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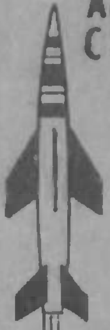

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WIND TUNNEL INVESTIGATIONS OF TRANSONIC TEST SECTIONS
PHASE 1

WILLIAM L. CHEW; ARO, INC.

OCTOBER 1953

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ARNOLD ENGINEERING DEVELOPMENT CENTER
TULLAHOMA, TENNESSEE

AEDC-TR-53-10

WIND TUNNEL INVESTIGATIONS OF TRANSONIC TEST SECTIONS

Phase I

Tests of a 22.5-Percent Open-Area Perforated-Wall Test Section in Conjunction with a Sonic Nozzle

By

William L. Chew; ARO, INC.

October 1953

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Unclassified

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ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

SUMMARY

The results presented are for a test section with four 22.5-percent open-area perforated walls in conjunction with a sonic nozzle. The major portion of the results presented are for walls with 1/4-in. diameter perforations in a 1/16-in. plate. Comparisons are made with results from tests with 1/16-in. diameter perforations. Variations in wall angle, diffuser flap position, tunnel pressure ratio, hole size, and initial expansion region were made to determine the effect on tunnel performance with and without auxiliary suction for a Mach number range of 0.8 to 1.2.

Blockage models of 1, 3, and 5 percent were installed to determine blockage effects on suction requirements. Boundary layer profiles were measured along the test section wall with and without the blockage models installed.

Taper strips improved the Mach number distributions considerably both in the supersonic and subsonic speed range.

With parallel walls and empty test section, a maximum Mach number of 1.125 was obtained with diffuser suction and a maximum tunnel pressure ratio of 1.4. Mach number 1.0 was attained with a tunnel pressure ratio of 1.25. With parallel walls and diffuser flaps closed, the minimum auxiliary suction requirement to attain Mach number 1.0 was 2.2 percent of the main flow. A 5 percent blockage body increased the auxiliary suction to 3.65 percent.

With parallel walls and closed diffuser flaps, increasing the hole size from 1/16 to 1/4 in. reduced the minimum auxiliary suction from 3.65 to 2.2 percent of the main flow to attain Mach number 1.0.

The optimum operating condition for the tunnel at any wall angle is with auxiliary suction and the diffuser flaps completely closed.

INTRODUCTION

The Transonic Model Tunnel of the Propulsion Wind Tunnel (PWT) at the Arnold Engineering Development Center, on recommendations of the Working Panel of the PWT and authorized by the Air Force, was designed and constructed by ARO, Inc. It was first operated in October 1952. The Model Tunnel is a 1/16-scale pilot model of the test section and adjacent components of the Transonic Circuit of the PWT, namely, contraction section, nozzle section, test section, plenum chamber and diffuser.

One of the principal objectives of the Transonic Model Tunnel is to provide aerodynamic characteristics of transonic test section configurations with respect to establishment of transonic flow, quality of flow, auxiliary suction requirements, power requirements with and without auxiliary suction, and boundary layer conditions with specific emphasis on the PWT transonic circuit.

As the auxiliary air system for the full scale PWT will not be completed at the same time as the tunnel circuit, the PWT will operate for a time without auxiliary suction. The Transonic Model Tunnel results will be directly applicable in determining the test-section and diffuser configuration necessary to provide at least limited operation of the PWT under conditions of no auxiliary suction and limited suction through the use of diffuser flaps.

Studies are currently being conducted in the Transonic Model Tunnel on perforated walls with variation in percent open area in conjunction with Laval nozzles to cover a range of Mach numbers from 0.8 to 1.6.

This report is the first in a series to be presented on tests conducted in the Transonic Model Tunnel on characteristics of a transonic test section with perforated walls.

LIST OF SYMBOLS

F_D	Adjustable diffuser flaps, deflection in inches of clear opening below test section wall.
P	Static pressure, pounds per square foot.
P_c	Plenum chamber pressure, pounds per square foot.
P_o	Stagnation pressure, pounds per square foot.
P_o'	Downstream diffuser static pressure, pounds per square foot.
U_o	Stream velocity, feet per second.
U_x	Velocity in boundary layer.
W_A	Auxiliary weight flow, pounds per minute.
W_T	Tunnel weight flow, pounds per minute.
W_A/W_T	Auxiliary weight flow, percent of main flow.
θ_w	Test section wall angle, positive angles are divergence, negative angles are convergence.
λ	Tunnel pressure ratio $\frac{P_o}{P_o'}$
δ^*	Boundary layer displacement thickness, inches.

EQUIPMENT

The Transonic Model Tunnel is an open-circuit continuous-flow tunnel, consisting of the main air supply unit, the auxiliary suction equipment, and the test leg. The test leg includes the settling chamber, contraction section, nozzle section, plenum chamber, test section, and diffuser. A sketch of the Model Tunnel installation is shown in Fig. 1.

The main tunnel air-supply unit has a pressure ratio of approximately 1.4 and a volume flow capacity in excess of that required to generate flows in the main stream. For these tests the excess flow was either entirely by-passed to the atmosphere or partially recirculated directly to the compressor inlet to raise the operating temperatures for condensation control in the test section. Stagnation temperatures were normally in excess of 140 F, with resulting average Reynolds numbers of approximately 5.3×10^6 per foot.

The contraction section, nozzle region, test section, plenum chamber and diffuser were 1/16-scale geometric replicas of the transonic circuit of the PWT. The tunnel components enclosed in the plenum chamber shell are shown in Fig. 2. The plenum shell was constructed in two halves: one half was fixed; the other half was hinged at the top, opening for ready access to the tunnel elements enclosed in the plenum shell. The nozzle region was designed for interchangeable, contoured nozzle blocks for Mach numbers up to 1.6. The air channel in the nozzle region was formed on the top and bottom by the contoured nozzle and on the sides by parallel walls. The sonic nozzles for these tests are shown in Fig. 2, and the contour ordinates are presented in Table I. Pressure seals were installed slightly below the contoured surface of the nozzle between the side walls and nozzle blocks to prevent leakage into the plenum chamber. The cross-sectional area at the nozzle exit was 1 sq ft.

The test section, 1 ft square and 37.5 in. long from the nozzle exit to the end of the test section, was formed by fixed, parallel side walls and adjustable top and bottom walls.

The top and bottom walls were joined to the nozzle exit by flexure joints which permitted these walls to be diverged or converged up to 1 deg. The test section walls were designed so that wall configuration changes could be made with relative ease. Fig. 3 shows the installation of the 22.5-percent open perforated walls with the near side wall removed. A sketch of the geometry of the 1/4-in. and 1/16-in. diameter hole perforated plates is shown in Fig. 4. The perforated plate in most configurations was commercially available stock.

The first 14-1/2-in. of the diffuser was square in cross section and is designated the adjustable diffuser-flap section. For these tests only the top and bottom flaps were adjustable, the side walls were fixed at 3-deg divergence, and the top and bottom flaps were hinged at the downstream end at 3 deg divergence when closed with the test section top and bottom walls parallel. A pressure seal was installed at the edges of the diffuser flaps to prevent flow into or out of the plenum chamber.

The square diffuser flap section was joined to the conical diffuser by a 30-in. long transition section. The conical diffuser had a 7-deg included angle and a 30-in. diameter at the downstream end. The downstream end of the diffuser was joined to a constant area duct, which discharged to the atmosphere. A 30-in. butterfly valve at the end of the diffuser was used to control the pressure ratio across the test section.

The components of the auxiliary suction system used to evacuate the plenum chamber for plenum pressure control are shown in Fig. 1. The flow through the auxiliary system was measured with a calibrated sharp-edged orifice of 7-in. diameter. The source of power for the plenum evacuation was a steam-jet air ejector capable of removing up to 15 percent of the main flow.

A static probe was used to measure the axial static pressure distributions in the test section. The static probe was 1-in. diameter with pressure orifices spaced at 2-in. intervals. It was supported on the forward end in the settling chamber and on the aft end in the conical diffuser (Fig. 3). Static pressures from the static probe were recorded by photographing a multitube mercury manometer.

Dummy blockage models of 1, 3, and 5 percent of the test section cross-section area and fineness ratio of 10 were installed on the axial centerline static probe with the midstation of the bodies 22-in. downstream of the nozzle exit. Photographs of the models installed are shown in Fig. 5.

Straight taper strips were made and installed on the outside of the test section walls to permit a linear variation in the open area from 0 percent open at the nozzle exit to 22.5 percent open 10-in. downstream of the nozzle exit.

TEST PROCEDURE

Static pressure distributions, from which the Mach numbers were computed, were obtained along the centerline of the tunnel with the static probe. The Mach number in the test section was changed by varying the pressure ratio across the tunnel in combination with variations in the diffuser-flap opening or with variations in the auxiliary plenum suction. The tunnel pressure ratio, λ, is defined as the ratio of stagnation pressure P_o to the static pressure P_o' downstream in the diffuser where the local dynamic head is small. The plenum chamber pressure P_c and axial static pressure distributions were taken for a range of Mach numbers from 0.8 to 1.2.

In determining the auxiliary suction requirements, the auxiliary weight flows were measured for variations in the tunnel pressure ratio for M=0.9 to M=1.2. All tests were made with the axial static pressure tube mounted in the tunnel. Auxiliary suction requirements were obtained with the top and bottom test section walls parallel, converged 30 min., and diverged 30 min. For each wall angle, θ_w, the procedure was repeated with variations in the diffuser-flap (F_D) position from closed to 1 in. open.

Auxiliary suction requirements were obtained with the 1, 3, and 5 percent blockage models installed in the test section with parallel walls. The 5-percent blockage body was also installed in the diverged and converged wall configuration.

Boundary layer profiles were taken along the lower wall at three stations with a ten tube probe for M=0.9 to M=1.2. The boundary layer probe was 1.2 in. high and was made with 0.030 O. D. stainless steel tubing. Profiles were also measured at the mid- and downstream stations with the blockage bodies installed.

RESULTS

Mach Number Distribution in Test Section

The initial tests on the 22.5-percent perforated walls were made with 1/16-in. diameter perforations. Mach number distributions are presented in Fig. 6 for parallel walls to show that good distributions were obtained over a wide speed range with the use of taper strips. Effects of the addition of taper strips are discussed below.

Results of tests on the 22.5-percent walls with 1/4-in. diameter holes to obtain Mach number distributions for parallel walls are shown in Fig. 7 (a). The distribution up to $M = 1.0$ has very small gradients with variations in Mach number of ± 0.002. Above $M = 1.0$, over expansion occurred in the initial expansion region. The compression wave in this region was apparently reflected through the test section as minor disturbances, resulting in Mach number variations of ± 0.005. The addition of the straight taper strips on the initial 10 in. of the test section reduced the over expansion with only minor variations along the test section for Mach numbers over 1.0 for parallel walls, as seen in Fig. 7 (b). It appears that further improvements in the distribution could be made by refinements in the shape of the taper strips. Distributions for 30-min. divergence of the top and bottom walls are shown in Fig. 7 (c). Minor variations in the distribution of ± 0.002 up to $M = 1.1$ are indicated. Distributions for 30-min. convergence are shown in Fig. 7 (d). Mach number distributions for speeds above $M = 1.0$ are essentially the same whether auxiliary suction or diffuser suction is used. A comparison in the distributions for $M = 1.1$ is presented in Fig. 8. At a subsonic $M = 0.9$ with changes in suction quantities and tunnel pressure ratios, a change in the distribution at the rear of the test section did not alter the distributions in the test section (Fig. 9).

The average test section centerline Mach number was plotted versus the plenum chamber static pressure in Fig. 10 to show the calibration between the plenum chamber pressure and test section Mach number for the various wall slopes. The dashed curve indicates zero pressure difference between plenum chamber and test section. The data for the diverged walls show essentially zero pressure difference between plenum and test section centerline with an increase in the pressure difference as the walls are converged.

Diffuser Suction Requirements

With sufficient tunnel pressure ratio to position the tunnel shock in the diffuser flap section, an expansion occurred around the corner at the test section exit. The low pressure region, as a result of the expansion, was utilized as a means of diffuser suction. The pressure distribution as a result of expansions in the diffuser flap section for varying tunnel pressure ratio may be seen in Fig. 19. Figure 11 shows the effect of tunnel pressure ratio on the Mach number with the diffuser flaps open 1 in. The test section Mach number was increased from 0.98 to 1.205 by diverging the walls from converged 30 min. to diverged 30 min. at a maximum tunnel pressure ratio of 1.4. Note that with closed flaps and parallel walls, the choking Mach number is 0.85.

Auxiliary Suction Requirements

Auxiliary suction requirements to produce M = 0.9 to 1.2 for the parallel wall configuration and closed diffuser flaps are shown in Fig. 12 (a). Figure 12 (b) shows the auxiliary suction requirements for the same wall configuration without the taper strips installed.

Figure 13 compares the minimum auxiliary suction requirements to produce a given Mach number with and without taper strips. The data show no difference in the suction requirements up to M = 1.0 for the 1/4-in. perforated walls. As the Mach number was increased from M = 1.0 to M = 1.2, the data show slightly higher suction requirements without the use of taper strips. To expand the flow from M = 1.0 to M = 1.2 required an increase in auxiliary suction from 2.2 to 4.3 percent of main flow for parallel walls with taper strips.

Results for minimum suction requirements from tests with 1/16-in. diameter perforations with and without taper strips are also shown on Fig. 13 for comparison with the 1/4-in. diameter hole results. These data show that with the addition of taper strips on the 1/16-in. perforated walls reduced the minimum suction in excess of 1 percent of the main flow for all Mach numbers tested. For M = 1.0, the variation in auxiliary suction with tunnel pressure ratio with and without taper strips is shown in Fig. 14. The data for the 1/16-in. perforated walls indicate that with the taper strips the auxiliary suction requirements for a M = 1.0 was reduced from 4.85 to 3.65 percent of the main flow. Boundary layer profiles measured along the test section wall showed a thicker boundary layer along the wall without the use of taper strips. A comparison of the test section axial distributions with and without taper strips (Fig. 15) shows that without the addition of taper strips over expansion occurs. This over expansion results in lower local pressure in the test section causing flow into the test section from the plenum chamber. Compression, caused by the inflow, increases the local pressure in the test section above that in the plenum chamber, resulting in flow from the test section to the plenum chamber. This inflow and outflow continues along the test section until equilibrium is reached. The addition of taper strips minimized over expansions. The thicker boundary layer was probably caused by the effects of inflow and outflow at the walls due to the pressure differences between the plenum chamber and the test section as a result of over expansion and compressions. It is evident that the taper strips improved the Mach number distributions considerably in both the supersonic and the subsonic speed range.

The variation with Mach number in the minimum auxiliary suction requirements for the 1/4-in. diameter hole perforations with parallel walls and diffuser flaps closed is shown again in Fig. 16. The dashed curve is from one dimensional flow theory and for comparison purposes has been placed so that it intersects the experimental data at M=1.0. This comparison shows that the increase in flow through the walls required to expand to test Mach numbers above 1.0 is slightly less than the theoretical.

Figures 17(a) and 17(b) show the auxiliary suction requirements for wall positions other than parallel with closed diffuser flaps. The effect of wall angle on the auxiliary suction at M=1.0 with the diffuser flaps closed is shown in Fig. 18. With the walls diverged 30 min., a Mach number of 1.0 is attained at a tunnel pressure ratio of 1.16 with zero percent auxiliary suction. As the walls were moved to the parallel and converged positions the suction requirements increase to 2.2 and 5.6 percent respectively at the same tunnel pressure ratio. Also note from Fig. 18 that as the walls were moved from diverged toward converged position, the tunnel pressure ratio decreases for the point where the minimum suction requirements begin to increase.

Figures 19, 20, and 21 show the effect of tunnel pressure ratio on shock location and suction requirements at M=1.0 for parallel, diverged, and converged wall positions. The left-hand plot of Fig. 19 shows that as the tunnel pressure ratio was reduced from 1.404 to 1.145 the shock position has moved upstream but was still in the diffuser flap section with constant auxiliary suction values, as seen in the right-hand plot. Further reduction in tunnel pressure ratio with increasing suction requirements showed a pressure rise in the distribution at the rear portion of the test section. With the increased flow into the plenum through the perforations at the end of the test section, the local boundary layer was reduced, and the stream lines were turned in the direction of the perforated walls. This condition resulted in initial diffusion occurring in the aft end of the test section. Better diffuser efficiency was obtained with a thinner boundary layer at the entrance to the diffuser and with initial pressure recovery already established in the aft end of the test section.

Figure 22 shows the effect of the 1, 3, and 5 percent blockage models on the auxiliary suction requirements for M=0.9 to M=1.2 with parallel test section walls. Figure 22 (b) for M=1.0 the data indicate that the suction requirements for a 5-percent blockage model in comparison to the tunnel empty condition had increased from 2.2 percent to 3.65 percent.

With the same plate thickness (1/16-in.), a comparison of the suction requirements for 1/4-in. and 1/16-in. diameter hole perforated plate at M=1.0 is shown in Fig. 23. Note that a reduction from 3.65 percent to 2.2 percent of main flow was realized by increasing the hole size from 1/16-in. to 1/4-in. diameter.

A comparison of the Mach number distributions for the 1/16-in. and 1/4-in. diameter perforated parallel walls with taper strips is shown in Fig. 24. With the 1/16-in. holes there was a decreasing Mach number gradient in the test section 10 in. downstream, whereas with the 1/4-in. holes there was a flat distribution or generally increasing Mach number gradient. Note also that the length of the expansion region for the 1/16-in. holes was further downstream from the nozzle exit than that for the 1/4-in. holes. This effect of hole size is not totally understood yet and will be investigated further.

To show the effect of diffuser flap suction on auxiliary suction the diffuser flaps were varied from closed to 1-in. open. Figure 25 shows the effect of wall angle and diffuser flap position on the auxiliary suction requirements at M = 1.0. For parallel walls, as the flaps moved from the closed to the open position, the auxiliary suction requirements were reduced with resulting increases in tunnel pressure ratio. With the flaps closed and a tunnel pressure ratio of 1.15 the auxiliary suction was 2.2 percent of the main flow. When the flaps were opened with a constant suction value, an increase in tunnel pressure ratio was necessary to maintain M = 1.0. The results indicate that from 0 percent to 1.5-percent suction the 1-in. flap was most effective. From 1.5-percent to 2.2-percent suction, reduced flap openings were superior.

Boundary Layer

Boundary layer profiles are presented in Figs. 26 and 27 to show the effect of wall angle on the profiles along the wall at M = 1.0. The results shown in Fig. 26 are profiles measured 2.3 in. downstream of the nozzle exit on the bottom wall for parallel, diverged, and converged walls. Wall angle had no measurable effect on the profiles. Profiles measured at 16.79 in. and 30.68 in. are presented in Fig. 27. Varying the wall angle from diverged to converged positions reduced the boundary layer thickness at both stations. The velocities near the wall did not go to zero as would be expected with solid walls. The boundary layer displacement thickness was calculated (Figs. 26 and 27) and plotted in Fig. 28 to show the growth of boundary layer displacement thickness along the test section walls.

Boundary layer profiles were taken at the wall for the two downstream stations with the 1, 3, and 5-percent blockage models installed. Results at M = 1.0 with parallel walls are presented in Fig. 29 to show the effect of the model on the boundary layer as compared to the profile for empty tunnel. Note that velocities near the wall with the models installed do not go to zero.

POWER REQUIREMENTS

The air horsepower was calculated to show the effect of various tunnel parameters on the auxiliary and total horsepower requirements. When the air horsepower was calculated, the reference stagnation pressure and temperature were taken as one atmosphere and 520 R. The pressure boost of the auxiliary system was assumed to be from plenum chamber pressure to stagnation condition. The compressor efficiency for all calculations was assumed 100 percent.

Air horsepower requirements are presented in Fig. 30 for the condition of no auxiliary suction. Thus, when diffuser suction with varying pressure ratio was utilized as a means of Mach number control, a pressure ratio of 1.25 and 575 hp/sq ft was required for parallel walls and M = 1.0. The dotted curve superimposed for varying auxiliary suction and a pressure ratio of 1.125 shows a total horsepower of 350/sq ft.

The auxiliary and total air horsepower requirements for M = 0.9 to M = 1.2 with parallel walls and closed diffuser flaps are shown in Fig. 31. Constant tunnel pressure ratio lines have been superimposed. To avoid high suction values, an optimum operating range would be at a tunnel pressure ratio of approximately 1.125. The total horsepower requirements increased from 320 hp at M = 0.9 to 410 hp for M = 1.2, an increase of 90 hp/sq ft of test section area. At M = 1.0 and a tunnel pressure ratio of 1.125, the auxiliary power was 17 percent of the main power.

The effect of wall angle on the power requirements at M = 1.0 is shown in Fig. 32. The dotted curve indicates for each wall angle the minimum total power required where M = 1.0 exists over the entire test section length (Figs. 19-21). Thus, the data (Fig. 32) show that less total power was required by converging the walls. Also, the boundary layer thickness was considerably greater with diverged walls, so that from this view point, the parallel or converged wall configurations are superior.

Figure 33 shows the effect of model blockage on the power requirements at M = 1.0 with parallel walls and closed diffuser flaps. For a tunnel pressure ratio of 1.15, the horsepower for empty tunnel was 400 hp/sq ft. The horsepower increased with model blockage to 420 hp/sq ft of test section area for the 5-percent model, an increase of 5 percent.

Figure 34 shows the effect of diffuser flap position on the total air horsepower requirements for M = 1.0. The results indicate that at a constant tunnel pressure ratio of 1.25 moving the diffuser flap to the open position reduced the total power. Reducing the tunnel pressure ratio to 1.15 required that the diffuser flaps be in the closed position for minimum total power. That the optimum operating condition for the tunnel would be with auxiliary suction and no diffuser flap opening is especially significant.

The effect of hole size on power requirements is shown in Fig. 35 for the parallel wall and closed diffuser flaps for M = 1.0. At a pressure ratio of 1.125 the total horsepower for the 1/16-in. diameter hole configuration was 400 hp/sq ft while for the 1/4-in. hole configuration it was only 350 hp/sq ft. The auxiliary suction power for the 1/4-in. and 1/16-in. perforated walls was 17 and 23 percent of the main power respectively.

CONCLUSIONS

The results of tests on a 22.5 percent perforated wall transonic test section in conjunction with a sonic nozzle may be summarized as follows:

1. Good Mach number distributions were obtained over most of the test section length for M=0.8 to M=1.1 for all wall angles tested. Excellent distributions were obtained when suitable taper strips were used to minimize over-expansion of the flow at the entrance to test section at supersonic Mach numbers.

2. M=1.0 was attained in the empty test section with parallel walls at a tunnel pressure ratio of 1.25, when the diffuser flaps were at their full open position (F_D = 1 in. for these tests) and no auxiliary suction was utilized. For this configuration (F_D = 1 in., no auxiliary suction) a maximum M=1.125 was attained at the maximum available tunnel pressure ratio of 1.4.

3. M=1.0 was attained in the empty test section with parallel walls and diffuser flaps closed and sealed, when a minimum of 2.2 percent of the main flow was removed by the auxiliary suction system. A minimum removal of 4.3 percent was required to obtain M=1.2 for this configuration.

4. With parallel walls and diffuser flaps closed, blockage models of 1, 3, and 5 percent of the tunnel cross-sectional area required an increase in the auxiliary suction flow to obtain a given Mach number. At M=1.0 with the 5 percent model, a flow of 3.65 percent of the main flow was required as compared to the tunnel empty requirements of 2.2 percent.

5. A decrease in the hole size from 1/4 in. to 1/16 in. diameter increased the auxiliary suction requirements from 2.2 to 3.65 percent of the main flow for M=1.0 with parallel walls and closed diffuser flaps.

6. The minimum total horsepower at M=1.0 for any given amount of auxiliary suction was obtained when the diffuser flaps were kept completely closed. This result applies to the region of auxiliary suction quantities which are larger than the minimum value required for unchoking the test section with the diffuser flaps completely closed.

7. In the auxiliary suction region below the minimum value, as defined in 6, choking at M=1.0 could be prevented by opening the diffuser flaps. This result could be achieved, however, only in a greatly restricted region of Mach number and model size and with considerable increase of total horsepower.

8. In the auxiliary suction region above the minimum value as defined under 6, the total horsepower for any constant flap opening decreased continuously at a diminishing rate when the auxiliary suction was increased. It can be expected that at extremely large auxiliary suction values above the range of these tests, the total horsepower will reach an absolute minimum value and finally will start to rise again.

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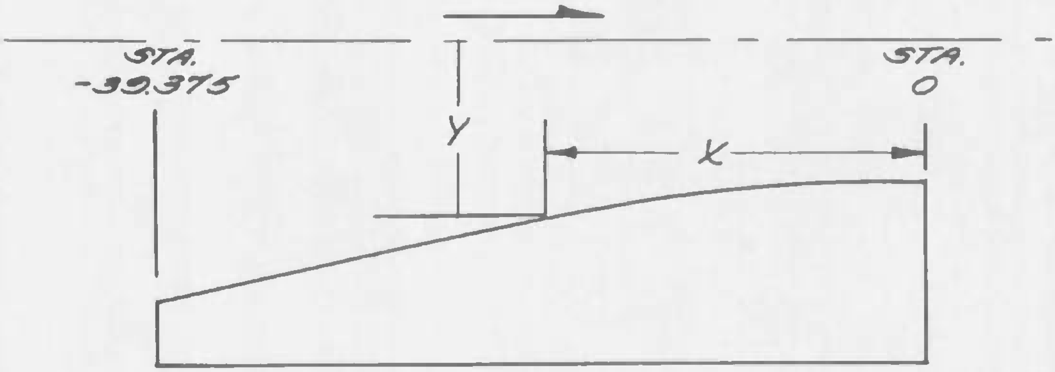
PWT-TRANSONIC MODEL TUNNEL

SONIC NOZZLE ORDINATES

TABLE I



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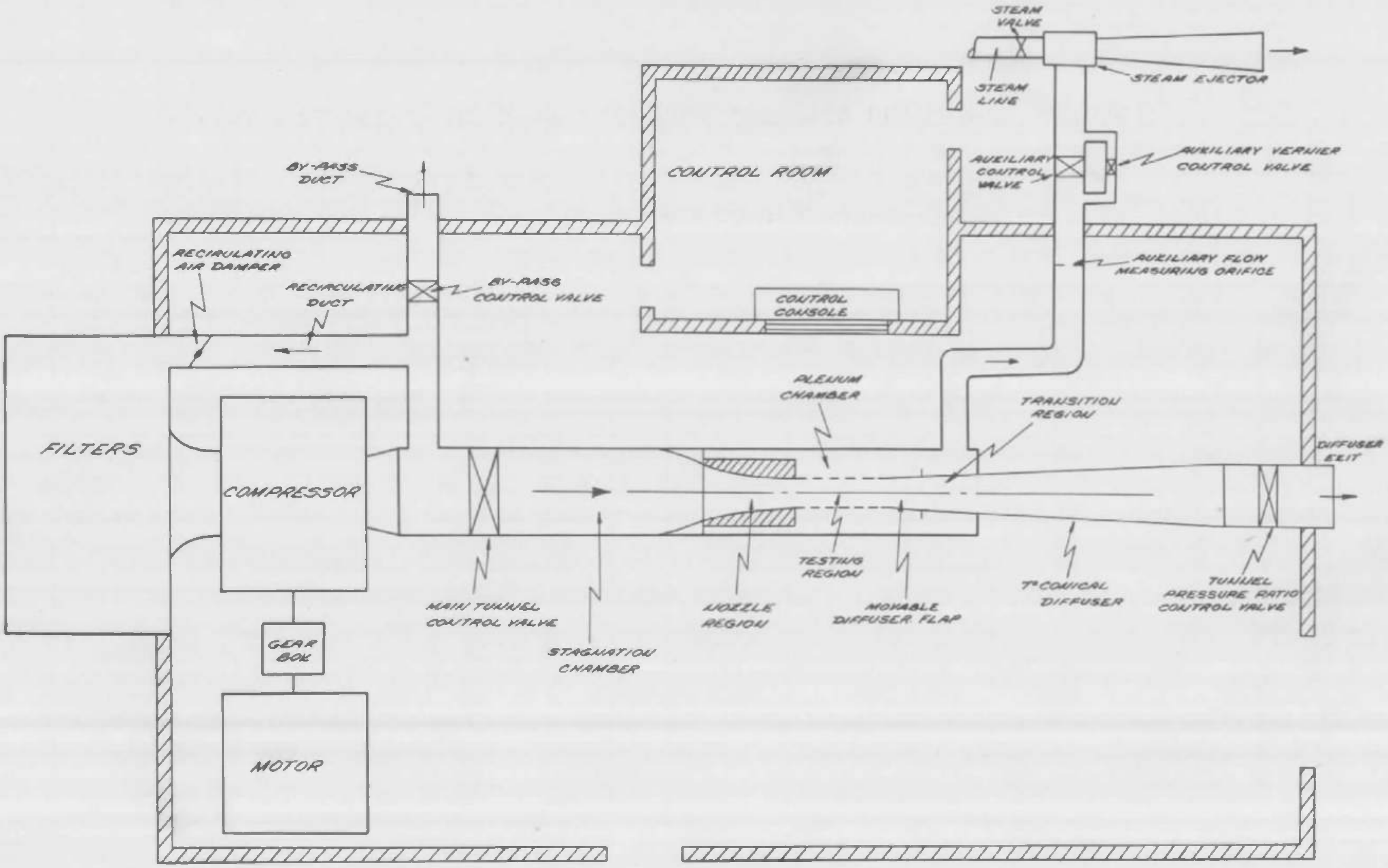

FIGURE 1. SKETCH OF PWT – TRANSONIC MODEL TUNNEL INSTALLATION

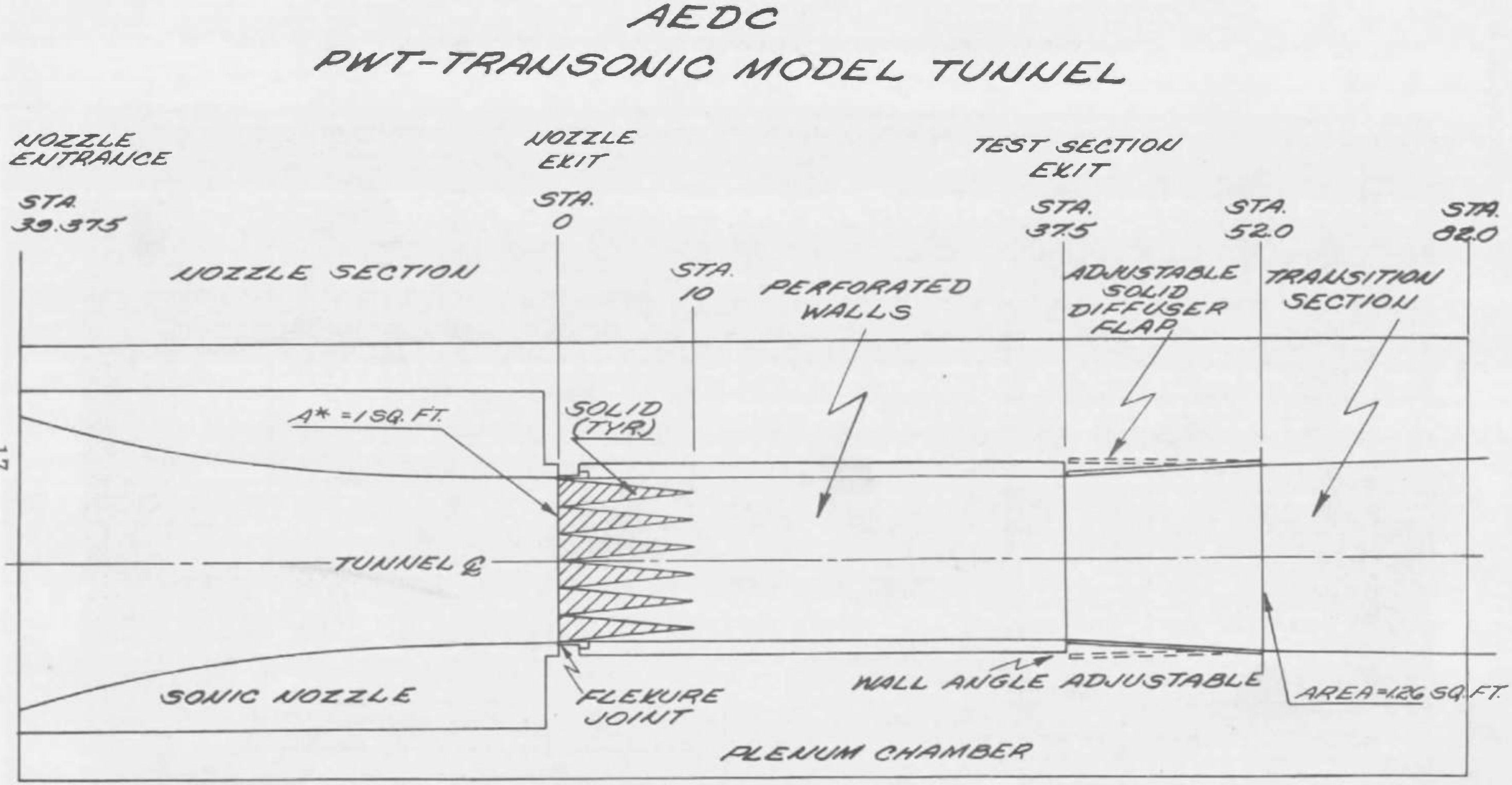

FIGURE 2. SKETCH OF TUNNEL SECTIONS ENCLOSED IN THE PLENUM SHELL

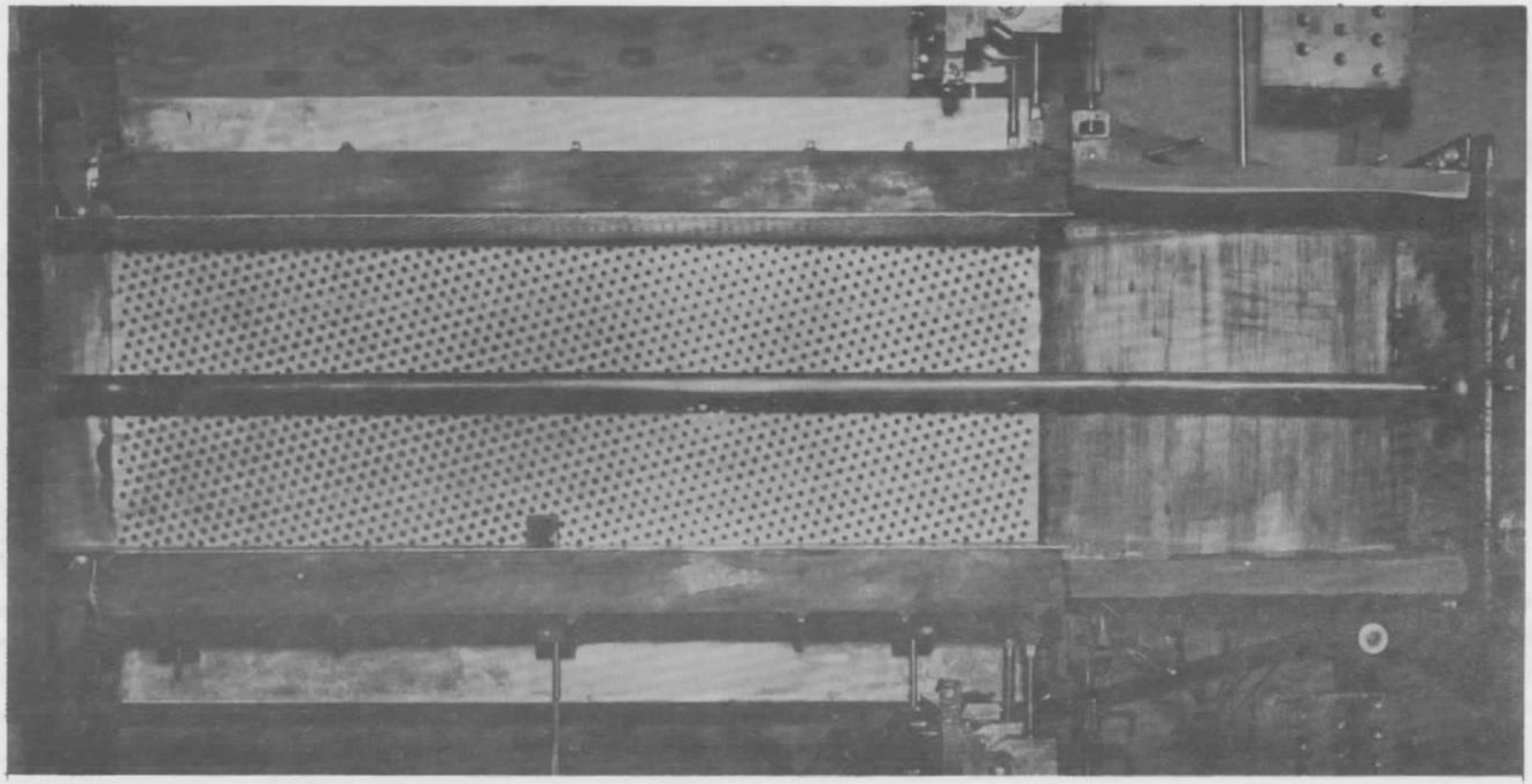

FIGURE 3. PHOTOGRAPH OF PERFORATED PLATE INSTALLATION

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PWT-TRANSONIC MODEL TUNNEL
22.5% PERFORATED METAL PLATE

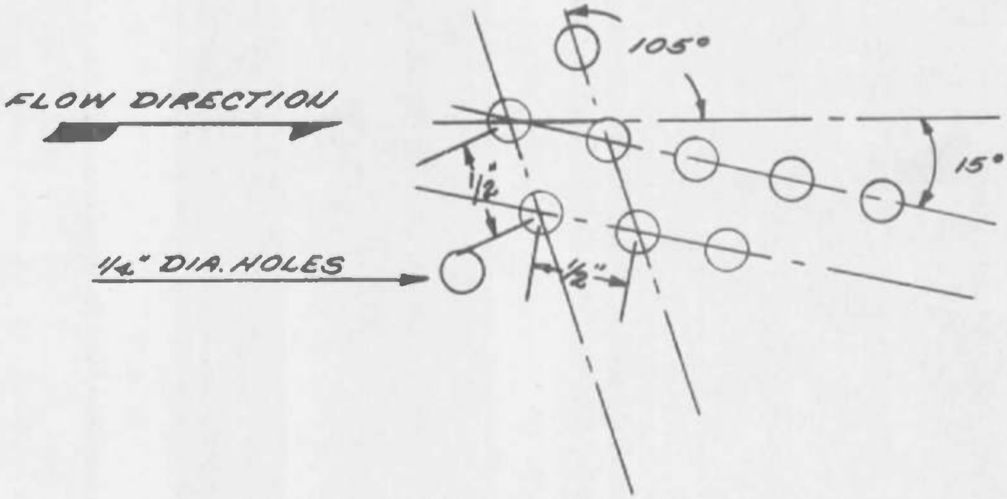


PLATE THICKNESS 0.063 INCHES

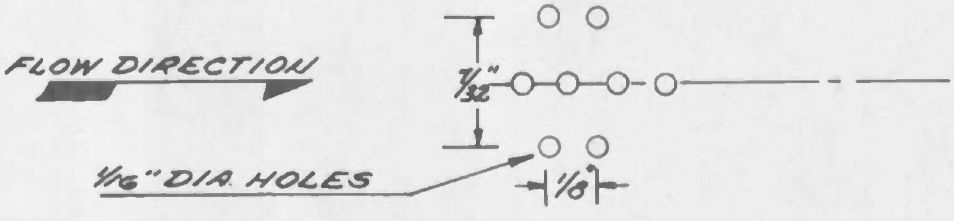


PLATE THICKNESS 0.0598 INCHES

FIGURE 4. SKETCH OF PERFORATED PLATE HOLE GEOMETRY

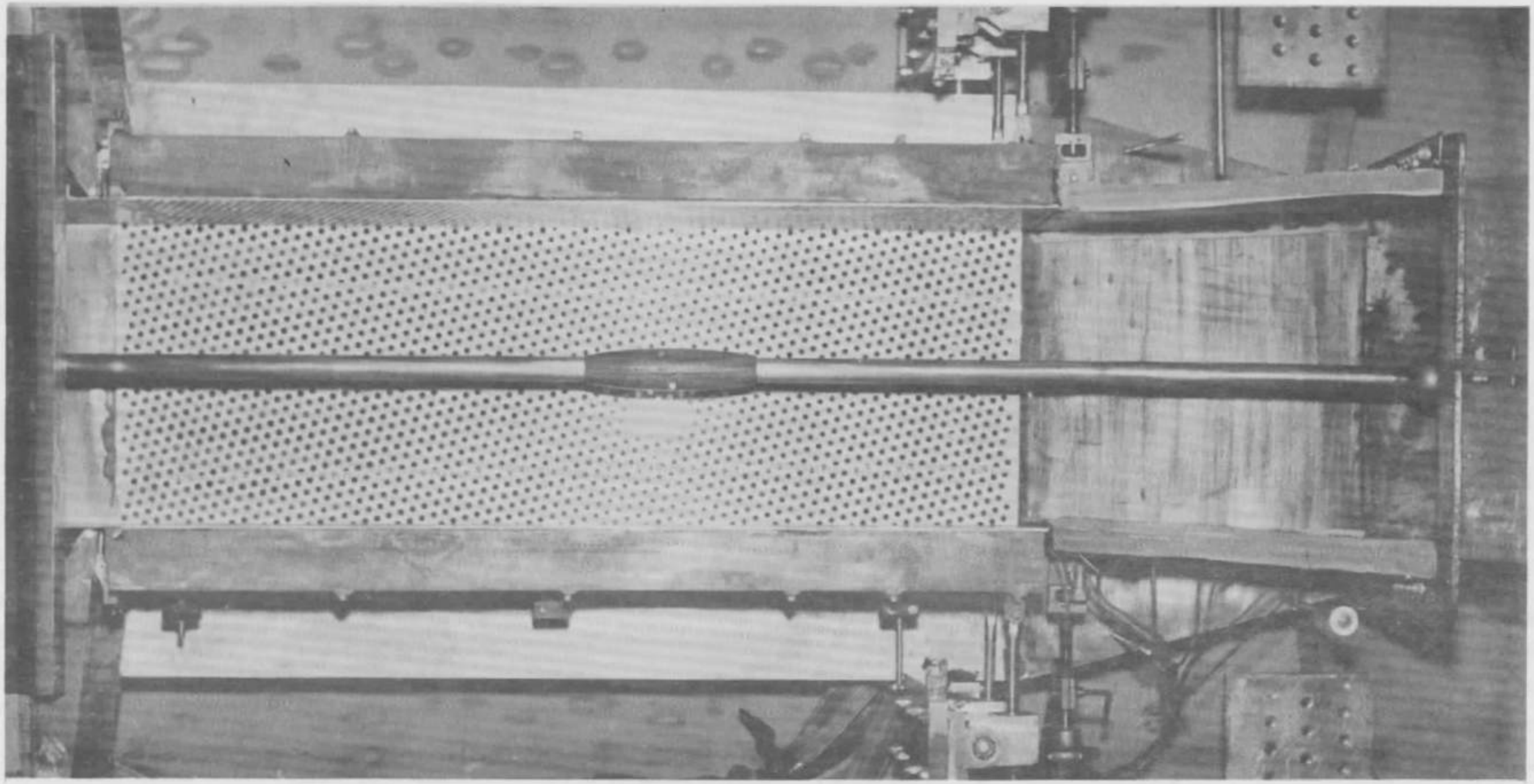


FIGURE 5. PHOTOGRAPHS OF BLOCKAGE MODELS INSTALLED IN TUNNEL
(A). 1 PERCENT BODY

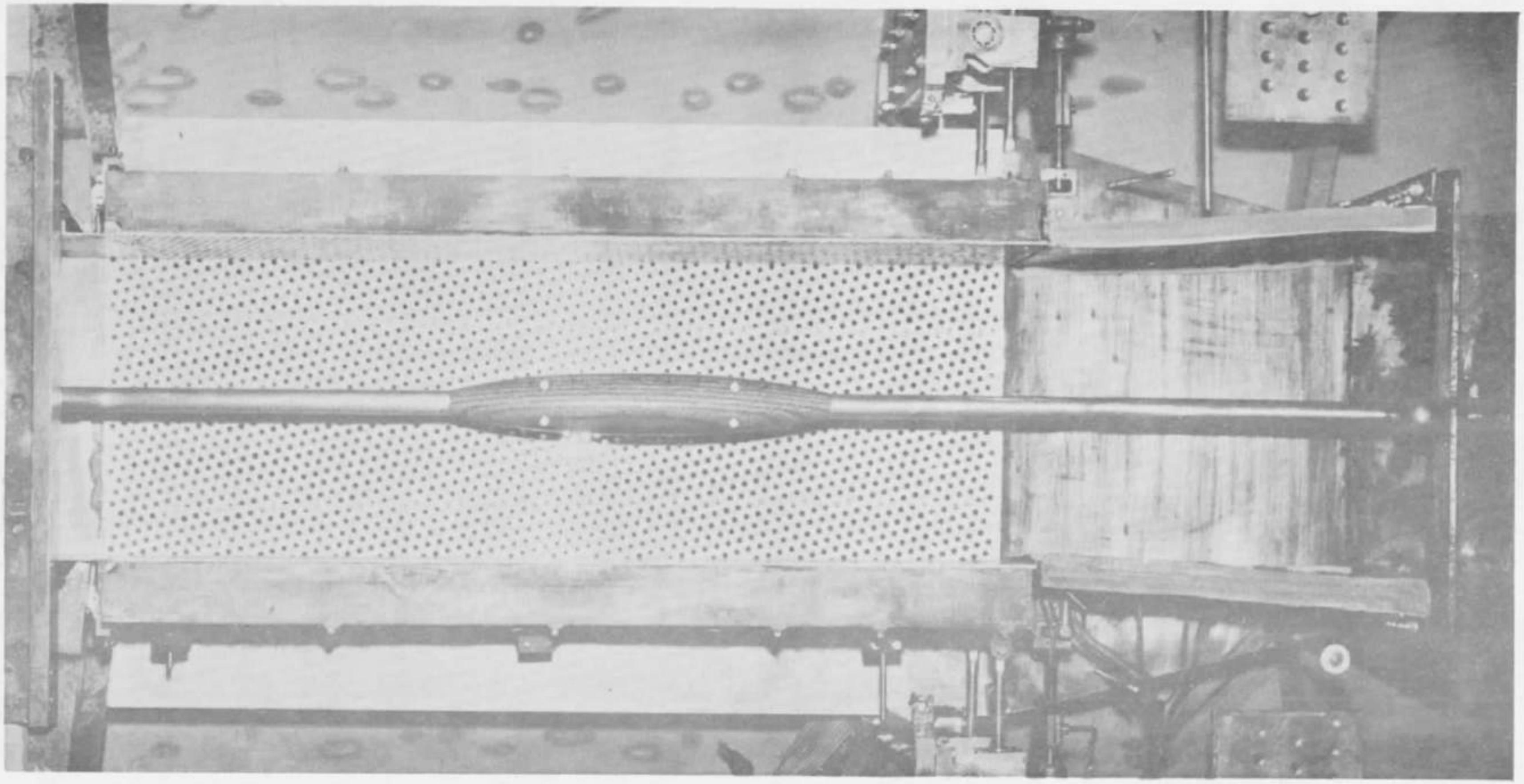


FIGURE 5. CONTINUED
(B). 3 PERCENT BODY

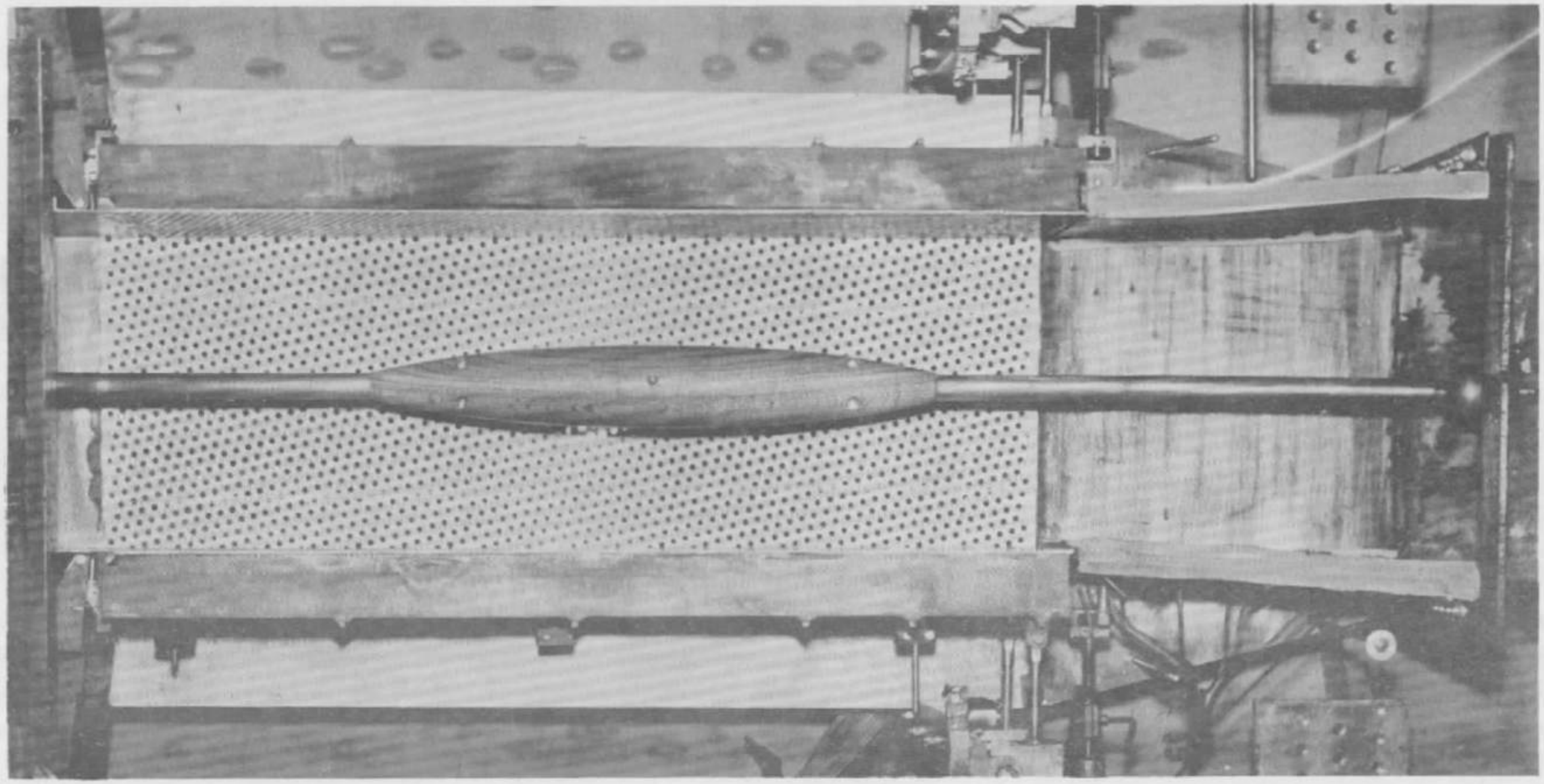


FIGURE 5. CONCLUDED
(C). 5 PERCENT BODY

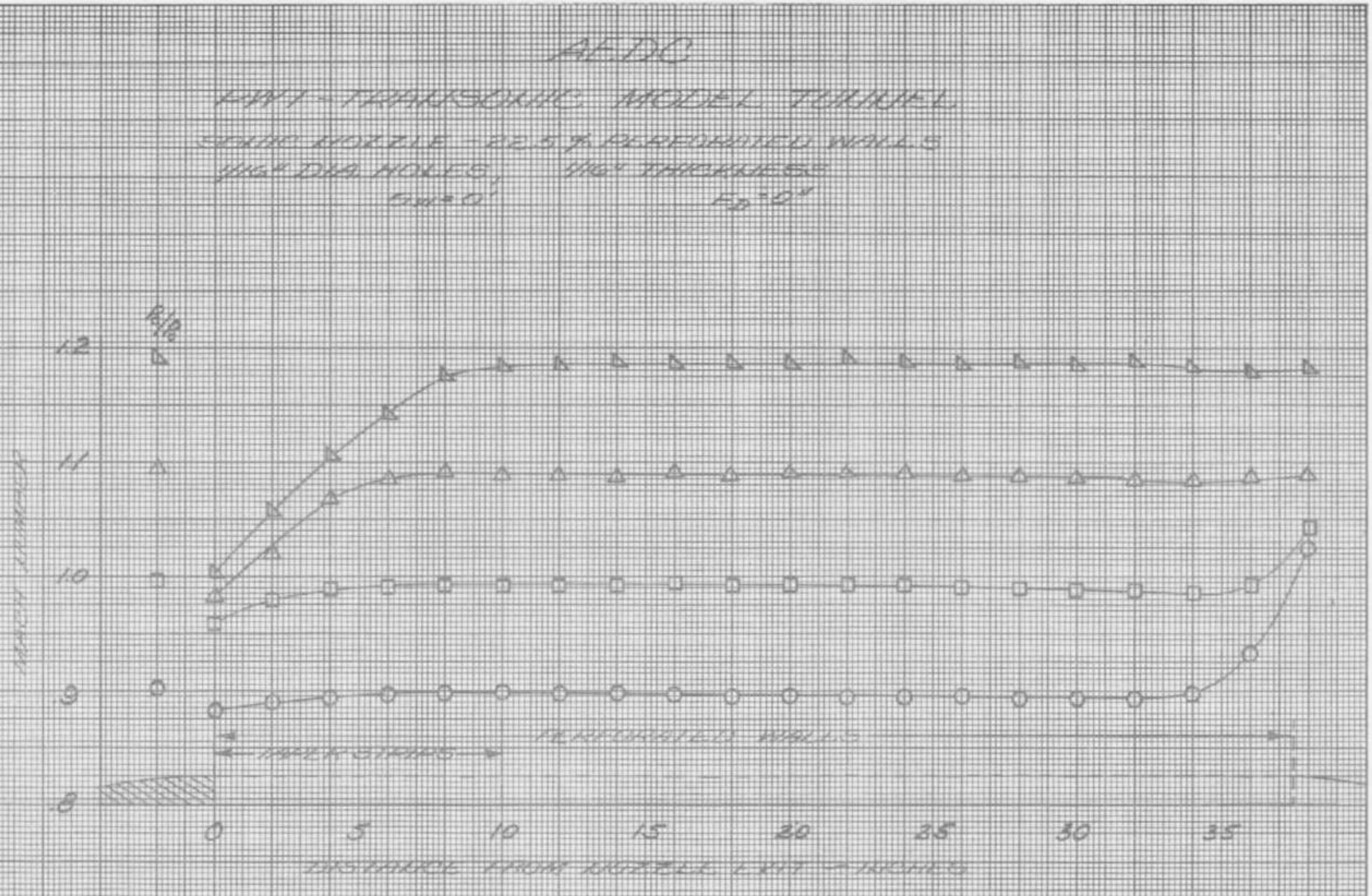
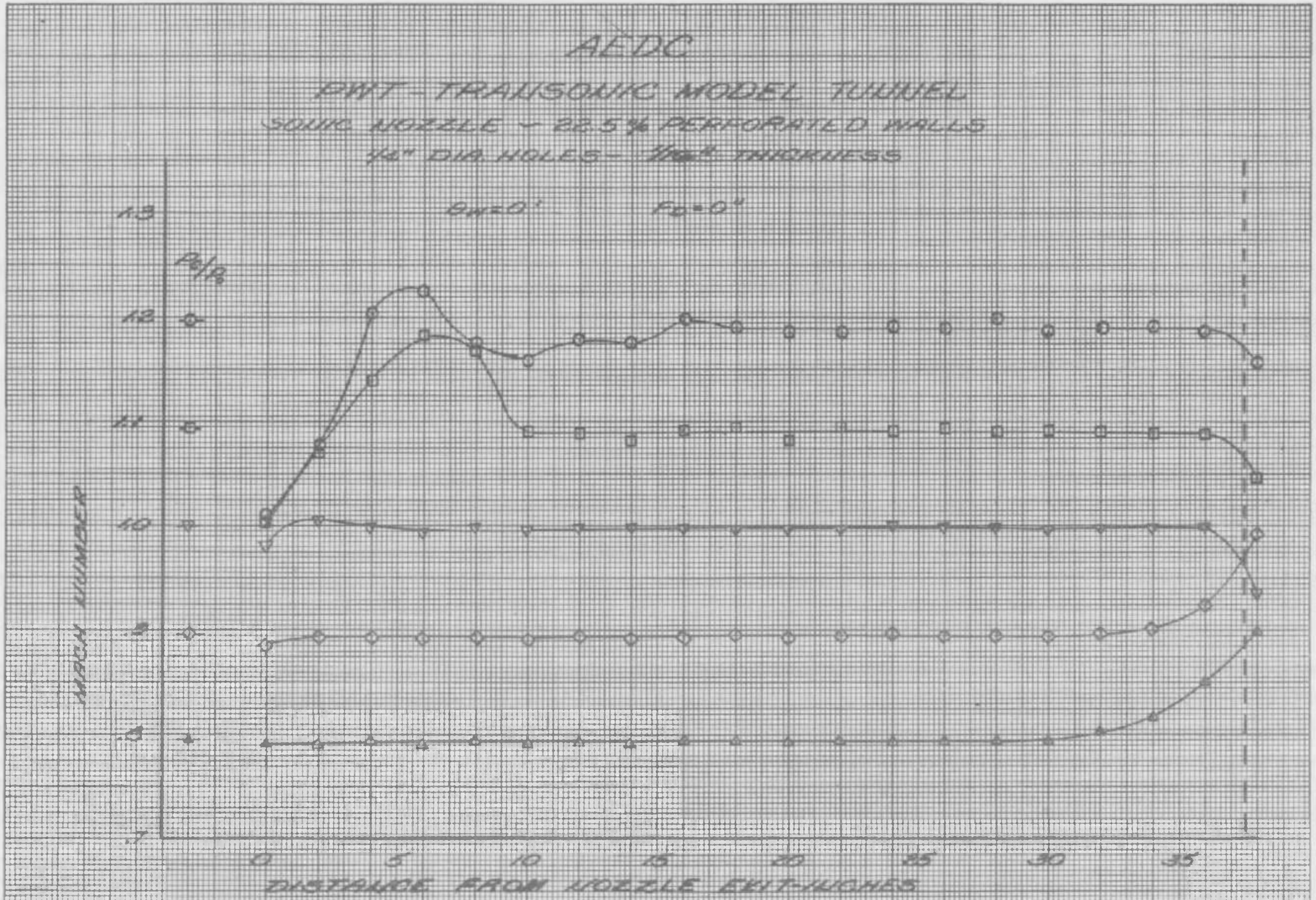


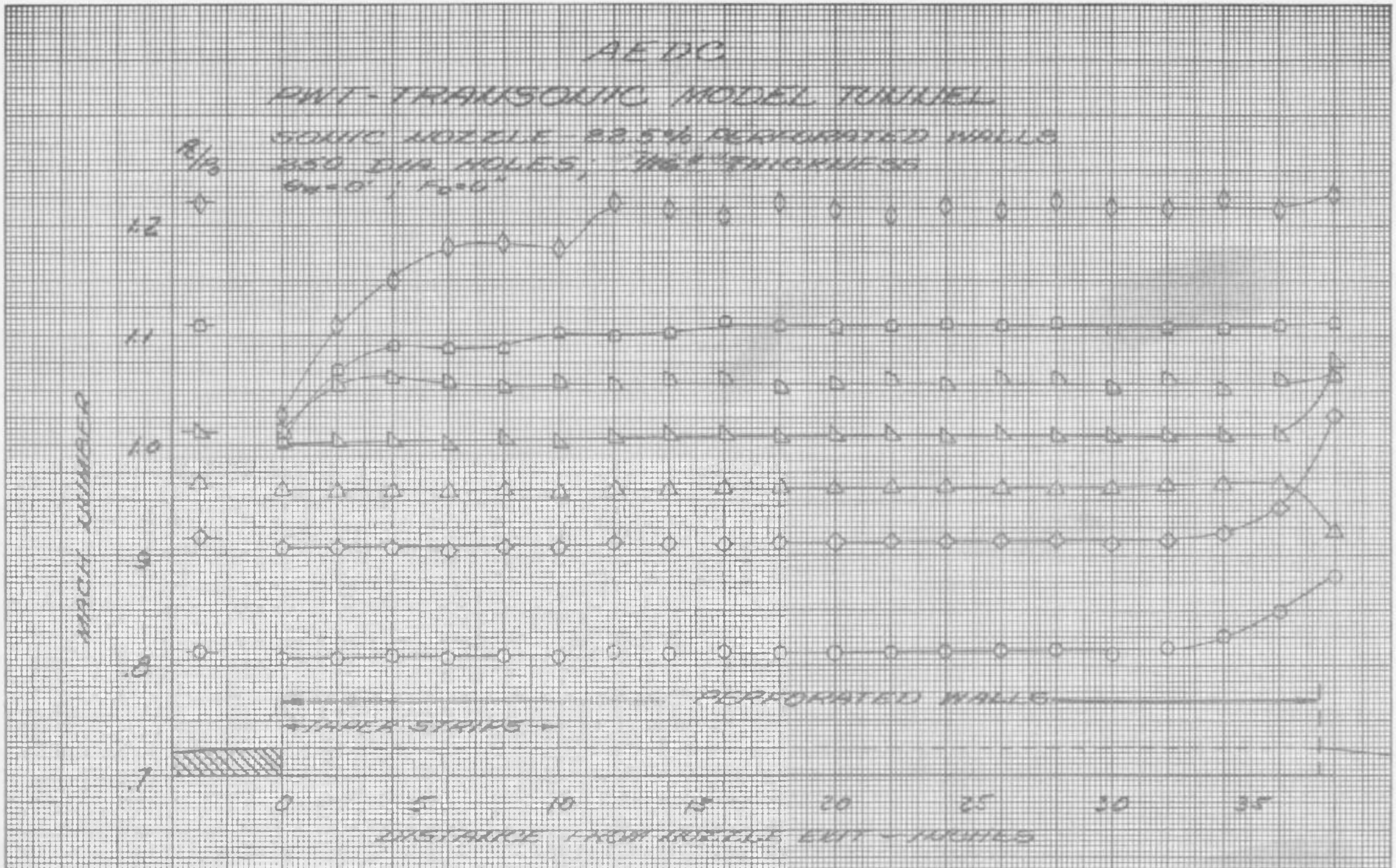
FIGURE 6: MACH NUMBER DISTRIBUTION FOR PARALLEL WALLS WITH 1/16 INCH DIAMETER HOLES AND TAPER STRIPS.



(a) PARALLEL WALL - WITHOUT TAPER STRIPS

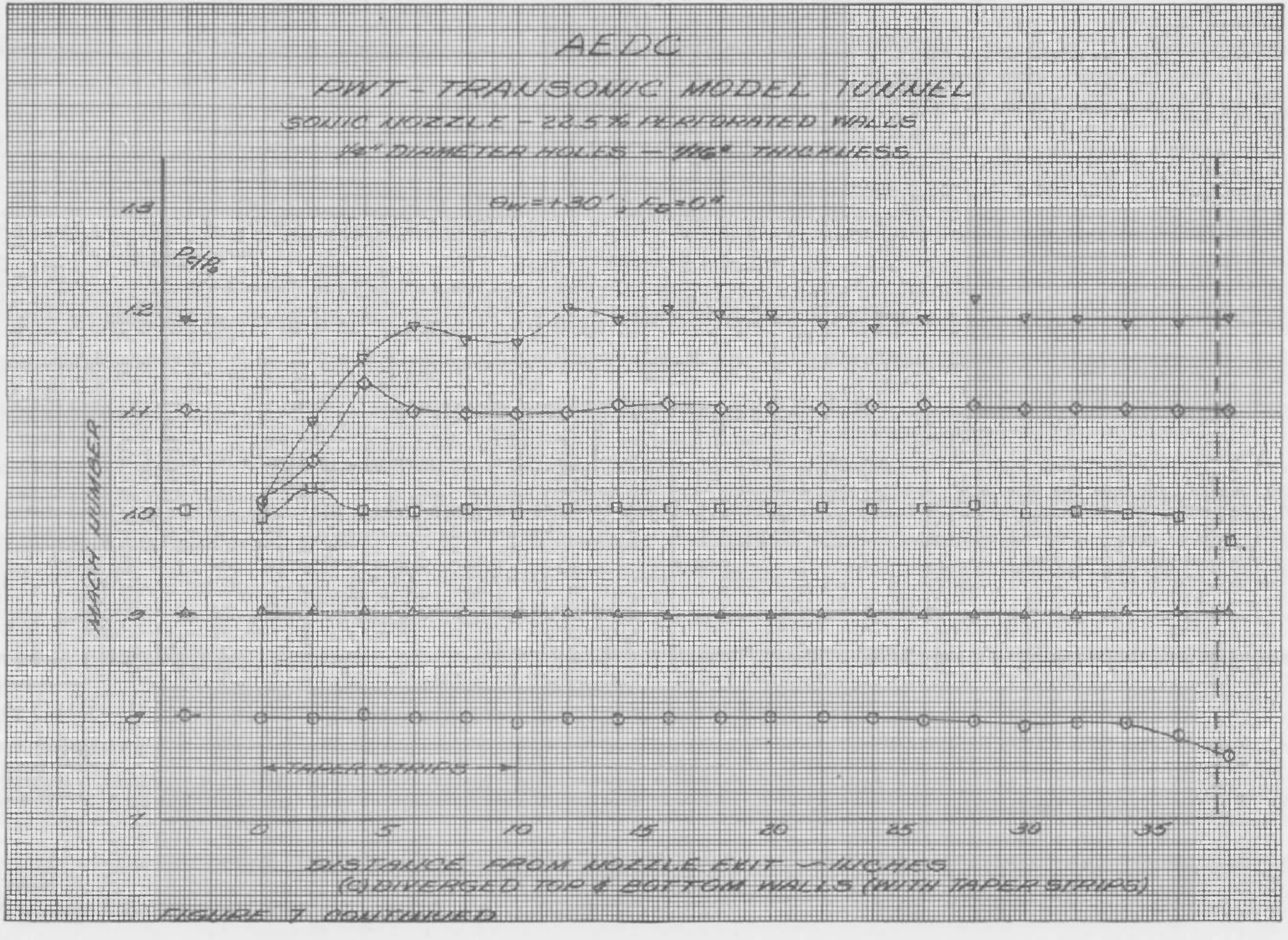
FIGURE 7 TEST SECTION CENTERLINE MACH NO. DISTRIBUTIONS

10-14-53
BR



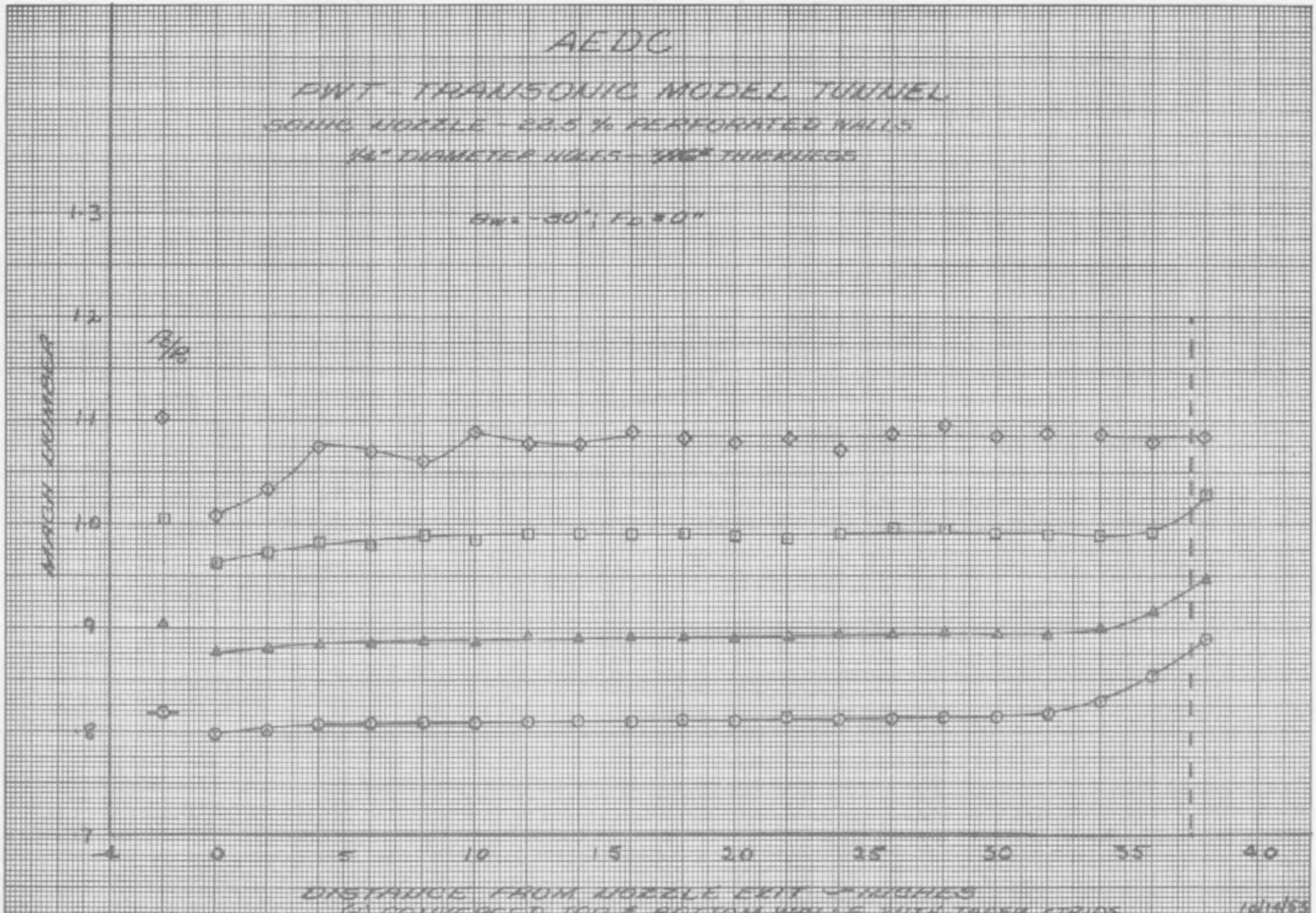
(b) PARALLEL WALLS WITH TAPER STRIPS

FIGURE 7 CONTINUED



(c) DIVERGED TOP & BOTTOM WALLS (WITH TAPER STRIPS)

FIGURE 7 CONTINUED



(c) CONVERGED TOP & BOTTOM WALLS WITH TAPER STRIPS

FIGURE 7 CONCLUDED

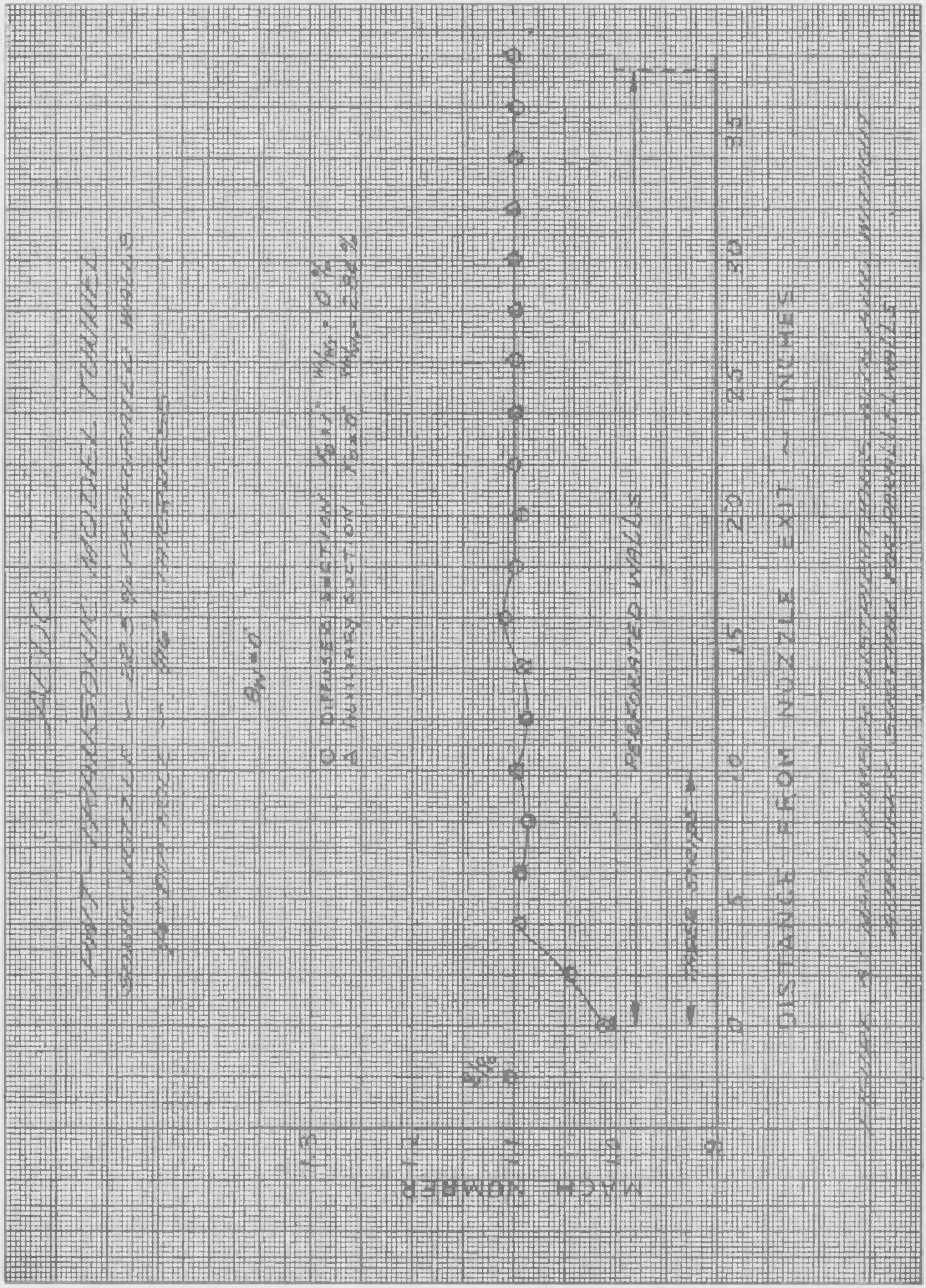


FIGURE 8 MACH NUMBER DISTRIBUTIONS WITH AND WITHOUT AUXILIARY SUCTION FOR PARALLEL WALLS

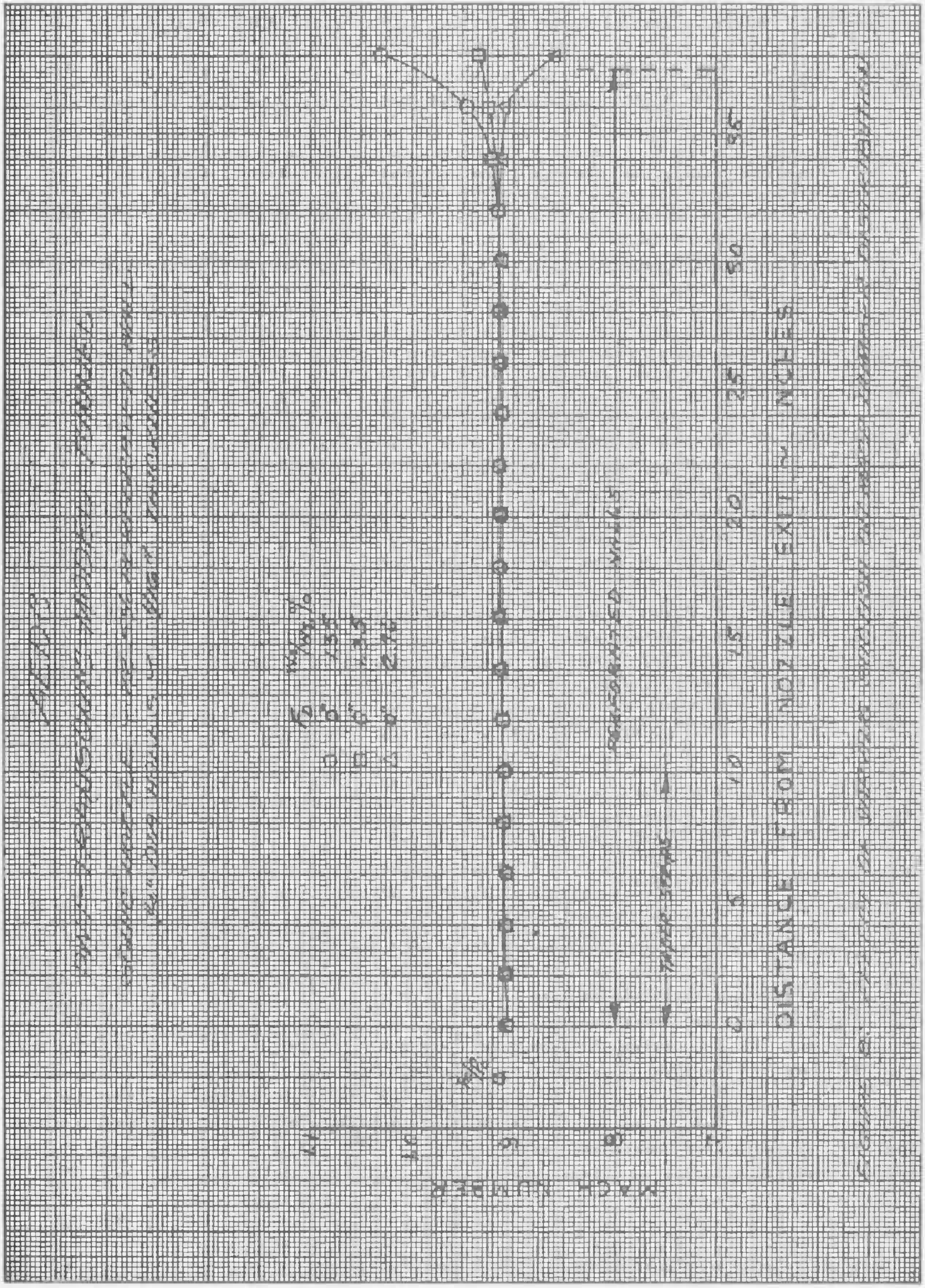


FIGURE 8. EFFECT OF VARYING SUCTION ON MACH NUMBER DISTRIBUTION

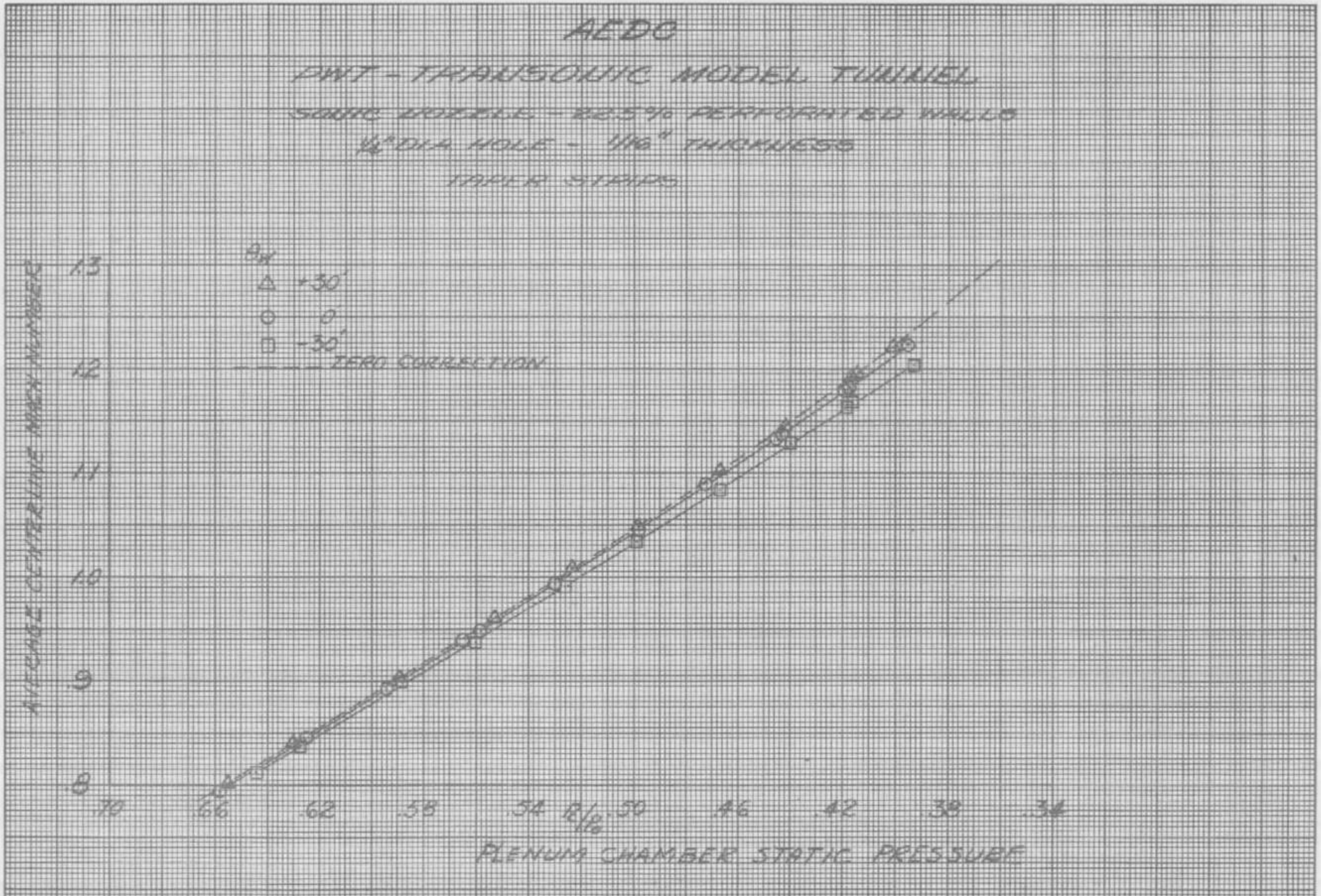


FIGURE 10. TEST SECTION CENTERLINE CALIBRATION

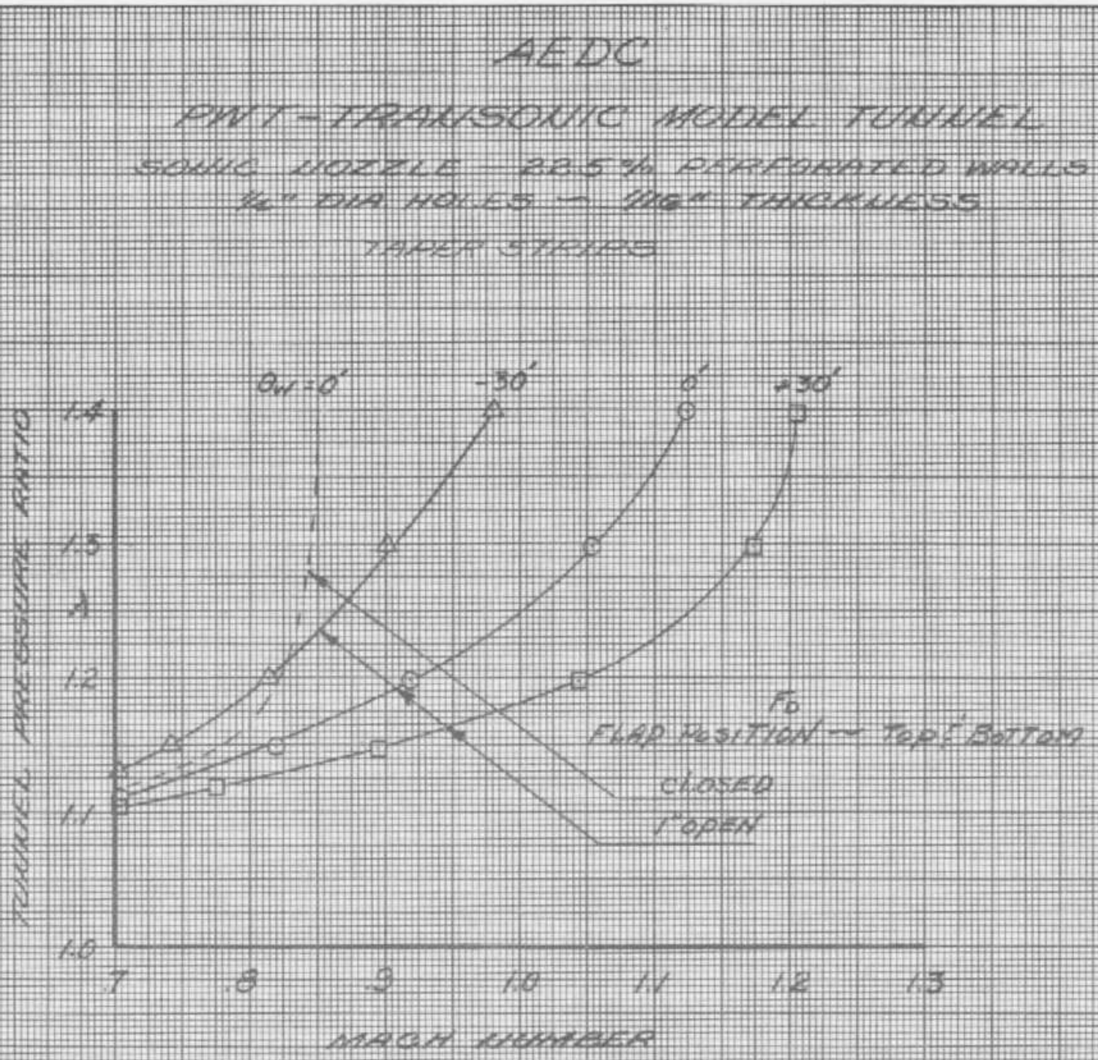
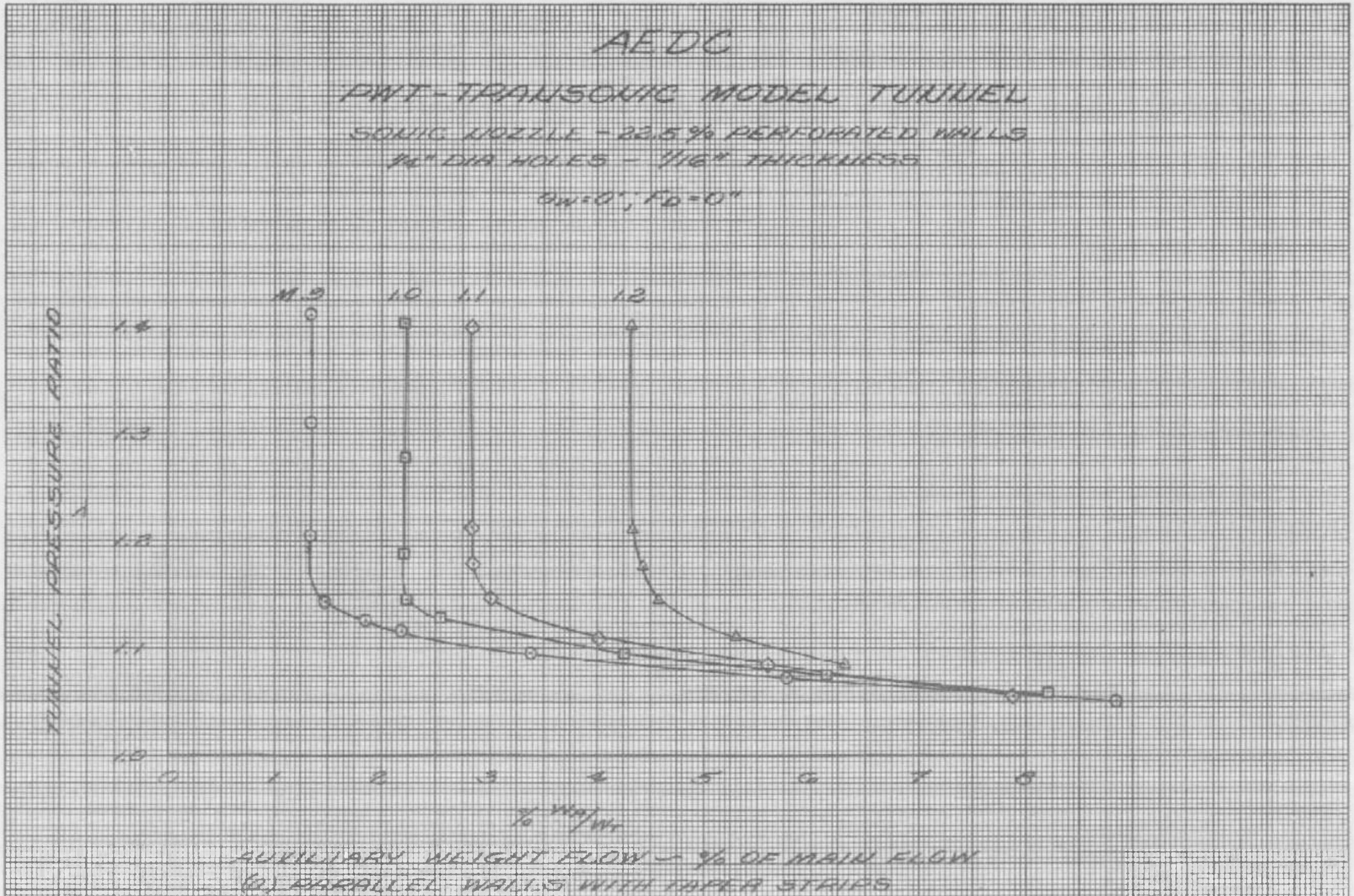
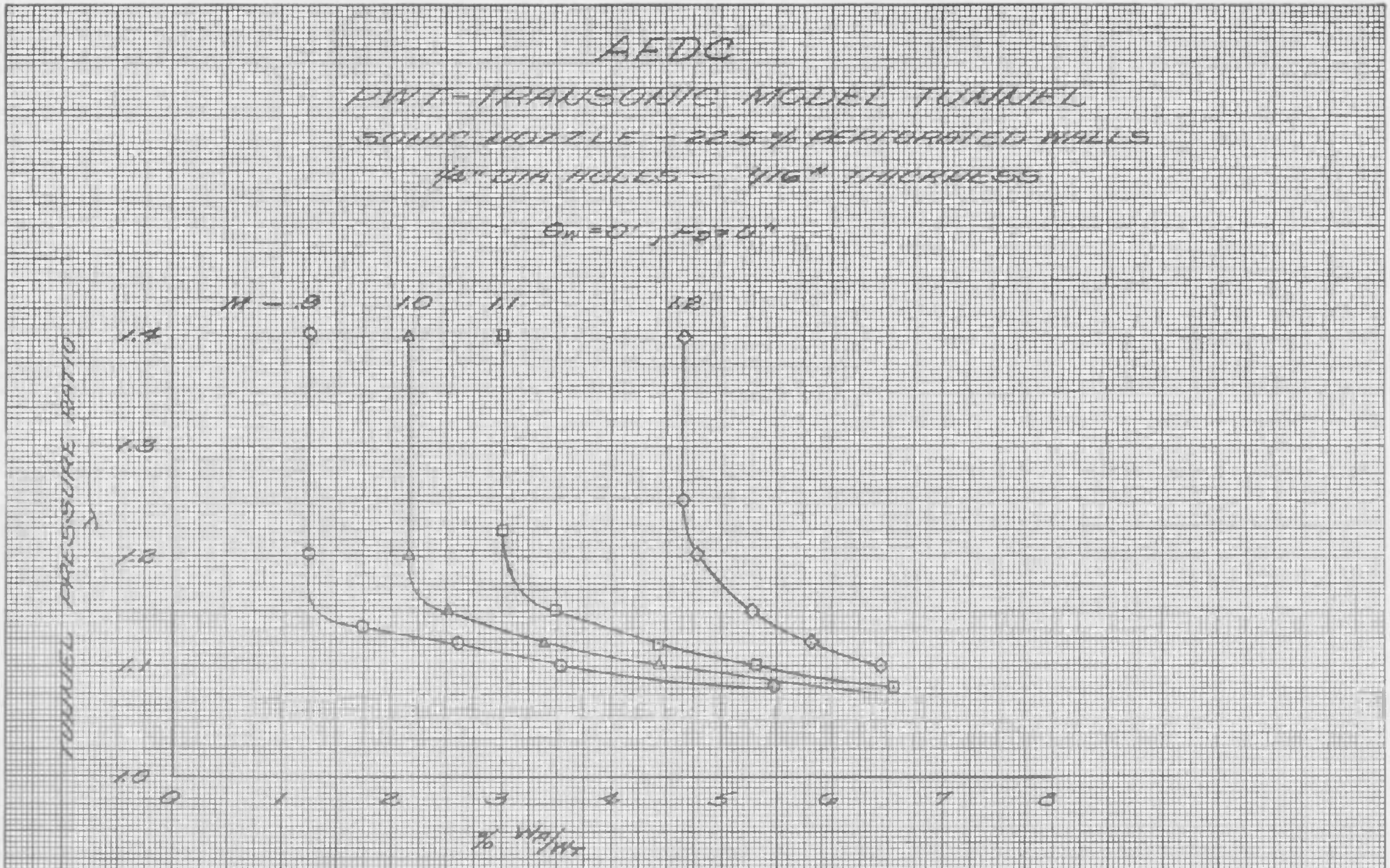


FIGURE 11: VARIATIONS IN MACH NUMBER WITH TUNNEL PRESSURE RATIO WITHOUT AUXILIARY SUCTION.



(a) PARALLEL WALLS WITH TAPER STRIPS

FIGURE 12: VARIATION IN AUXILIARY SUCTION WITH TUNNEL PRESSURE RATIO FOR 1/4" DIAMETER PERFORATED WALLS



(b) PARALLEL WALLS WITHOUT TAPER STRIPS

FIGURE 12. CONCLUDED

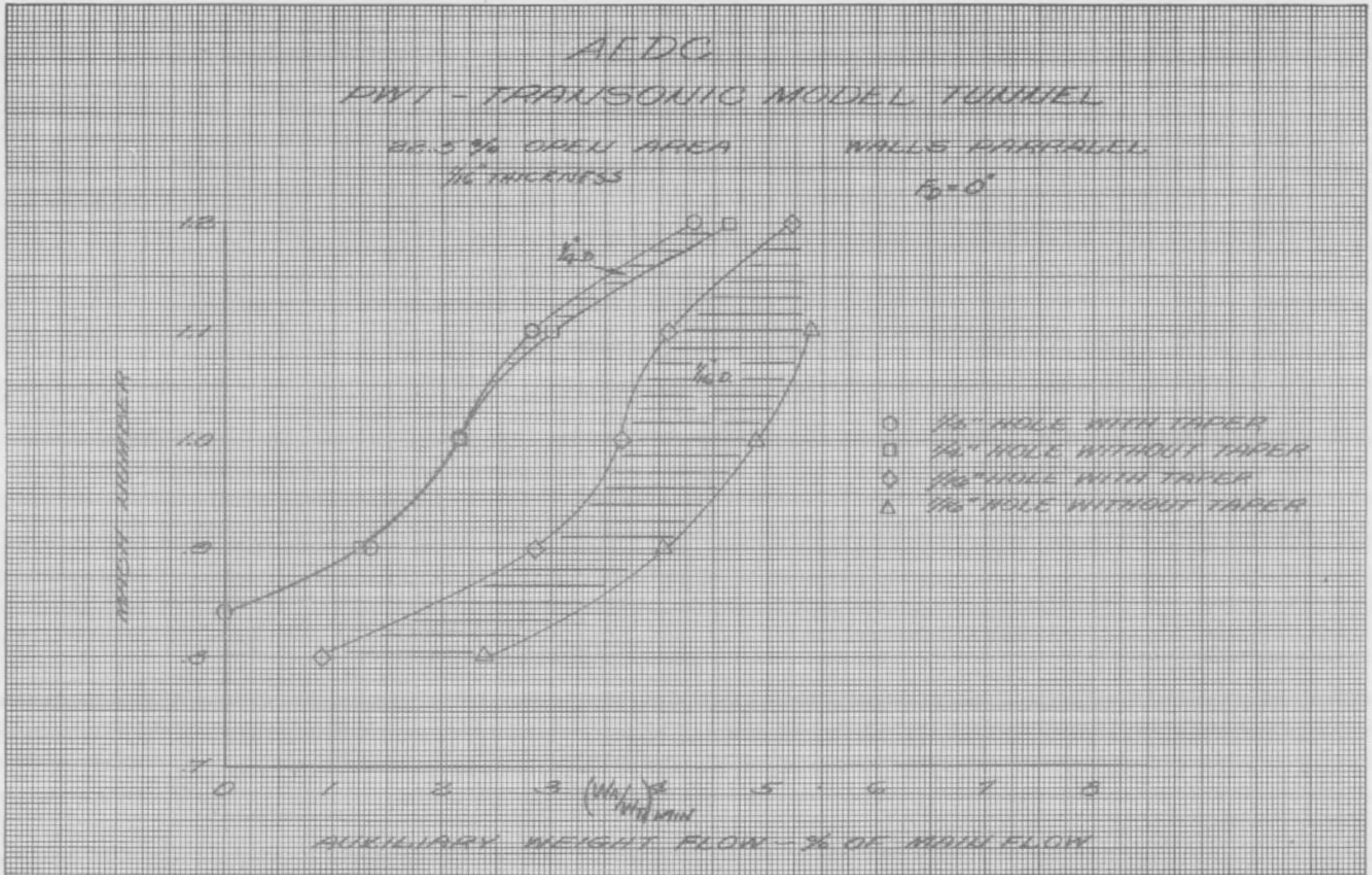


FIGURE 13: VARIATIONS IN MINIMUM AUXILIARY SUCTION REQUIREMENTS WITH MACH NUMBER

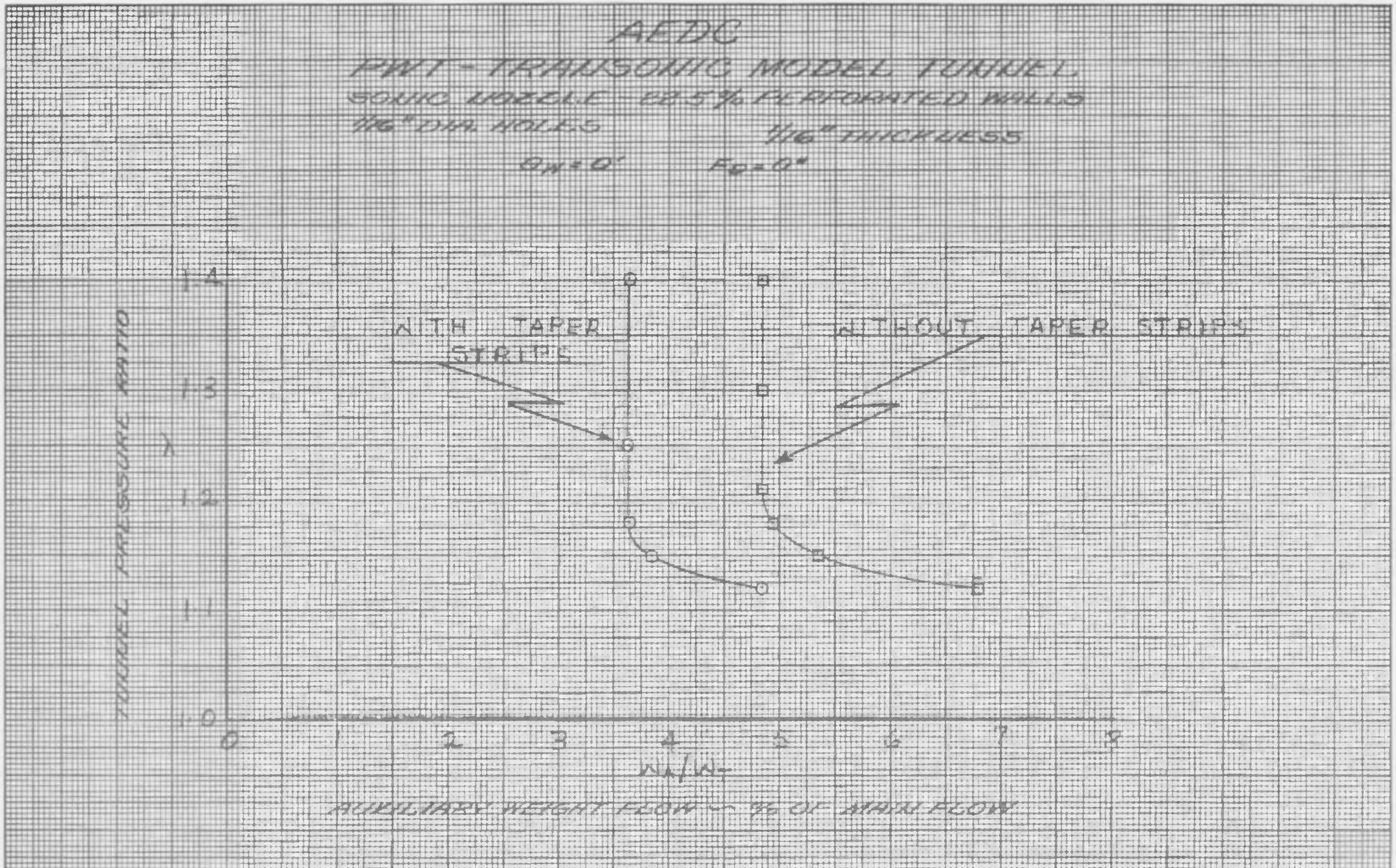


FIGURE 16. EFFECT OF TAPER STRIPS ON AUXILIARY SUCTION FOR M=1.0 WITH 1/16 INCH DIA. PERFORATIONS.

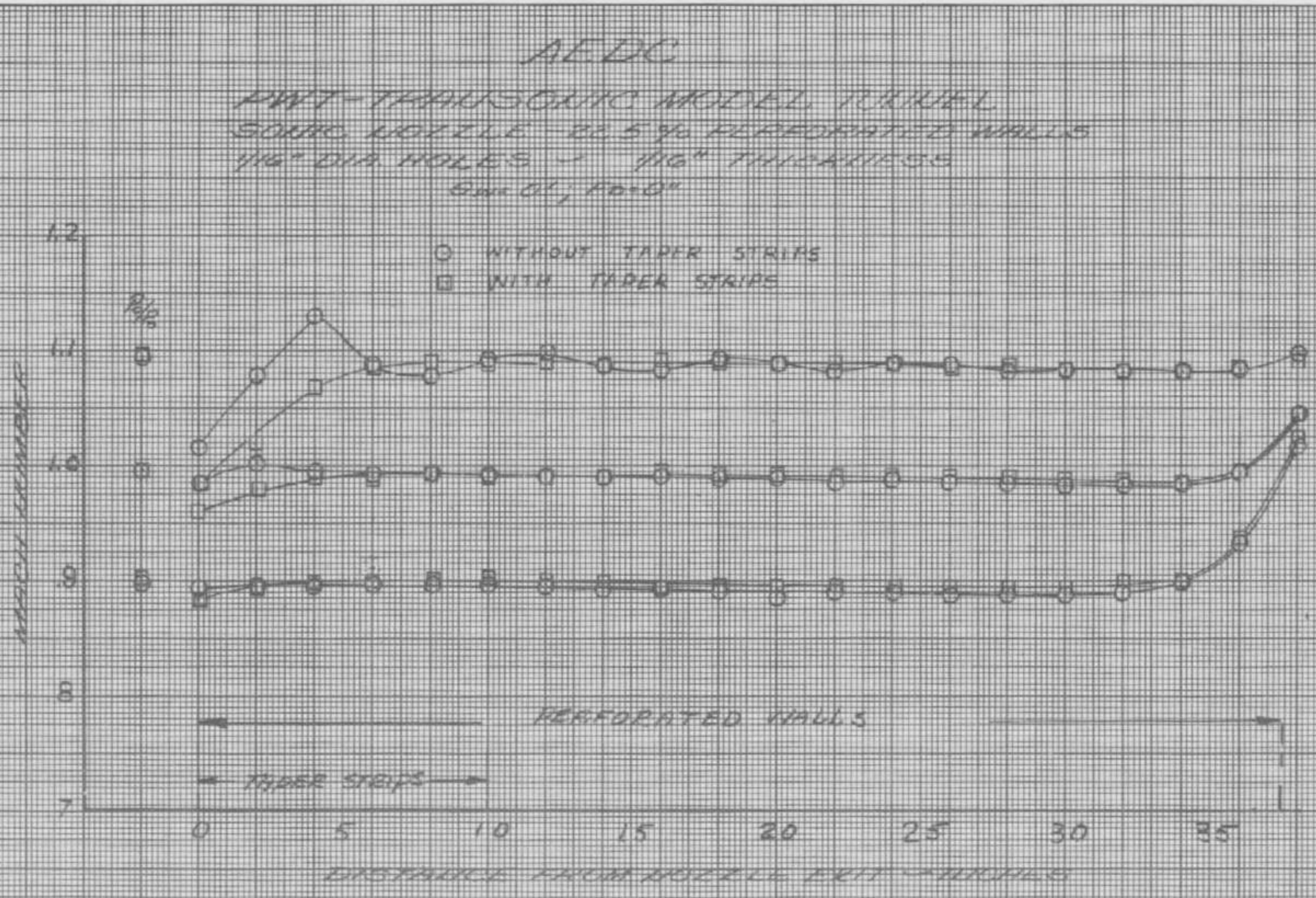


FIGURE 15: EFFECT OF TAPER STRIPS ON MACH NUMBER DISTRIBUTION

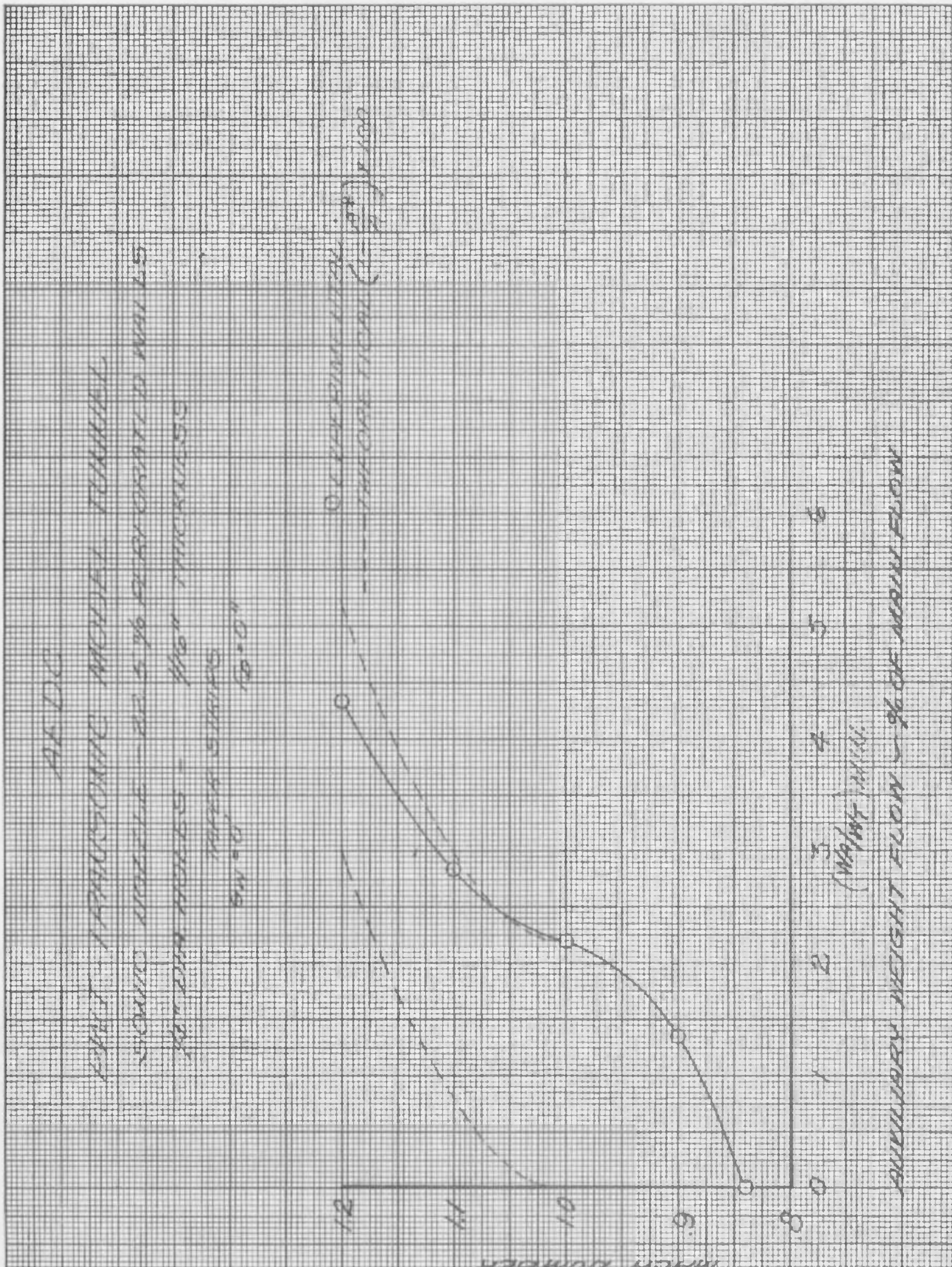
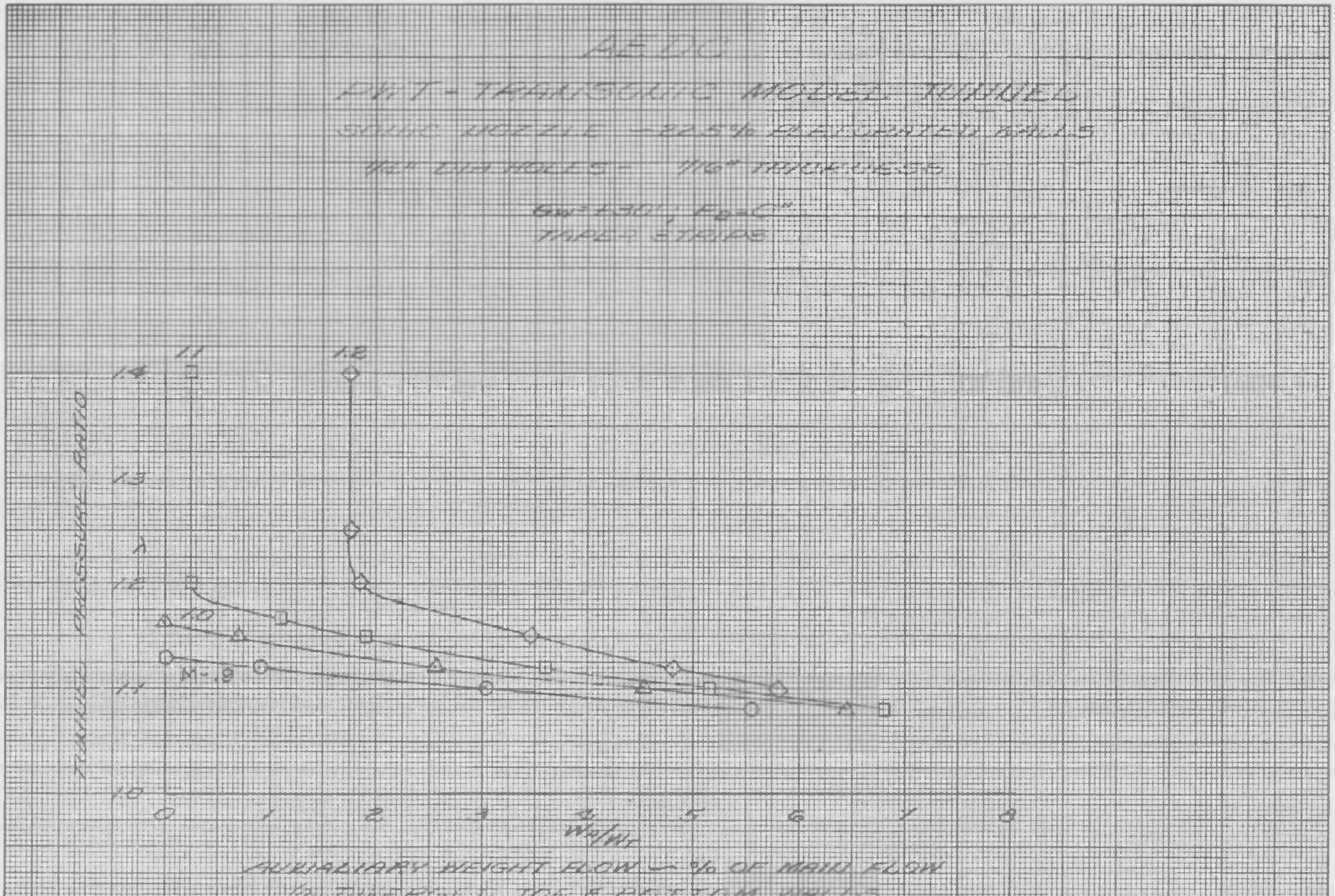
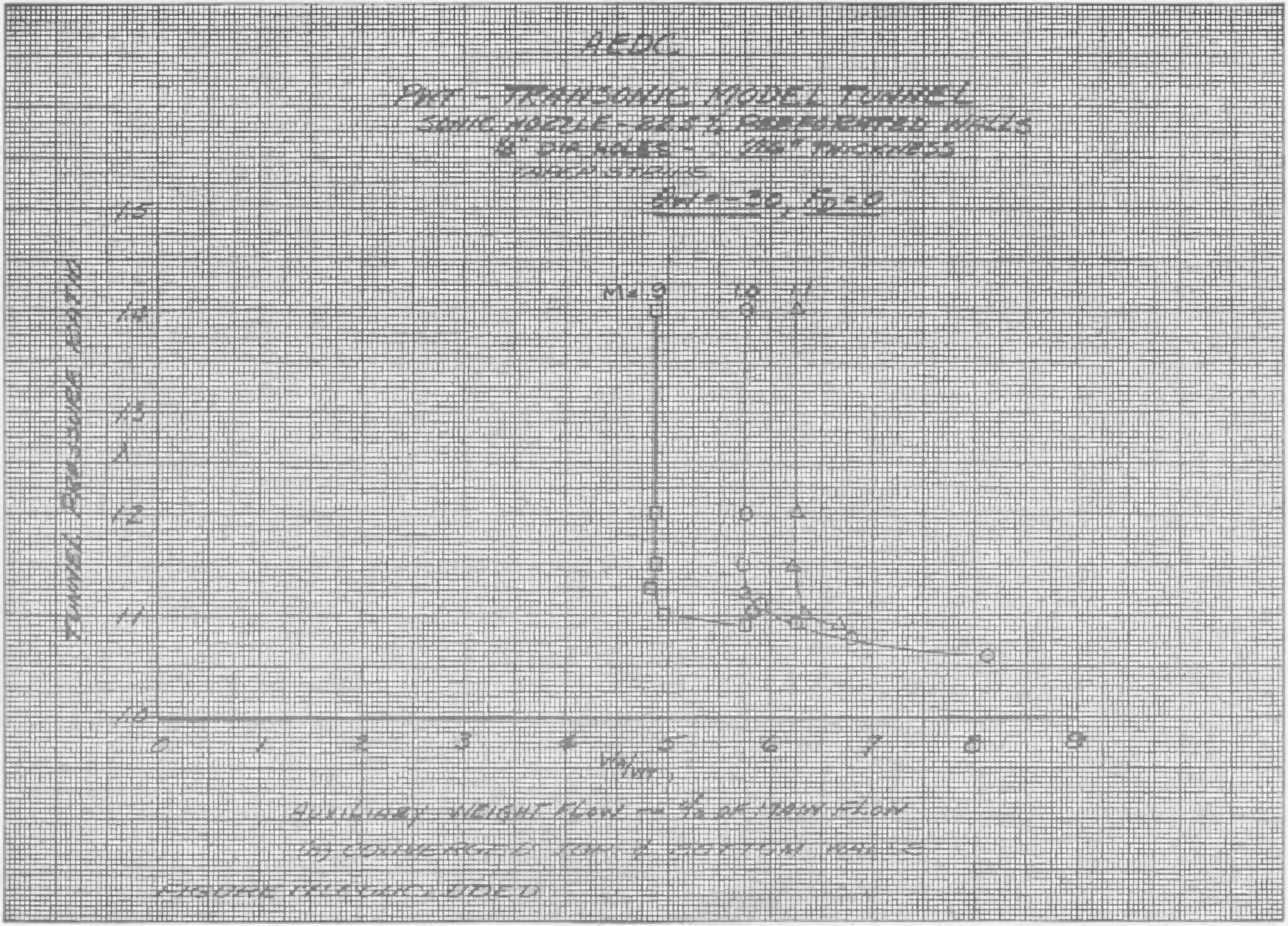


FIGURE 16. VARIATION IN [illegible] AUXILIARY SUCTION WITH MACH NUMBER



(b) DIFFUSER TOP & BOTTOM WALLS

FIGURE 17: VARIATION IN AUXILIARY SUCTION WITH TUNNEL PRESSUR
RATIO FOR 1/4" DIAMETER HOLES


AEDC
PWT - TRANSONIC MODEL TUNNEL
SONIC NOZZLE - 22.5% PERFORATED WALLS
1/8" DIA HOLES - .188" THICKNESS
M = .9
1.0
1.1
1.5
1.4
1.3
1.2
1.1
1.0
0
1
2
3
4
5
6
7
8
9
Wa/WT, %
AUXILIARY WEIGHT FLOW — % OF MAIN FLOW
BY COMBINED TOP & BOTTOM WALLS
PROBE PRESSURE USED

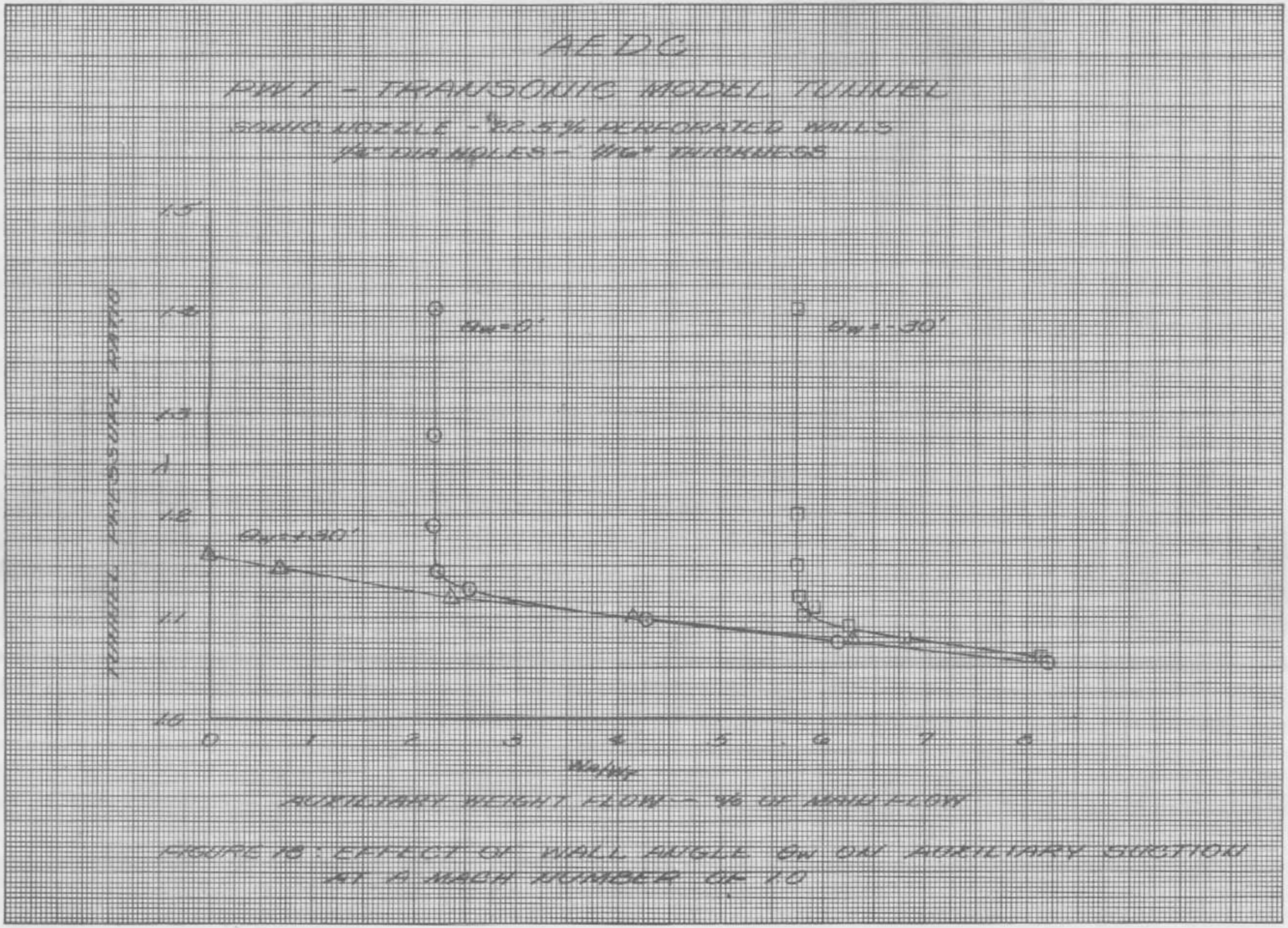


FIGURE 18: EFFECT OF WALL ANGLE θw ON AUXILIARY SUCTION AT A MACH NUMBER OF 1.0

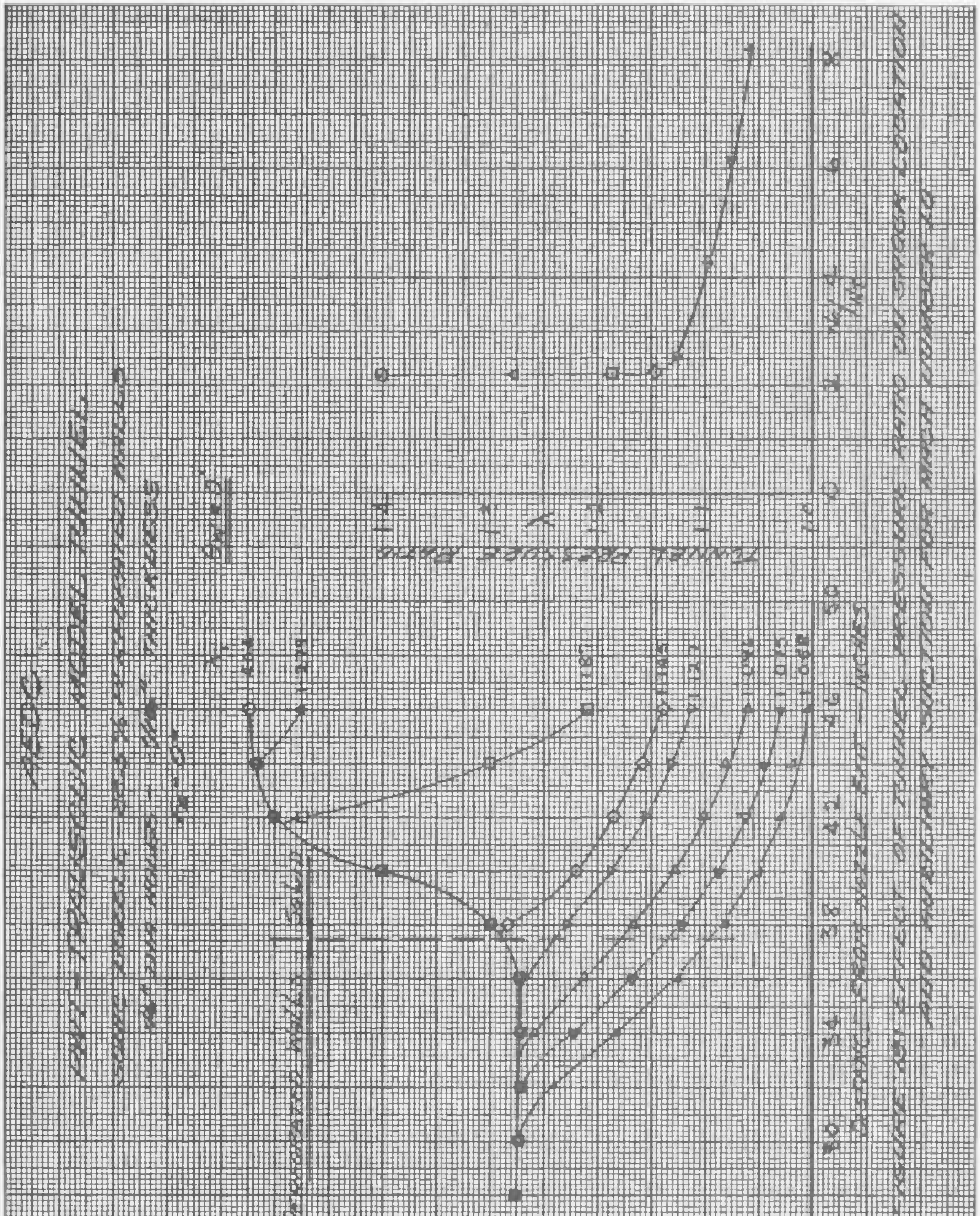


FIGURE 13 EFFECT OF TUNNEL PRESSURE RATIO ON SHOCK LOCATION AND AUXILIARY SUCTION FOR MACH NUMBER 1.0

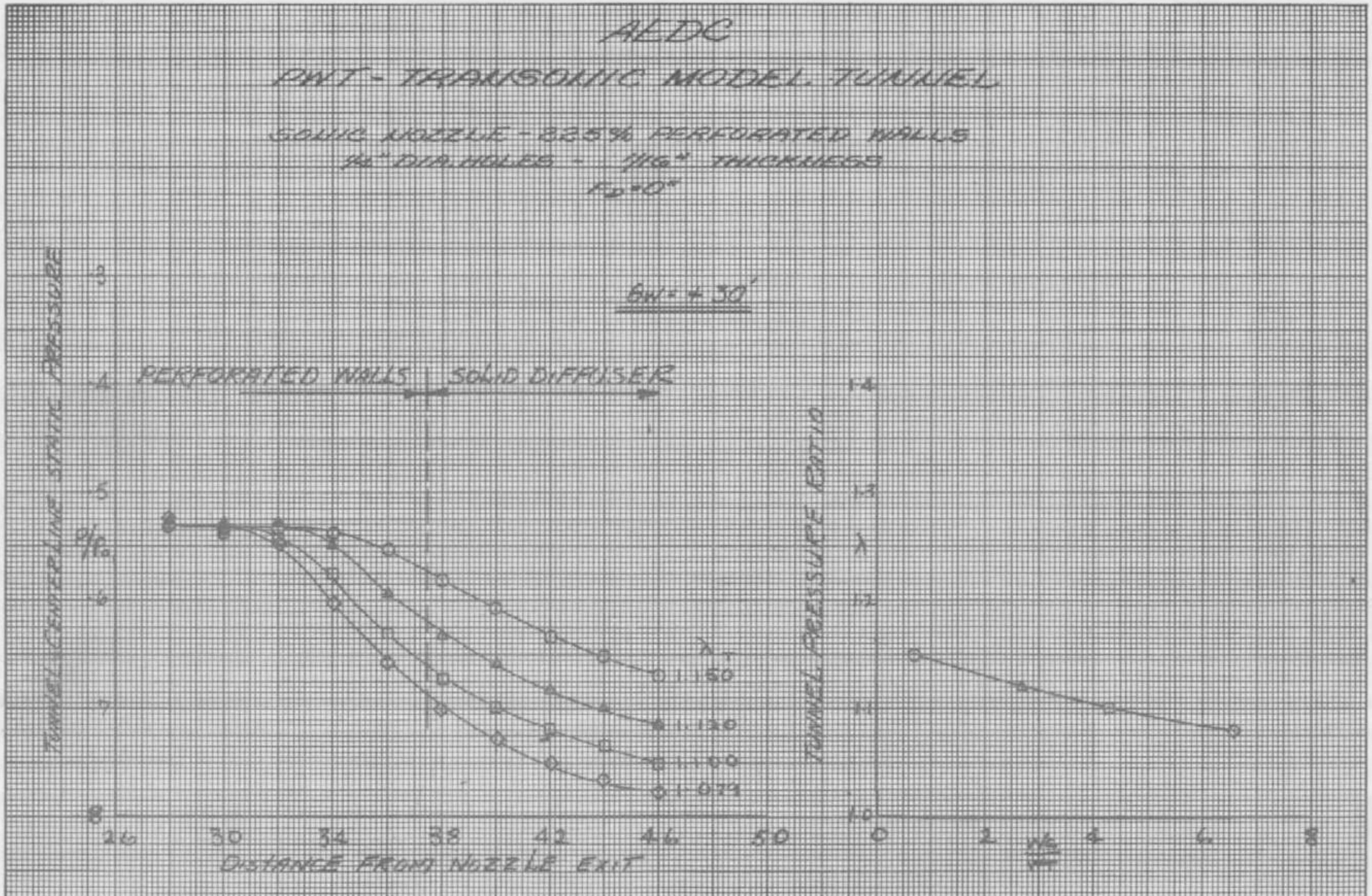


FIGURE 20: EFFECT OF TUNNEL PRESSURE RATIO ON SHOCK LOCATION AND AUXILIARY SUCTION FOR MACH NUMBER 1.0 WITH DIVERGED WALLS

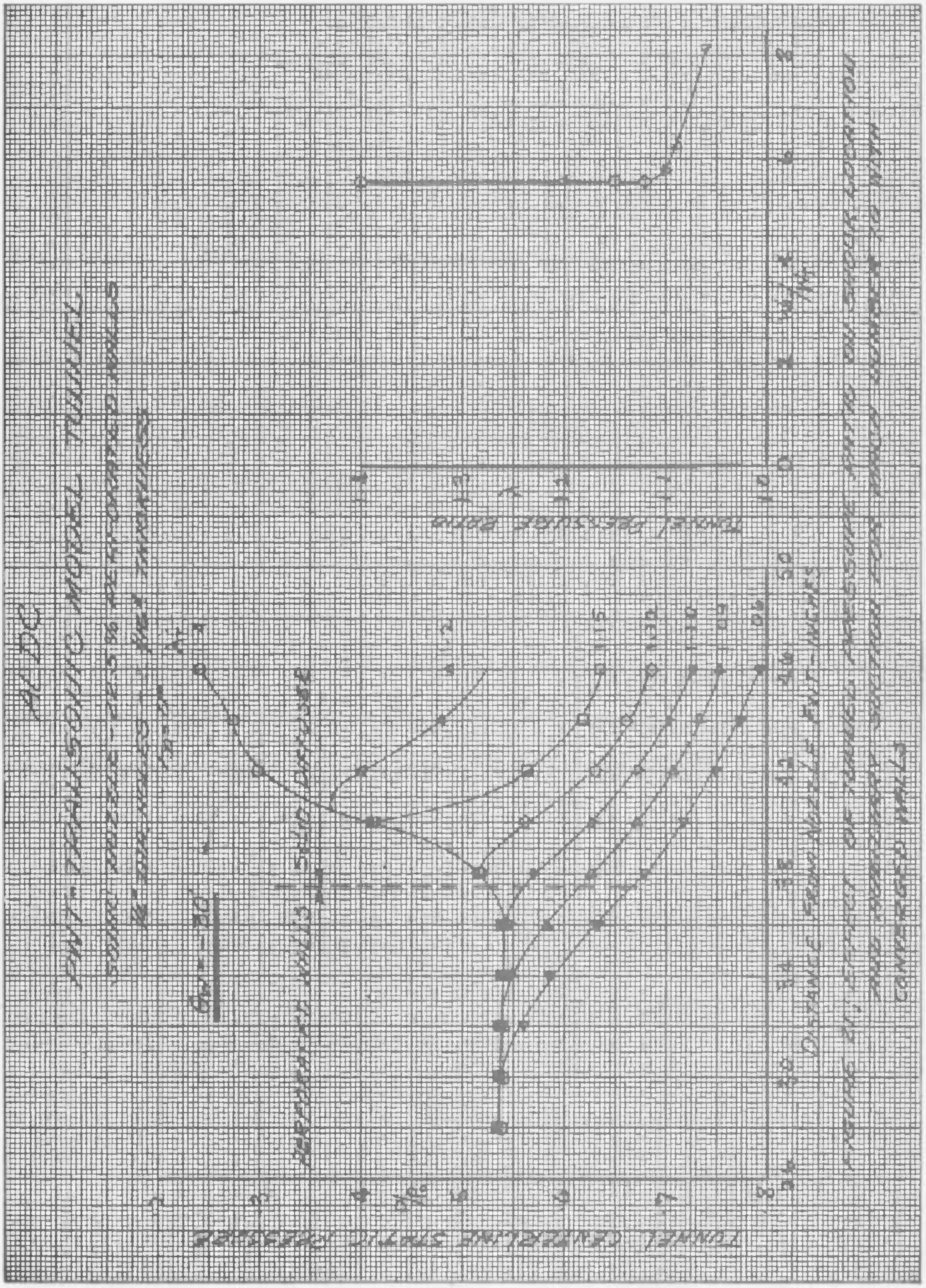
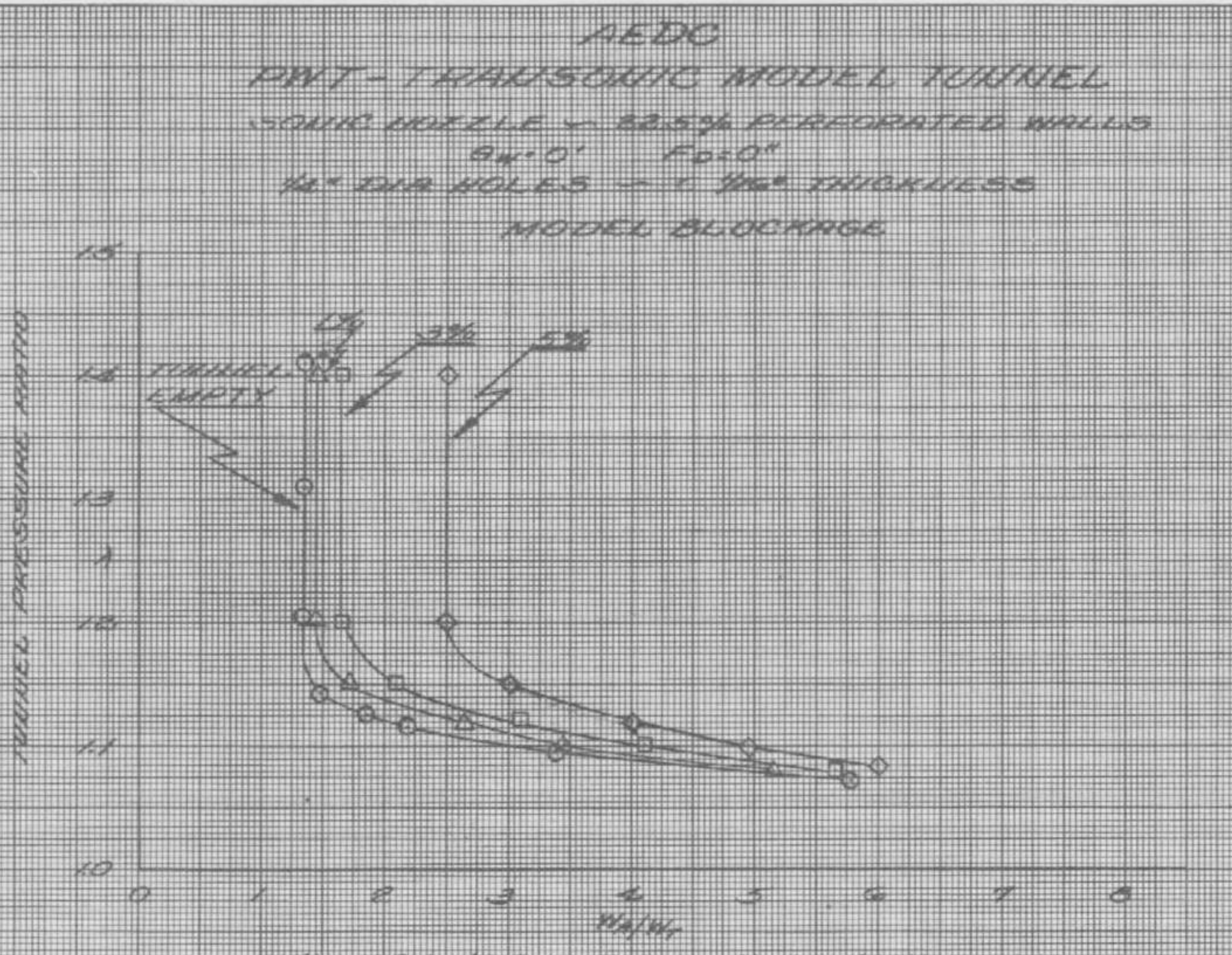
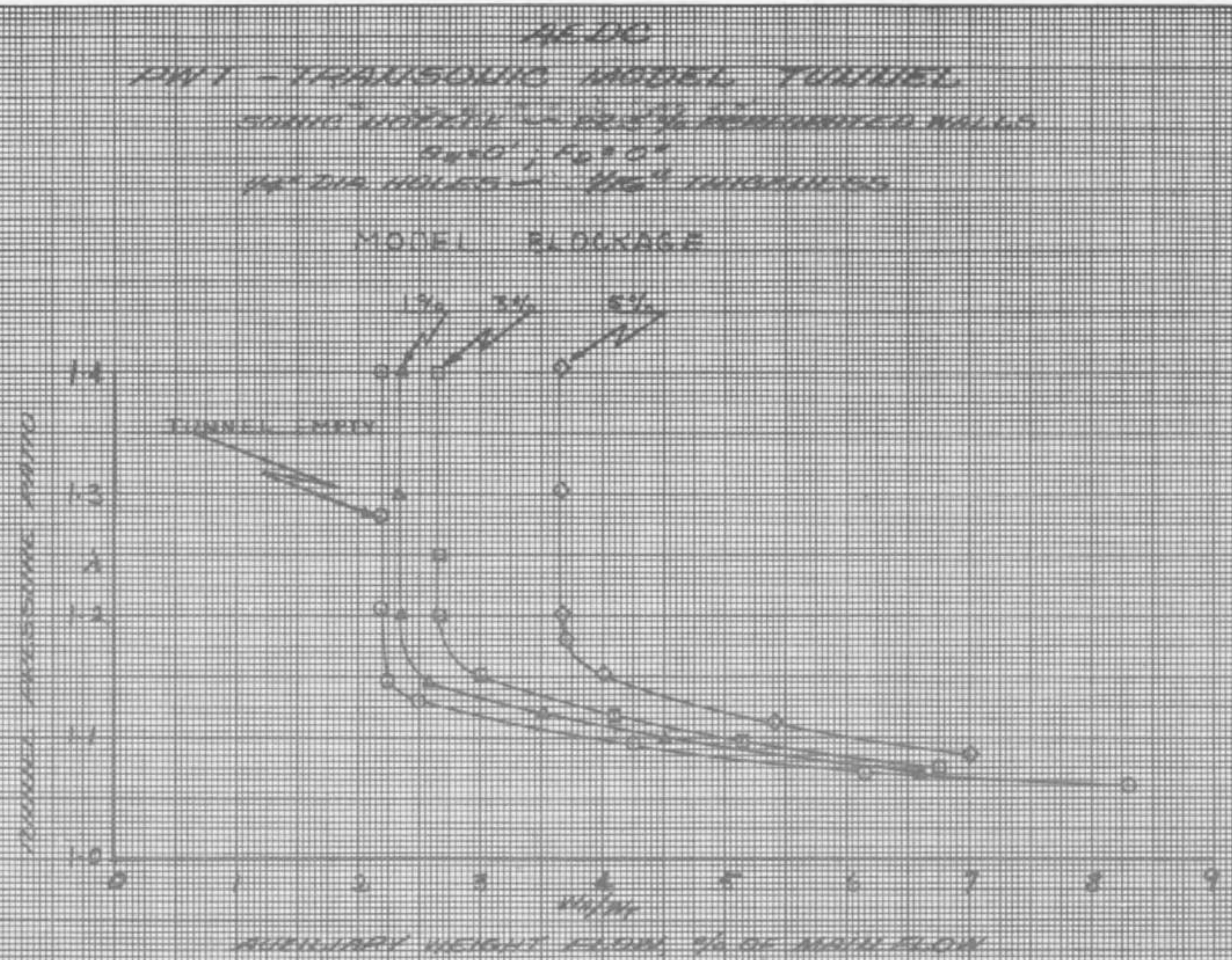


FIGURE 21. EFFECT OF TUNNEL PRESSURE RATIO ON SHOCK LOCATION AND AUXILIARY SUCTION FOR MACH NUMBER 1.0 WITH CONVERGED WALLS



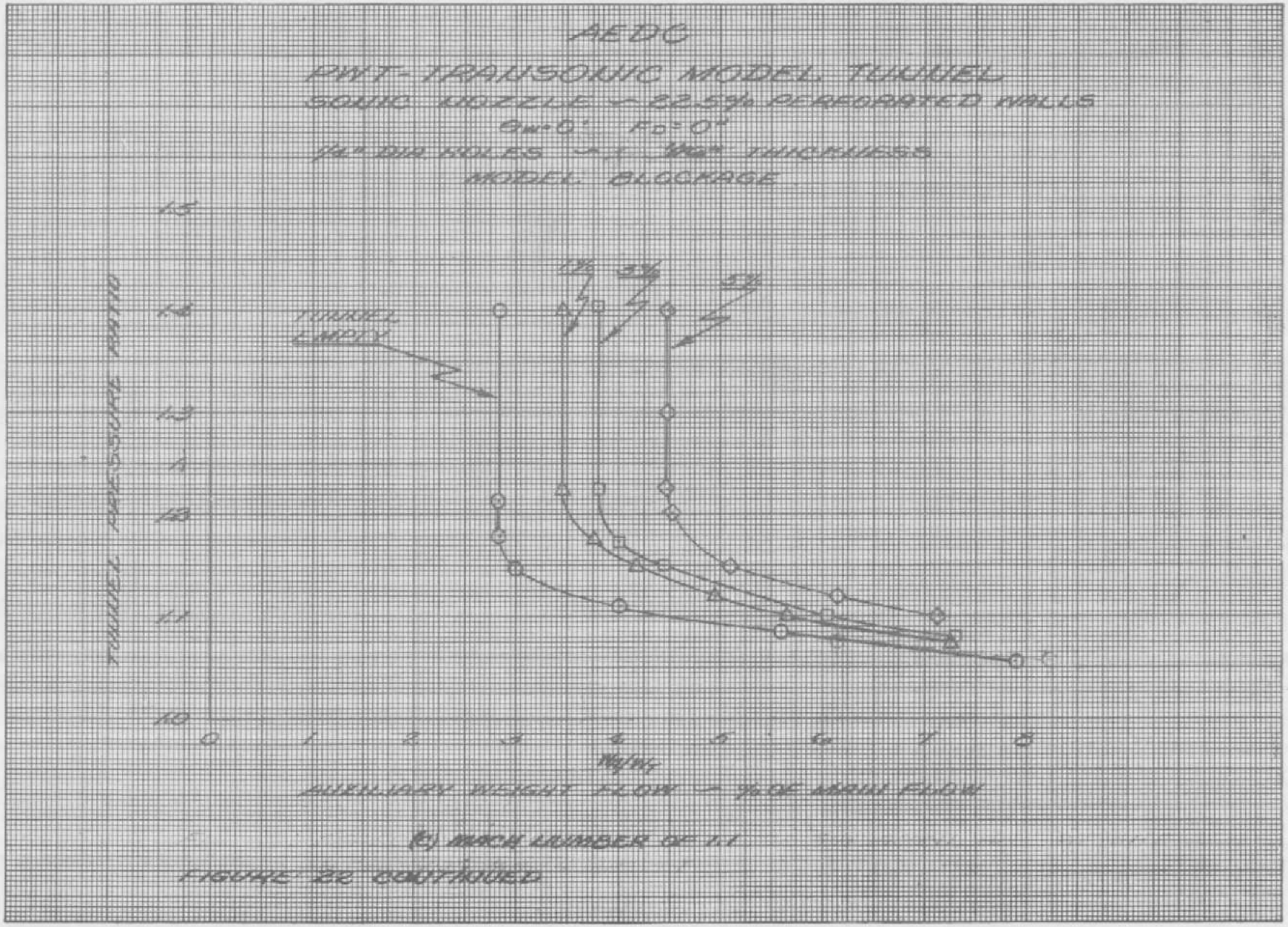
(a) MACH NUMBER .8

FIGURE 22 EFFECT OF MODEL BLOCKAGE ON AUXILIARY SUCTION



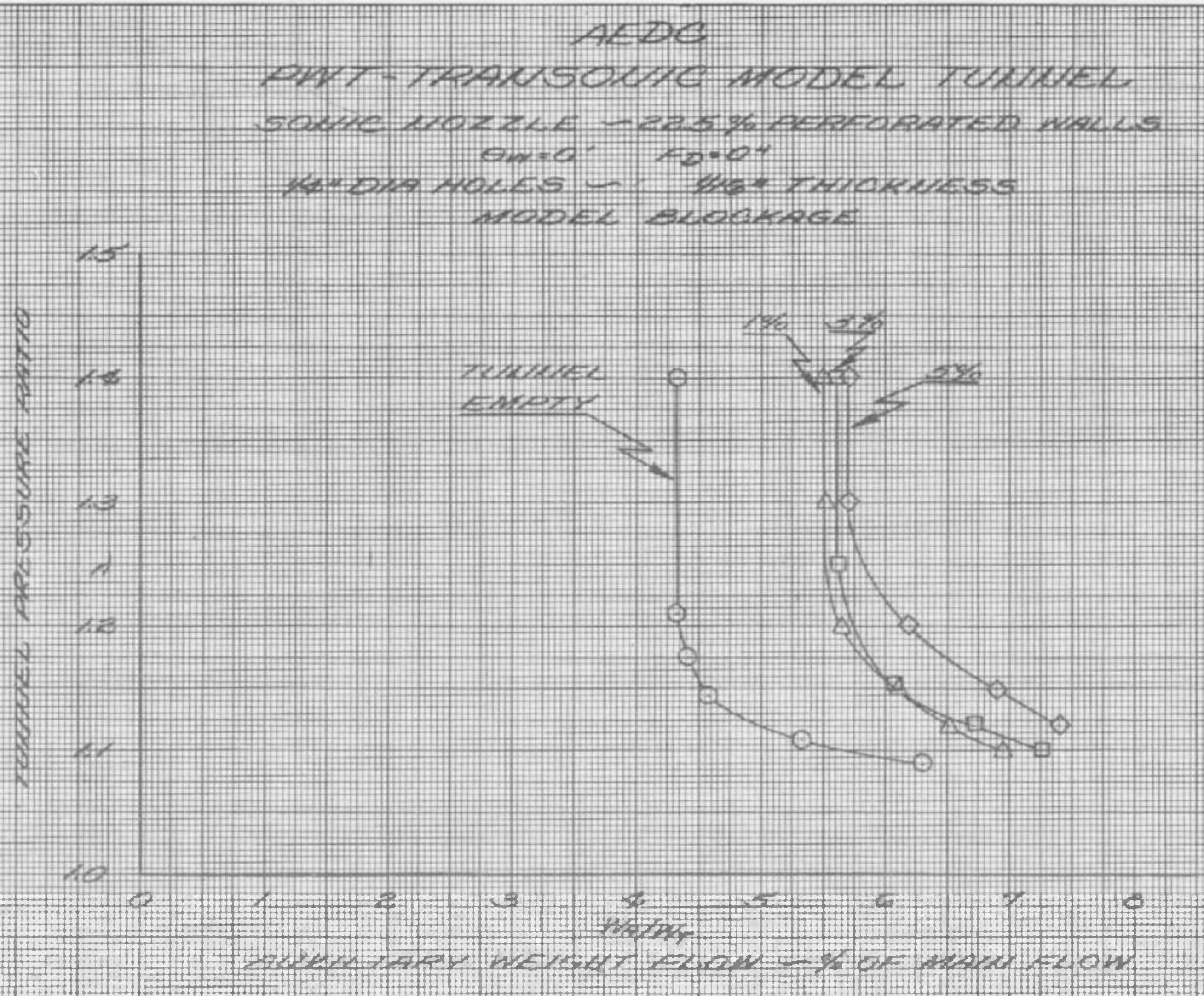
(b) MACH NUMBER 1.0

FIGURE 26 CONTINUED



(c) MACH NUMBER OF 1.1

FIGURE 22 CONTINUED



(d) MACH NUMBER 1.2

FIGURE 22. CONCLUDED

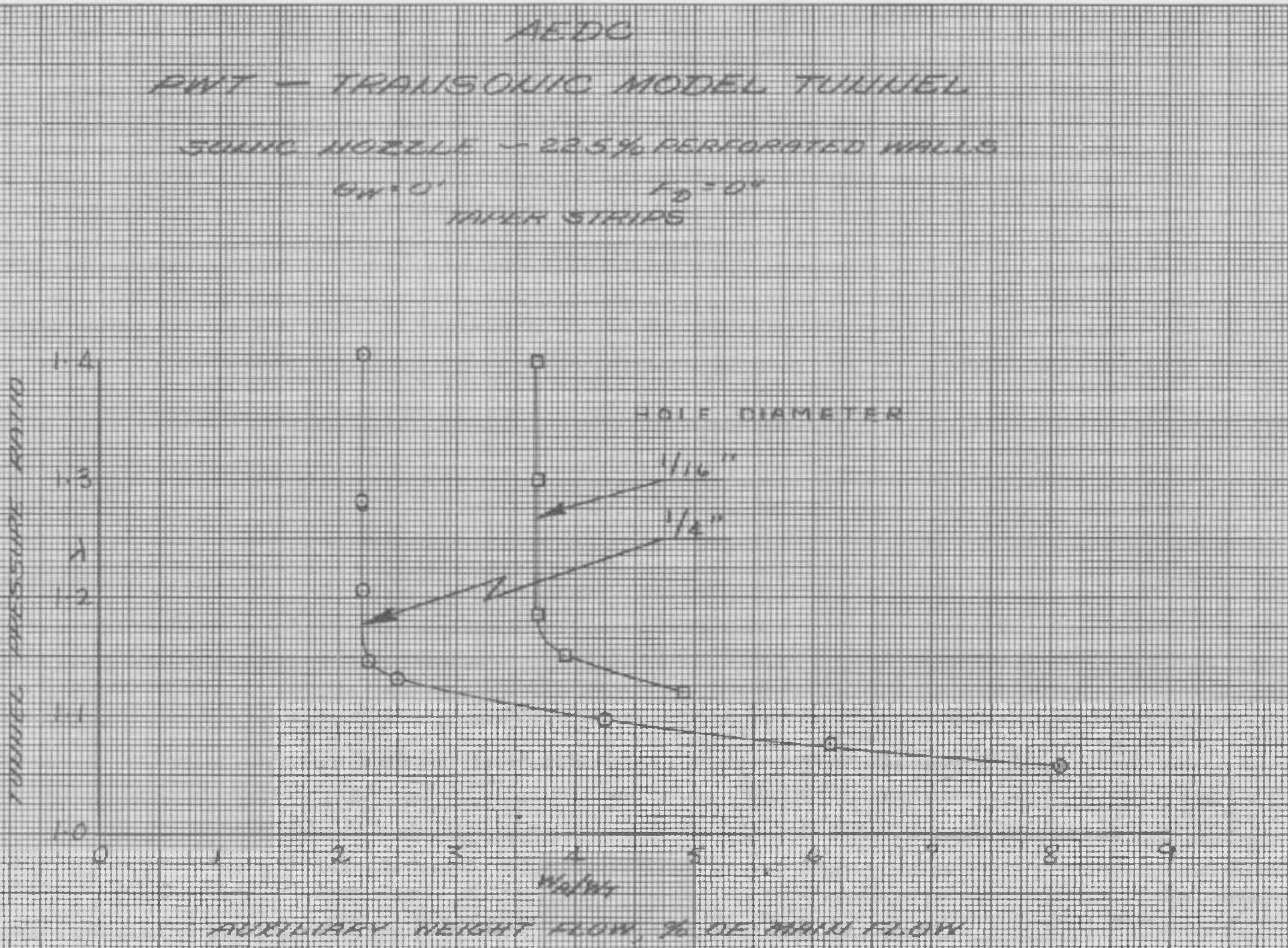


FIGURE: 23— EFFECT OF HOLE DIAMETER ON AUXILIARY SUCTION FLOW AT MACH NO. 1.0

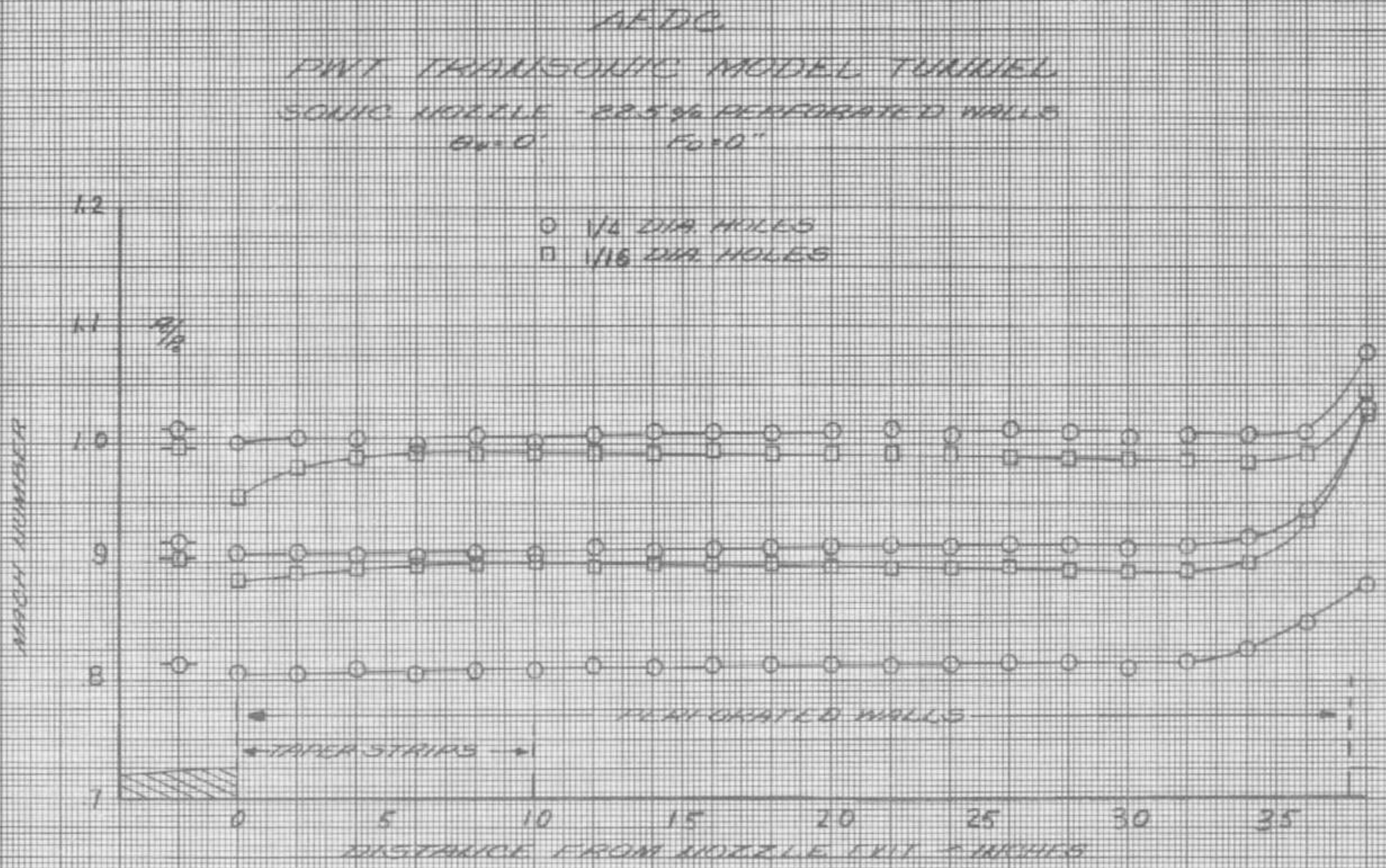


FIGURE 24: COMPARISON OF MACH NUMBER DISTRIBUTIONS WITH VARIATIONS IN HOLE SIZE WITH TAPER STRIPS.

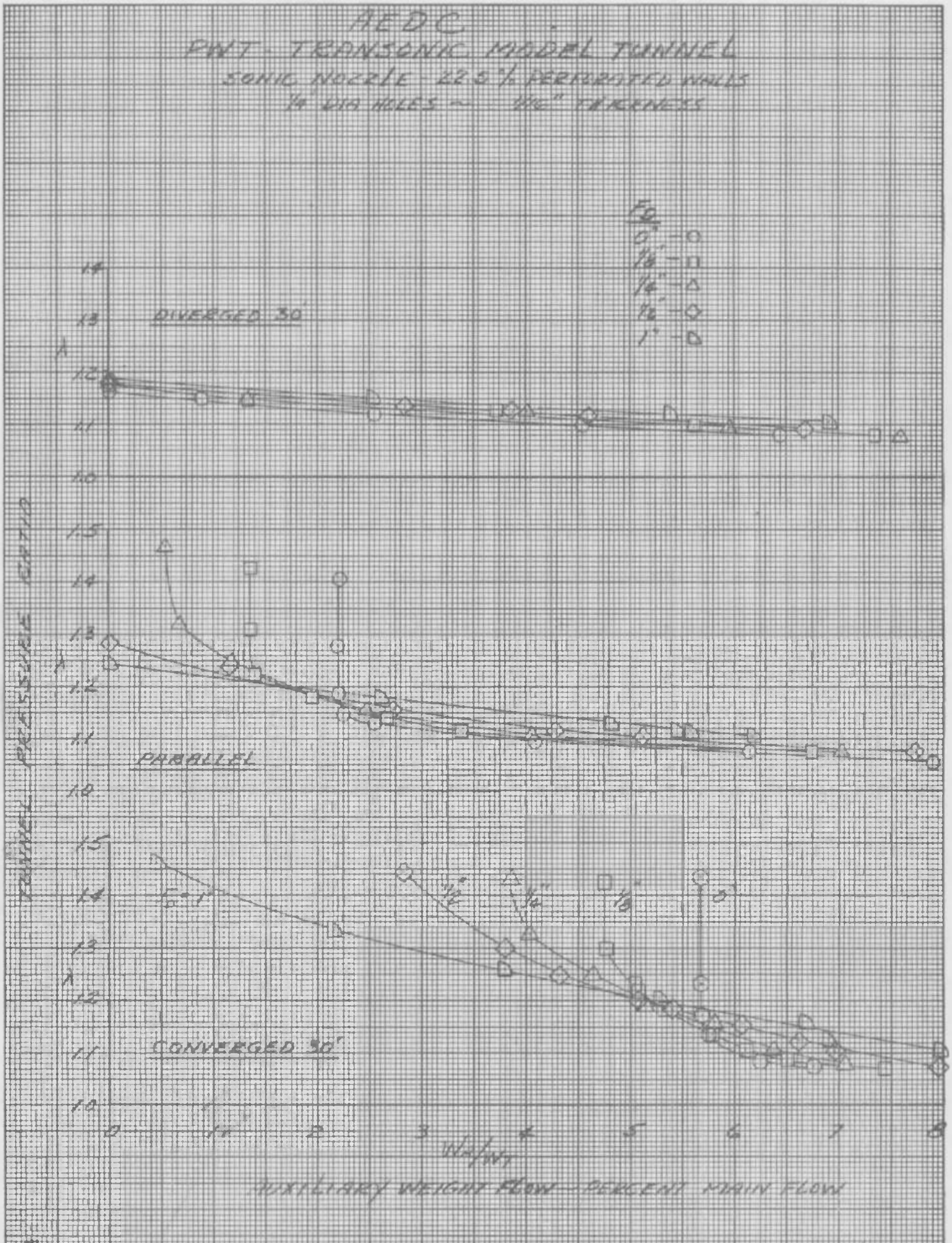


FIG 25 EFFECT OF WALL ANGLE AND FLAP POSITION ON AUXILIARY SUCTION AT MACH NUMBER 1.0

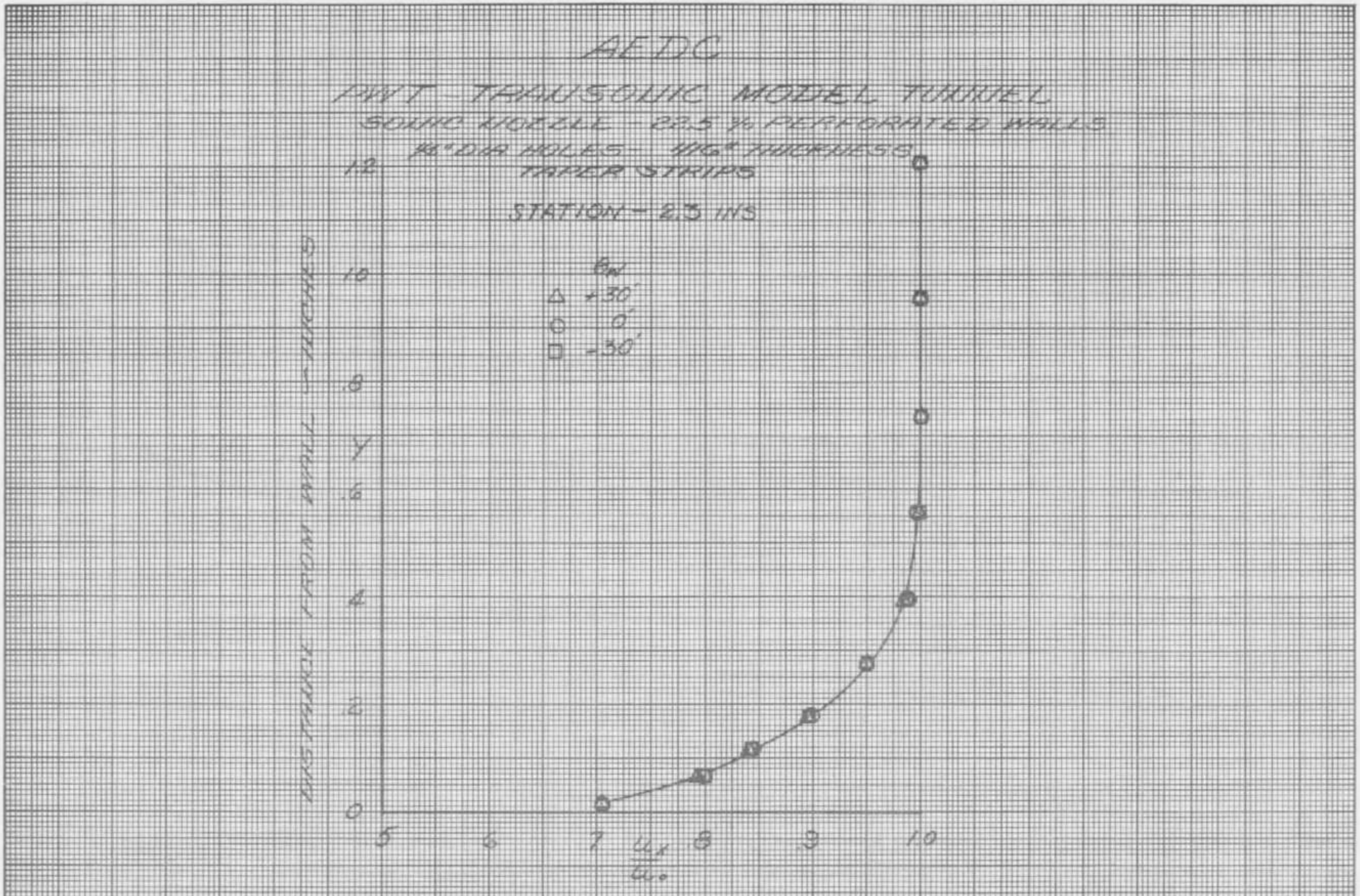


FIGURE 26: BOUNDARY LAYER PROFILES ALONG TEST SECTION WALL AT MACH NUMBER 1.0

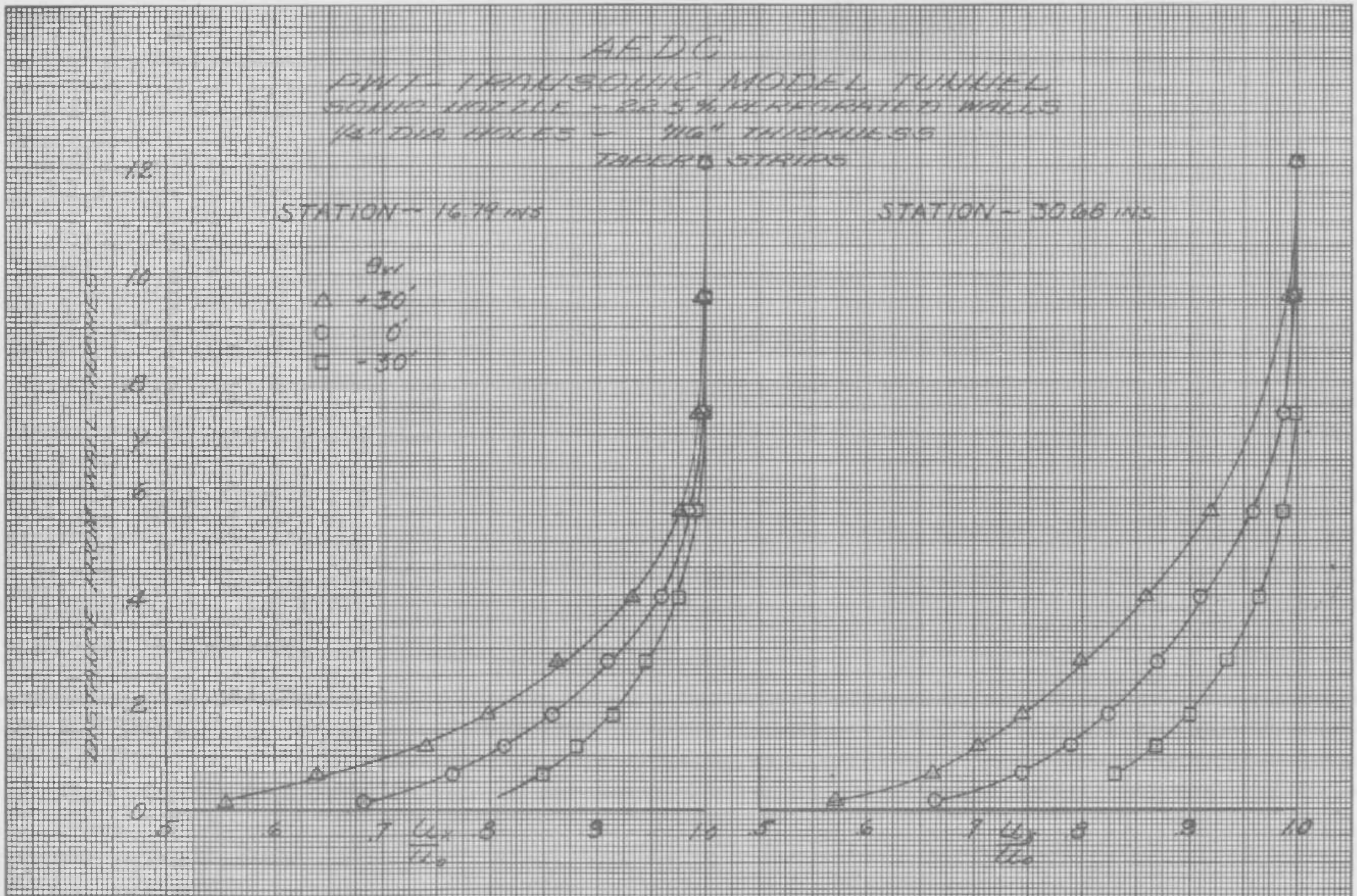


FIGURE 27: BOUNDARY LAYER PROFILES ALONG TEST SECTION WALL AT MACH NUMBER 1.0

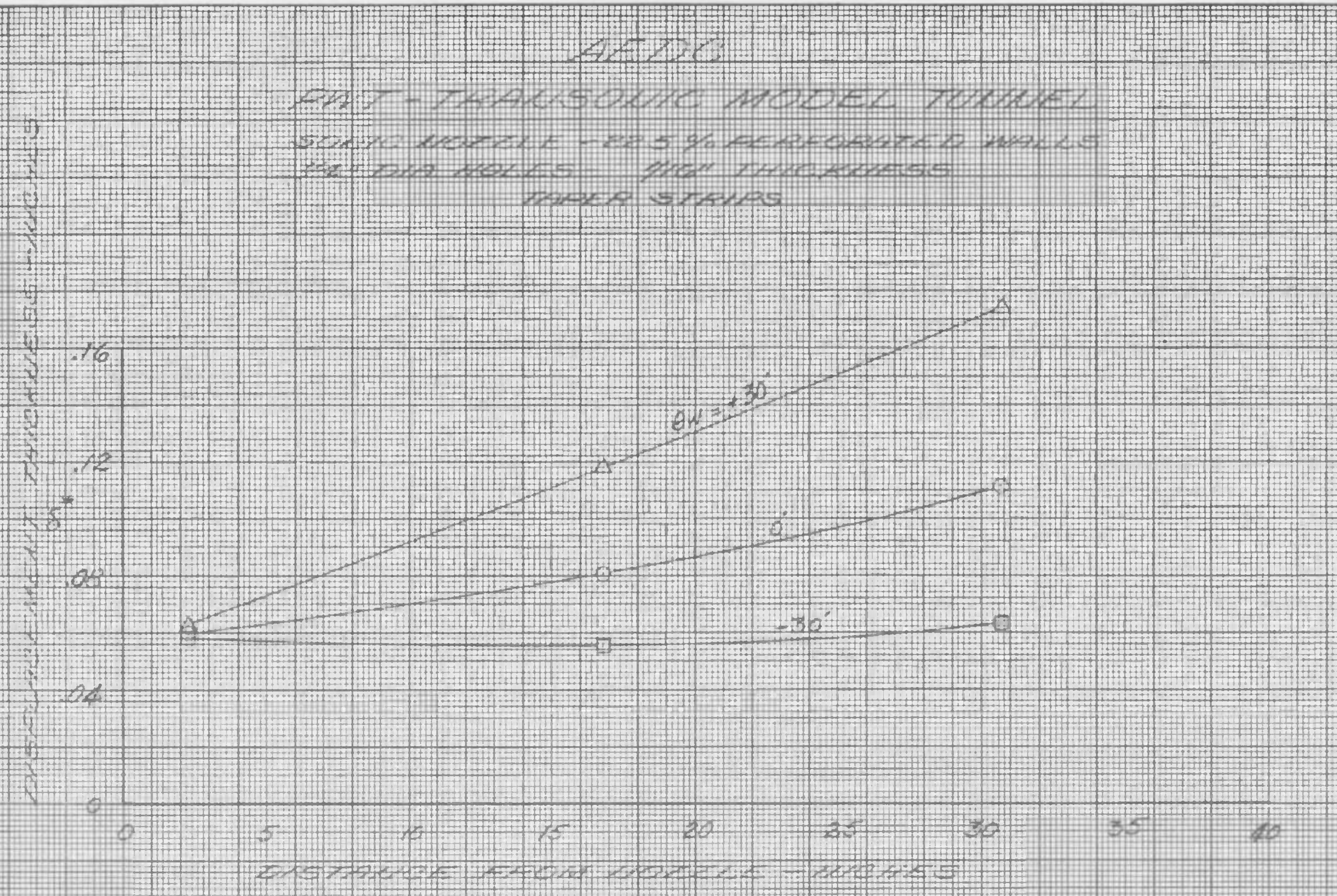


FIGURE 28: GROWTH OF BOUNDARY LAYER DISPLACEMENT THICKNESS ALONG TEST SECTION WALL AT MACH NUMBER 1.0.

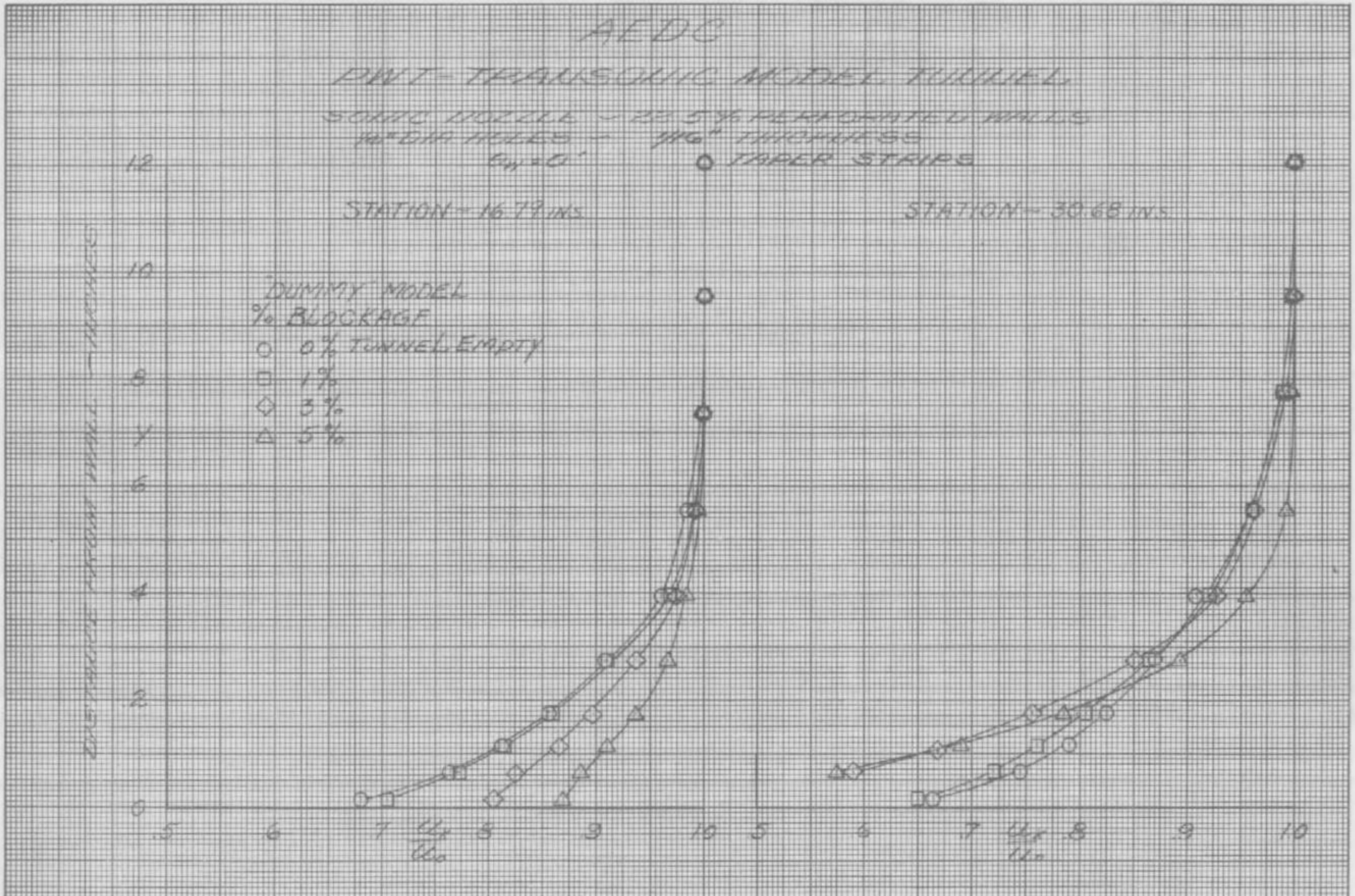


FIGURE 23: EFFECT OF MODEL BLOCKAGE ON TEST SECTION WALL BOUNDARY LAYER PROFILES AT MACH NUMBER 1.0.

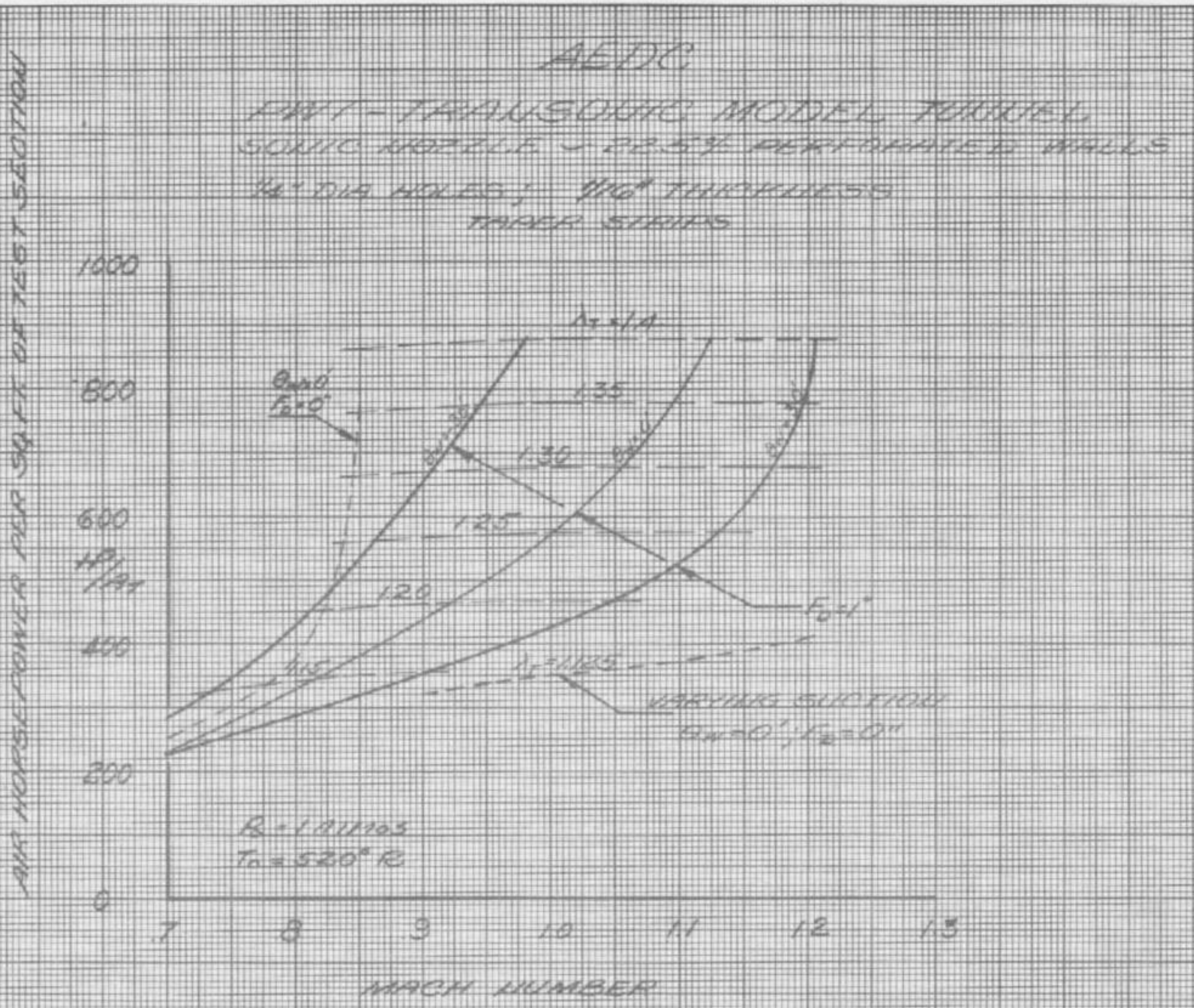


FIGURE 30. VARIATIONS IN POWER REQUIREMENT WITH MACH NUMBER WITHOUT AUXILIARY SUCTION

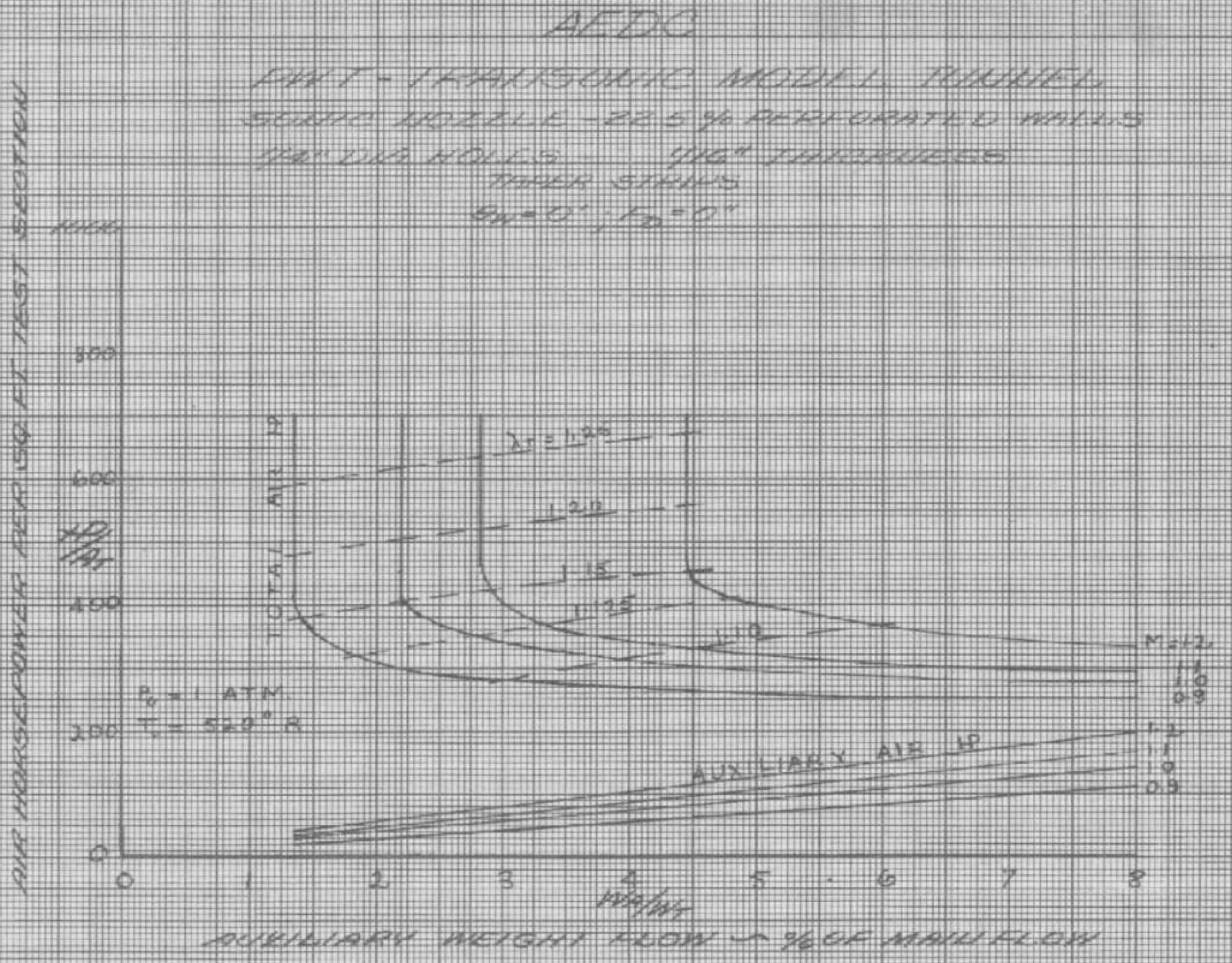


FIGURE 31 POWER REQUIREMENTS FOR 22.5% PERFORATED PARALLEL WALLS WITH 1/4" DIAMETER HOLES

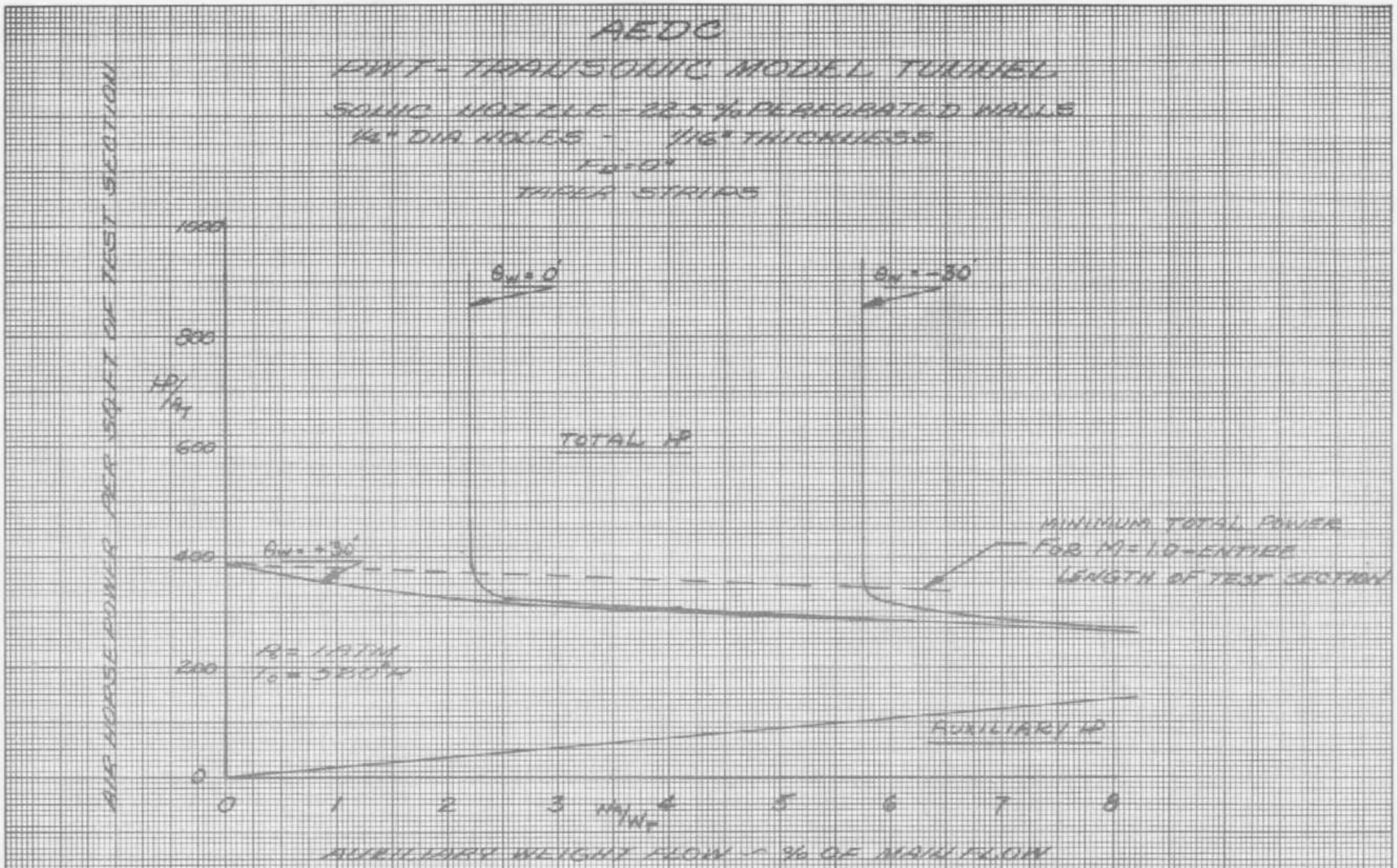


FIGURE 32: EFFECT OF WALL ANGLE ON POWER REQUIREMENTS AT A MACH NO OF 1.0

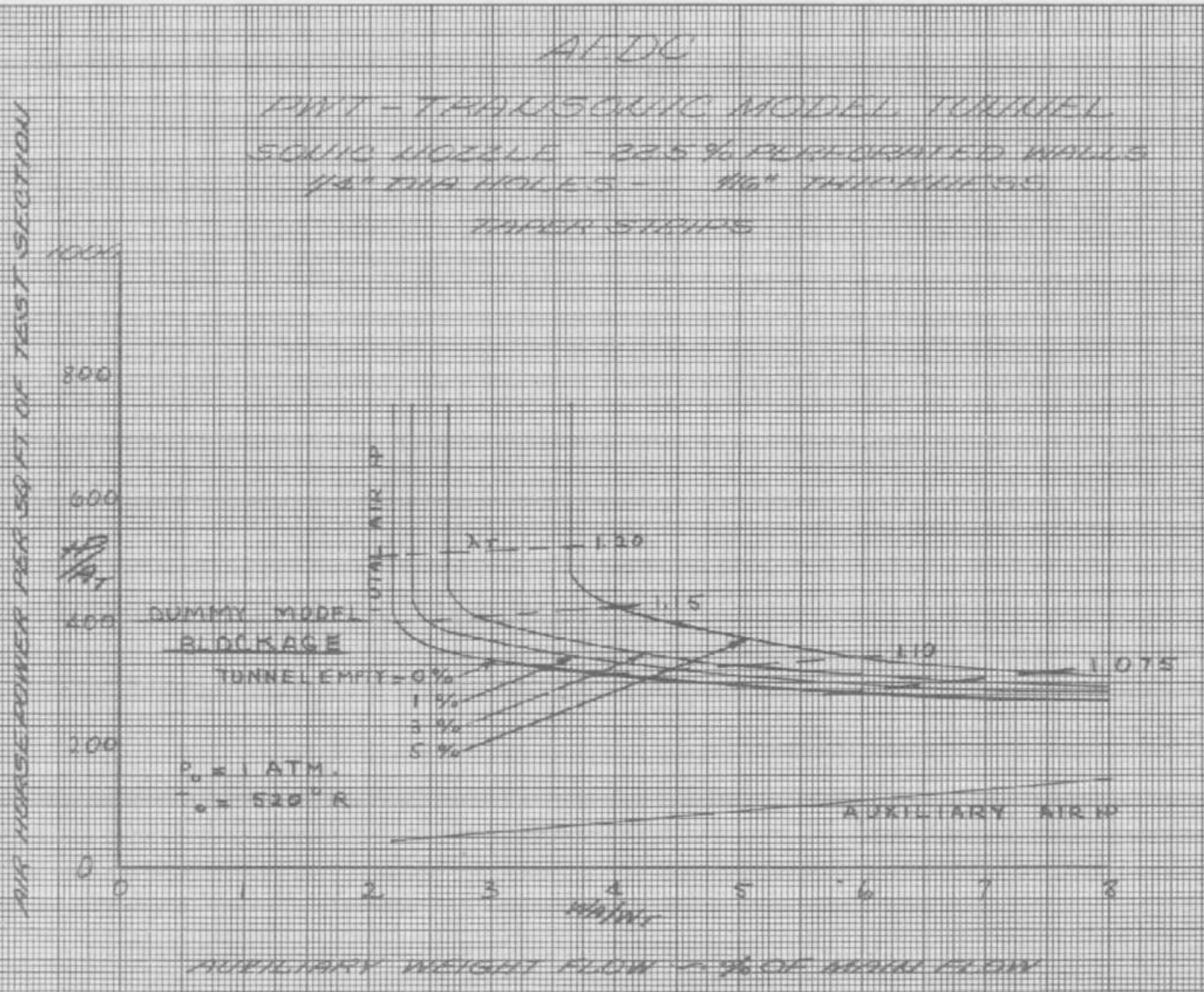


FIGURE 33: EFFECT OF MODEL BLOCKAGE ON POWER REQUIREMENTS AT MACH NUMBER 1.0

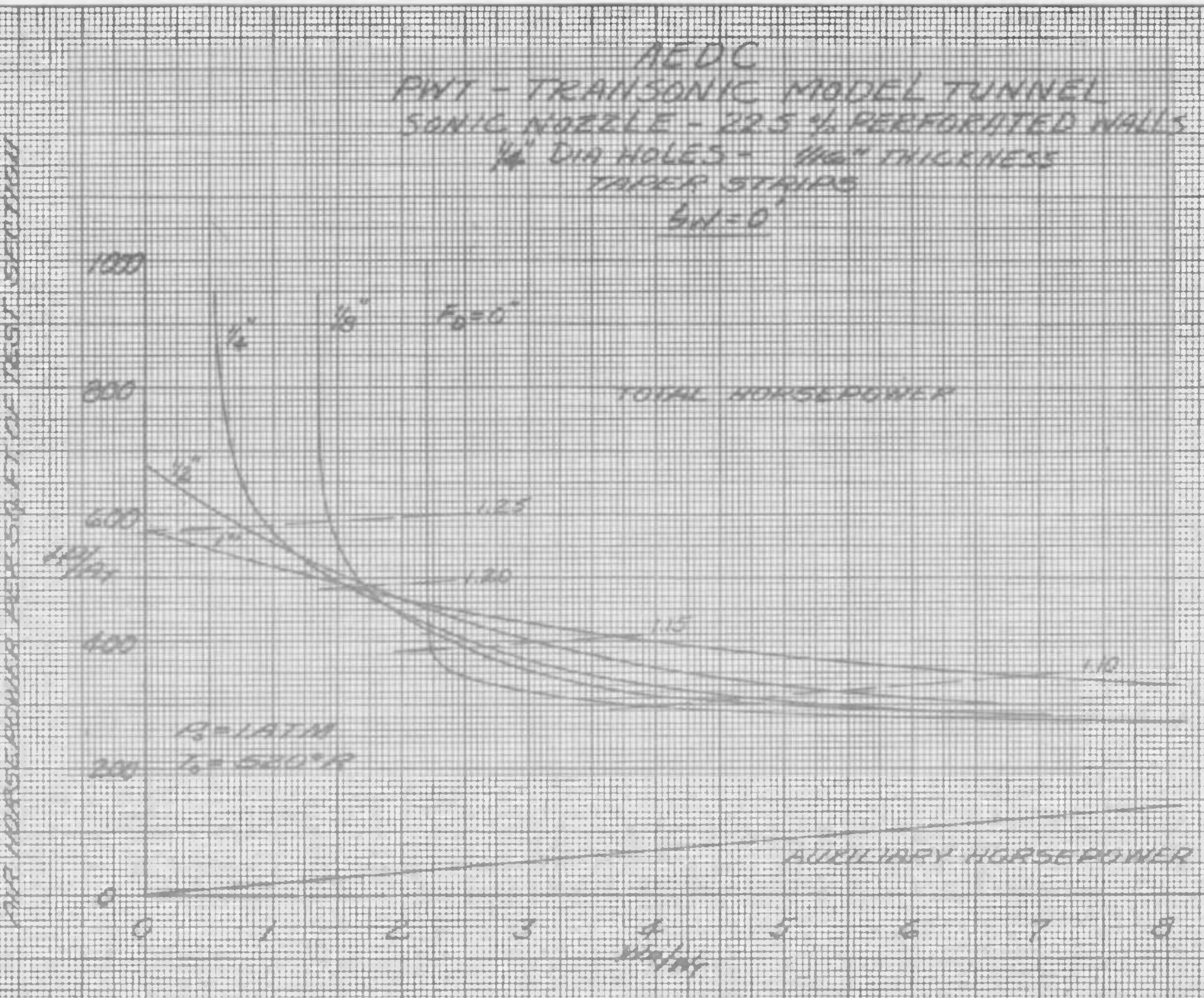


FIGURE 34 EFFECT OF DIFFUSER FLAP POSITION ON POWER REQUIREMENTS AT MACH NUMBER 1.0

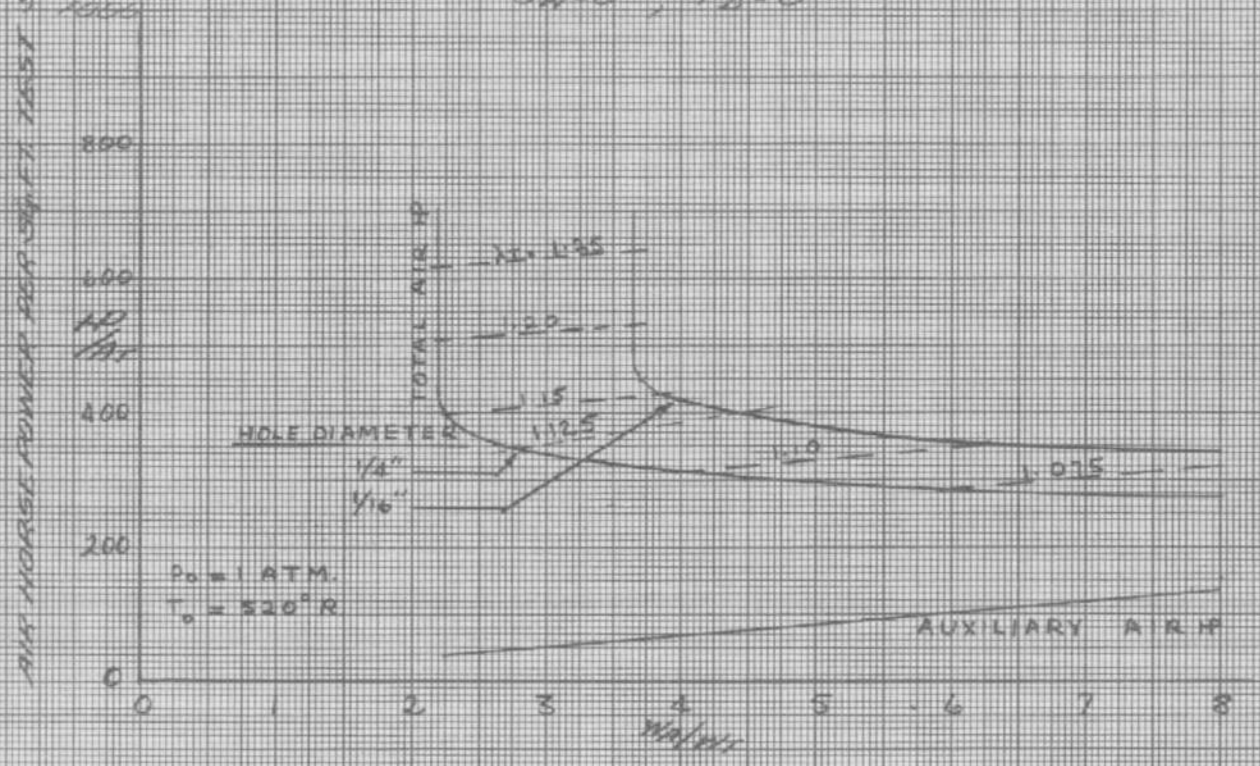
AEDC

PWT - TRANSONIC MODEL TUNNEL

SONIC NOZZLE - 22.5% PERFORATED WALLS

TAPER STRIPS

$\theta_W = 0°$; $F_D = 0''$



AUXILIARY WEIGHT FLOW — % OF MAIN FLOW

FIGURE 35 EFFECT OF HOLE SIZE ON POWER REQUIREMENTS AT MACH NUMBER 1.0