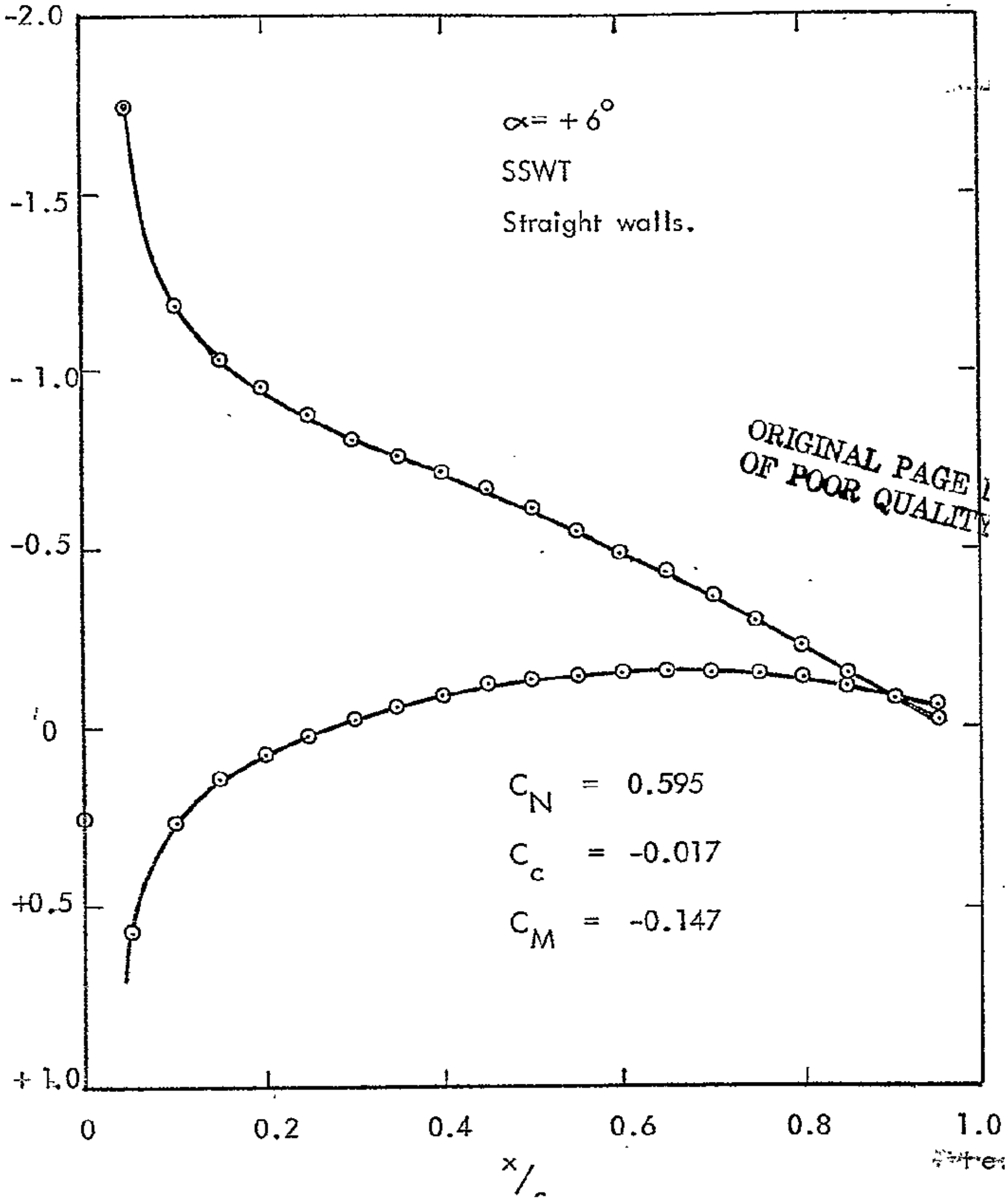


FIG. 3.7 0012.64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTIONS.

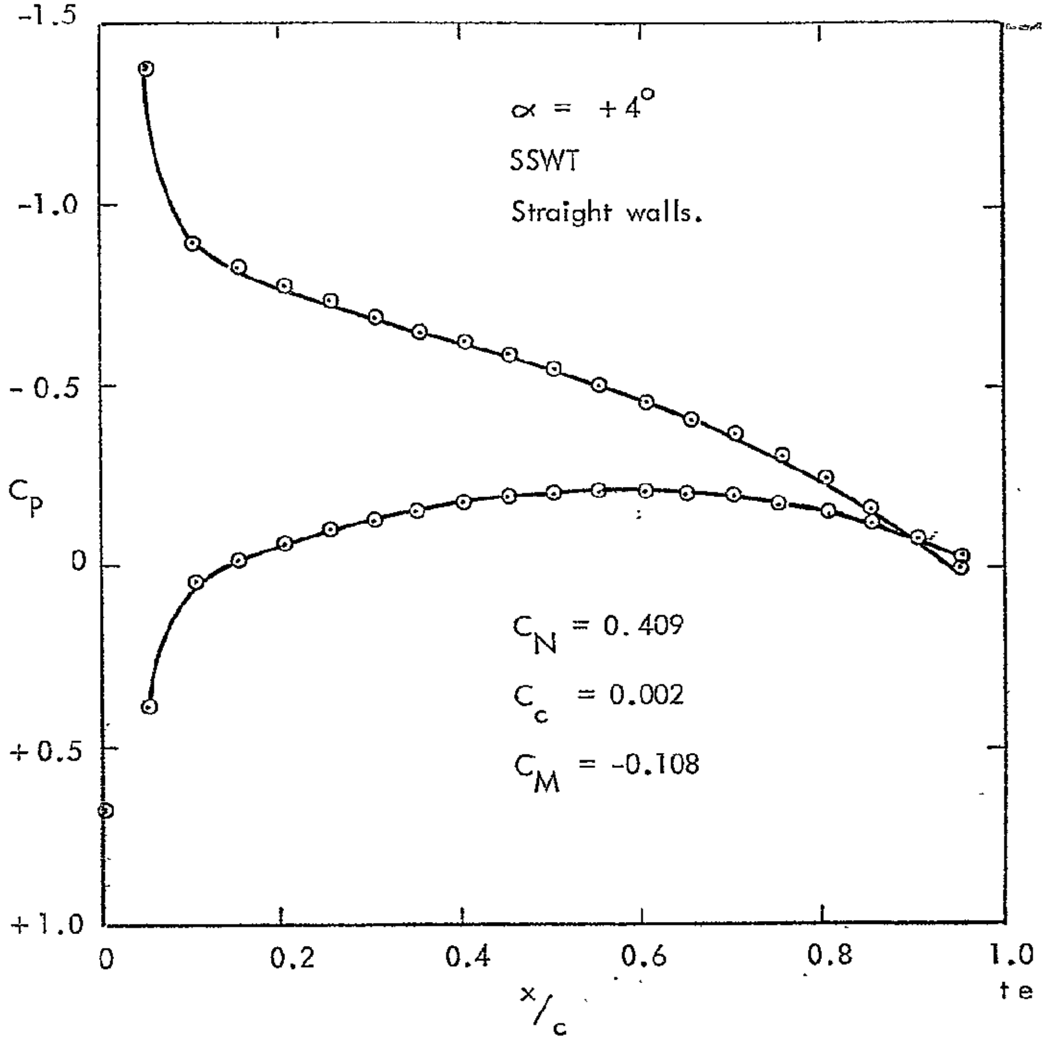


FIG . 3.8 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTIONS.

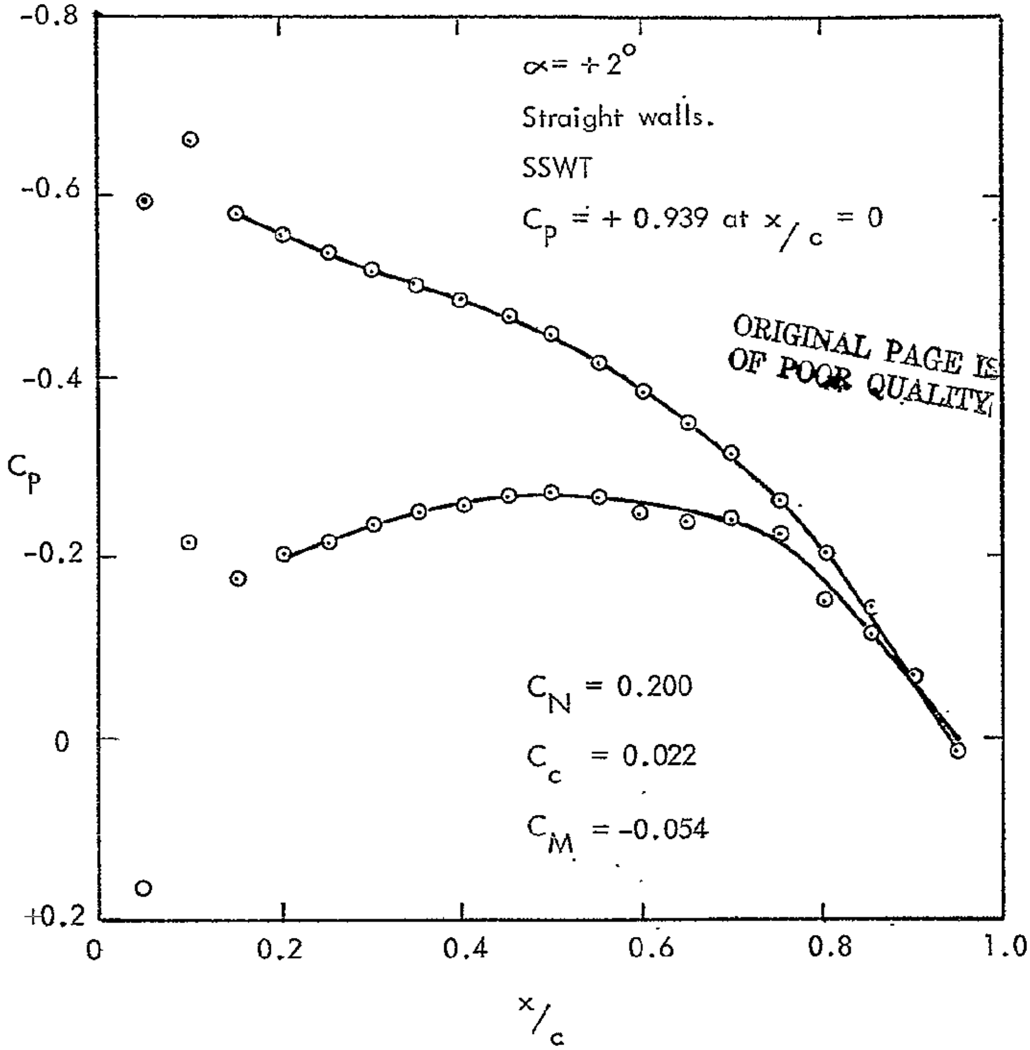


FIG . 3.9 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTION

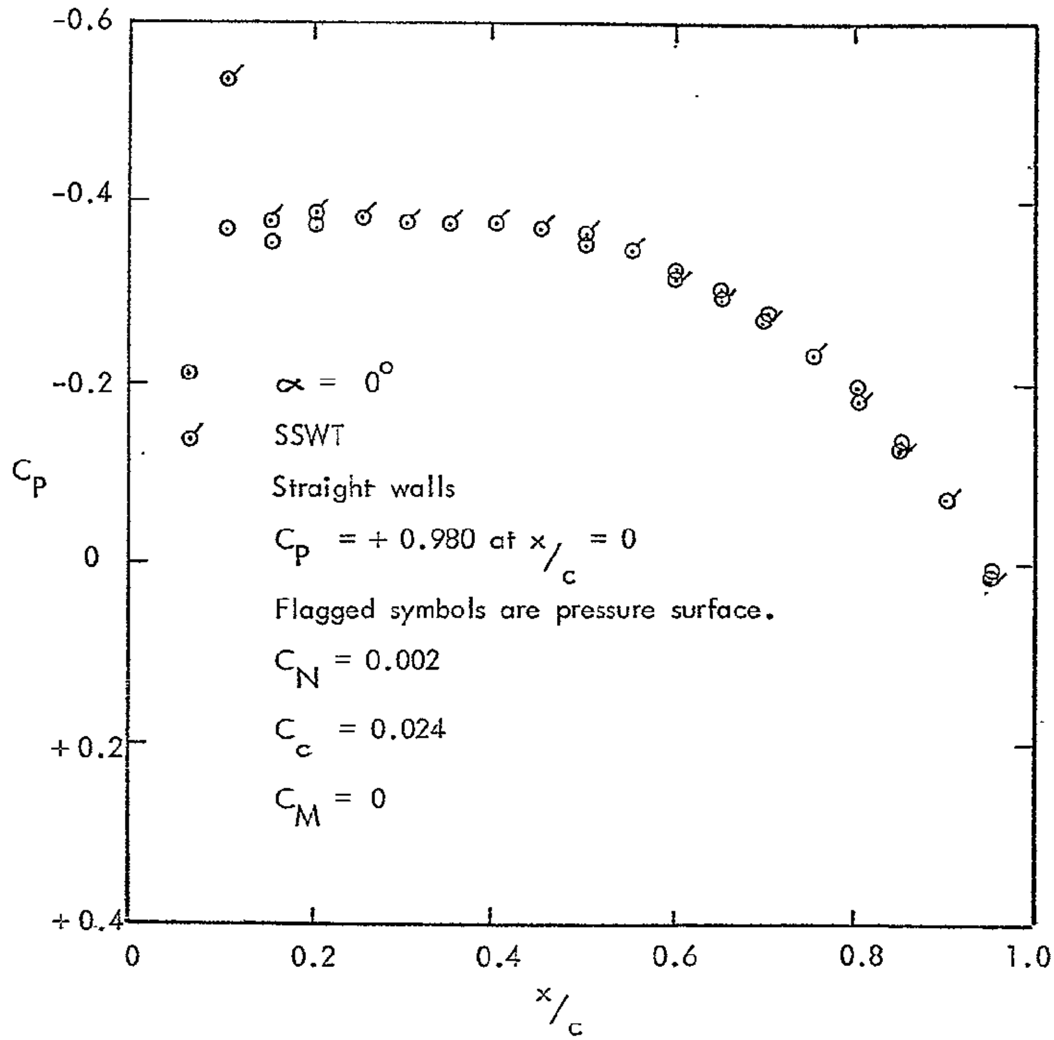


FIG.3.10 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTION.

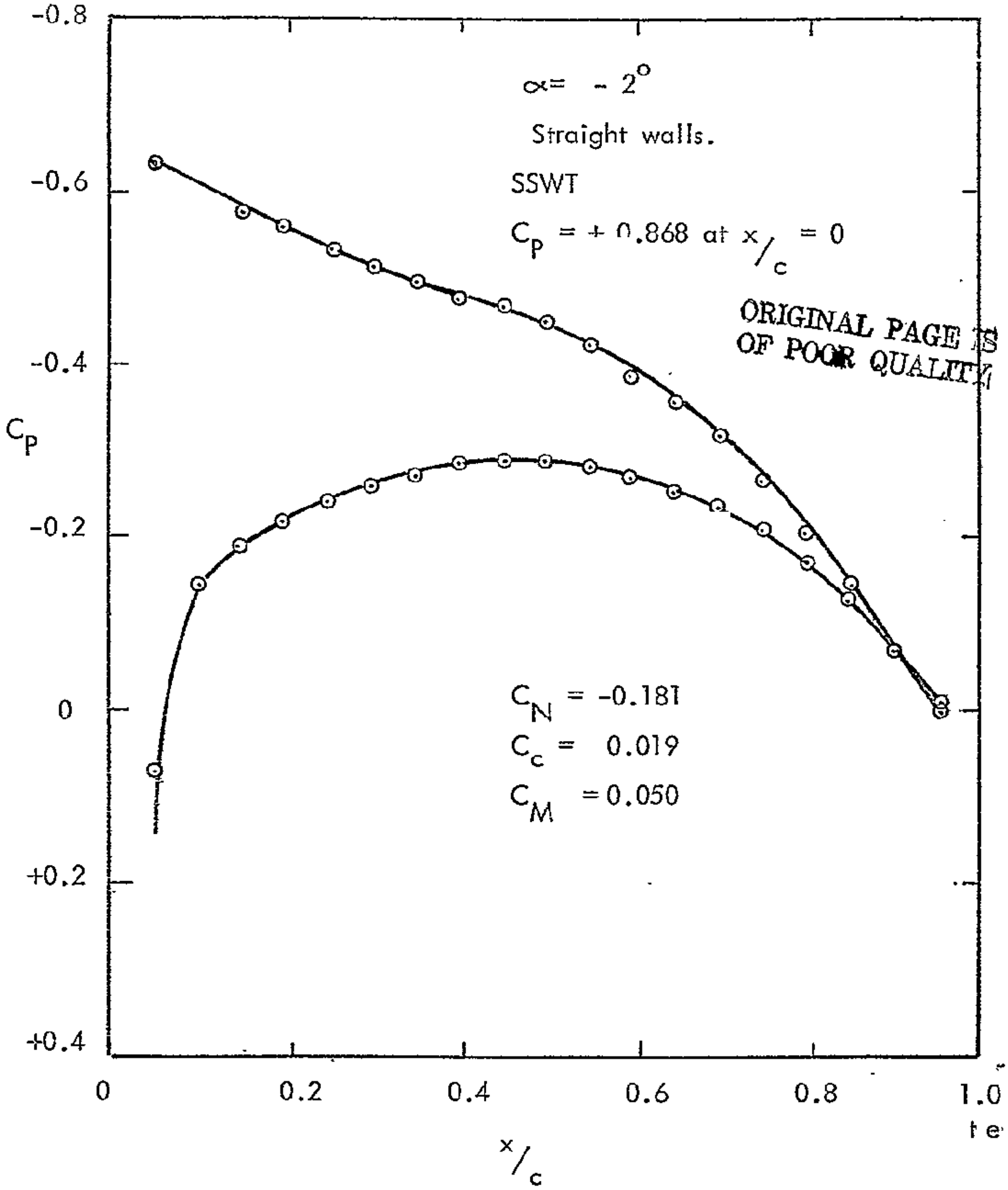


FIG.3.11 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRUTION.

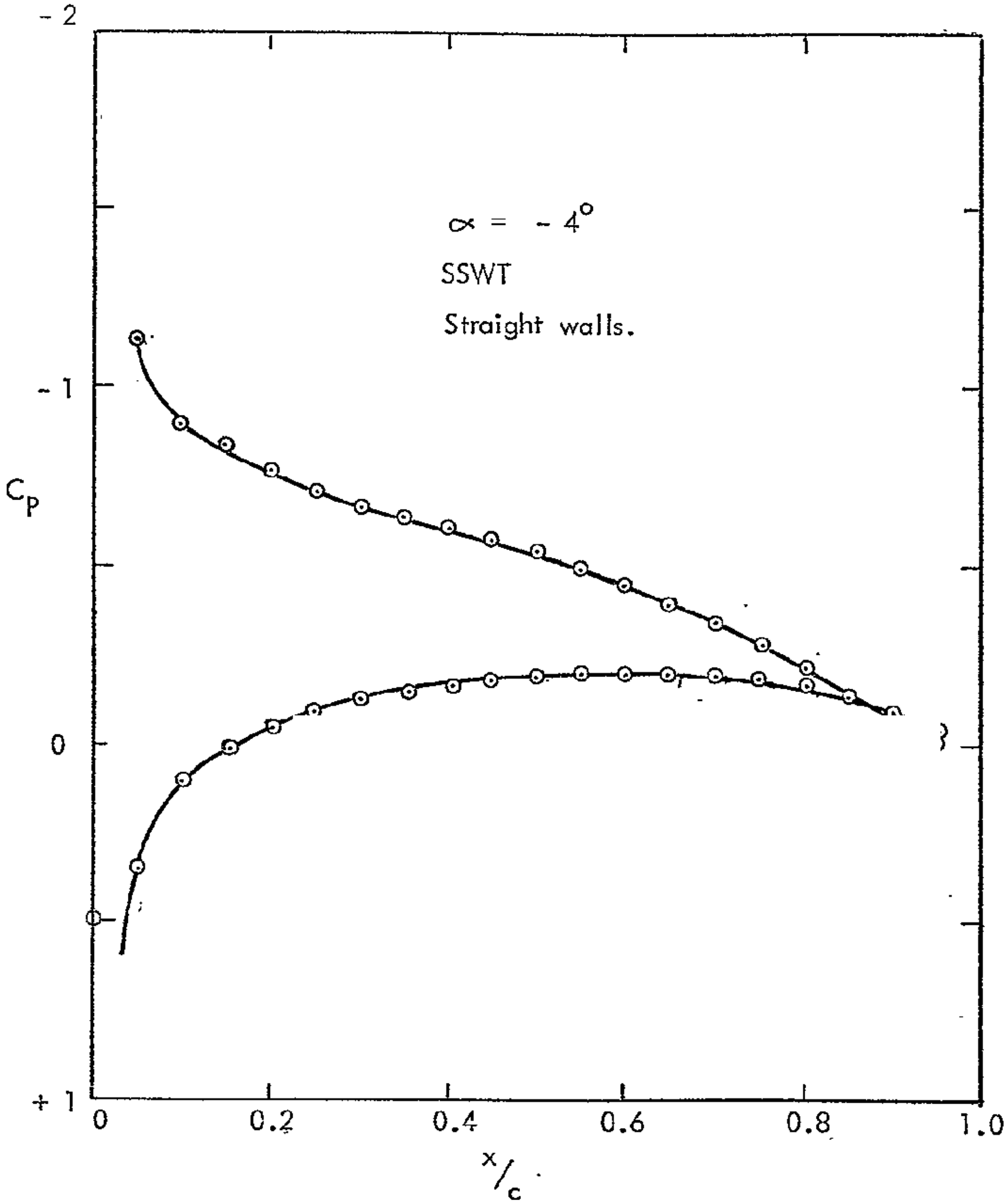


FIG. 3.12 0012-64 AIRFOIL MIDSPAN PRESSURE DISTRIBUTION.

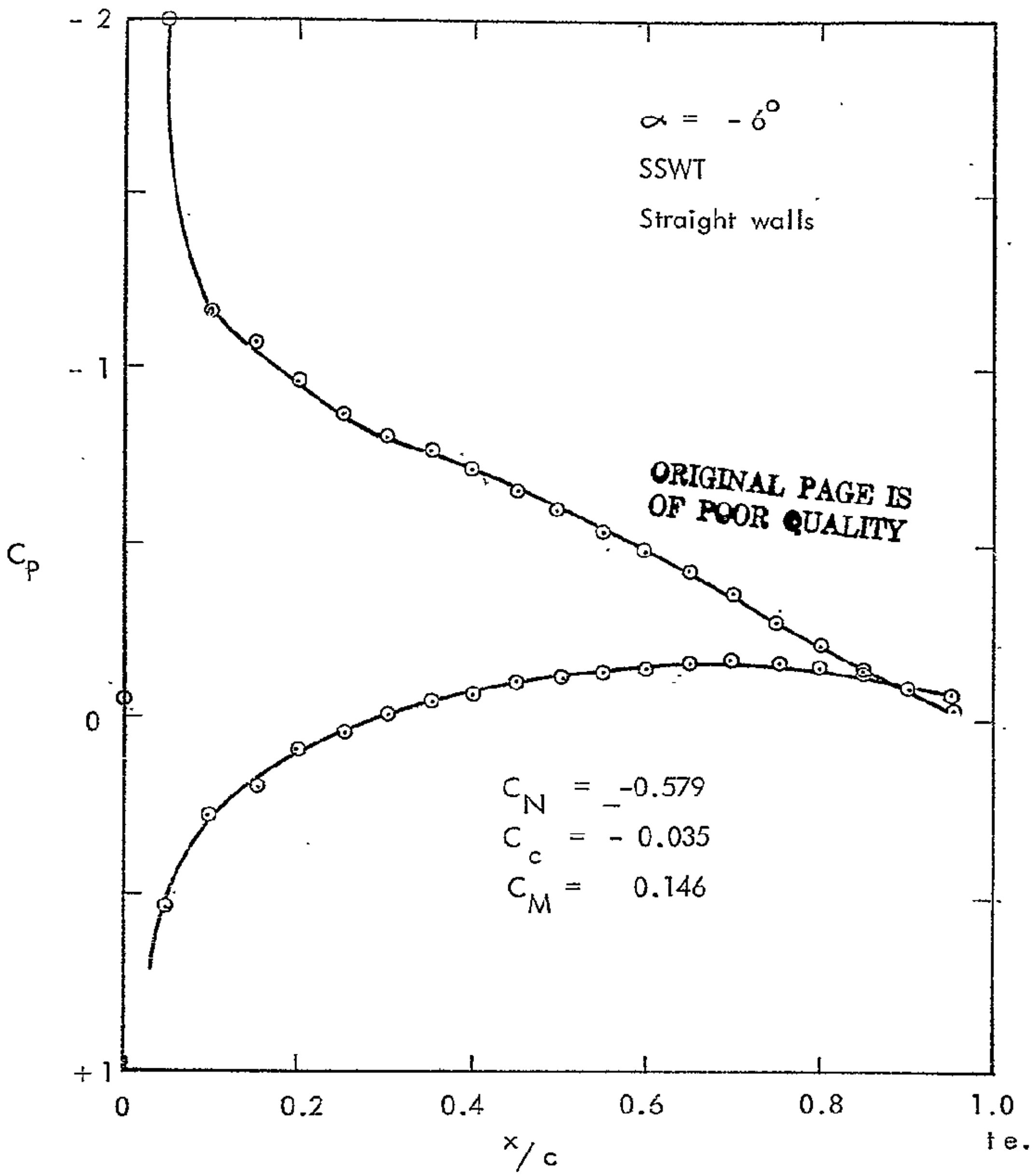


FIG. 3.13 0012-64 AIRFOIL MID-SPAN PRESSURE DISTRIBUTION

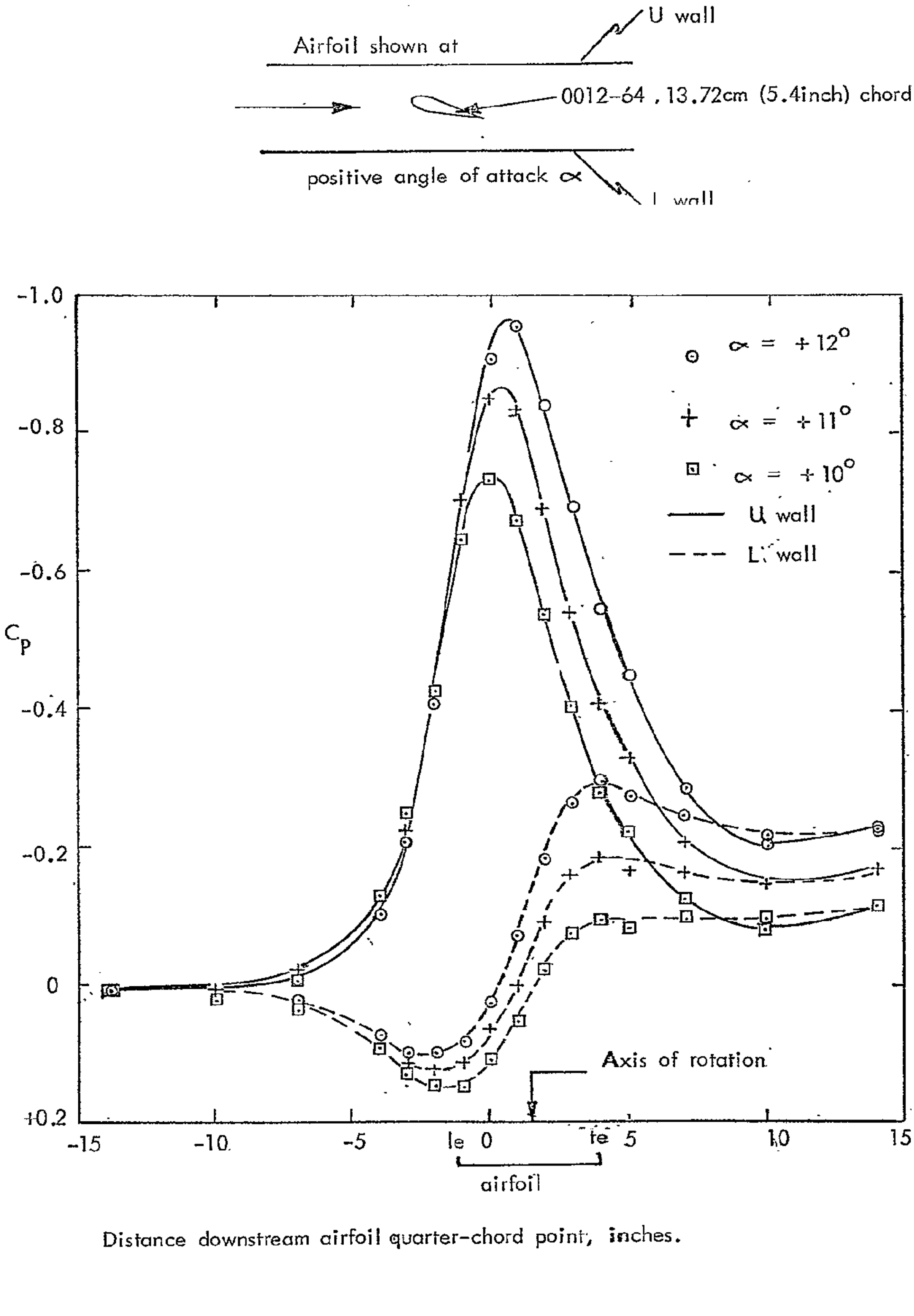


FIG. 3.14 SSWT TEST SECTION FLEXIBLE WALL PRESSURE DISTRIBUTIONS, WALLS STRAIGHT.

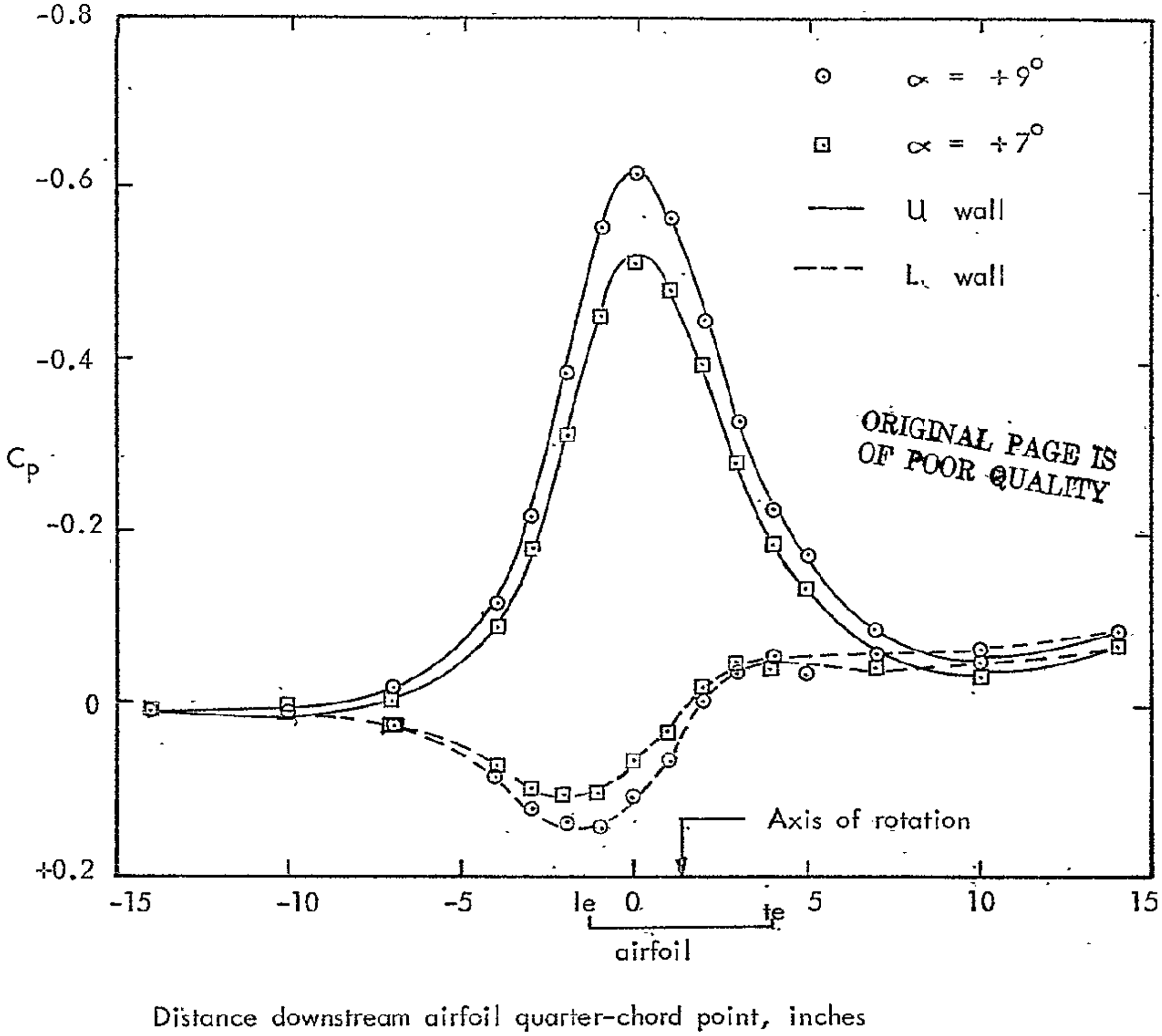


FIG.3.15 SSWT TEST SECTION FLEXIBLE WALL PRESSURE DISTRIBUTIONS, WALLS STRAIGHT.

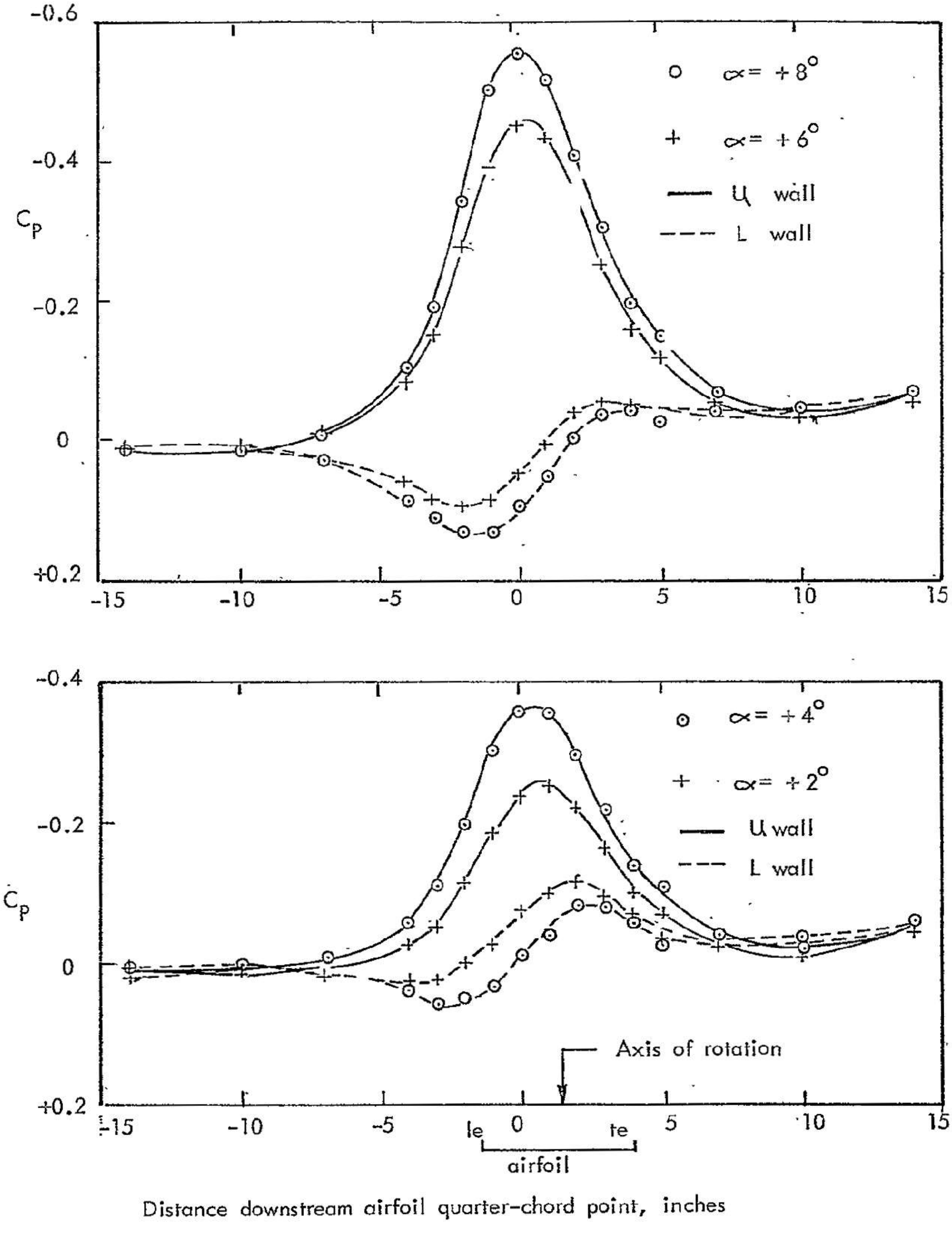


FIG. 3.16 SSWT TEST SECTION FLEXIBLE WALL PRESSURE DISTRIBUTIONS, WALLS STRAIGHT.

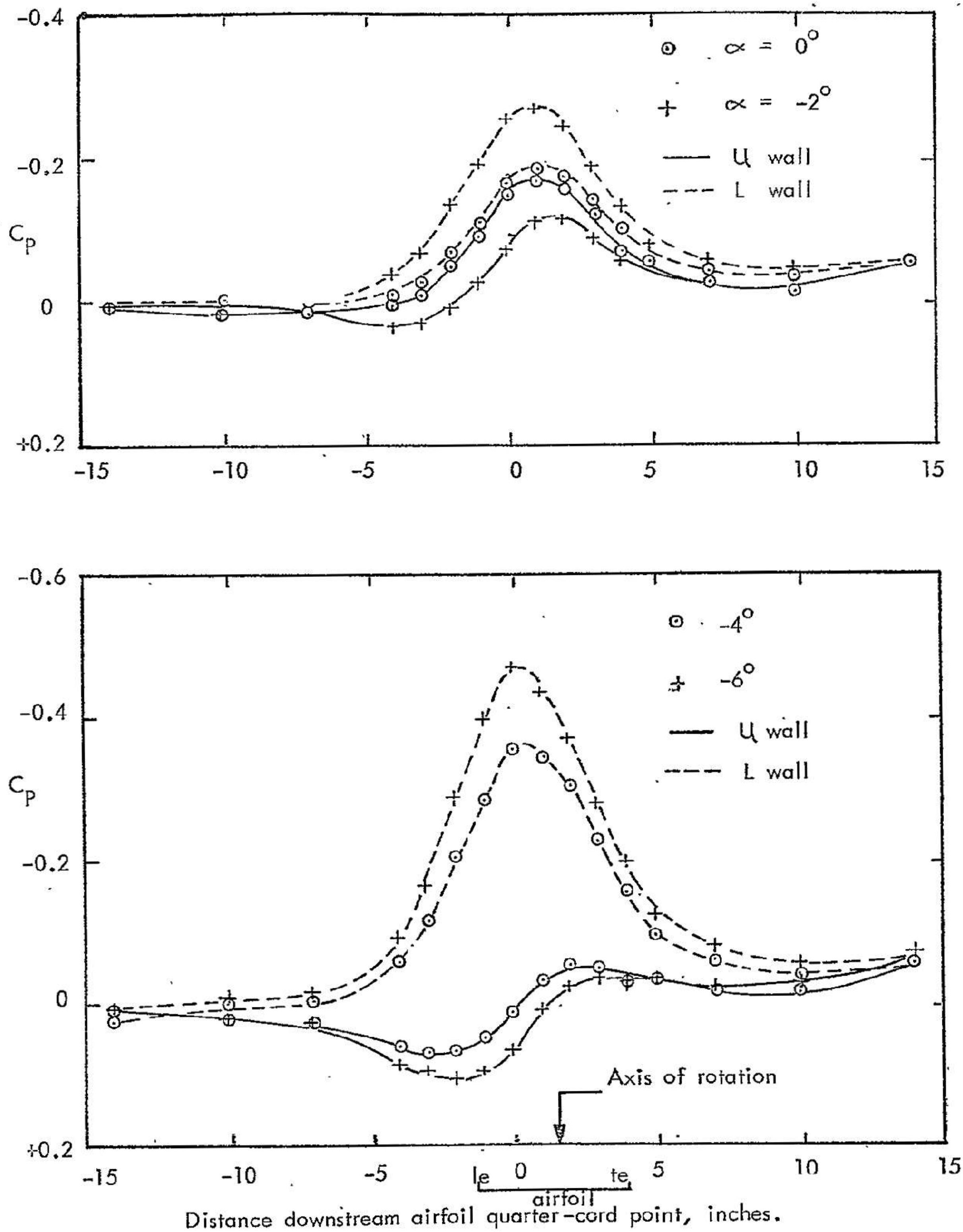


FIG. 3.17 SSWT TEST SECTION FLEXIBLE WALL PRESSURE DISTRIBUTIONS, WALLS STRAIGH

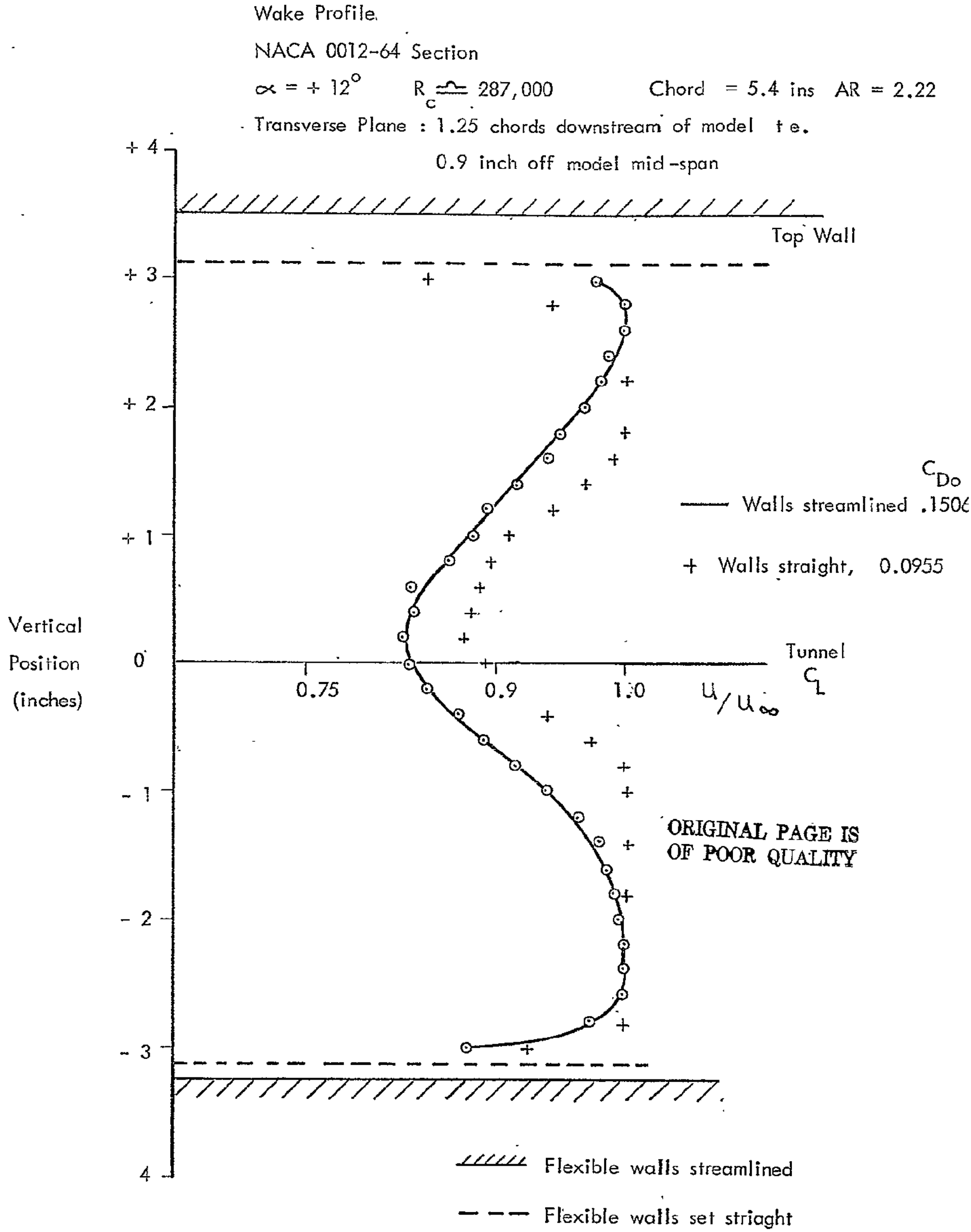


FIG 4.1 SSWT WAKE PROFILES FOR NACA 0012-64 SECTION, ∝= + 12°

Wake Profile

NACA 0012-64 Section

$\alpha = +6^{o}$ $R_c \simeq 287{,}000$ Chord = 5.4 ins AR = 2.2?

Transverse Plane : 1.25 chords downstream of model t e

0.9 inch off model mid-span

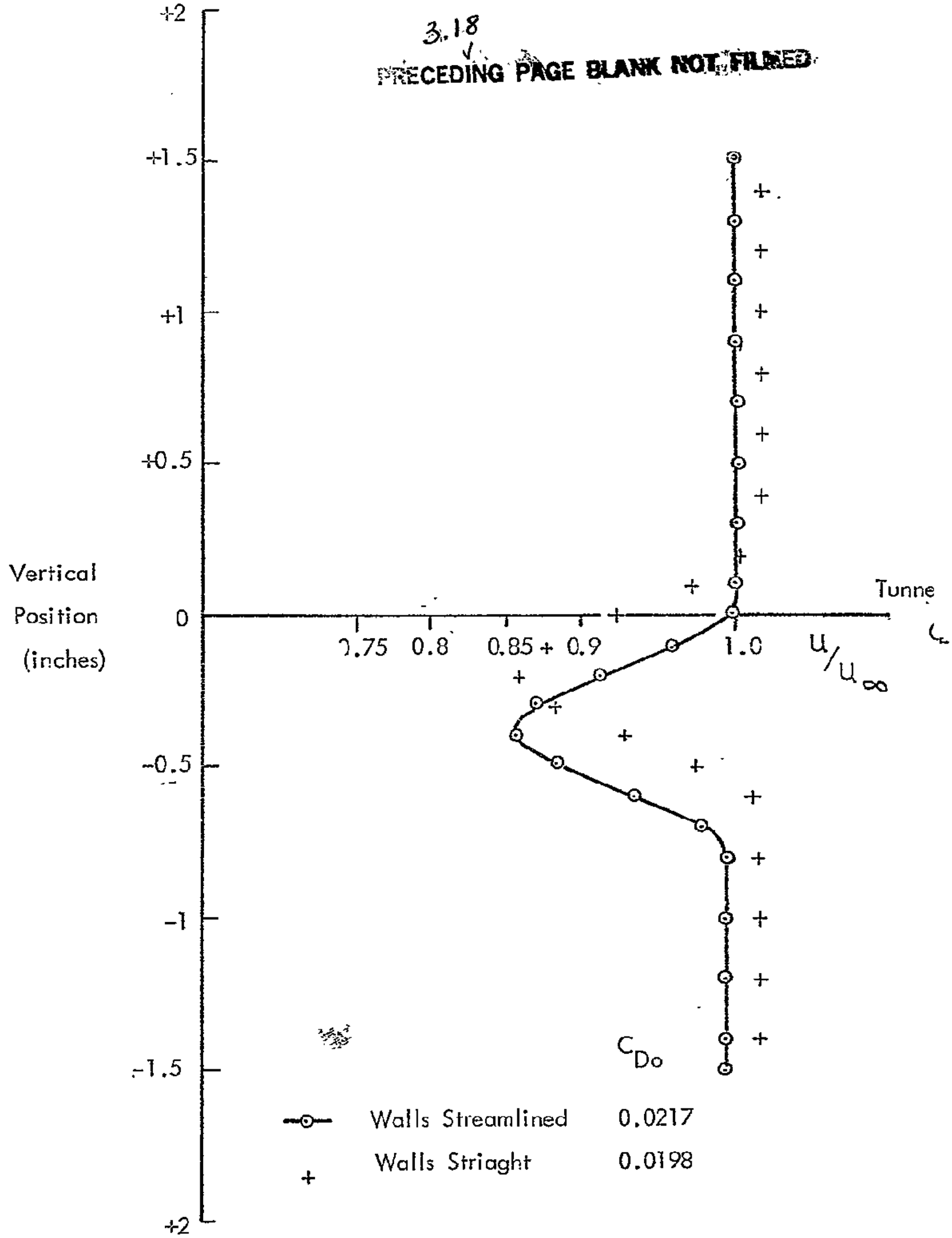


FIG. 4.2 SSWT WAKE PROFILES FOR NACA 0012-64 SECTION $\alpha = +6^{o}$

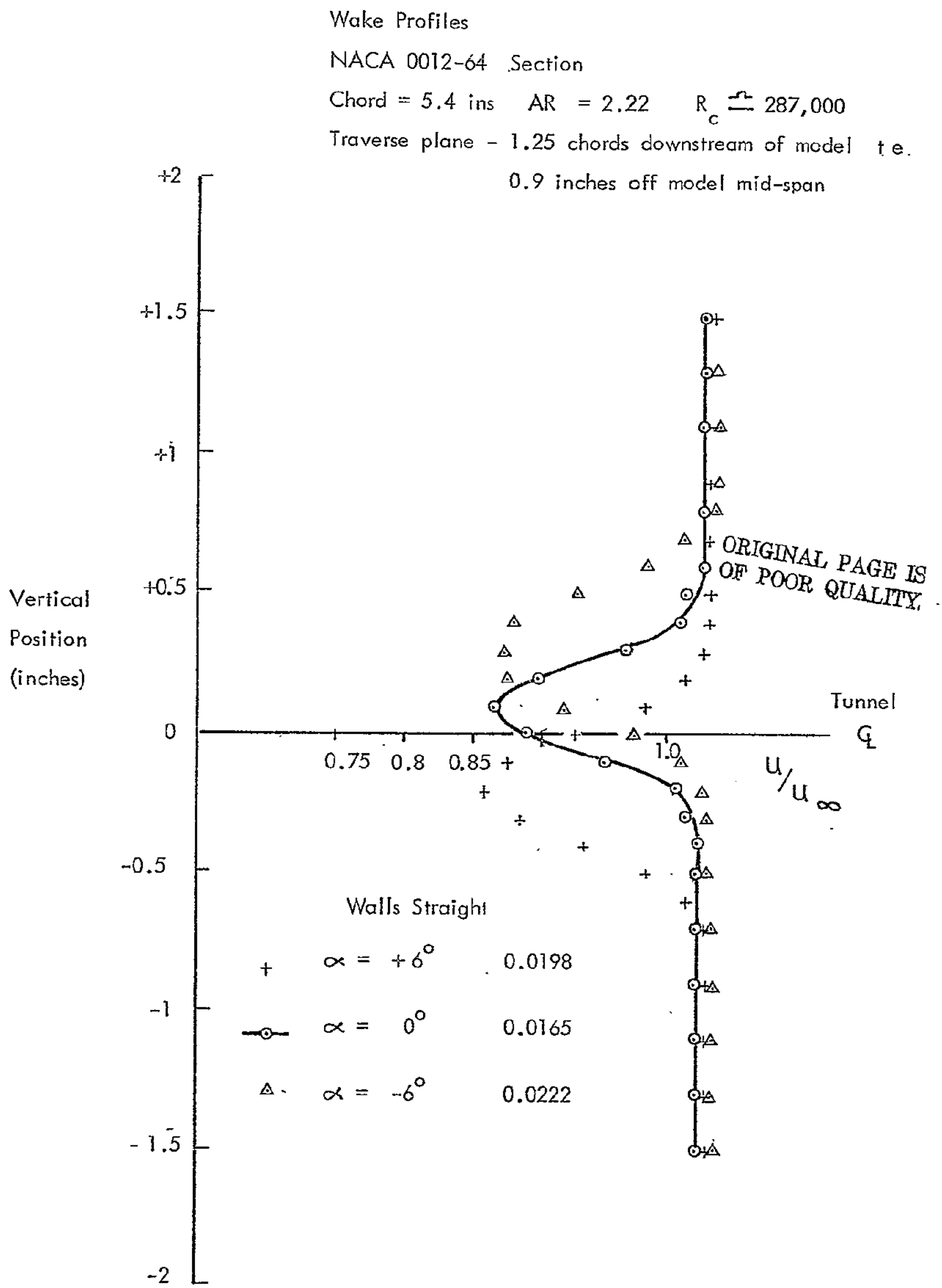


FIG. 4.3 SSWT WAKE PROFILES FOR NACA 0012-64 SECTION, UNSTALLED.

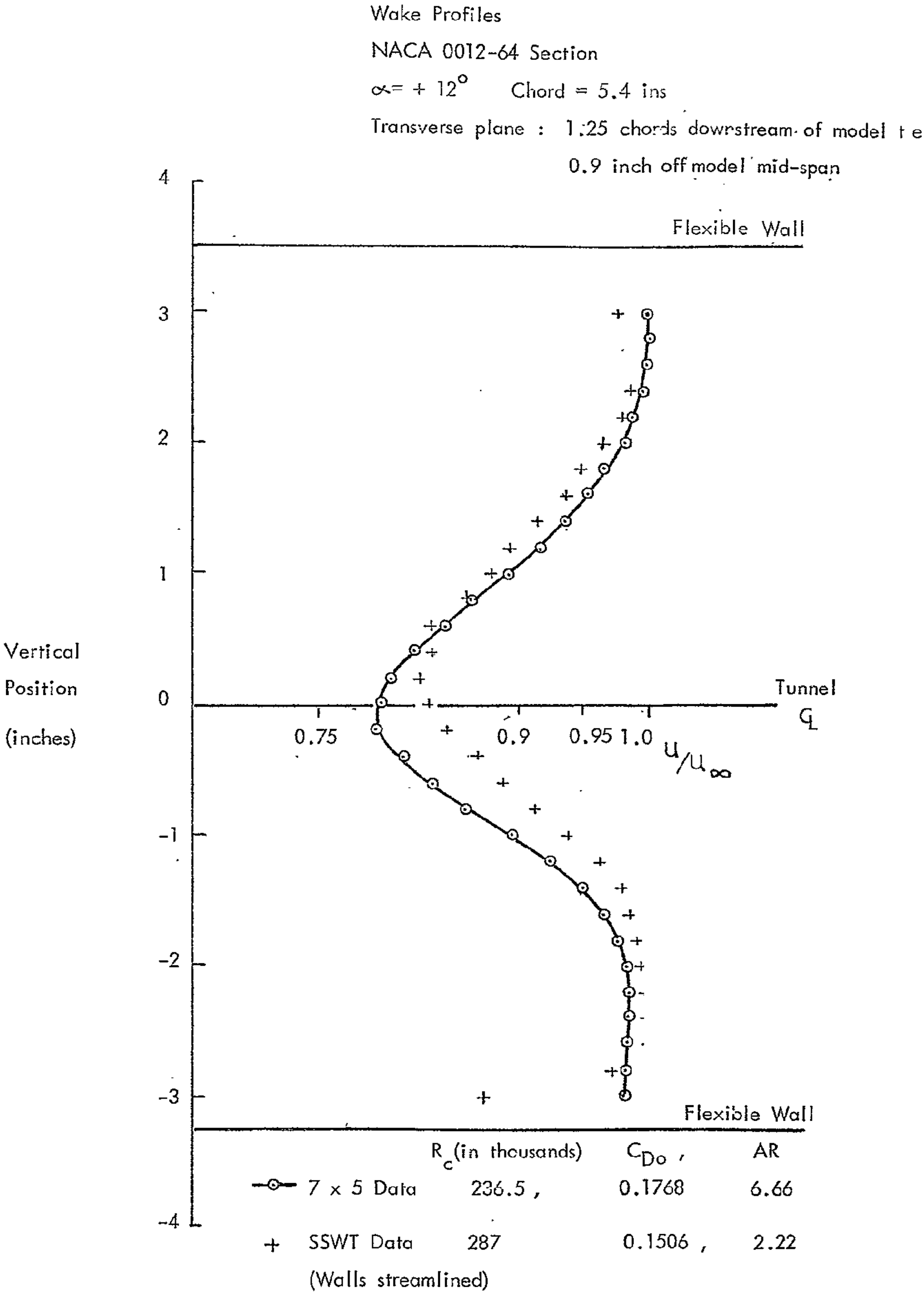


FIG. 4.4 CONPARISON OF WAKE PROFILES FROM 7 x 5 and SSWT , $\alpha = +12^\circ$.

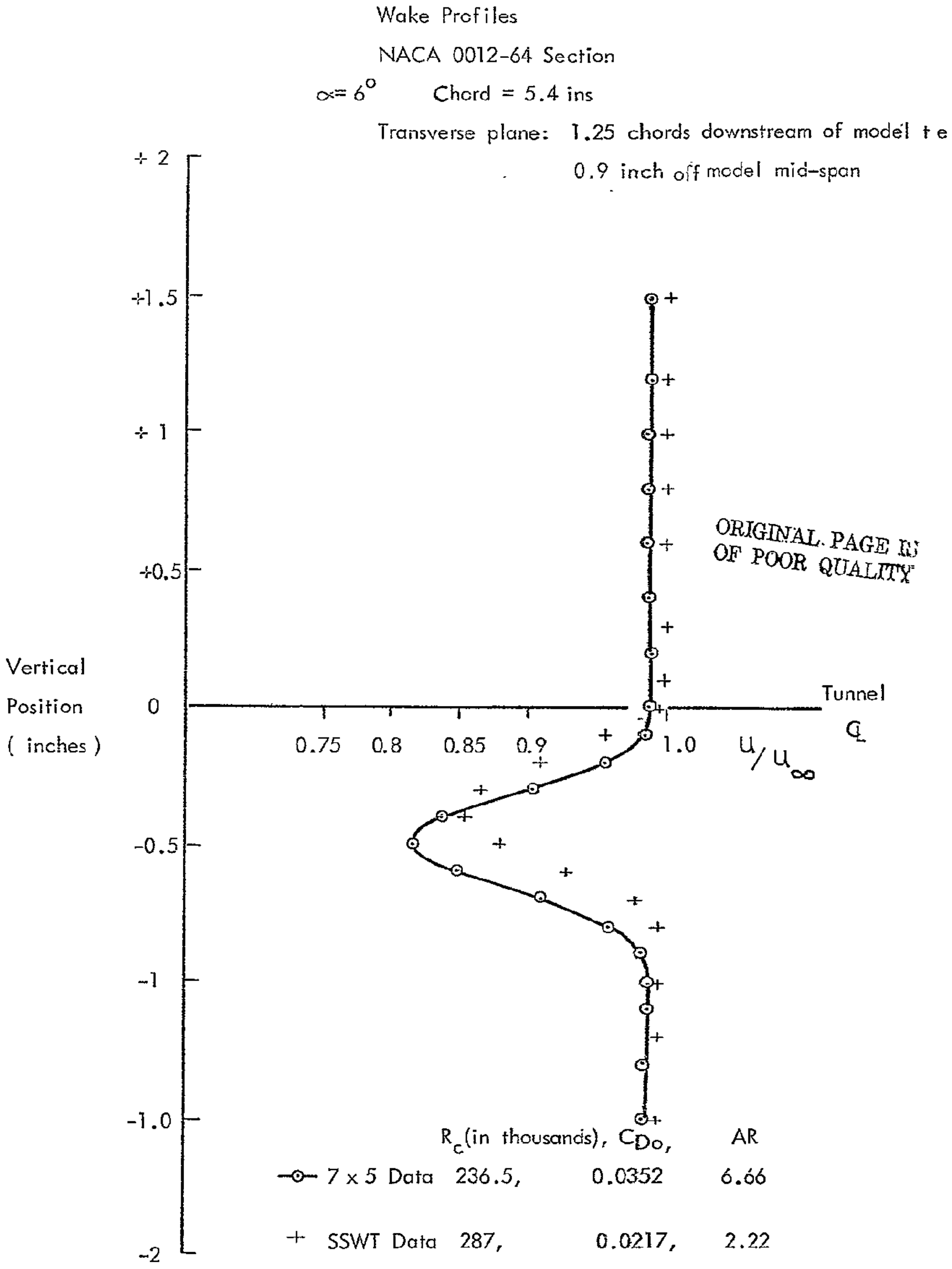


FIG. 4.5 COMPARISON OF PROFILES FROM 7 x 5 and SSWT, $\alpha = 6^{\circ}$

NACA 0012-64 Section

Chord 5.4 ins AR = 6.66

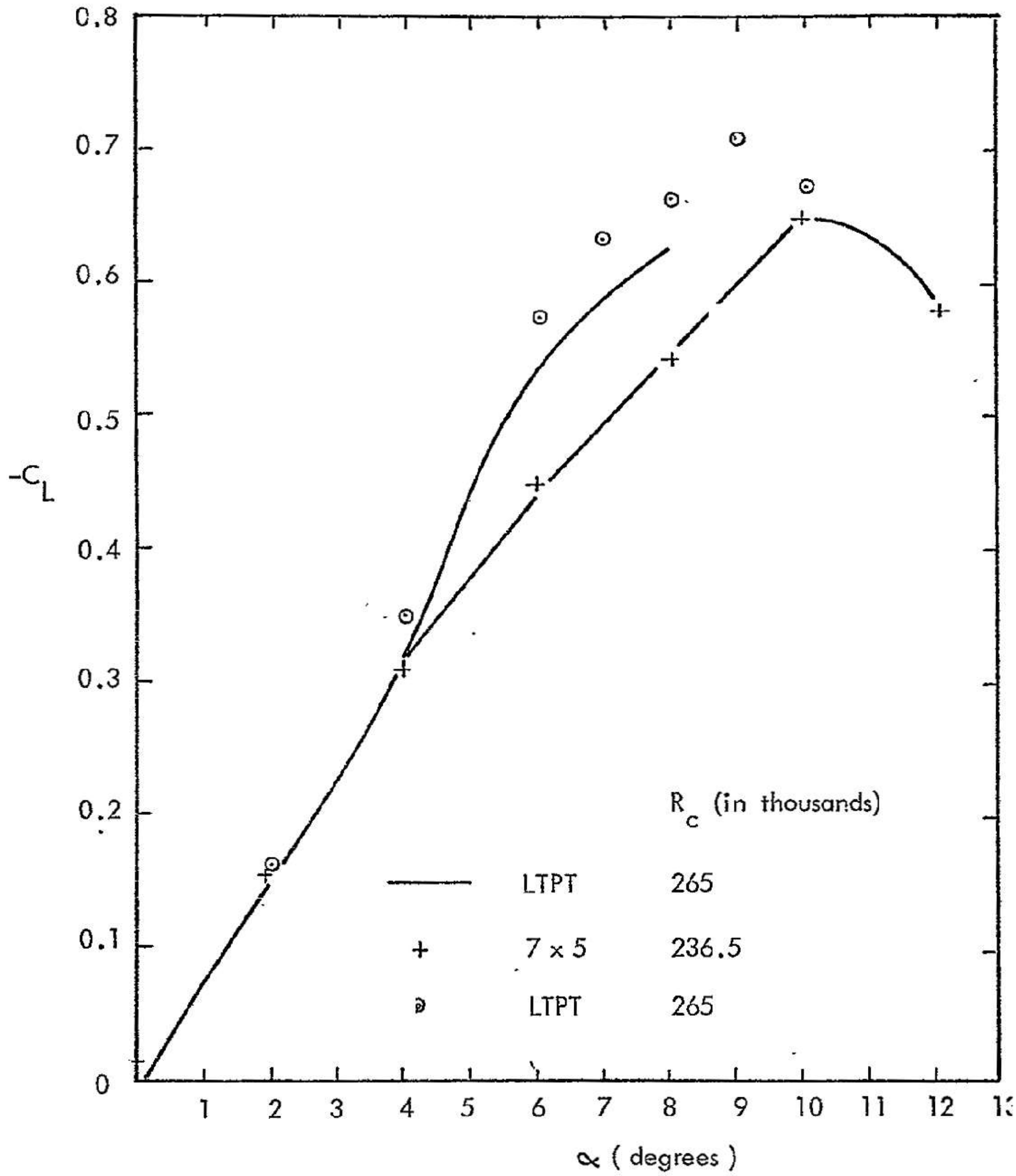


FIG . 4.6 AIRFOIL LIFT COEFFICIENT DATA FROM 7 x 5 and LTPT TESTS

NACA 0012-64 Section

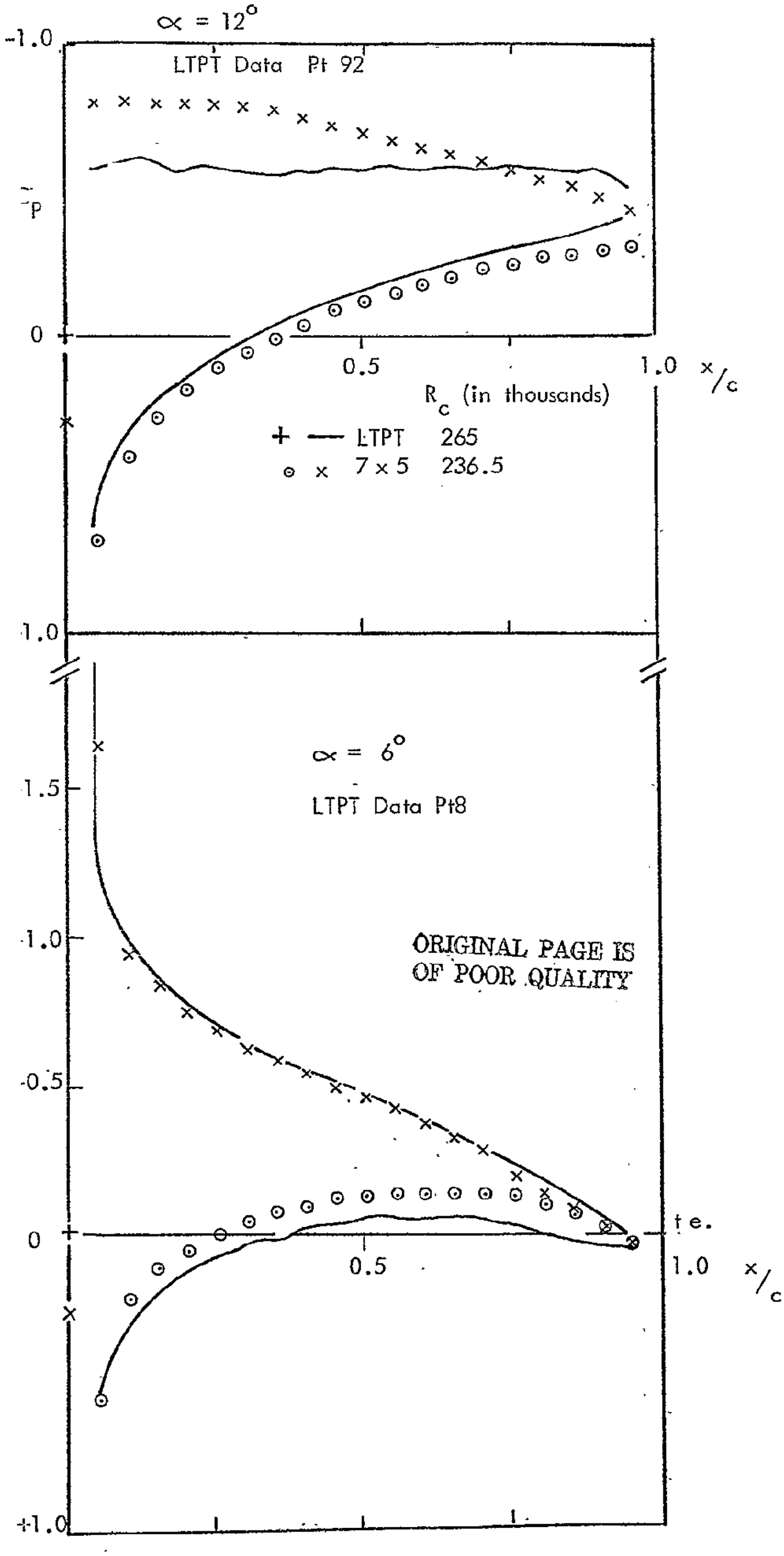


FIG. 4.7 AIRFOIL PRESSURE DISTRIBUTIONS FROM 7 x 5 and LTPT

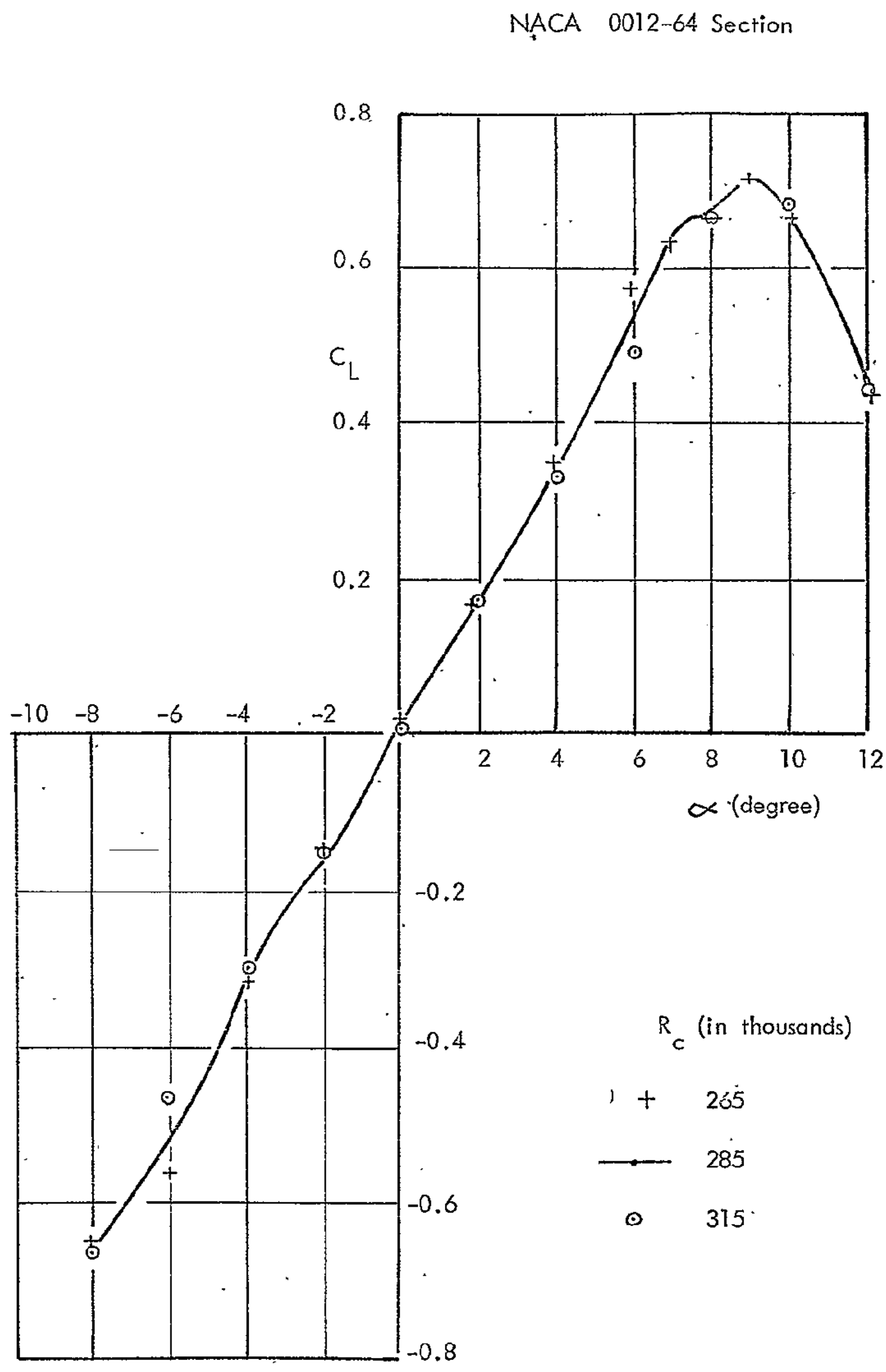


FIG . 4.8 SUMMARY OF LTPT LIFT COEFFICIENT DATA

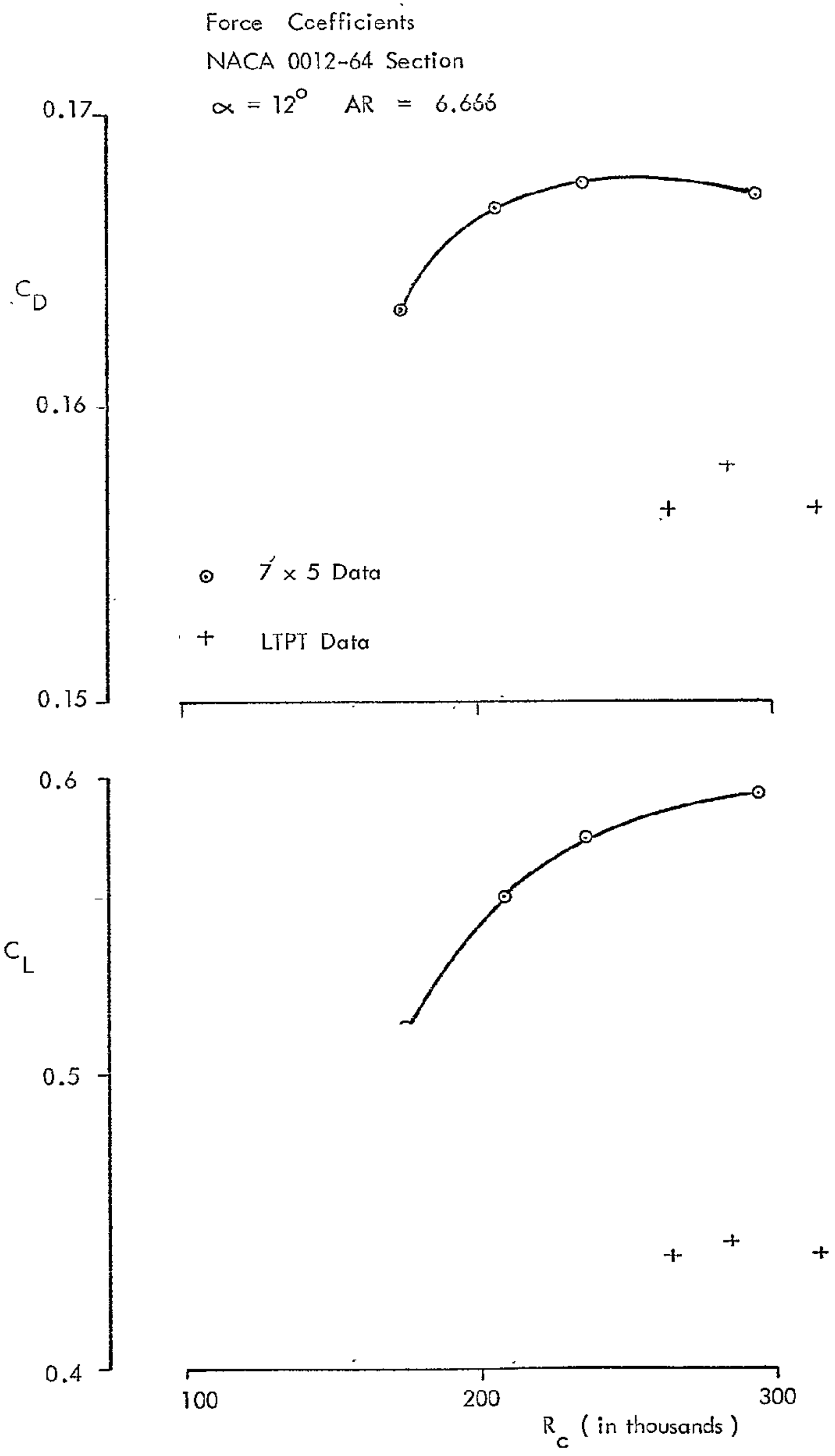
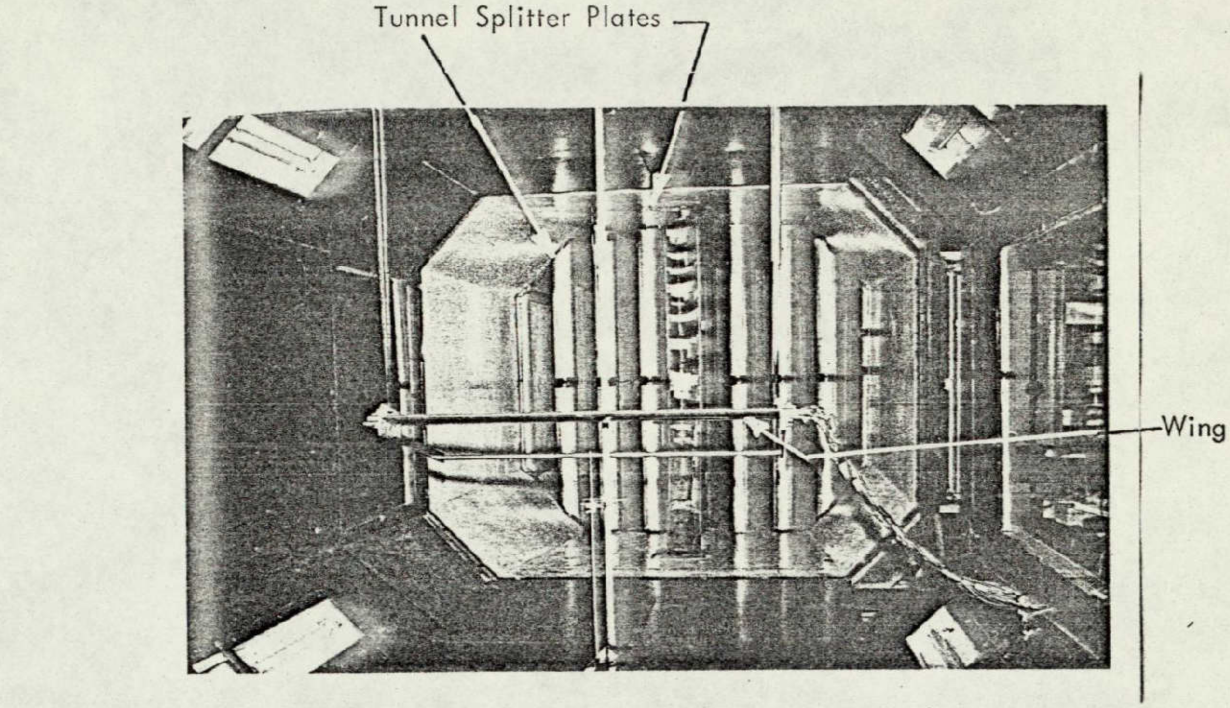
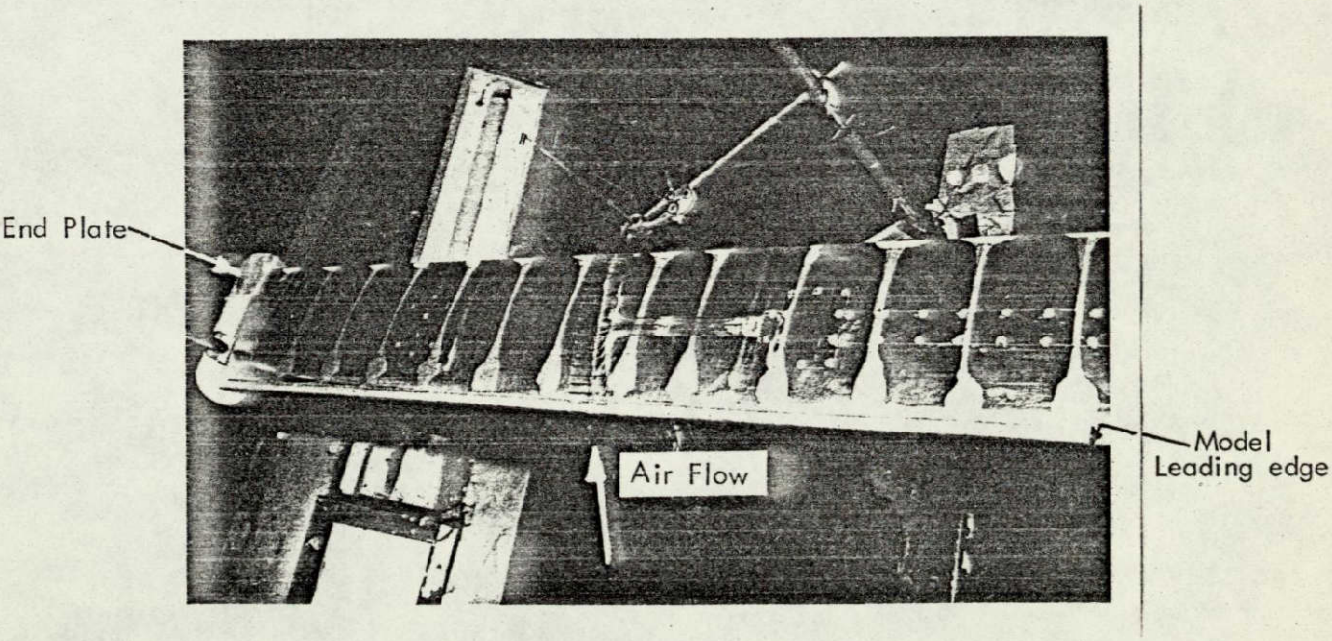


FIG . 4.9 REYNOLDS NUMBER EFFECTS ON NACA 0012-64 SECTION FORCE COEFFICIENTS.

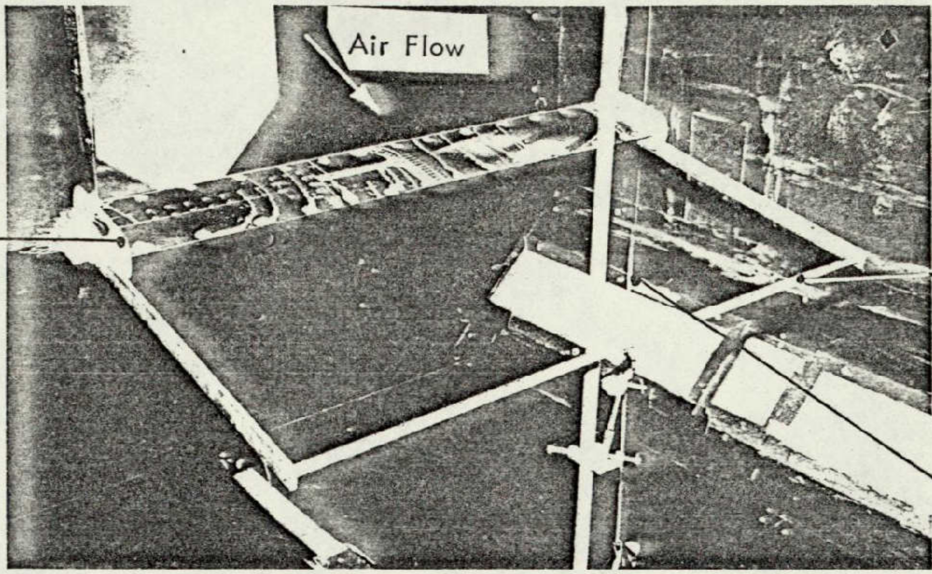


(i) Wing model (Span 0.91 m, AR 6.66) mounted in 7 x 5 . test section

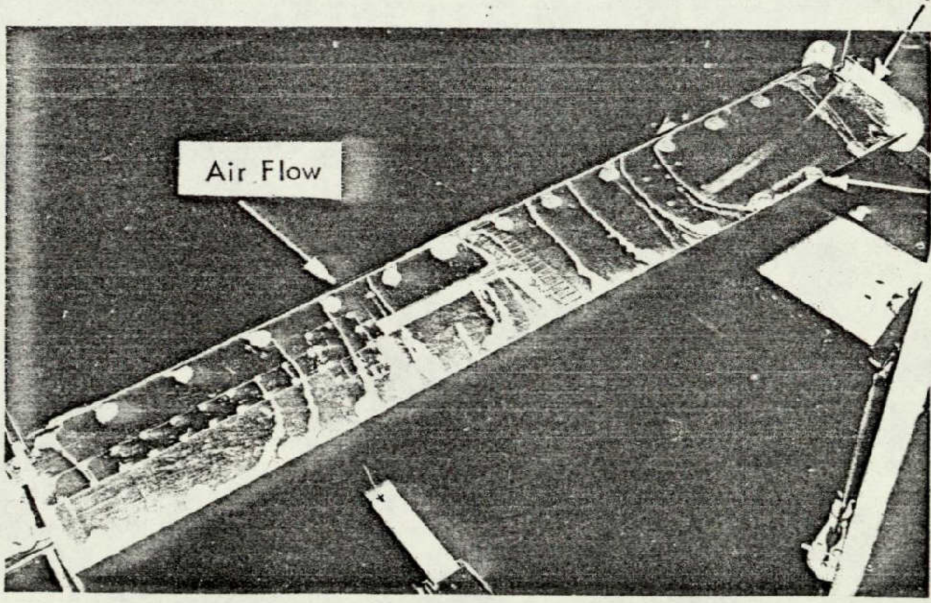


(ii) Flow visualisation on model's suction surface at $\alpha = 6^{o}$. The oil streaks show uniform flow over the complete span.

FIG. 4.10a NACA 0012-64 SECTION TESTS IN 7 x 5 WIND TUNNEL.



(iii) General view of wing model mounting to the 7 x 5 three component balance.



(iv) Flow visualisation of 3-D effects present on the suction surface of the wing model at $\alpha = 12^{\circ}$

FIG . 4.10b NACA 0012-64 SECTION TESTS IN 7 x 5 WIND TUNNEL.

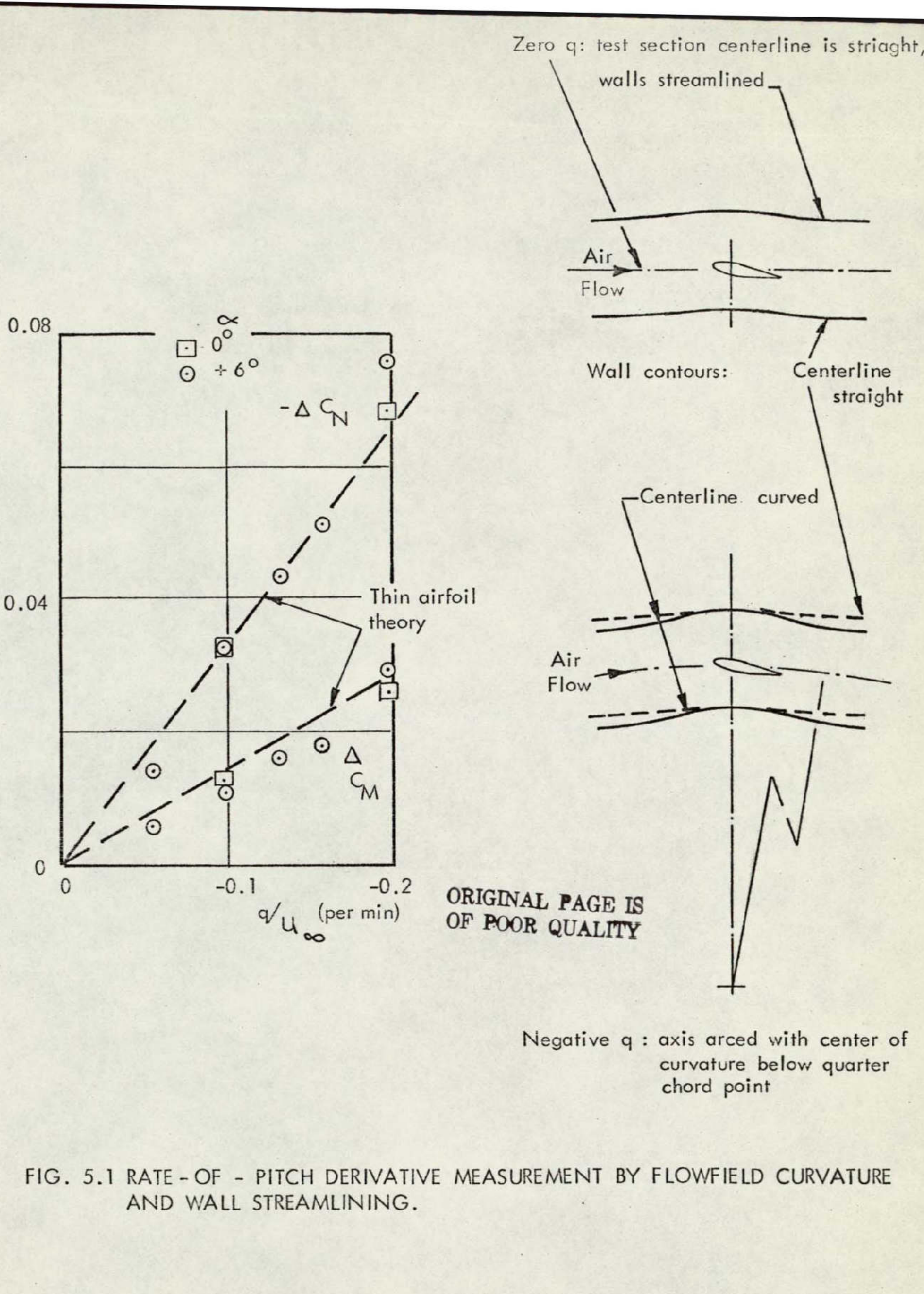


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FIG. 5.1 RATE - OF - PITCH DERIVATIVE MEASUREMENT BY FLOWFIELD CURVATURE AND WALL STREAMLINING.

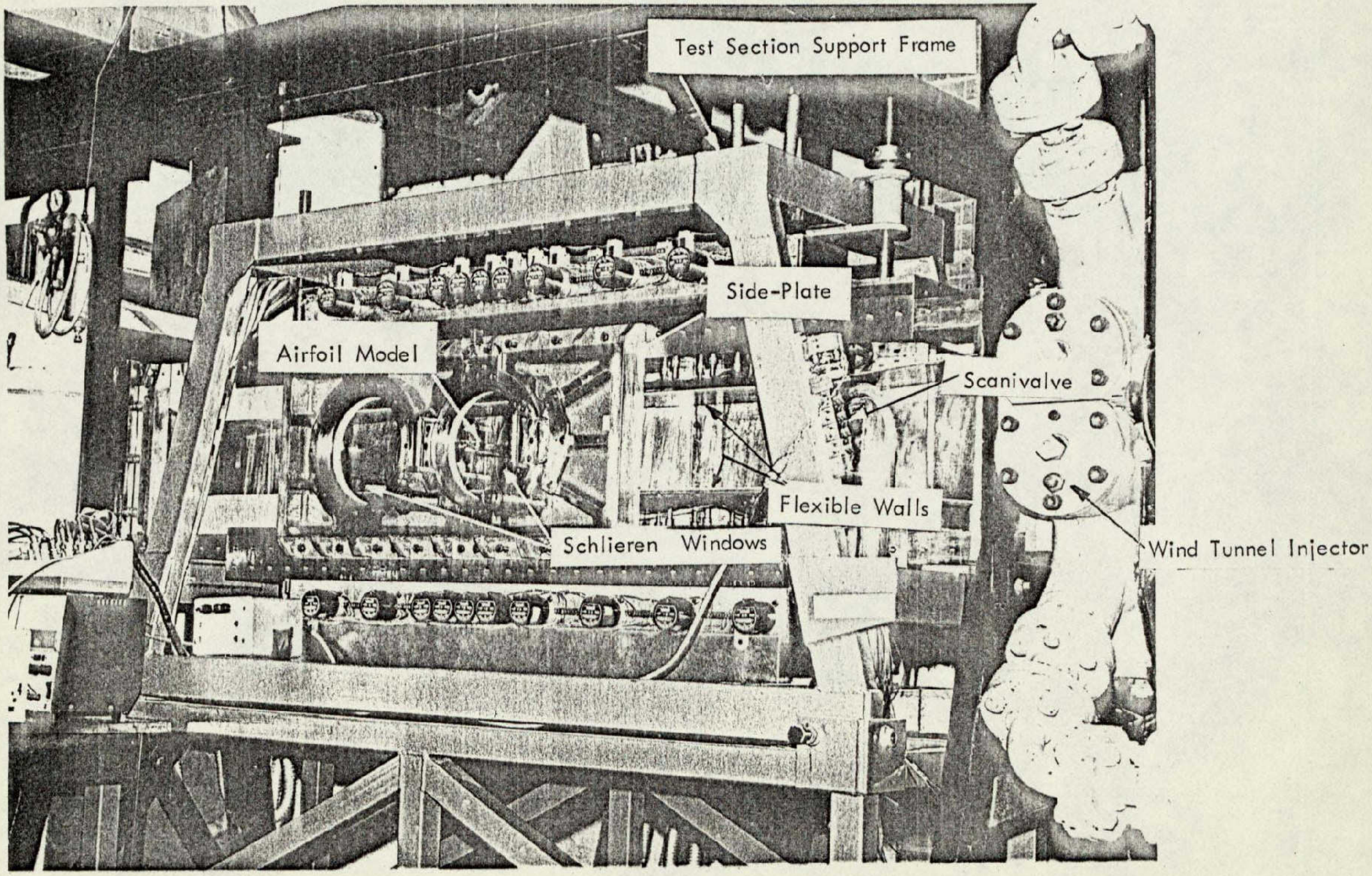

FIG . 6.1 TRANSONIC SELF STREAMLINING TEST SECTION

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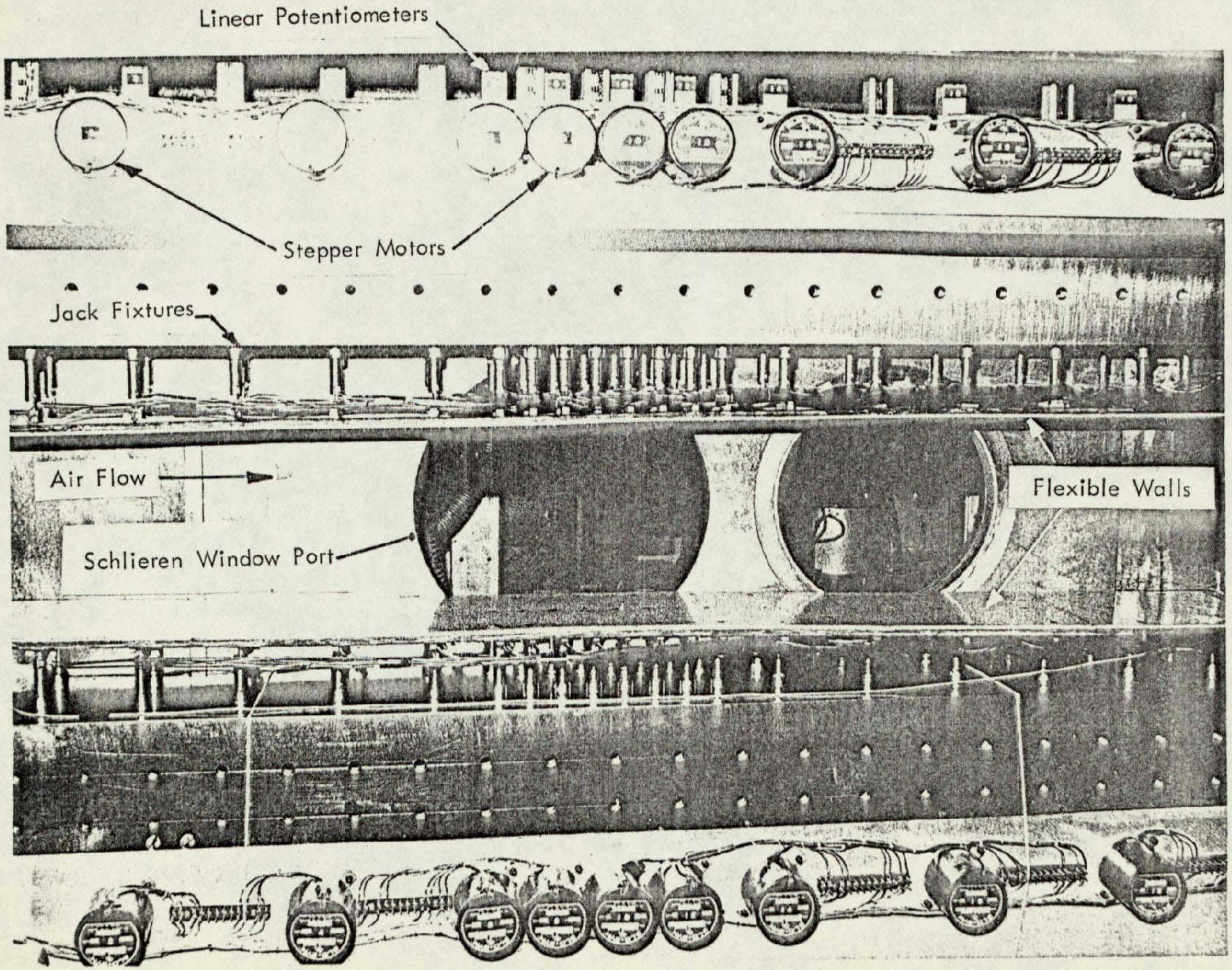

FIG. 6.2 TRANSONIC SELF - STREAMLINING TEST SECTION