AEDC-TR-66-80

JUL 19 1966
NOV 1 1967

CHECK CALIBRATION OF THE AEDC 16-FT TRANSONIC TUNNEL

J. A. Gunn
ARO, Inc.

May 1966

PROPERTY OF U. S. AIR FORCE
AEDC LIBRARY
AF 40(600)1200

Distribution of this document is unlimited.

PROPULSION WIND TUNNEL FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

When U. S. Government drawings specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Qualified users may obtain copies of this report from the Defense Documentation Center.

References to named commercial products in this report are not to be considered in any sense as an endorsement of the product by the United States Air Force or the Government.

CHECK CALIBRATION OF THE AEDC 16-FT TRANSONIC TUNNEL

J. A. Gunn
ARO, Inc.

Distribution of this document is unlimited.

AF - AEDC
Arnold AFB Tenn

FOREWORD

The work reported herein was sponsored by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 65402234.

The results of this calibration were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The calibration was conducted from May 5 to 14, 1965, under ARO Project No. PB9340, and the results of this calibration program were incorporated into the data reduction program for subsequent tests. The organization of this final report was accomplished under ARO Project No. PB3642. The manuscript was submitted for publication on March 23, 1966.

This technical report has been reviewed and is approved.

Francis M. Williams
Major, USAF
AF Representative, PWT
DCS/Test

Jean A. Jack
Colonel, USAF
DCS/Test

ABSTRACT

Tests were conducted in the Propulsion Wind Tunnel, Transonic (16T) of the Propulsion Wind Tunnel Facility (PWT) to determine the test section Mach number calibration and Mach number distributions. During the test, Mach number was varied from 0.50 to 1.60, and the wall angle from -1.00 to +1.00 deg, while holding tunnel total pressure at 1000 psfa and tunnel temperature at 120°F. At all Mach numbers the region from Station 1 to Station 20 was considered the test region. The results show that the tunnel calibration is a function of test section wall angle, and that all wall angles in the calibrated Mach number range produce Mach number distributions acceptable for testing. This was the first calibration after the installation of the modified main compressor utilizing fiber glass rotor blades.

CONTENTS

		Page
	ABSTRACT	iii
	NOMENCLATURE	vii
I.	INTRODUCTION	1
II.	APPARATUS	
	2.1 Basic Tunnel and Support Equipment	1
	2.2 Calibration Equipment	2
III.	PROCEDURE	
	3.1 Calibration Procedure	3
	3.2 Data Reduction Procedure	3
IV.	RESULTS AND DISCUSSION	4
V.	CONCLUSIONS	6
	REFERENCES	6
	APPENDIXES:	
	I. Linearized Calibration Equations	41
	II. Supplemental Calibration Information	46
	III. Standard Deviation	47

ILLUSTRATIONS

Figure		
1.	Propulsion Wind Tunnel Facility	9
2.	16-ft Transonic Tunnel Test Section	10
3.	Typical Hole Pattern in the 6-Percent-Open Inclined-Hole Walls	11
4.	Photograph of Empty Test Section Showing Solid Plates	12
5.	Variation of Optimum Test Section Wall Angle, θ_W*, with Mach Number (From Ref. 2)	13
6.	Variation of Optimum Test Leg Pressure Ratio, λ_T*, with Mach Number (From Ref. 2 - Corrected by Fig. II-1)	14
7.	Tunnel Calibration Based on Solid Plate Orifices	15
8.	Tunnel Calibration Based on Perforated Plate Orifices	16

Figure		Page
9.	Effect of Wall Angle on the Test Section Calibration - Data Obtained from Tunnel 1T Using Long Static Probe (From Ref. 4)	17
10.	Effect of Wall Angle on the Test Section Calibration - Tunnel 16T Data from Solid Plates Compared with Earlier Short Static Probe Data	18
11.	Effect of Wall Angle on the Test Section Calibration - Tunnel 16T Data from Orifices on Perforated Walls	19
12.	Mach Number Distribution on Solid Plates at Various Wall Angles	
	a. M_∞ = 0.80 to 1.20 at θ_W = -1.00 deg	20
	b. M_∞ = 0.80 to 1.20 at θ_W = -0.75 deg	21
	c. M_∞ = 0.50 to 1.00 at θ_W = -0.50 deg	22
	d. M_∞ = 1.05 to 1.50 at θ_W = -0.50 deg	23
	e. M_∞ = 0.70 to 1.00 at θ_W = -0.25 deg	24
	f. M_∞ = 1.05 to 1.60 at θ_W = -0.25 deg	25
	g. M_∞ = 0.50 to 1.00 at θ_W = 0 deg	26
	h. M_∞ = 1.05 to 1.60 at θ_W = 0 deg	27
	i. M_∞ = 0.90 to 1.60 at θ_W = +0.25 deg	28
	j. M_∞ = 0.50 to 1.00 at θ_W = +0.50 deg	29
	k. M_∞ = 1.00 to 1.60 at θ_W = +0.50 deg	30
	l. M_∞ = 1.30 to 1.60 at θ_W = +0.75 deg	31
	m. M_∞ = 0.50 to 1.00 at θ_W = +1.00 deg	32
	n. M_∞ = 1.05 to 1.60 at θ_W = +1.00 deg	33
13.	Statistical Evaluation of Empty Test Section Mach Number Deviations at Various Nominal Mach Numbers	
	a. M_∞ = 0.60, 0.80, 1.00, and 1.20.	34
	b. M_∞ = 1.40 and 1.60.	35
14.	Local Mach Number Variation at θ_W = 0 deg, θ_W = 0.25 deg, and $\theta_W = \theta_W$* Based on 95-Percent Confidence Level	
	a. θ_W = 0 deg.	36
	b. θ_W = 0.25 deg	37
	c. $\theta_W = \theta_W$*	38
15.	Lower Wall Mach Number Distribution Through Contraction, Nozzle, and Test Section for Various Test Section Mach Numbers at θ_W = 0 deg.	39

NOMENCLATURE

b, b_θ, k, k_θ	Defined in Appendix I
M_c	Mach number as computed from p_c/p_t
$M_{c(\ell, m)}$, $M_{c(m, h)}$	Defined in Appendix I
M_{TP}	Mach number as computed from the average of Mach number measurements along the perforated plate from station 1 to 20
M_{TS}	Mach number as computed from the average of Mach number measurements along the solid plate from station 1 to 20
M_∞	Free-stream Mach number
$M_{\infty(\ell, m)}$, $M_{\infty(m, h)}$	Defined in Appendix I
p_c	Plenum chamber static pressure, psf
p_i	Compressor inlet static pressure, psf
p_P	Static pressure measured on perforated plate, psf
p_S	Static pressure measured on solid plate, psf
p_t	Stilling chamber total pressure, psf
p_∞	Free-stream static pressure, psf
θ_w	Test cart wall angle, deg (positive when walls are diverged)
$\theta_w{}^*$	Optimum wall angle, deg
$\lambda_t{}^*$	Optimum tunnel pressure ratio, p_t/p_i

SUBSCRIPTS

h	High transonic Mach number range
ℓ	Low transonic Mach number range
m	Mid transonic Mach number range
x	Axial station number, ft

SECTION I
INTRODUCTION

The Propulsion Wind Tunnel, Transonic (16T) began shakedown and operation in July of 1956. In August 1961 Tunnel 16T was removed from service by a main compressor failure. The compressor rotor has been redesigned and installed with fiber glass reinforced plastic blades. The results of the test section calibration with the plastic bladed compressor are presented in this report. This calibration was initiated to determine empty test section Mach number distribution and Mach number calibration over a wide range of test section wall angles.

SECTION II
APPARATUS

2.1 BASIC TUNNEL AND SUPPORT EQUIPMENT

Tunnel 16T is a continuous flow, closed-circuit tunnel capable of operation at Mach numbers from 0.50 to 1.60 and stagnation pressures from approximately 100 to 4000 psf. The location of Tunnel 16T and its relationship to the rest of the PWT facility are shown in Fig. 1. The compressor drive system consists of four electric motors with a maximum power rating of 216,000 hp. The main compressor is a constant speed, three-stage, axial flow compressor with variable stator blades for inlet volume flow control. The calibration of the compressor with fiber glass blades is given in Ref. 1. Temperature control is provided by an air-to-water heat exchanger located just upstream of the stagnation region. The stagnation temperature control is automatic and will maintain the average temperature to ±1°F of the set temperature through the normal temperature range from 90 to 125°F with estimated deviations across the stagnation region of no more than ±5°F.

Supersonic Mach numbers are generated by a flexible, two-dimensional Laval nozzle. Fifty contours are available for supersonic Mach numbers from 1.00 to 1.65. A 10-ft variable porosity flow stabilization region, shown in Fig. 2, connects the solid plate nozzle and the porous test section. The removable test section is 40 ft long and 16 ft square with 6-percent porosity walls. Figure 3 is a sketch of a portion of the wall showing the hole pattern and cross-section details. The test section sidewalls can be converged to 2 deg and diverged to 1 deg. A scavenging scoop is located in the diffuser to remove the

products of combustion during propulsion tests. A closed tip is installed on the scoop during aerodynamic tests.

Plenum suction is required for removal of air through the test section walls to prevent choking in the transonic range. For initial operation plenum suction was provided by opening the diffuser flaps. As its units became operational, auxiliary suction was provided by the Plenum Evacuation System (PES). The PES consists of two increments of compressors which can operate independently. All or a portion of the air removed from the plenum may be energized by the PES and returned to the tunnel in the diffuser. Pressure level control and drying are maintained by removing air from the tunnel (either from the plenum or from ports in the scavenging scoop support strut) and exhausting it to the atmosphere. Dry make-up air is returned to the tunnel downstream of the scavenging scoop from the PWT dryer building which uses silica gel as a desiccant. The Rocket Test Facility (RTF) exhauster plant may be used to supplement the PES in removing air for drying and pressure control.

2.2 CALIBRATION EQUIPMENT

The test section Mach number distributions were obtained from static pressure orifices 0.090 in. in diameter. These orifices were installed on 1-ft centers in the test section floor on lines 1 ft either side of the tunnel centerline. The orifices on the east side of the centerline were set in a 2-ft-wide solid plate extending from station 0 to station 30, whereas the orifices on the west side of the centerline were positioned in the perforated test section liner plates with an orientation to the perforations as exhibited in Fig. 3. The location of the solid plates in the empty test section is shown in Fig. 4.

In addition to the orifices in the test section, other orifices in the tunnel floor, placed nominally on the centerline, extend from station -80 to station 39. These orifices were used to determine flow development and decay. Most orifices were connected to both transducers and unity oil manometers.

SECTION III
PROCEDURE

3.1 CALIBRATION PROCEDURE

Variables during this empty test section calibration were Mach number and wall angle. The general procedure followed was to set a chosen wall angle and vary Mach number through the desired range. Nominal Mach number was set by adjusting plenum pressure using tables from previous calibration data, and tunnel pressure ratio was regulated to give the best test section Mach number distribution. This was determined visually from a 100-in. manometer board in the control room. For Mach numbers up to and including 1.05, the nozzle was set on the sonic contour. Above Mach number 1.05 supersonic contours were used.

Throughout this calibration a stagnation pressure of 1000 psf was maintained. Most of the test was conducted at a stagnation temperature of 120°F; however, some data were obtained at a stagnation temperature of 100°F. Check points showed that there was no noticeable difference in data at 120 and 100°F. A tunnel humidity level of 0.001 lb of water per pound of mixture or less was maintained for Mach numbers greater than 1.2.

3.2 DATA REDUCTION PROCEDURE

The on-line printout consisted of basic tunnel conditions (stagnation temperature, stagnation pressure, and plenum pressure) and calibration data. Several on-line plots were used to observe data which were not tabulated on-line, and an off-line printout supplied the ratio, p/p_t, for all orifices.

Since most model testing is done in the test section region from station 1 to station 20, the calibration data were based on that length. The on-line program printed out the average Mach number on the solid plates, M_{TS}, and the average Mach number on the perforated walls, M_{TP}, for stations 1 to 20.

The following relations were computed to determine tunnel calibration:

$$M_c = \sqrt{5\left[\left(\frac{p_c}{p_t}\right)^{-2/7} - 1\right]} \tag{1}$$

$$M_{TS_x} = \sqrt{5\left[\left(\frac{p_{S_x}}{p_t}\right)^{-\frac{2}{7}} - 1\right]} \tag{2}$$

$$M_{TP_x} = \sqrt{5\left[\left(\frac{p_{P_x}}{p_t}\right)^{-\frac{2}{7}} - 1\right]} \tag{3}$$

$$M_{TS} = \frac{\sum_{x=1}^{20} M_{TS_x}}{20} \tag{4}$$

$$M_{TP} = \frac{\sum_{x=1}^{20} M_{TP_x}}{20} \tag{5}$$

The procedure used to reduce the results of this calibration to a form which is employed for on-line data reduction is given in Appendix I.

SECTION IV
RESULTS AND DISCUSSION

Previous calibrations (Ref. 2) have established parameters for optimum shock cancellation and minimum base pressure interference for certain bodies of revolution. These parameters are θ_W* for optimum cart wall angle (Fig. 5) and λ* for optimum tunnel pressure ratio (Fig. 6, which was corrected according to Appendix II). However, facility limitations, different test requirements, and a variety of model sizes and shapes frequently dictate that the tunnel should be operated at test section wall angles other than θ_W*. The main objective of this test, therefore, was to obtain empty test section Mach number distributions and calibrations for a range of wall angles from +1.00 to -1.00 deg. This "complete" calibration will allow tests to be conducted within this wall angle range with a high degree of certainty in the Mach number settings.

Other previous calibrations (Ref. 3) have shown that the ratio of plenum chamber pressure, p_c, to stagnation pressure, p_t, can be used as a reference to set test section Mach number. The calibration of M_{TS} and M_{TP} for various wall angles is presented in Figs. 7 and 8. In these figures the calibration reference, p_c/p_t, is given in the form M_c. Comparison of these plots raised the question of which Mach number, M_{TS} or M_{TP} represented the free-stream Mach number, M_∞. The PWT 1-ft Transonic Tunnel (1T) calibration data obtained from a long

centerline probe and given in the plenum coefficient form, $(p_\infty - p_c)/p_t$, is shown in Fig. 9 (Ref. 4). A comparison of the Tunnel 1T data with the Tunnel 16T data (Figs. 10 and 11) indicates that results obtained from the solid plates in Tunnel 16T exhibit the same general trend as the data from the long centerline probe. Tunnel 16T calibration data (Ref. 3) from a short static pipe are compared with the solid plate data in Fig. 10. The agreement of the data is excellent and points out conclusively that the calibration data obtained from orifices in solid plates on the tunnel floor represent the free-stream Mach number.

The Mach number distributions measured on the solid plates from station 1 to station 20, free-stream Mach number, M_∞, and the reference Mach number, M_c, are presented in Fig. 12. It will be shown in the following discussion that in general the best empty test section distributions are obtained at $\theta_W = 0.25$ deg.

Although the data in Fig. 12 can be used to determine model positioning, it is difficult to resolve from these data which wall angle gives the best overall distribution at a given Mach number. A more complete analysis of the distribution was obtained by using the standard deviation method (explained in Appendix III) based on a 95-percent, 2σ confidence level. The data acquired from this statistical approach should be used primarily to compare one set of data with another, but it is probably indicative of absolute values of deviation.

Figure 13, which is a plot of the 2σ Mach number deviation versus θ_W for constant nominal Mach numbers, indicates that in almost all cases the lowest Mach number deviation occurs at $\theta_W = 0.25$ deg. This result is most pronounced in the supersonic range where very distinct minimum points or "buckets" appear. This phenomenon may be explained by the physical fact that the angle made by a nozzle side wall and the tunnel centerline at the nozzle exit (station -10) ranges from 0.22 to 0.32 deg in the Mach number range above 1.10. If the nozzle exit angle does not match the test section wall angle then flow disturbances, which extend through the test region, will be generated at the nozzle-test section intersection point. The 2σ deviation throughout the Mach number range for $\theta_W = 0$ deg, $\theta_W = 0.25$ deg, and $\theta_W = \theta_W{}^*$ is given in Fig. 14.

For all Mach number and wall angle combinations tested, the region between stations 1 and 20 is suitable for model testing. However, Fig. 12 shows that flow disturbances are prevalent for negative wall angles in the supersonic range especially in the front of the test cart. Proper model positioning can minimize this problem. It is shown in Figs. 13 and 14 that the (*) conditions mentioned previously are not

necessarily synonymous with the best empty test section Mach number distribution. As explained in Ref. 2, θ_W* and λ* represent optimum conditions for minimizing test section wall interference with models of a particular type and size.

Development of flow in Tunnel 16T is illustrated in Fig. 15. The flow characteristics of this plot are: a gradual acceleration of flow in the contraction region, a smooth development of flow in the nozzle, and a flat distribution in the test section. The distribution in the bulge region may have little meaning since the calculations assumed isentropic flow.

SECTION V
CONCLUSIONS

The following conclusions were reached as a result of the calibration of Tunnel 16T:

1. The Mach number obtained from the average of 20 Mach number measurements along the solid plate represents the free-stream Mach number, and agrees well with the calibration from a short static pipe.
2. All Mach number and wall angle combinations tested were found to be suitable for model testing, but, in general, the best empty tunnel Mach number distributions were obtained at $\theta_W = 0.25$.

REFERENCES

1. Parli, C. L. "Aerodynamic Calibration of the AEDC 16-FT Transonic Tunnel Compressor with Fiberglass Rotor Blades." AEDC-TR-65-242 (AD474436), November 1965.

2. Nichols, J. H. "Determination of Optimum Operating Parameters for the PWT 16-Ft Transonic Circuit Utilizing One-Percent Bodies of Revolution." AEDC-TN-59-100 (AD225362), September 1959.

3. Chevalier, H. L. "Calibration of the PWT 16-FT Transonic Circuit with a Modified Model Support System and Test Section." AEDC-TN-60-164 (AD241785), August 1960.

4. Chew, William L., Jr. "Determination of Operating Parameters for the 1-Foot Transonic Tunnel Utilizing Cone-Cylinder Bodies of Revolution." AEDC-TN-60-69 (AD235384), April 1960.

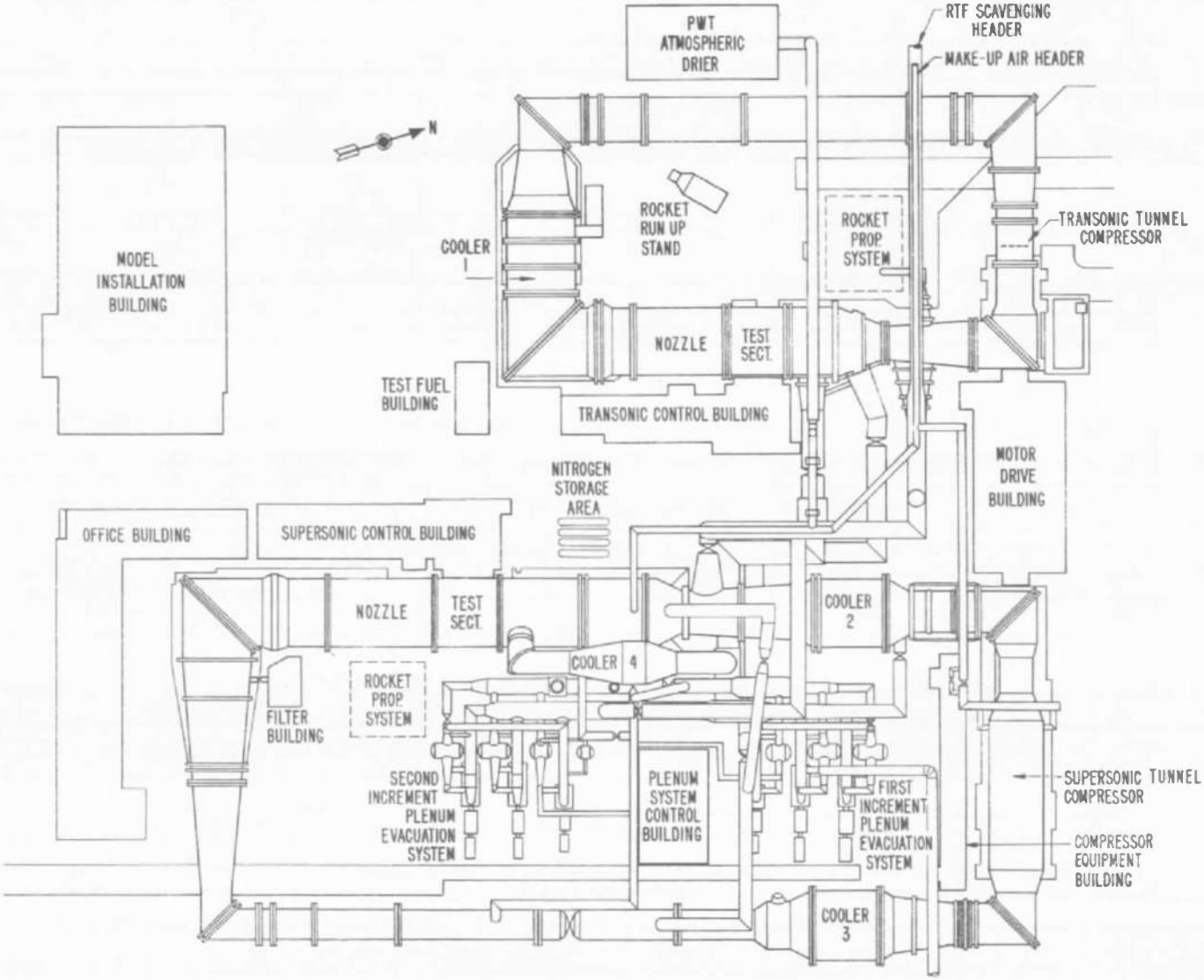


Fig. 1 Propulsion Wind Tunnel Facility

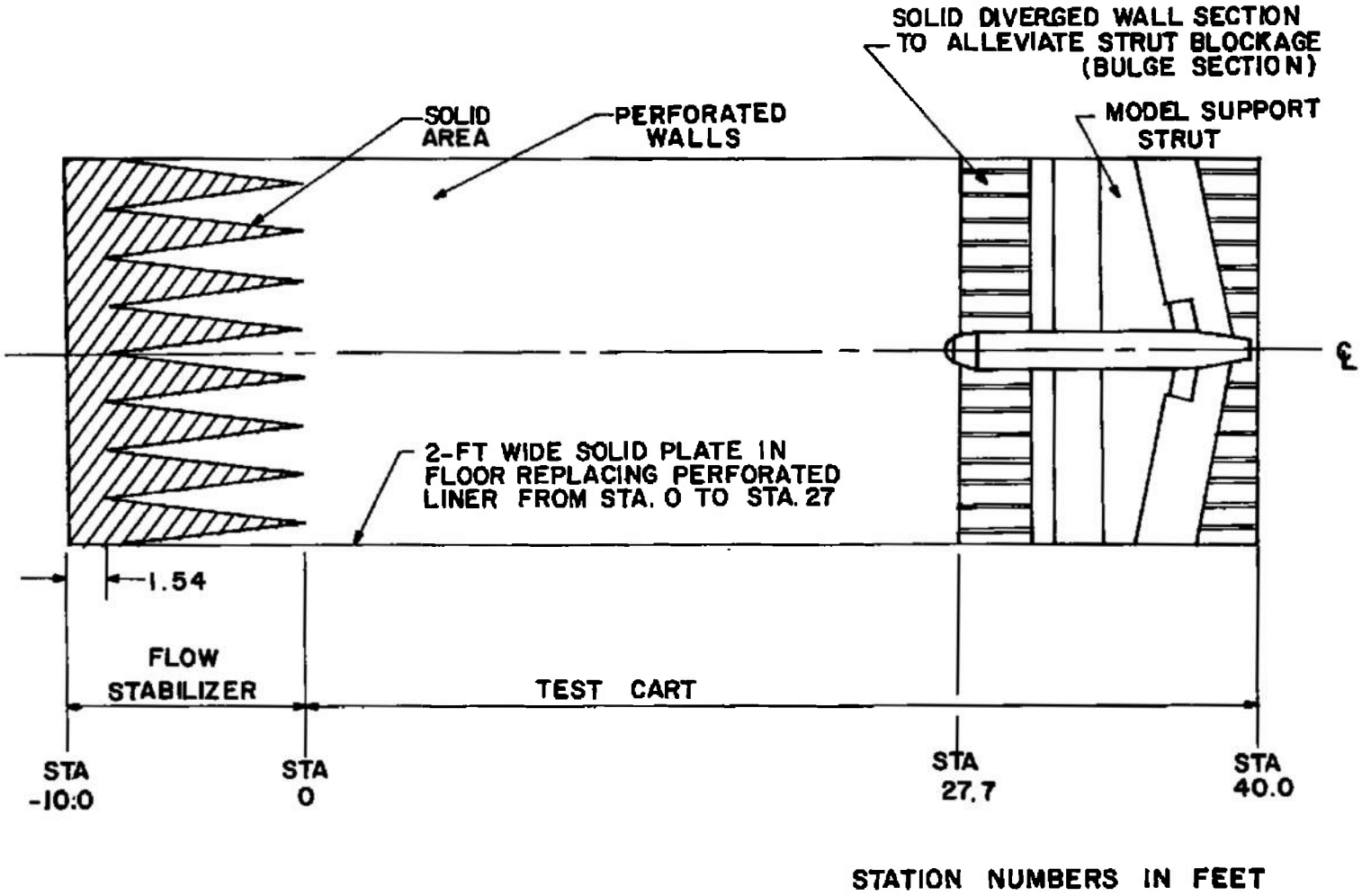


Fig. 2 16-ft Transonic Tunnel Test Section

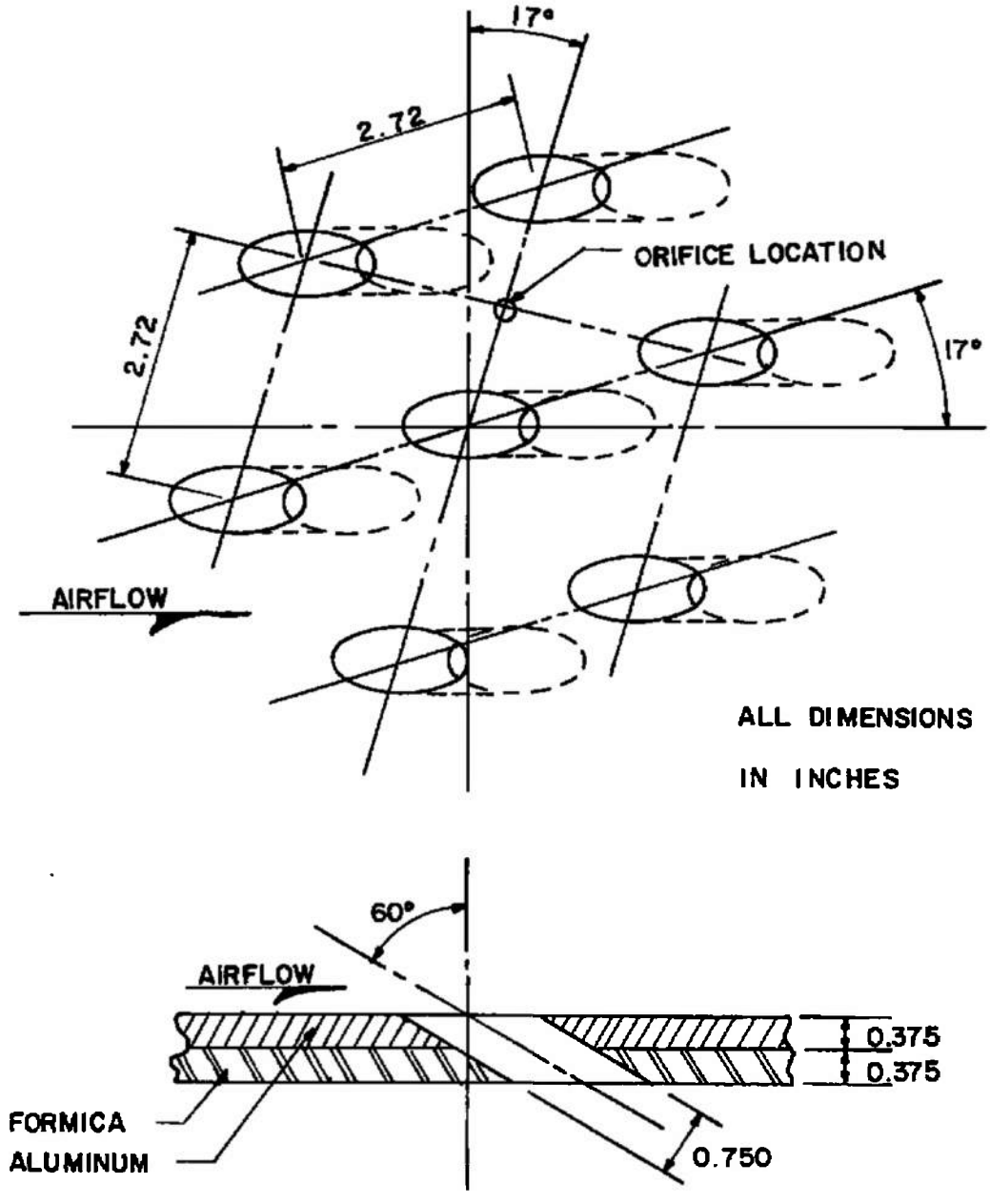


Fig. 3 Typical Hole Pattern in the 6-Percent-Open Inclined-Hole Walls

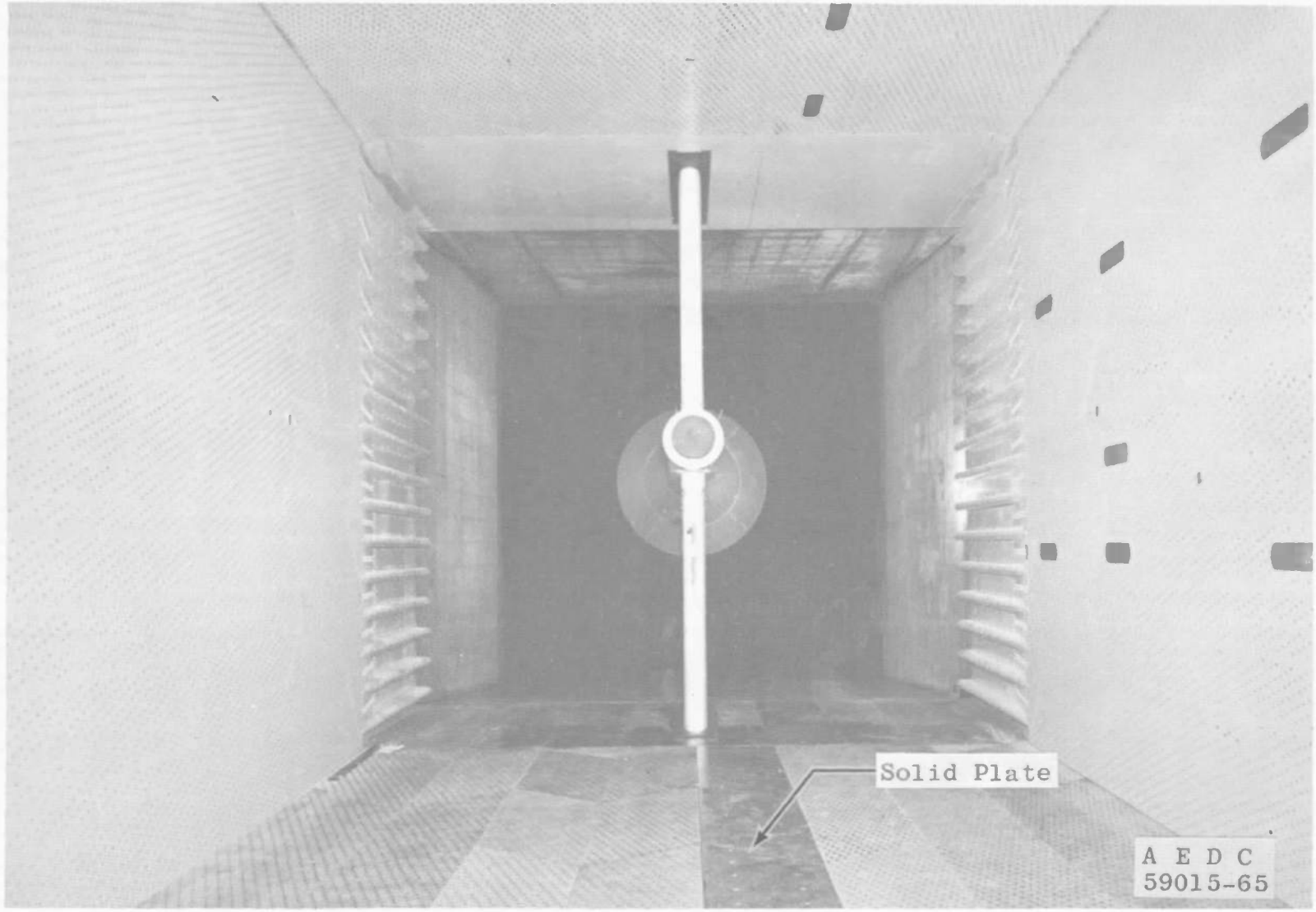


Fig. 4 Photograph of Empty Test Section Showing Solid Plates

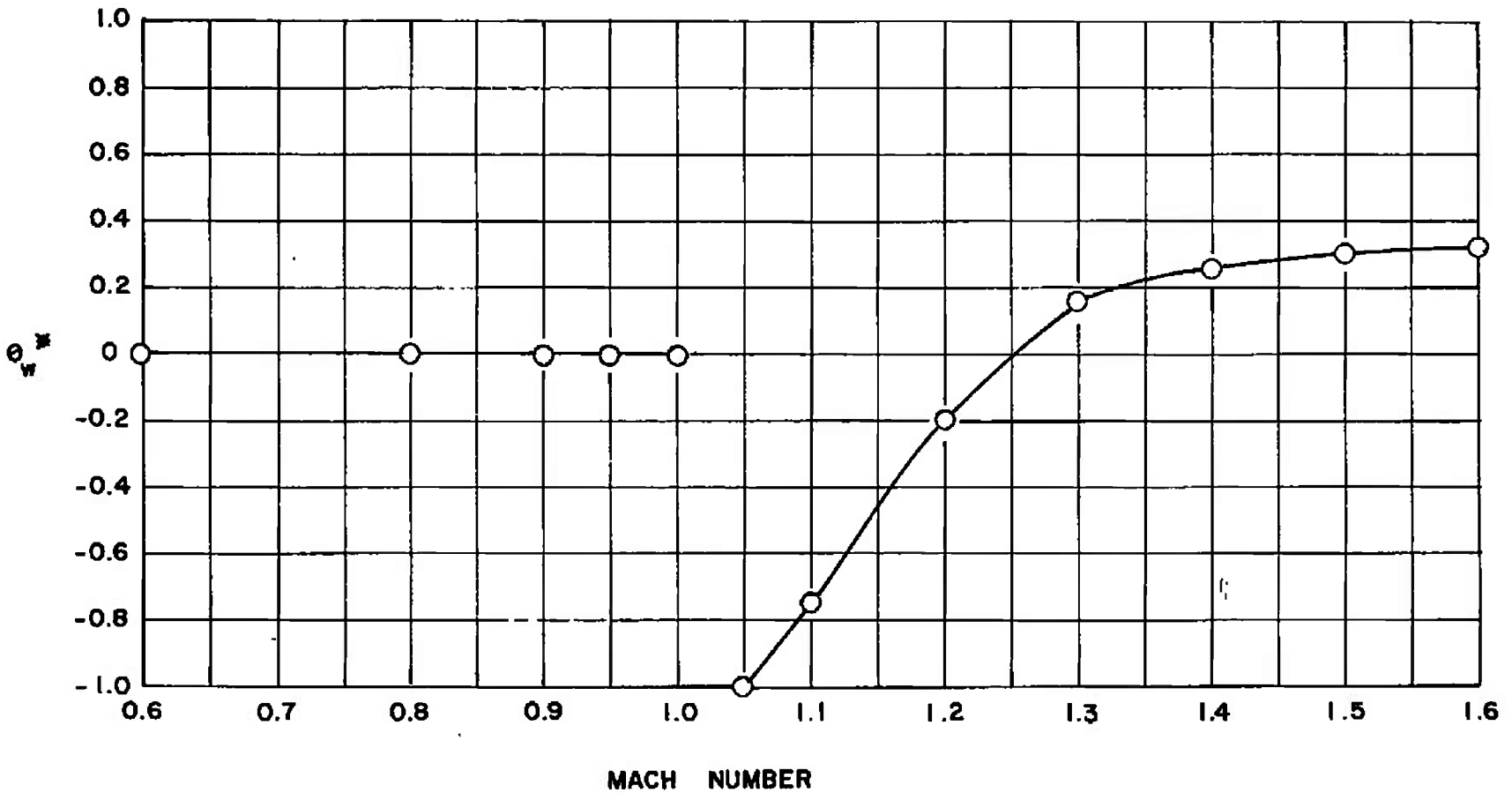


Fig. 5 Variation of Optimum Test Section Wall Angle, θ_w^*, with Mach Number (From Ref. 2)

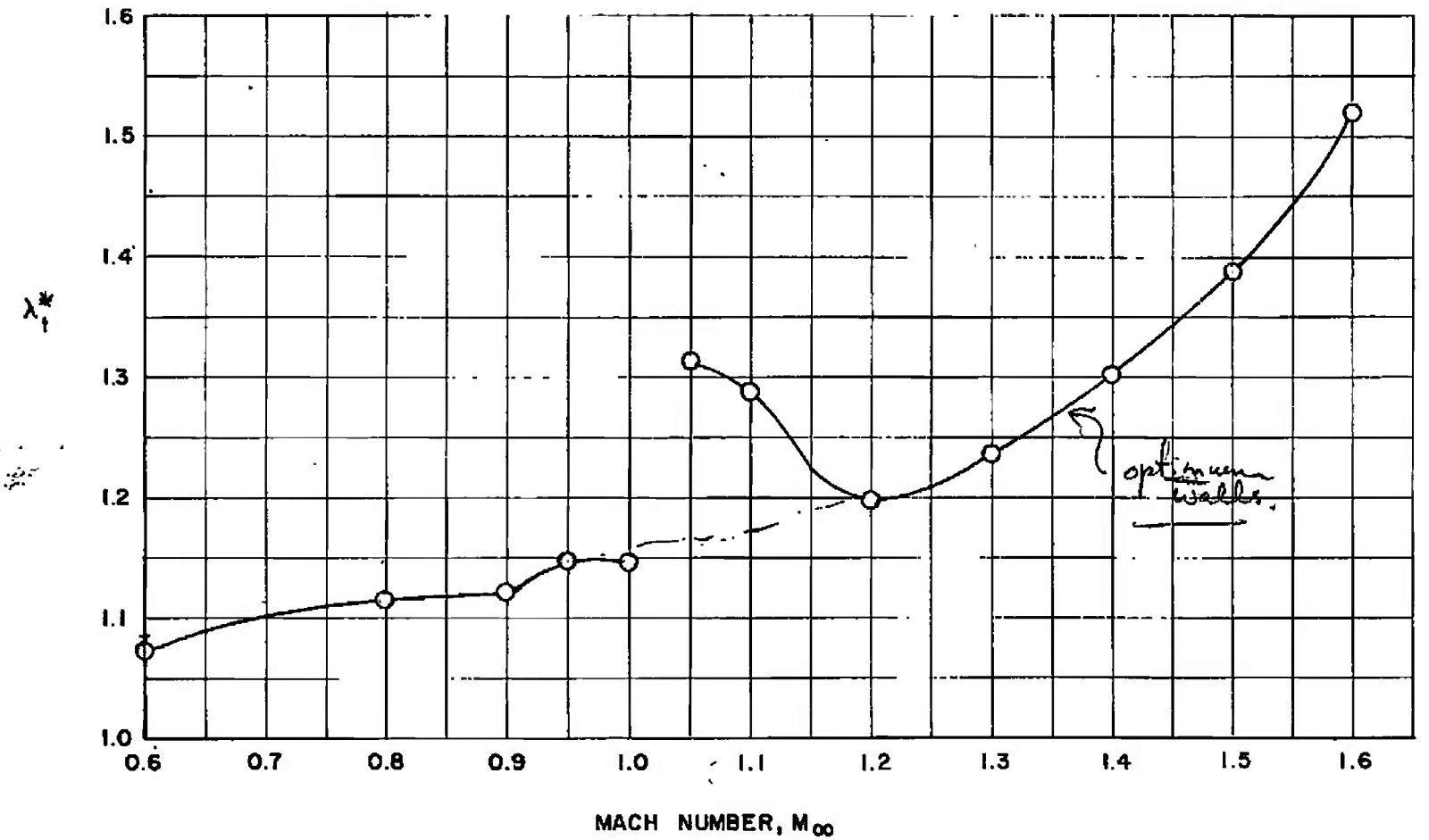


Fig. 6 Variation of Optimum Test Leg Pressure Ratio, λ_T^*, with Mach Number (From Ref. 2 – Corrected by Fig. II-1)

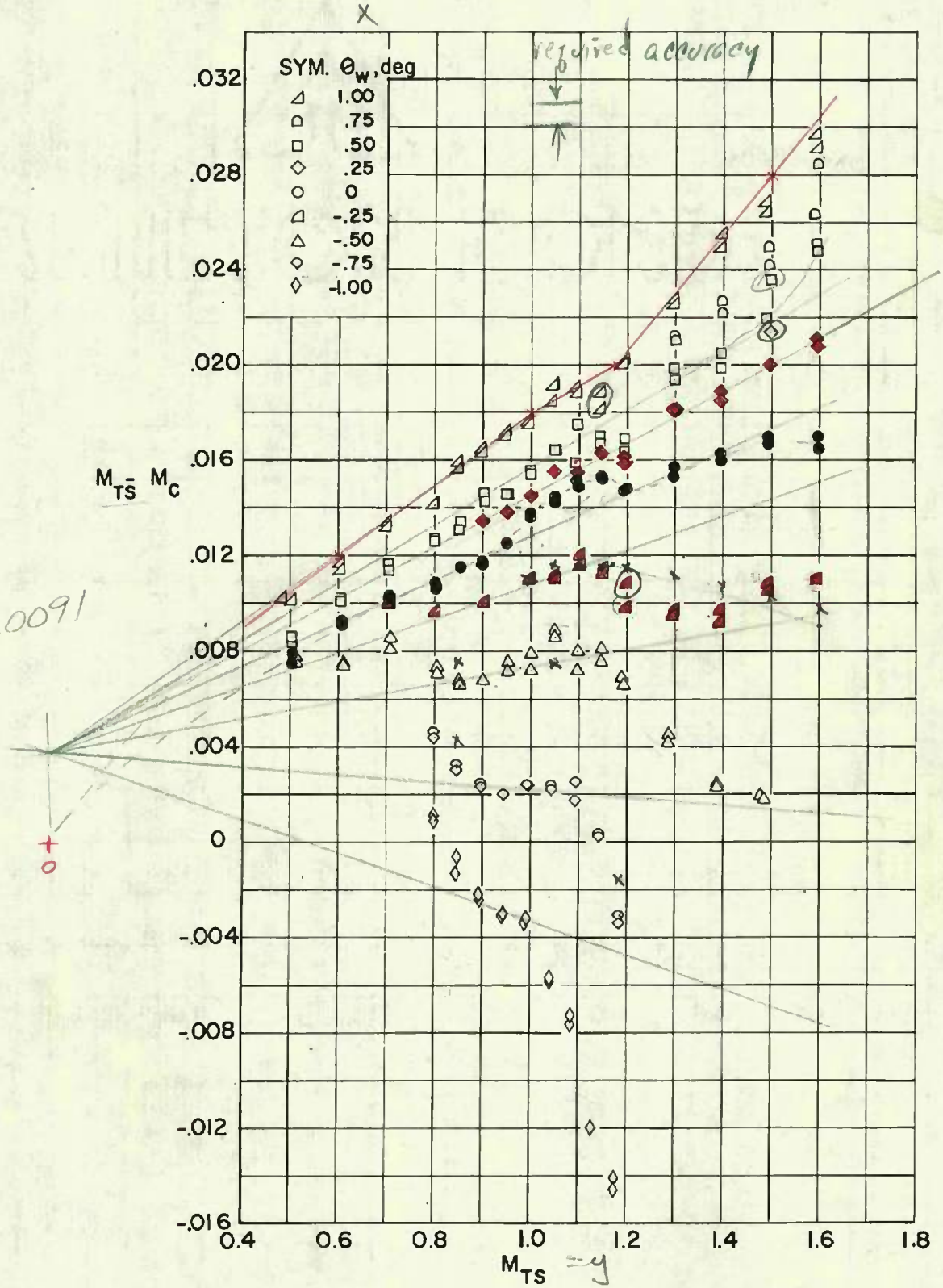


Fig. 7 Tunnel Calibration Based on Solid Plate Orifices

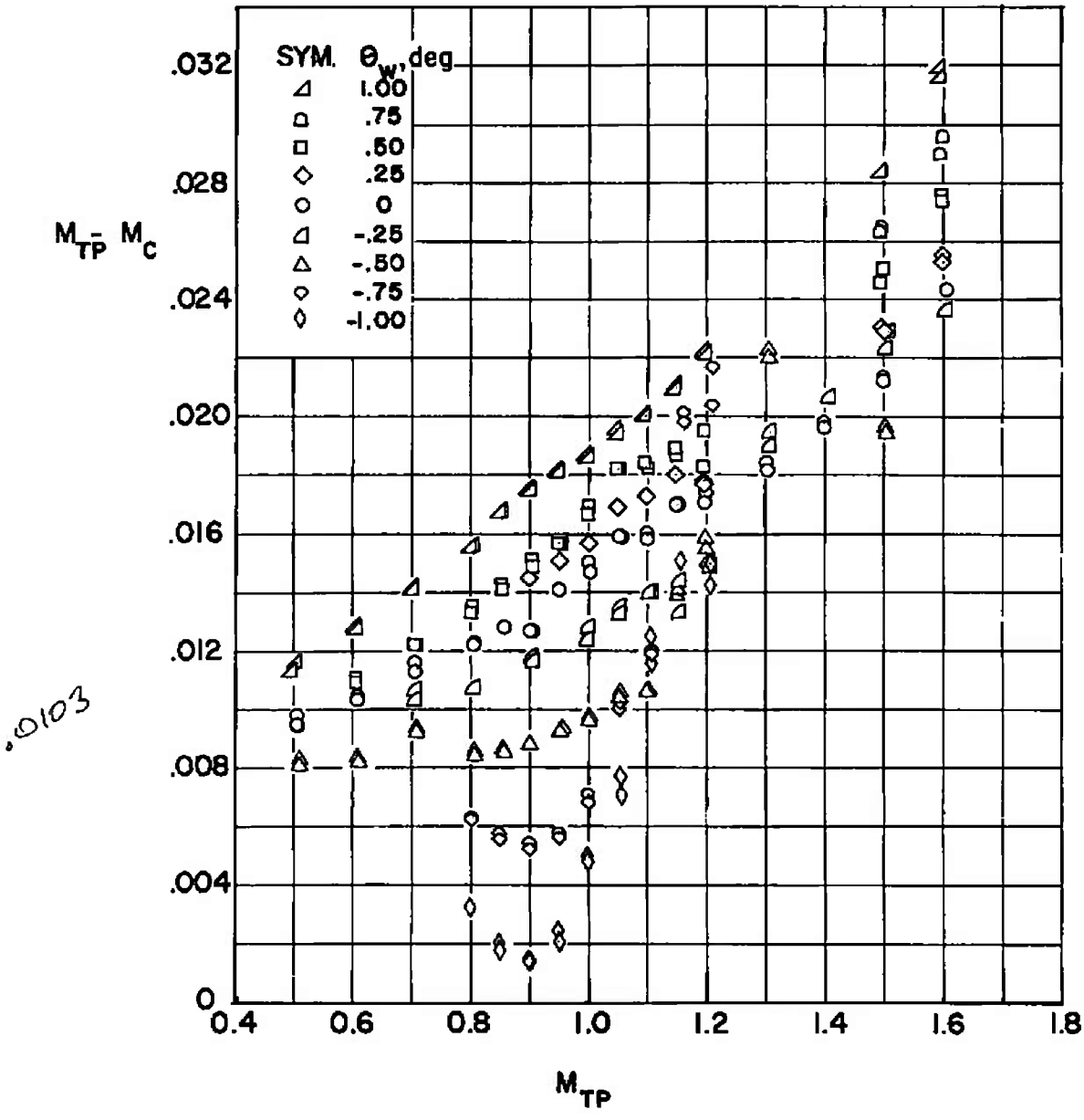


Fig. 8 Tunnel Calibration Based on Perforated Plate Orifices

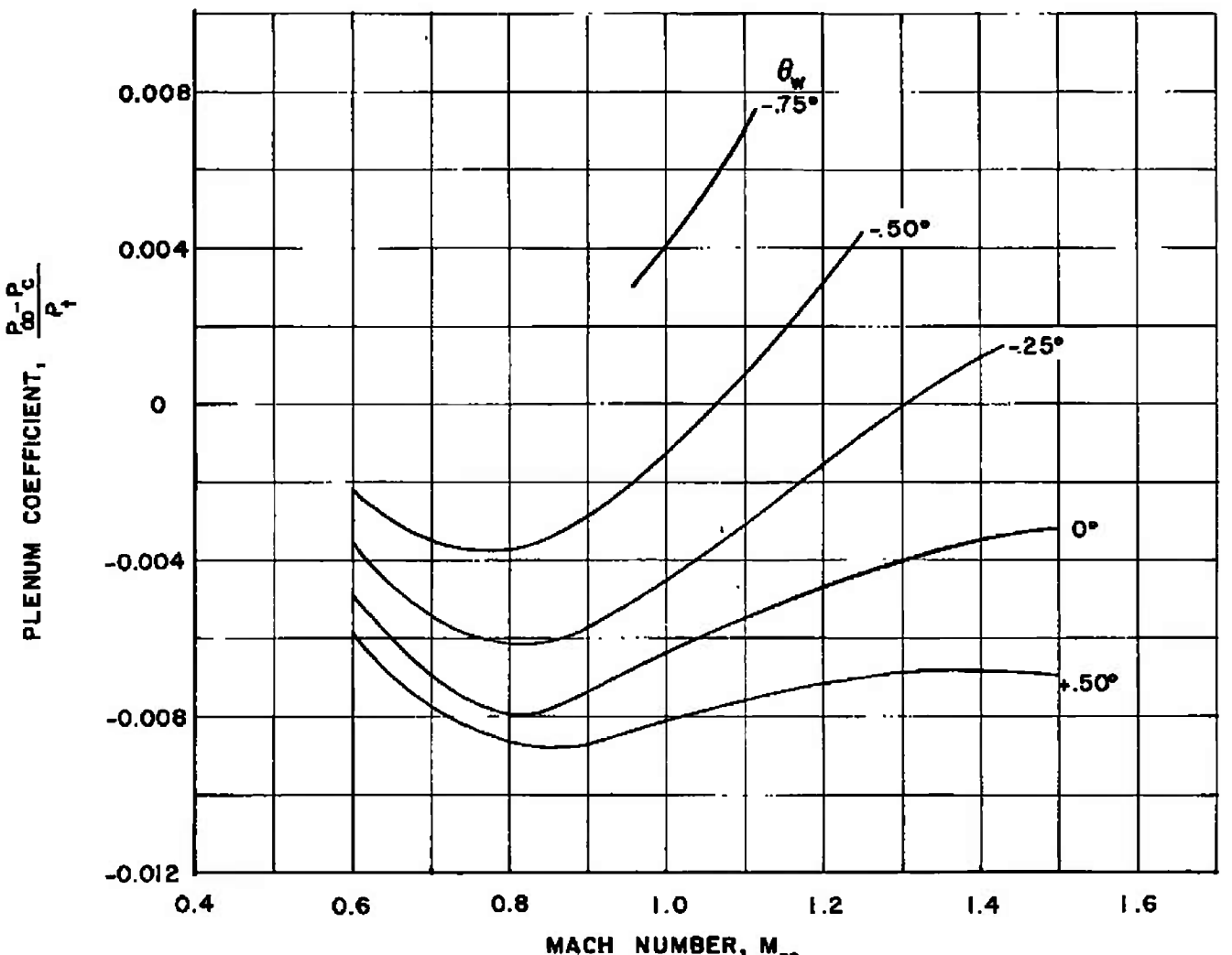


Fig. 9 Effect of Wall Angle on the Test Section Calibration – Data Obtained from Tunnel 1T Using Long Static Probe (From Ref. 4)

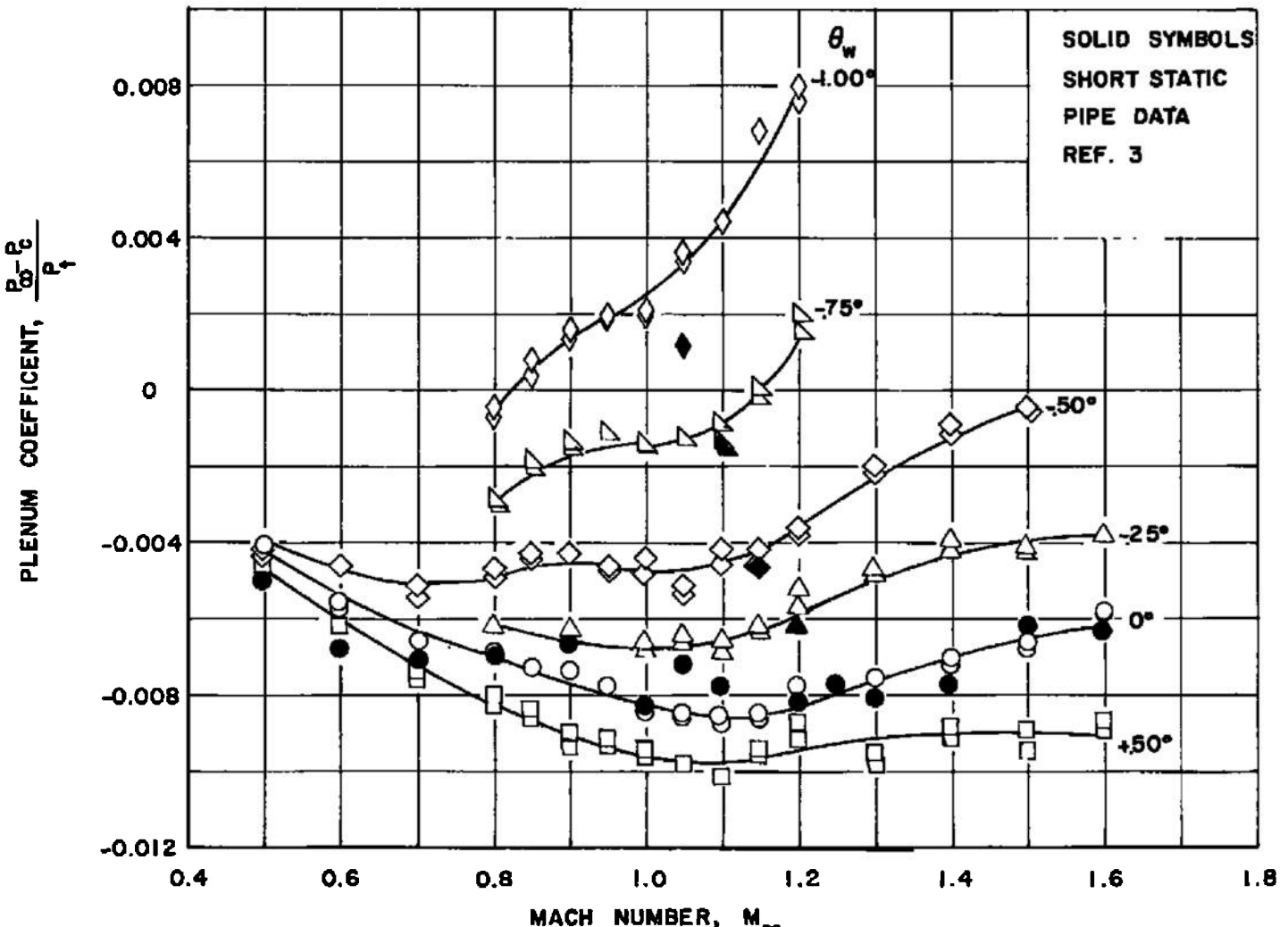


Fig. 10 Effect of Wall Angle on the Test Section Calibration – Tunnel 16T Data from Solid Plates Compared with Earlier Short Static Probe Data

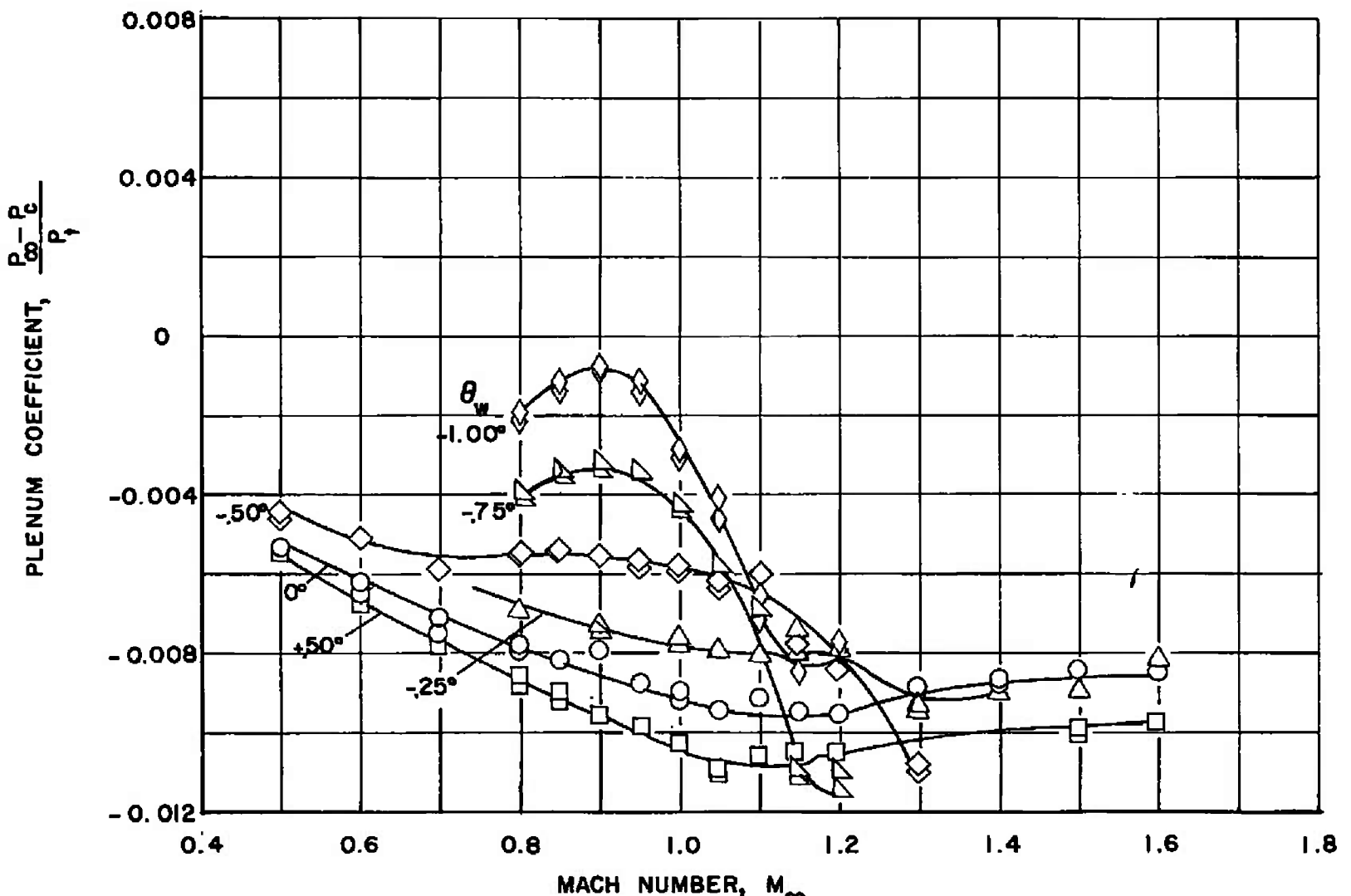
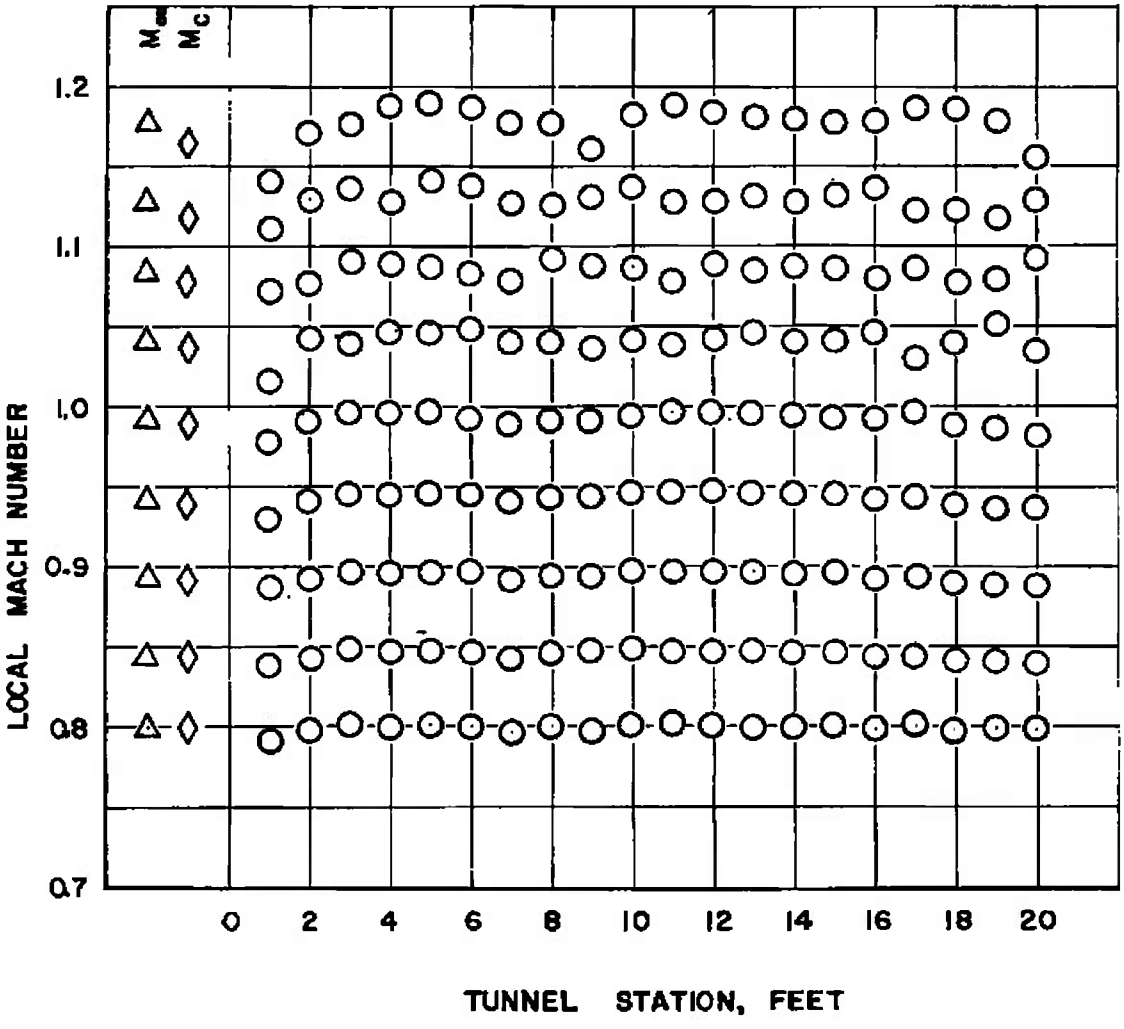
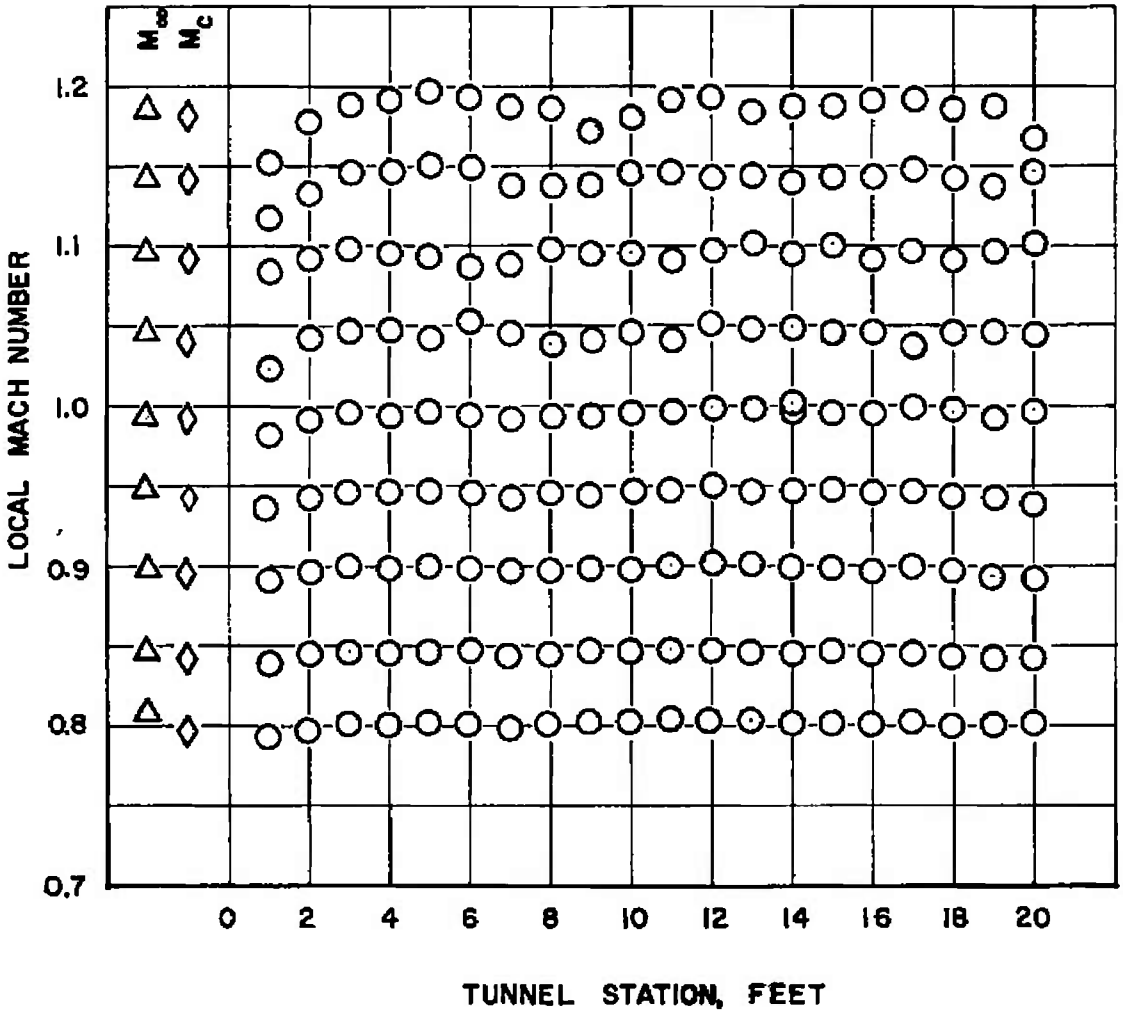


Fig. 11 Effect of Wall Angle on the Test Section Calibration – Tunnel 16T Data from Orifices on Perforated Walls



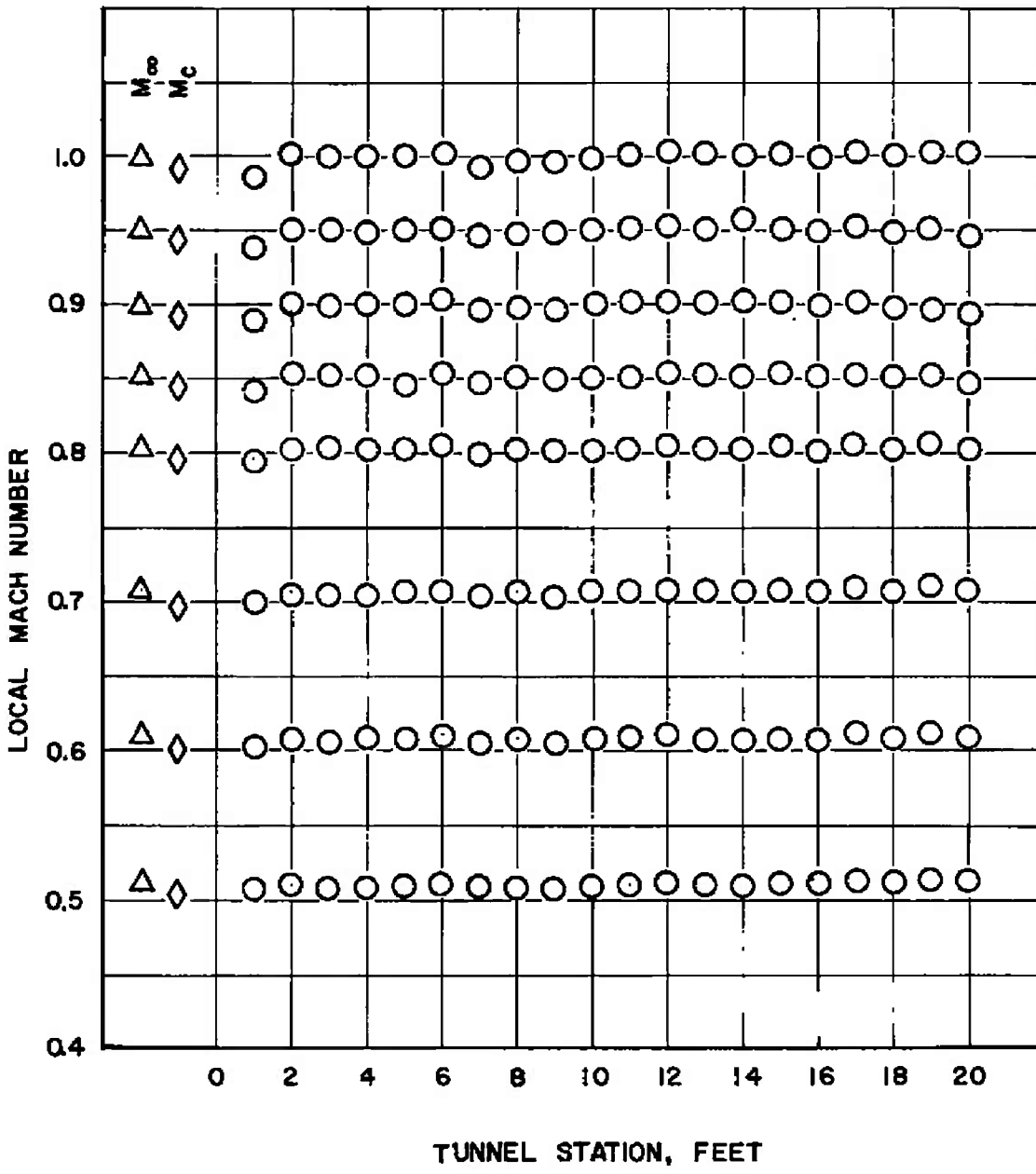
a. M_∞ = 0.80 to 1.20 at θ_w = −1.00 deg

Fig. 12 Mach Number Distribution on Solid Plates at Various Wall Angles



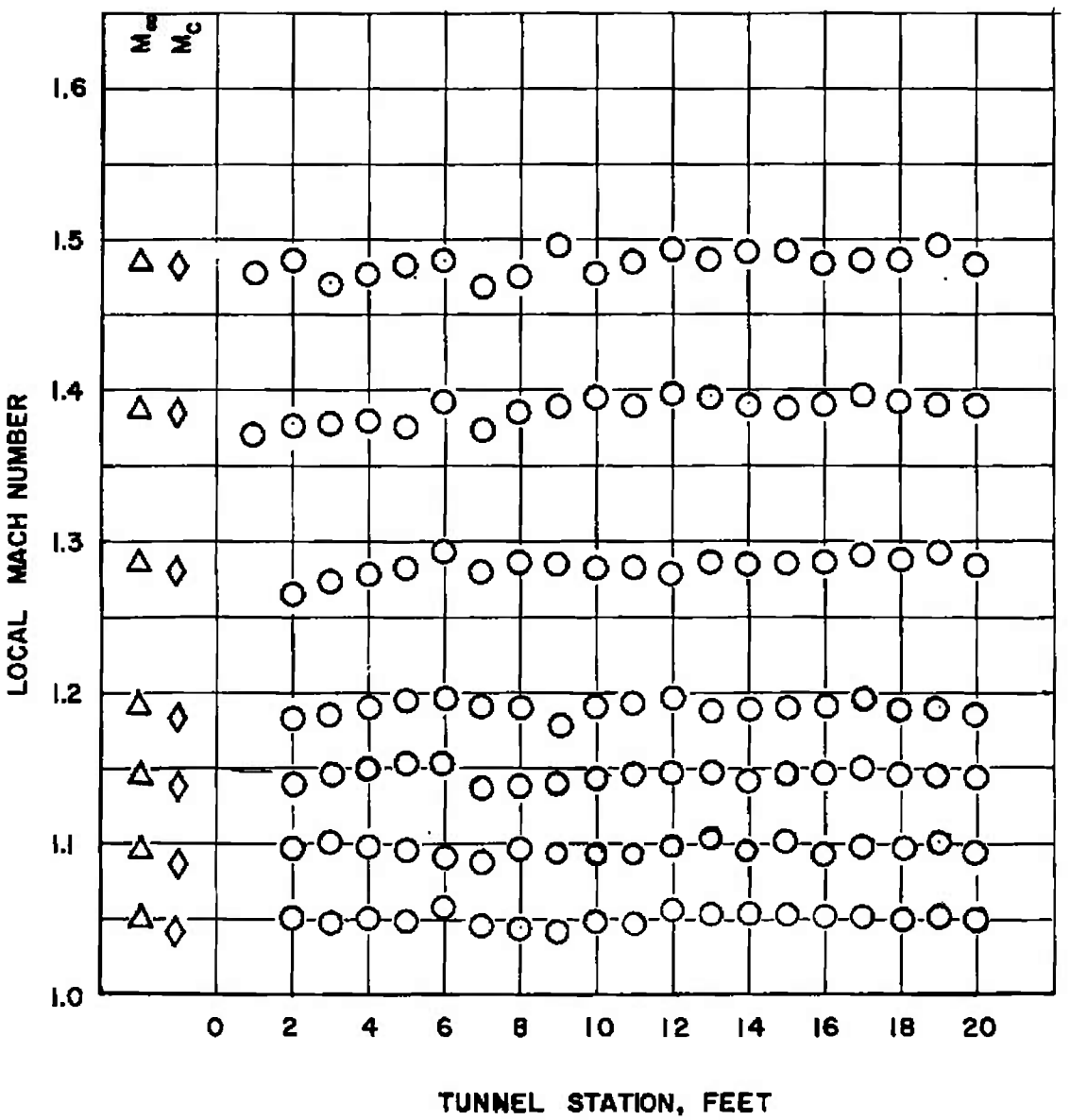
b. M_∞ = 0.80 to 1.20 at θ_w = −0.75 deg

Fig. 12 Continued



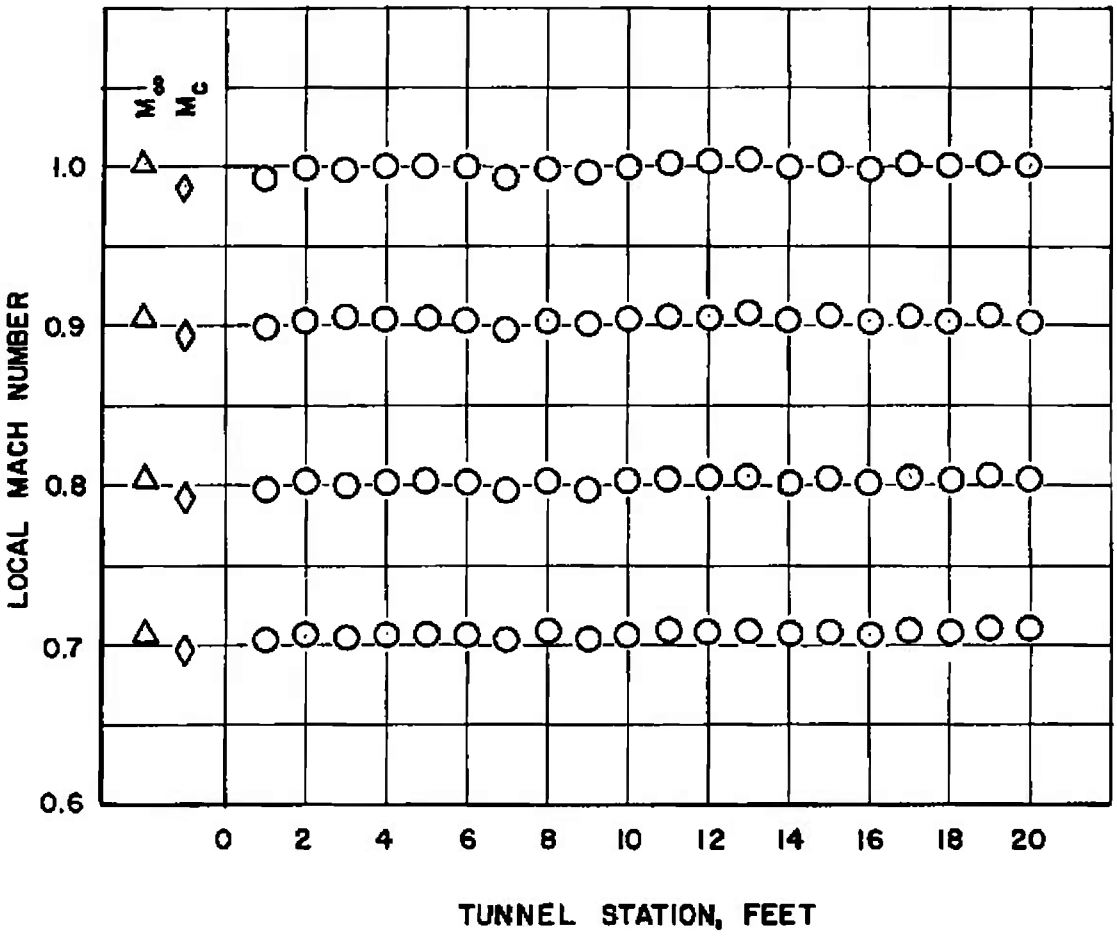
c. M_∞ = 0.50 to 1.00 at θ_w = −0.50 deg

Fig. 12 Continued



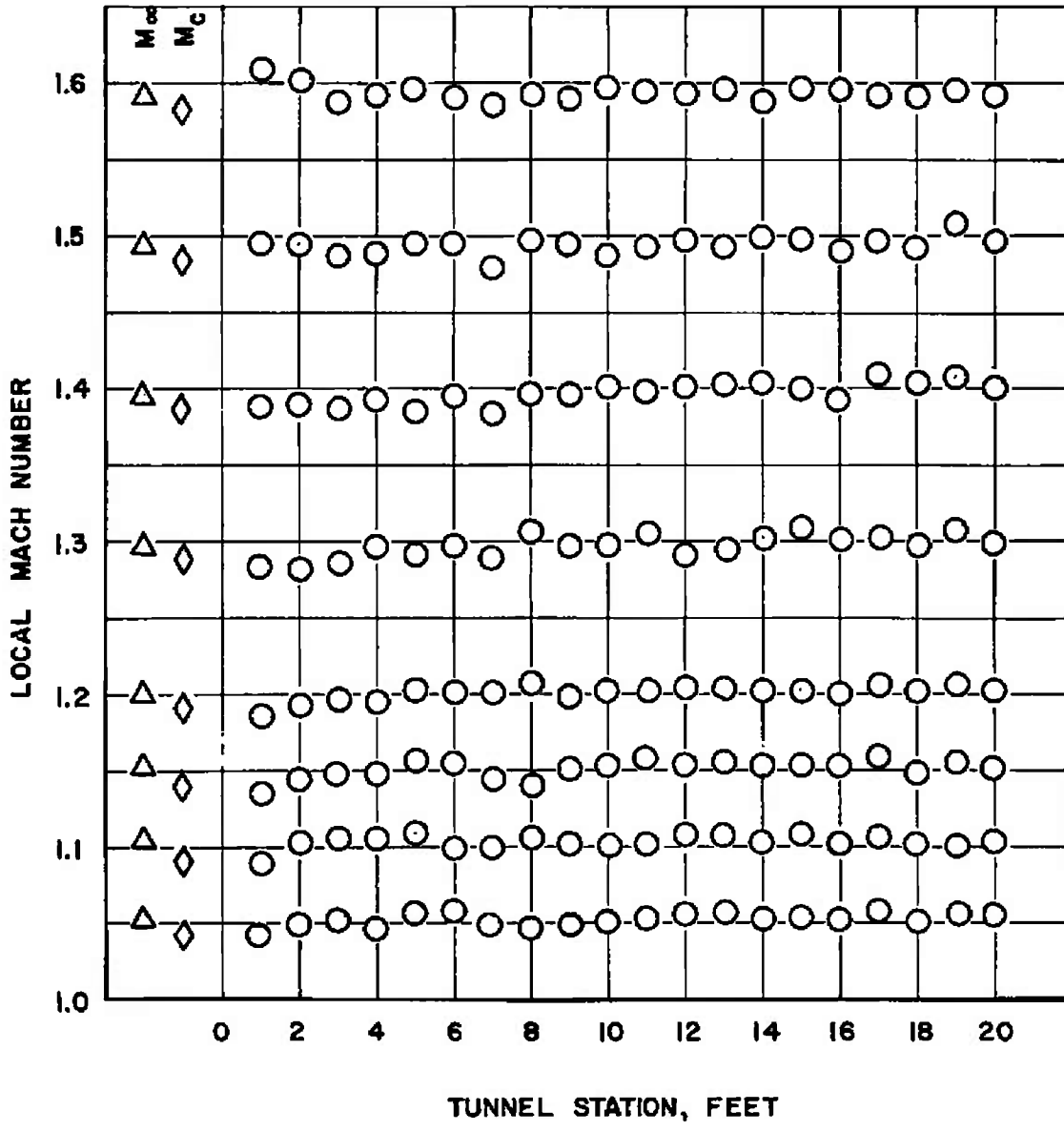
d. M_∞ = 1.05 to 1.50 at θ_w = −0.50 deg

Fig. 12 Continued



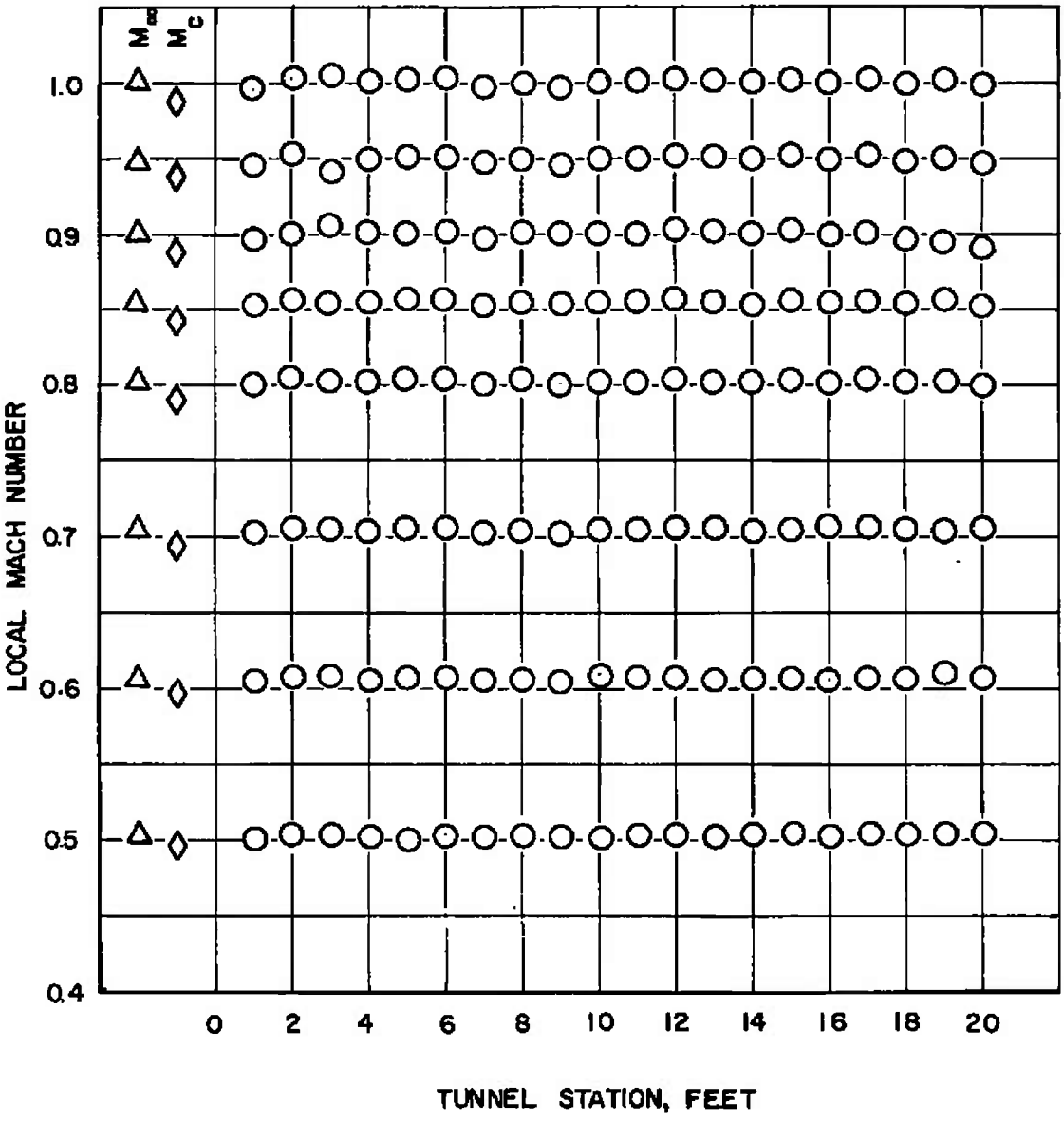
e. M_∞ = 0.70 to 1.00 at θ_w = −0.25 deg

Fig. 12 Continued



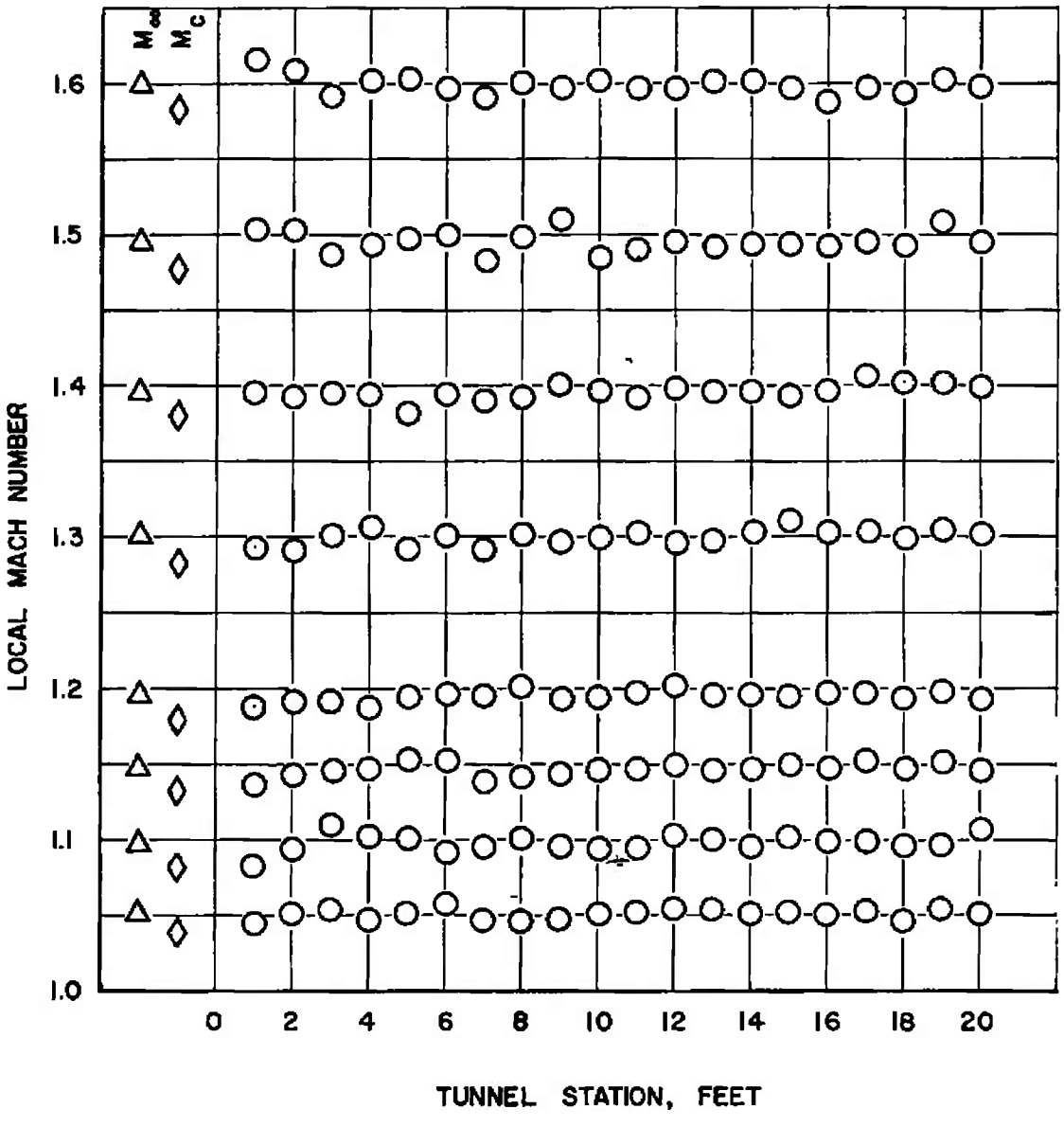
f. M_∞ = 1.05 to 1.60 at θ_w = −0.25 deg

Fig. 12 Continued



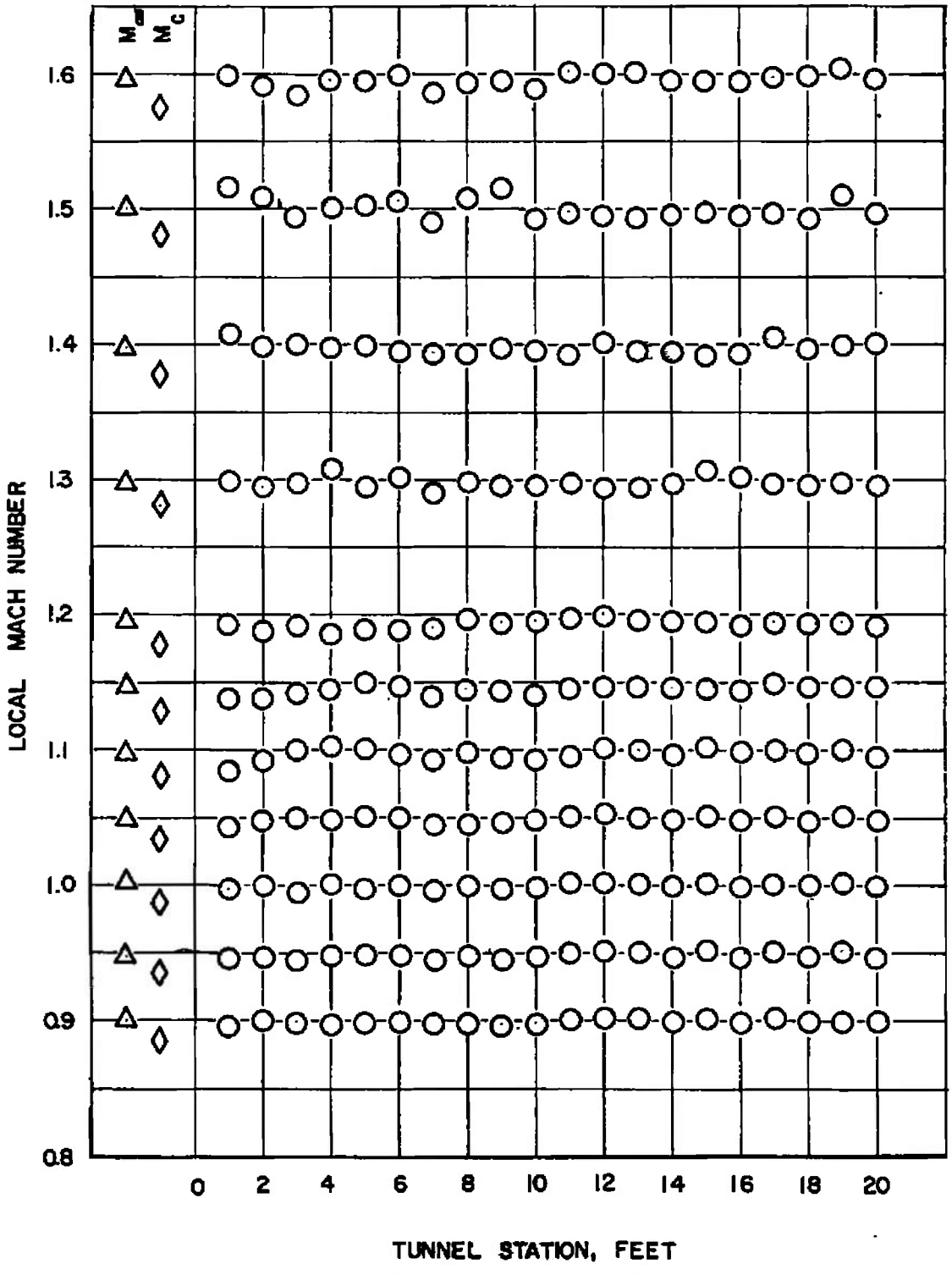
g, M_∞ = 0.50 to 1.00 at θ_w = 0 deg

Fig. 12 Continued



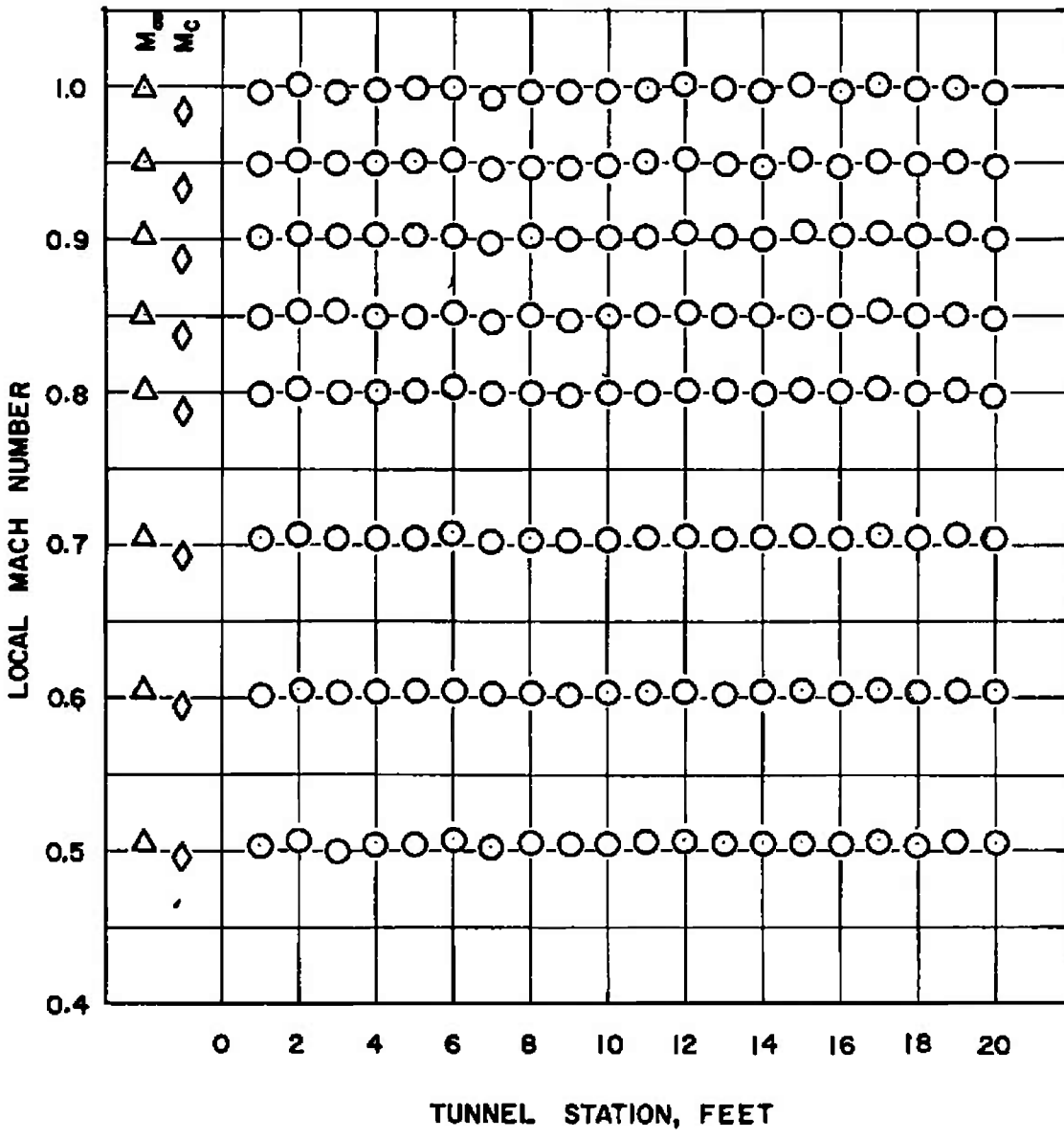
h. M_∞ = 1.05 to 1.60 at θ_w = 0 deg

Fig. 12 Continued



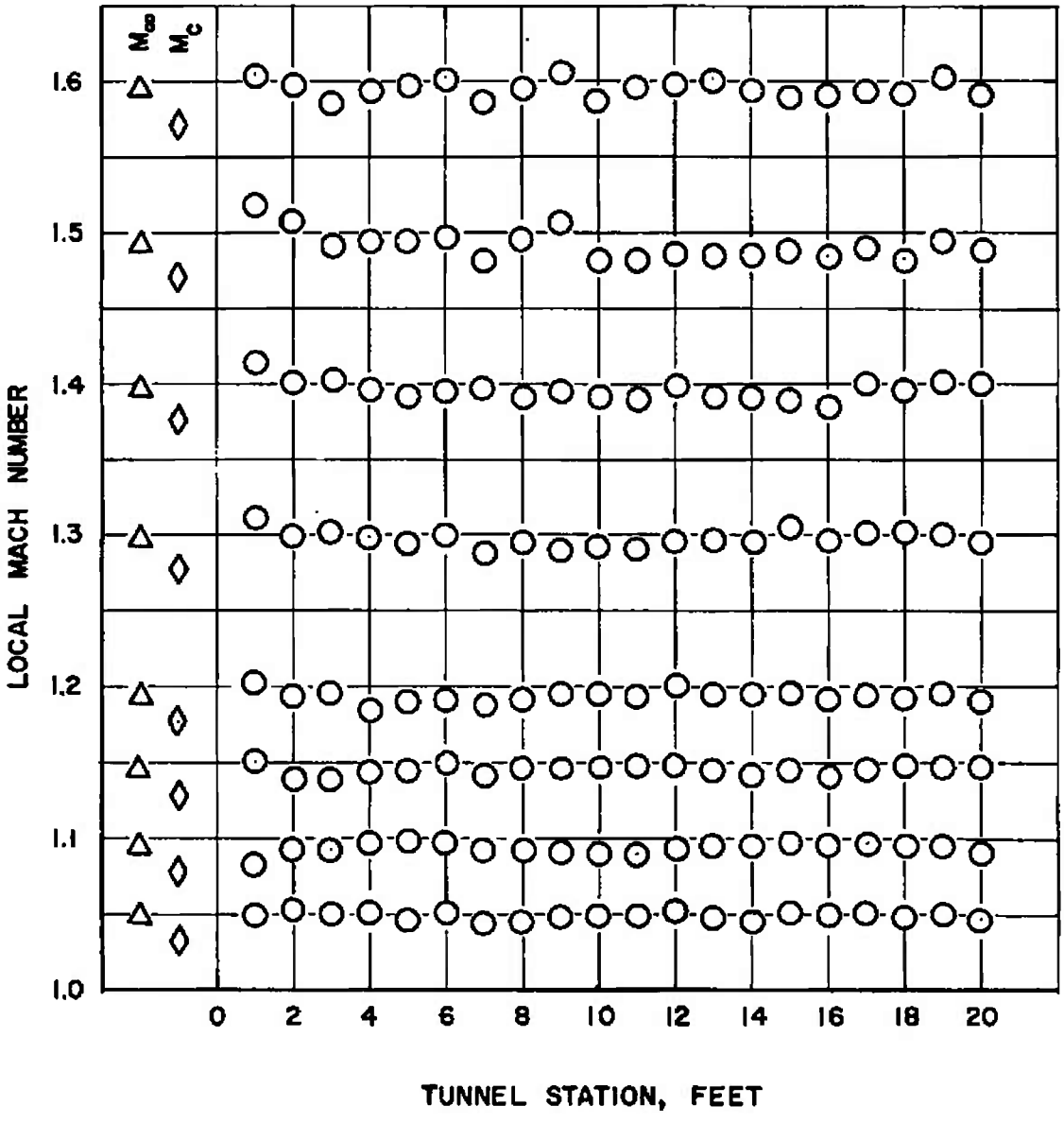
i. M_∞ = 0.90 to 1.60 at θ_w = + 0.25 deg

Fig. 12 Continued



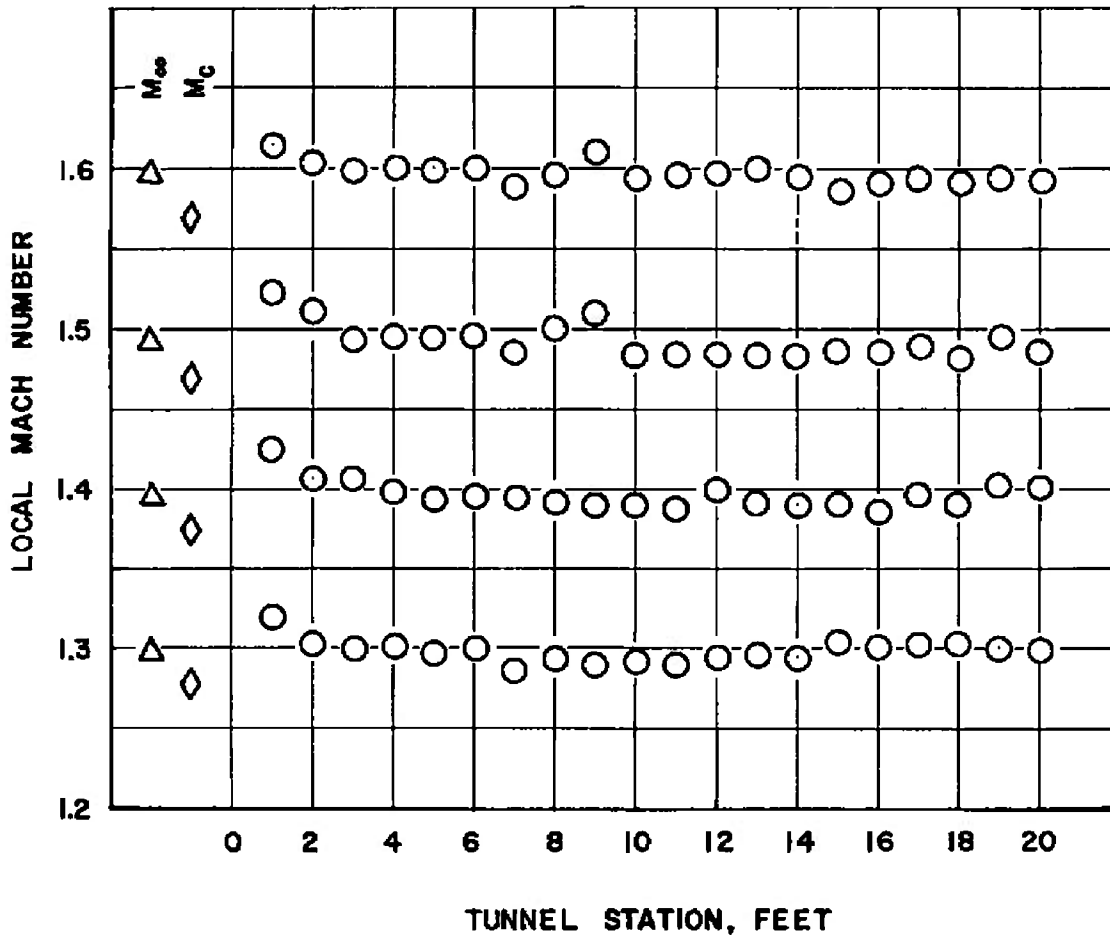
j. M_∞ = 0.50 to 1.00 at θ_w = +0.50 deg

Fig. 12 Continued



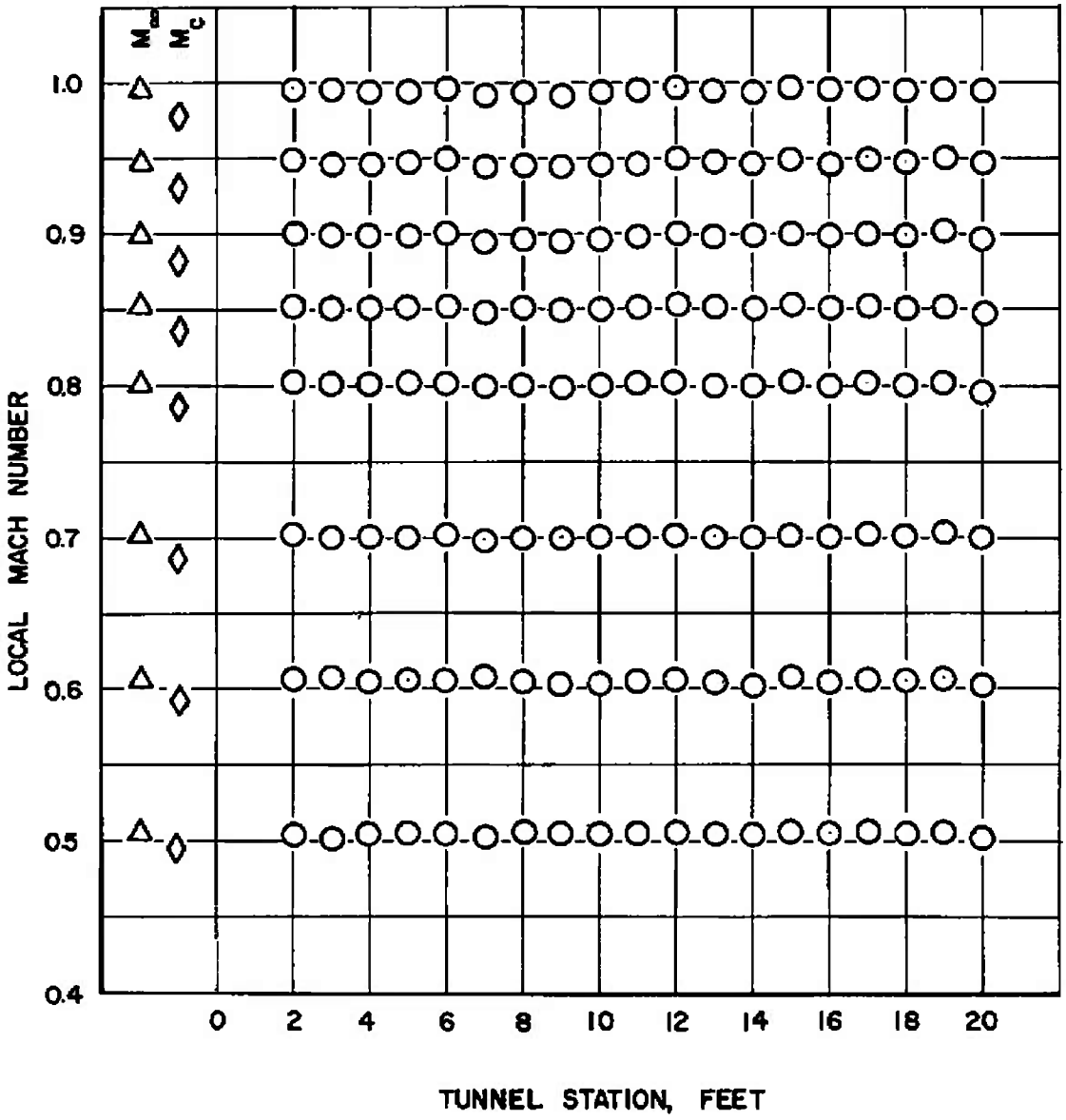
k. M_∞ = 1.00 to 1.60 at θ_w = + 0.50 deg

Fig. 12 Continued



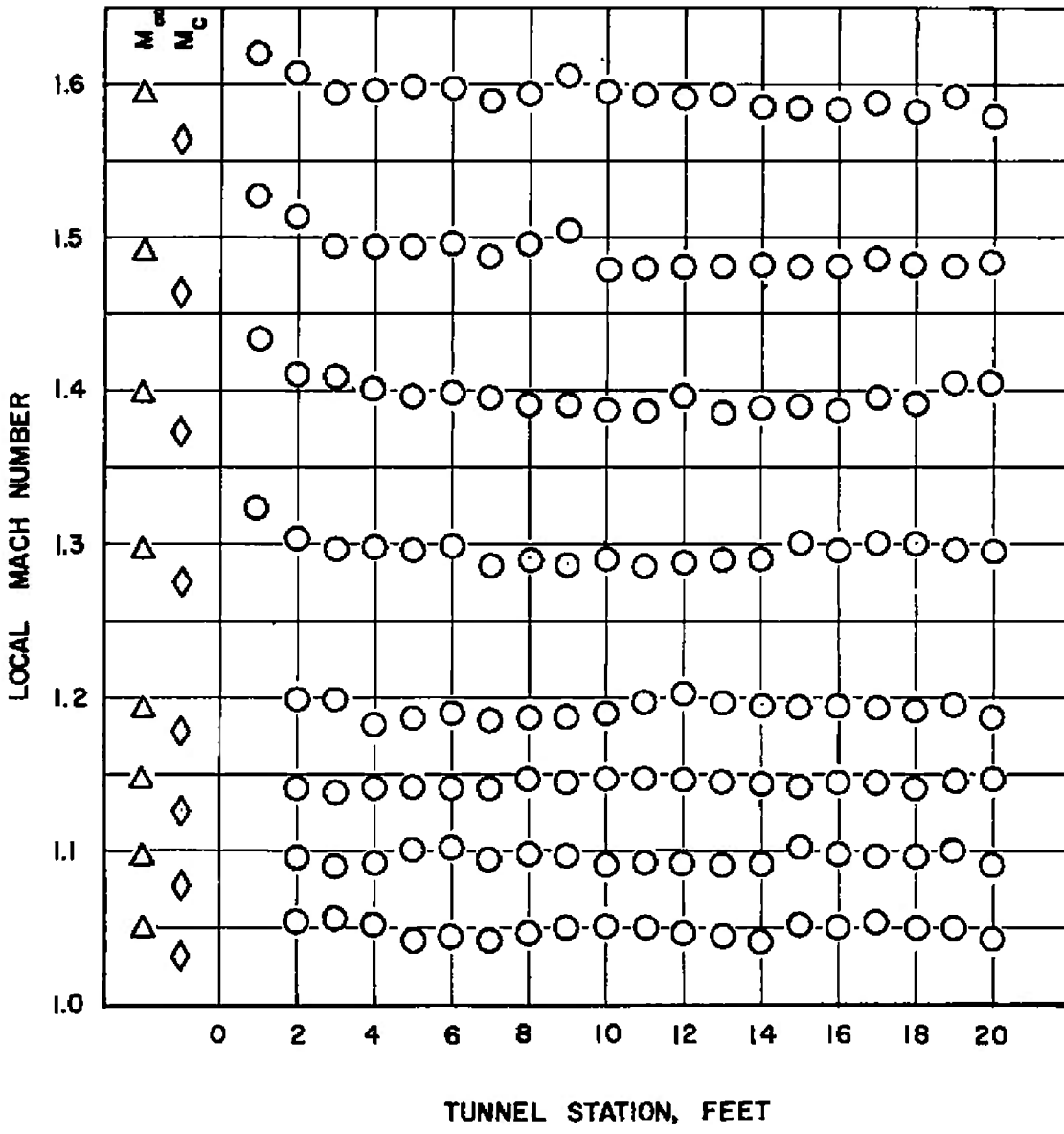
l. M_∞ = 1.30 to 1.60 at θ_w = +0.75 deg

Fig. 12 Continued



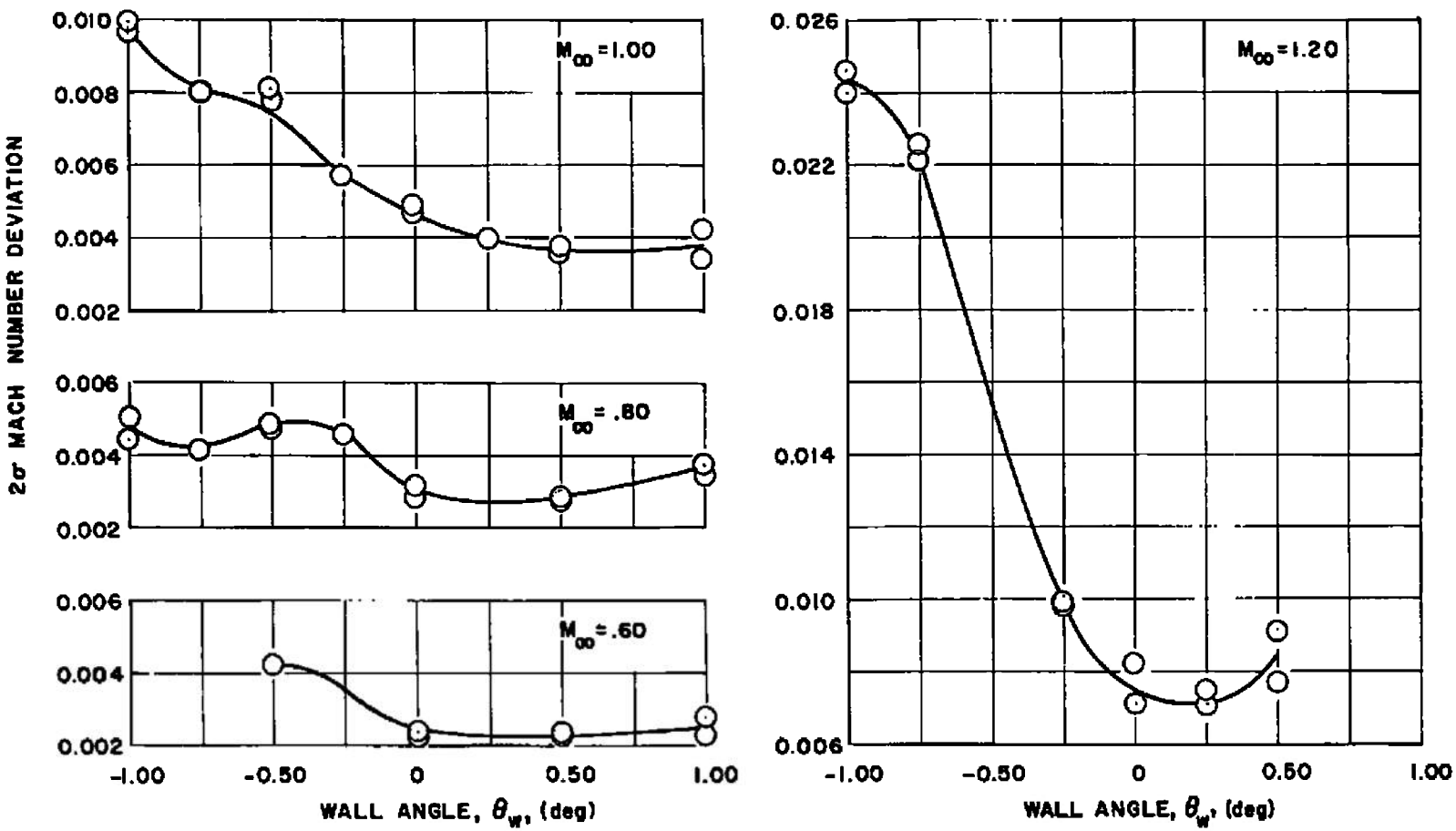
m. M_∞ = 0.50 to 1.00 at θ_w = + 1.00 deg

Fig. 12 Continued



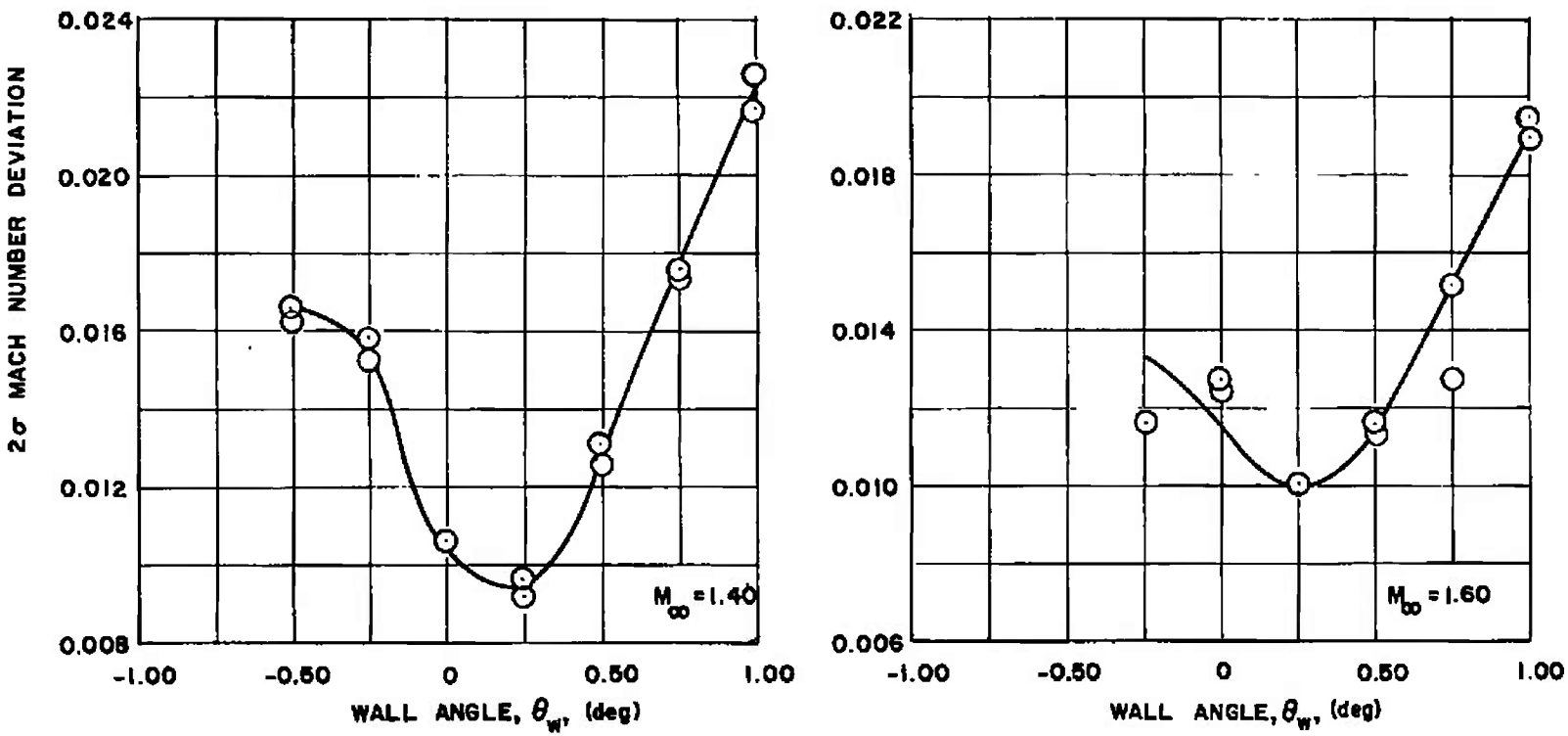
n. M_∞ = 1.05 to 1.60 at θ_w = + 1.00 deg

Fig. 12 Concluded



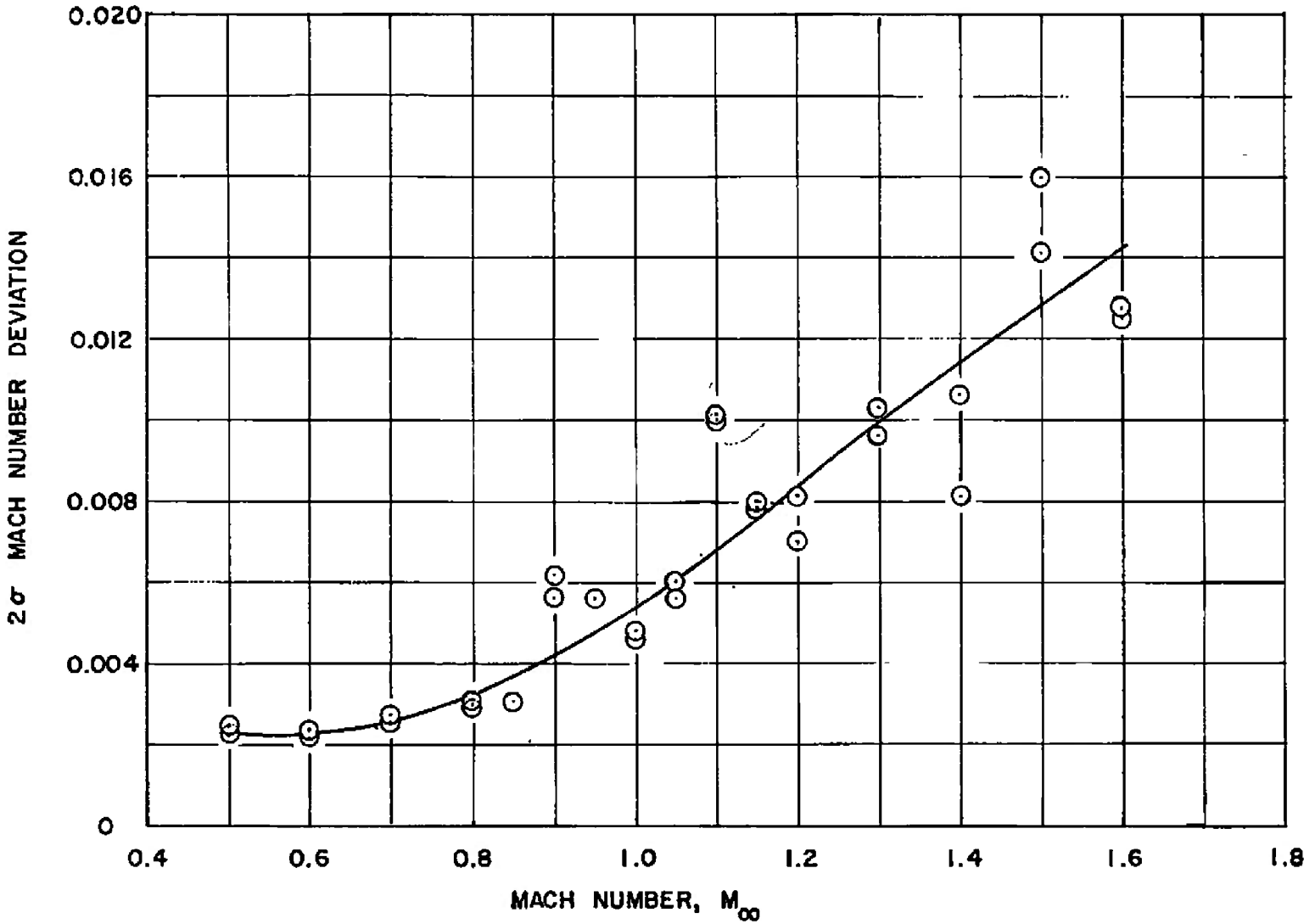
a. M_∞ = 0.60, 0.80, 1.00, and 1.20

Fig. 13 Statistical Evaluation of Empty Test Section Mach Number Deviations at Various Nominal Mach Numbers



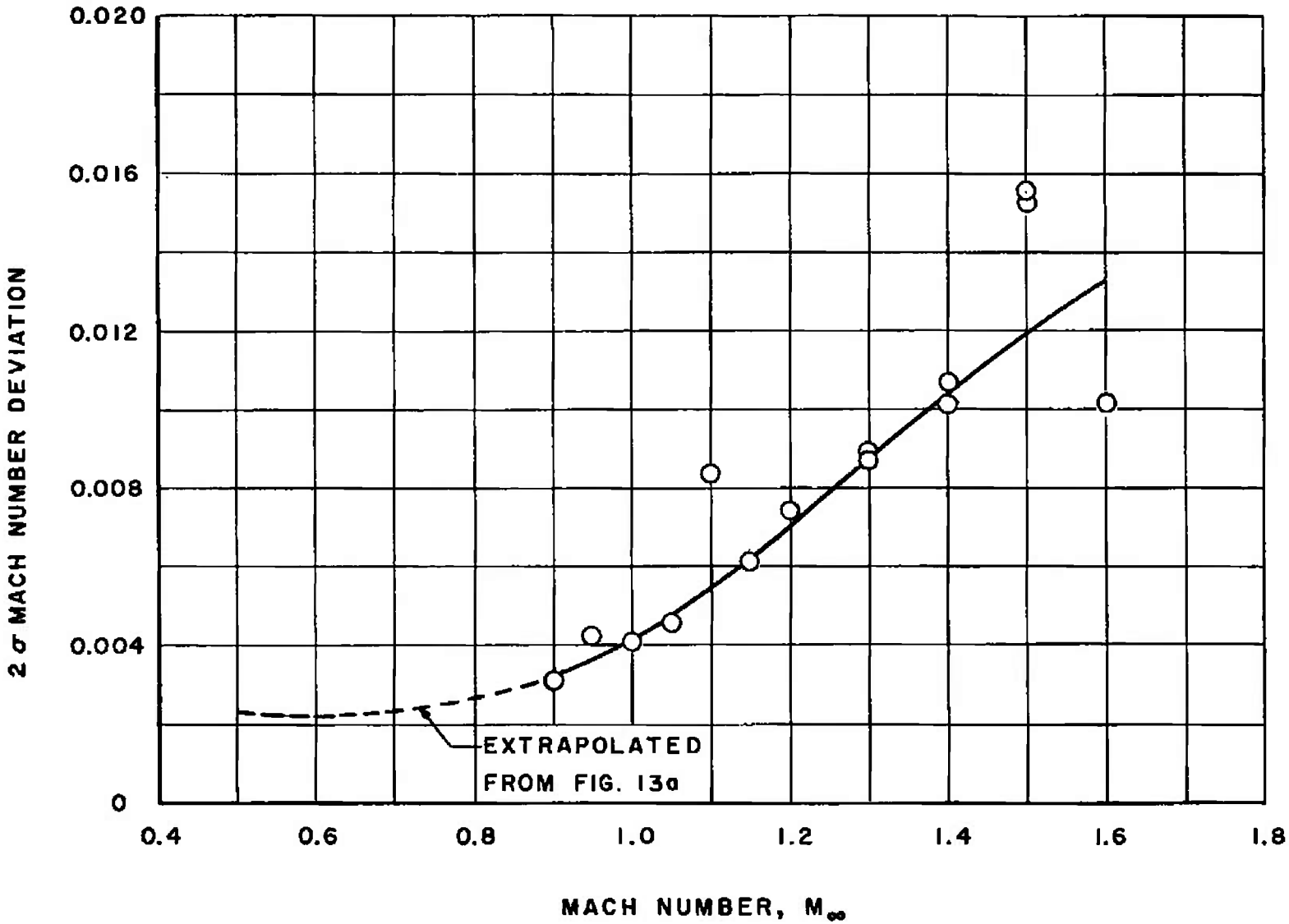
b. M_∞ = 1.40 and 1.60

Fig. 13 Concluded



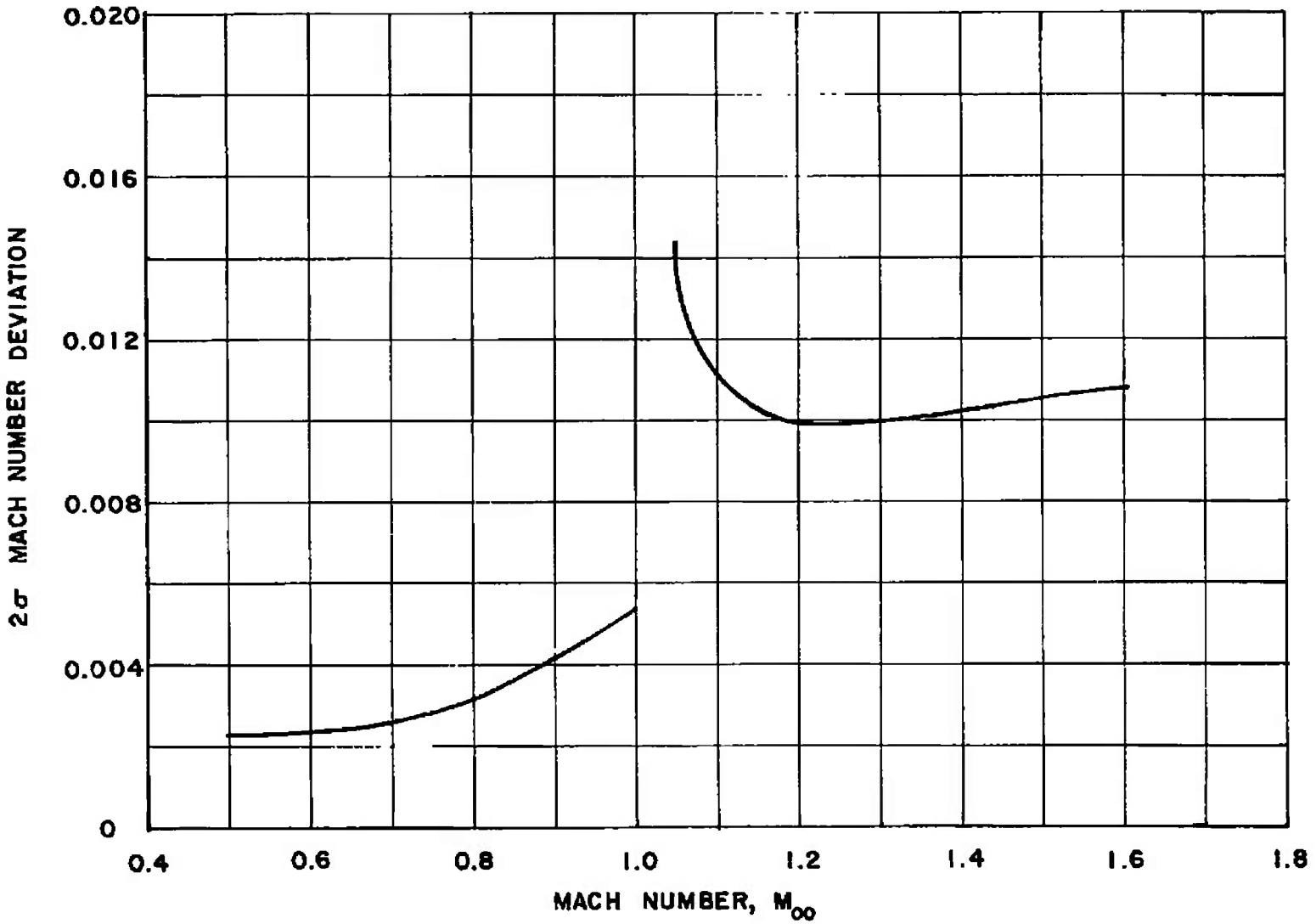
a. $\theta_w = 0$ deg

Fig. 14 Local Mach Number Variation at $\theta_w = 0$ deg, $\theta_w = 0.25$ deg, and $\theta_w = \theta_w^*$ Based on 95-percent Confidence Level



b. $\theta_w = 0.25$ deg

Fig. 14 Continued



c. $\theta_w = \theta_w^*$

Fig. 14 Concluded

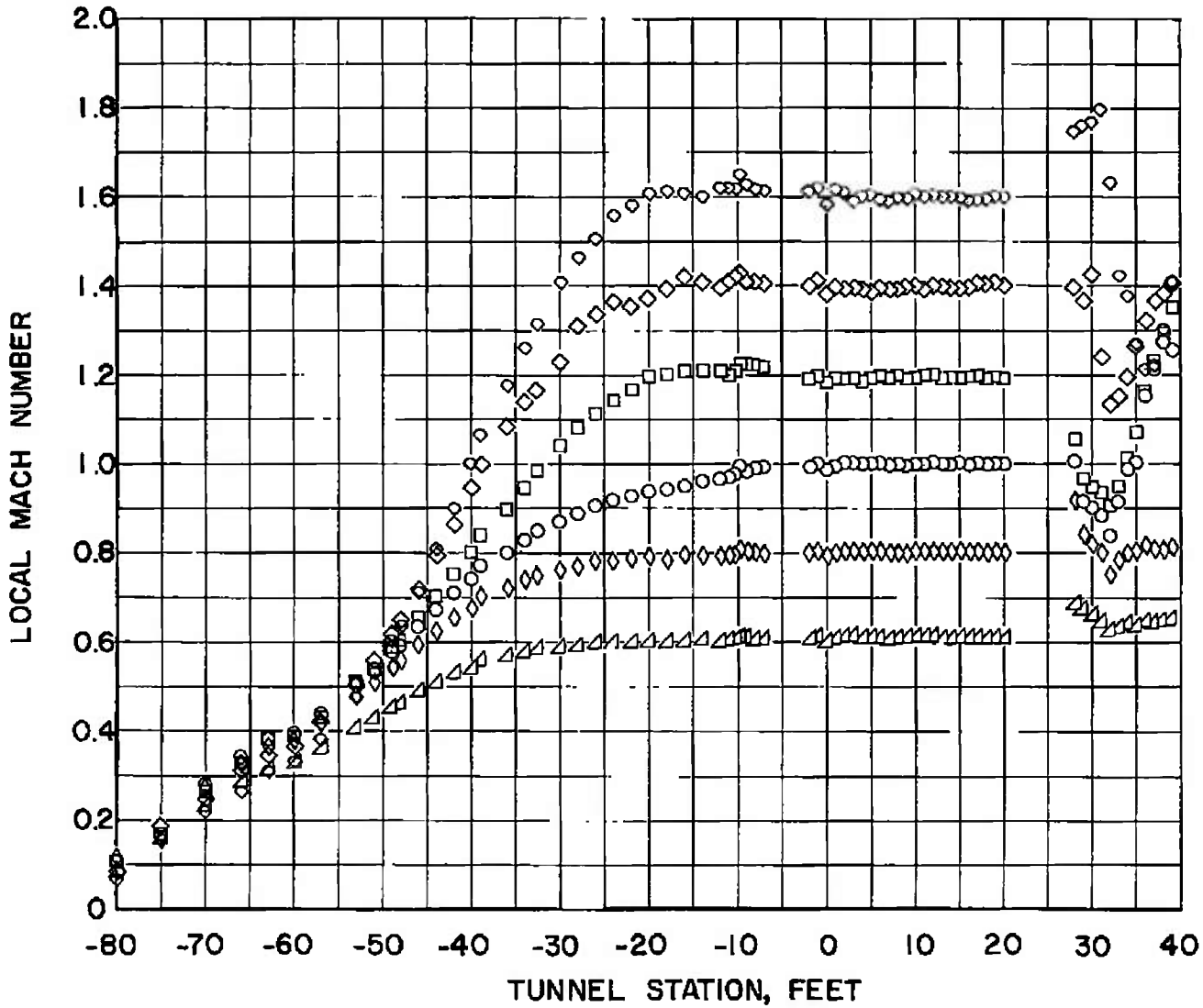


Fig. 15 Lower Wall Mach Number Distribution through Contraction, Nozzle, and Test Section for Various Test Section Mach Numbers at $\theta_w = 0$ deg

APPENDIX I
LINEARIZED CALIBRATION EQUATIONS

A goal of this test program was to reduce the calibration to a form which could be easily stored in the computer for on-line data reduction. This goal was achieved in the following manner:

The relation between (M_{TS} - M_c) and M_{TS}, Fig. 7, for a constant wall angle was approximated graphically by three straight-line segments. These segments formed the low, mid, and high transonic Mach number ranges. It should be noted that the parameters (M_{TS} - M_c) and M_{TS} were used instead of the more straightforward approach of M_{TS} and M_c to give more resolution to the data and, therefore, facilitate the graphical means of obtaining the calibration relations.

In any range the general equation of a line segment for a constant wall angle is:

$$(M_{TS} - M_c) = k M_{TS} + b \tag{I-1}$$

where k and b are the slope and intercept, respectively. Rearranging Eq. (I-1) gives

$$M_{TS} = \left(\frac{1}{1-k}\right) M_c + \left(\frac{b}{1-k}\right) \tag{I-2}$$

and defining the parameters

$$k_\theta = \left(\frac{1}{1-k}\right) \tag{I-3}$$

$$b_\theta = \left(\frac{b}{1-k}\right) \tag{I-4}$$

results in the equation

$$M_{TS} = k_\theta M_c + b_\theta \tag{I-5}$$

From the text it was concluded that

$$M_\infty = M_{TS} \tag{I-6}$$

and therefore

$$M_\infty = k_\theta M_c + b_\theta \tag{I-7}$$

It was assumed that k_θ and b_θ are functions of θ_w, and therefore a family of line segments can be defined in each range. The graphically measured values of k and b were used to calculate k_θ and b_θ, which were reduced by a computer to a "sum-of-the-least-squares" curve fit

for each range. The six equations formed are as follows: (Note the subscripts ℓ, m, and h denote low, medium, and high Mach number ranges)

$$k_{\theta_\ell} = (4.68349 \times 10^{-3})\,\theta_w^5 + (-8.94881 \times 10^{-3})\,\theta_w^4 + (1.04264 \times 10^{-2})\,\theta_w^3 + (-1.29942 \times 10^{-2})\,\theta_w^2 + (9.51048 \times 10^{-3})\,\theta_w + (1.01274) \quad \text{(I-8)}$$

$$b_{\theta_\ell} = (-4.82642 \times 10^{-3})\,\theta_w^5 + (9.38471 \times 10^{-3})\,\theta_w^4 + (-5.37987 \times 10^{-3})\,\theta_w^3 + (4.35438 \times 10^{-3})\,\theta_w^2 + (-2.03608 \times 10^{-3})\,\theta_w + (1.37811 \times 10^{-3}) \quad \text{(I-9)}$$

$$k_{\theta_m} = (-2.75364 \times 10^{-3})\,\theta_w^5 + (2.80392 \times 10^{-3})\,\theta_w^4 + (5.77389 \times 10^{-3})\,\theta_w^3 + (-3.42326 \times 10^{-3})\,\theta_w^2 + (6.00905 \times 10^{-3})\,\theta_w + (1.00268) \quad \text{(I-10)}$$

$$b_{\theta_m} = (2.77071 \times 10^{-4})\,\theta_w^5 + (-9.56196 \times 10^{-5})\,\theta_w^4 + (-2.66601 \times 10^{-4})\,\theta_w^3 + (-5.66745 \times 10^{-3})\,\theta_w^2 + (1.54495 \times 10^{-3})\,\theta_w + (1.12929 \times 10^{-2}) \quad \text{(I-11)}$$

$$k_{\theta_h} = (-1.19467 \times 10^{-3})\,\theta_w^5 + (3.21790 \times 10^{-3})\,\theta_w^4 + (5.42545 \times 10^{-3})\,\theta_w^3 + (-2.48307 \times 10^{-2})\,\theta_w^2 + (3.78741 \times 10^{-2})\,\theta_w + (1.00519) \quad \text{(I-12)}$$

$$b_{\theta_h} = (-2.68307 \times 10^{-3})\,\theta_w^5 + (-3.23442 \times 10^{-3})\,\theta_w^4 + (5.51800 \times 10^{-3})\,\theta_w^3 + (1.85721 \times 10^{-2})\,\theta_w^2 + (-3.62867 \times 10^{-2})\,\theta_w + (8.25986 \times 10^{-3}) \quad \text{(I-13)}$$

Values of θ_W from -1.00 to +1.00 deg in increments of 0.10 deg were used to evaluate the intersection points of the straight line segments between adjoining regions. These intersection points were fitted to fifth-order polynomials for M_C and M_∞ as functions of θ_W. The resulting four equations are:

$$M_{c(\ell,m)} = (-1.07567 \times 10^{-1})\,\theta_w^5 + (4.54862 \times 10^{-3})\,\theta_w^4 + (1.67529 \times 10^{-1})\,\theta_w^3 + (-5.74300 \times 10^{-2})\,\theta_w^2 + (3.12362 \times 10^{-3})\,\theta_w + (9.85932 \times 10^{-1}) \quad \text{(I-14)}$$

$$M_{c(m,h)} = (5.01108 \times 10^{-2})\,\theta_w^5 + (8.42477 \times 10^{-2})\,\theta_w^4 + (-4.36116 \times 10^{-2})\,\theta_w^3 + (-1.80925 \times 10^{-1})\,\theta_w^2 + 5.92472 \times 10^{-2})\,\theta_w + (1.19274) \quad \text{(I-15)}$$

$$M_{\infty(\ell,m)} = (-1.22475 \times 10^{-1})\,\theta_w^5 + (1.12770 \times 10^{-2})\,\theta_w^4 + (1.88121 \times 10^{-1})\,\theta_w^3 + (-7.07909 \times 10^{-2})\,\theta_w^2 + (7.66990 \times 10^{-3})\,\theta_w + (1.00029) \qquad \text{(I-16)}$$

$$M_{\infty(m,h)} = (3.08744 \times 10^{-2})\,\theta_w^5 + (1.20774 \times 10^{-1})\,\theta_w^4 + (-2.02932 \times 10^{-2})\,\theta_w^3 + (-2.27465 \times 10^{-1})\,\theta_w^2 + (6.55277 \times 10^{-2})\,\theta_w + (1.21393) \qquad \text{(I-17)}$$

The equations $M_{\infty(\ell, m)}$ and $M_{\infty(m, h)}$ are used in the program which compiles the table for setting Mach number in Tunnel 16T while $M_{c(\ell, m)}$ and $M_{c(m, h)}$ are used in the on-line data reduction program which evaluates M_∞.

A plot of the linearized calibration equations for θ_W = -1.00 to +1.00 deg in increments of 0.25 deg is shown in Fig. I-1. The region in which linearization produced a deviation of ±0.001 or less in M_∞ from the calibration data is given in Fig. I-2.

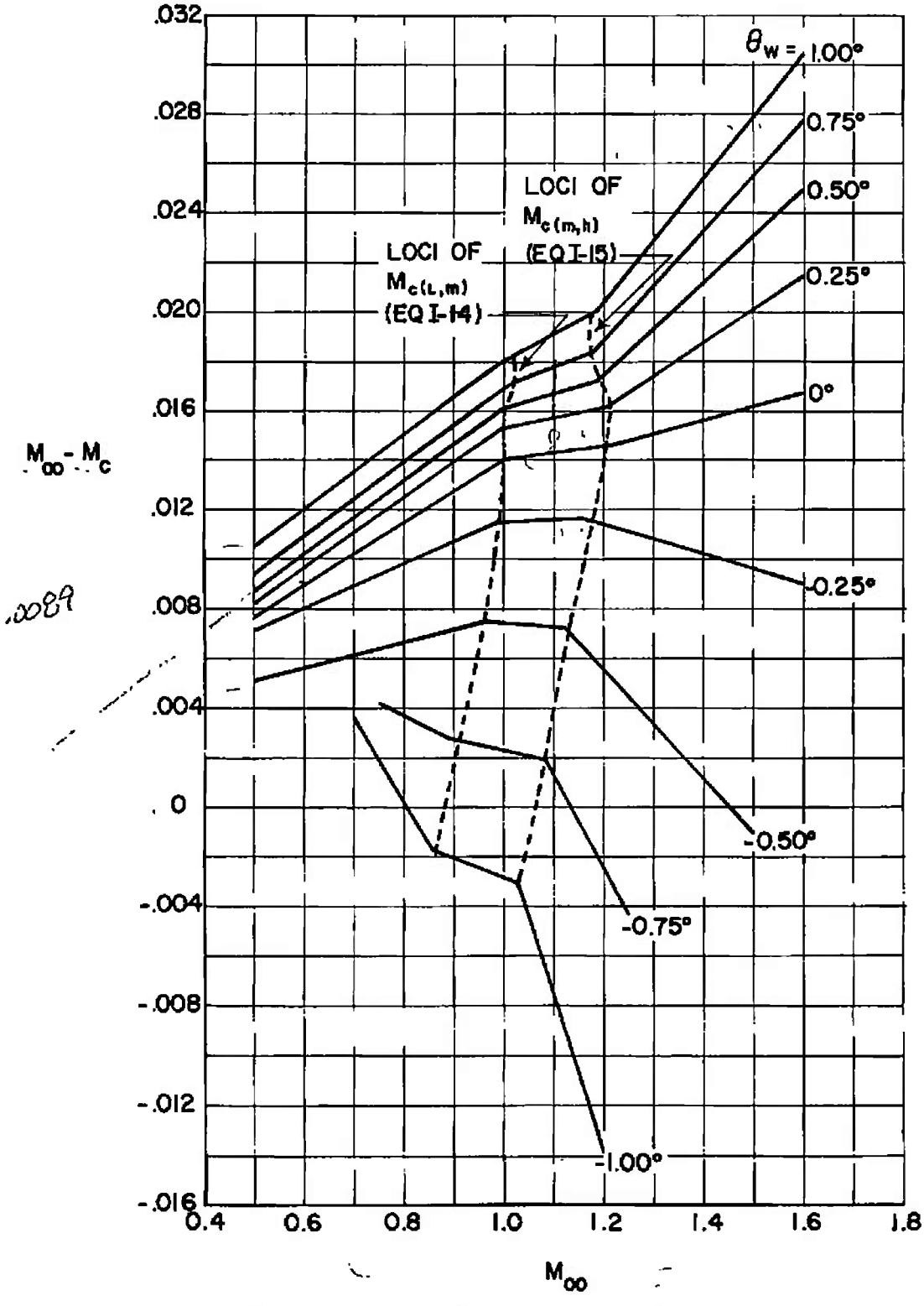


Fig. I-1 Calibration Reduced to Linear Functions

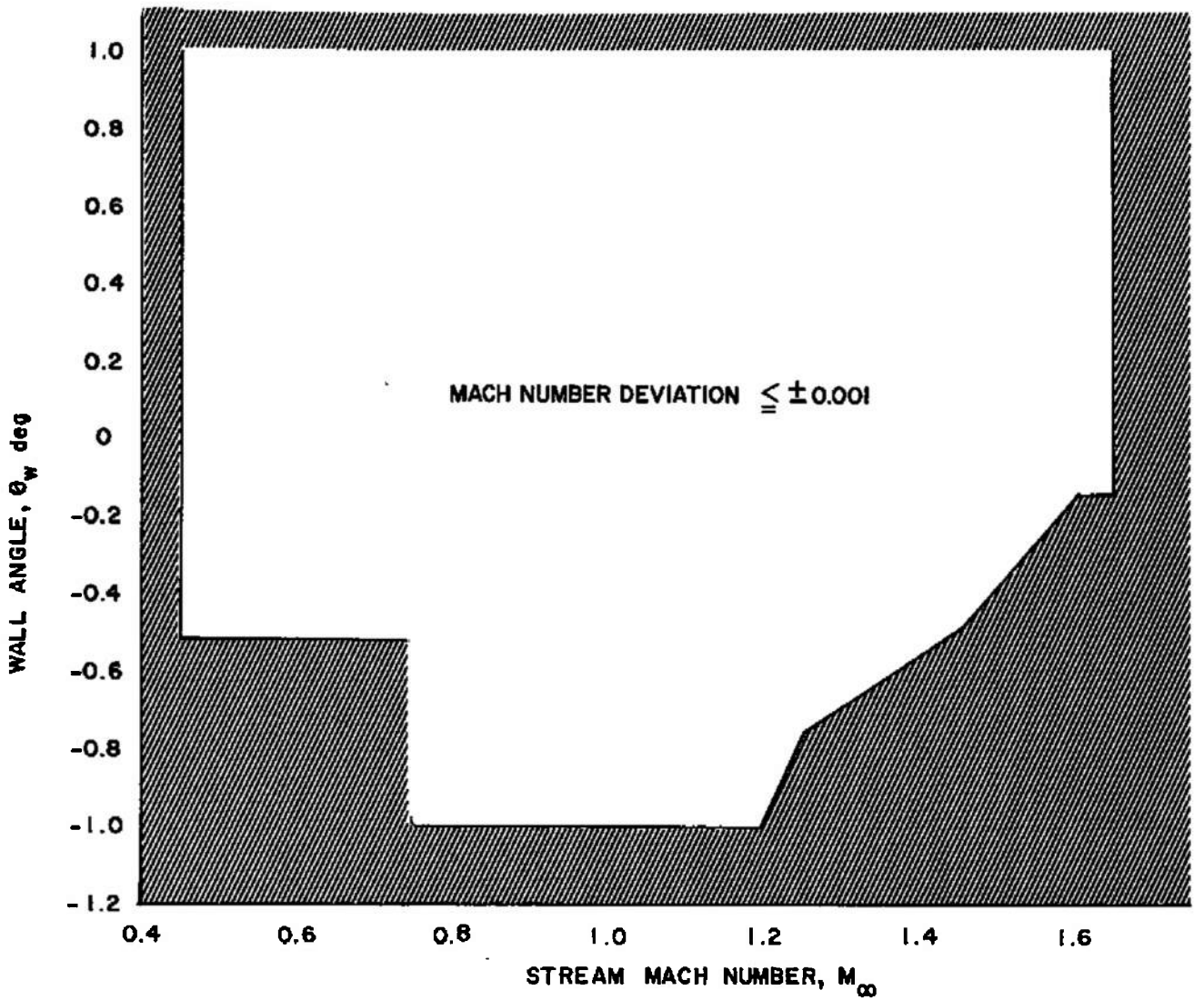


Fig. I-2 Operating Region in which Linearized Calibration Resulted in a Maximum Deviation of ±0.001 in Mach Number from Calibration Data

APPENDIX II
SUPPLEMENTAL CALIBRATION INFORMATION

In previous calibration reports, such as Refs. 2 and 3, the tunnel pressure ratio has been defined as the ratio of tunnel total pressure to the static pressure at the downstream end of the diffuser. This ratio has usually been given the symbols λ or λ_{210}. In April 1965 this definition was changed so that the tunnel pressure ratio, λ_T, is the ratio of tunnel total pressure to the compressor inlet static pressure. The correlation between λ_T and λ_{210} is given in Fig. II-1. This change is applicable to all Tunnel 16T calibration reports preceding April 1965.

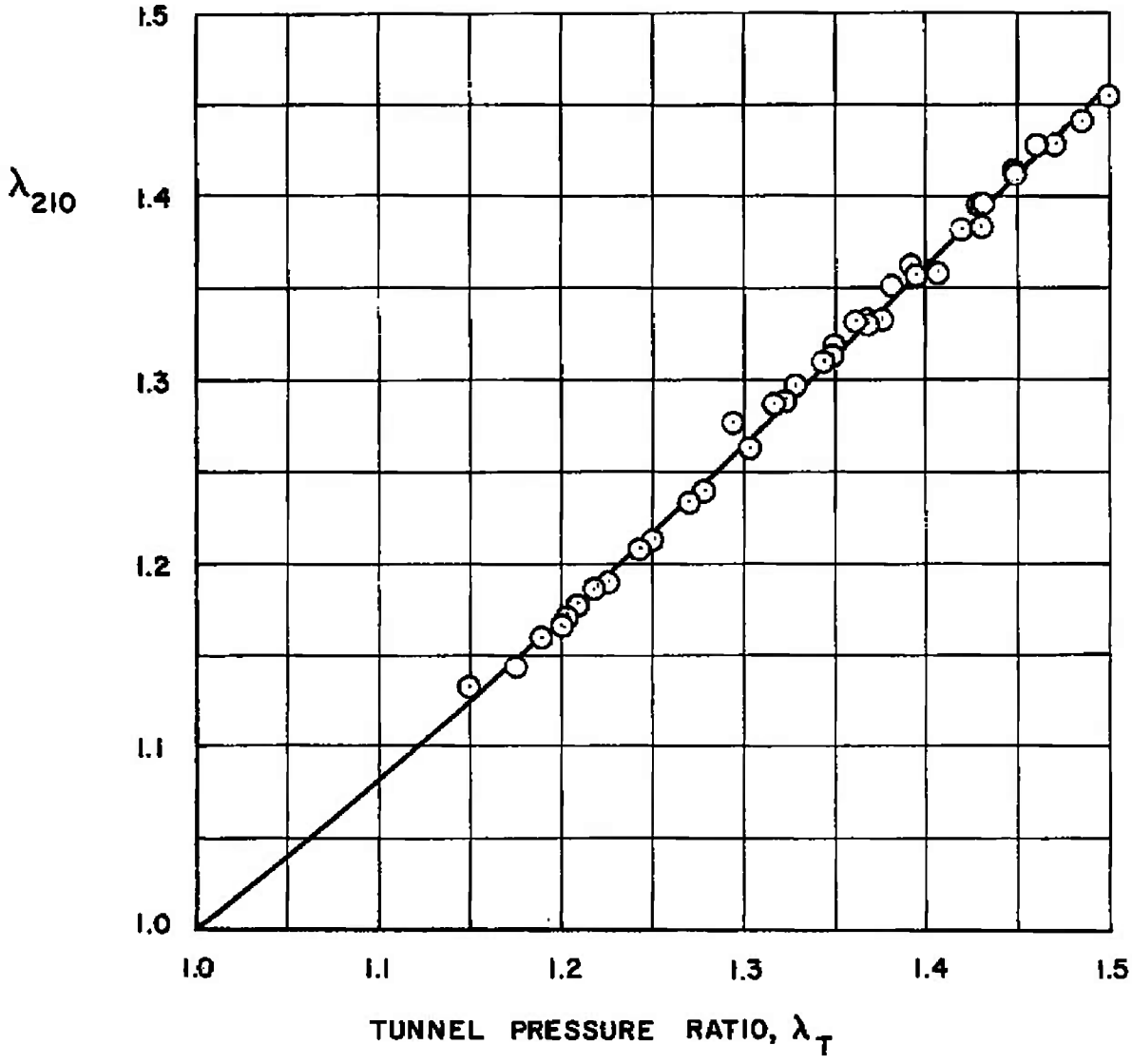


Fig. II-1 Relation between Previous Definition of Tunnel Pressure Ratio, λ_{210}, and Present Pressure Ratio, λ_T, Definition – Effective April 1965

APPENDIX III
STANDARD DEVIATION

The standard deviation, σ, of a set of n numbers, x_1, x_2, ... x_n, is approximately the root-mean-square (rms) deviation of the numbers from their average.

Even though the longitudinal deviations in Mach number from the geometric average may not be entirely a random function, the concept of random deviation may be applied to a large sample of data with some meaningful results. Mathematically applied to the Tunnel 16T Mach number data obtained from 20 orifices (n = 20) at a constant wall angle:

$$M_\infty = \frac{\sum_{i=1}^{n} M_{TS_i}}{n} \tag{III-1}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} \left(M_{TS_i} - M_\infty\right)^2}{n-1}} \tag{III-2}$$

The standard deviation is an extremely useful distribution function since it is a measure of the distribution band. For example, 95.4 percent of all numbers of a data set which has a normal distribution will fall between -2σ and $+2\sigma$.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Arnold Engineering Development Center ARO, Inc., Operating Contractor Arnold Air Force Station, Tennessee	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

CHECK CALIBRATION OF THE AEDC 16-FT TRANSONIC TUNNEL

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

N/A

5. AUTHOR(S) *(Last name, first name, initial)*

Gunn, J. A., ARO, Inc.

6. REPORT DATE May 1966	7a. TOTAL NO. OF PAGES 55	7b. NO. OF REFS 4
8a. CONTRACT OR GRANT NO. AF 40(600)-1200 b. Program Element 65402234 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-66-80 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* N/A	

10. AVAILABILITY/LIMITATION NOTICES

Qualified users may obtain copies of this report from DDC.

11. SUPPLEMENTARY NOTES N/A	12. SPONSORING MILITARY ACTIVITY Arnold Engineering Development Center Air Force Systems Command Arnold Air Force Station, Tennessee

13. ABSTRACT

Tests were conducted in the Propulsion Wind Tunnel, Transonic (16T) of the Propulsion Wind Tunnel Facility (PWT) to determine the test section Mach number calibration and Mach number distributions. During the test, Mach number was varied from 0.50 to 1.60, and the wall angle from -1.00 to +1.00 deg, while holding tunnel total pressure at 1000 psfa and tunnel temperature at 120°F. At all Mach numbers the region from Station 1 to Station 20 was considered the test region. The results show that the tunnel calibration is a function of test section wall angle, and that all wall angles in the calibrated Mach number range produce Mach number distributions acceptable for testing. This was the first calibration after the installation of the modified main compressor utilizing fiber glass rotor blades.

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification

14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Transonic Flow Wind Tunnels Calibration						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.