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June 1971

AN EXPERIMENTAL STUDY OF NOZZLES AND SPECIFIC HEAT RATIO EFFECTS ON OFF-DESIGN PERFORMANCE OF PARTIAL ADMISSION TURBINES

PREPARED BY

R. S. PETERSON
S. C. PASKEVICH

FOR THE
OFFICE OF NAVAL RESEARCH
WASHINGTON, D.C.

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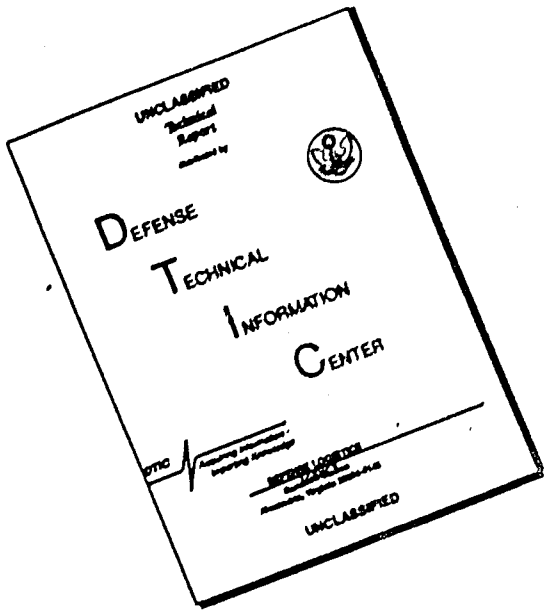

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13. ABSTRACT

A The? ~~This~~ report covers experimental work performed to determine the effect of nozzle divergence angle, specific heat ratio and plug nozzle configuration on turbine nozzle performance. Off design performance was the primary area of investigation. The effect of nozzle divergence angle was investigated with conical and contoured nozzles for two Mach numbers over a range of speed and pressure ratios. The performance of selected plug nozzle geometries was measured over a range of speed and pressure ratios. The influence on performance of the gas specific heat ratios was experimentally determined by testing the same nozzle with gases of different specific heat ratios. The reduced experimental data is presented in tabular form as well as graphic presentation in several formats.

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SUBJECT

In attaining optimum turbine performance, the nozzle is the single most influential component. Small, high specific energy turbines, generally operating at high pressure ratios, require supersonic converging-diverging nozzles for high efficiency. Such nozzles, however, yield poor performance at off-design pressure ratios. The object of this study was to obtain design information to improve performance.

A comprehensive experimental program was undertaken to optimize nozzle divergence and evaluate plug nozzles and the off-design effects of specific heat ratio. No real analysis work was to be performed under this contract with discussion and presentation sufficient only to serve as a guide to use of the report.

Nozzle performance was evaluated from test measurements of a complete turbine-nozzle system. All nozzles were tested on nitrogen and in Phase III, the nozzle which had shown the best performance on nitrogen was tested with Argon (γ = 1.68) and Freon 13 (γ = 1.18) to evaluate the effects of specific heat ratio. All testing was done with the same rotor. A total of eleven different nozzles were tested; 5 straight conical designs with the same design Mach Number (2.5) and area ratio, but different divergence angles downstream of the throat (7° to 15° half angle), a similar program with nozzles of design mach no. = 4, two annular throat plug nozzles and a 2 dimensional "half plug" design.

Results show that an optimum nozzle divergence exists but not for all conditions. The 11° and 13° half angle nozzles maintain a consistent advantage in peak efficien cy and range capability (minimum variation in efficiency during off-design pressure ratio operation), but only with the lower design pressure ratio nozzles tested (M_D = 2.5). No such clear advantage appeared in the results of the M_D = 4.0 nozzles tested; the performance of all divergence angles seemed to merge into one band of width on the same order as the scatter although the narrow (7°) nozzle displayed a small advantage in peak efficiency.

Plug nozzles exhibited no significant performance advantage over straight conical designs - their range (efficiency variation) appears marginally better in a few cases but the peak efficiency is consistently lower than the poorest conical design tested in the mach 2.5 series, and this more than makes up for it.

The effect of specific heat ratio seems to be a small reduction of peak efficiency and improved range (less efficiency variation over a range of pressure ratios).

Off-design speed effects as revealed by the shape of the u/C_o - η_T curve (pointed vs wide) appeared small throughout the study.

INTRODUCTION

Many military turbine applications require operation over a wide range of pressure ratios. Such applications would include any underwater device operating at varying depth and aero-space vehicles such as missiles aircraft and space vehicles that operate from sea level to outer space. This off-design regime often accounts for a significant portion of the mission profile.

Nozzle and rotor performance has a large effect on the ultimate obtainable turbine efficiency with the nozzle being much the more important, hence under a previous contract (N00014-66-C-0204) Sundstrand conducted a turbine off-design performance study, reported on in Reference 1; Sundstrand AER 486, dated April 1967, "Effect of Nozzle Geometry on Off-Design Performance of Partial Admission Impulse Turbines".

The present study extends the work done under the previous contract although primarily an experimental program whereas the previous one was principally analytical in nature.

The objectives of this study were to (I) experimentally optimize the divergence angle of straight conical supersonic turbine nozzles, (II) determine what, if any, off-design advantage can be gained with plug nozzles, (III) determine the effect of specific heat ratio on off-design performance.

1.0 EXPERIMENTAL APPARATUS, TEST TECHNIQUES AND DATA REDUCTION

This study was made using a test dynamometer designed and built by Sundstrand. The test apparatus and techniques were developed over a number of years while performing various turbine research and development studies.

1.1 TURBINE TEST DYNAMOMETER

The turbine test facility is illustrated in Figure 1 and is specifically designed to evaluate the effects of turbine geometry on performance. Rapid changes in rotors, nozzles, and rotor tip and side clearances are easily made. Shaft power is determined by a torque arm force measurement, the load being applied by an electrical homopolar dynamometer. Turbine bearing losses are included in the torque arm measurement since the entire rotating group is supported by special low friction ball bearings. The dynamometer is shown in Figures 2, 3 and 4. Typical test hardware is shown in Figure 5.

The facility is capable of testing turbines at pressure ratios up to 2500. The entire test unit is located in a vacuum chamber during tests such that exhaust pressures as low as 0.25 psia are possible. The maximum test turbine speed is 40,000 rpm. Turbine diameters up to approximately 7 inches can be accommodated. Output shaft power levels of up to 20 hp can be absorbed by the electrical load bank.

Tests to obtain turbine efficiency as a function of turbine geometry, pressure ratio, speed, and Reynolds number can be conducted.

Testing shows an average scatter of 5% in the turbine efficiency data (about 3 points). This scatter appears to be random, yielding an accurate and reliable mean when curve fitting techniques are used with large quantities of data, as in this present study. The nozzle flow rate is measured by an orifice plate flowmeter showing scatter in the flow data of .75%. Instrumentation to obtain complete pressure and temperature data throughout the turbine can be employed.

All tests were made with the shrouded turbine wheel and turbine exhaust housing shown in Figure 5. During all tests the radial tip clearance was .050 inch; the axial clearance between the nozzle and the wheel was .035 inch. Table III presents geometric parameters that were common during all tests and Table IV summarizes test conditions.

1.2 TURBINE NOZZLE TEST CONFIGURATIONS

Three types of nozzles were studied; straight conical, axi symetric plug nozzles (two styles), and a 2-dimensional or "half plug" design.

1.2.1 Conical Nozzles

All conical nozzles are in the same nozzle plate and were tested individually with the remainder plugged. The plate includes two sets of five nozzles of different design conditions (M_D = 2.5, A/A* = 2.63, and M_D = 4.0, A/A* = 10.72) with divergence half angles α_c from 7° to 15° in each set. The exit diameter of all conical nozzles is .282 inch. The relationship between nozzle exit and blades is shown in Figure 8. The conical nozzles are quite simple in design and are sketched with dimensions tabulated in Figure 6.

The conical nozzles were selected as the basis of comparison in this study since they are the most common type used in partial admission turbines.

1.2.2 Plug Nozzles

The plug nozzles are illustrated in Figure 7. The annular throat nozzles ("A" and "B") were designed per the procedure of Rao (Reference 2) and both have an exit diameter of .280. The 2-dimensional half plug (c) was also designed per his procedure, with an exit height of .280 and a throat height of .162. The design mach number of all plug nozzles was 2.5, for easy comparison with the M_D = 2.5 conicals.

All plug nozzles were machined in the same plate with their centerlines tangent to a common pitch diameter of 5.96 inch as were the conicals.

1.3 TEST TECHNIQUES

A test run was made by pressurizing the turbine inlet to a prescribed value (not greater than 240 psia) and adjusting the turbine back pressure to the prescribed level to obtain the desired pressure ratio. Data was then taken at 6 or 7 turbine speeds from 7000 to 35000 rpm. The speed was controlled by adjustment of the homopolar alternator load resistance (coarse adjustment) and the field voltage (fine adjustment). After the speed range was covered by increasing speed, the points were retaken as it was decreased back to the starting speed in order to minimize effects of mechanical hysteresis, resulting in 11 to 14 points per test run. Next the back pressure was adjusted to the next prescribed pressure ratio and the speed points repeated. At 5 pressure ratios per nozzle this resulted in approximately 55 to 65 data points per nozzle test and a program total of over 700.

The turbine pressure ratio was evaluated by measuring the pressure in the turbine nozzle plenum chamber, which the nozzle plate seats against, and pressure in the exhaust duct just downstream of the turbine. The turbine flow rate was measured by an orifice meter in the inlet line leading to the turbine plenum. At each data point conditions were allowed to stabilize before recording the data and then proceeding to the next point. Approximately three minutes of run time were required at each data point. With one exception, all pressures (and torque, which was reflected as a differential pressure) were detected with pressure transducers and recorded automatically on a strip chart. The orifice plate pressure was read on a Bourdon pressure gage and written manually on the chart and orifice plate ΔP was detected with a Bailey pressure transmitter and recorded on the strip chart. All temperatures were measured with copper constantan thermocouples and recorded on the trace. Speed was measured with a magnetic pickup and recorded manually from an electronic counter.

The torque readout device was calibrated before and after each run by the application of dead weight to the torque arm. If significant variations in the pre- and post-calibration points occurred, the data was discarded and a rerun made.

The data were recorded and later reduced by a computer program to obtain the desired performance parameters. The flow rate was determined from the orifice measurements as well as the perfect gas choked flow equation. In this manner the flow discharge coefficient was obtained; if an unexplainable variation in this coefficient was found the data was discarded as unreliable and the test was rerun.

1.4 DATA REDUCTION PROCEDURES

The data was reduced utilizing an IBM 1130 computer. The data reduction program (Sundstrand E2) includes curve fits of compressibility factor and ratio of specific heats for nitrogen, obtained from Reference 4. These properties are calculated as functions of local static temperature and pressure, and can be input when a gas other than nitrogen is used as the test fluid.

This program calculates the turbine gas flow from both the orifice measurements and from the perfect gas relationship for choked nozzles. Comparison of these two values yields the nozzle discharge coefficient. The turbine efficiency is then calculated based upon (1) the measured torque, speed, and orifice flow rate values and (2) the measured temperature difference. The second calculation is for a comparison only, since no attempt to obtain an adiabatic process was made. Other parameters such as the specific speed, specific diameter, torque coefficient, shaft horsepower, adiabatic head, velocity ratio, and wheel tip speed are also calculated.

The reduced turbine efficiency data is estimated to have an accuracy of 5%. This is considered acceptable in light of the fact is appears random with no systematic errors, strongly suggesting that the mean value is a valid representation of the true efficiency with the large quantities of data available.

To reduce the effect of irregular or scattered data points a least squares curve fit program was written and the data processed and cross plotted. An indication of the validity of this procedure is that the resulting computer plots agree in almost all predominant trends and values with some 25 manual summary plots made while data was being collected, and where the two disagree the computer plots appear the more reasonable.

LEAST SQUARES DATA SMOOTHING PROGRAM

The output of program E-2 was used in the least squares program to arrive at a smoothed data representation. To further reduce the effect of scatter, sets of data points were grouped together.

The general equation of the surface took the form:

$$\eta_T = A_1 + A_2\left(\frac{u}{c_o}\right) + A_3\left(\frac{u}{c_o}\right)^2 + A_4\left(\frac{u}{c_o}\right)^3$$

$$+ A_5 X + A_6 X^2 + A_7 X^3 + A_8\left(\frac{u}{c_o}\right) X$$

$$+ A_9\left(\frac{u}{c_o}\right)^2 X + A_{10}\left(\frac{u}{c_o}\right) X^2$$

For most groups of data (Groups I-V, and IX-XIII) the variable X represented nozzle half angle. For all other groups the variable X represented pressure ratio. Data groups XV-XVIII included only the first four terms of the general equation, and since only (3) mach 4.0 nozzles were tested the seventh term was omitted for all mach 4.0 data groups.

A listing of all data groups is shown on Table I.

These least square equations were used to form the smooth curves appearing on all computer made plots in this report. The plots were made on a "CAL COMP" plotter controlled by a subroutine called GRAF on Sundstrand's IBM 1130.

Empirical data points were omitted from the summary plots to illustrate trends more clearly. Instead, for reference they are shown on plots in Appendix A and listed in Appendix B.

It should be remembered when studying any one data set and curve, that the shape and position of the curve has been influenced by other data in that group not shown on the plot.

DATA LISTING

Appendix B contains a listing of all data points, a comparison of the empirical and smoothed data, and a rough measure of scatter for each point.

Scatter Percent Eff.

= (Empirical Data Point - Smoothed Data Point) x 100.

Scatter Percent Val.

= (Scatter Percent Eff.)/(Empirical Data Point)

Table II explains the exact interpretation of the titles appearing under the heading nozzle designation.

TABLE I

LIST OF DATA GROUPS

GROUP	NOZZLE DESIGNATIONS	APPROXIMATE PRESSURE RATIO	TEST GAS
I	Mach 2.5, 15° Half Angle	25:1	Nitrogen
	Mach 2.5, 13° Half Angle	25:1	Nitrogen
	Mach 2.5, 11° Half Angle	25:1	Nitrogen
	Mach 2.5, 9° Half Angle	25:1	Nitrogen
	Mach 2.5, 7° Half Angle	25:1	Nitrogen
II	Mach 2.5, 15° Half Angle	20:1	Nitrogen
	Mach 2.5, 13° Half Angle	20:1	Nitrogen
	Mach 2.5, 11° Half Angle	20:1	Nitrogen
	Mach 2.5, 9° Half Angle	20:1	Nitrogen
	Mach 2.5, 7° Half Angle	20:1	Nitrogen
III	Mach 2.5, 15° Half Angle	17:1	Nitrogen
	Mach 2.5, 13° Half Angle	17:1	Nitrogen
	Mach 2.5, 11° Half Angle	17:1 Design	Nitrogen
	Mach 2.5, 9° Half Angle	17:1	Nitrogen
	Mach 2.5, 7° Half Angle	17:1	Nitrogen
IV	Mach 2.5, 15° Half Angle	15:1	Nitrogen
	Mach 2.5, 13° Half Angle	15:1	Nitrogen
	Mach 2.5, 11° Half Angle	15:1	Nitrogen
	Mach 2.5, 9° Half Angle	15:1	Nitrogen
	Mach 2.5, 7° Half Angle	15:1	Nitrogen
V	Mach 2.5, 15° Half Angle	12:1	Nitrogen
	Mach 2.5, 13° Half Angle	12:1	Nitrogen
	Mach 2.5, 11° Half Angle	12:1	Nitrogen
	Mach 2.5, 9° Half Angle	12:1	Nitrogen
	Mach 2.5, 7° Half Angle	12:1	Nitrogen
VI	Plug Nozzle 'A'	25:1	Nitrogen
	Plug Nozzle 'A'	20:1	Nitrogen
	Plug Nozzle 'A'	17:1 Design	Nitrogen
	Plug Nozzle 'A'	15:1	Nitrogen
	Plug Nozzle 'A'	12:1	Nitrogen
VII	Plug Nozzle 'B'	25:1	Nitrogen
	Plug Nozzle 'B'	20:1	Nitrogen
	Plug Nozzle 'B'	17:1 Design	Nitrogen
	Plug Nozzle 'B'	15:1	Nitrogen
	Plug Nozzle 'B'	12:1	Nitrogen

TABLE I (CONTINUED)

GROUP	NOZZLE DESIGNATIONS	APPROXIMATE PRESSURE RATIO		TEST GAS
VIII	Plug Nozzle 'C'	25:1		Nitrogen
	Plug Nozzle 'C'	20:1		Nitrogen
	Plug Nozzle 'C'	17:1		Nitrogen
	Plug Nozzle 'C'	15:1		Nitrogen
	Plug Nozzle 'C'	12:1		Nitrogen
IX	Mach 4.0, 15° Half Angle	200:1		Nitrogen
	Mach 4.0, 11° Half Angle	200:1		Nitrogen
	Mach 4.0, 7° Half Angle	200:1		Nitrogen
X	Mach 4.0, 15° Half Angle	150:1		Nitrogen
	Mach 4.0, 11° Half Angle	150:1	Design	Nitrogen
	Mach 4.0, 7° Half Angle	150:1		Nitrogen
XI	Mach 4.0, 15° Half Angle	100:1		Nitrogen
	Mach 4.0, 11° Half Angle	100:1		Nitrogen
	Mach 4.0, 7° Half Angle	100:1		Nitrogen
XII	Mach 4.0, 15° Half Angle	50:1		Nitrogen
	Mach 4.0, 11° Half Angle	50:1		Nitrogen
	Mach 4.0, 7° Half Angle	50:1		Nitrogen
XIII	Mach 4.0, 15° Half Angle	25:1		Nitrogen
	Mach 4.0, 11° Half Angle	25:1		Nitrogen
	Mach 4.0, 7° Half Angle	25:1		Nitrogen
XIV	Mach 2.5, 11° Half Angle	35:1		Argon
	Mach 2.5, 11° Half Angle	28:1		Argon
	Mach 2.5, 11° Half Angle	25:1	Design	Argon
	Mach 2.5, 11° Half Angle	21:1		Argon
	Mach 2.5, 11° Half Angle	17:1		Argon
XV	Mach 4.0, 11° Half Angle	80:1		Nitrogen
XVI	Mach 4.0, 11° Half Angle	60:1		Nitrogen
XVII	Mach 4.0, 11° Half Angle	40:1		Nitrogen
XVIII	Mach 2.5, 11° Half Angle	13:1	Design	Freon 13

TABLE II

LIST OF NOZZLE DESIGNATIONS

NOZZLE DESIGNATION	INTERPRETATION
2.57	Mach 2.5 Nozzle, 7° Half Angle Nitrogen Test
2.59	Mach 2.5 Nozzle, 9° Half Angle Nitrogen Test
2.511	Mach 2.5 Nozzle, 11° Half Angle Nitrogen Test
2.513	Mach 2.5 Nozzle, 13° Half Angle Nitrogen Test
2.515	Mach 2.5 Nozzle, 15° Half Angle Nitrogen Test
4.7	Mach 4.0 Nozzle, 7° Half Angle Nitrogen Test
4.11	Mach 4.0 Nozzle, 11° Half Angle Nitrogen Test
4.15	Mach 4.0 Nozzle, 15° Half Angle Nitrogen Test
Plug 'A'	Plug Nozzle 'A", Nitrogen Test (See Figure 7)
Plug 'B'	Plug Nozzle 'B', Nitrogen Test (See Figure 7)
Plug 'C'	Plug Nozzle 'C', Nitrogen Test (See Figure 7)
Argon 2.511	Mach 2.5 Nozzle, 11° Half Angle Argon Test
Freon 2.511	Mach 2.5 Nozzle, 11° Half Angle Freon Test

TABLE III

TURBINE AND NOZZLE DATA COMMON TO ALL TEST CONFIGURATIONS*

Nozzle:

Nozzle Angle	16°
Exit Diameter	.28 inch
Pitch Diameter	5.96 inches
Number of Nozzles	1.0

Rotor:

Pitch Diameter	5.78 inches
Blade Angles (inlet and exit)	25°
Blade Height	0.42 inch
Blade Chord	0.3 inch
Number of Blades	115

Clearances:

Rotor Tip Radial	.050 inch
Nozzle To Rotor	0.035 inch
Rotor To Exhaust Housing	.060 inch

Gas Conditions

Inlet Temperature	Approx. 20-60°F
Inlet Pressure	Up To 240 psia

*Unless exception noted

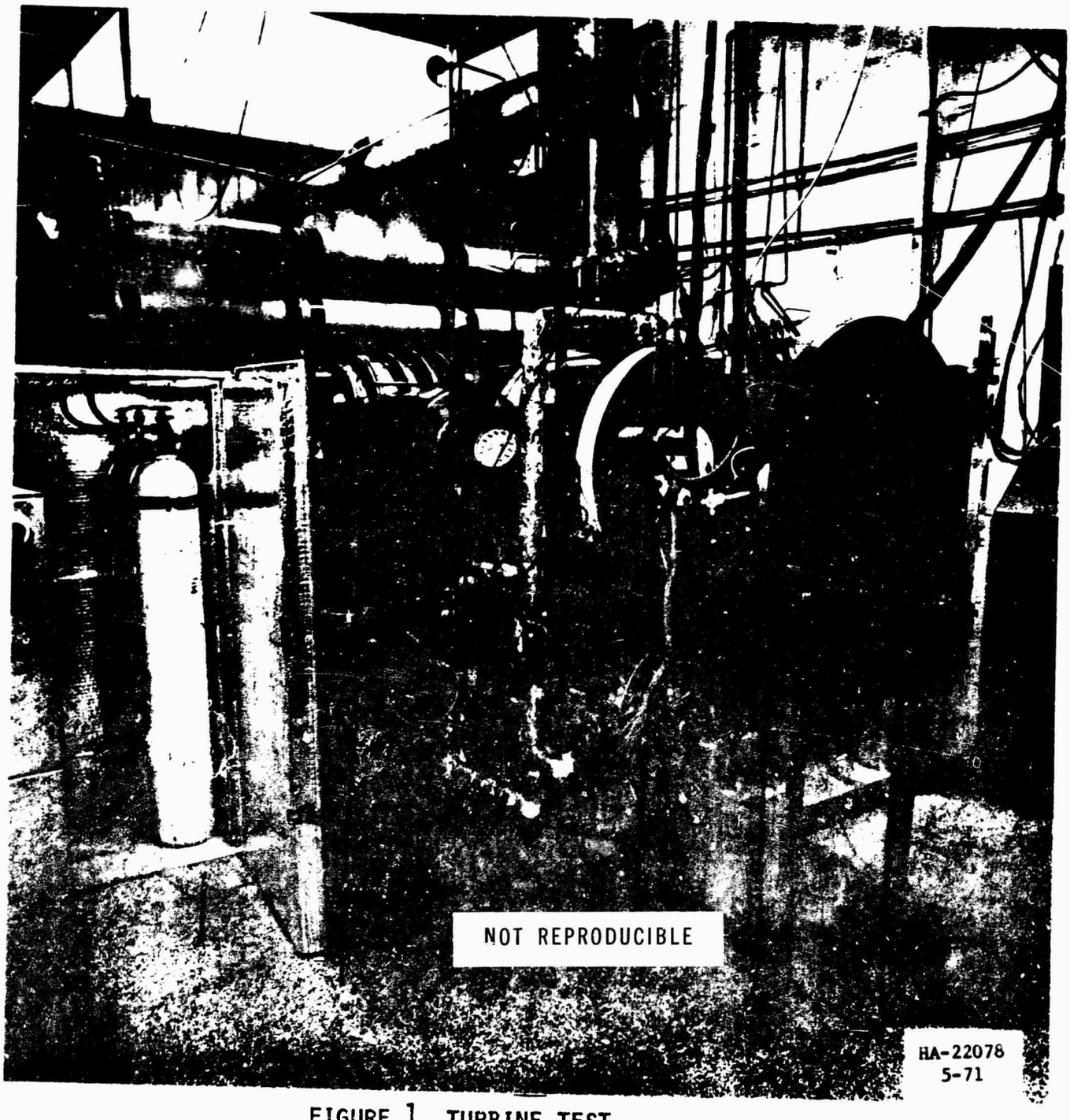

FIGURE 1 TURBINE TEST CHAMBER AND APPARATUS.

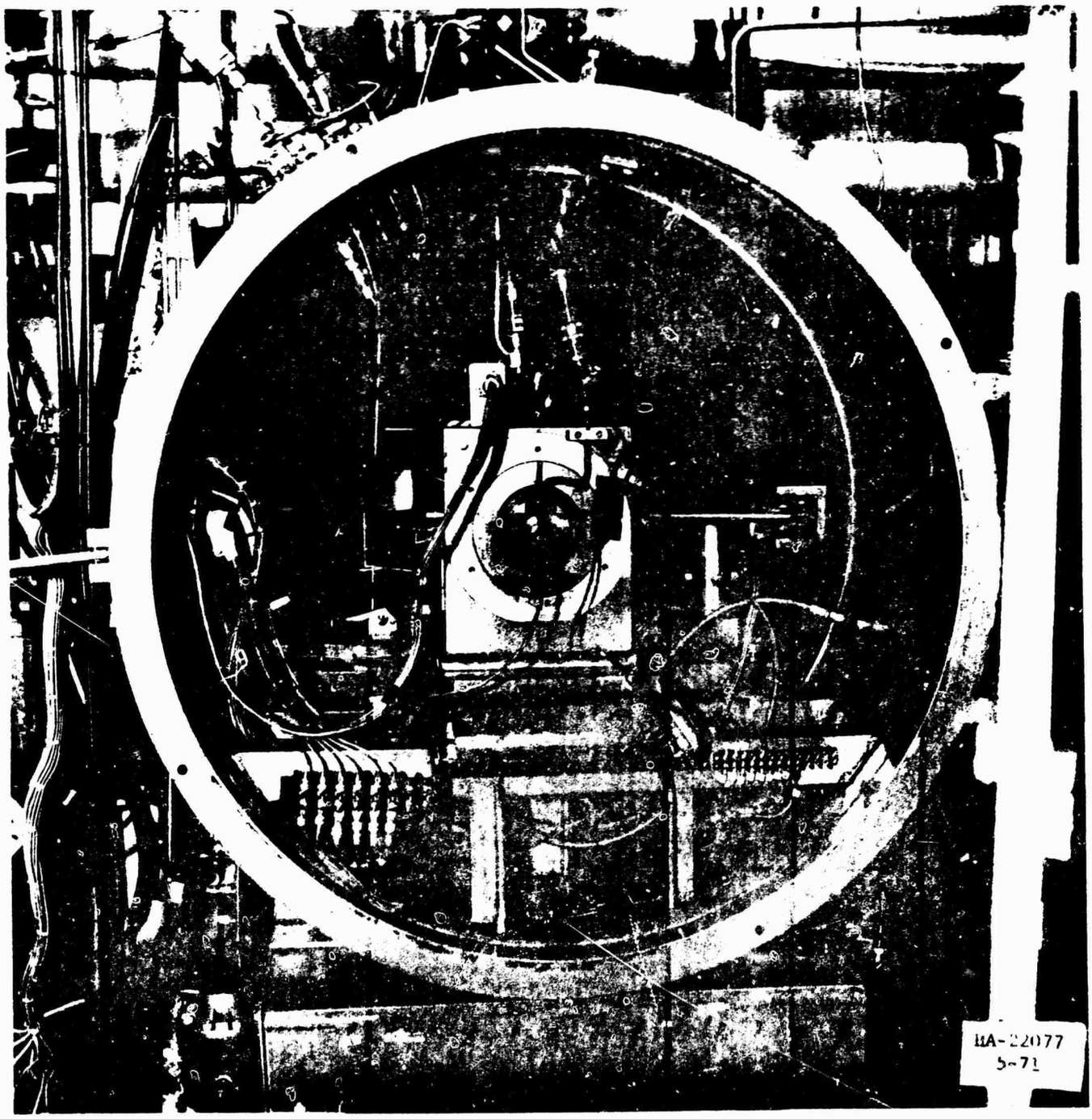

FIGURE 2 INSIDE OF TEST CHAMBER WITH RIG INSTALLED

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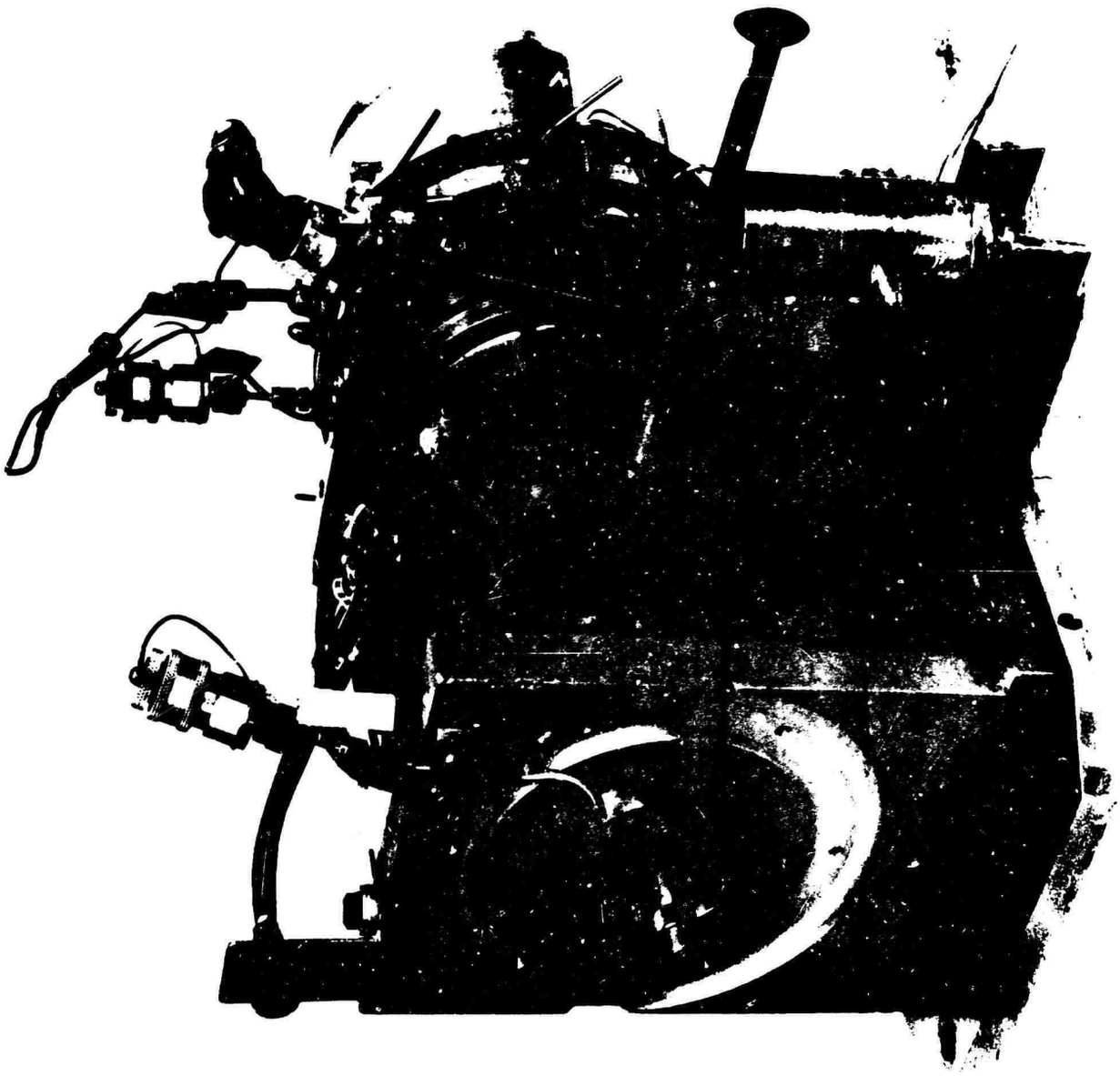

FIGURE 3 TURBINE TEST RIG

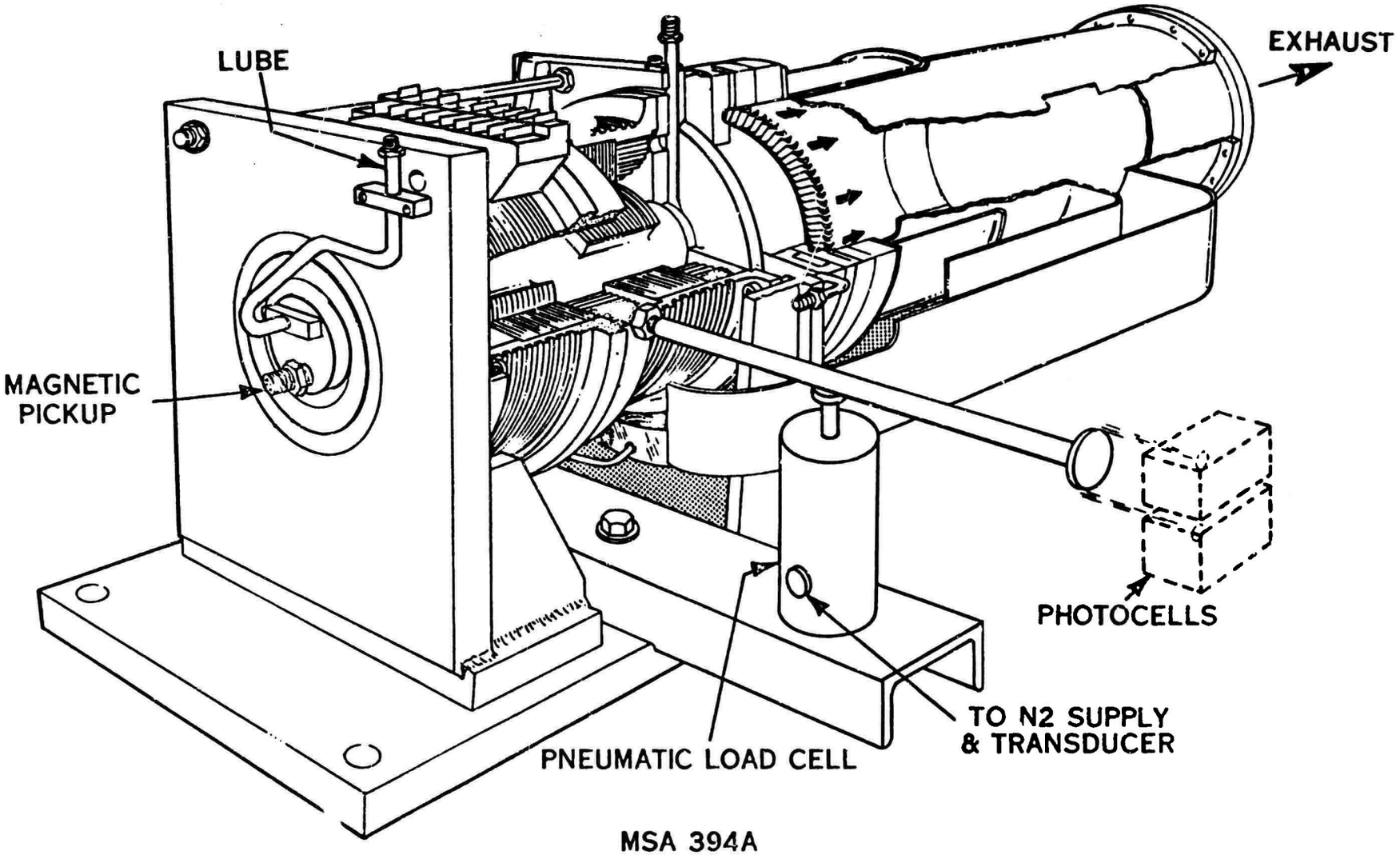

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FIGURE 4 TURBINE TEST RIG-
DIAGRAM

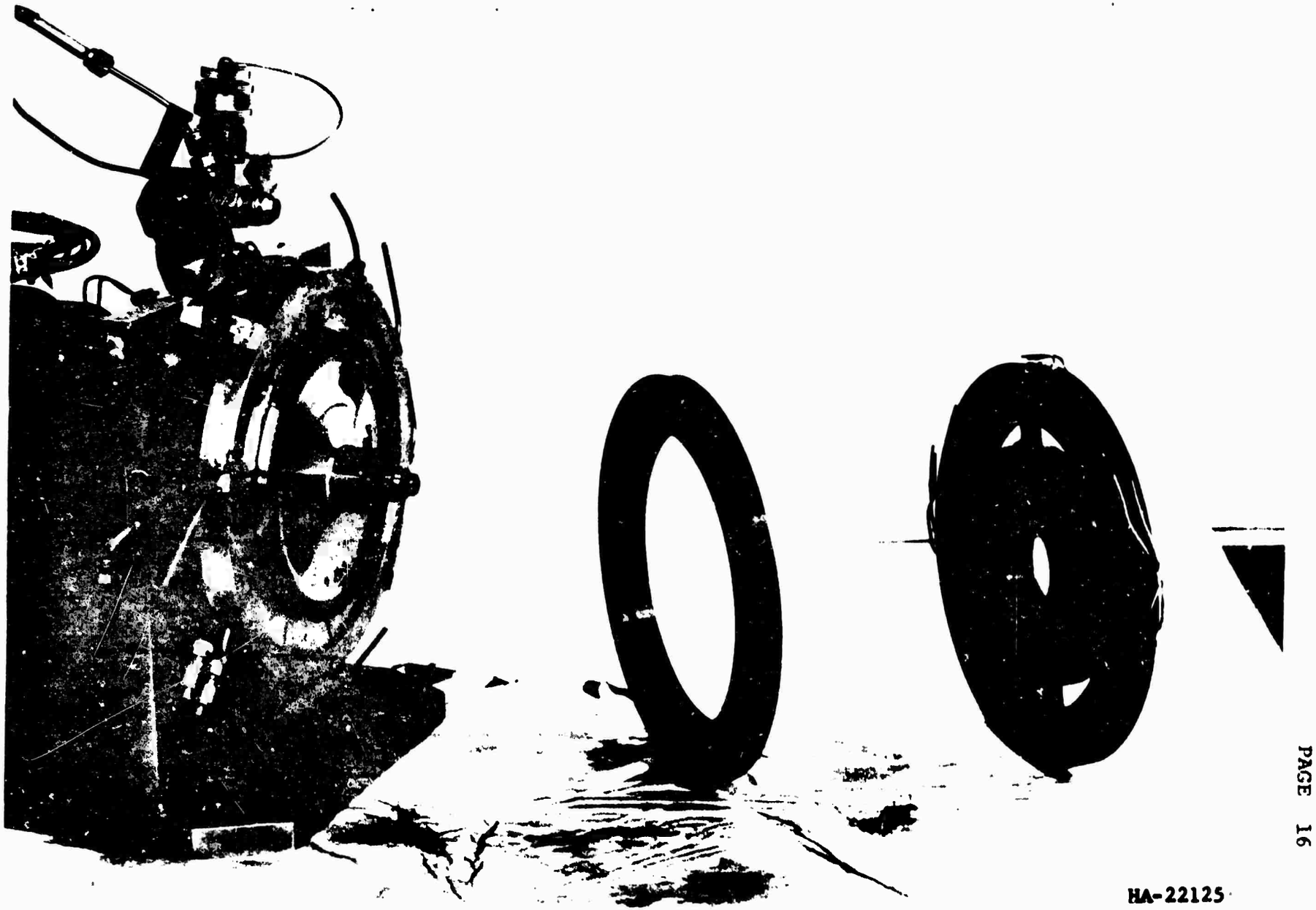
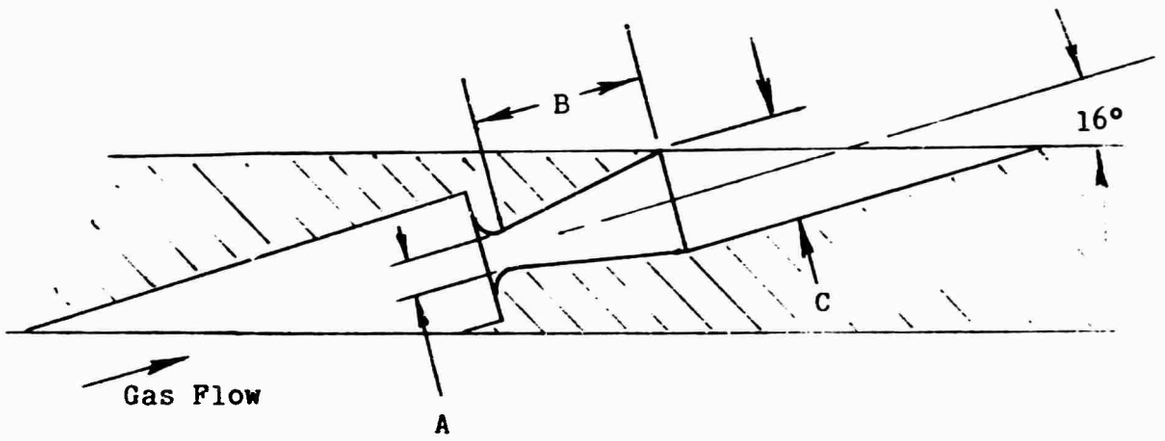


FIGURE 5 TEST RIG AND COMPONENTS

TYPICAL NOZZLE CROSS SECTION

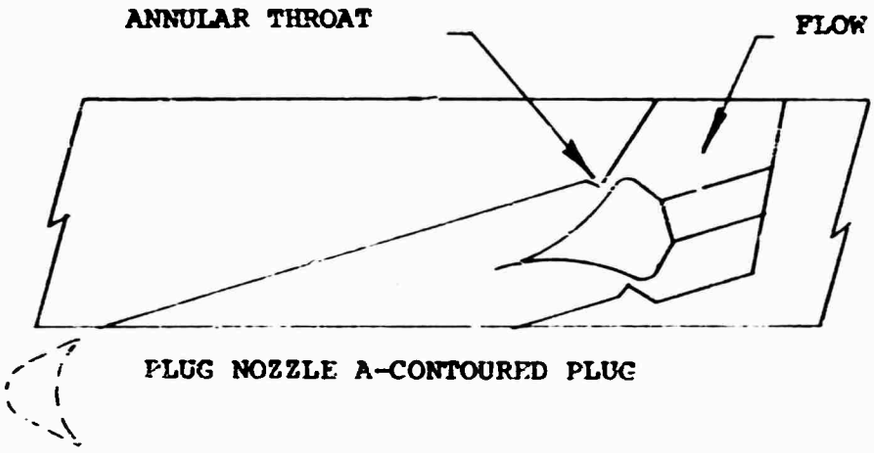


$\gamma = 1.4$

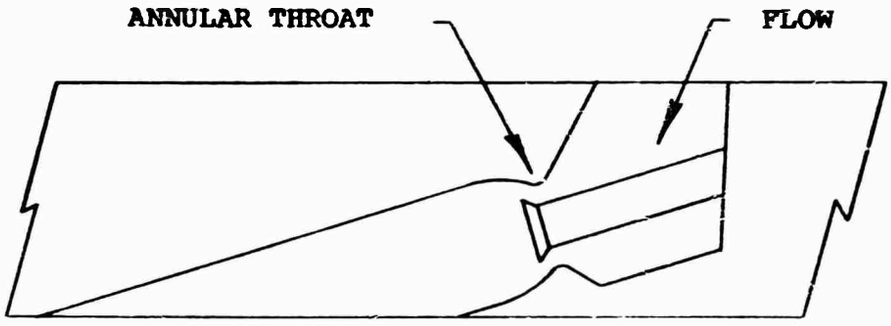
Design Mach No.	Divergence Angle	Dim. A	Dim. B	Dim. C
2.5	14°	.173	.4439	.282
2.5	18°	.173	.3441	.282
2.5	22°	.173	.2804	.282
2.5	26°	.173	.2361	.282
2.5	30°	.173	.2034	.282
4.0	14°	.086	.7982	.282
4.0	18°	.086	.6188	.282
4.0	22°	.086	.5042	.282
4.0	26°	.086	.4245	.282
4.0	30°	.086	.3657	.282

Dim C = Constant permits identical nozzle height/blade height ratio for both expansion ratios.

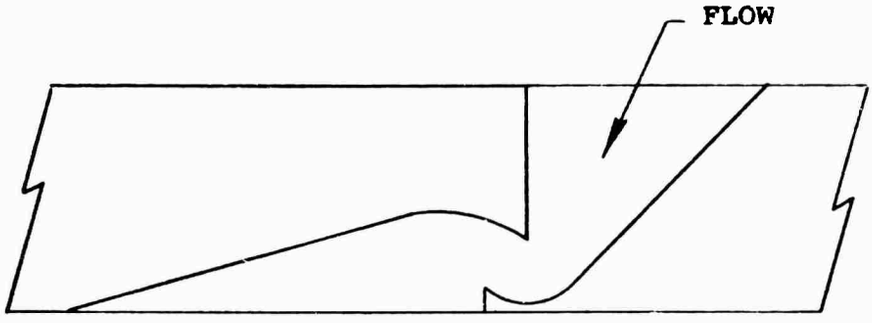
Figure 6 Conical Nozzles Tested



PLUG NOZZLE A-CONTOURED PLUG



PLUG NOZZLE B-BLUNT PLUG



PLUG NOZZLE C - 2 DIMENSIONAL HALF PLUG

FIGURE 7 - PLUG NOZZLES TESTED

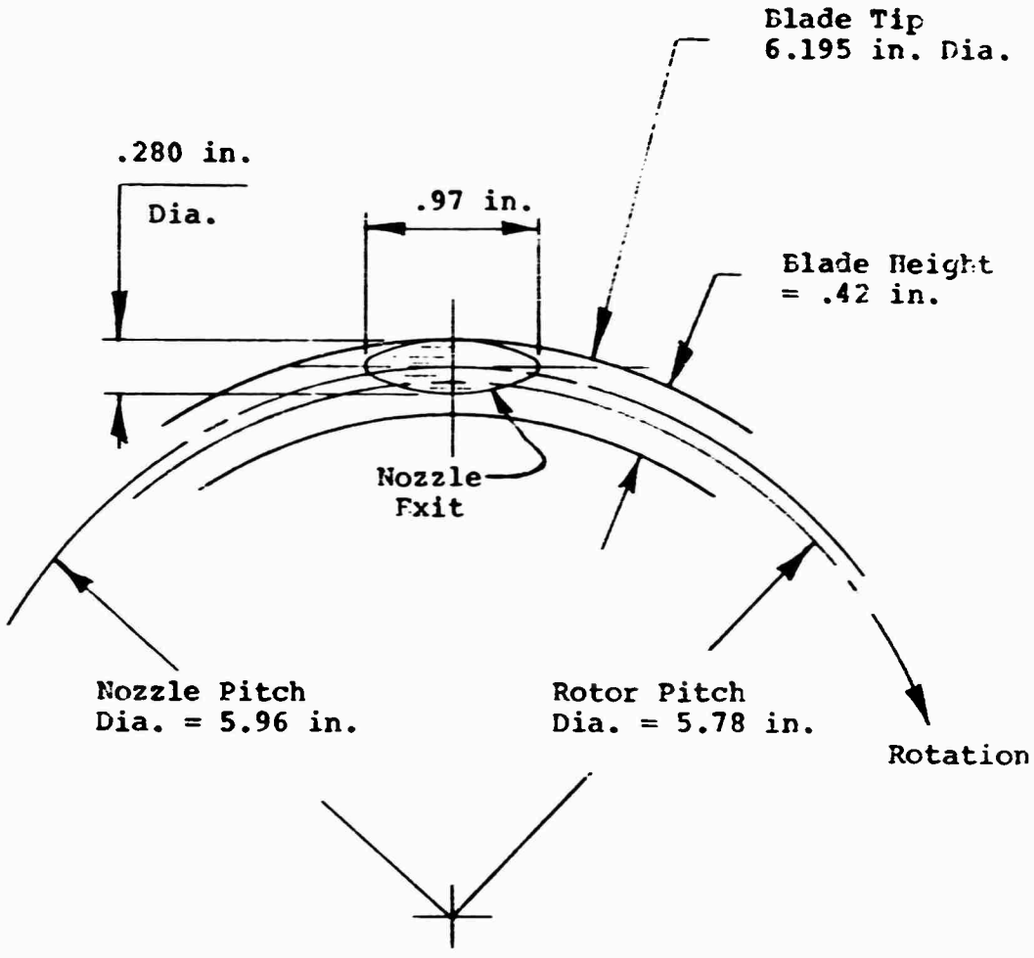


Figure 8.

CONICAL NOZZLE EXIT AND ROTOR OUT LINE -
LOOKING THROUGH ROTOR BLADES

2.0 EXPERIMENTAL RESULTS AND DISCUSSION

The work of this program can be divided into three phases or subprograms:

Phase I — Nozzle divergence angle evaluations - 7° to 15° half angle. (Figure 6). Five nozzles of design mach no = 2.0 and three of M_D = 4.0 were tested.

Phase II — Evaluation of performance of three styles of plug nozzles (Figure 7):
- Plug Nozzle "A" - Pointed Plug
- Plug Nozzle "B" - Blunt Plug
- Plug Nozzle "C" - 2-dimensional Half Plug

Phase III — Tests to determine the effect of specific heat ratio on performance. Tests were made at γ = 1.18, 1.40, 1.68.

Nominal test conditions are listed in Table IV.

BASIS OF COMPARISON

In this study the measure of nozzle influence on performance is variation of turbine efficiency over a span of off-design pressure ratios ("Range"; good range indicates small variation). Other measures such as hydraulic efficiency, nozzle coefficient, etc. could have been chosen. Although not always strictly correct because of small variations in per unit losses, efficiency is in most cases a valid index. It is usually plotted against velocity ratio (u/C_o) but sometimes against other parameters.

RESULTS OF DIVERGENCE TESTS

The results of Phase I (divergence) testing are summarized in Figures 9 to 38.

M_D = 2.5 nozzle results are shown in Figures 9 to 13, 19-23, and 29-33. They show peak efficiency is maximized at divergence angles of 11° to 13° (half angle) with 11° predominating above design pressure ratio and 13° below. The difference is not great, however. This is illustrated clearly in the basic plots of Figures 9-13 and in the efficiency vs divergence cross plots of Figures 19 to 23.

Plots summarizing efficiency vs velocity ratio at pressure ratios above and below design for different nozzles (Figures 29 to 33) clearly show off-design efficiency trends and suggest range is best with either small (7°) or large (15°) half angles, dropping slightly in between. However, the peak efficiency of intermediate angles is significantly greater than the extremes and more than makes up a small deficiency in range.

The tests at design mach no. = 4.0 (for γ= 1.4),shown in Figures 14 to 18, reveal no such optimum divergence. The performance of all nozzles is very similar; essentially independent of divergence on or off design. All curves of any given pressure ratio are closely bunched, and all efficiency vs divergence angle curves (Figures 24-28) are essentially flat, indicating no real optimum. The 7° nozzle shows some advantage in peak efficiency but this is slight and may not be significant. The summaries (Figures 34 to 38) indicate a similar conclusion; little variation in off-design performance from angle to angle. Though somewhat obscured by different losses it appears the range capability of the M_D = 4.0 nozzles is not so great as the mach 2.5's, at least not as good as the best ones.

The M_D = 4.0 nozzles were tested at a ΔP (P_o-P_e) four times greater than the M_D = 2.5's and may account for some of the similarity in performance shown by all mach 4.0 nozzles.

PLUG NOZZLES

The results of Phase II tests are summarized in Figures 39 to 43. The two best conical nozzles are shown on the same plot for comparison. These tests, particularly plug nozzle C, show greater than average scatter, but the conclusions are obvious and not affected. Peak efficiency and range are inferior to all M_D = 2.5 conical nozzles tested. Direct comparison is valid here because test conditions were identical.

An interesting observation is that plug nozzles "B" (blunt plug) and "C" (half plug) exhibit a very low discharge coefficient of .60 to .63, suggesting severe contraction exists in this type design as in sharp edged orifices.

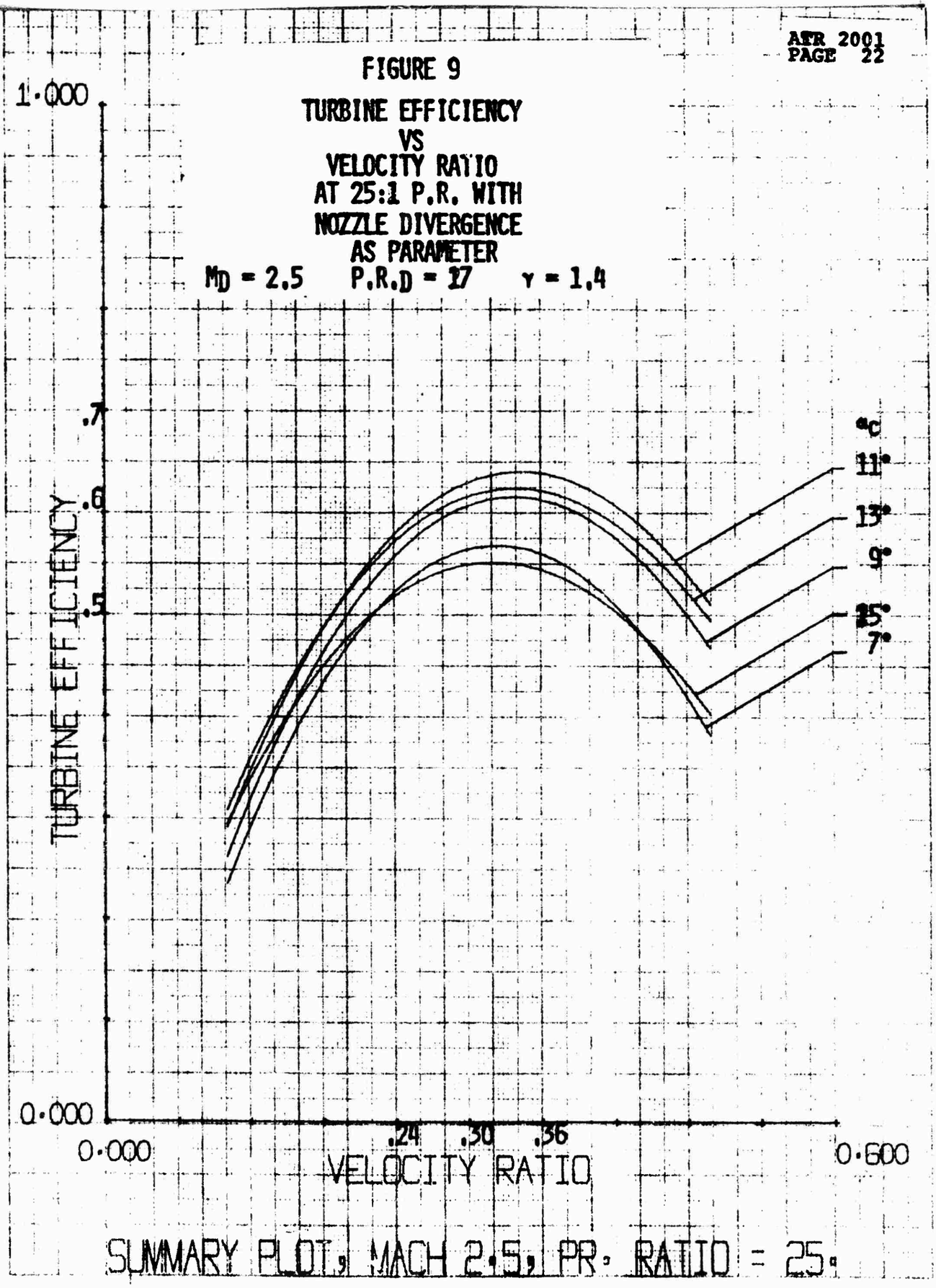
SPECIFIC HEAT RATIO

The results of Phase III (specific heat) tests are summarized in Figures 44 and 45. Figure 44 shows performance with 11° half angle and specific heat ratios from 1.18 (Freon 13) to 1.68 (Argon), with each at its own design condition. It suggests a maximum in efficiency occurs, probably at γ = 1.4, with efficiency dropping off above and below. The Argon and Nitrogen summary plots (Figures 45 and 31) show substantially better range for the Argon (γ = 1.68) than Nitrogen (γ = 1.4), suggesting that off-design performance improves with increased specific heat ratio. Peak efficiency is less in most cases although not enough to overcome the range advantage shown by the higher specific heat ratio gas.

FIGURE 9

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 25:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.4$

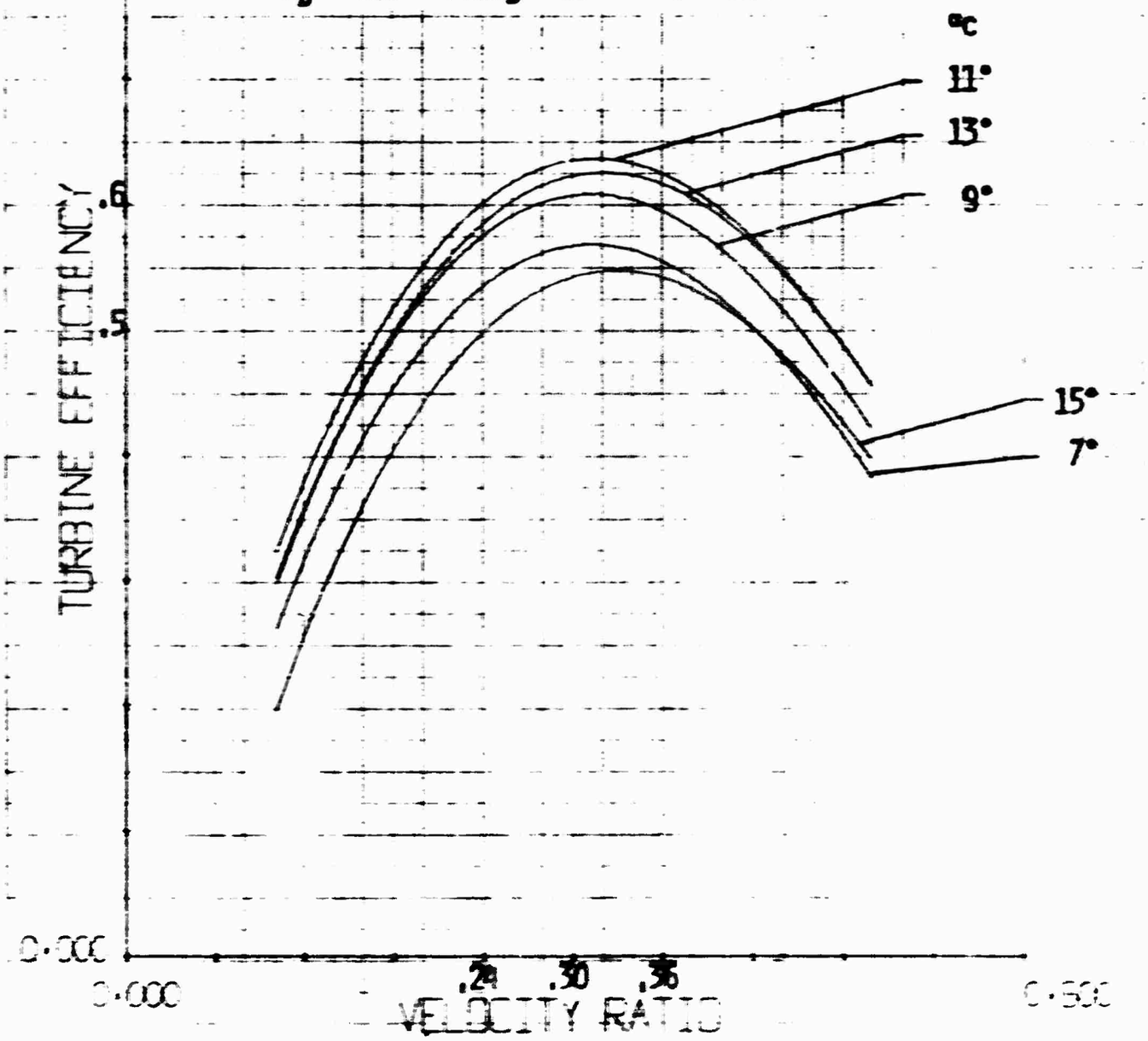


SUMMARY PLOT, MACH 2.5, PR. RATIO = 25.

FIGURE 10

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 20:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.4$

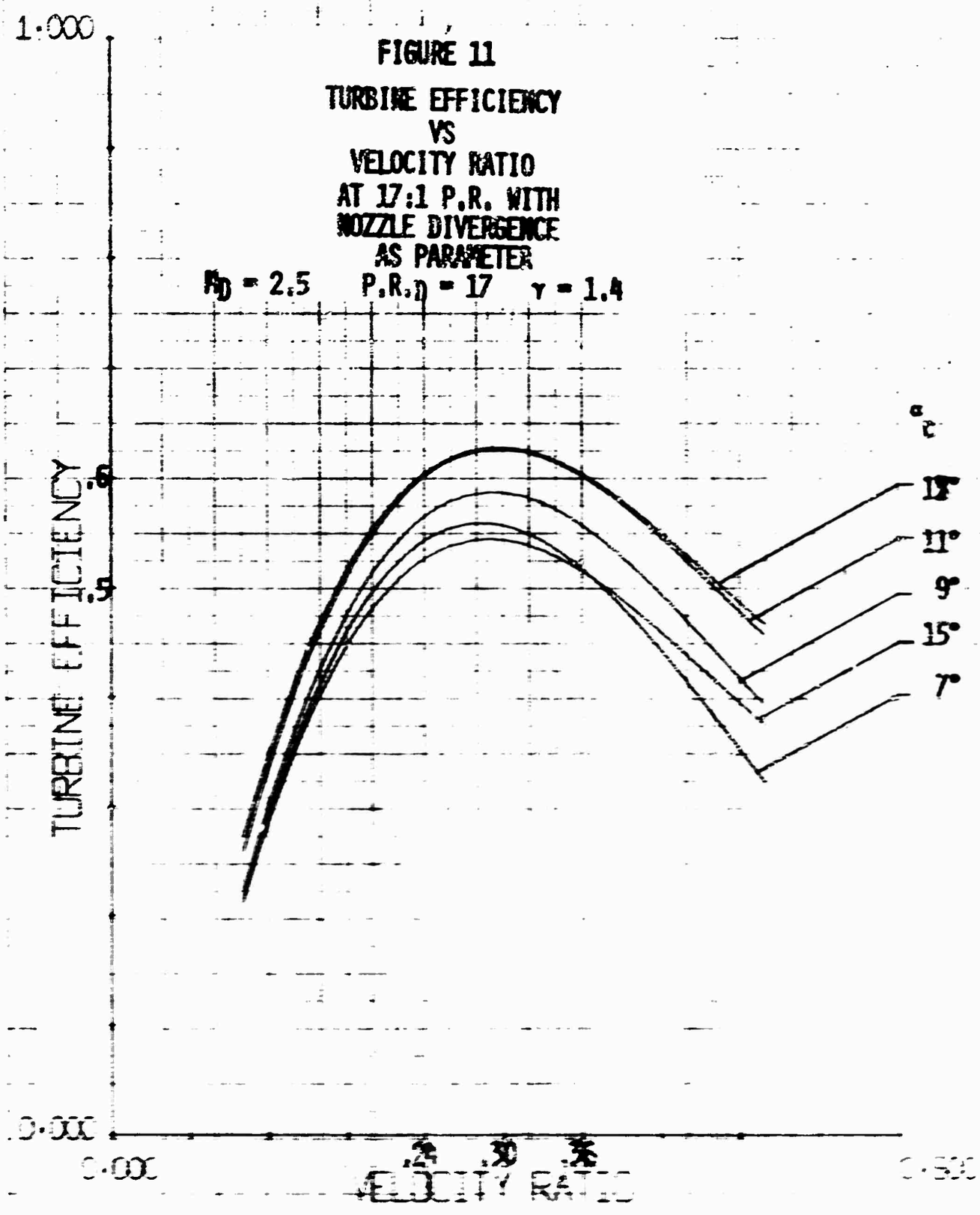


SUMMARY PLOT, MACH 2.5, PR. RATIO = 20.

FIGURE 11

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 17:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

$R_D = 2.5$ P.R.$_T$ = 17 $\gamma = 1.4$

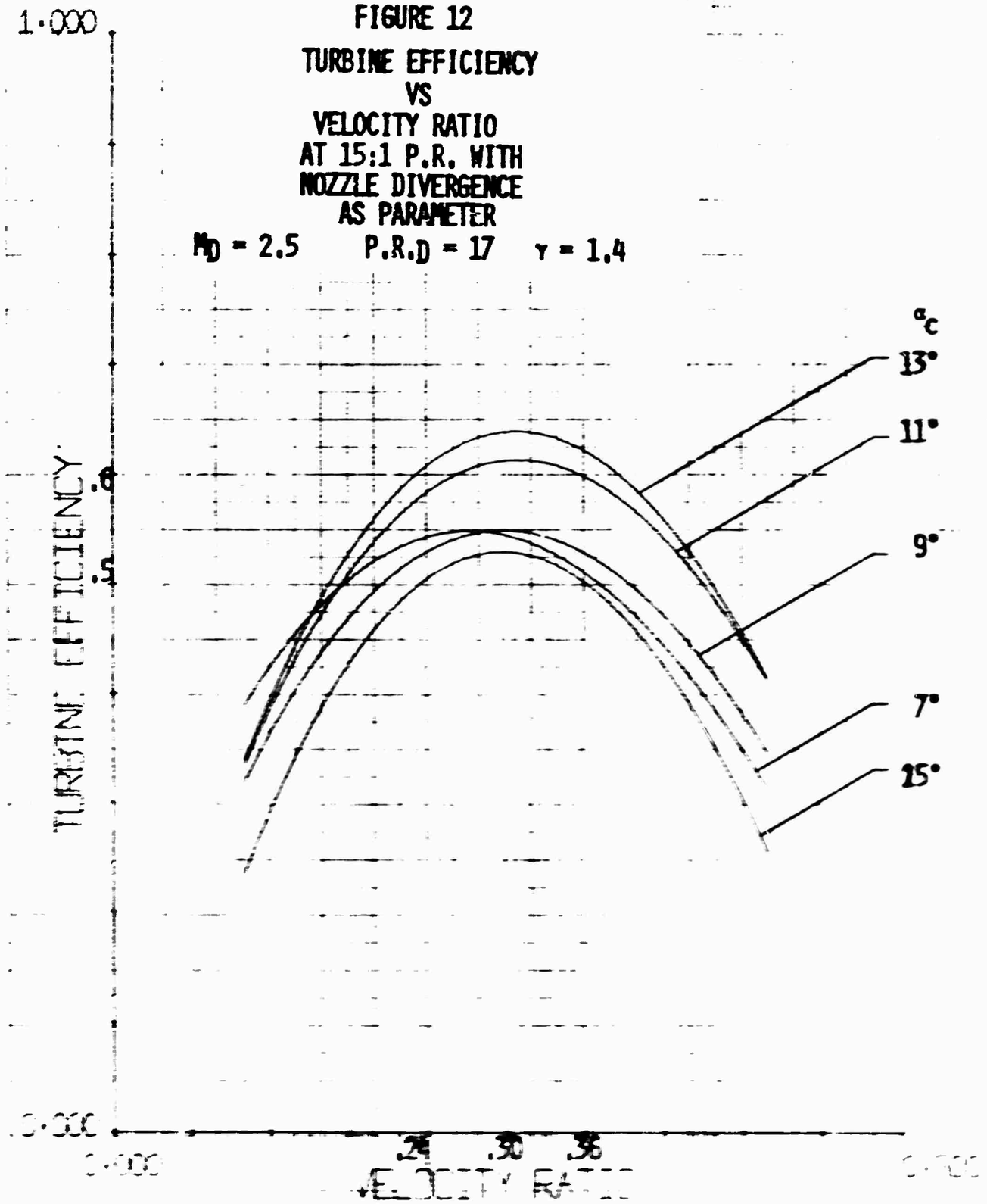


SUMMARY PLOT, MACH 3.5, PR RATIO = 17.

FIGURE 12

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 15:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.4$

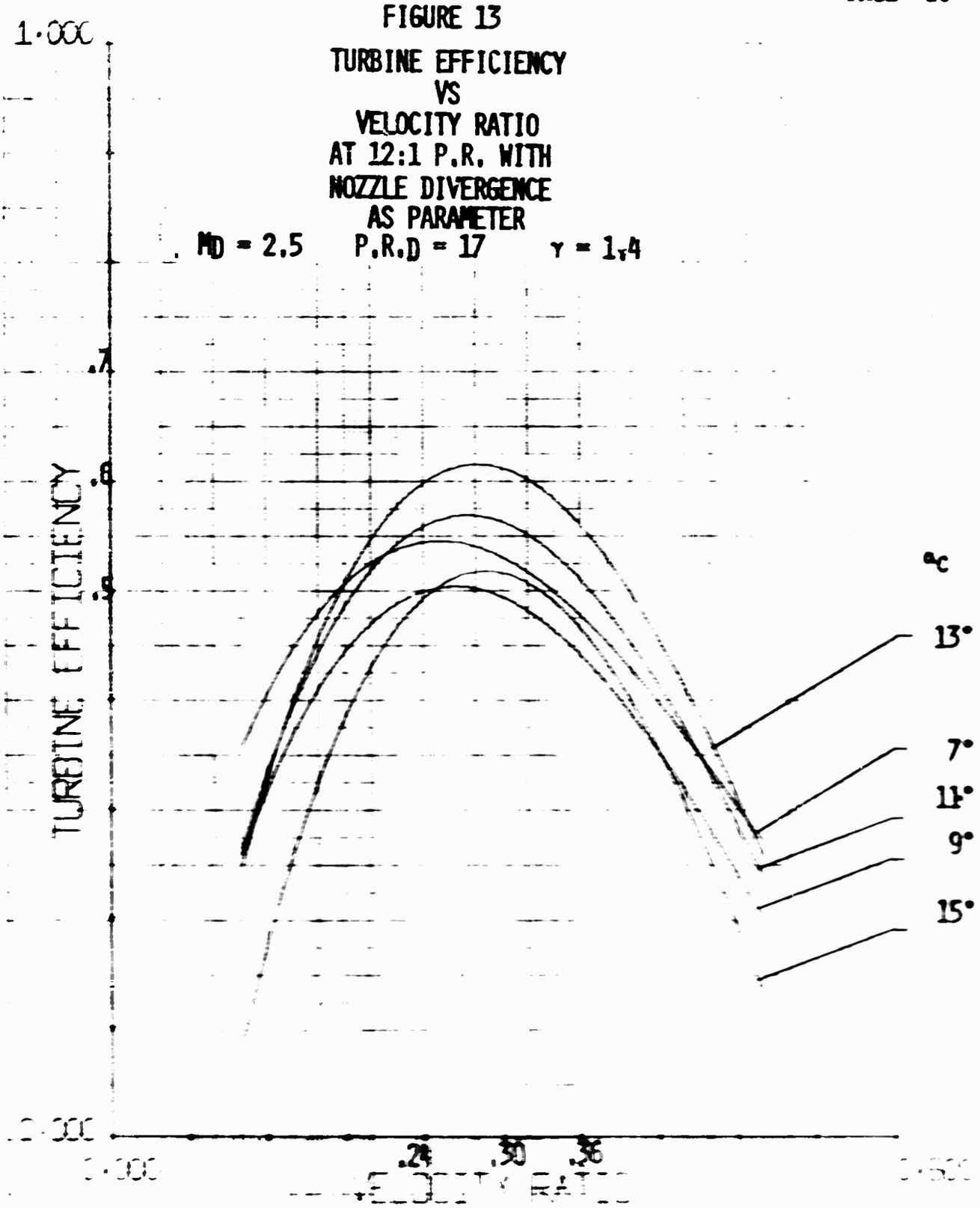


SUMMARY PLOT, MACH #'S, P.R. RATIO = 15.

FIGURE 13

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 12:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.4$

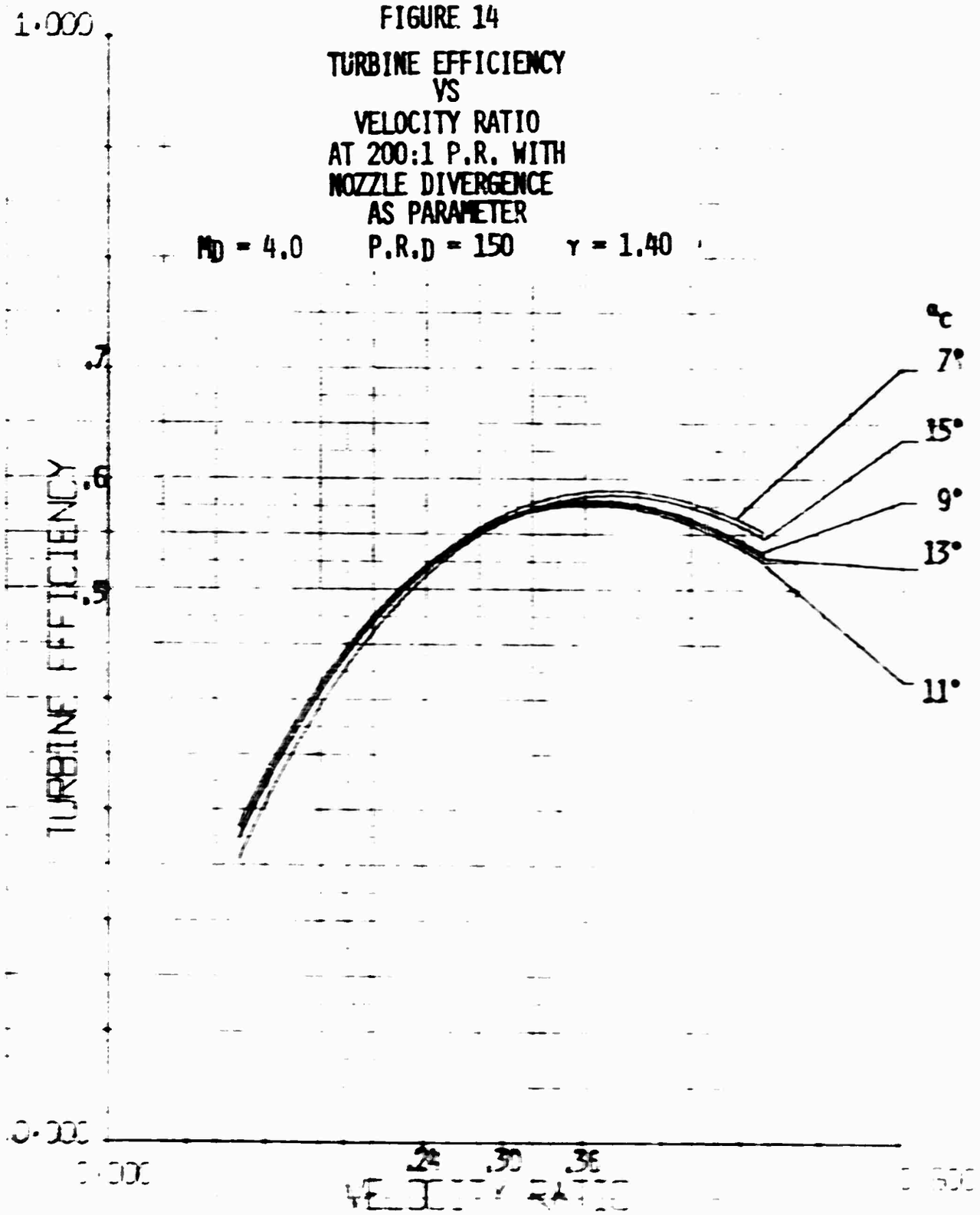


SUMMARY PLOT, MACH 2.5, PR RATIO = 12:1

FIGURE 14

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 200:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

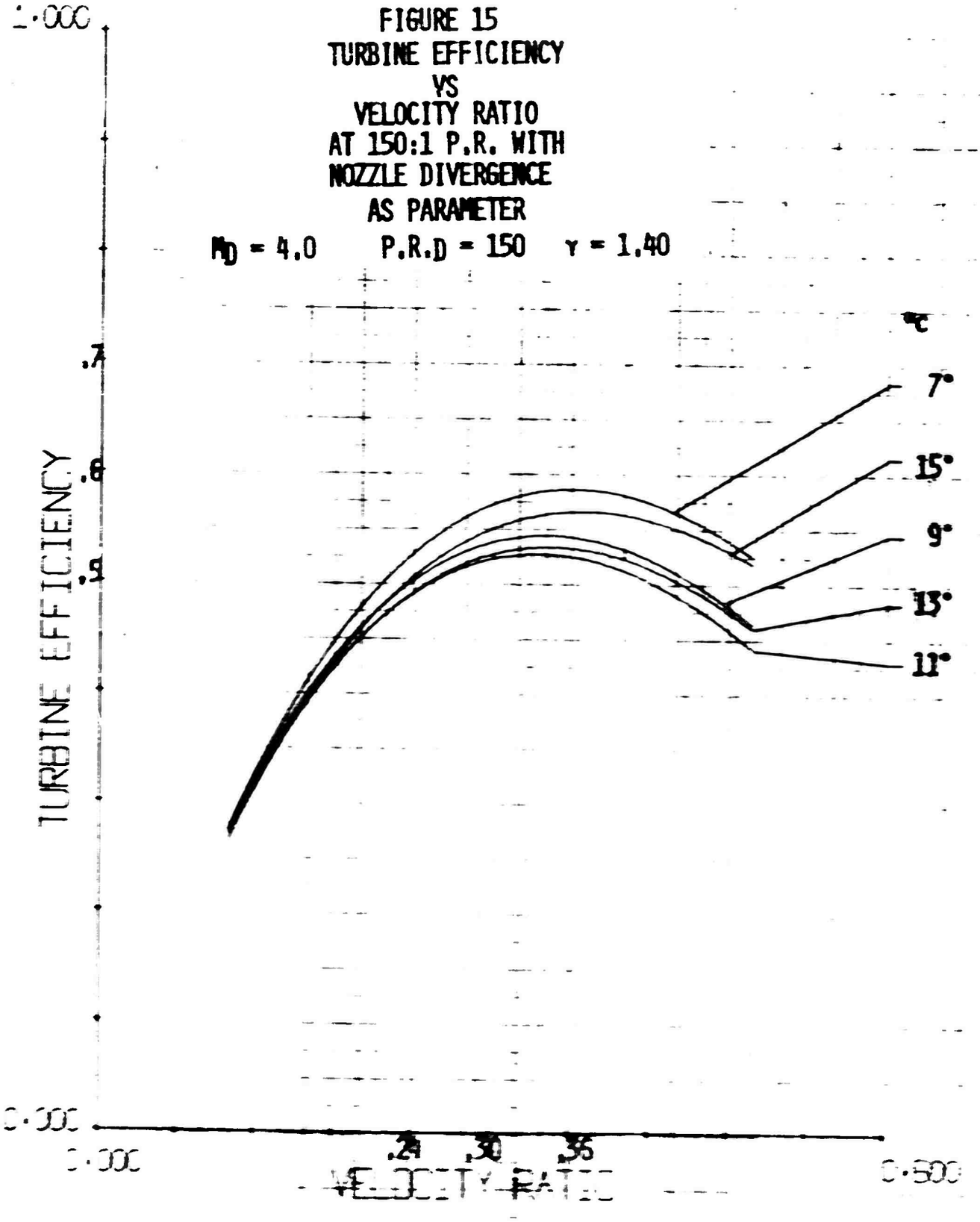
$M_D = 4.0$ $P.R._D = 150$ $\gamma = 1.40$



SUMMARY PLOT: MACH 4.0; PR RATIO 200:

FIGURE 15
TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 150:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

$M_D = 4.0$ P.R.D = 150 $\gamma = 1.40$

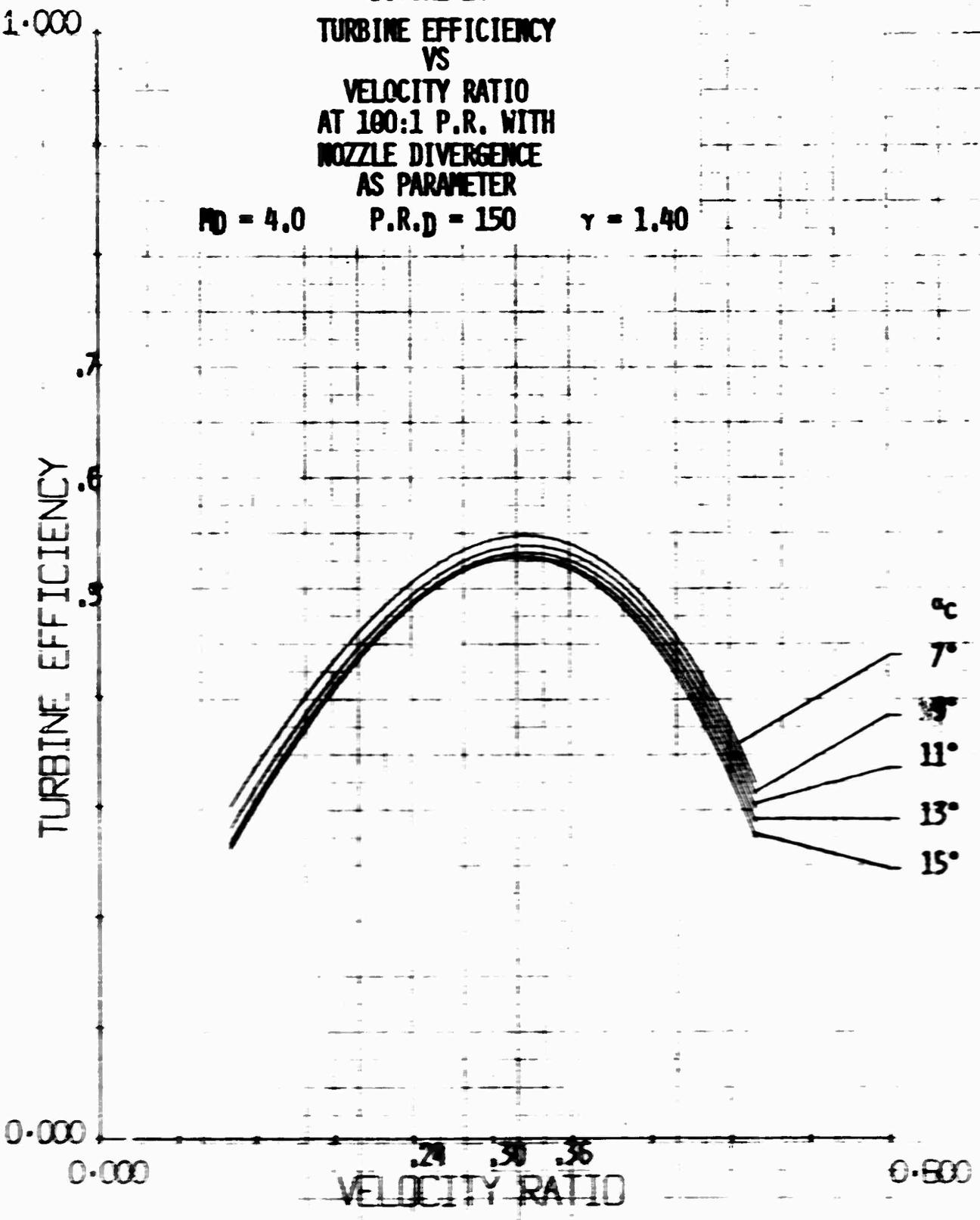


SUMMARY PLOT: MACH 4.0; PR. RATIO=150

FIGURE 16

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 100:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

M_D = 4.0 P.R.$_D$ = 150 γ = 1.40

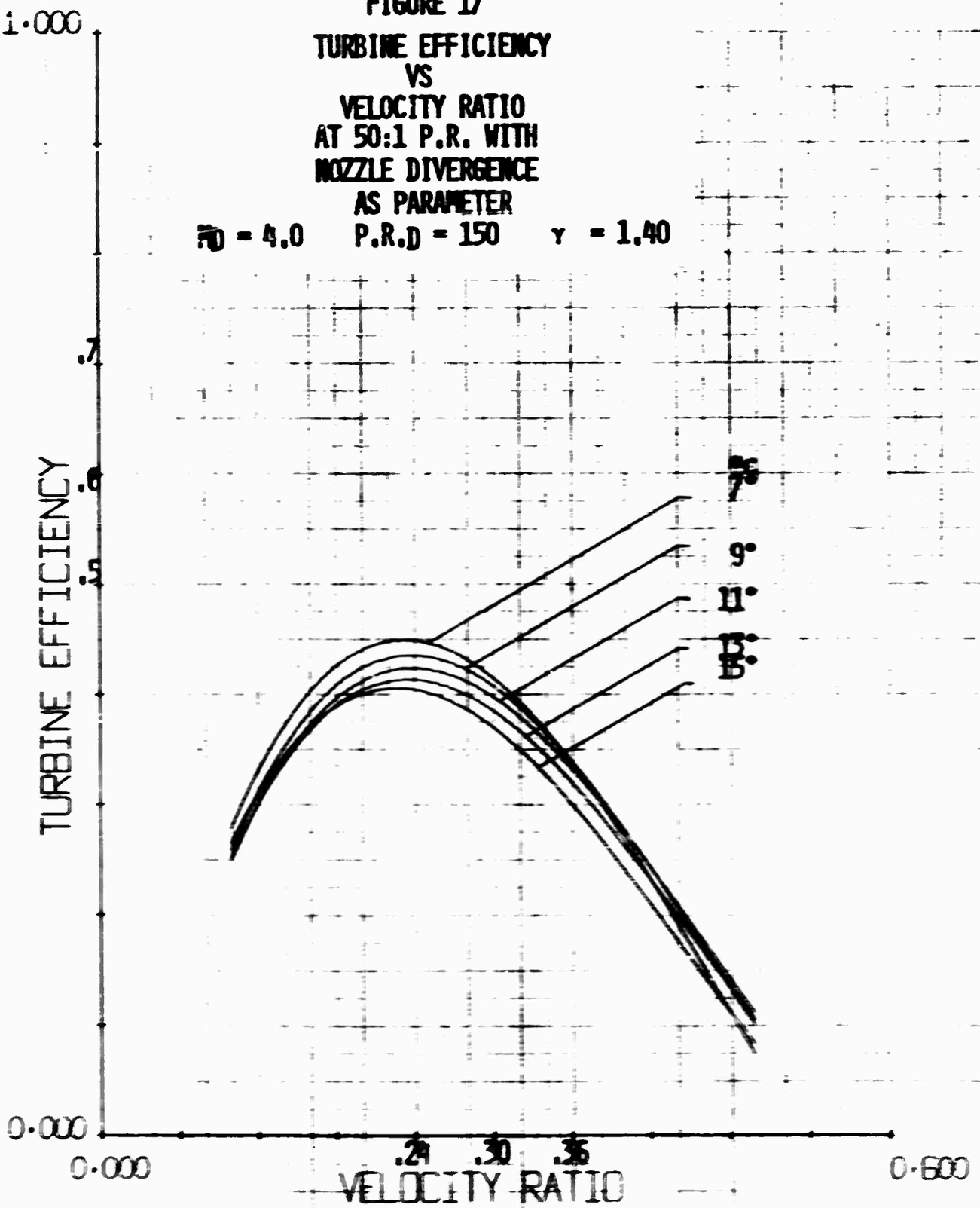


SUMMARY PLOT, MACH 4.0, PR. RATIO=100.

FIGURE 17

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 50:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

M_D = 4.0 P.R.D = 150 γ = 1.40

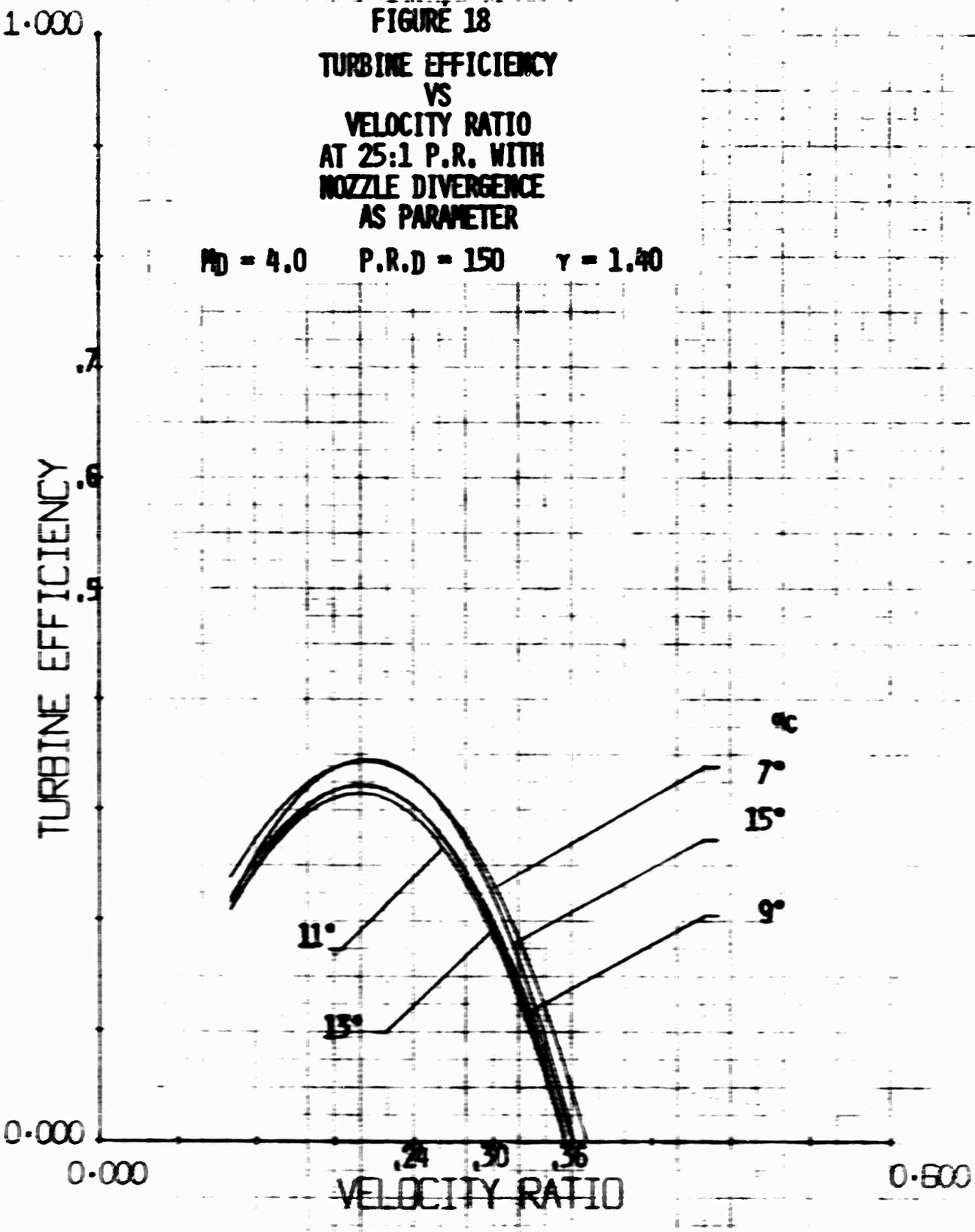


SUMMARY PLOT, MACH 4.0, PR. RATIO=50.

FIGURE 18

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 25:1 P.R. WITH
NOZZLE DIVERGENCE
AS PARAMETER

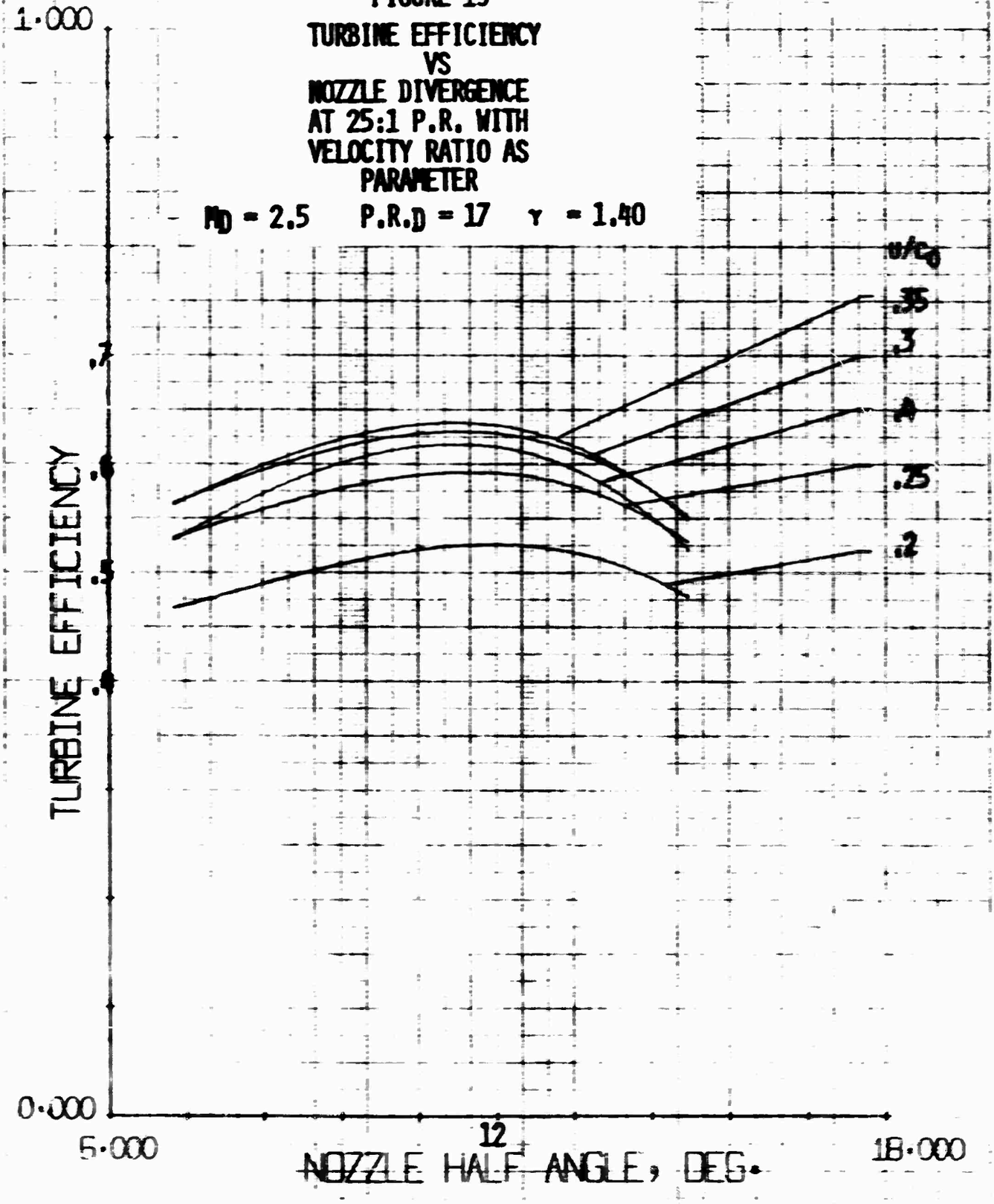
M_D = 4.0 P.R.D = 150 γ = 1.40



SUMMARY PLOT; MACH 4·0, PR· RATIO=25·

FIGURE 19
TURBINE EFFICIENCY
VS
NOZZLE DIVERGENCE
AT 25:1 P.R. WITH
VELOCITY RATIO AS
PARAMETER

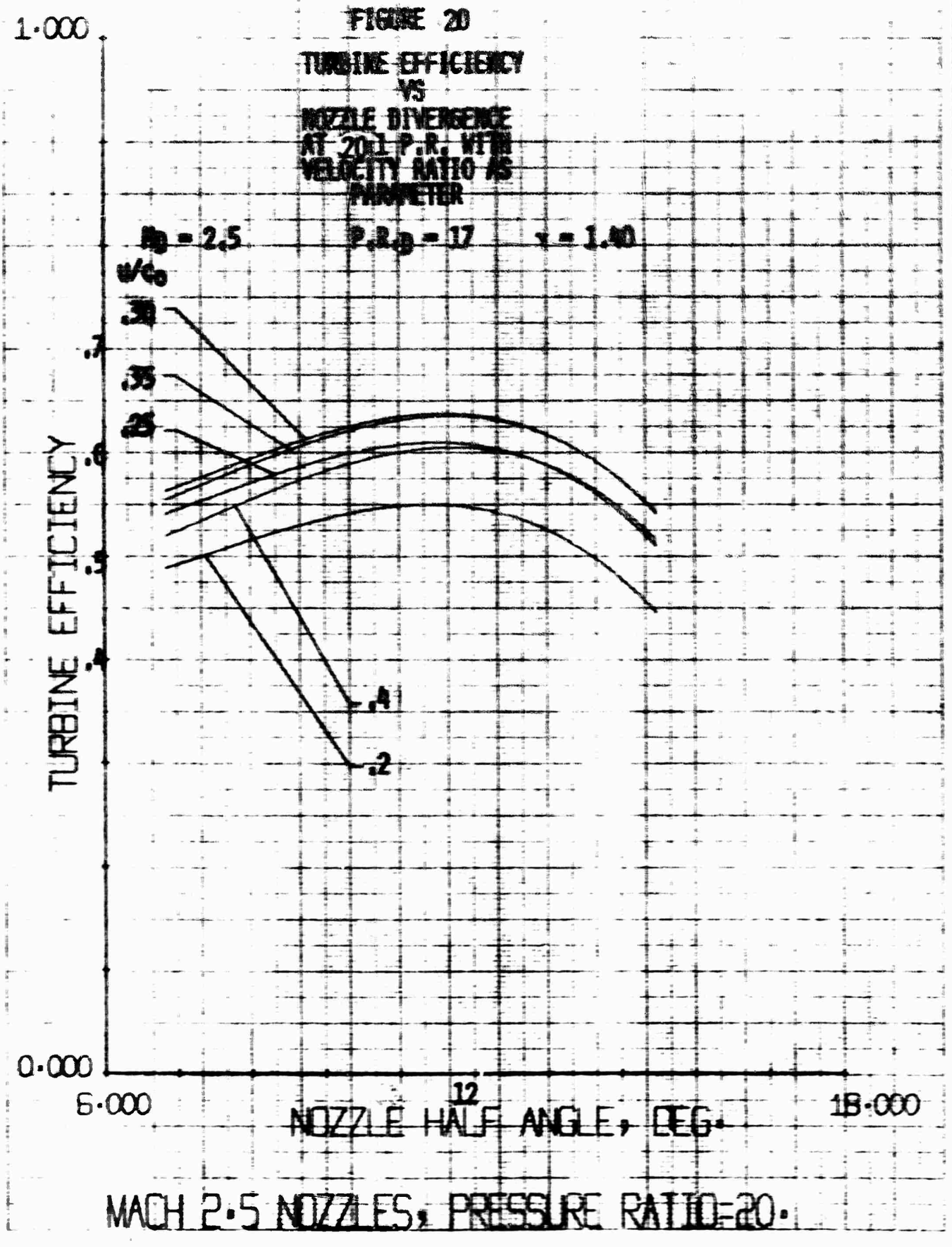
$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.40$



MACH 2.5 NOZZLES, PRESSURE RATIO=25.

FIGURE 20

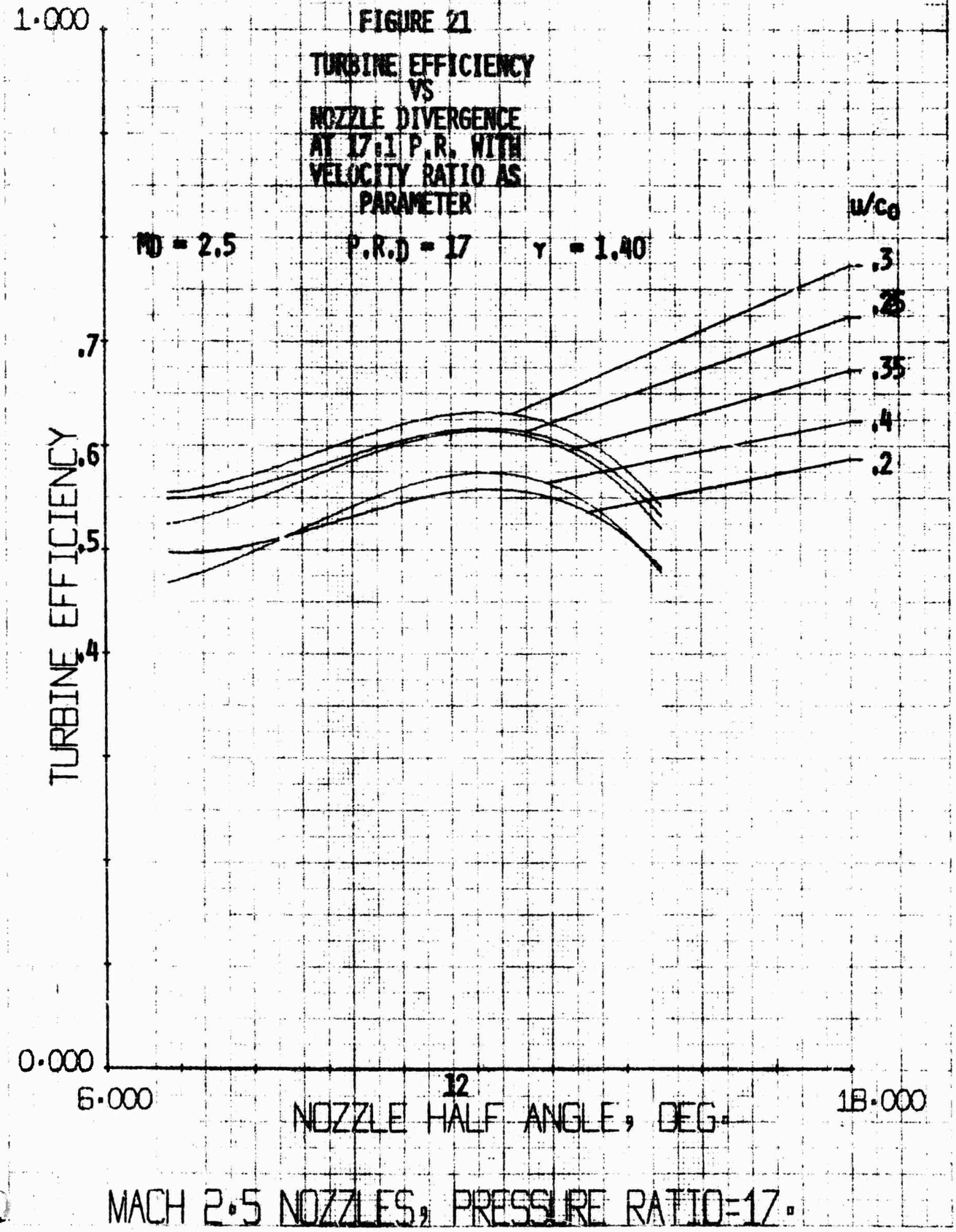
TURBINE EFFICIENCY
VS
NOZZLE DIVERGENCE
AT 20:1 P.R. WITH
VELOCITY RATIO AS
PARAMETER



MACH 2.5 NOZZLES, PRESSURE RATIO=20.

FIGURE 21

TURBINE EFFICIENCY VS NOZZLE DIVERGENCE AT 17:1 P.R. WITH VELOCITY RATIO AS PARAMETER

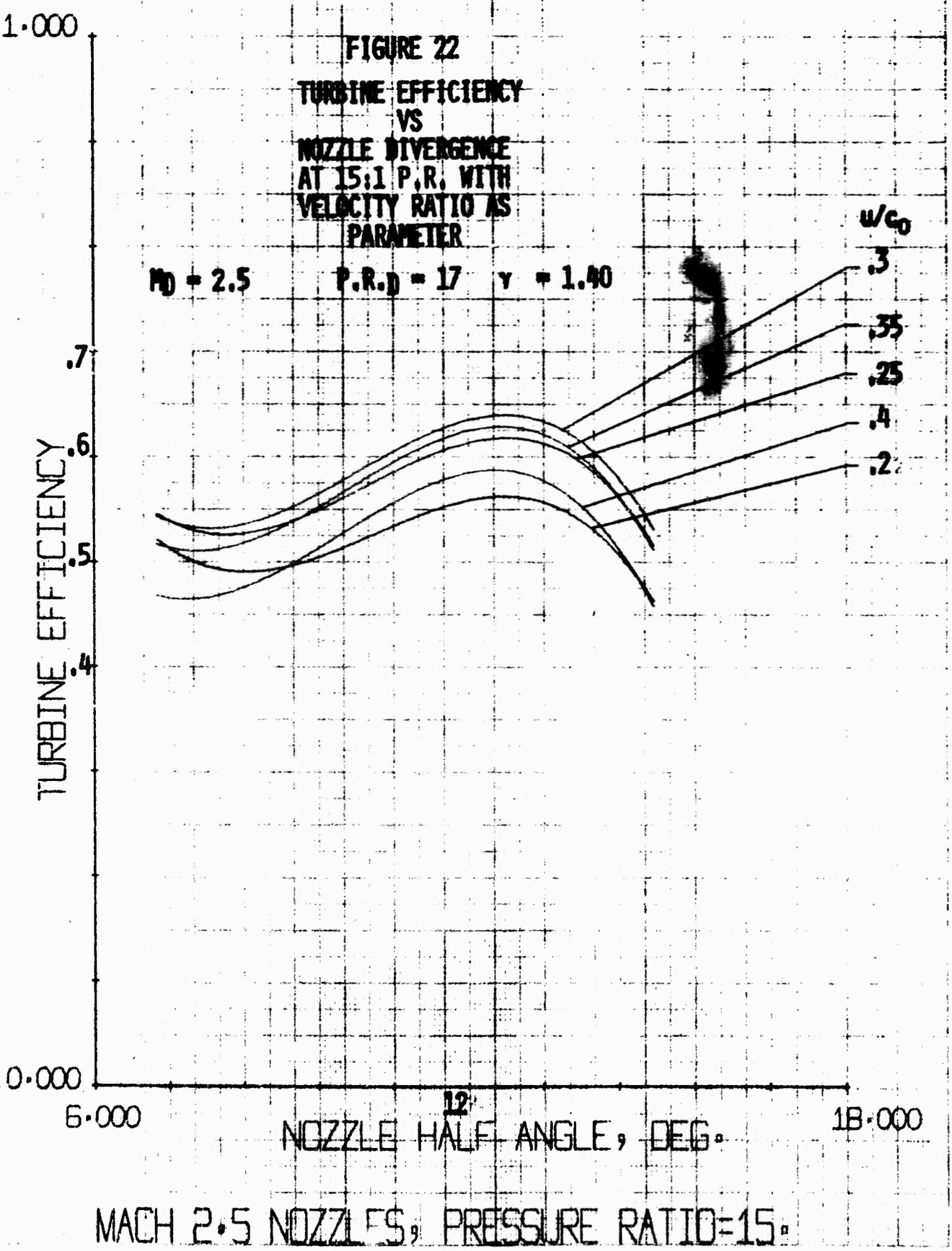


MACH 2.5 NOZZLES, PRESSURE RATIO=17.

FIGURE 22

TURBINE EFFICIENCY
VS
NOZZLE DIVERGENCE
AT 15:1 P.R. WITH
VELOCITY RATIO AS
PARAMETER

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.40$

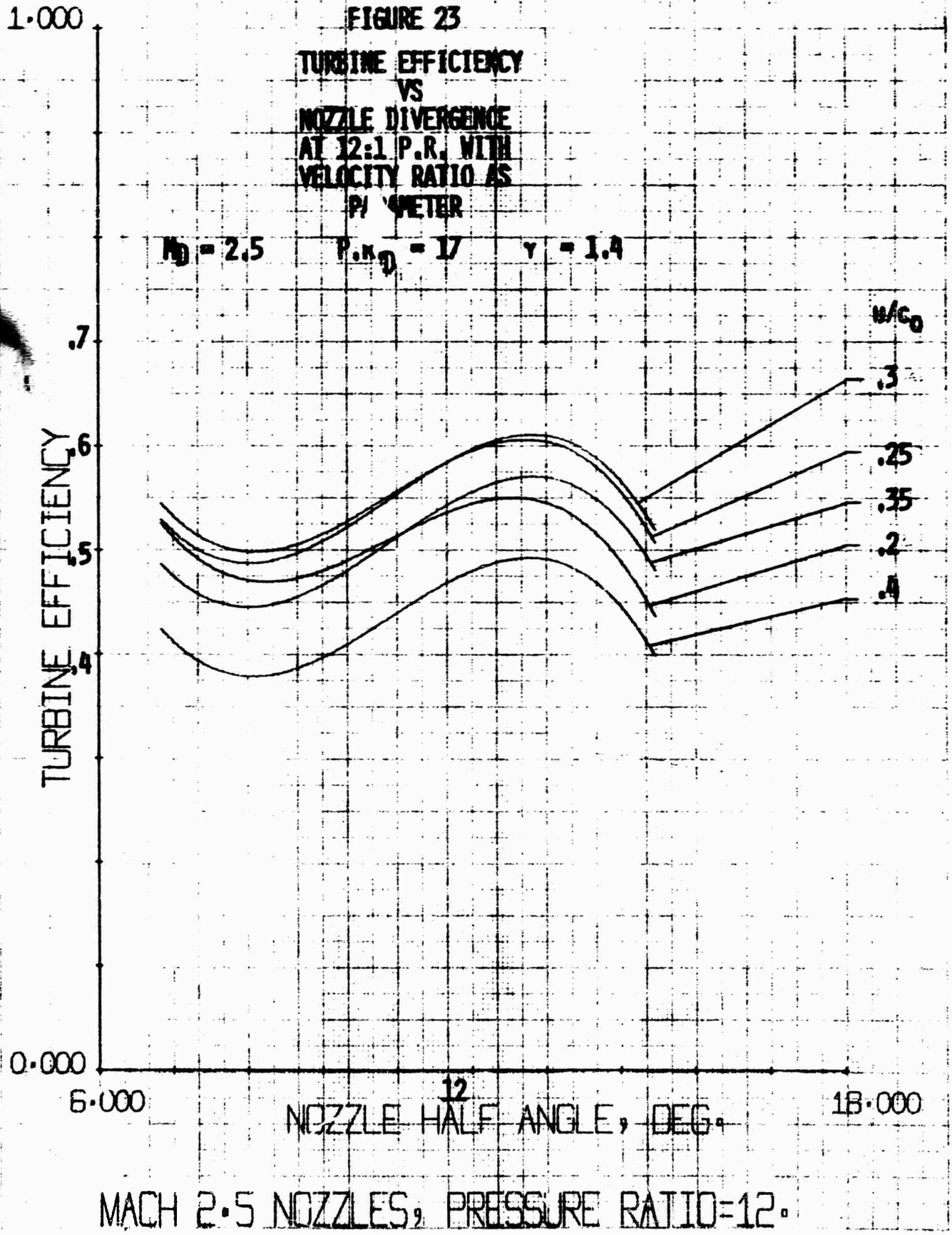


MACH 2.5 NOZZLES, PRESSURE RATIO=15.

FIGURE 23

TURBINE EFFICIENCY
VS
NOZZLE DIVERGENCE
AT 12:1 P.R. WITH
VELOCITY RATIO AS
P/ 'METER

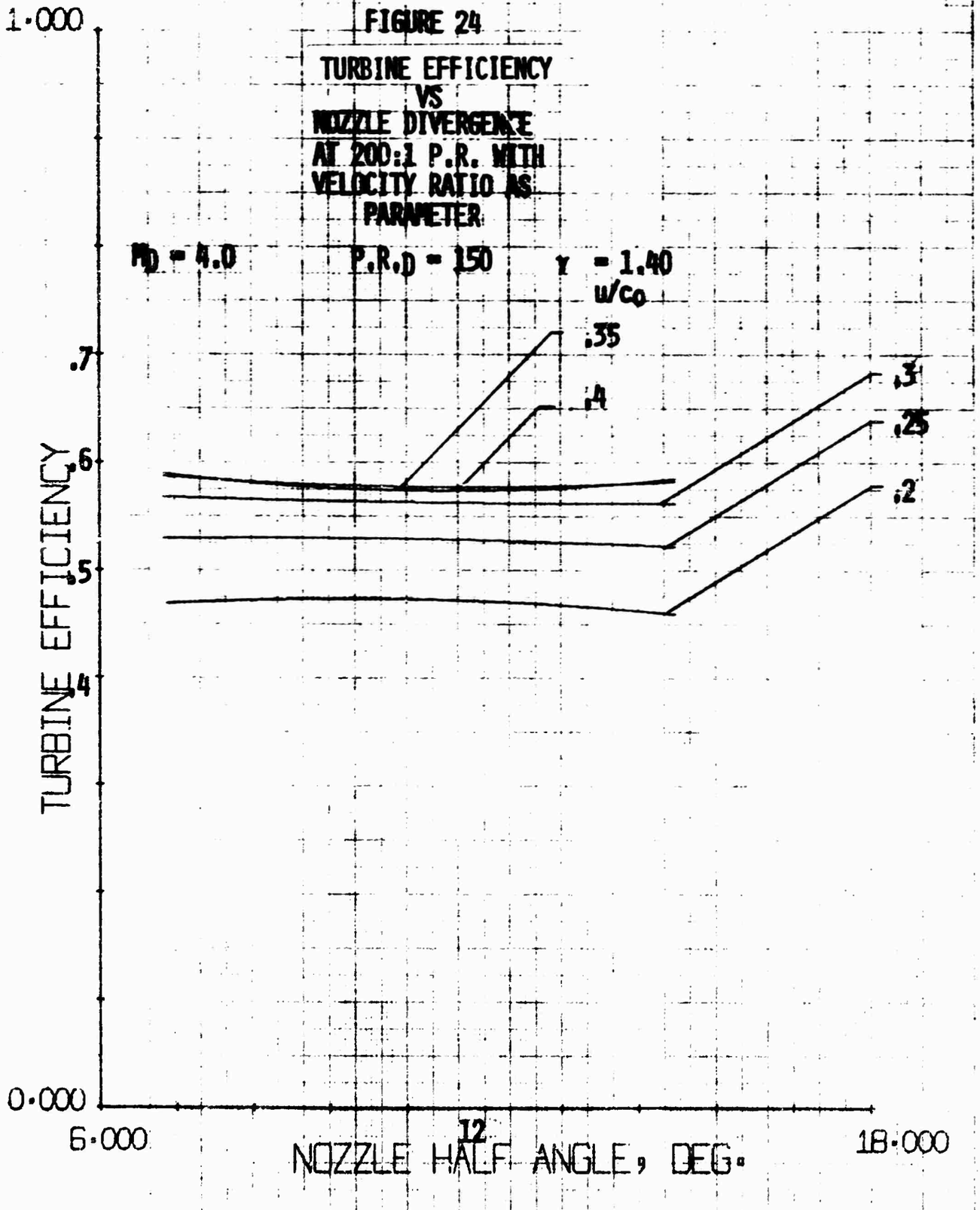
$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.4$



MACH 2·5 NOZZLES, PRESSURE RATIO=12.

FIGURE 24

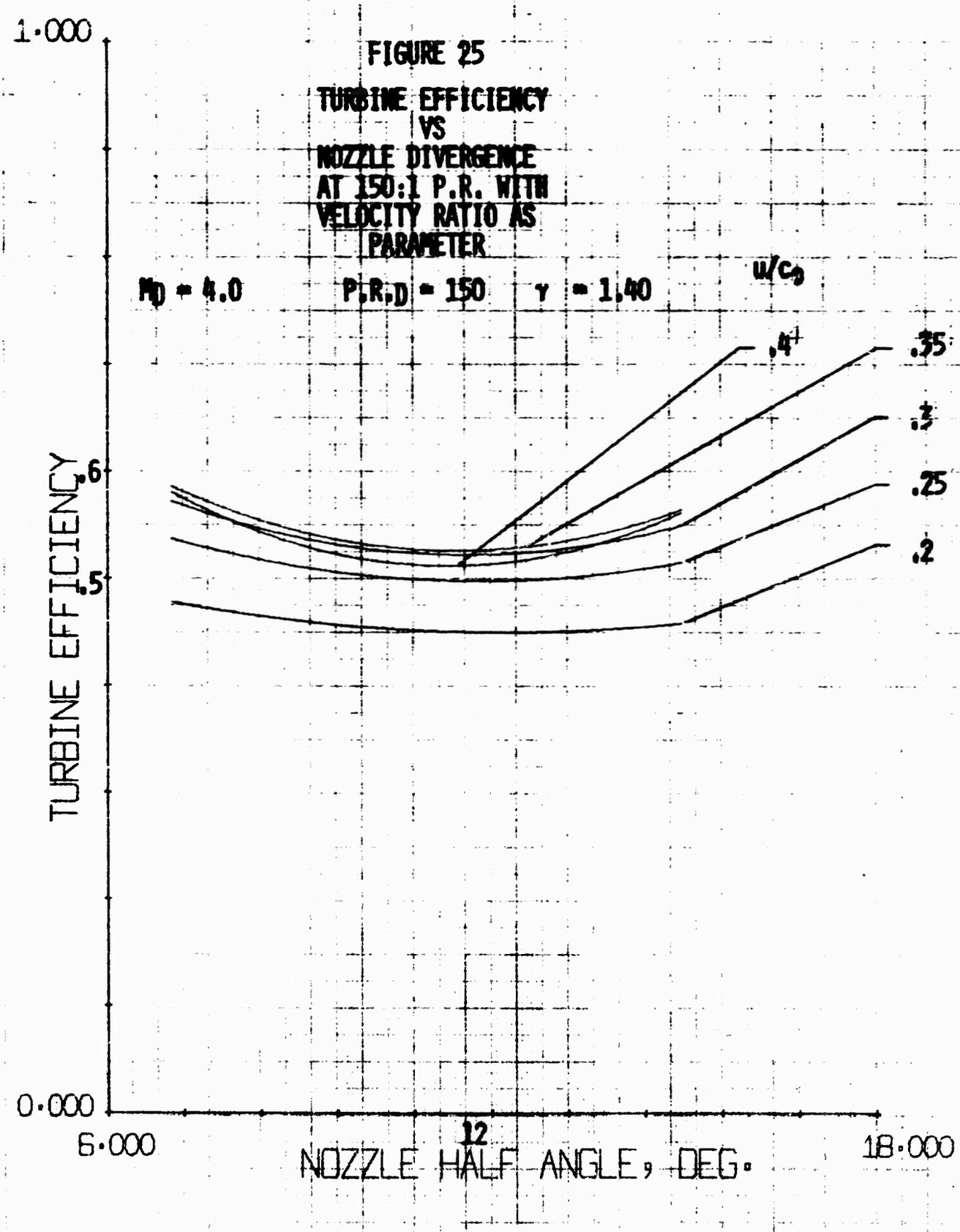
TURBINE EFFICIENCY
VS
NOZZLE DIVERGENCE
AT 200:1 P.R. WITH
VELOCITY RATIO AS
PARAMETER



MACH 4.0 NOZZLES, PRESSURE RATIO=200.

FIGURE 25

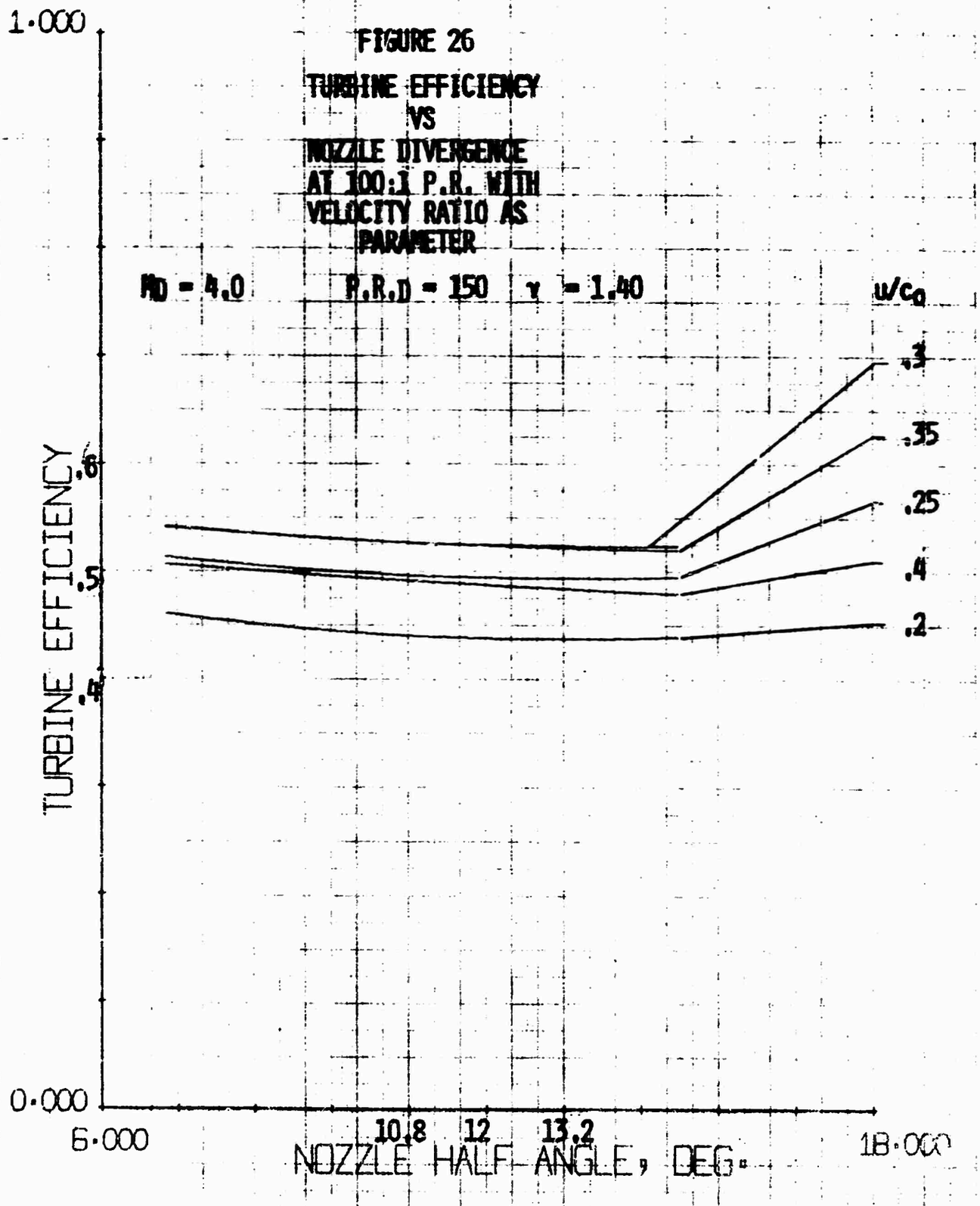
TURBINE EFFICIENCY VS NOZZLE DIVERGENCE AT 150:1 P.R. WITH VELOCITY RATIO AS PARAMETER



MACH 4.0 NOZZLES, PRESSURE RATIO=150.

FIGURE 26

TURBINE EFFICIENCY
VS
NOZZLE DIVERGENCE
AT 100:1 P.R. WITH
VELOCITY RATIO AS
PARAMETER

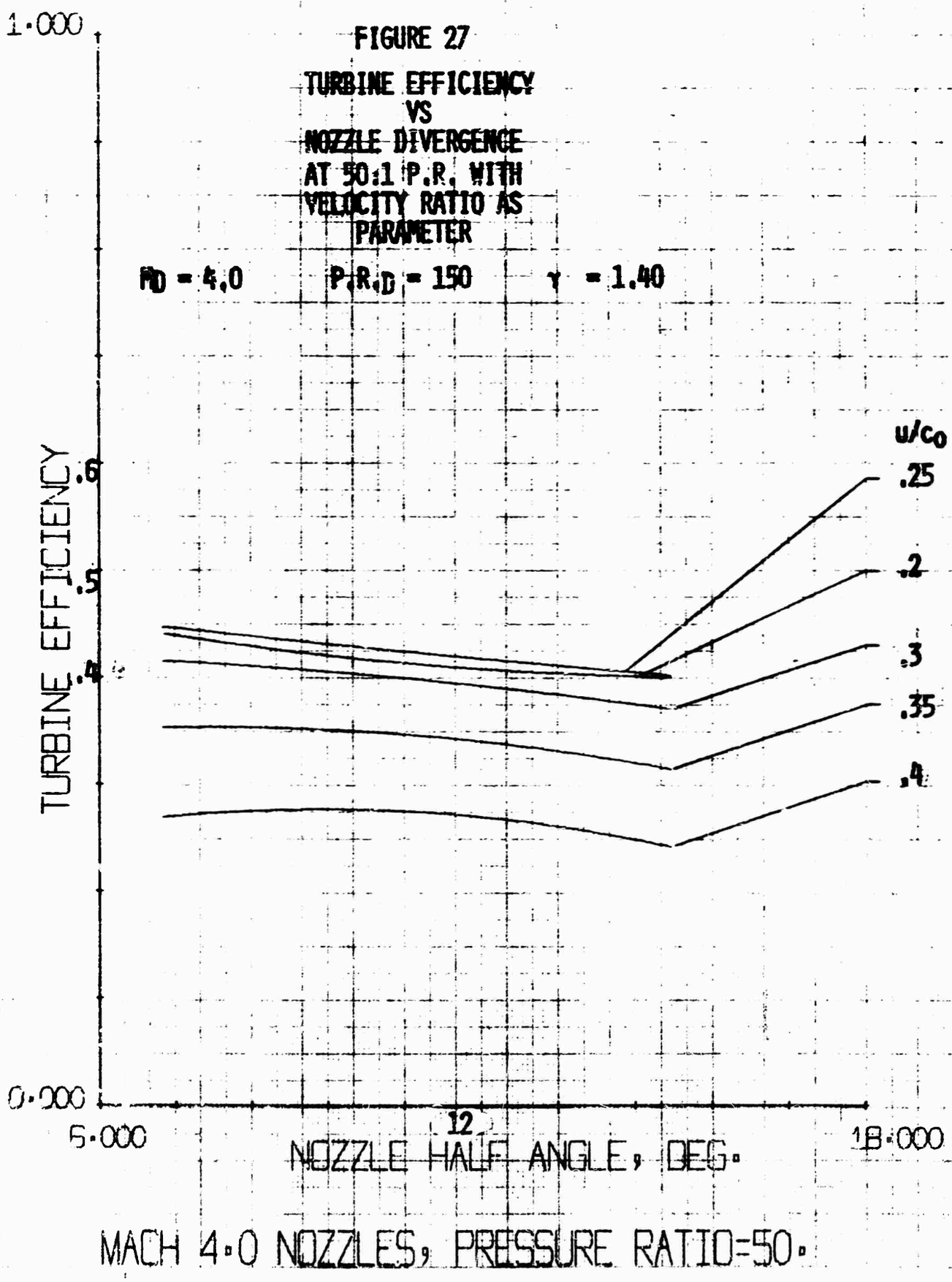


MACH 4.0 NOZZLES, PRESSURE RATIO=100.

FIGURE 27

TURBINE EFFICIENCY
VS
NOZZLE DIVERGENCE
AT 50:1 P.R. WITH
VELOCITY RATIO AS
PARAMETER

$M_D = 4.0$ $P.R._D = 150$ $\gamma = 1.40$

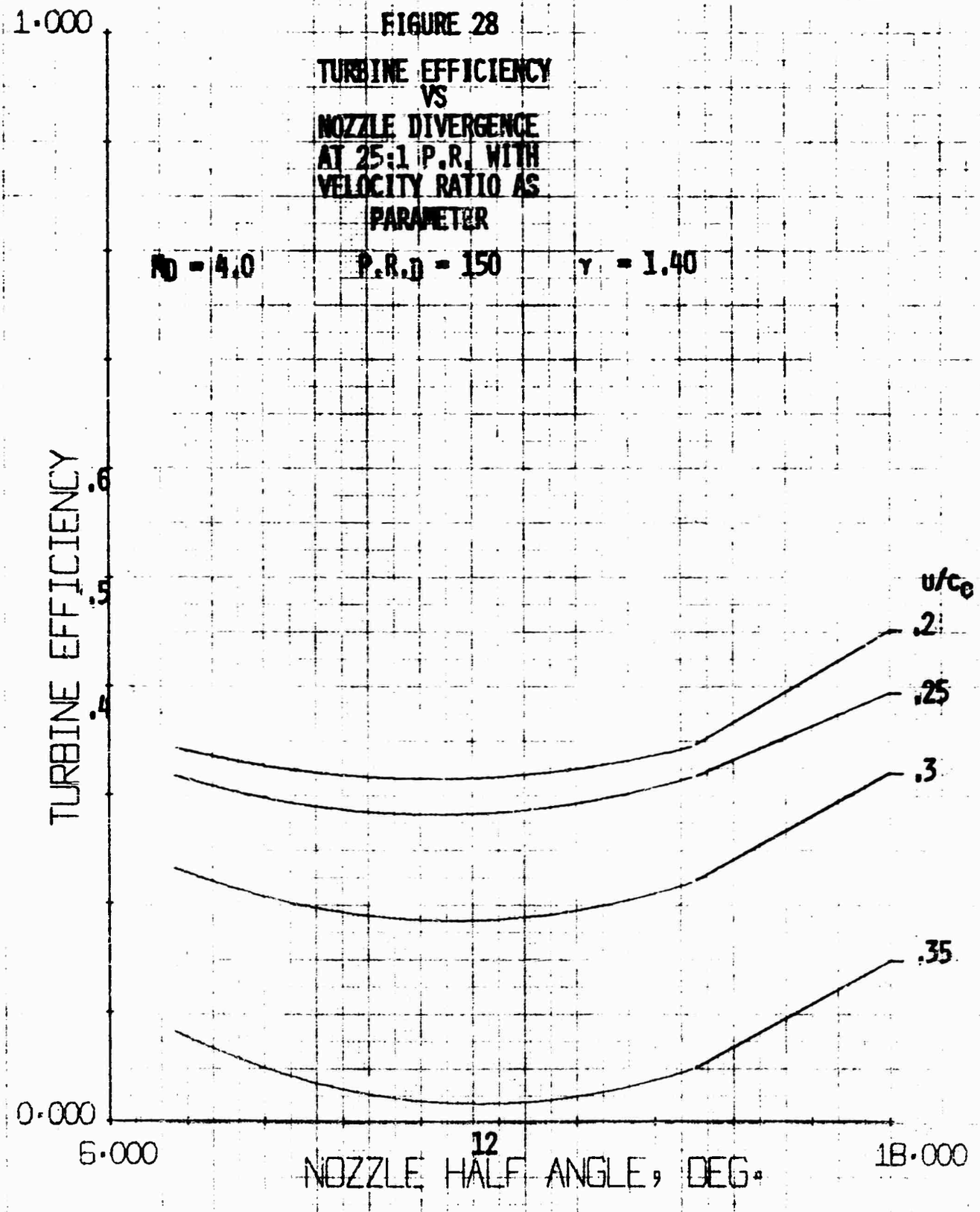


MACH 4.0 NOZZLES, PRESSURE RATIO=50.

FIGURE 28

TURBINE EFFICIENCY
VS
NOZZLE DIVERGENCE
AT 25:1 P.R. WITH
VELOCITY RATIO AS
PARAMETER

$M_D = 4.0$ $P.R._D = 150$ $\gamma = 1.40$

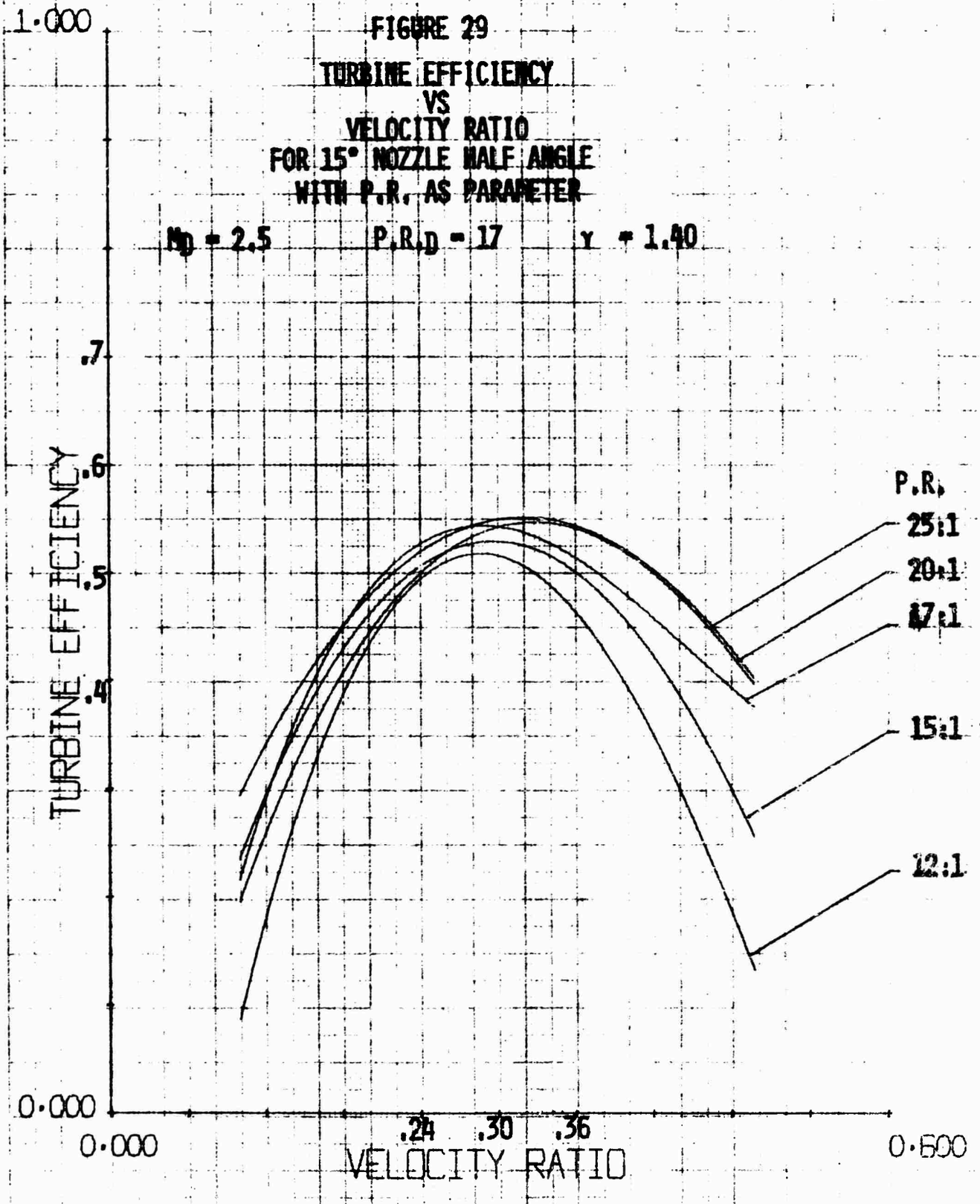


MACH 4.0 NOZZLES, PRESSURE RATIO=25.

FIGURE 29

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 15° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.40$

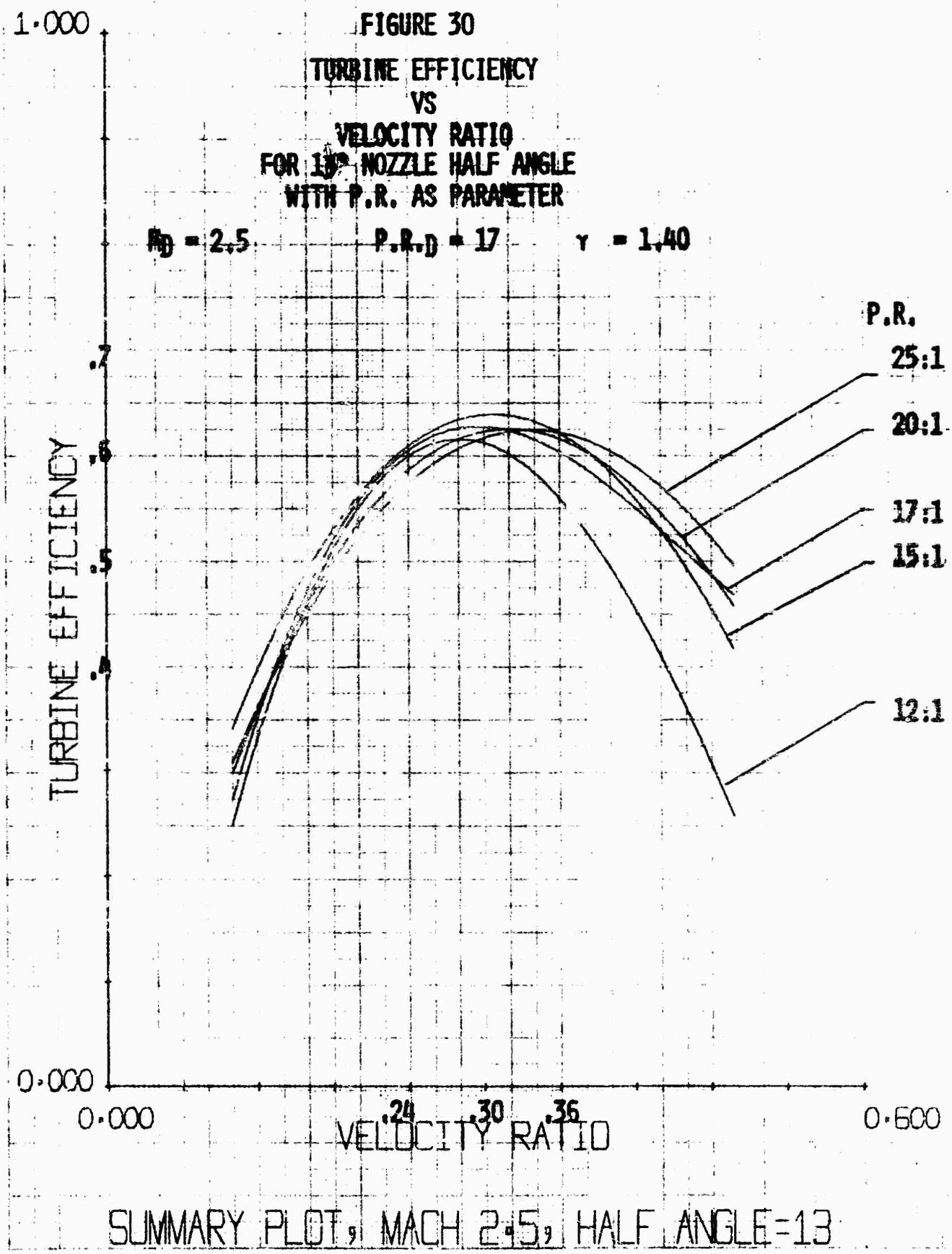


SUMMARY PLOT, MACH 2.5, HALF ANGLE=15

FIGURE 30

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 13° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.40$

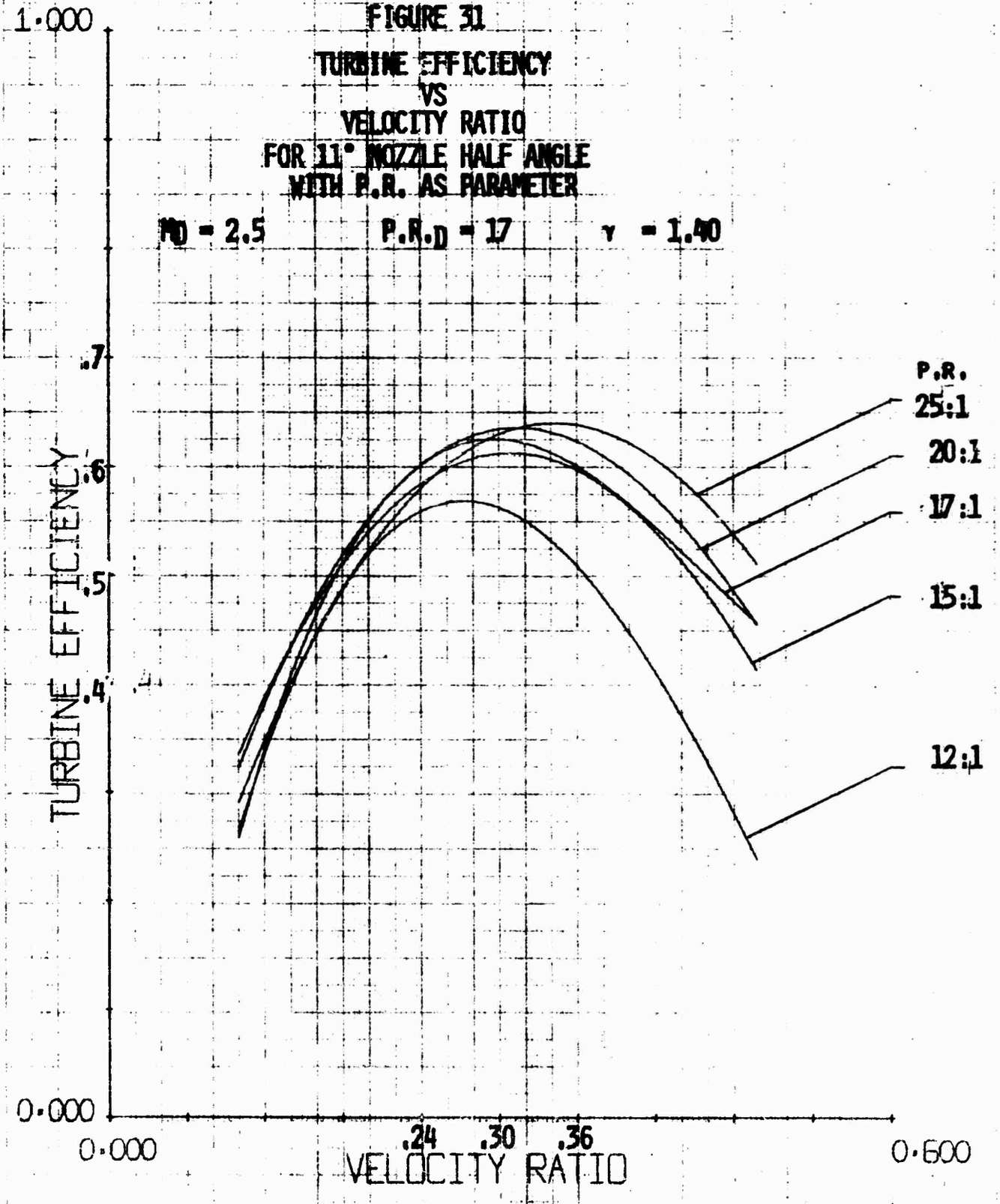


SUMMARY PLOT, MACH 2.5, HALF ANGLE=13

FIGURE 31

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 11° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_0 = 2.5$ $P.R._D = 17$ $\gamma = 1.40$

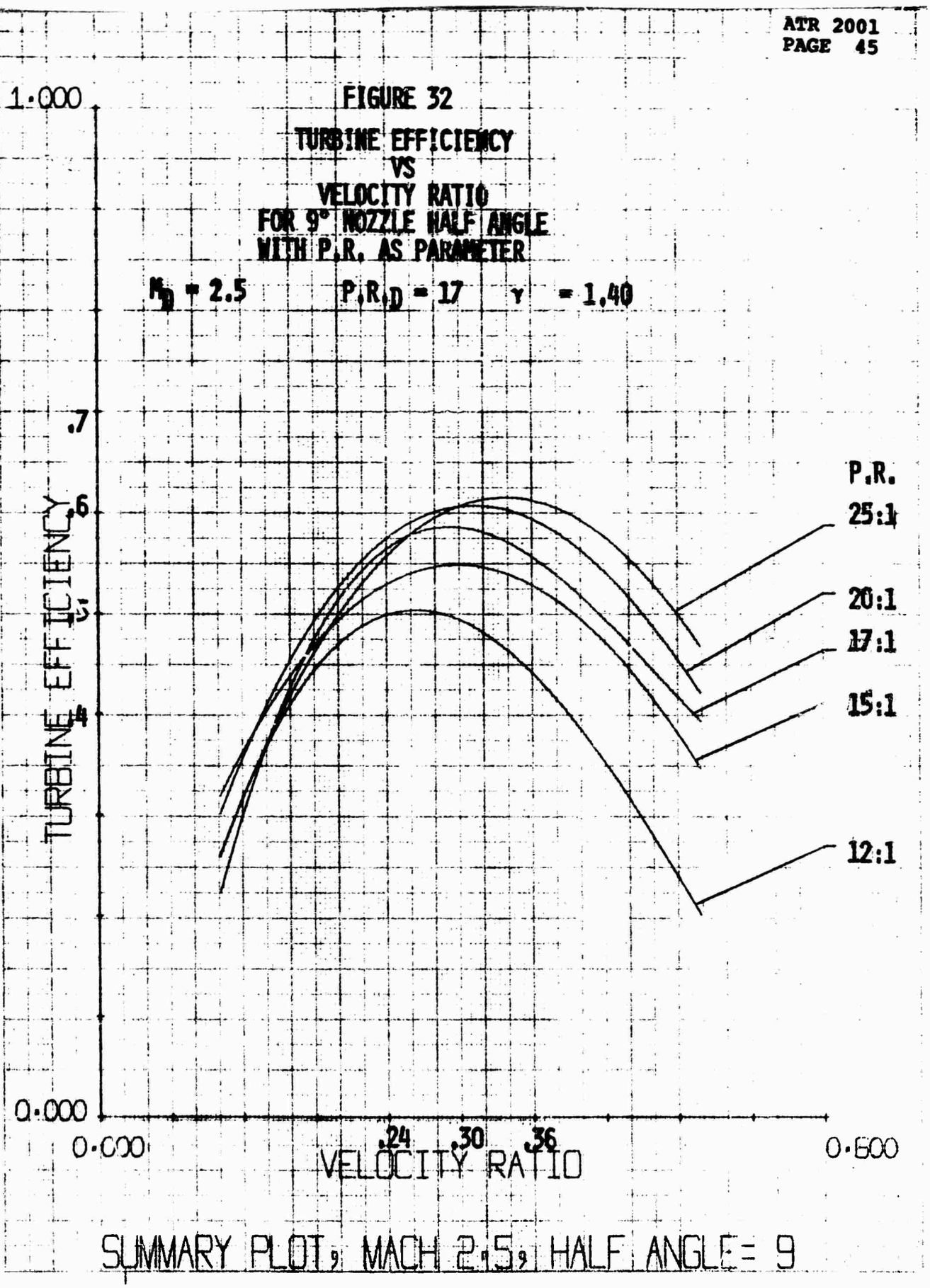


SUMMARY PLOT, MACH 2.5, HALF ANGLE=11

FIGURE 32

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 9° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_0 = 2.5$ $P_tR_tD = 17$ $\gamma = 1.40$

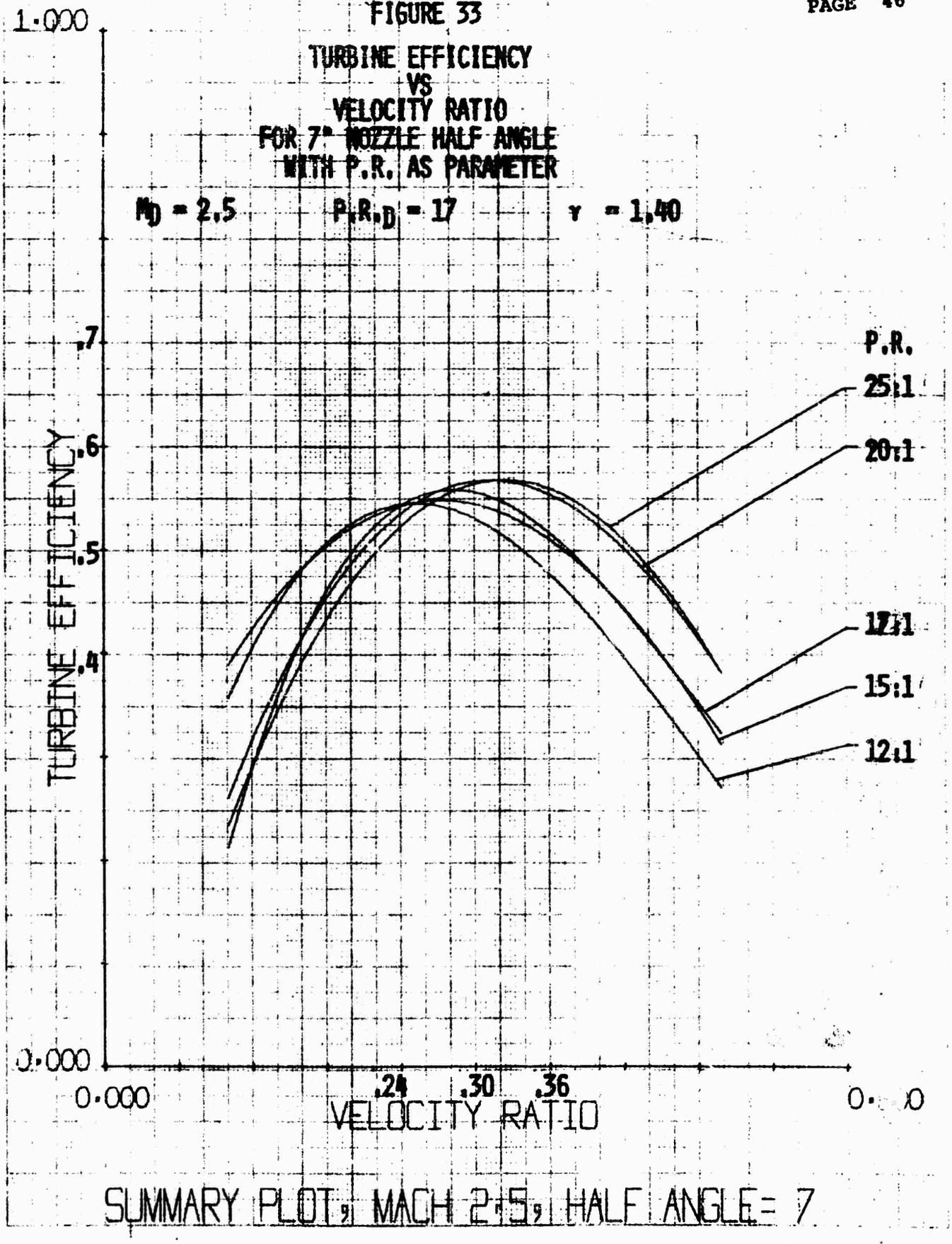


SUMMARY PLOT; MACH 2.5, HALF ANGLE = 9

FIGURE 33

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 7° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.40$

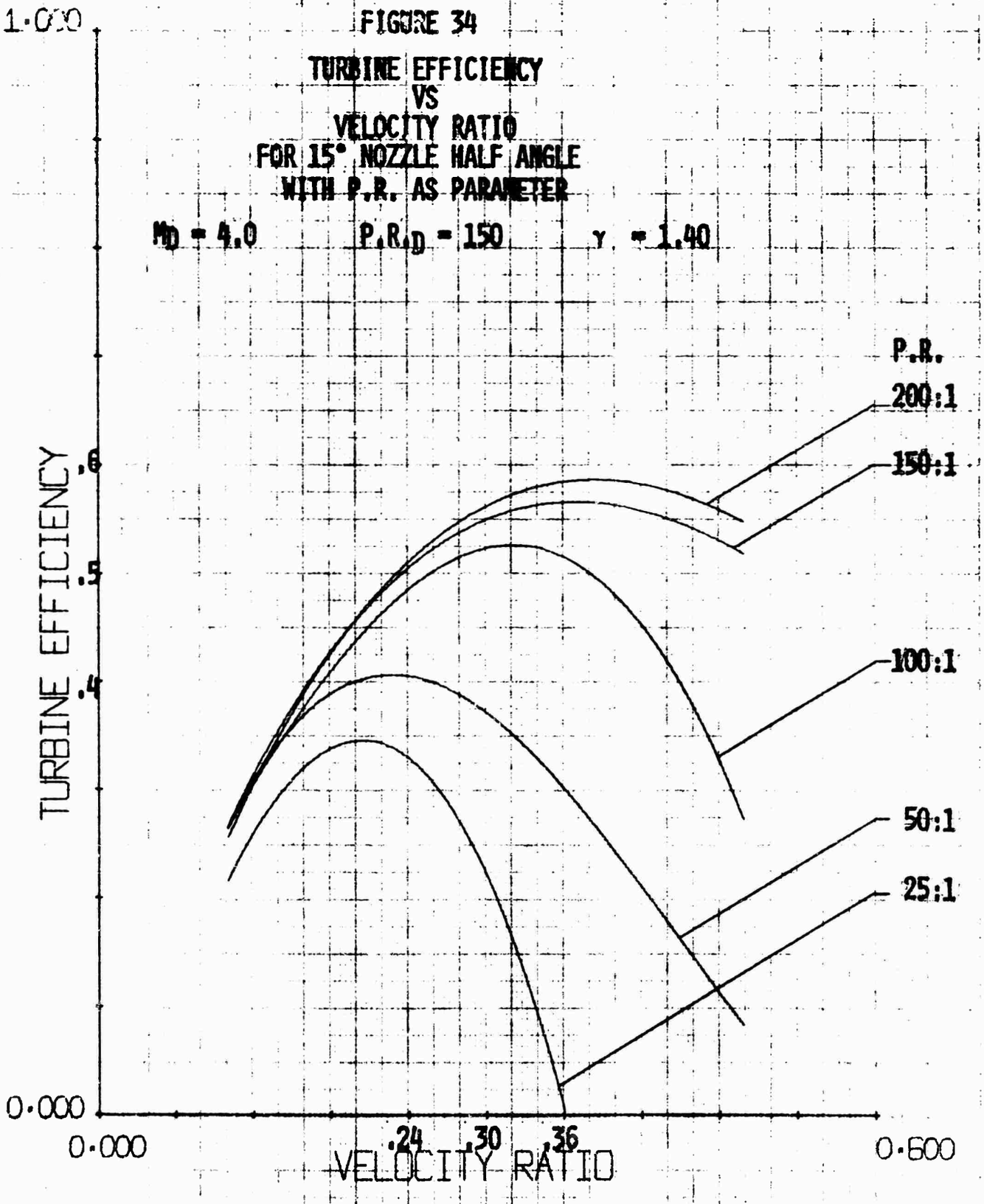


SUMMARY PLOT; MACH 2.5, HALF ANGLE = 7

FIGURE 34

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 15° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_D = 4.0$ $P.R._D = 150$ $\gamma = 1.40$

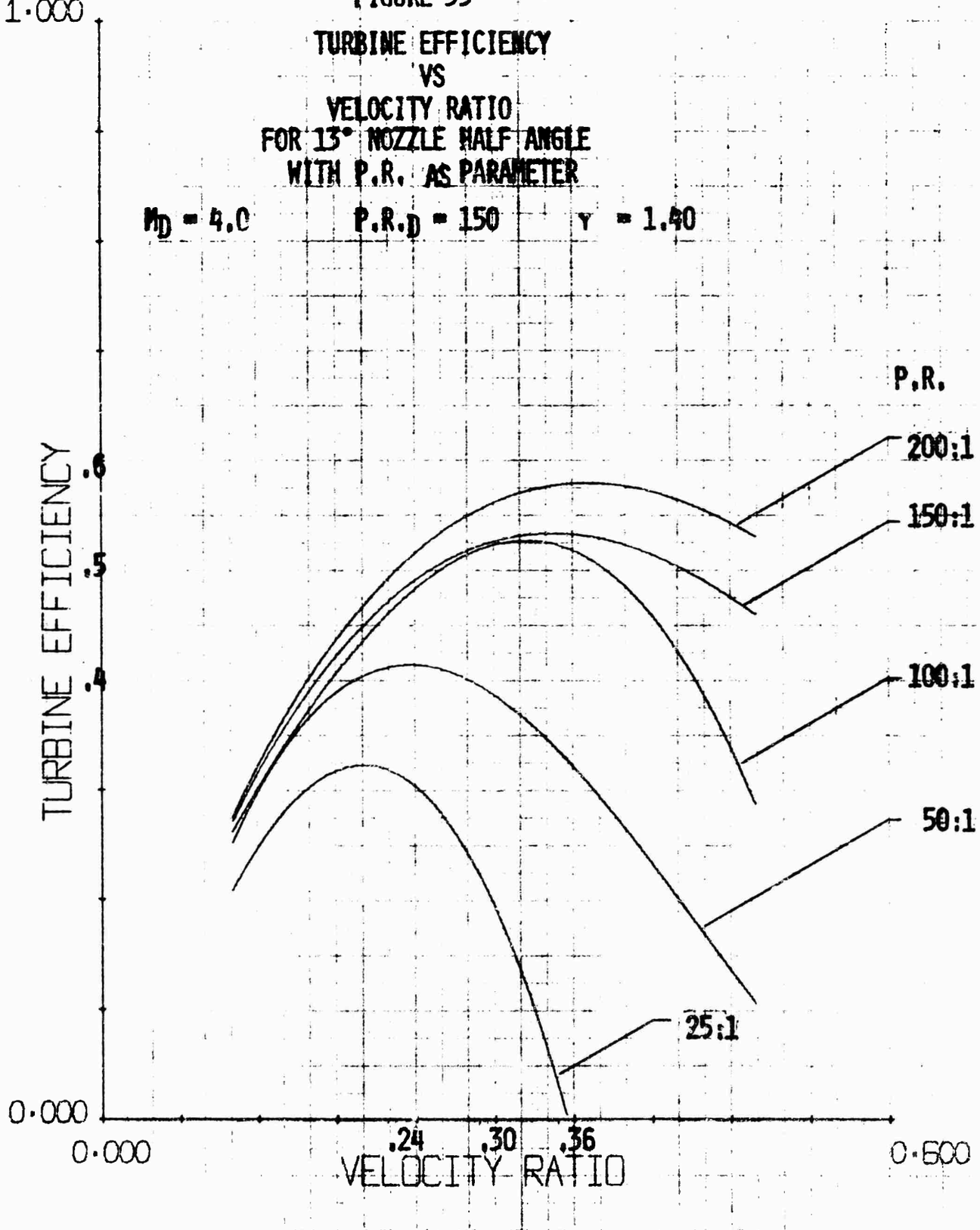


SUMMARY PLOT, MACH 4.0, HALF ANGLE=15°

FIGURE 35

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 13° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

M_D = 4.0 P.R.$_D$ = 150 γ = 1.40

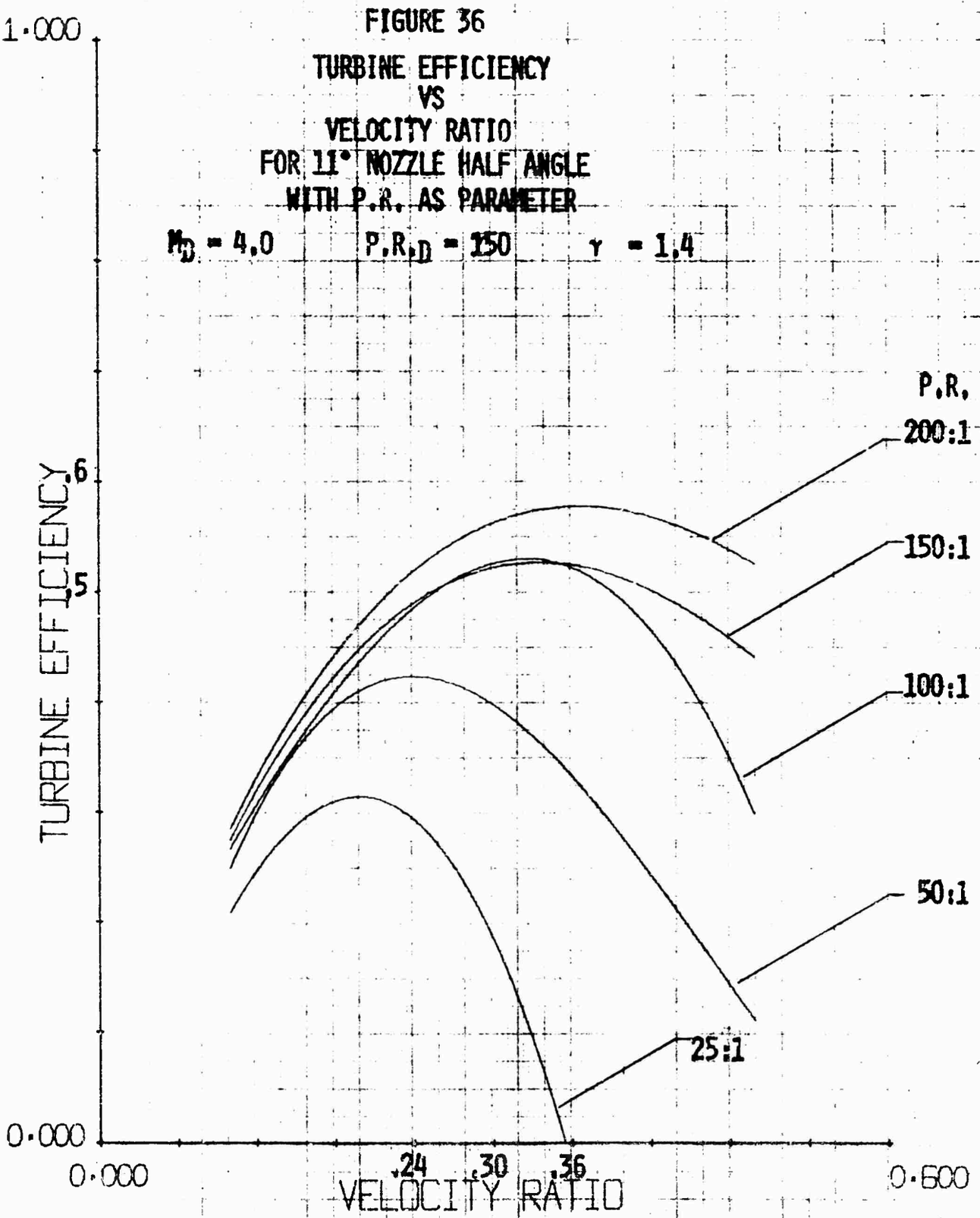


SUMMARY PLOT, MACH 4.0, HALF ANGLE=13°

FIGURE 36

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 11° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_D = 4.0$ $P.R._D = 150$ $\gamma = 1.4$

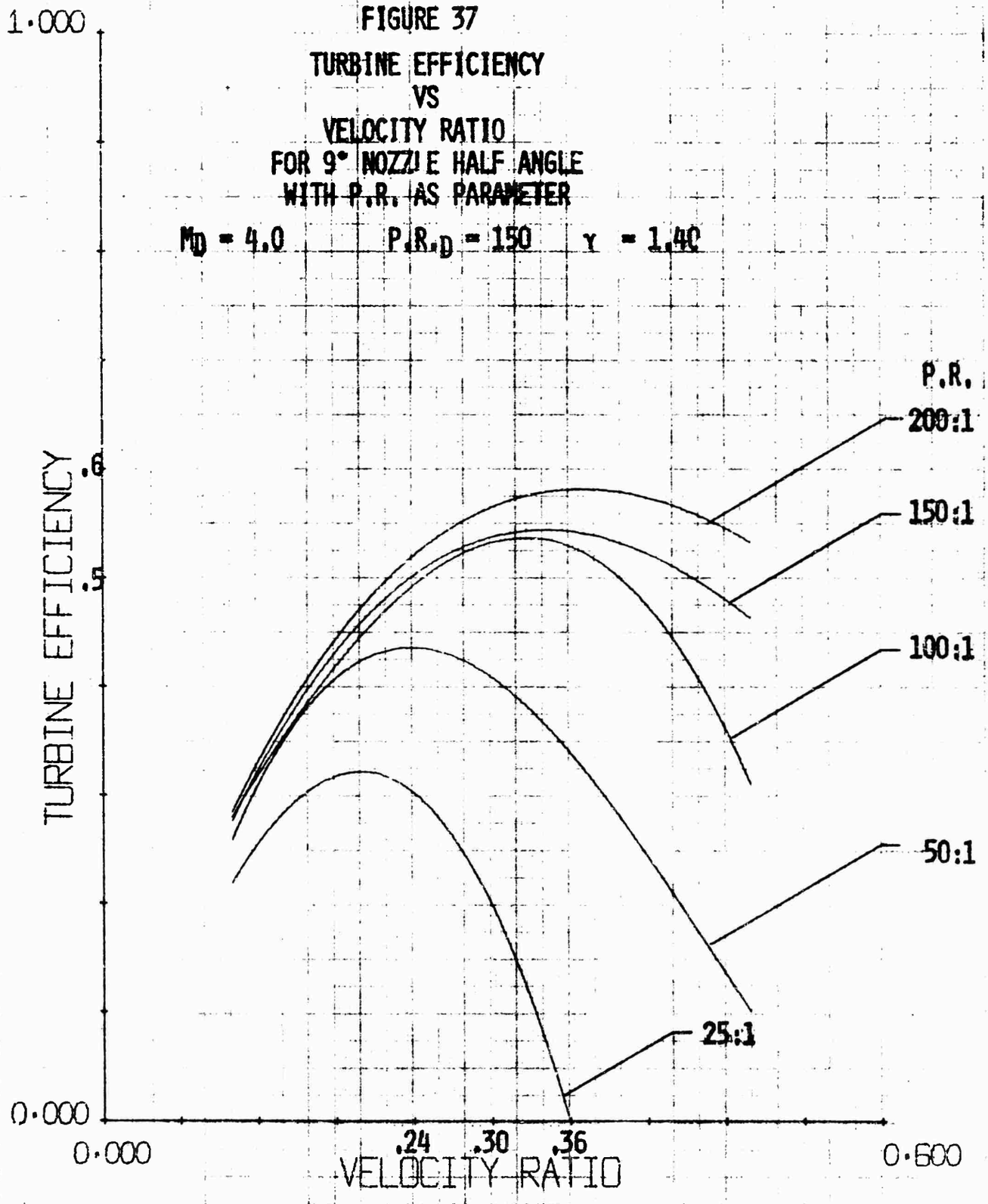


SUMMARY PLOT, MACH 4.0, HALF ANGLE = 11°

FIGURE 37

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 9° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_D = 4.0$ $P.R._D = 150$ $\gamma = 1.40$

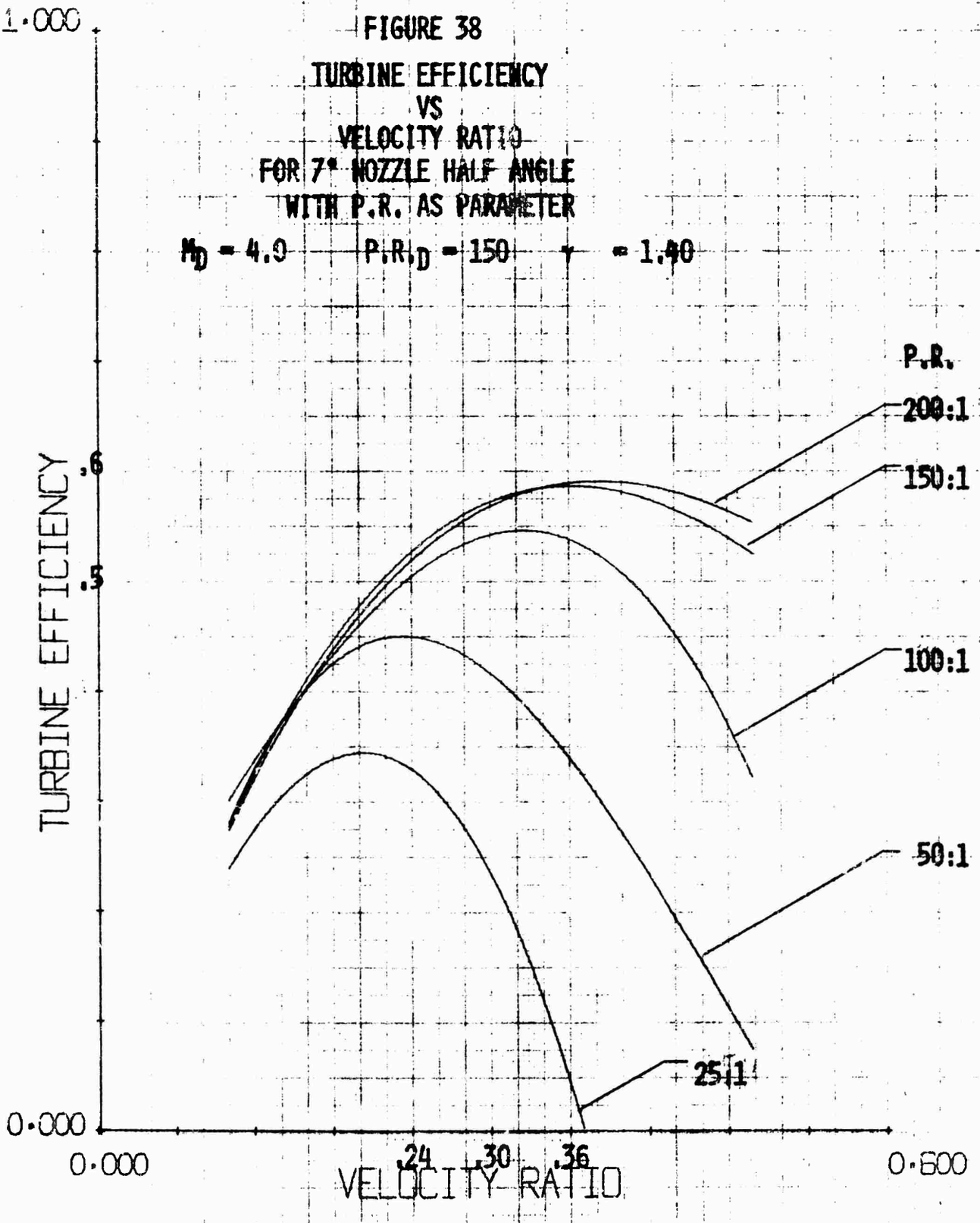


SUMMARY PLOT; MACH 4.0, HALF ANGLE=9°

FIGURE 38

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 7° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_D = 4.0$ $P.R._D = 150$ $\gamma = 1.40$

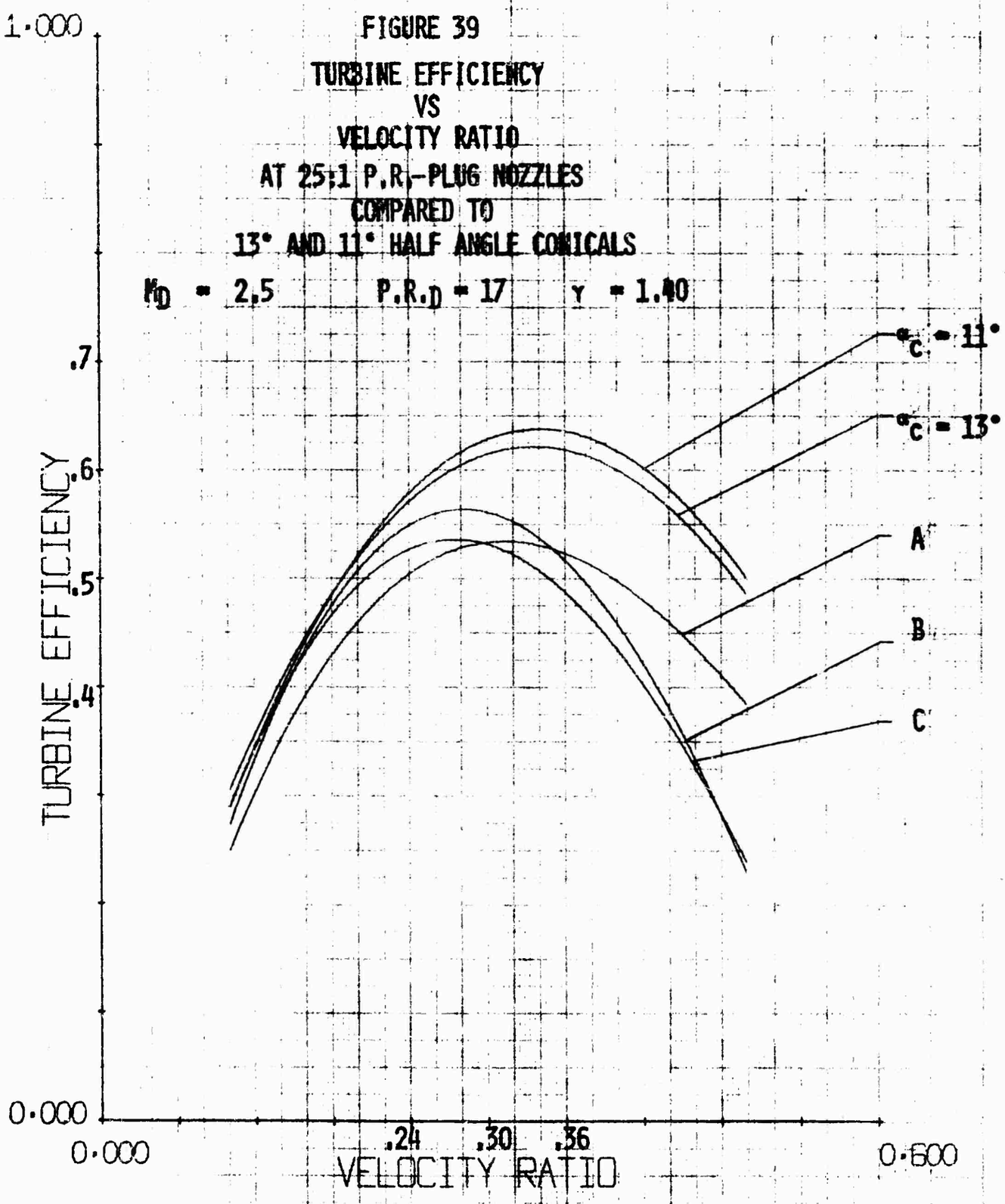


SUMMARY PLOT; MACH 4.0; HALF ANGLE=7

FIGURE 39

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 25:1 P.R.-PLUG NOZZLES
COMPARED TO
13° AND 11° HALF ANGLE CONICALS

K_D = 2.5 P.R.$_D$ = 17 γ = 1.40

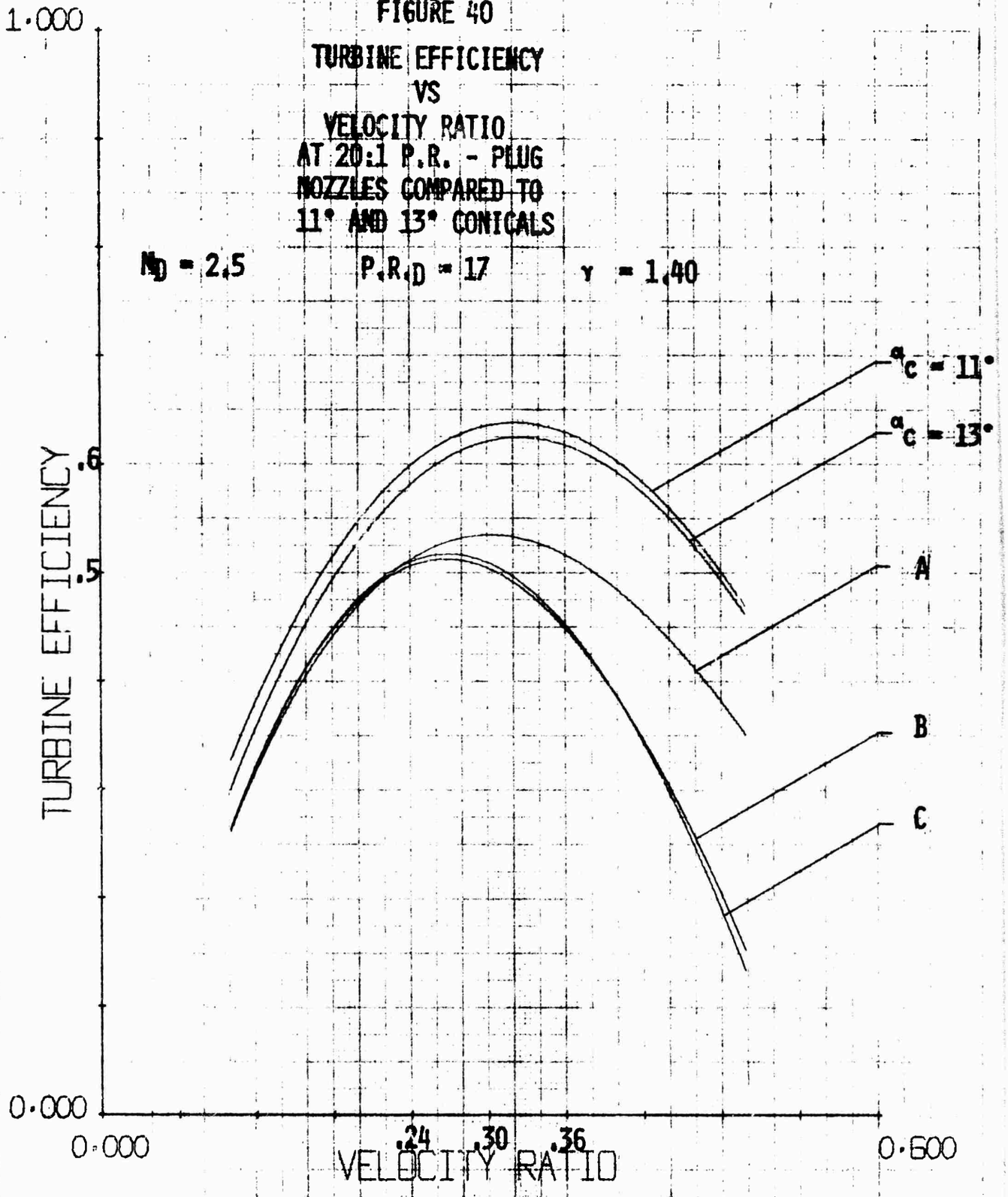


PLUG NOZZLE COMPARISON, PR. RATIO = 25

FIGURE 40

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 20:1 P.R. - PLUG
NOZZLES COMPARED TO
11° AND 13° CONICALS

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.40$

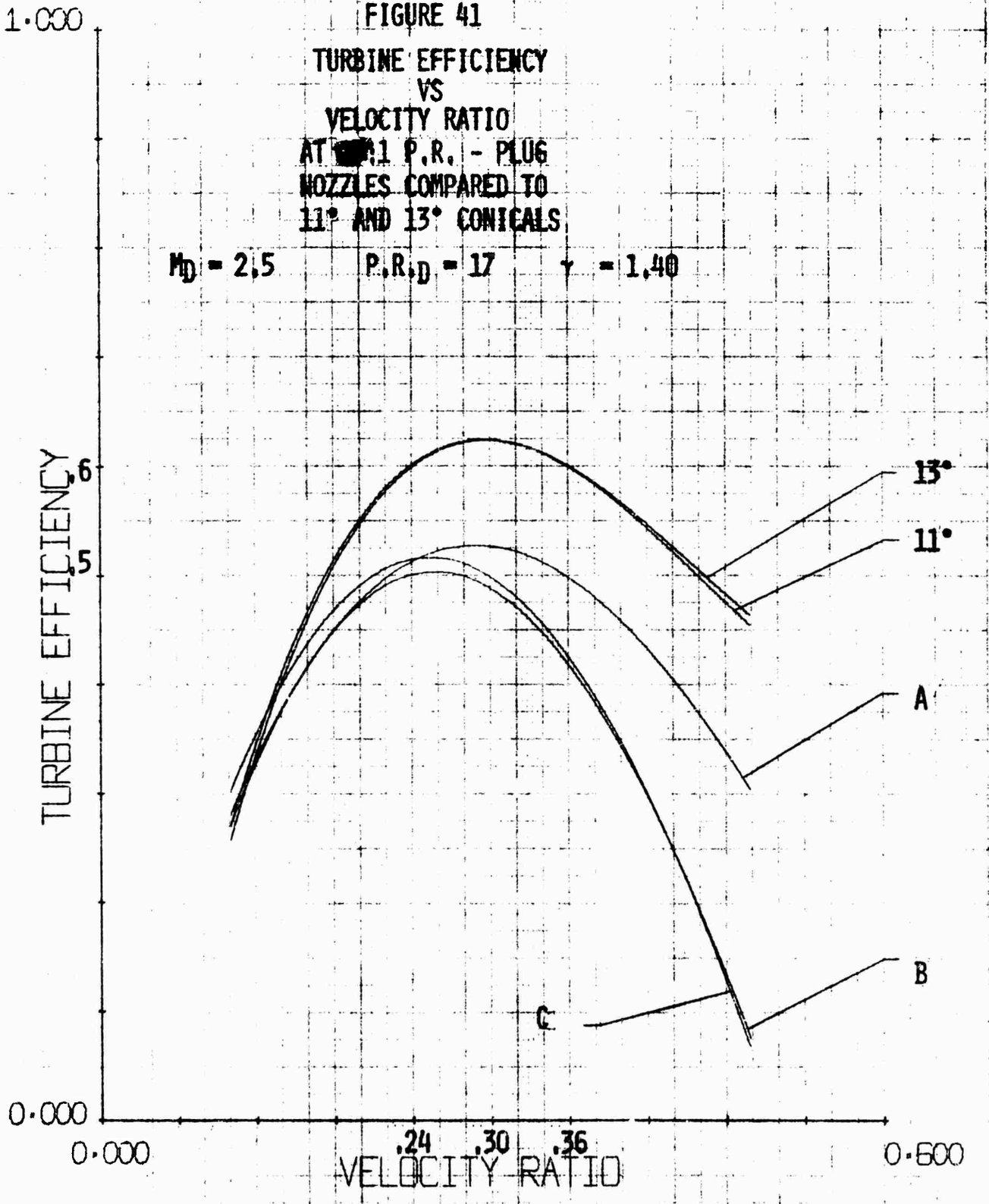


PLUG NOZZLE COMPARISON, PR. RATIO = 20

FIGURE 41

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT [redacted]:1 P.R. - PLUG
NOZZLES COMPARED TO
11° AND 13° CONICALS

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.40$

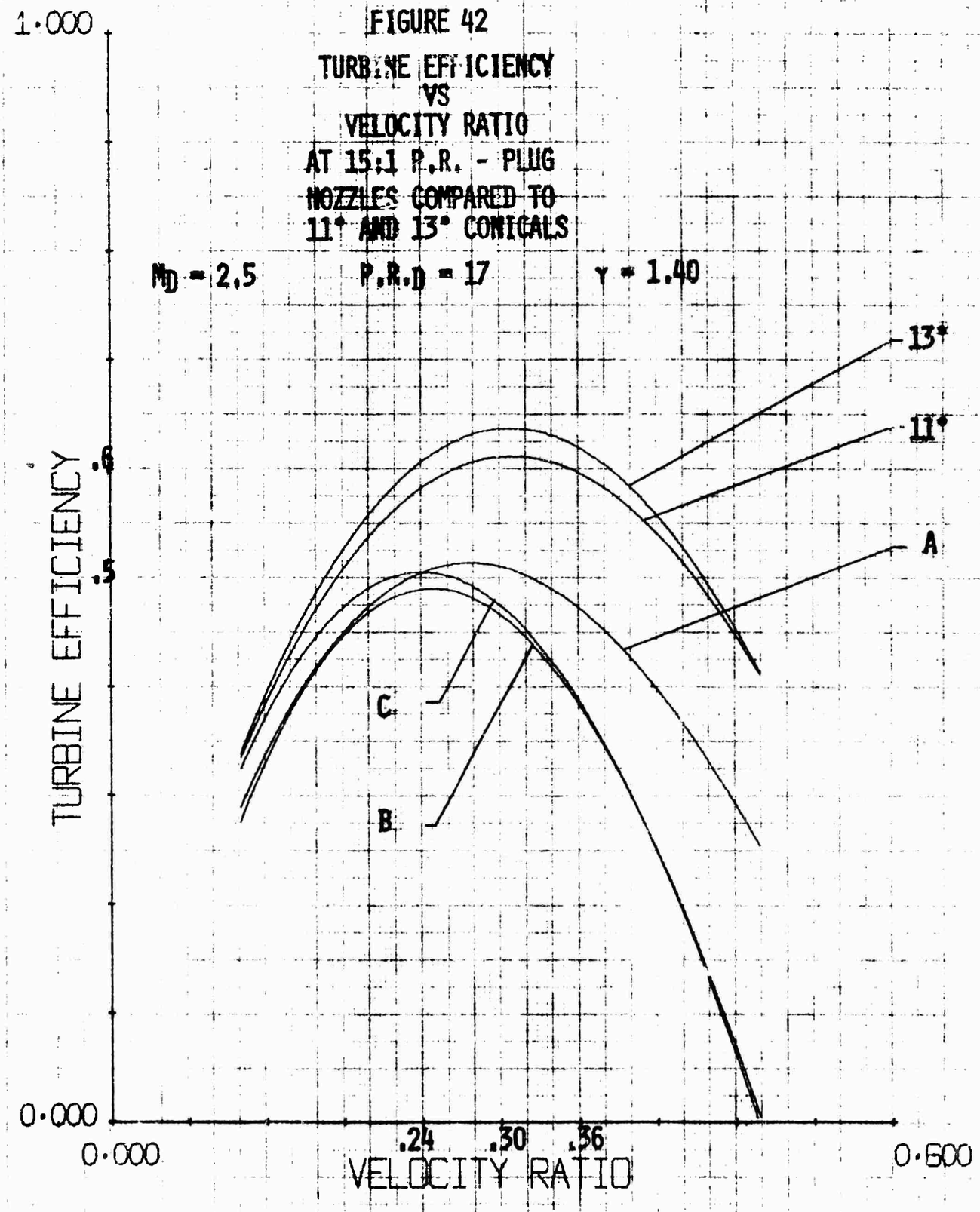


PLUG NOZZLE COMPARISON, PR. RATIO = 17

FIGURE 42

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 15:1 P.R. - PLUG
NOZZLES COMPARED TO
11° AND 13° CONICALS

$M_D = 2.5$ $P.R._D = 17$ $\gamma = 1.40$

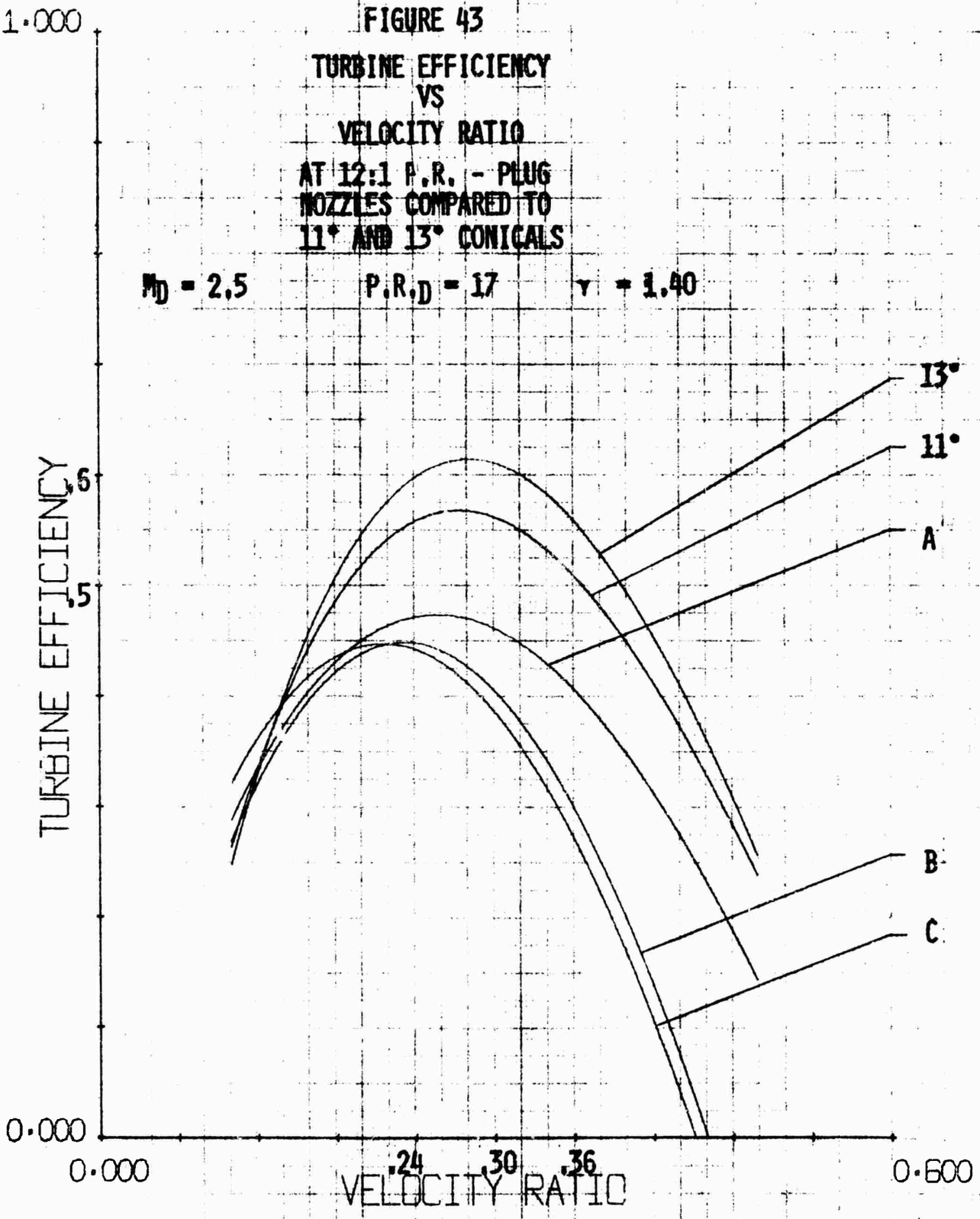


PLUG NOZZLE COMPARISON, PR. RATIO = 15

FIGURE 43

TURBINE EFFICIENCY
VS
VELOCITY RATIO
AT 12:1 P.R. - PLUG
NOZZLES COMPARED TO
11° AND 13° CONICALS

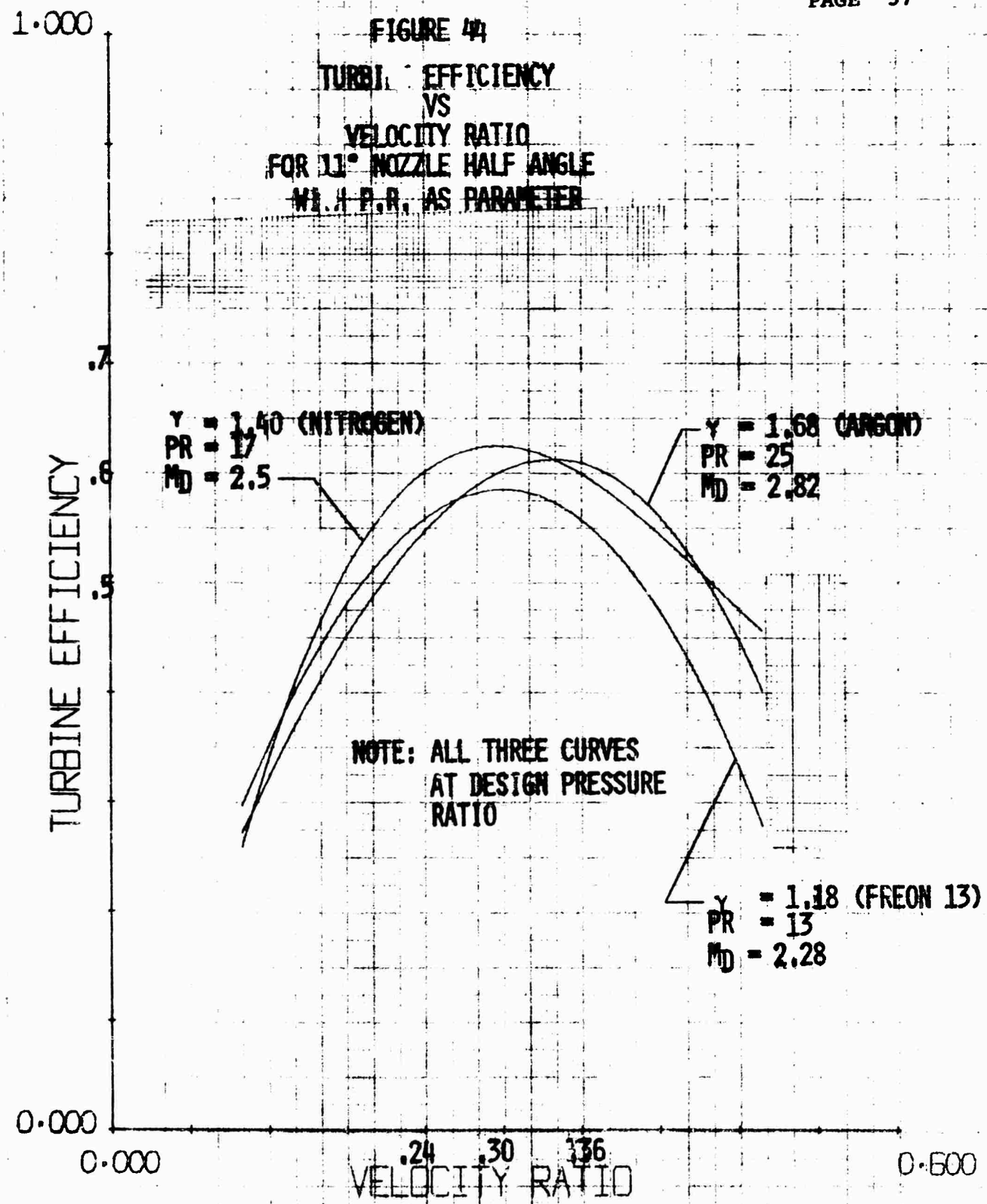
M_D = 2,5 $P.R._D$ = 17 γ = 1.40



PLUG NOZZLE COMPARISON, PR. RATIO = 12

FIGURE 44

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 11° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

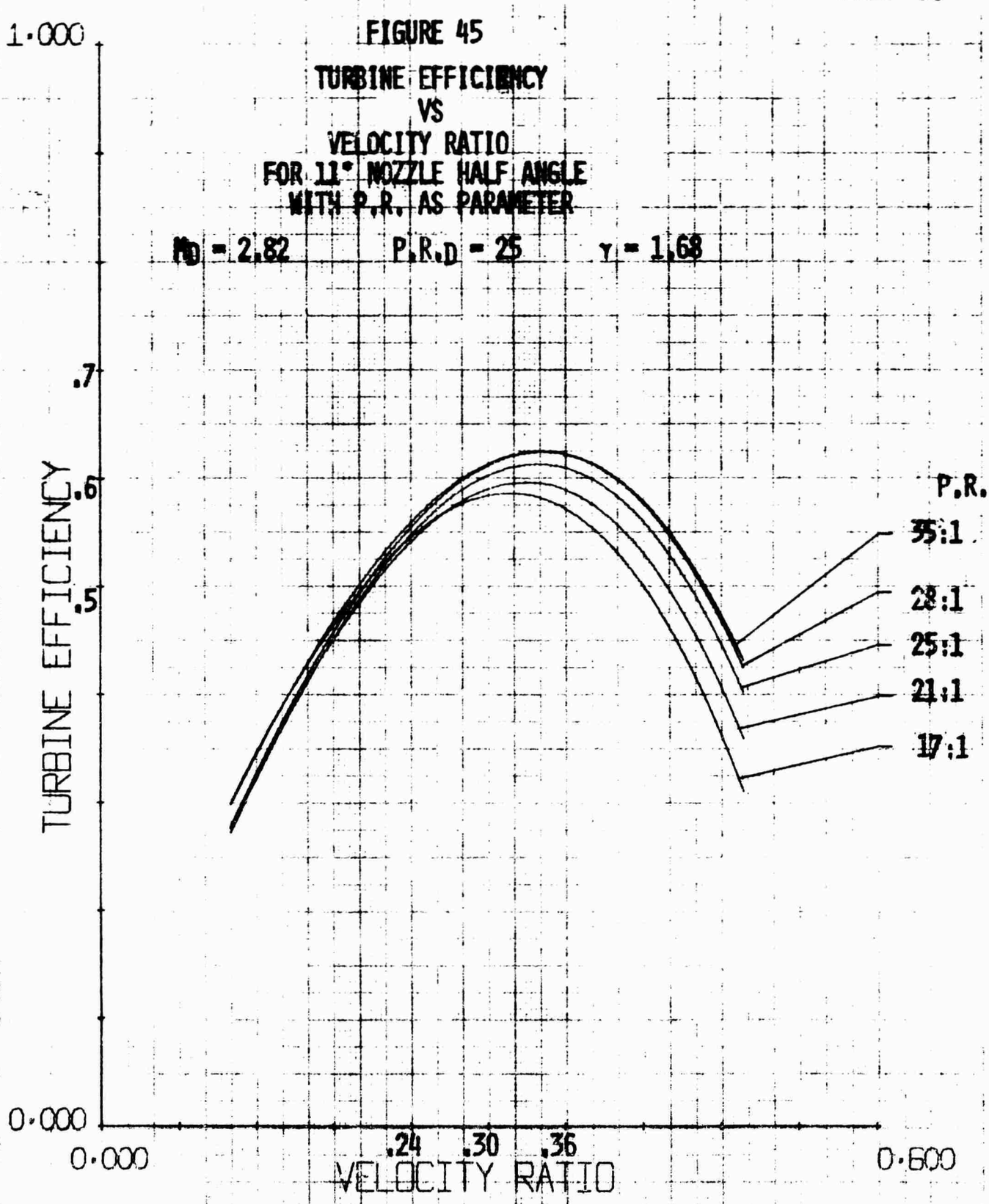


SUMMARY PLOT, ARGON, FREON, NITROGEN

FIGURE 45

TURBINE EFFICIENCY
VS
VELOCITY RATIO
FOR 11° NOZZLE HALF ANGLE
WITH P.R. AS PARAMETER

$M_D = 2.82$ $P.R._D = 25$ $\gamma = 1.68$



SUMMARY PLOT, ARGON, HALF ANGLE=11

TABLE IV

NOMINAL TEST CONDITIONS

Nozzle/Test (See Table II)	Nozzle Inlet Pressure psia	Exhaust Pressure psia		P.R.	Inlet Temp. °F
2.57	60	2.4	All Press. Each Nozzle ↑	25	↑
2.59	60	3.0		20	
2.511	60	3.5		17 des.	
2.513	60	4.0		15	
2.515	60	5.0		12	20-70
Plug A	60				↓
Plug B	60		↓		
Plug C	60				
4.7	240	1.2	All Press. Each Nozzle ↑	200	↑
		1.6		150 des.	
4.11	240	2.4		100	20-70
		4.8		50	
4.15	240	9.6	↓	25	↓
	98	2.8		35	↑
	98	3.5		28	
Argon 2.511	98	3.9		25 des.	0-60
	98	4.6		21	
	98	5.8		17	↓
Freon 2.511	91	7.1		12.8 des.	38-50

3.0 CONCLUSIONS

1) Turbines with low mach number supersonic nozzles should use nozzle half angles of about 12° to optimize performance.

2) Performance with high design mach number nozzles appears essentially independent of nozzle divergence.

3) Plug and contoured nozzles should be used with caution in turbines. Testing of three types showed no performance advantages.

4) Off-design performance improves with increased specific heat ratio.

5) Peak efficiency appears to exhibit a maximum as a function of specific heat ratio (at $\gamma = 1.4$) although this effect is small.

4.0 RECOMMENDATIONS

Since this effort was primarily an experimental study the discussion and conclusions are on the order of obvious observations. The large quantity of data were organized in only an elementary way and a thorough theoretical analysis and interpretation of it would be a significant contribution to the advancement of turbine performance and design.

5.0 SYMBOLS

A	nozzle area	$in.^2$
C_D	nozzle discharge coefficient	$\frac{W\text{-measured}}{W\text{-theoretical}}$
C_o	isentropic spouting velocity	ft/sec
D_e	diameter of nozzle exit	in.
D*	diameter of nozzle throat	in.
M	mach number	
P	static pressure	psia
P_T	total pressure	psia
PR	total to static pressure ratio	
U	turbine tip speed	ft/sec
W	nozzle weight flow	lb/sec
α_c	nozzle cone half angle	degrees
γ	gas ratio of specific heats	
η_t	turbine efficiency	

SUBSCRIPTS

O	nozzle entrance
*	nozzle throat
e	nozzle exit plane
D	design

6.0 LIST OF REFERENCES

1. Barber, R. E. and Schultheiss, M. J., "The Effect of Nozzle Geometry on Off-Design Performance of Partial Admission Impulse Turbines", Sundstrand Aviation AER 486, April 1967.

2. Rao, G. V. R., "Approximation of Optimum Thrust Nozzle Contours", Jet Propulsion Vol. 30, June 1960.

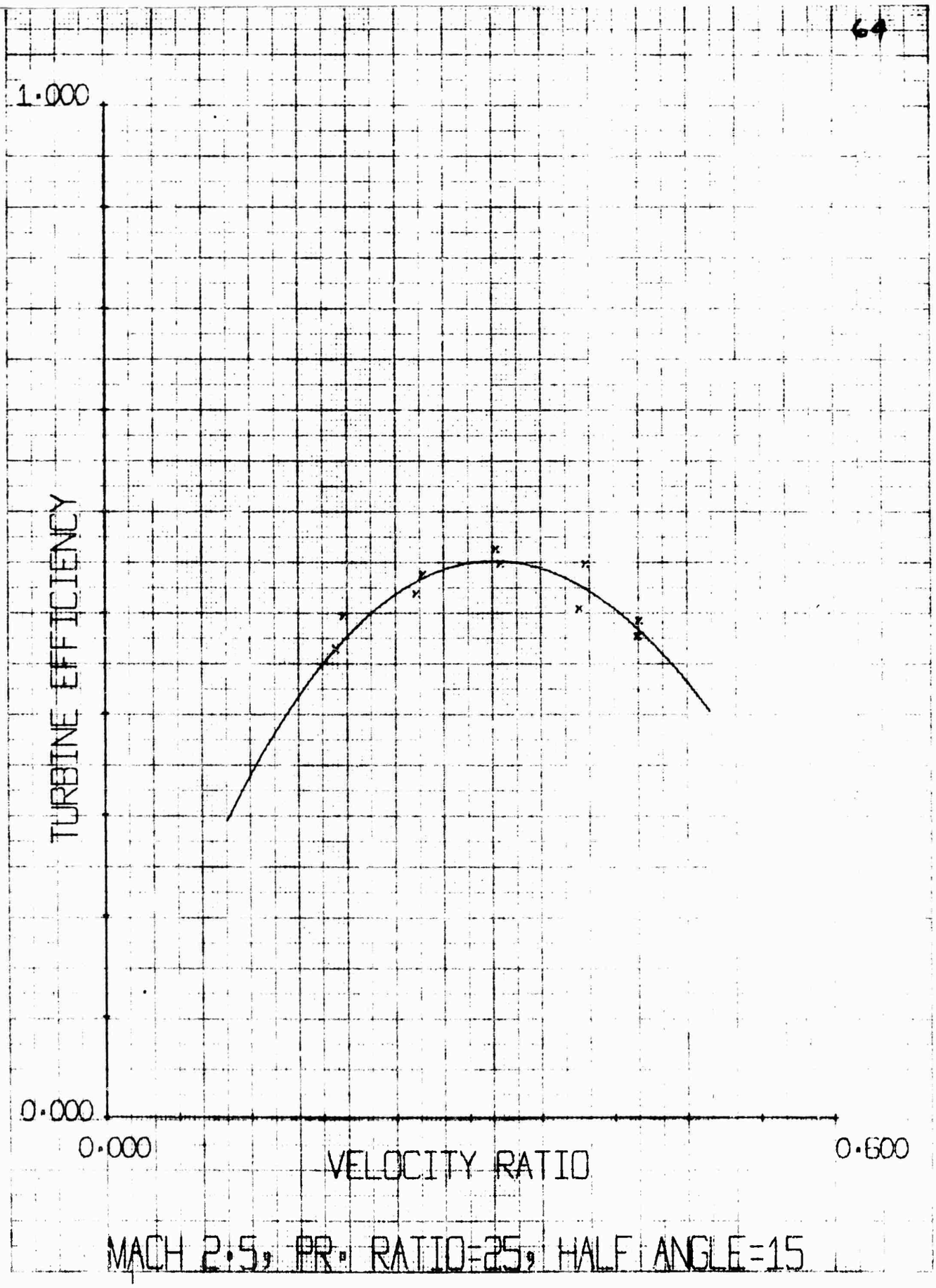
3. Carnahan, B., Luter, H. A. and Wilkes, J. O., "Applied Numerical Analysis", John Wiley and Sons, 1969.

4. "Tables of Thermal Properties of Gases", National Bureau of Standards, Circular 564, 1955.

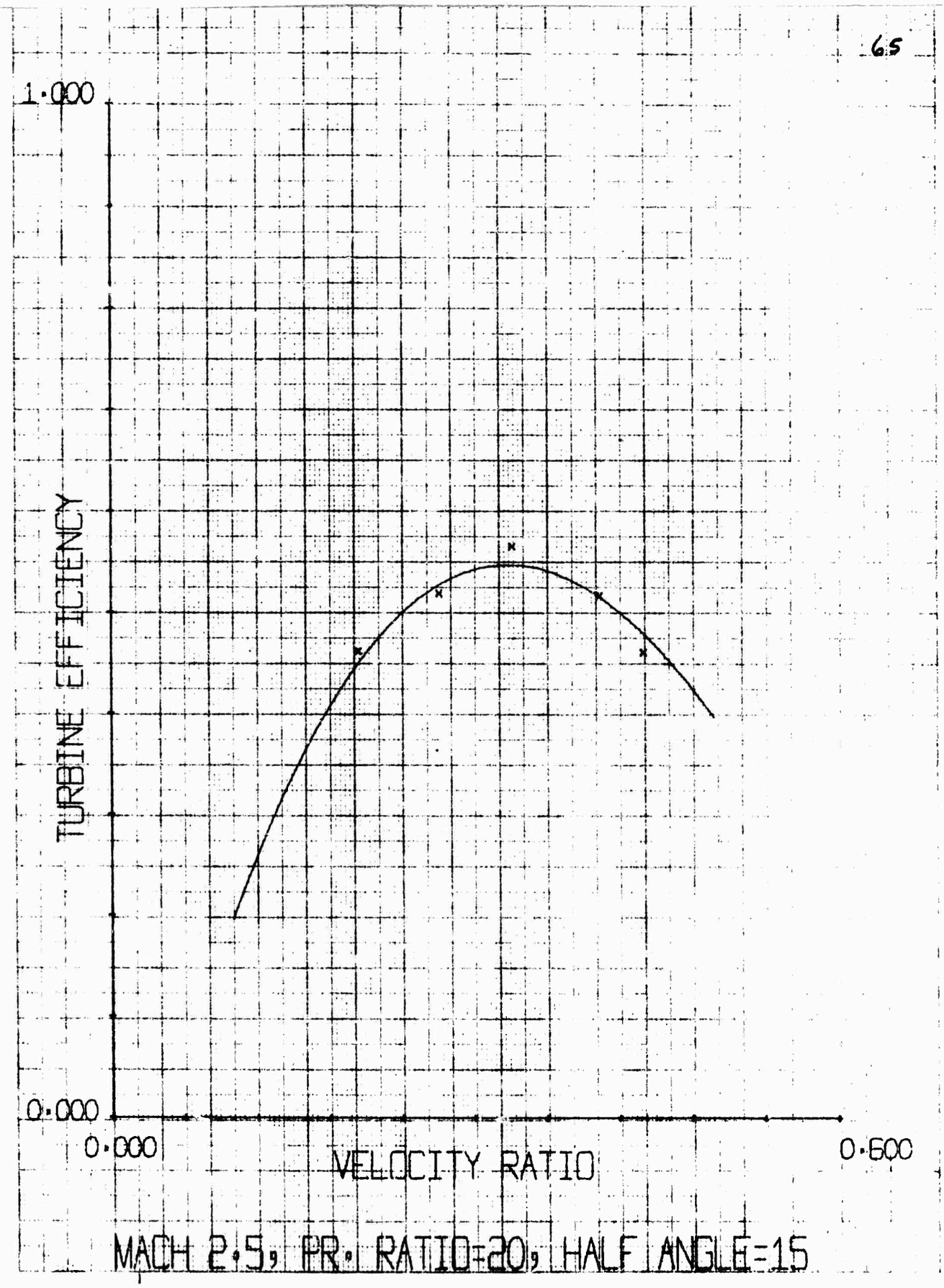
5. El Dupont De Nemours & Co., "Freon 13 Thermodynamic Properties"; Pressure Enthalpy Diagram for Freon 13; "Transport Properties of Freon Flour-ocarbons".

APPENDIX A

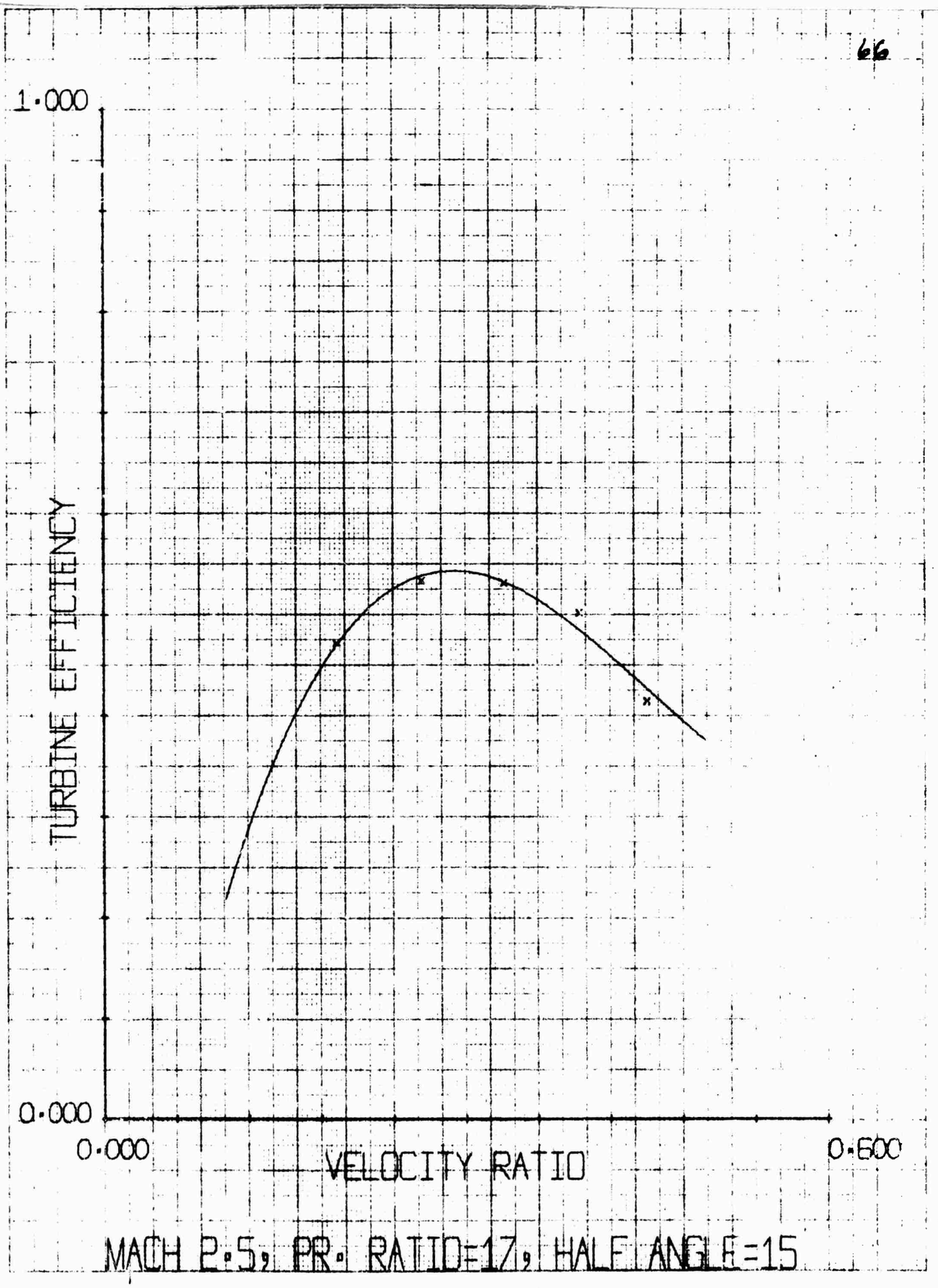
GRAPHS OF INDIVIDUAL TEST RESULTS WITH EMPIRICAL DATA POINTS



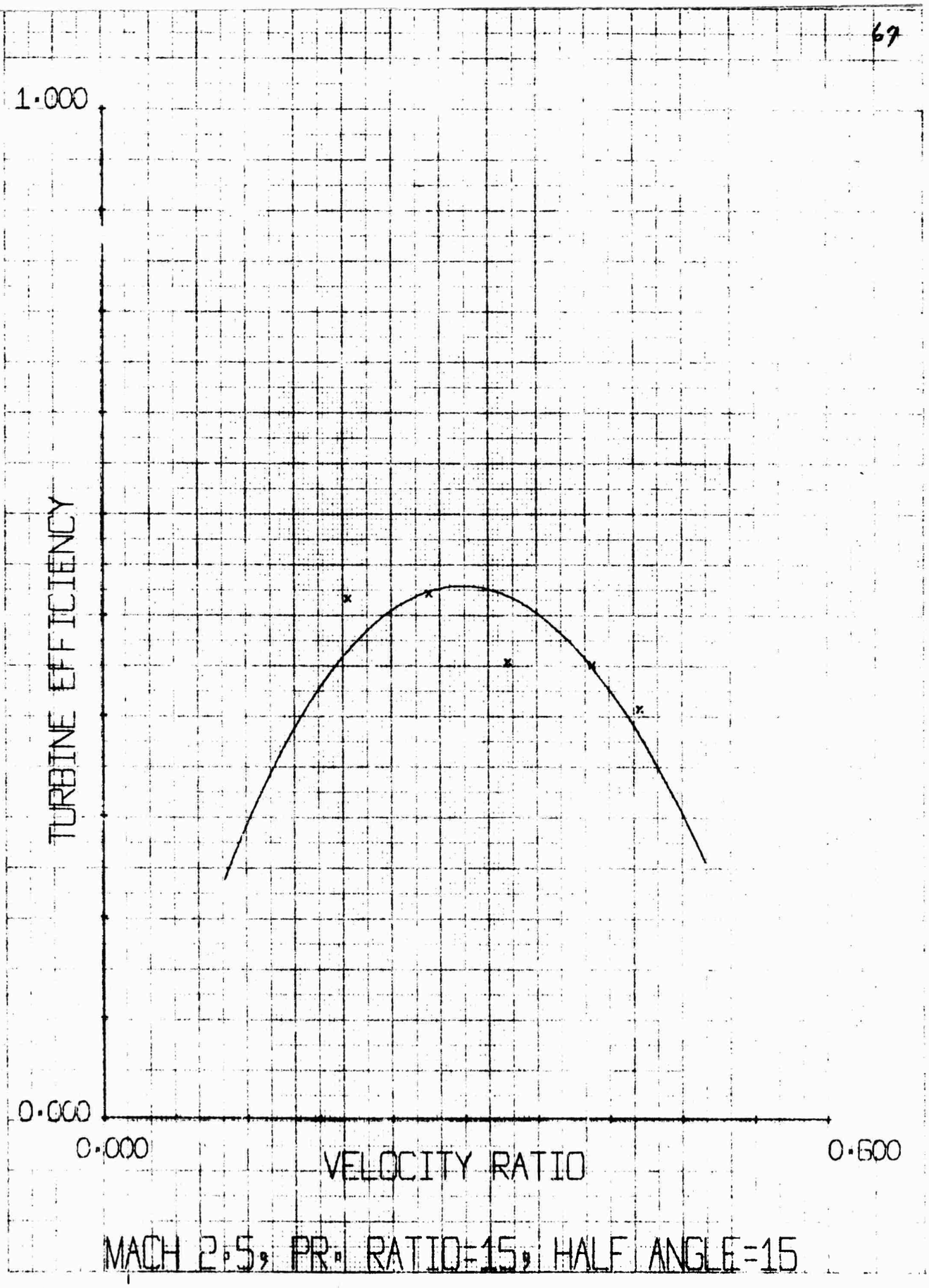
MACH 2·5, PR· RATIO=25, HALF ANGLE=15



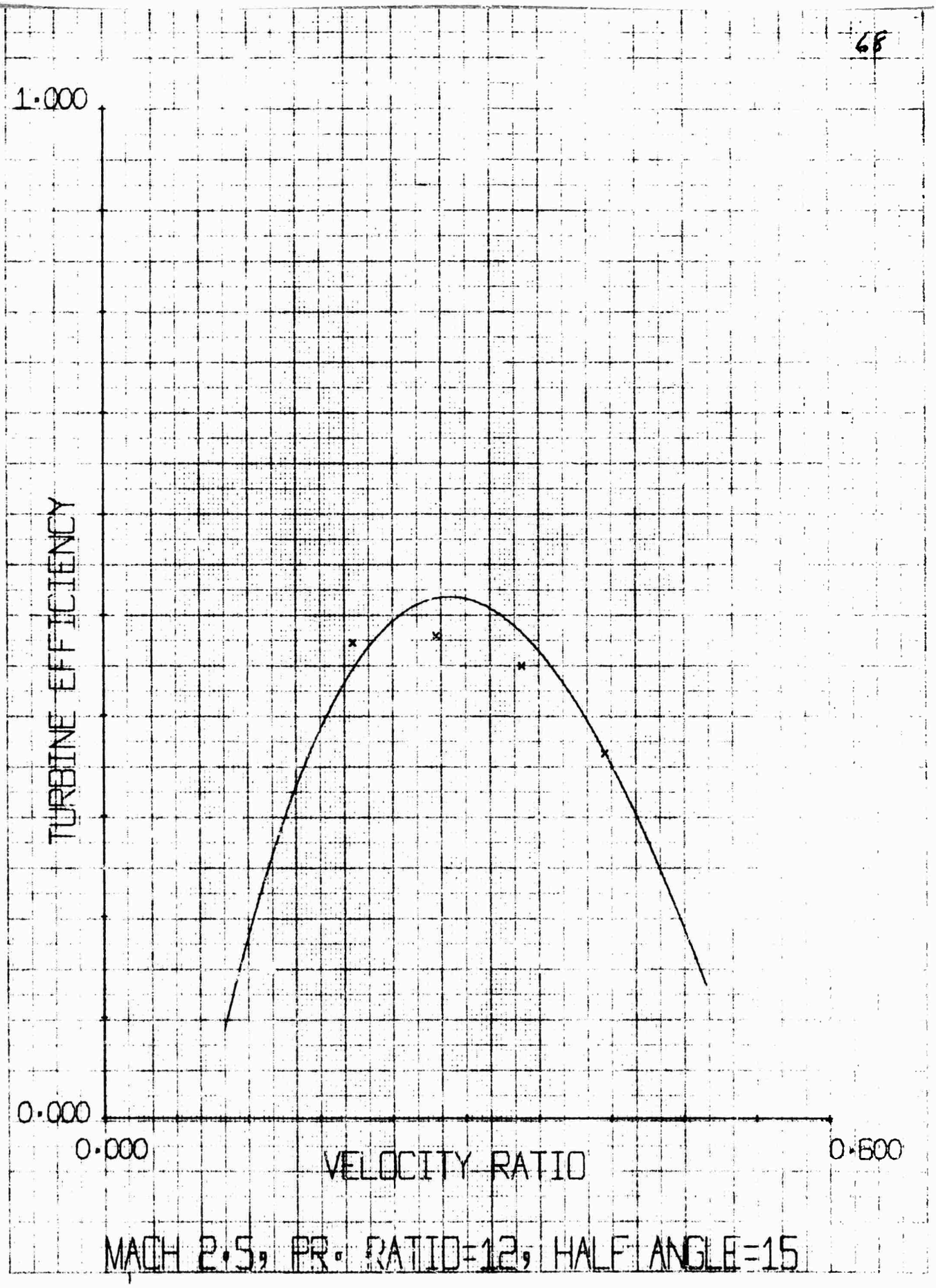
MACH 2.5, PR. RATIO=20, HALF ANGLE=15



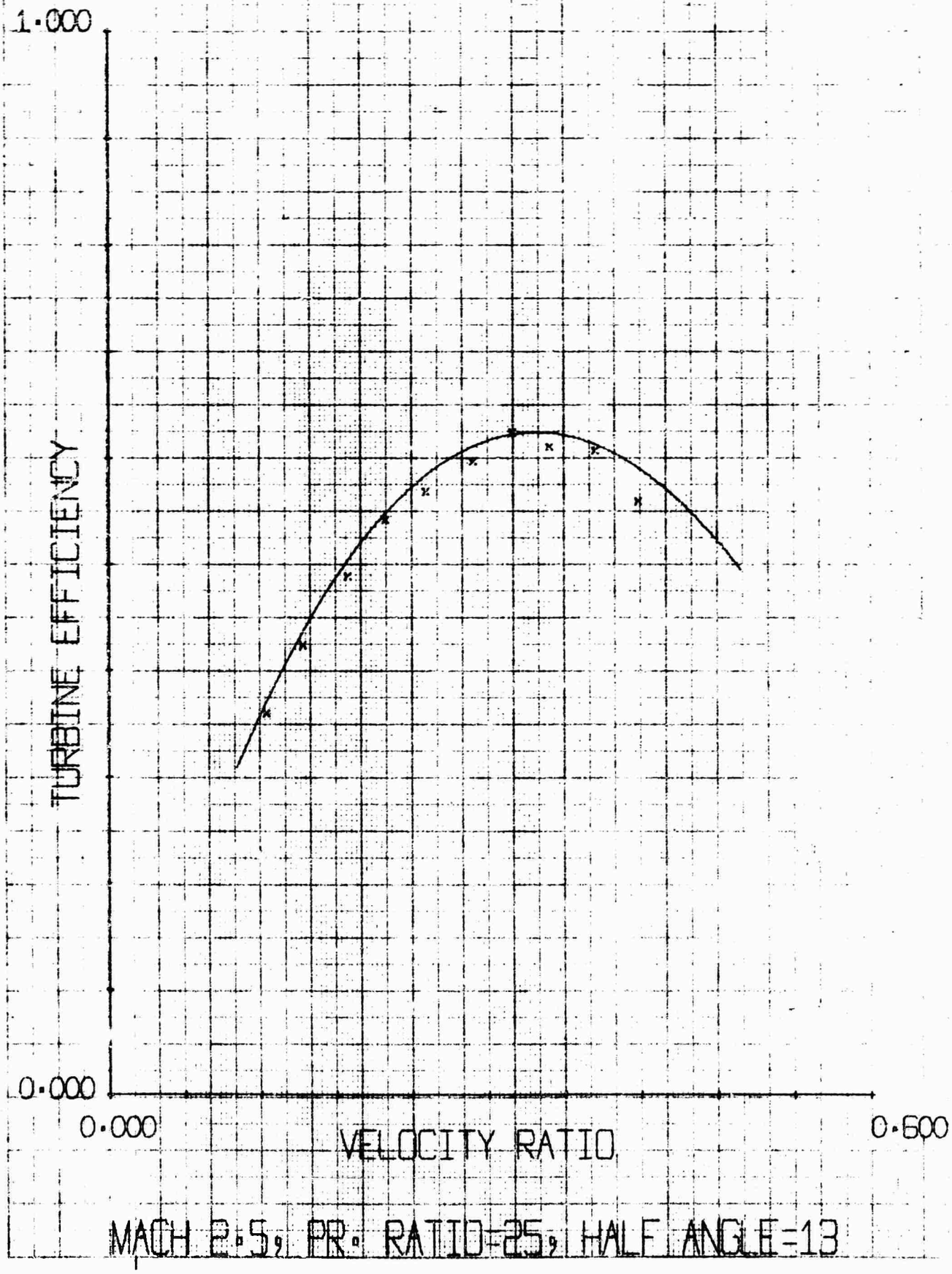
MACH 2·5, PR· RATIO=17, HALF ANGLE=15



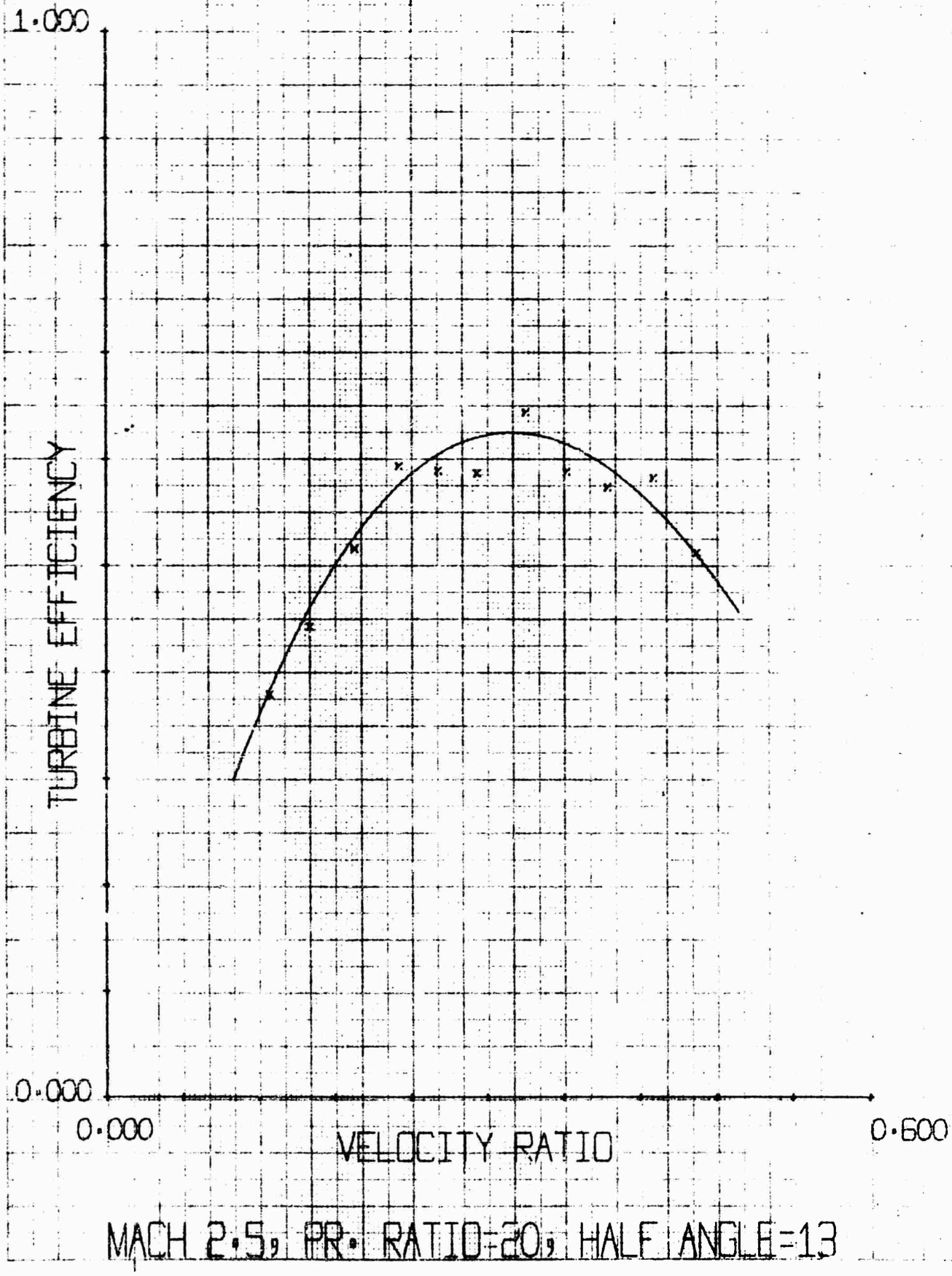
MACH 2·5, PR. RATIO=15, HALF ANGLE=15



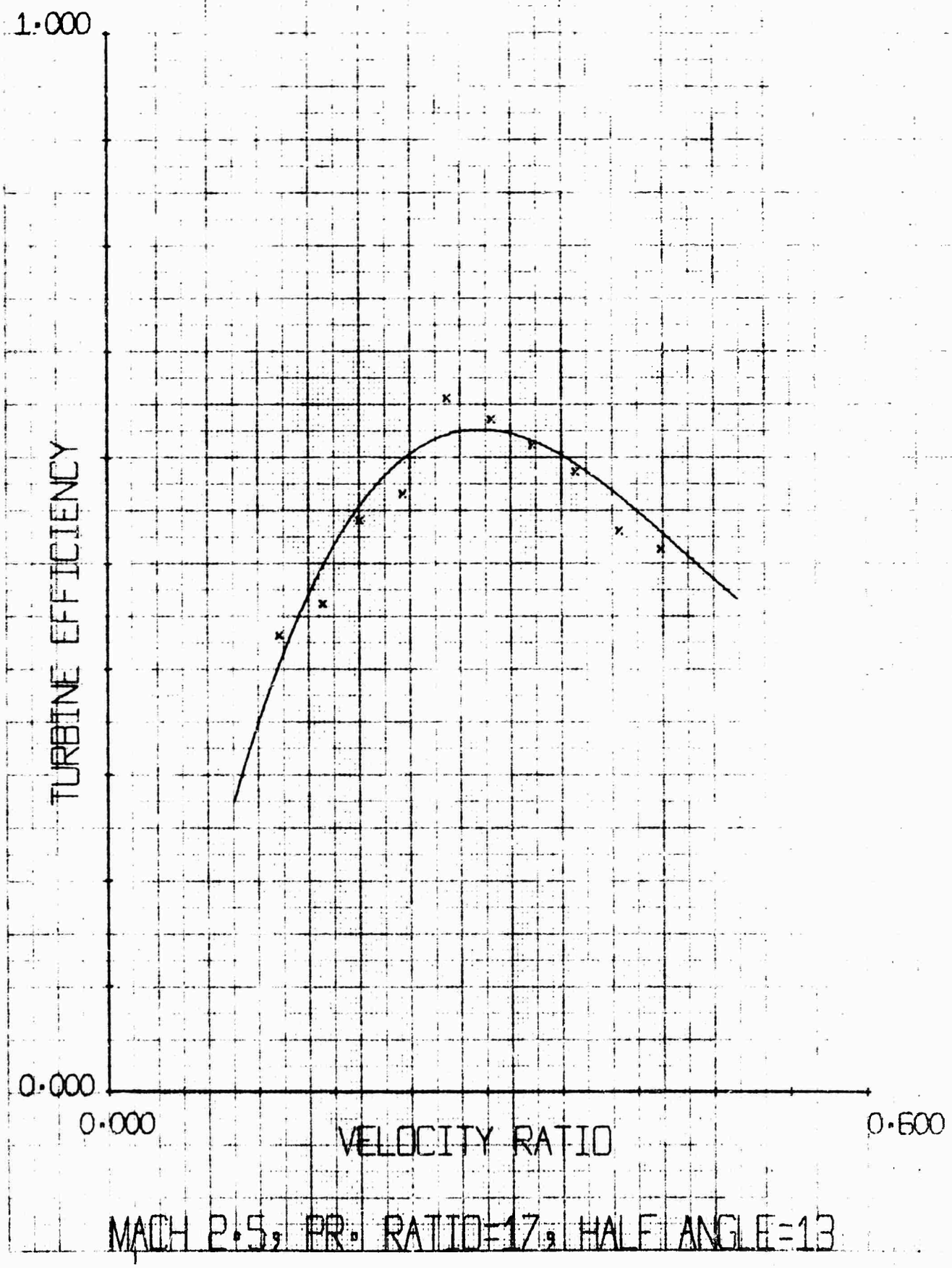
MACH 2·5, PR. RATIO=12, HALF ANGLE=15



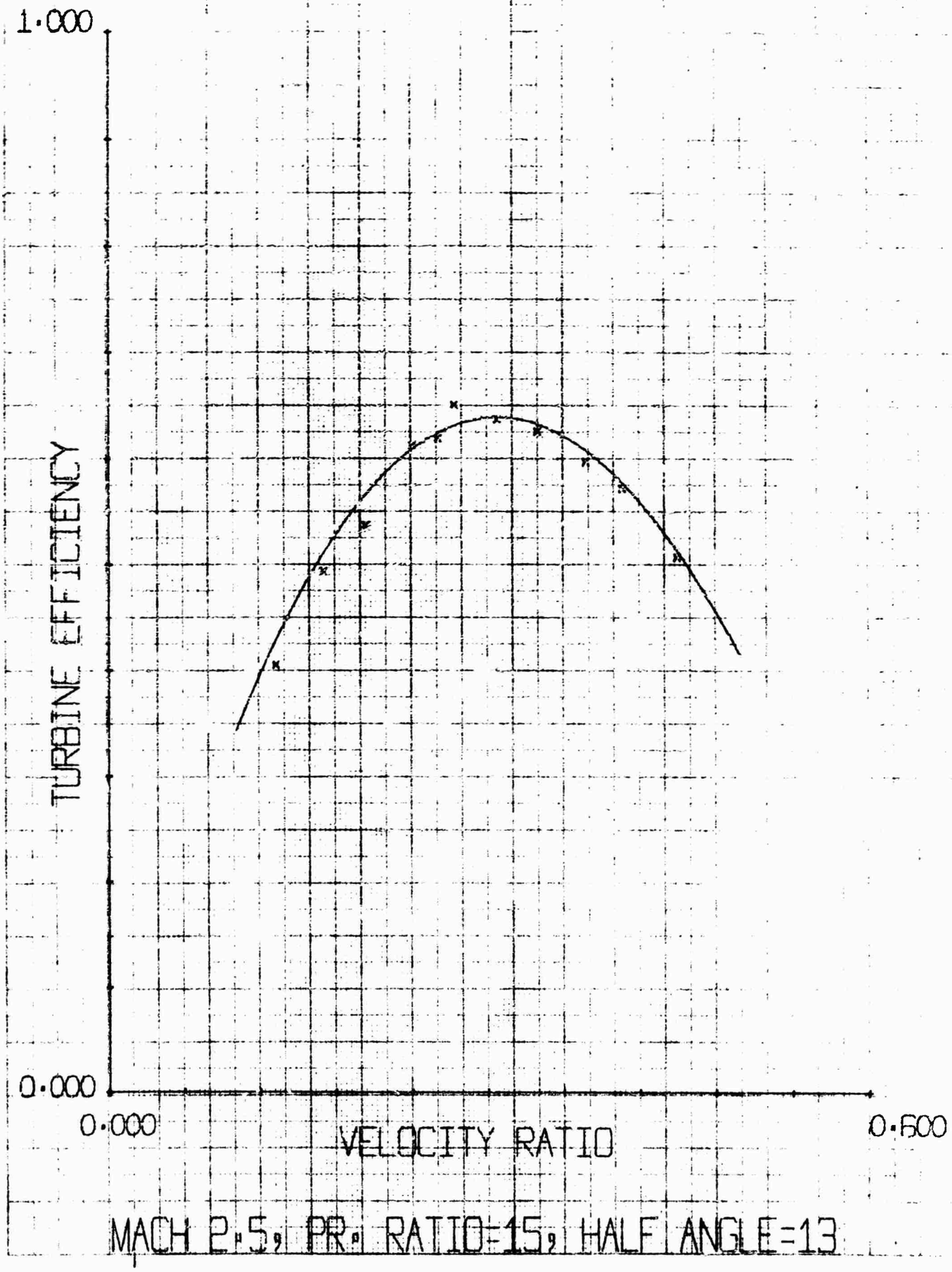
MACH 2·5, PR. RATIO=25, HALF ANGLE=13



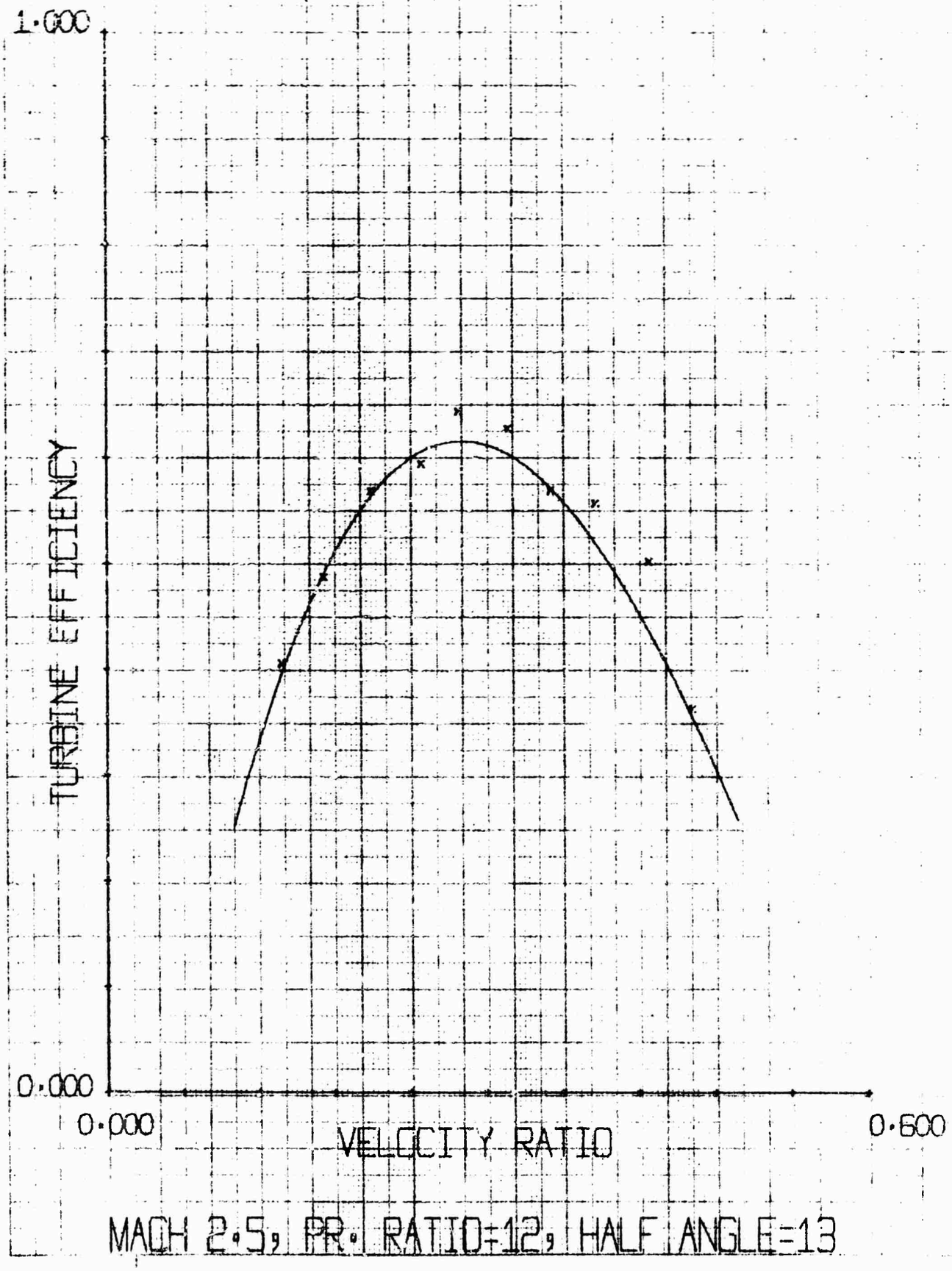
MACH 2.5, PR. RATIO=20, HALF ANGLE=13



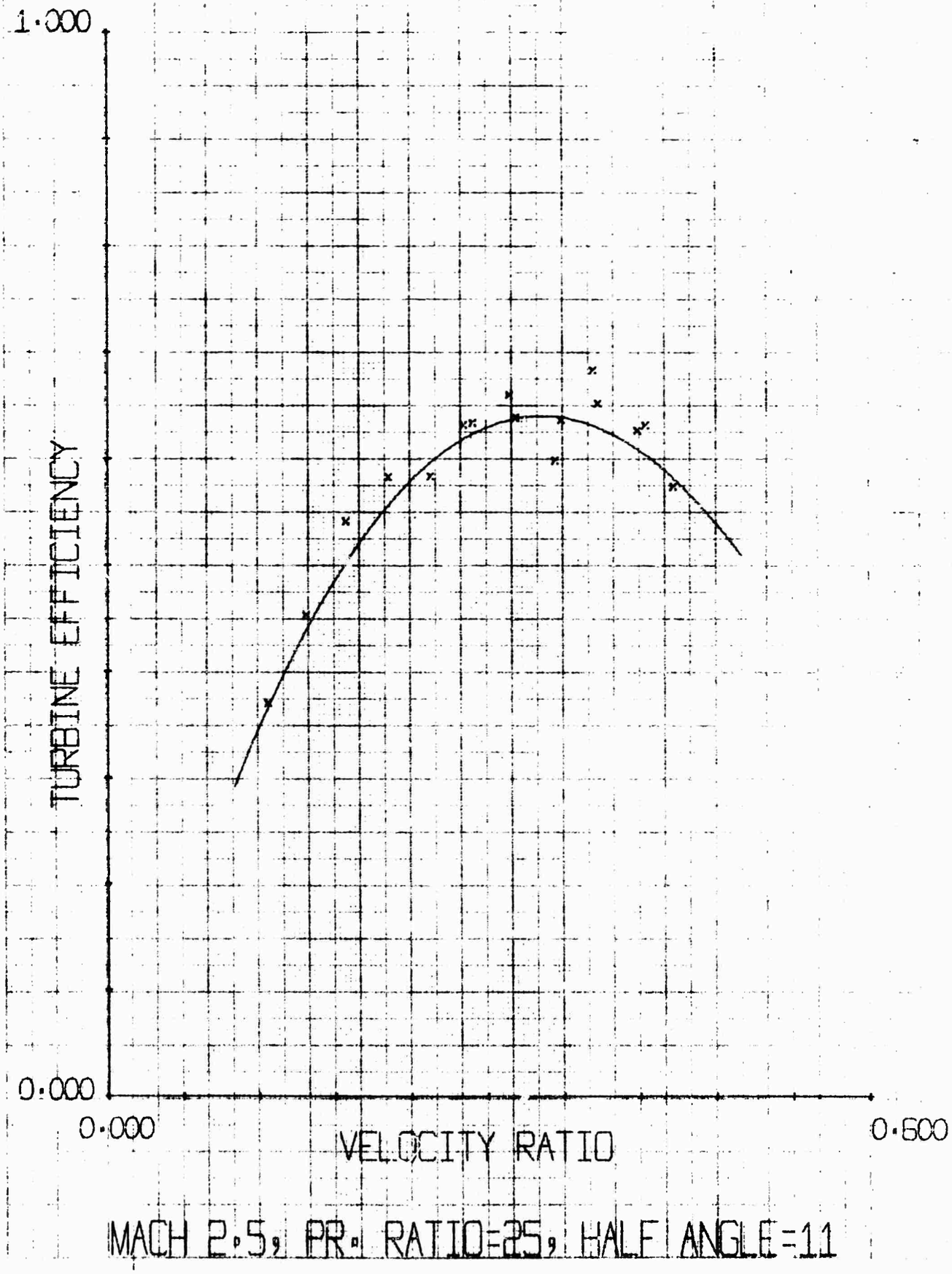
MACH 2.5, PR. RATIO=17, HALF ANGLE=13



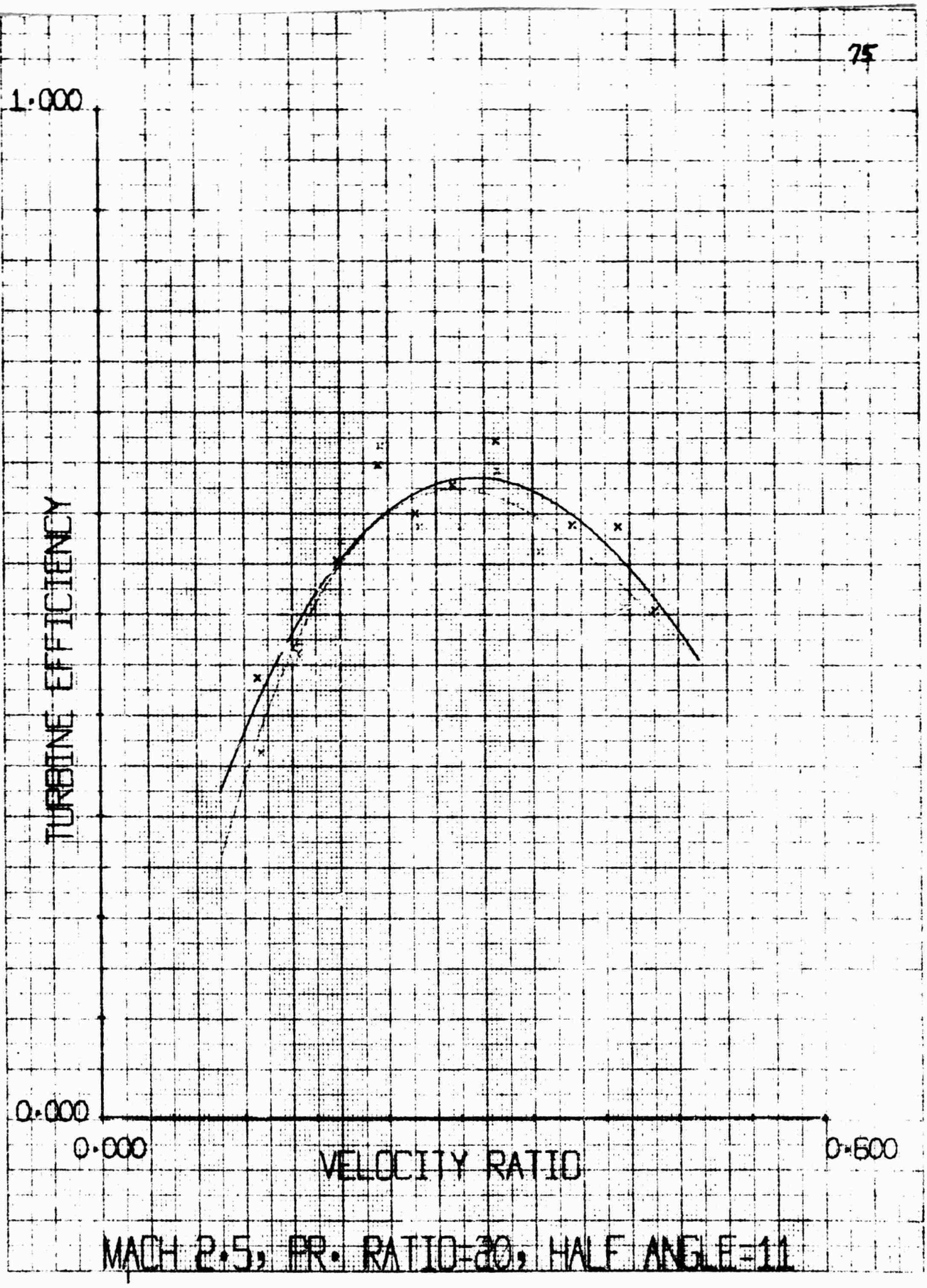
MACH 2·5, PR. RATIO=15, HALF ANGLE=13



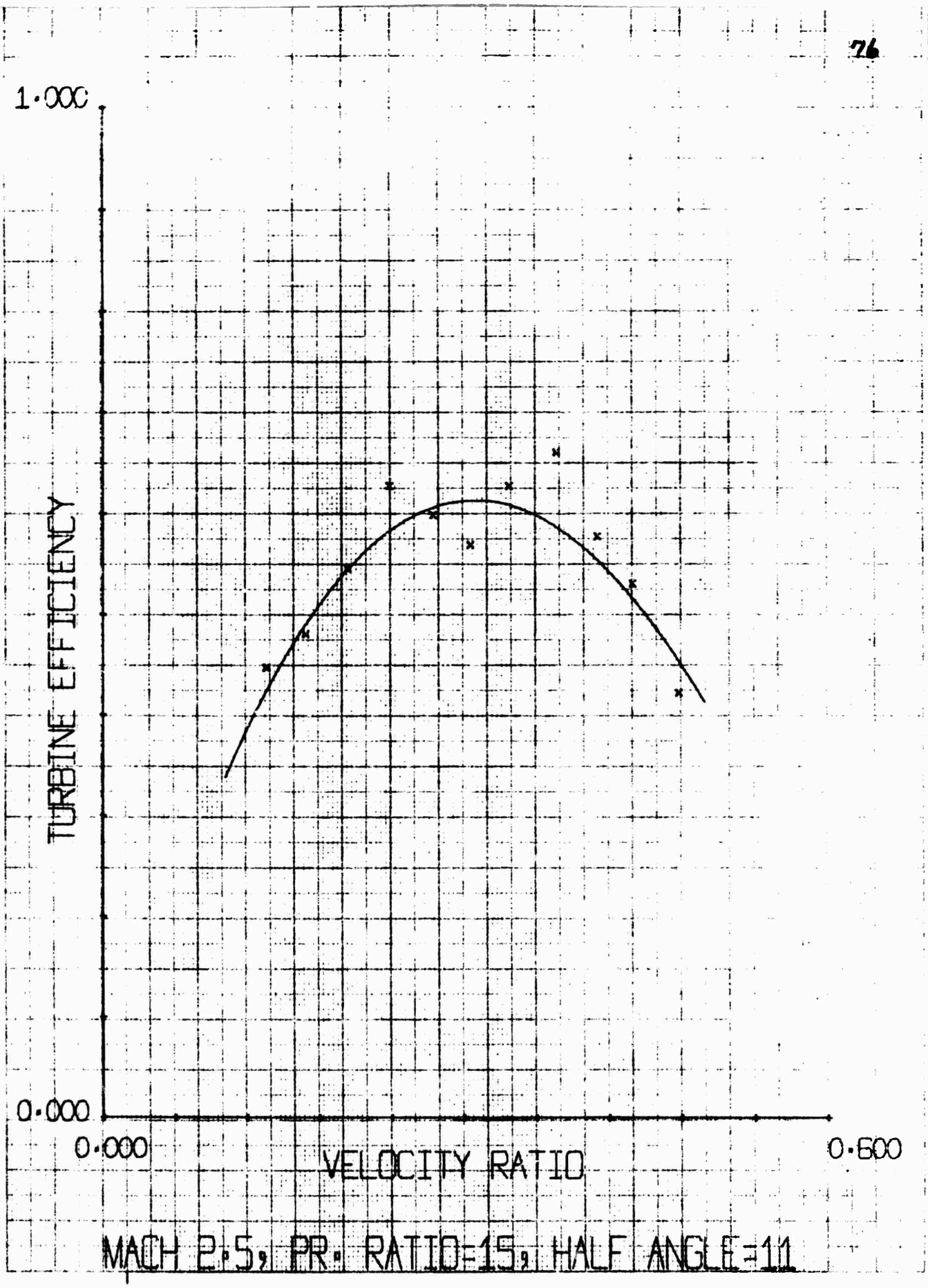
MACH 2·5, PR. RATIO=12, HALF ANGLE=13



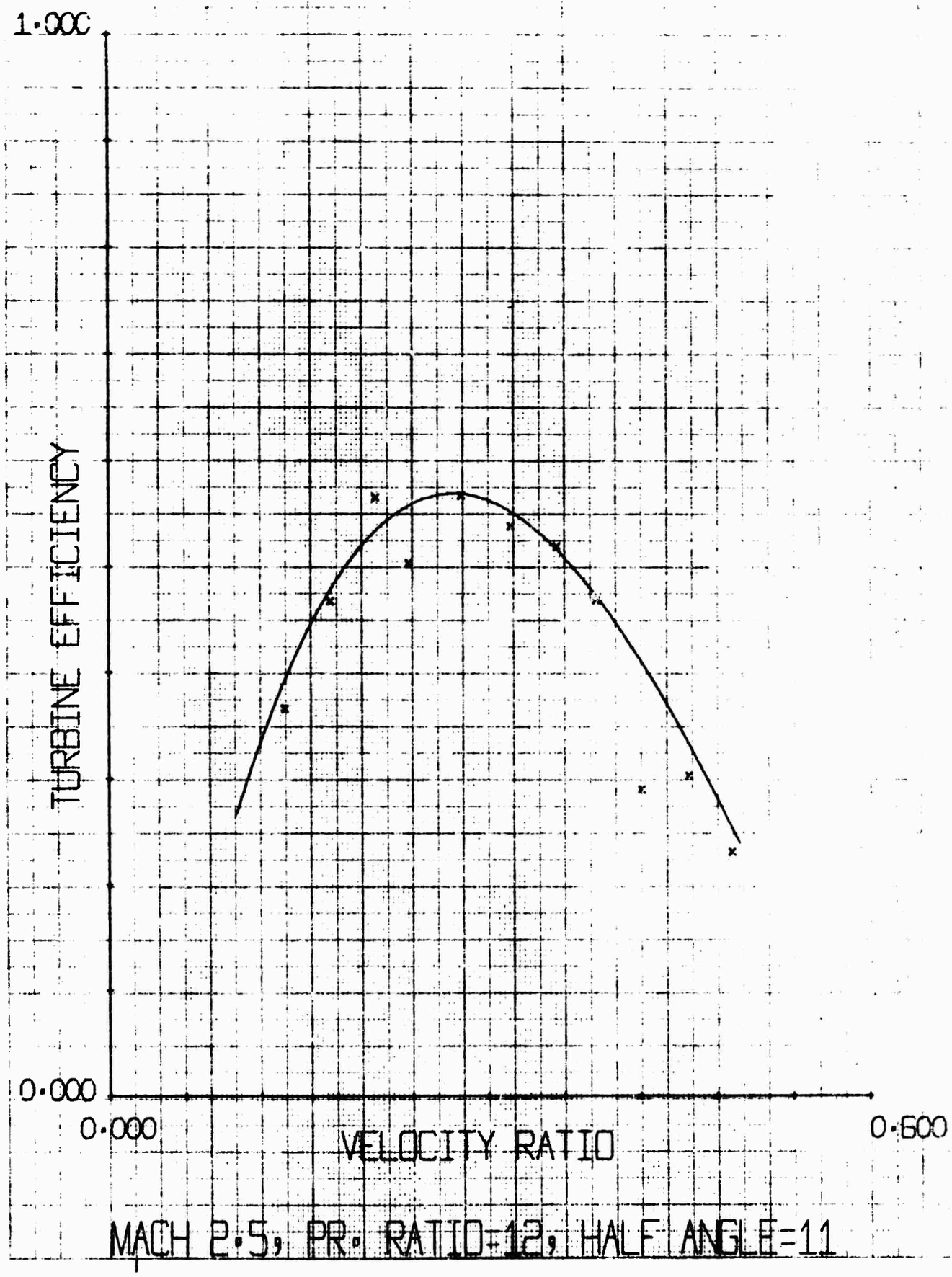
MACH 2·5, PR. RATIO=25, HALF ANGLE=11



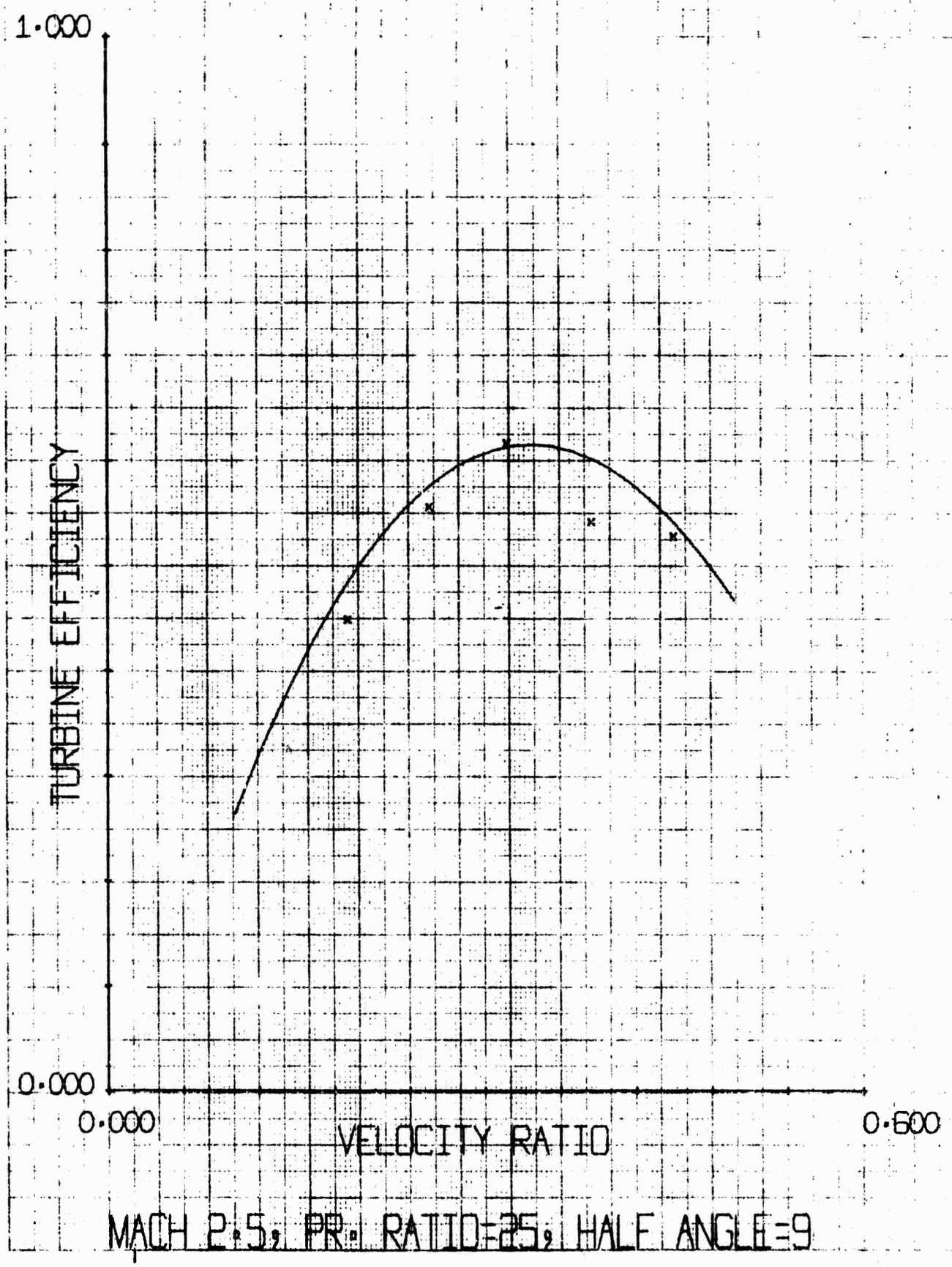
MACH 2.5, PR. RATIO=30, HALF ANGLE=11



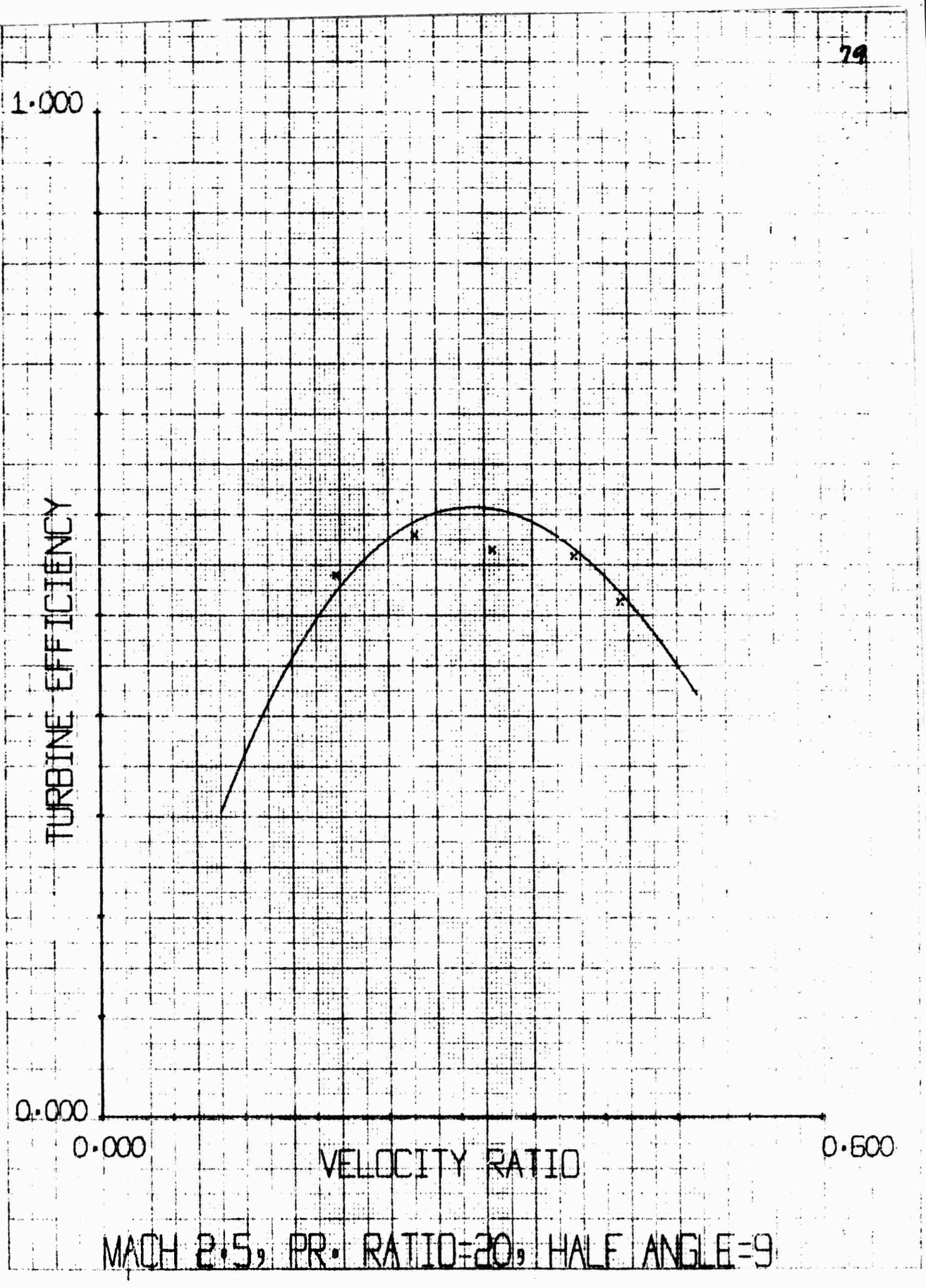
MACH 2·5, PR. RATIO=15, HALF ANGLE=11



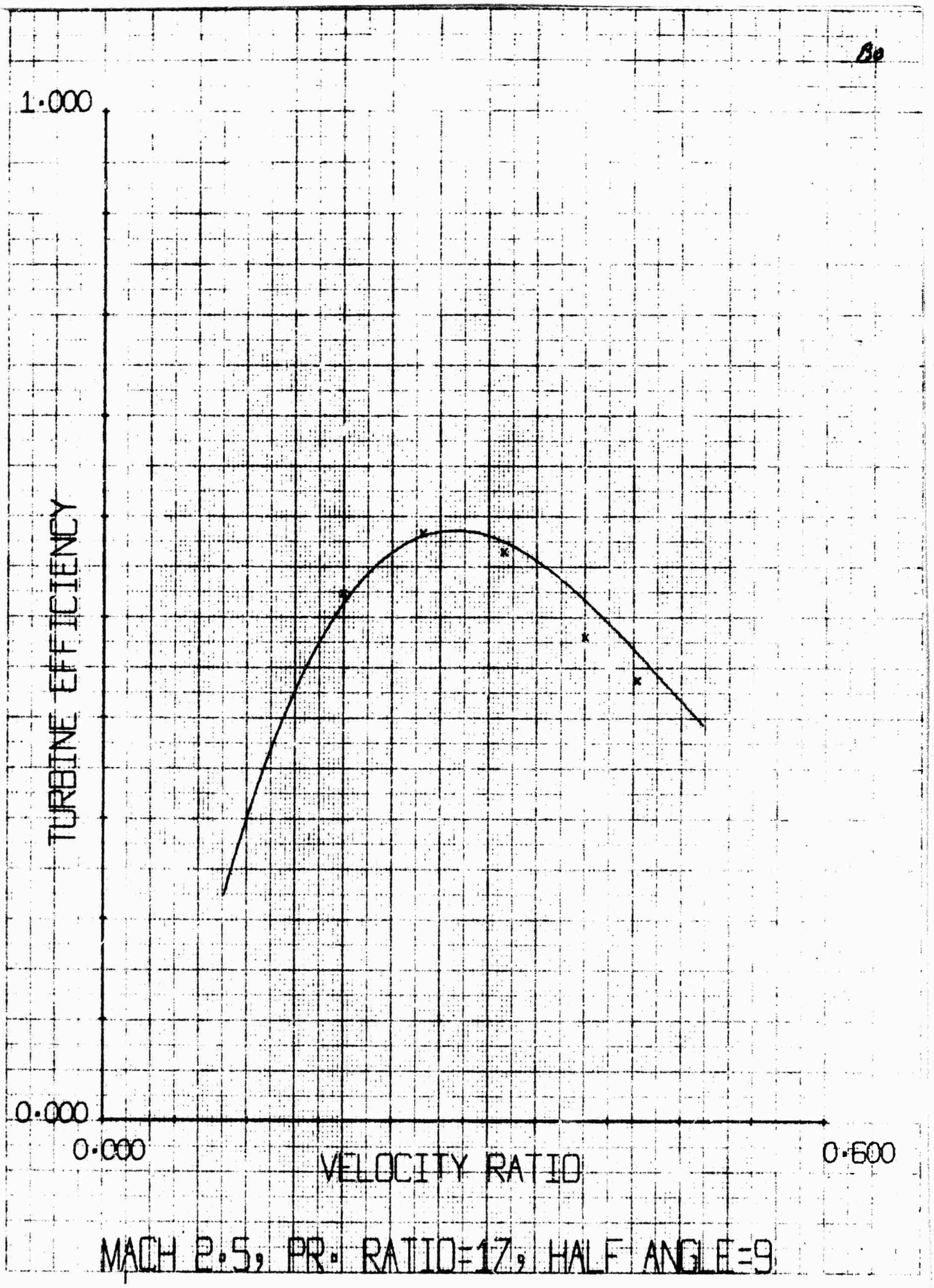
MACH 2·5, PR. RATIO=12, HALF ANGLE=11



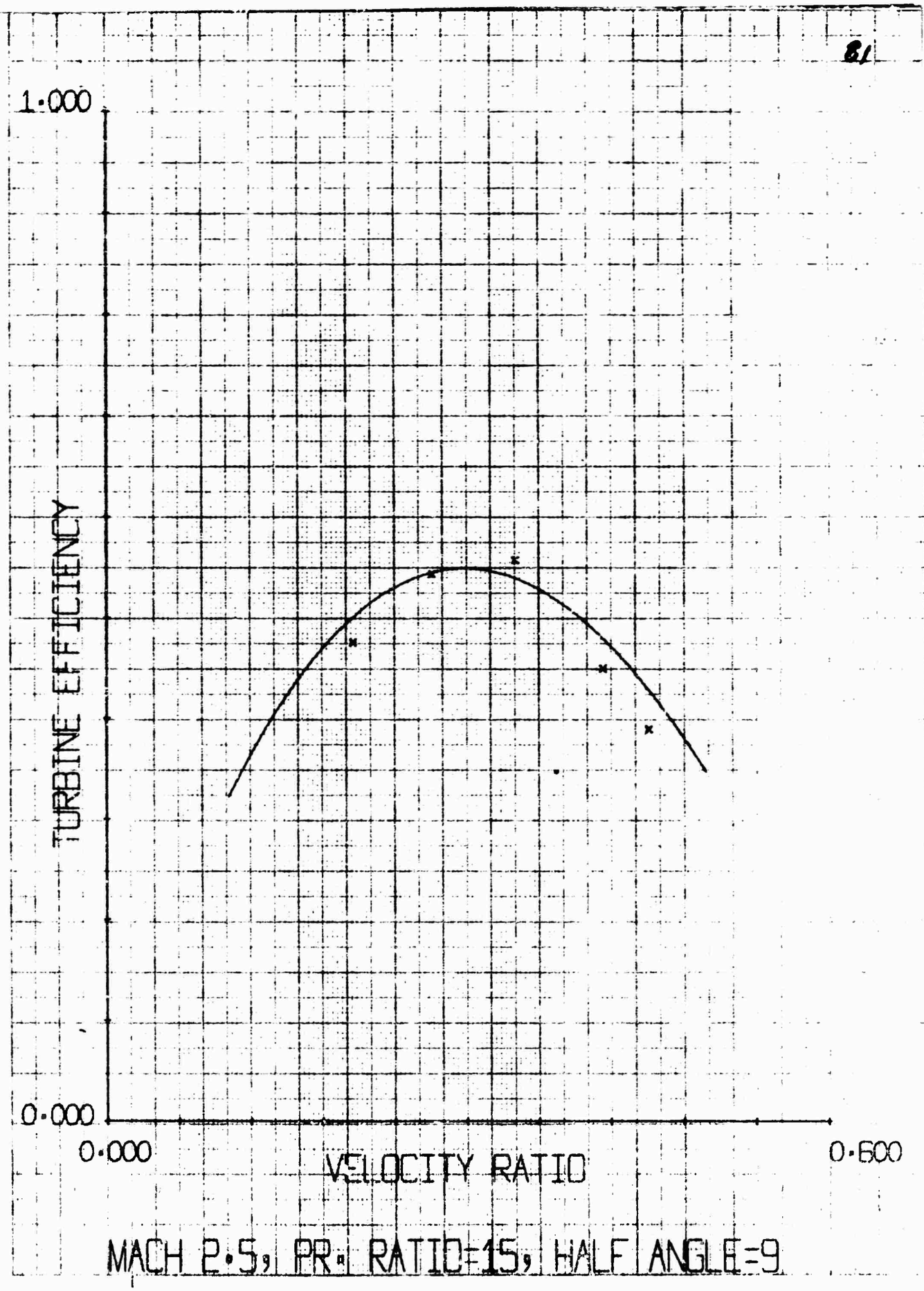
MACH 2·5, PR. RATIO=25, HALF ANGLE=9



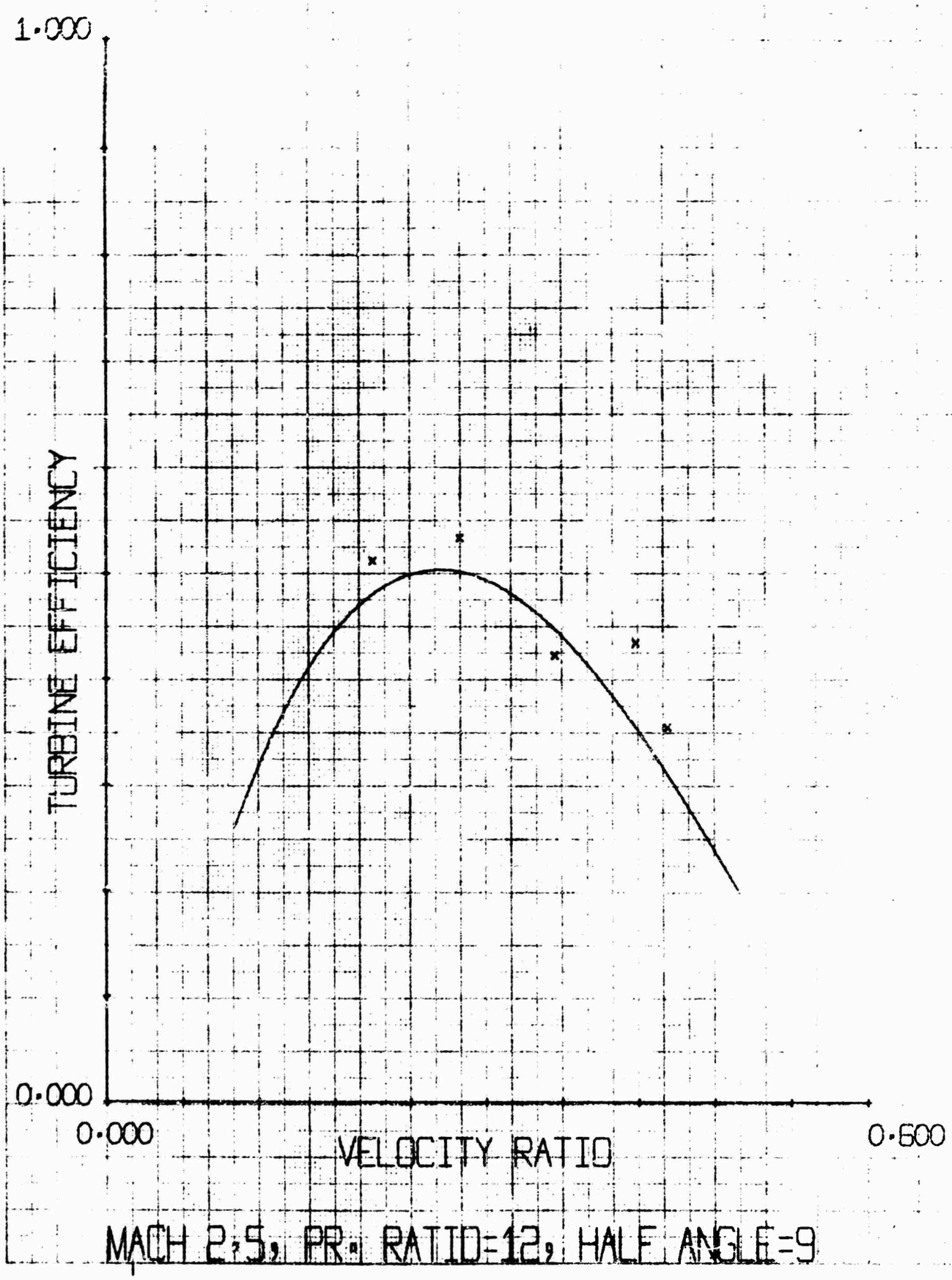
MACH 2·5, PR· RATIO=20, HALF ANGLE=9



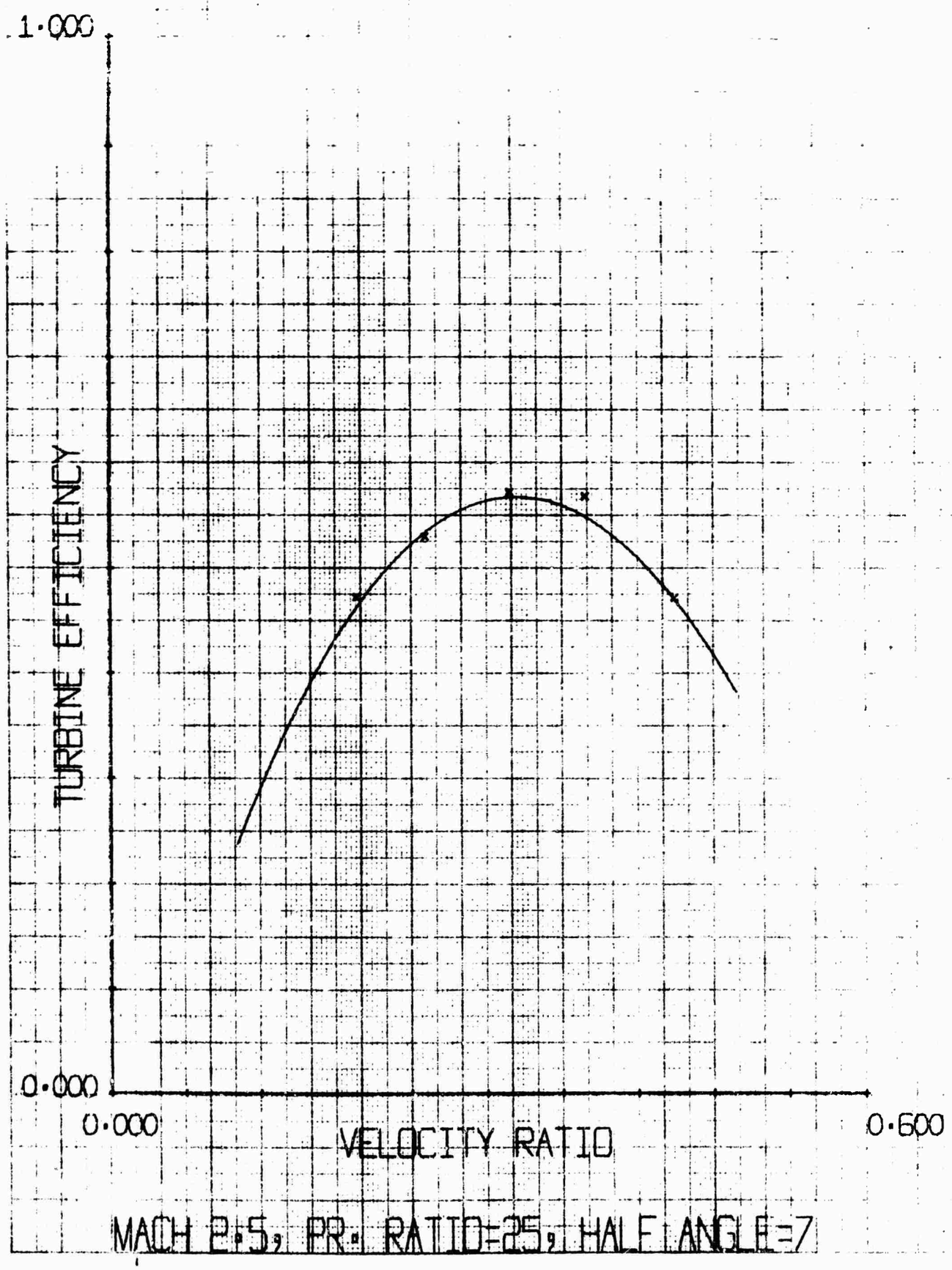
MACH 2·5, PR· RATIO=17, HALF ANGLE=9



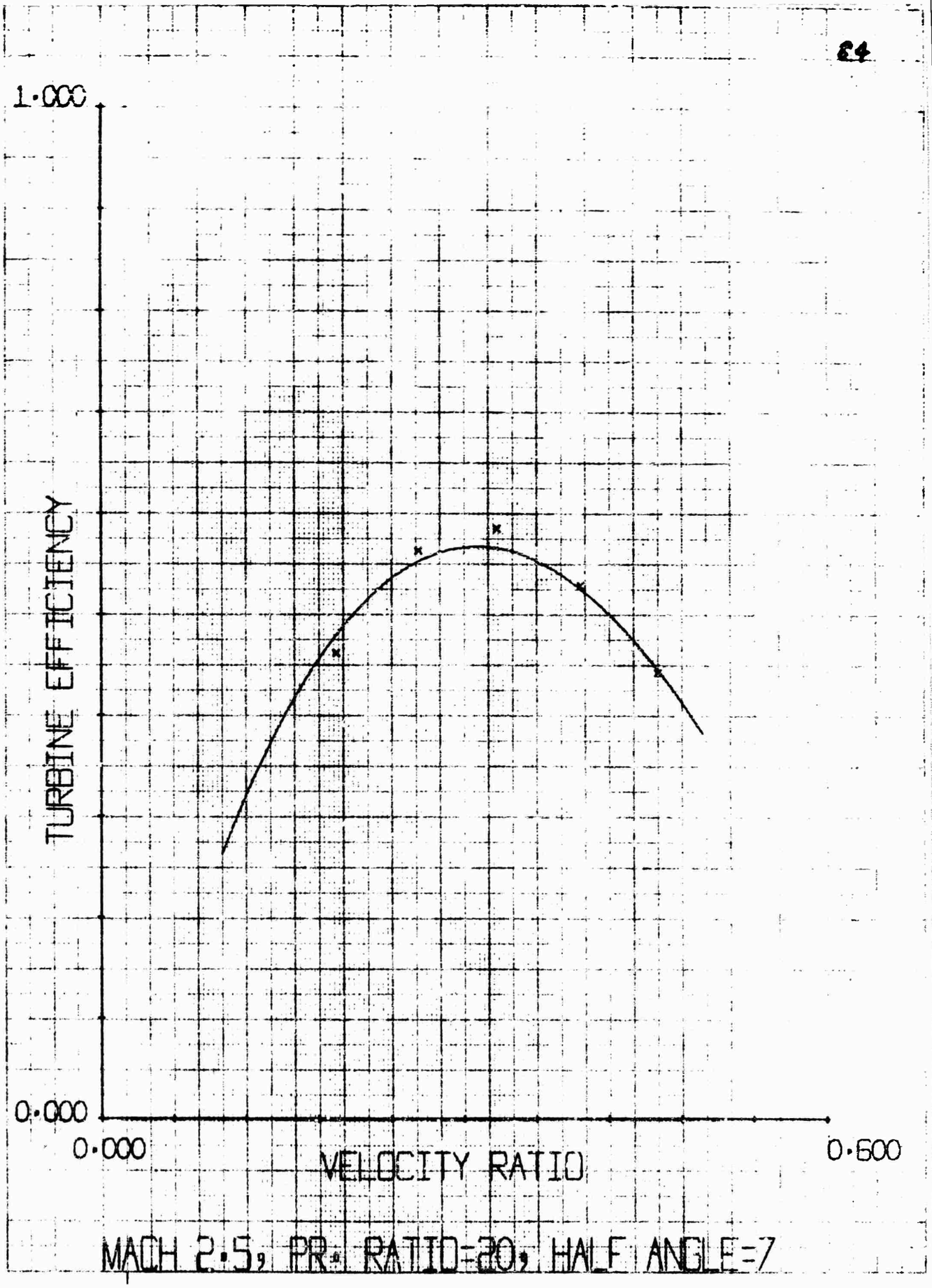
MACH 2·5, PR. RATIO=15, HALF ANGLE=9



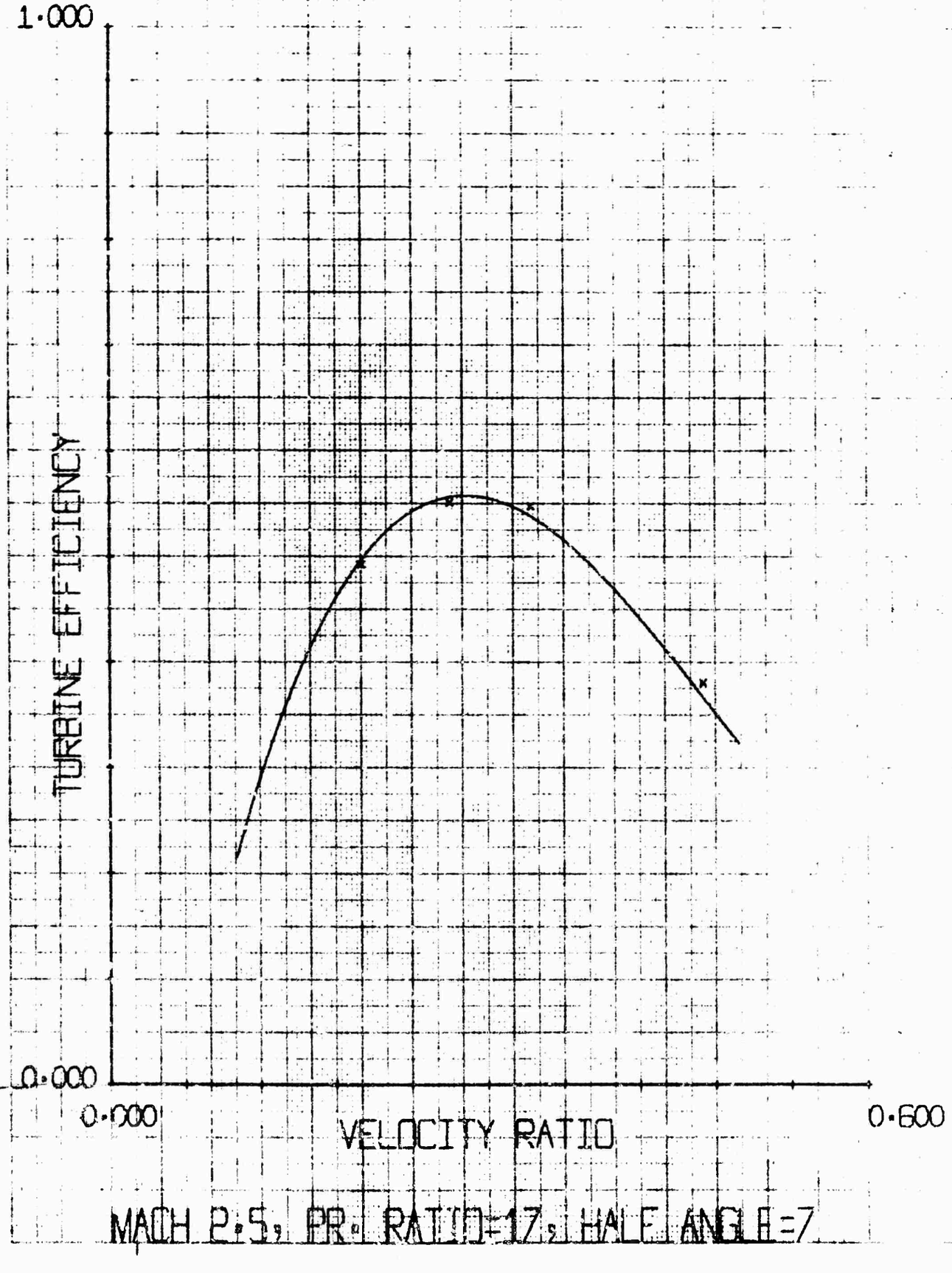
MACH 2,5, PR. RATIO=12, HALF ANGLE=9



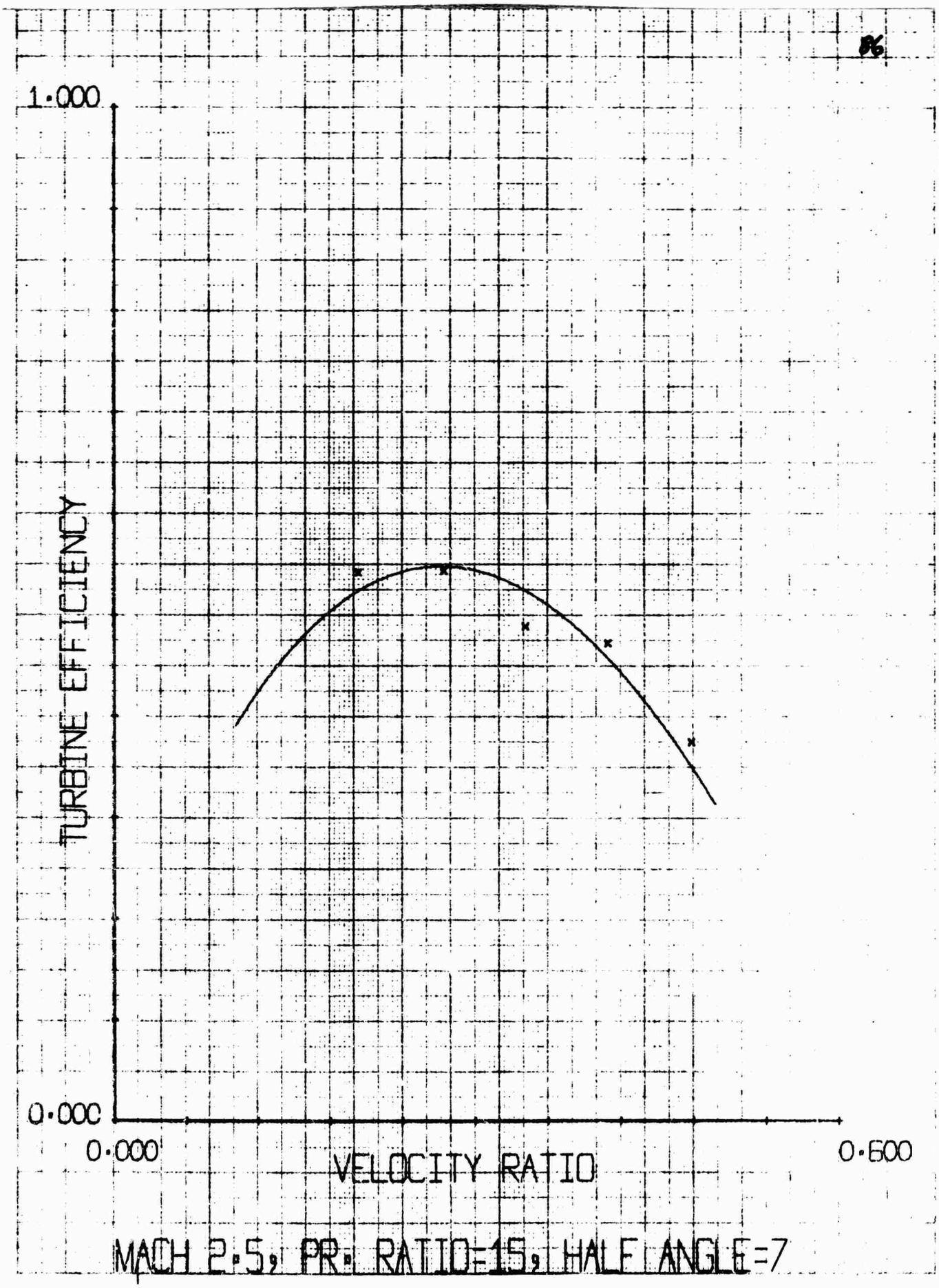
MACH 2·5, PR. RATIO=25, HALF ANGLE=7



MACH 2·5, PR. RATIO=20, HALF ANGLE=7



MACH 2·5, PR. RATIO=17, HALF ANGLE=7



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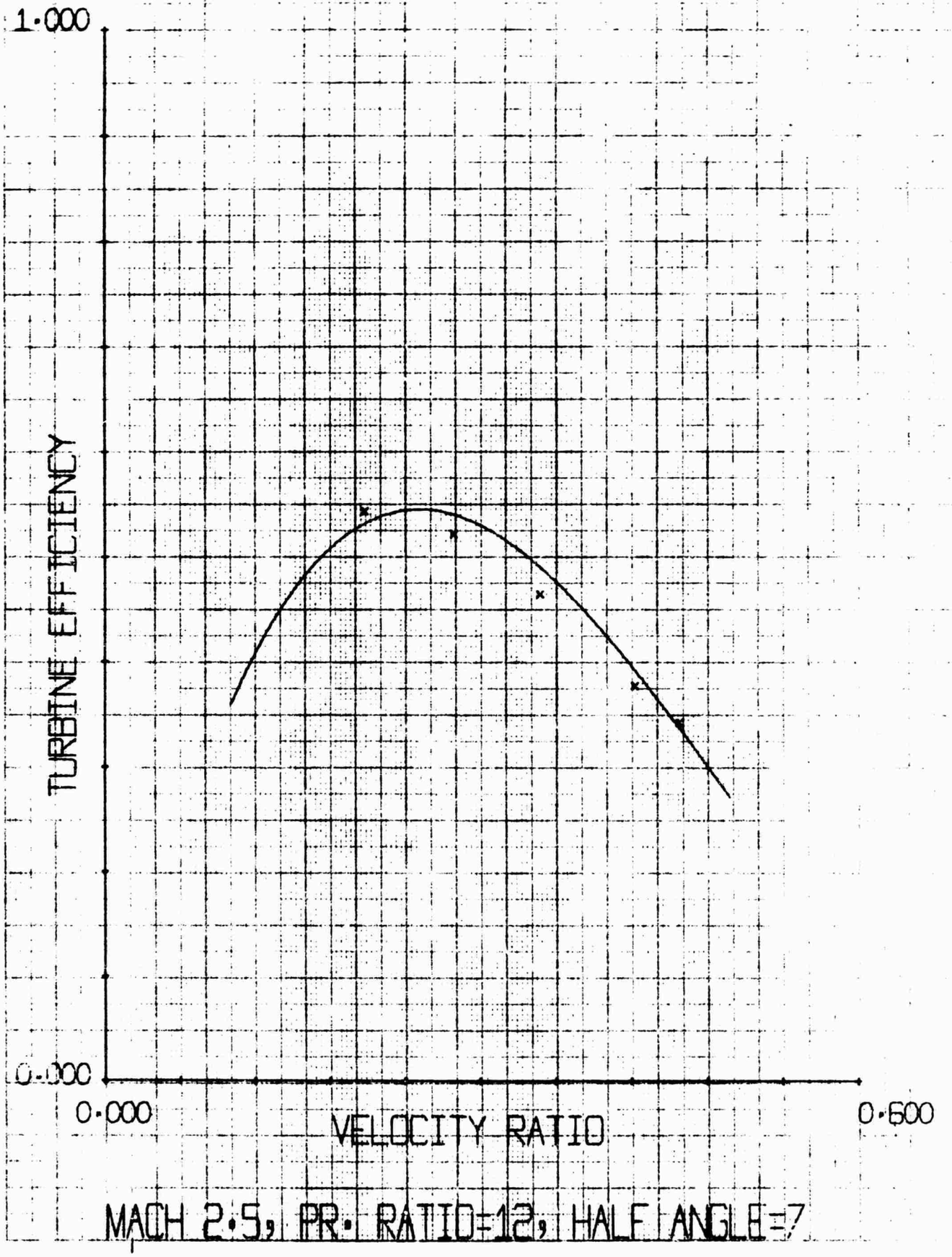

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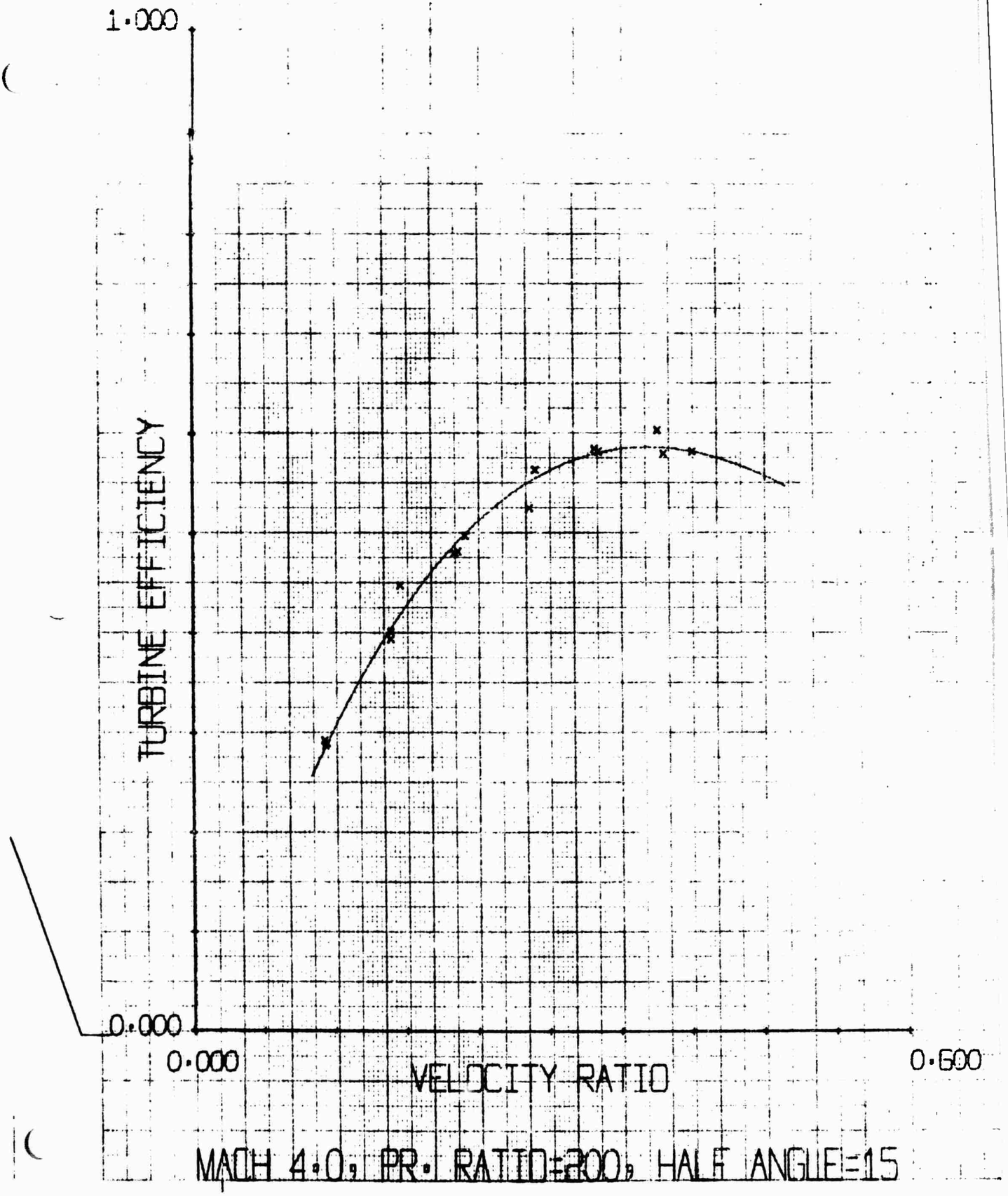
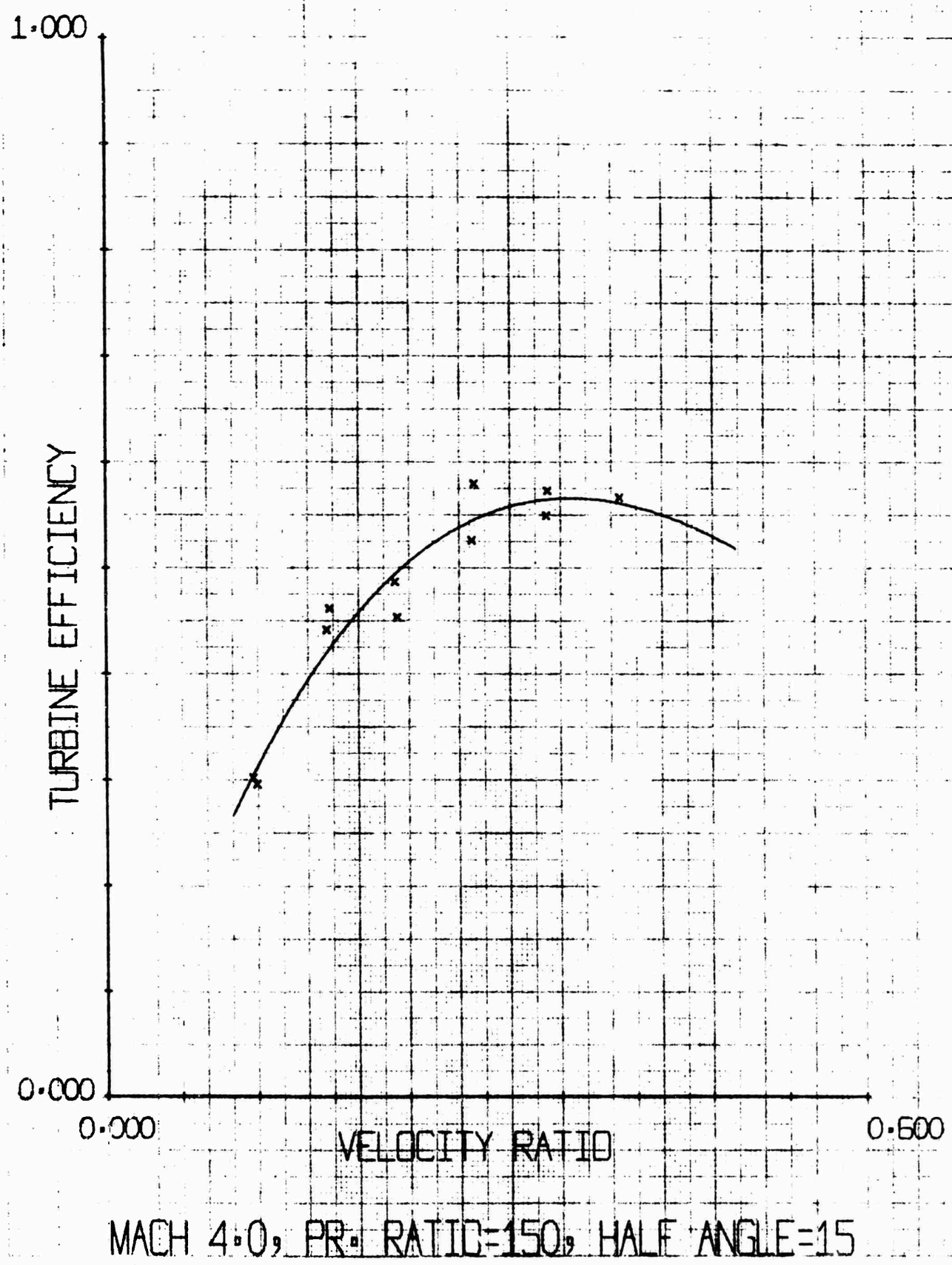


MACH 4·0, PR· RATIO=200, HALF ANGLE=15



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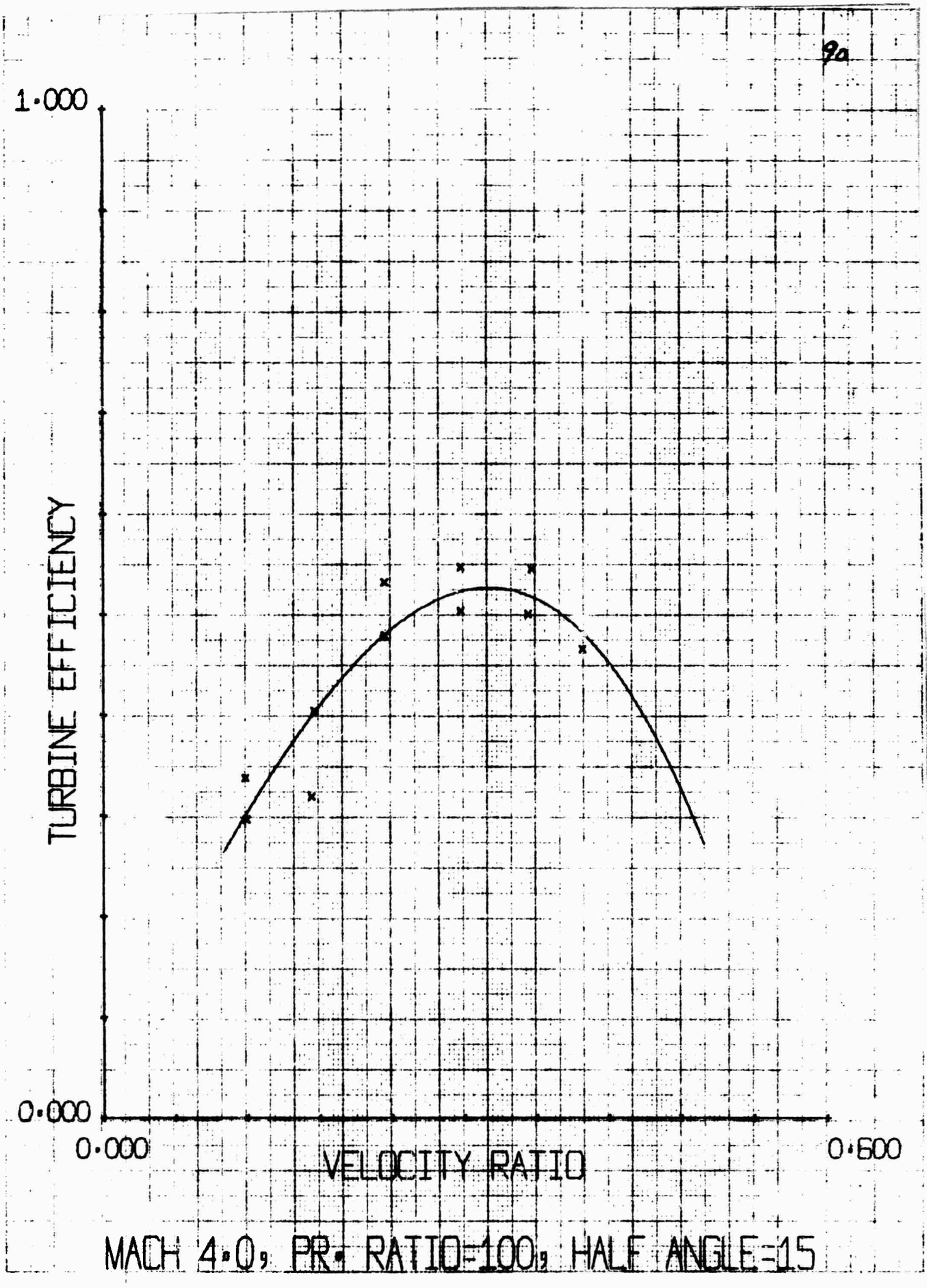

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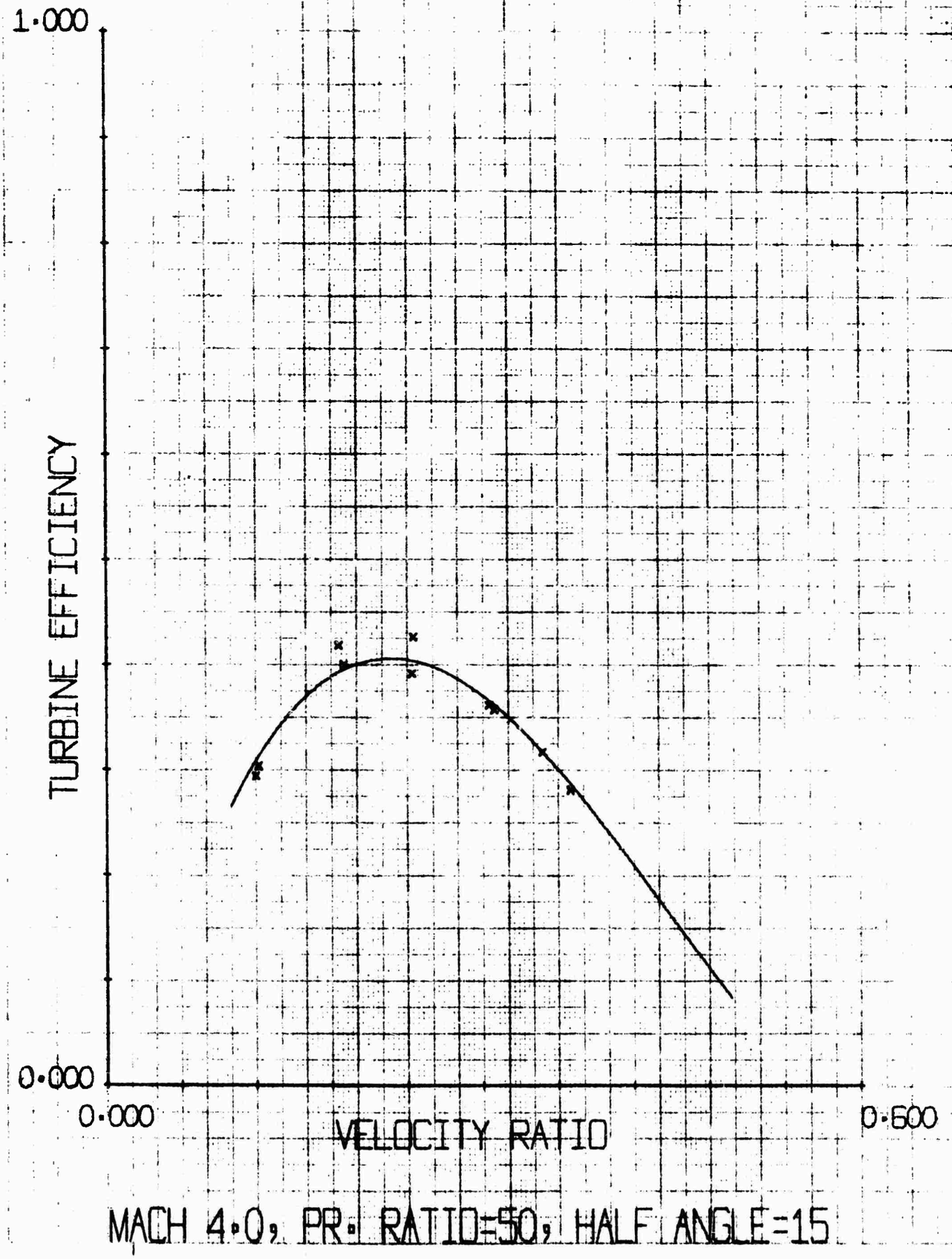
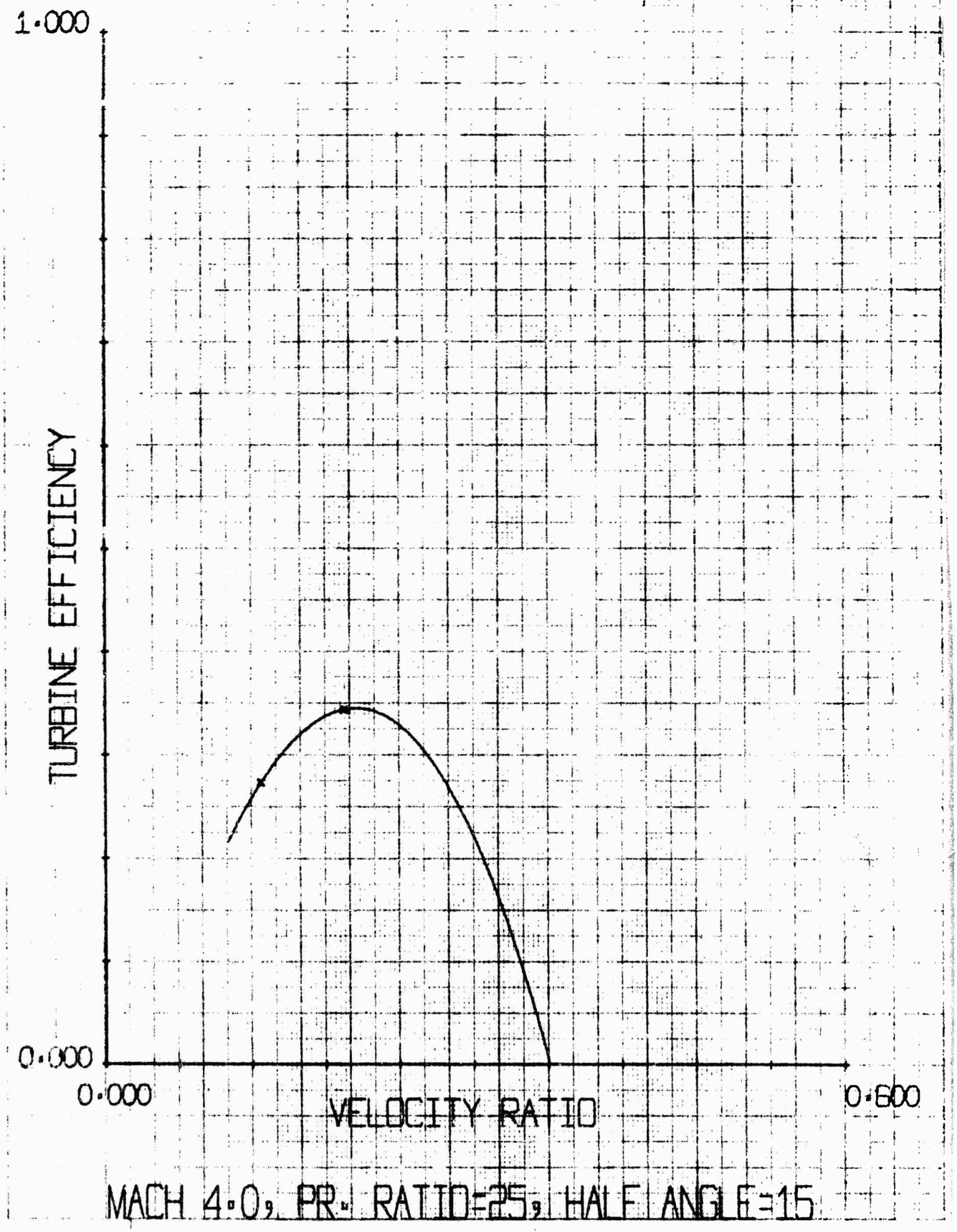
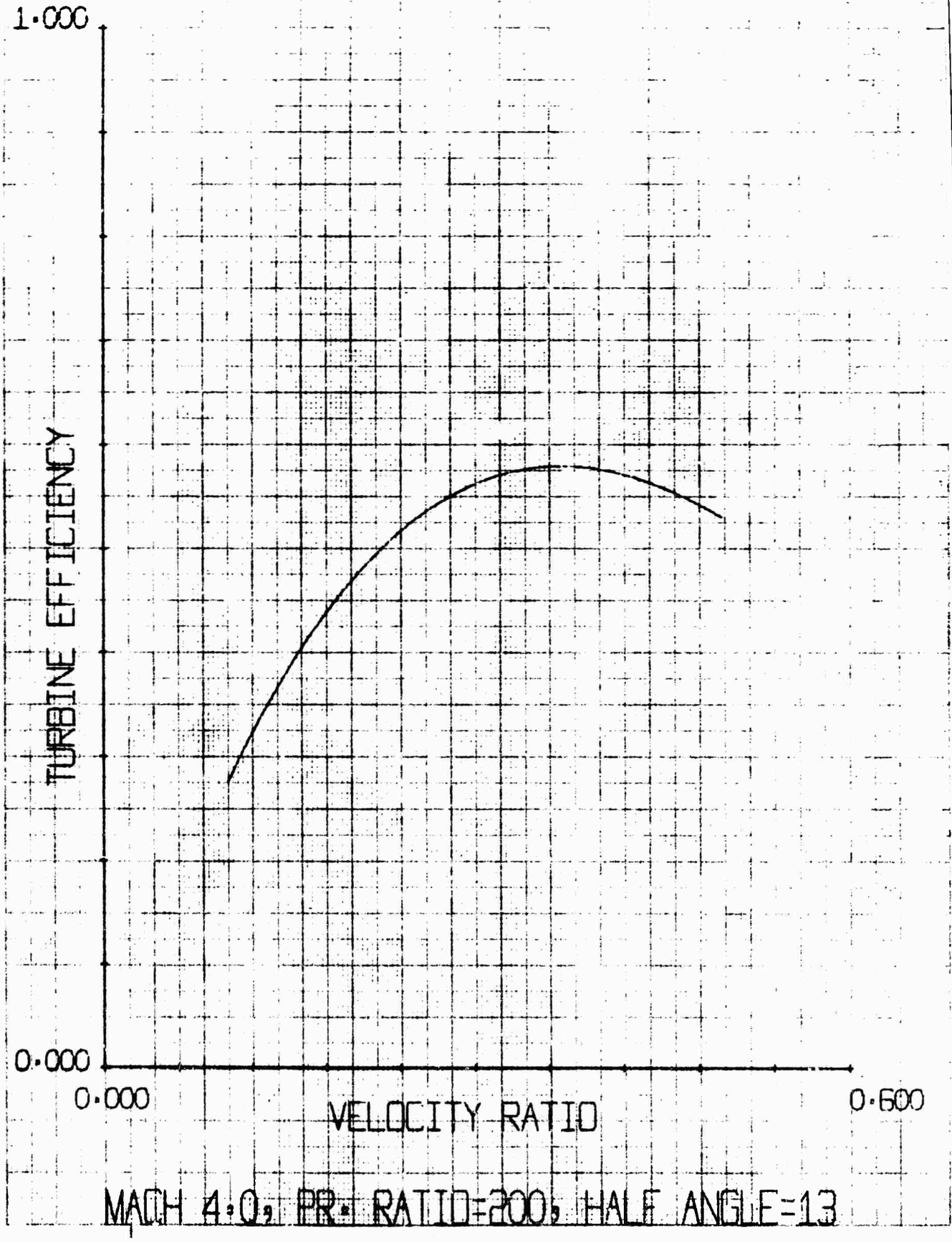
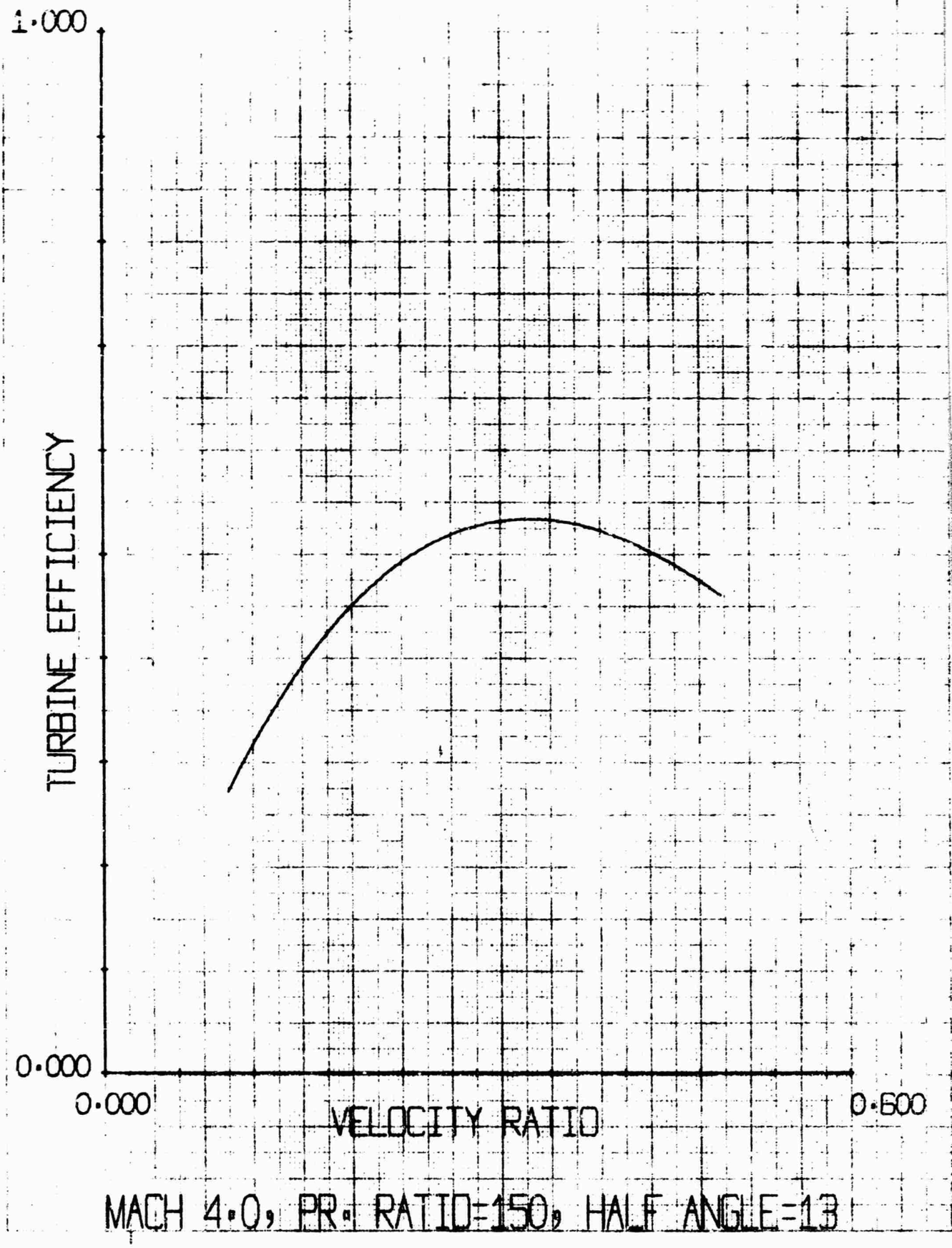


MACH 4·0, PR· RATIO=50, HALF ANGLE=15



MACH 4·0, PR. RATIO=25, HALF ANGLE=15


1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
MACH 4·0, PR· RATIO=200, HALF ANGLE=13



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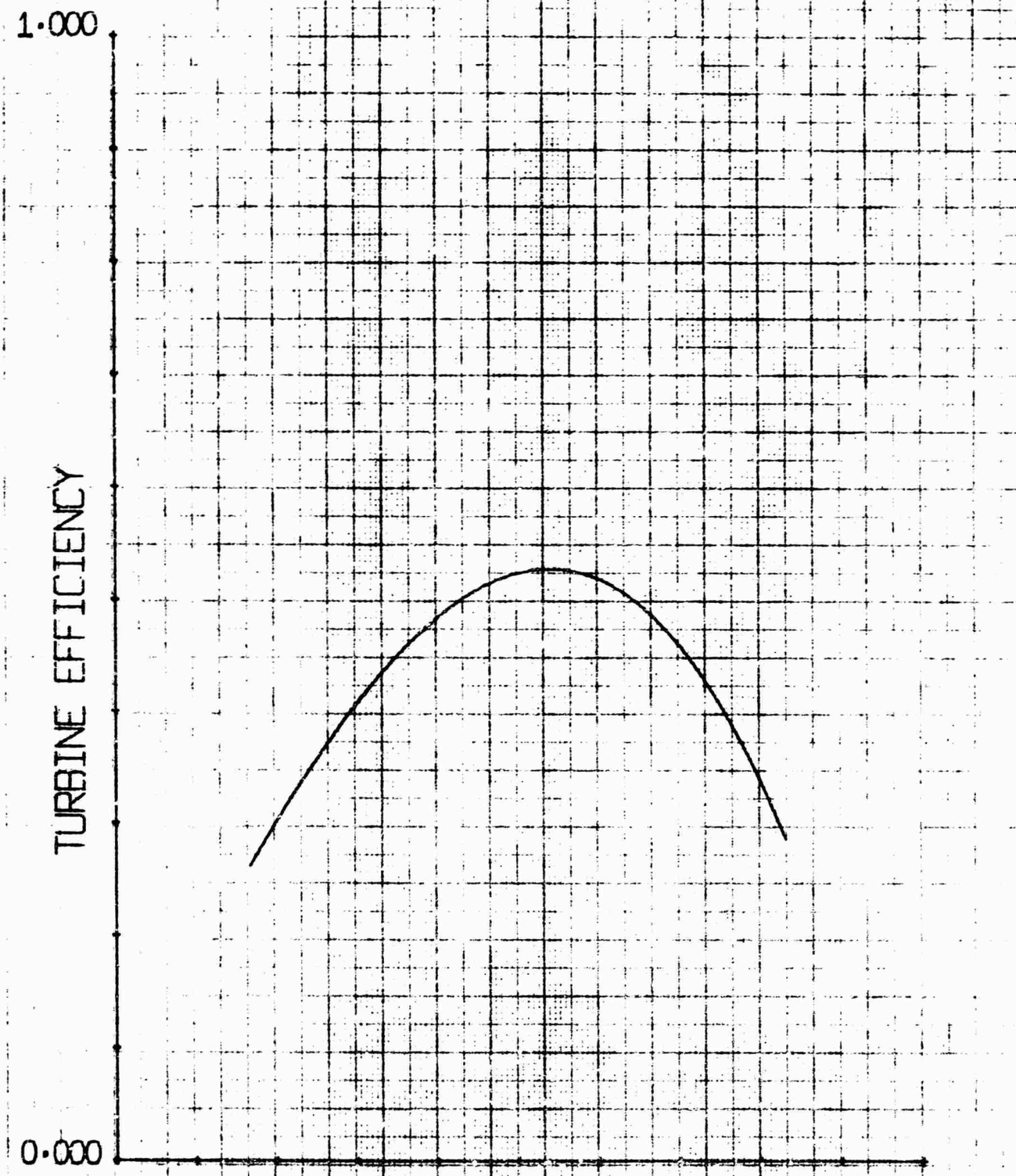
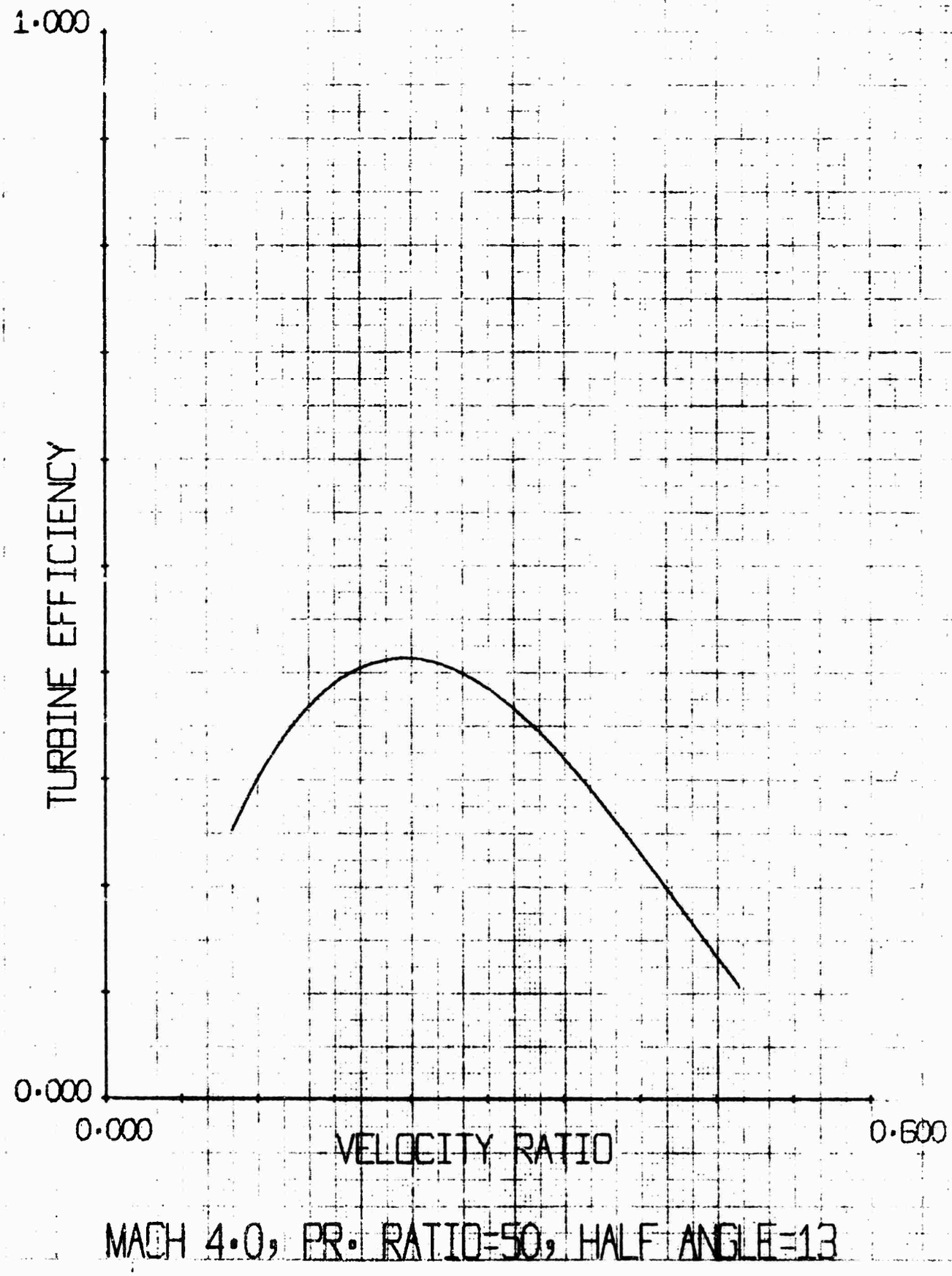
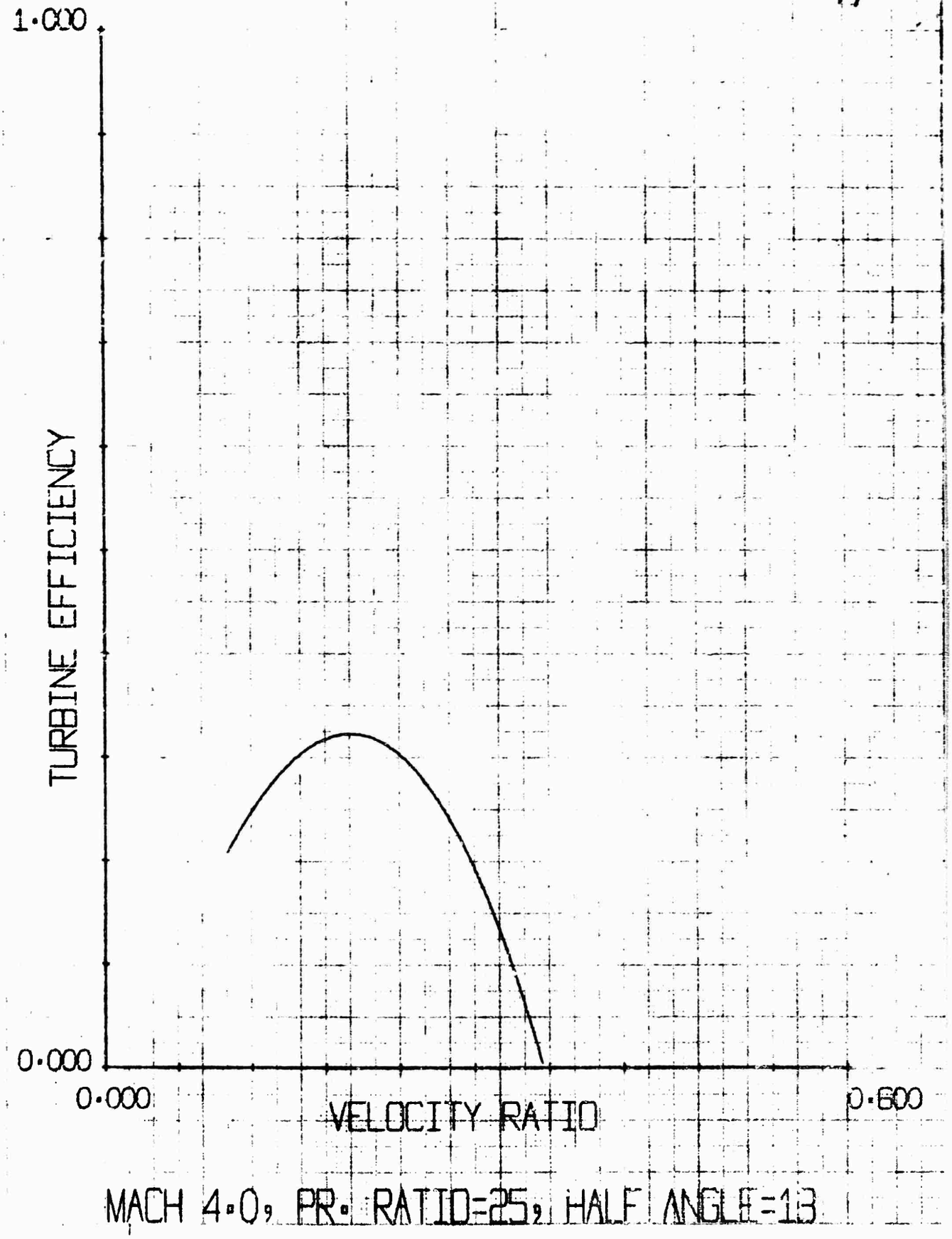


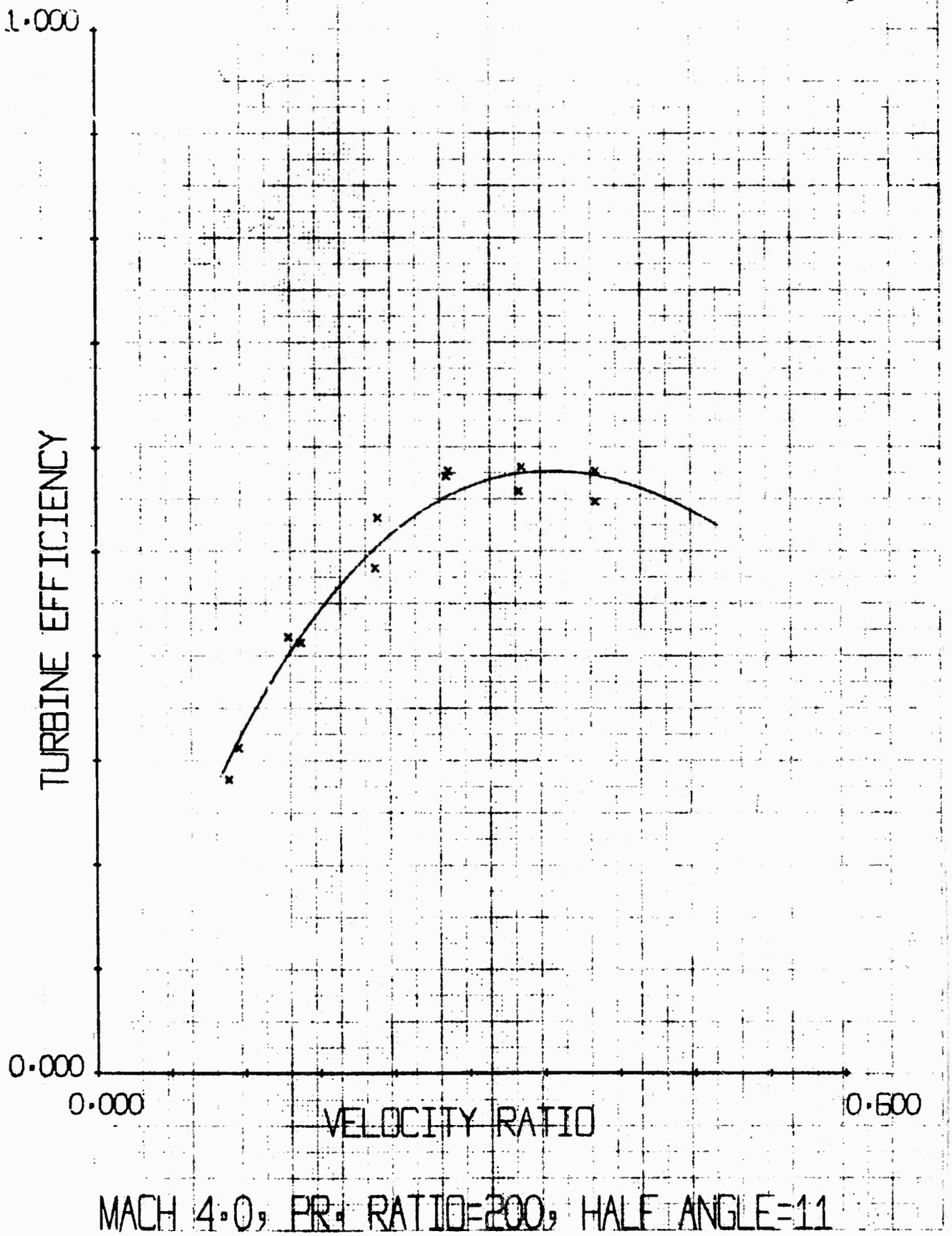
MACH 4·0, PR· RATIO=100, HAL· ANGLE=13



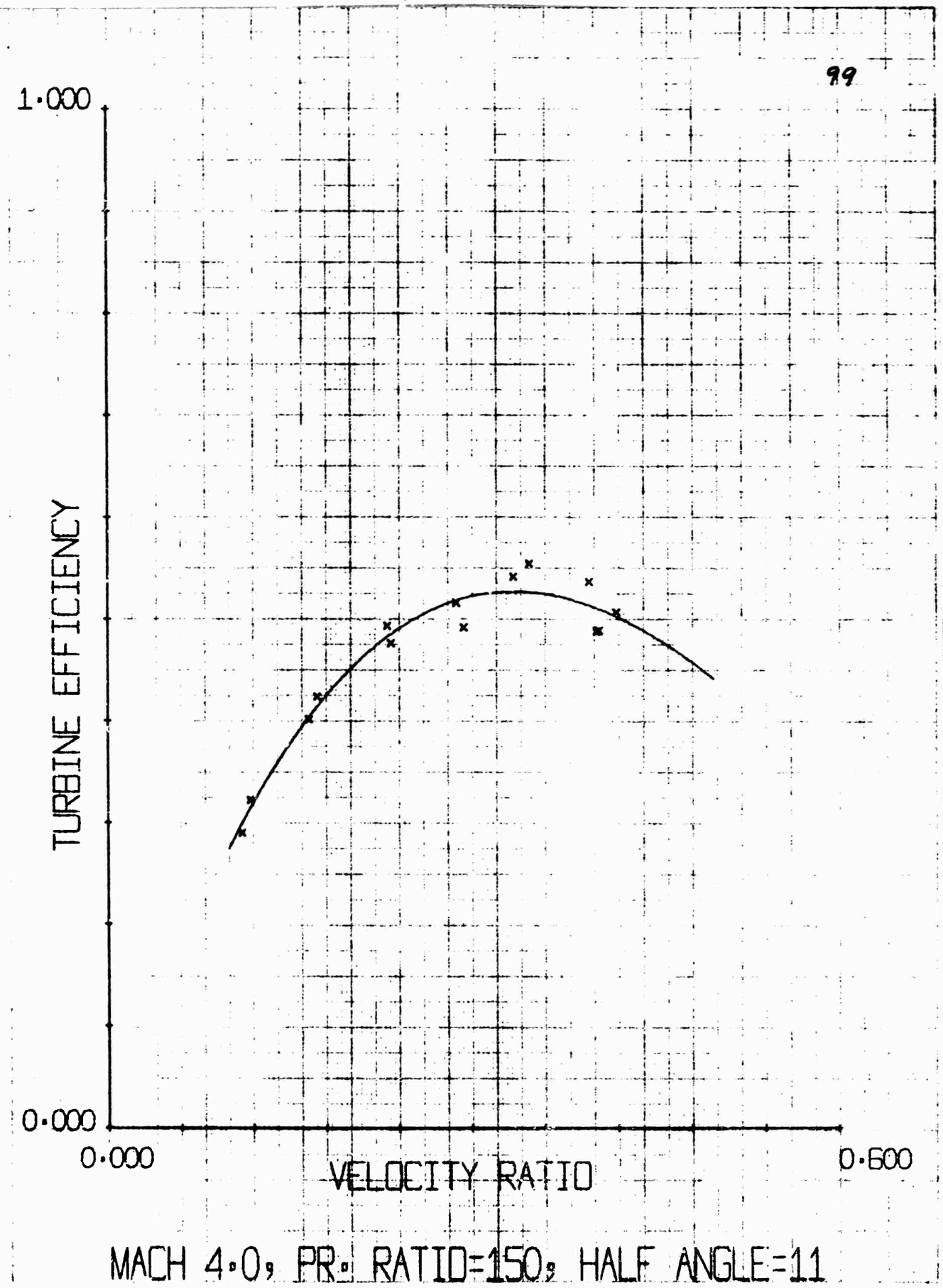
MACH 4·0, PR. RATIO=50, HALF ANGLE=13



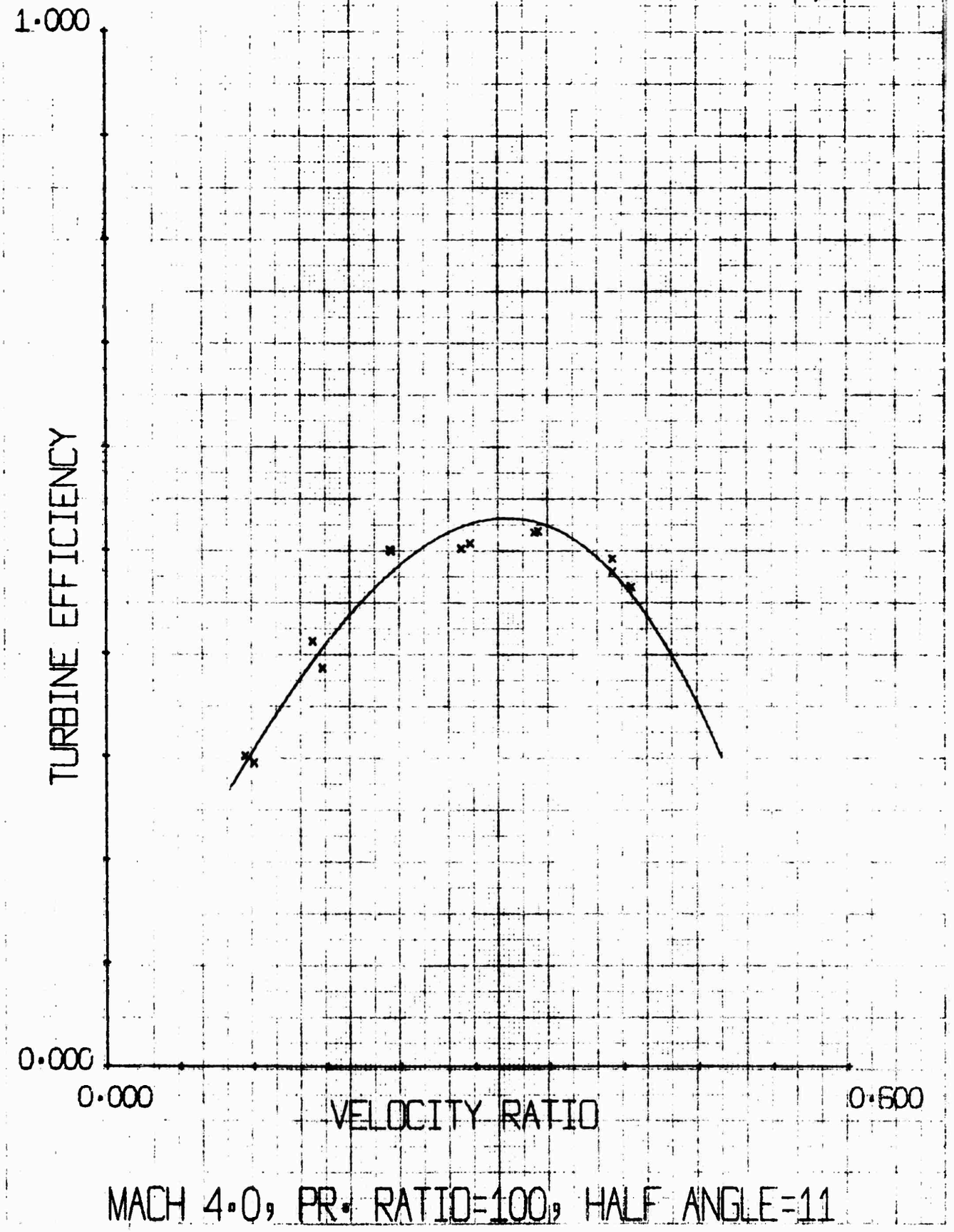
MACH 4·0, PR. RATIO=25, HALF ANGLE=13



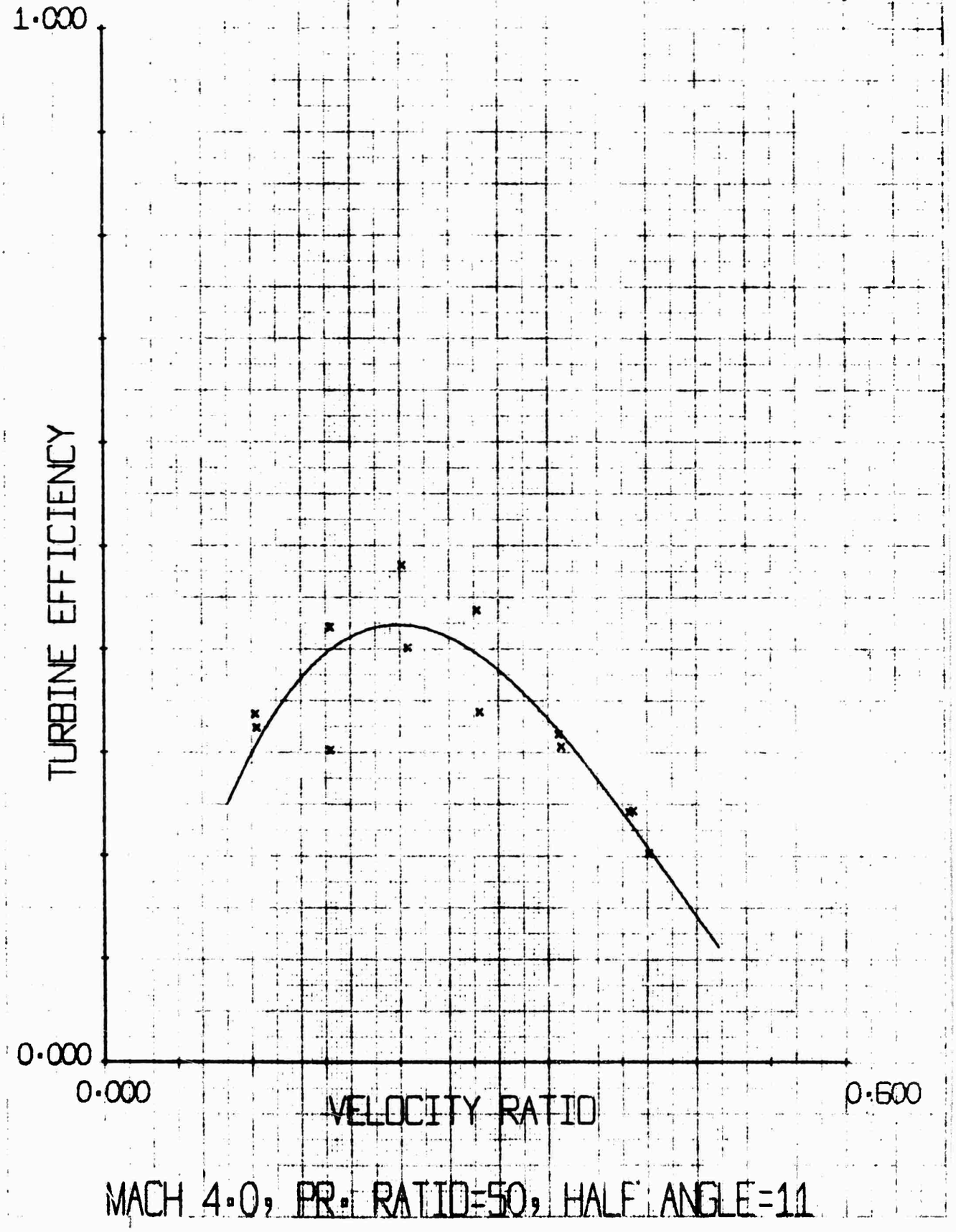
MACH 4·0, PR. RATIO=200, HALF ANGLE=11



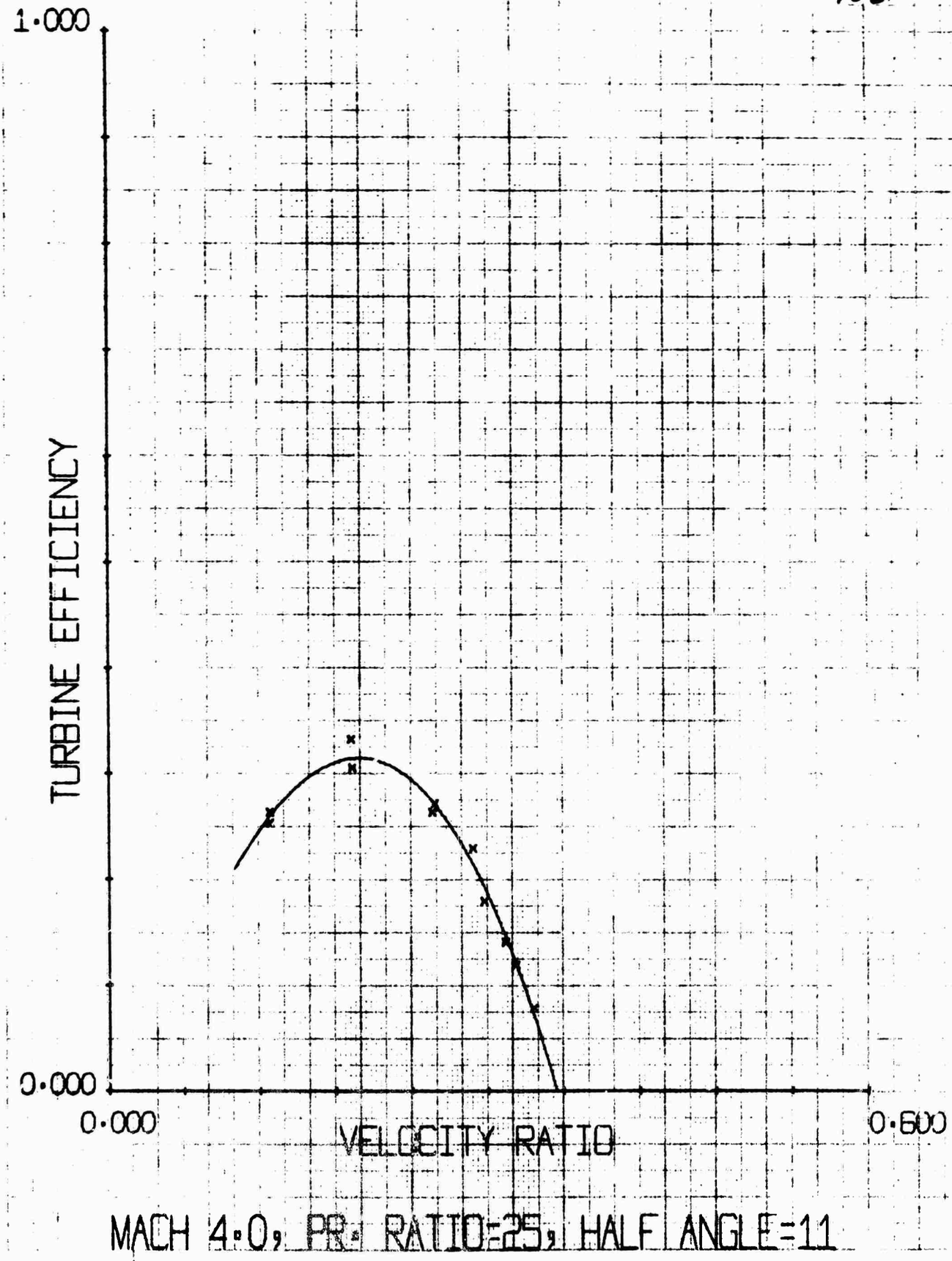
MACH 4·0, PR. RATIO=150, HALF ANGLE=11



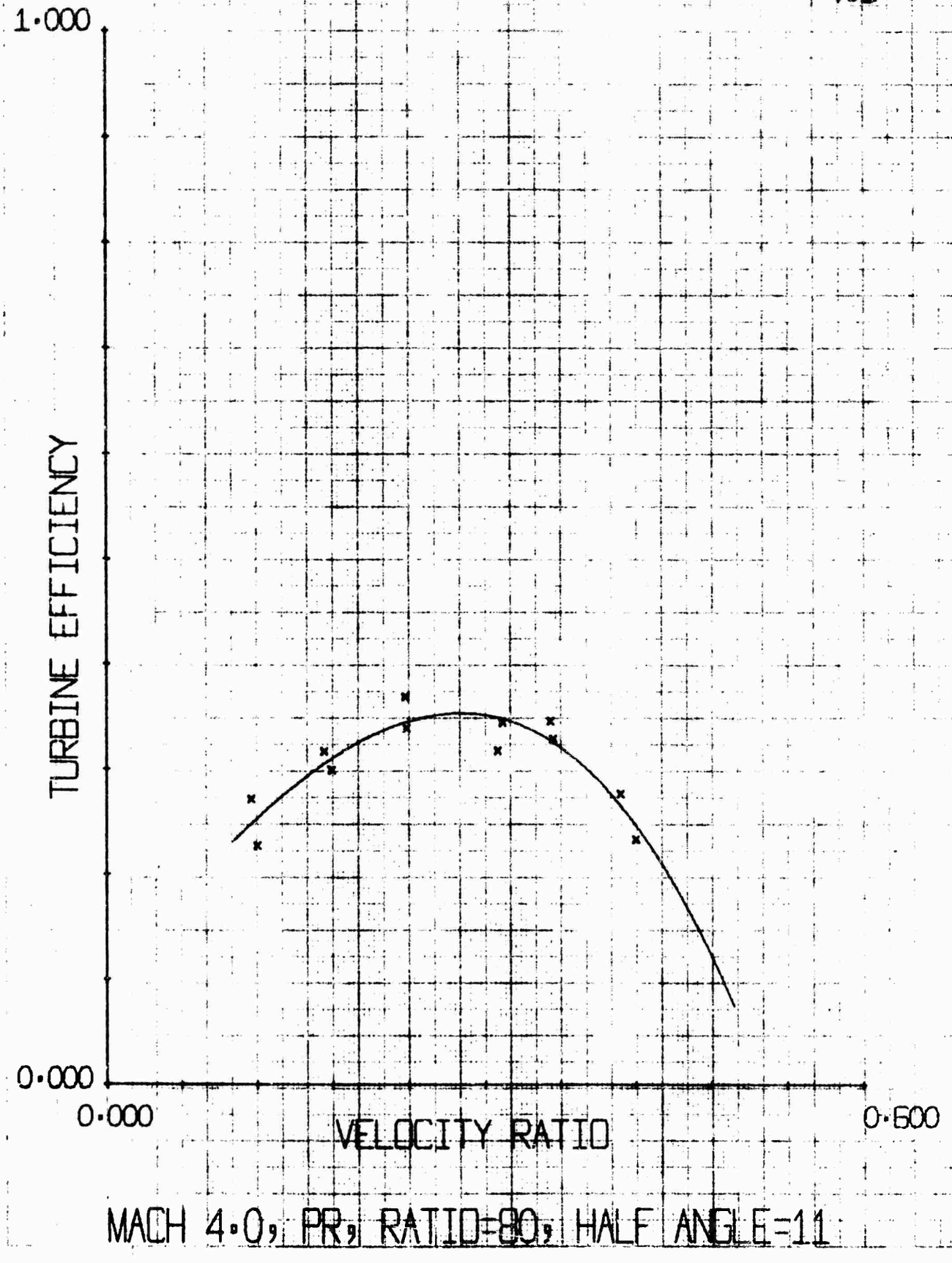
MACH 4·0, PR. RATIO=100, HALF ANGLE=11



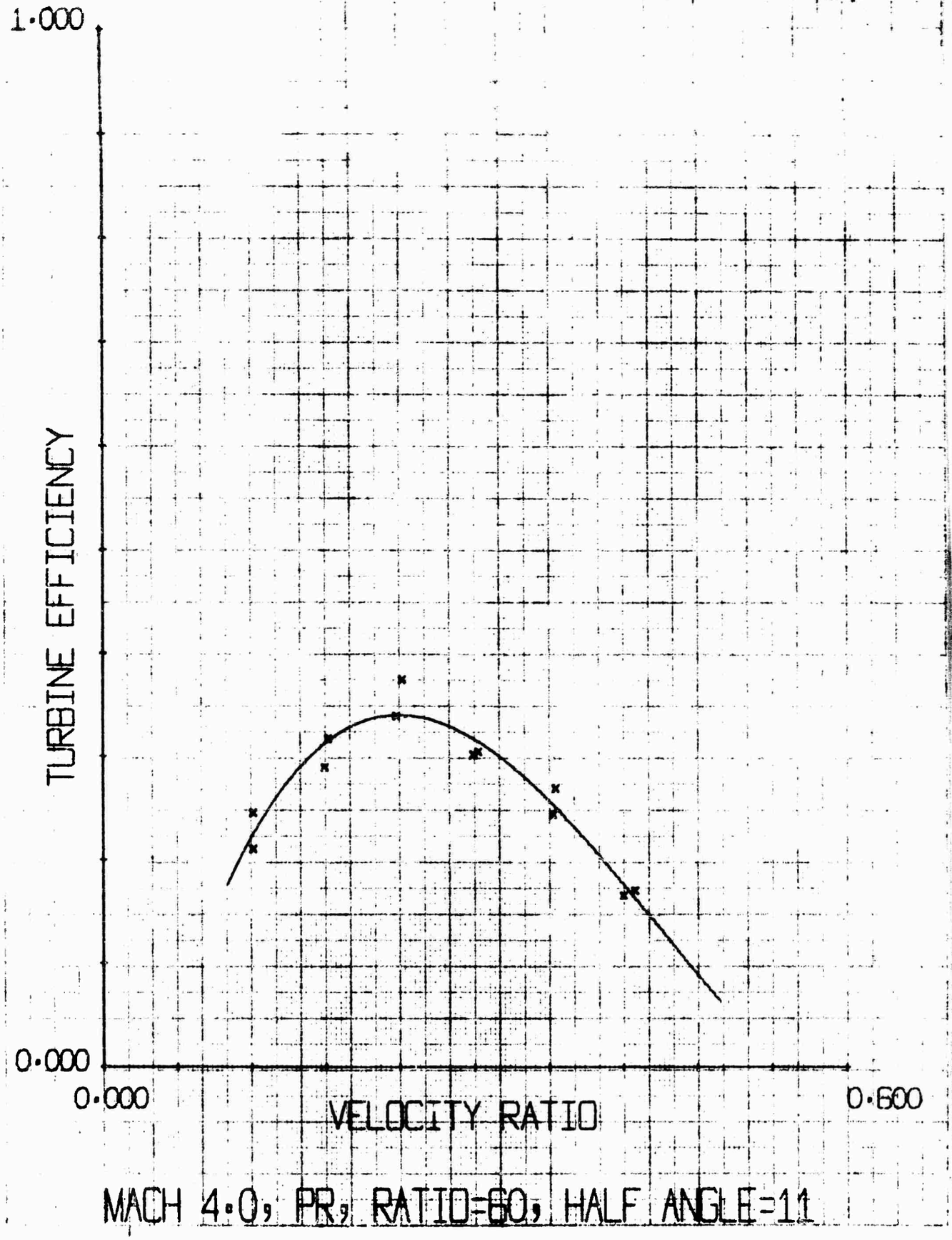
MACH 4·0, PR. RATIO=50, HALF ANGLE=11



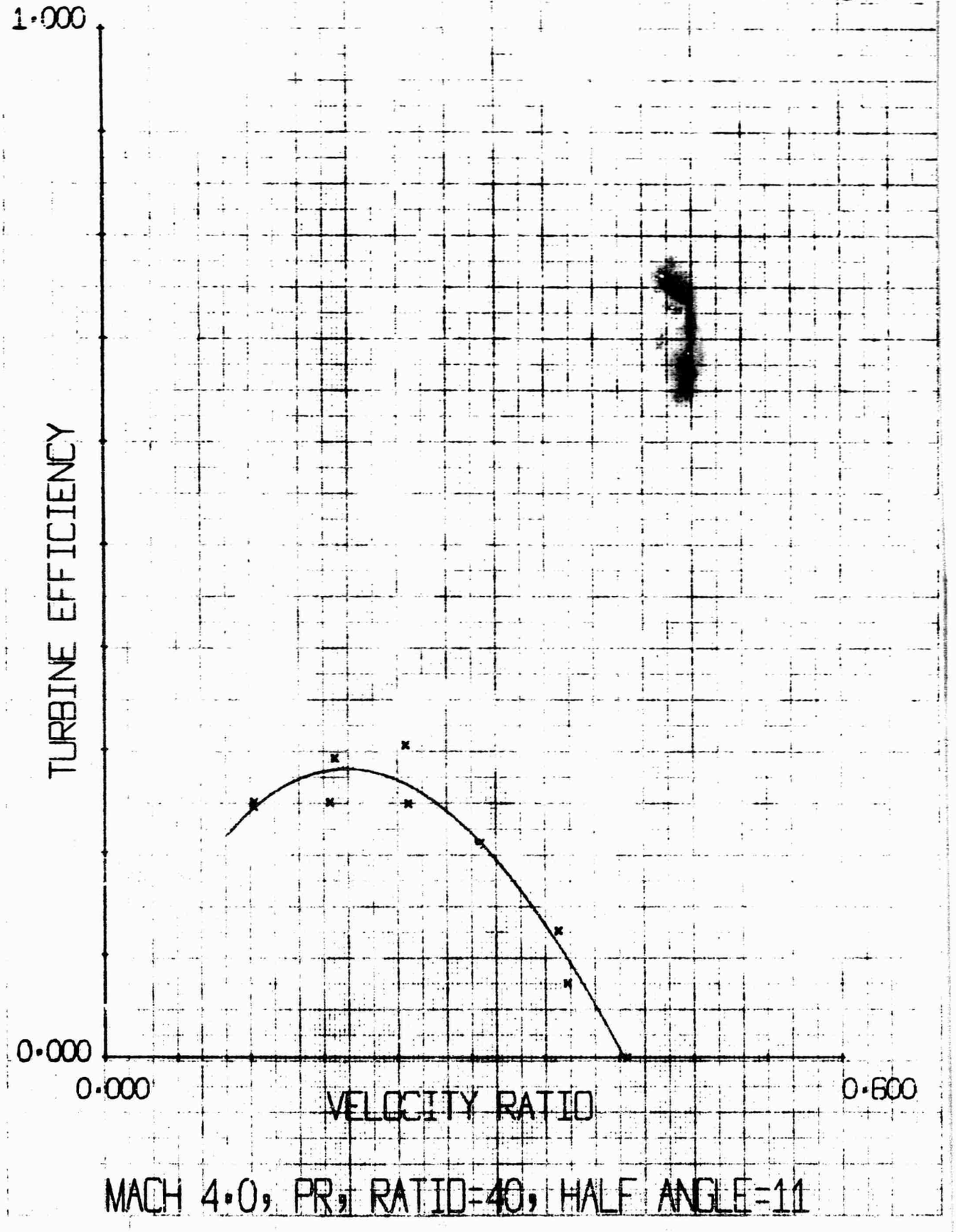
MACH 4·0, PR. RATIO=25, HALF ANGLE=11



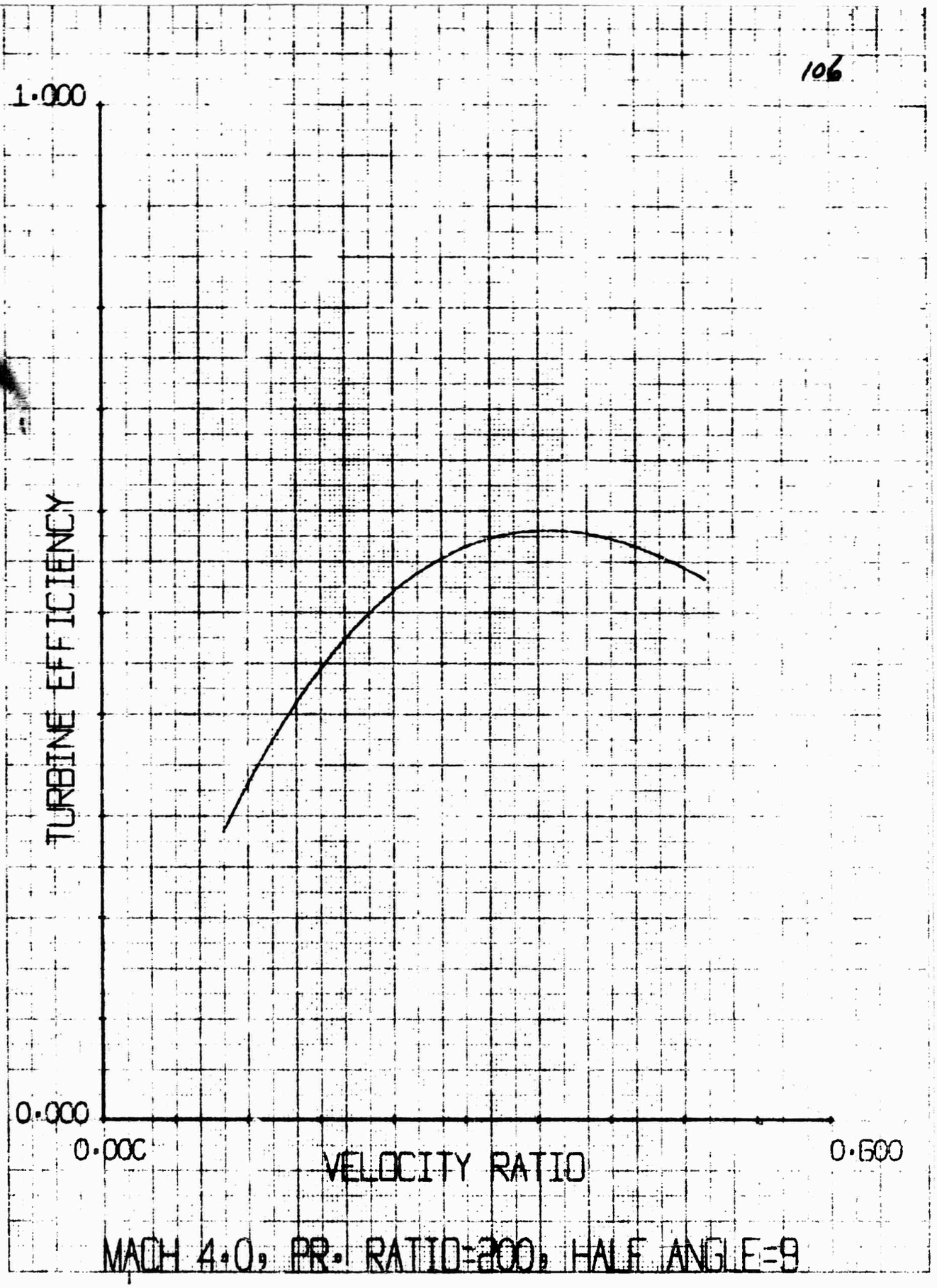
MACH 4·0, PR, RATIO=80, HALF ANGLE=11



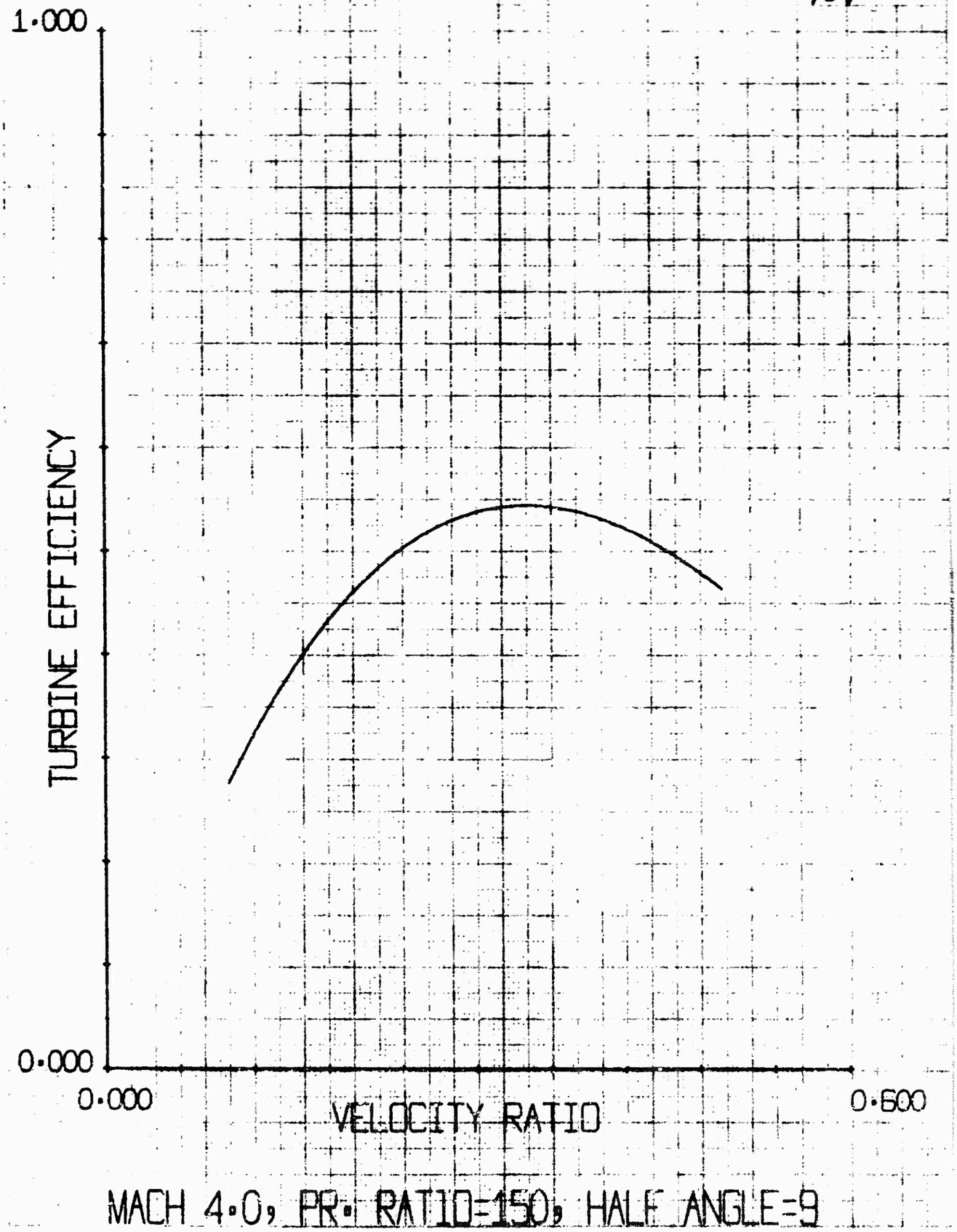
MACH 4·0, PR, RATIO=60, HALF ANGLE=11



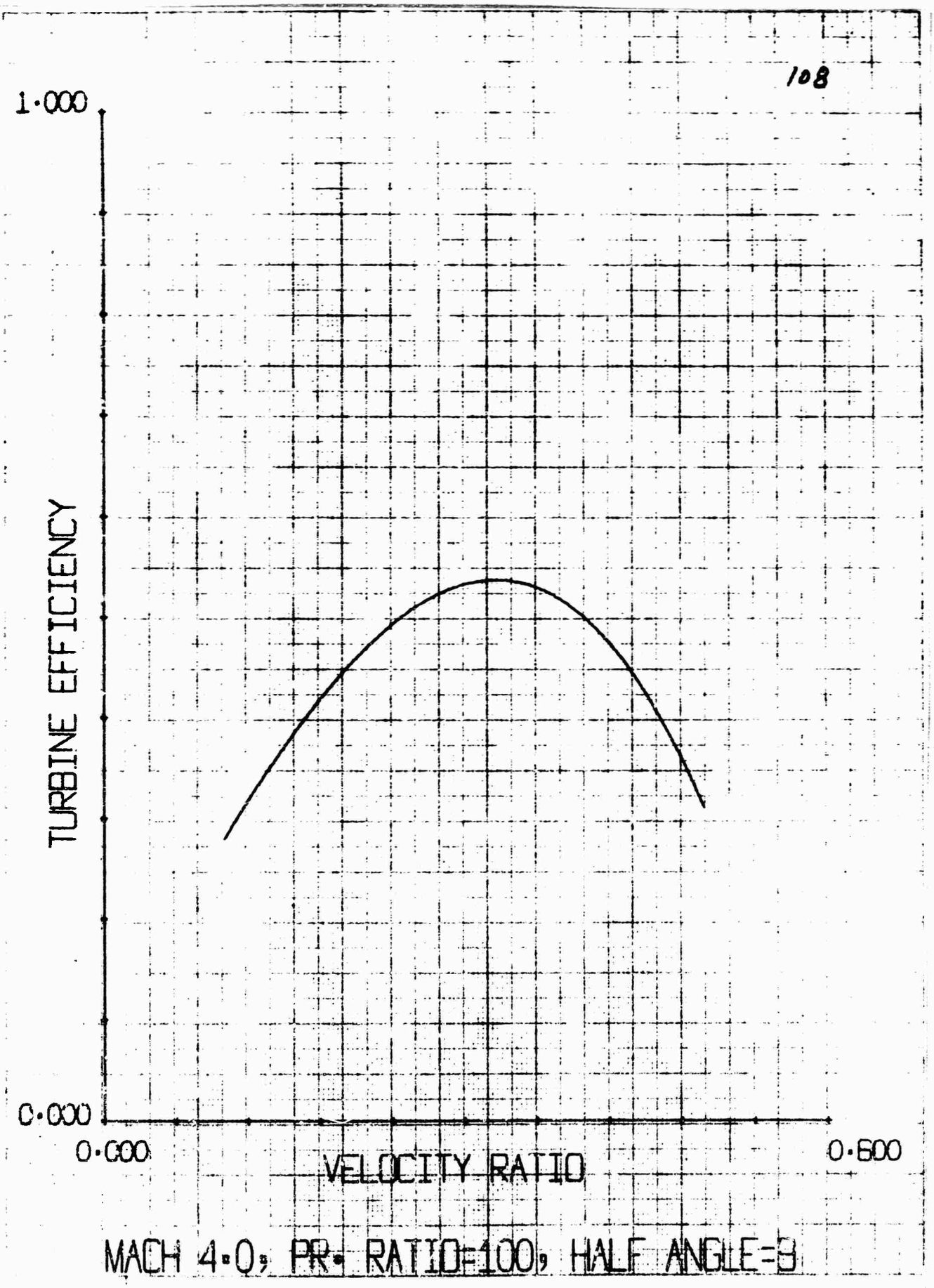
MACH 4·0, PR; RATID=40, HALF ANGLE=11



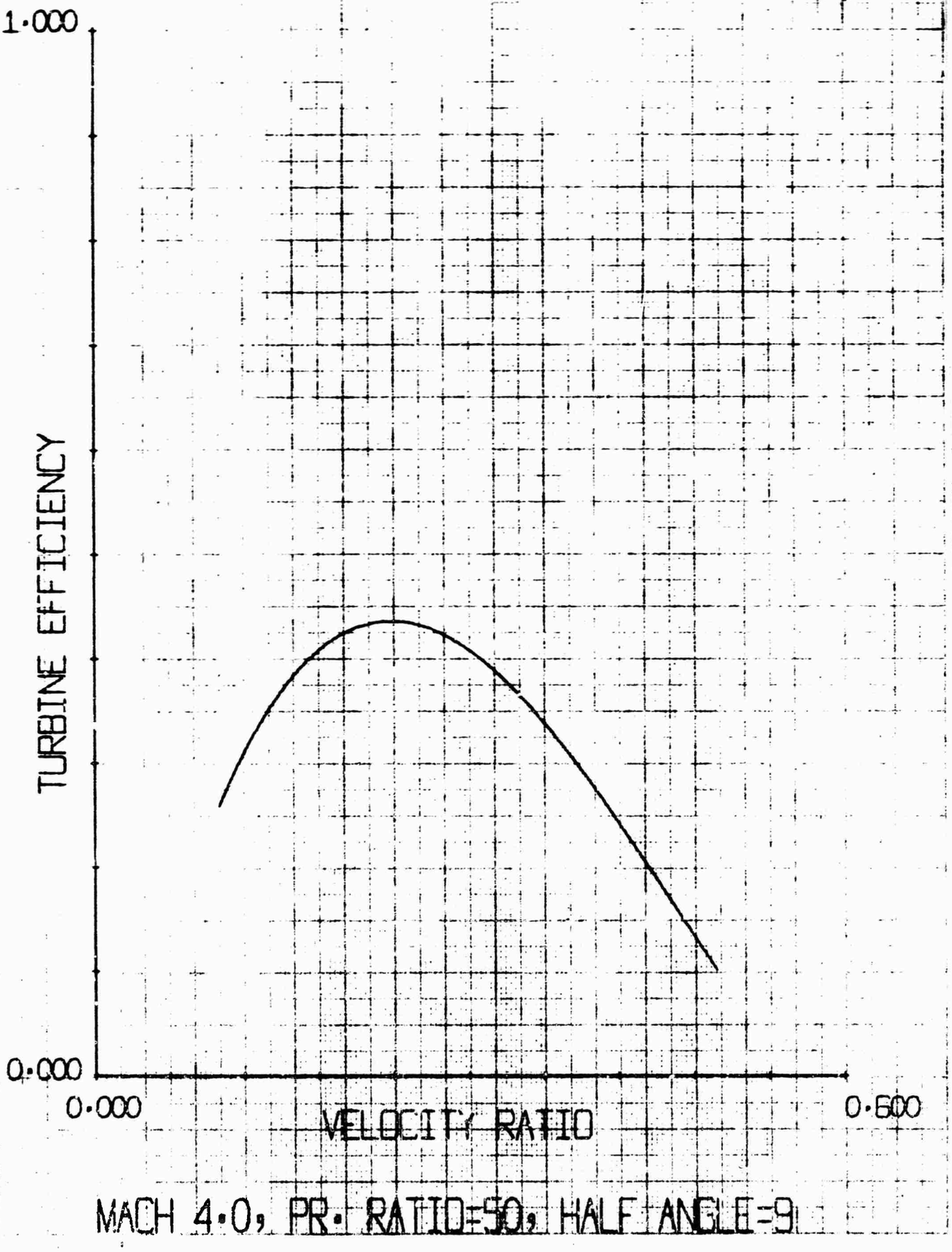
MACH 4·0, PR· RATIO=200, HALF ANGLE=9



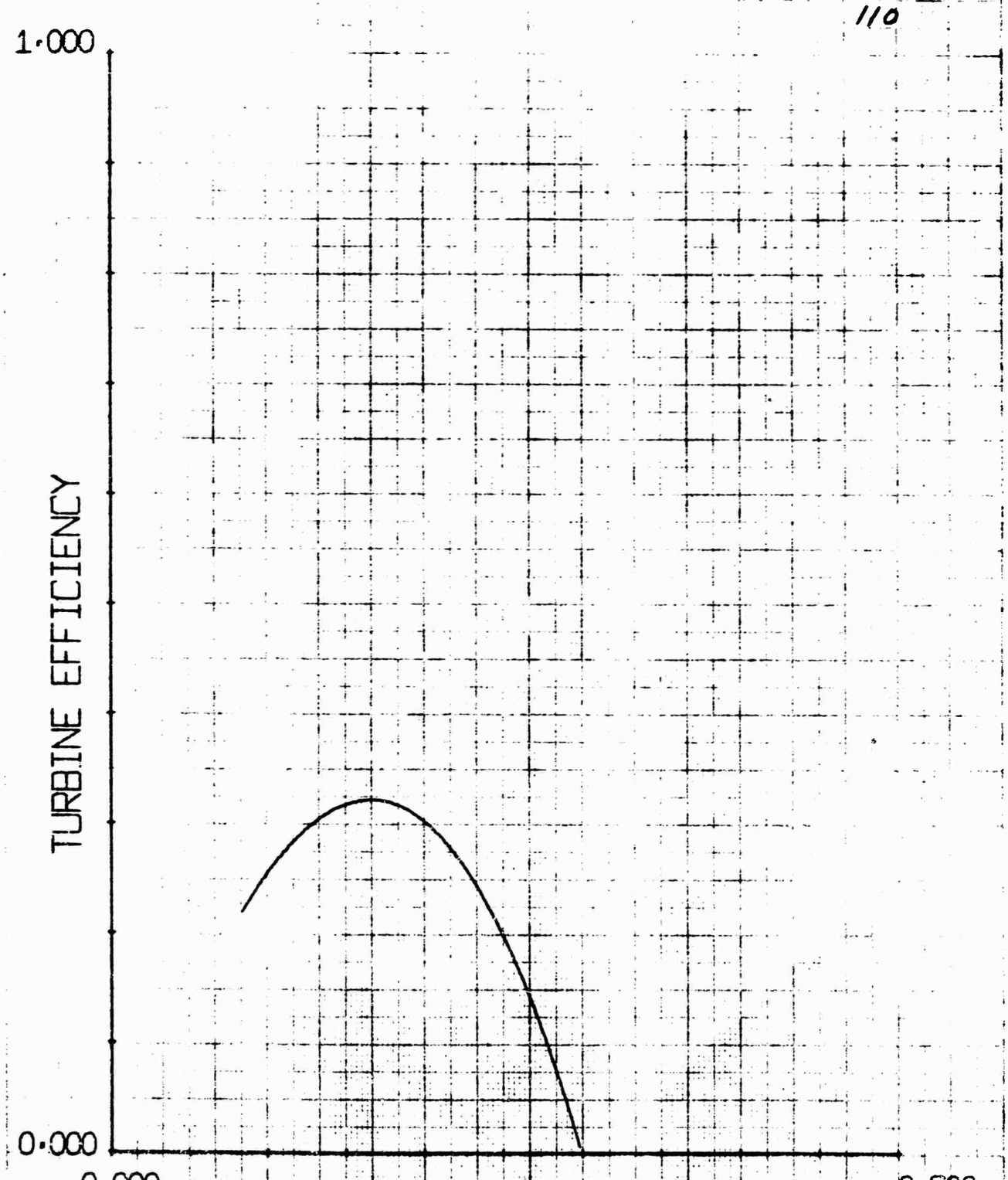
MACH 4·0, PR· RATIO=150, HALF ANGLE=9



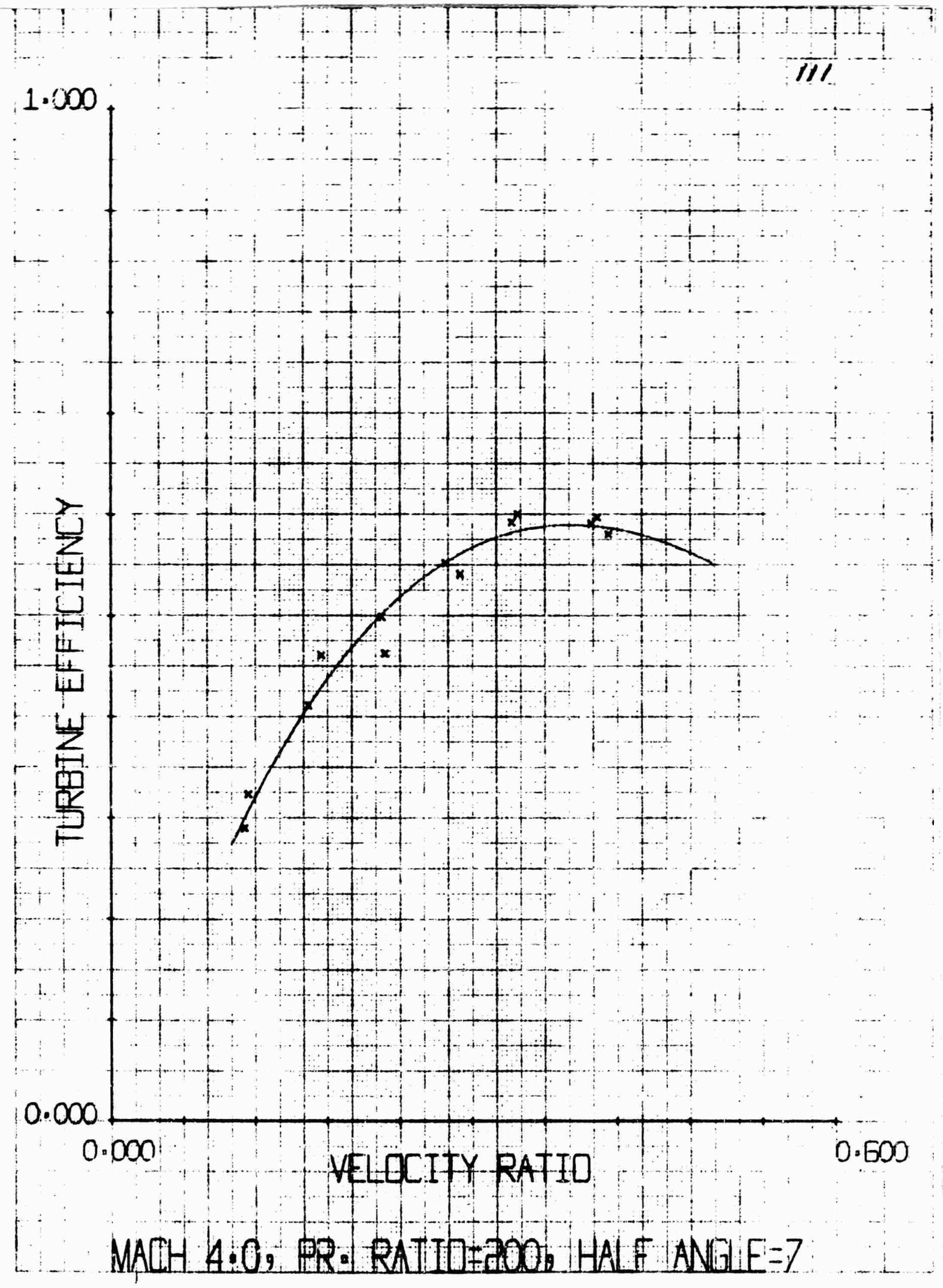
MACH 4·0, PR· RATIO=100, HALF ANGLE=8



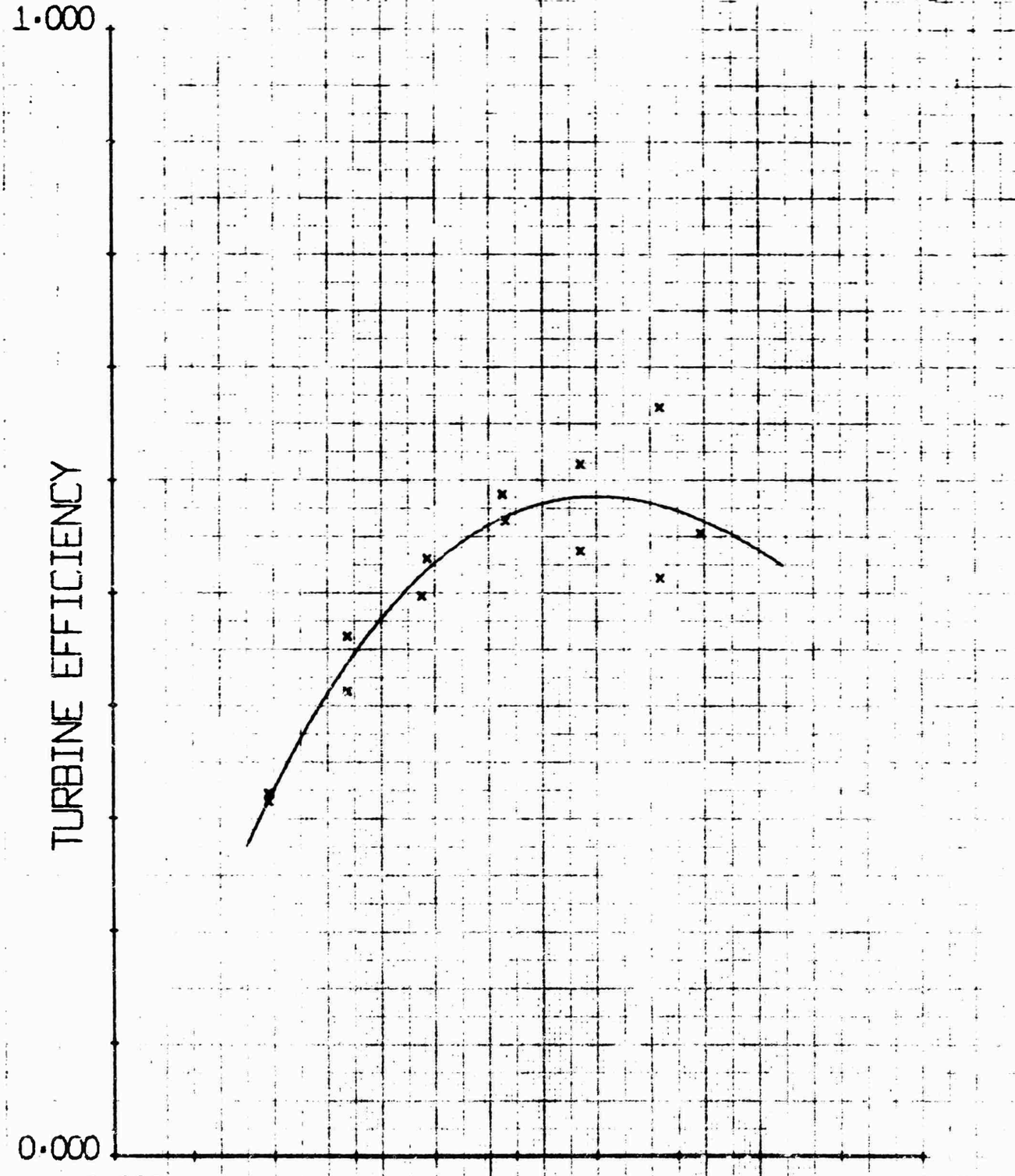
MACH 4·0, PR· RATIO=50, HALF ANGLE=9



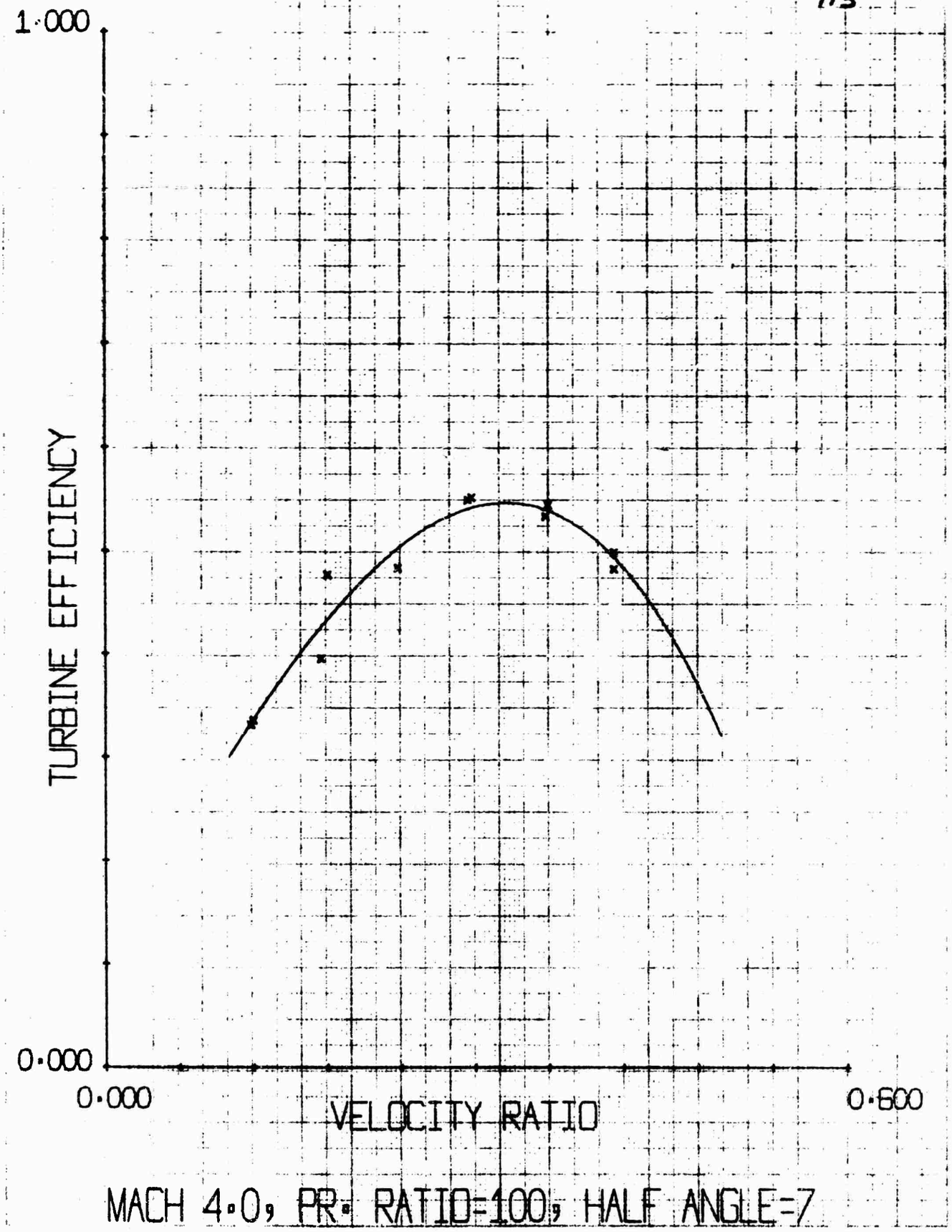
MACH 4·0, PR· RATIO=25, HALF ANGLE=9



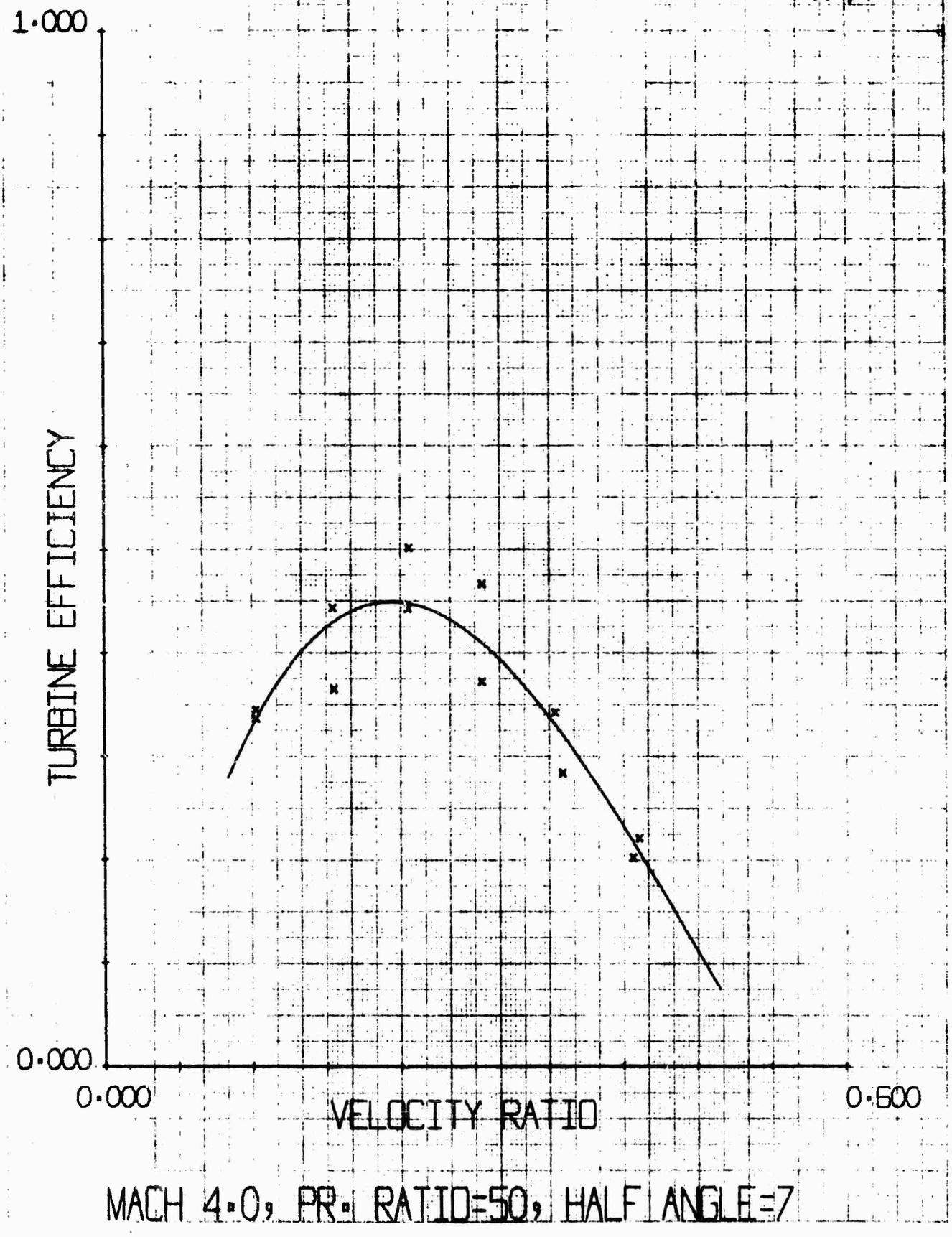
MACH 4·0, PR· RATIO=200, HALF ANGLE=7



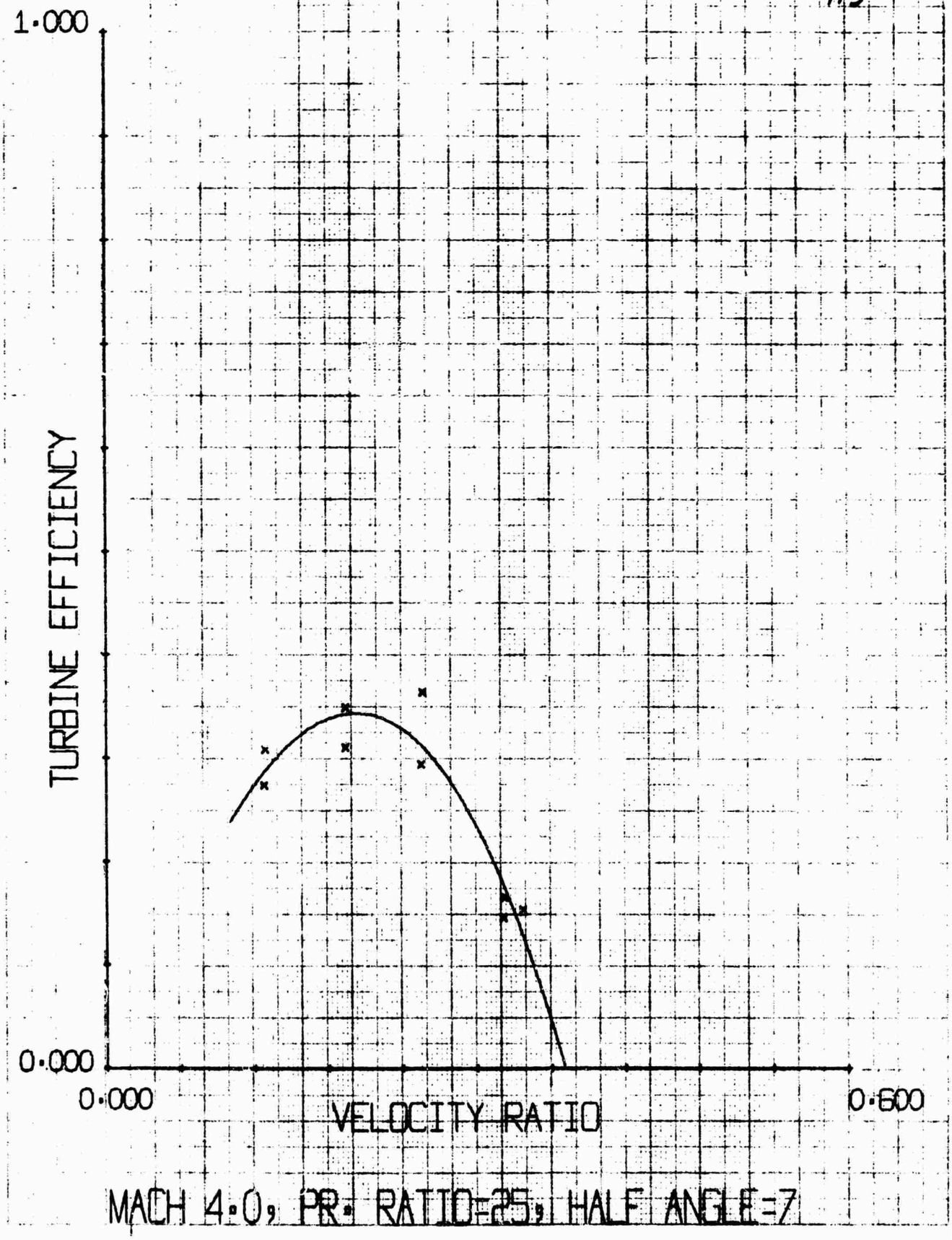
MACH 4·0, PR. RATIO=150, HALF ANGLE=7



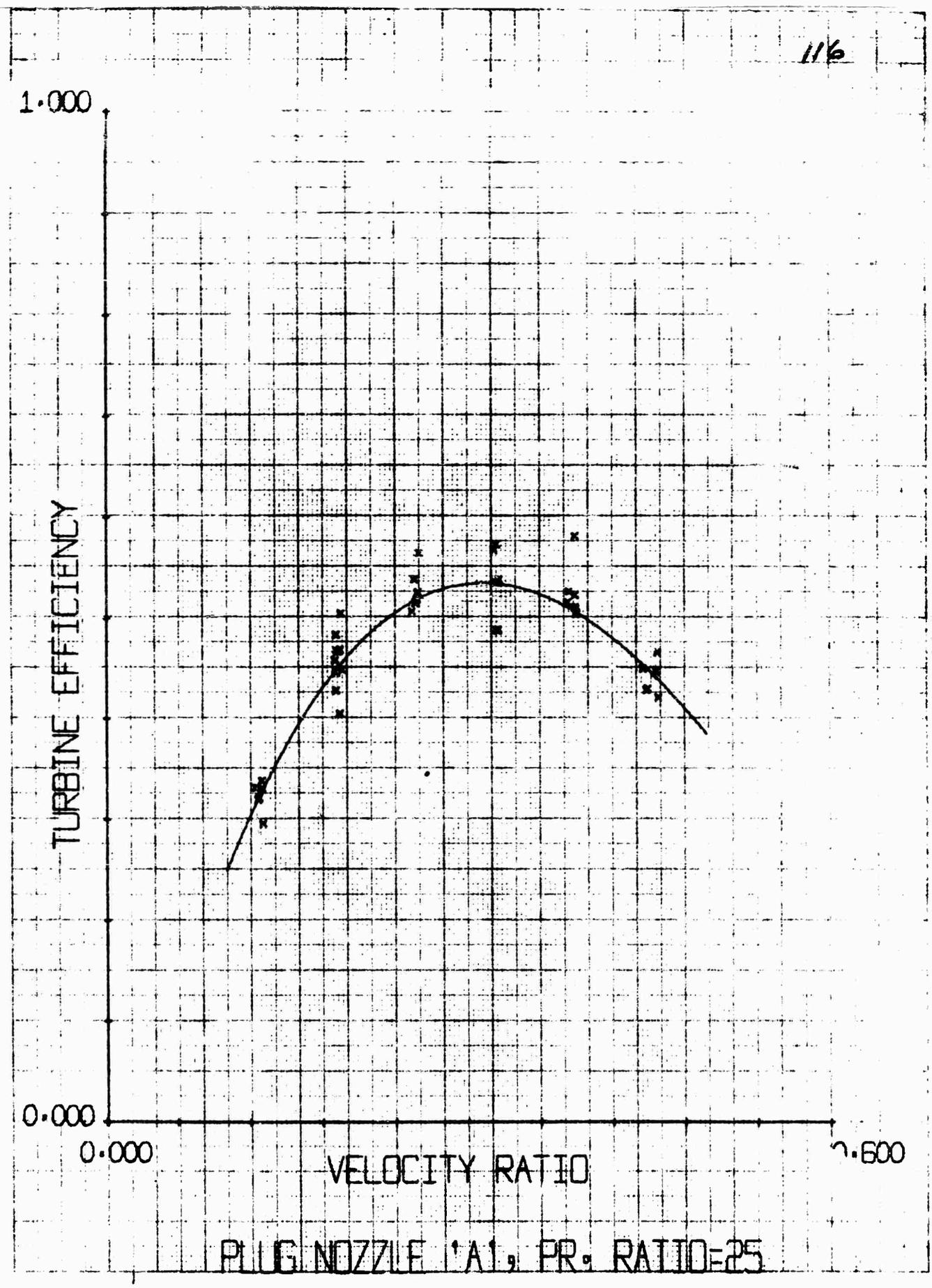
MACH 4·0, PR· RATIO=100, HALF ANGLE=7

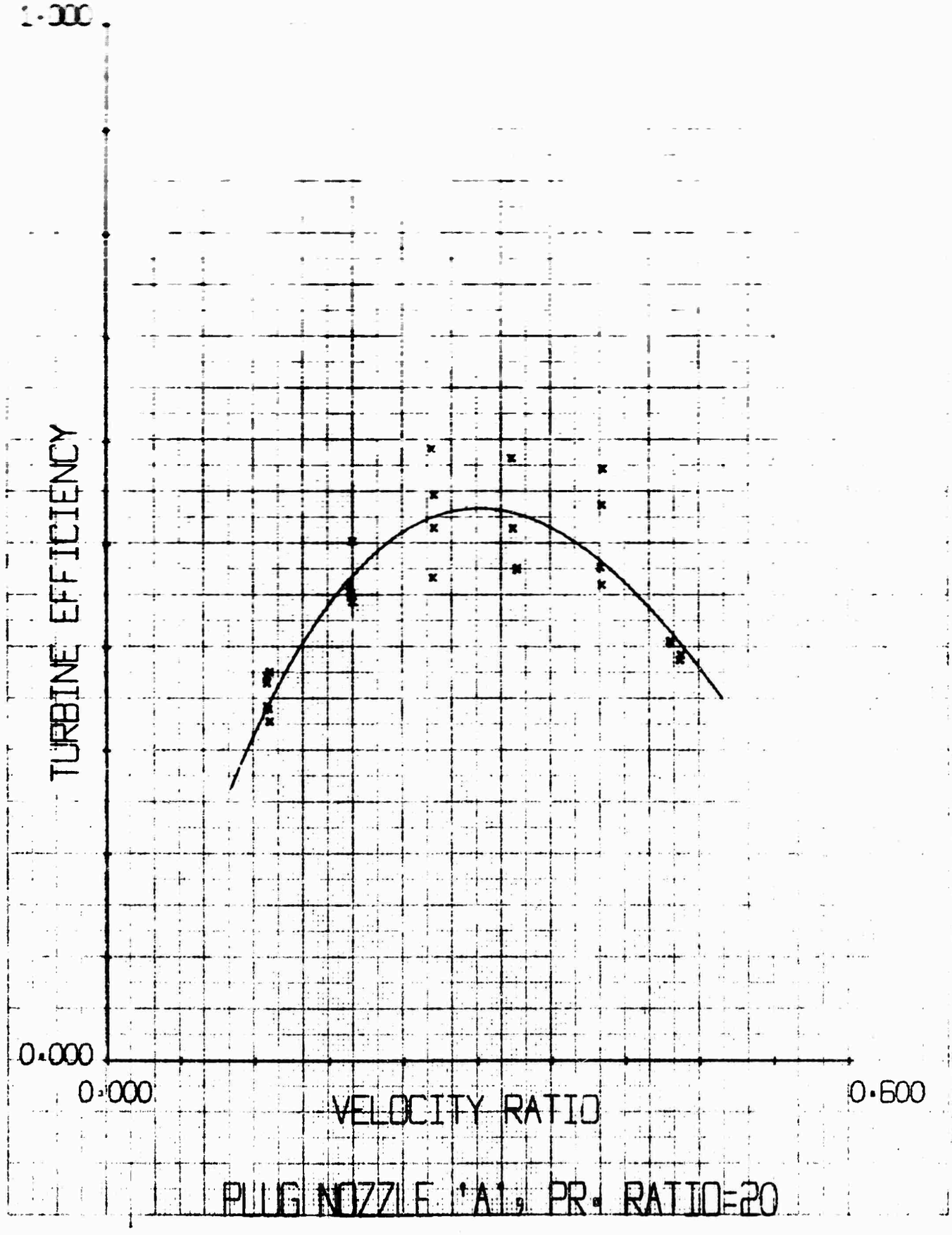


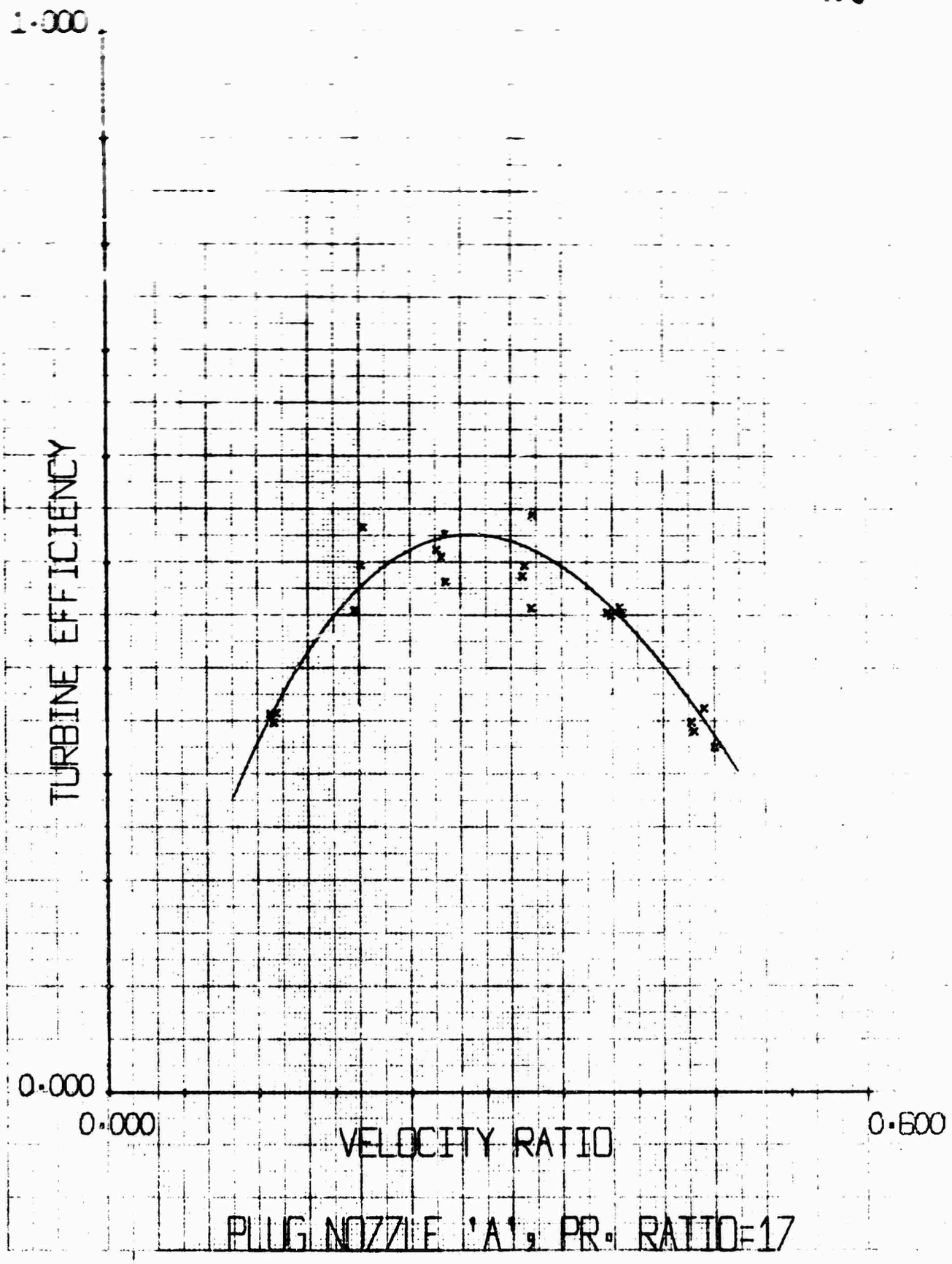
MACH 4·0, PR. RATIO=50, HALF ANGLE=7

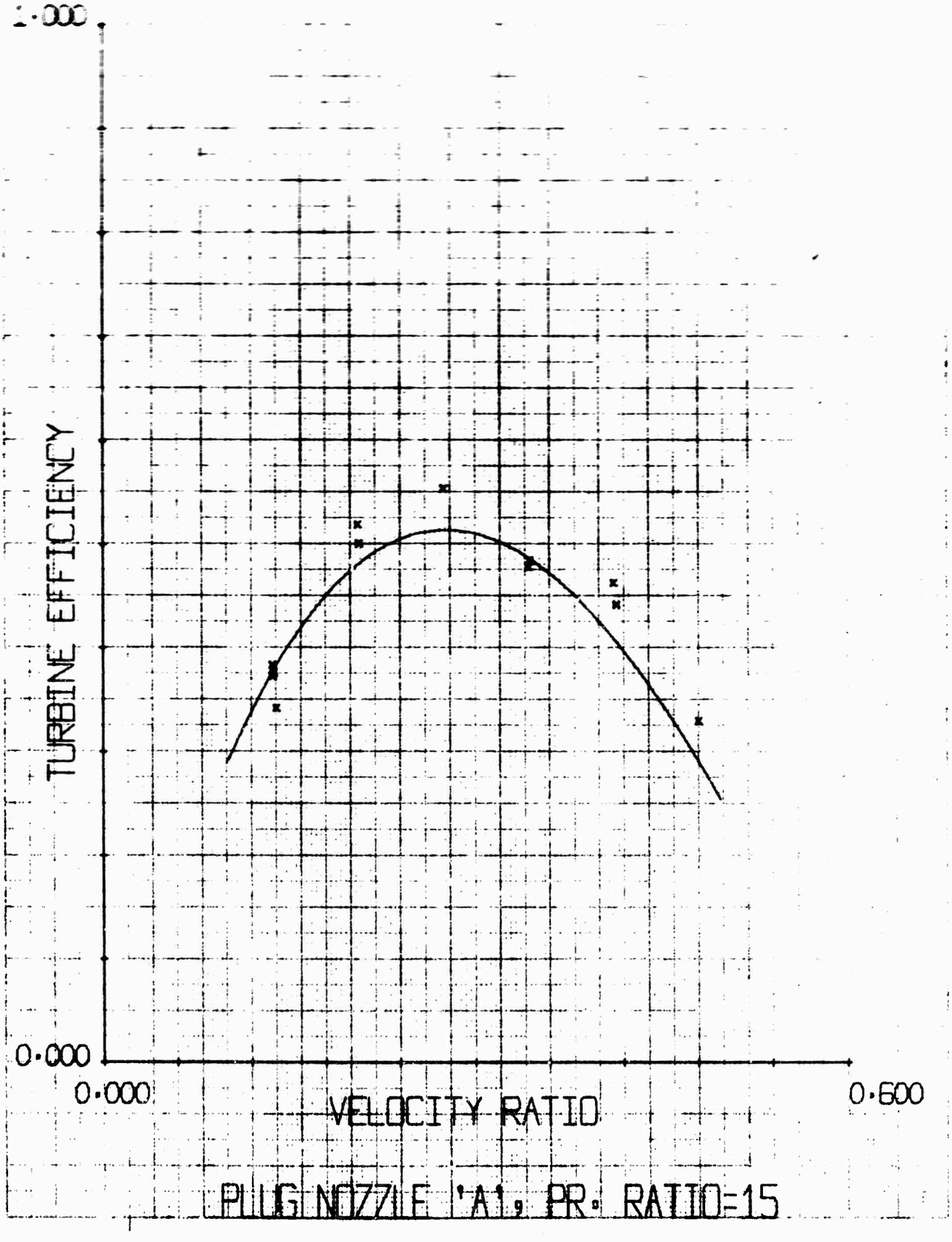


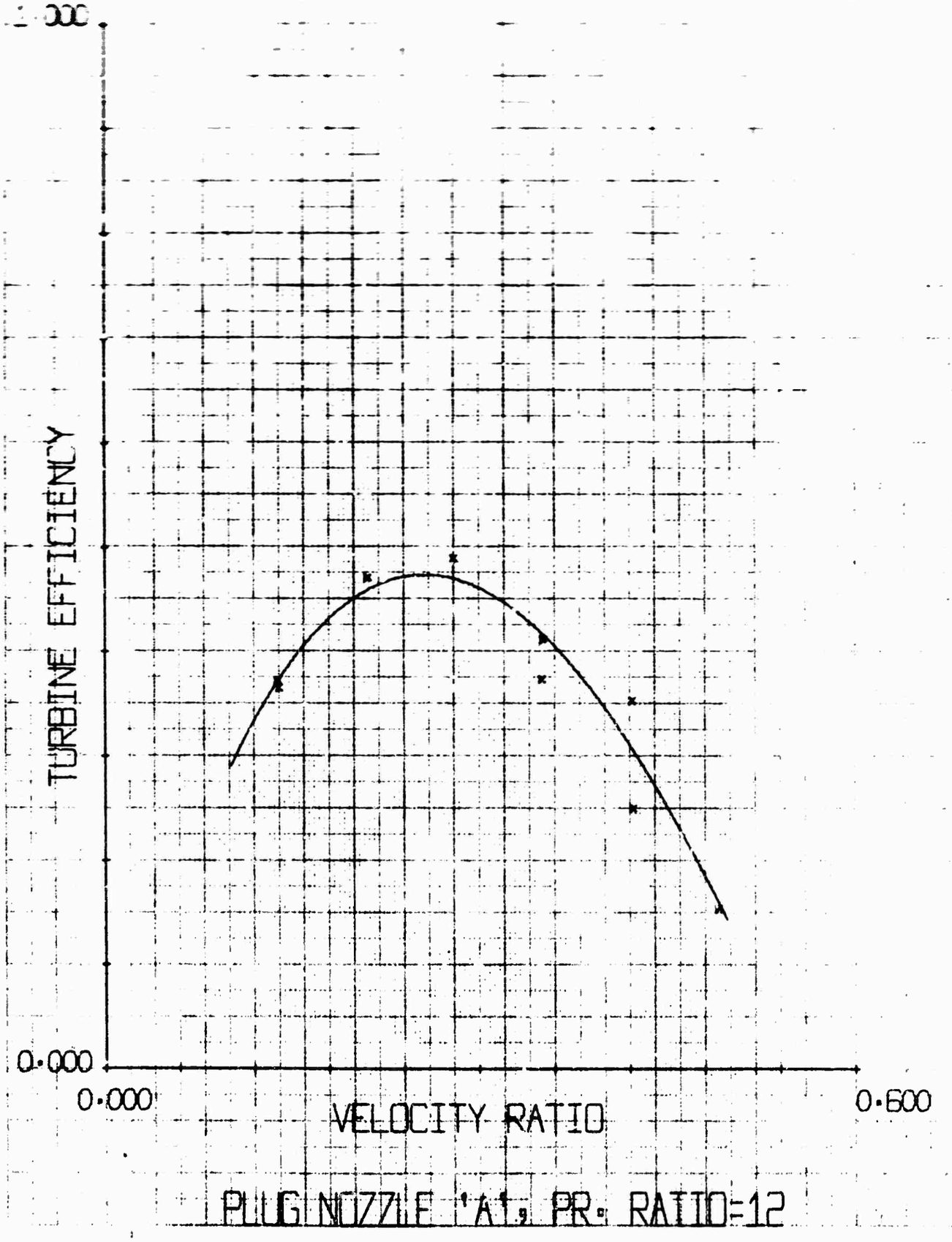
MACH 4·0, PR· RATIO=25, HALF ANGLE=7


1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
·600
PLUG NOZZLE 'A1, PR. RATIO=25

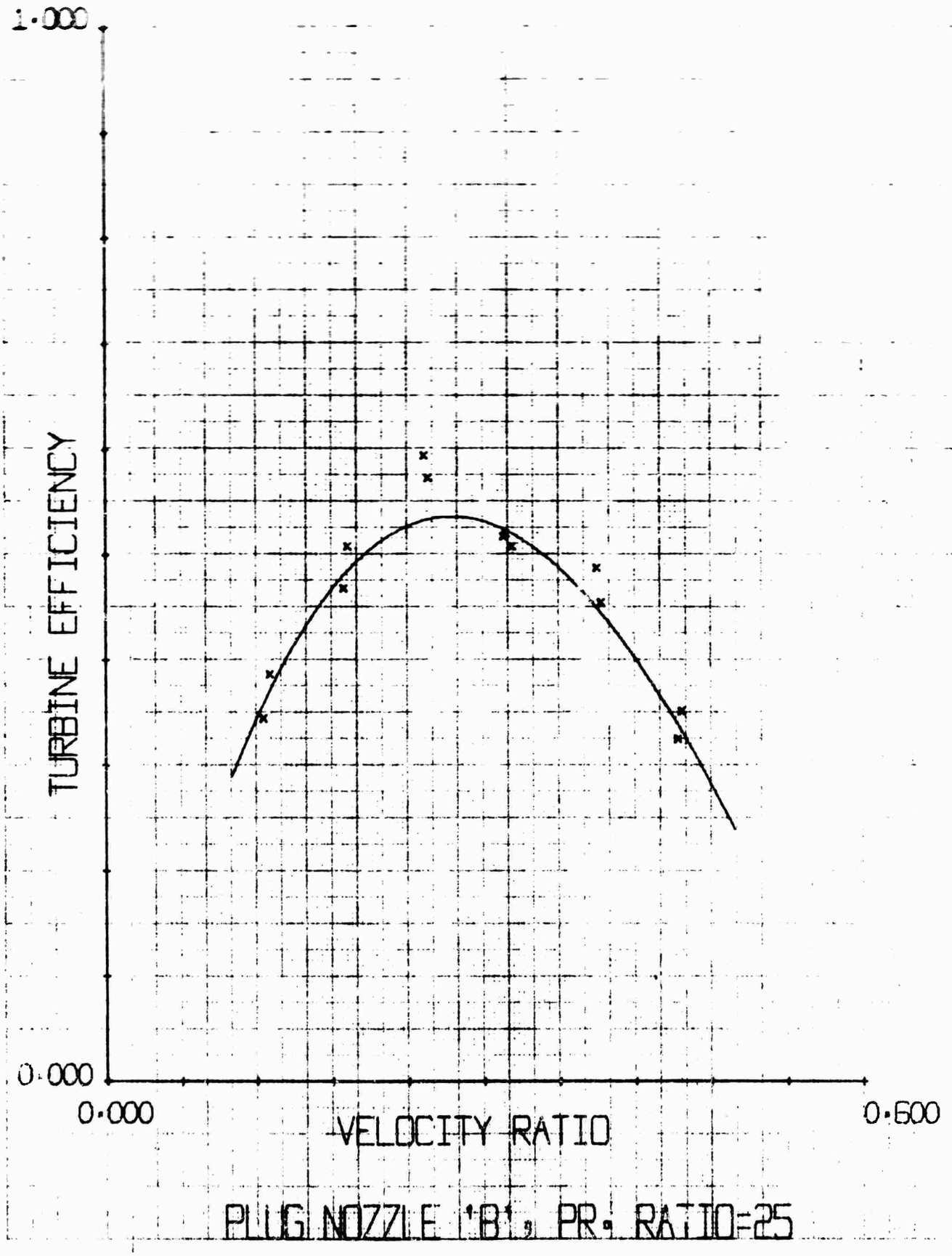

1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
PLUG NOZZLE 'A', PR. RATIO=20


1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
PLUG NOZZLE 'A', PR. RATIO=17

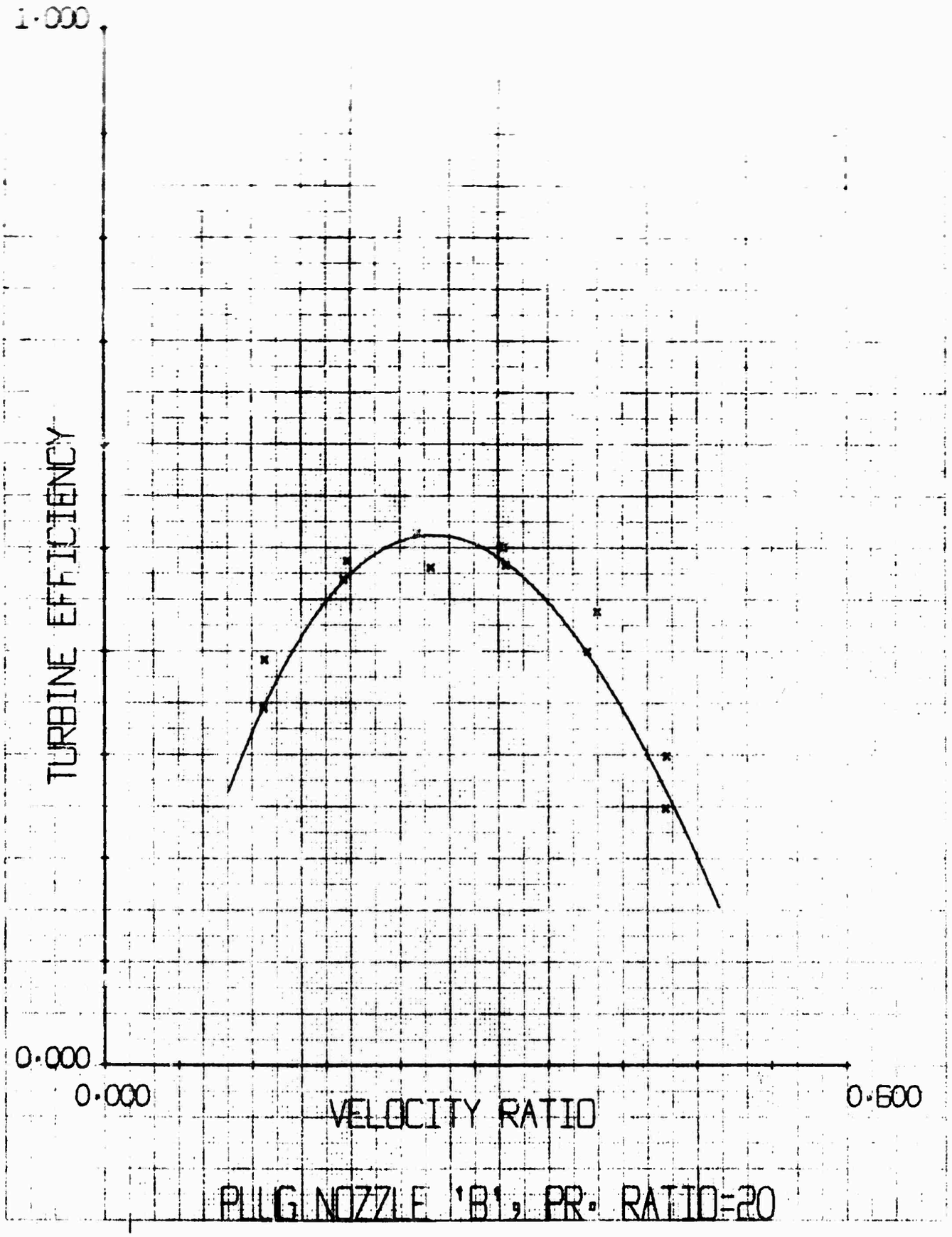

1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
PLUG NOZZLE 'A1, PR. RATIO=15

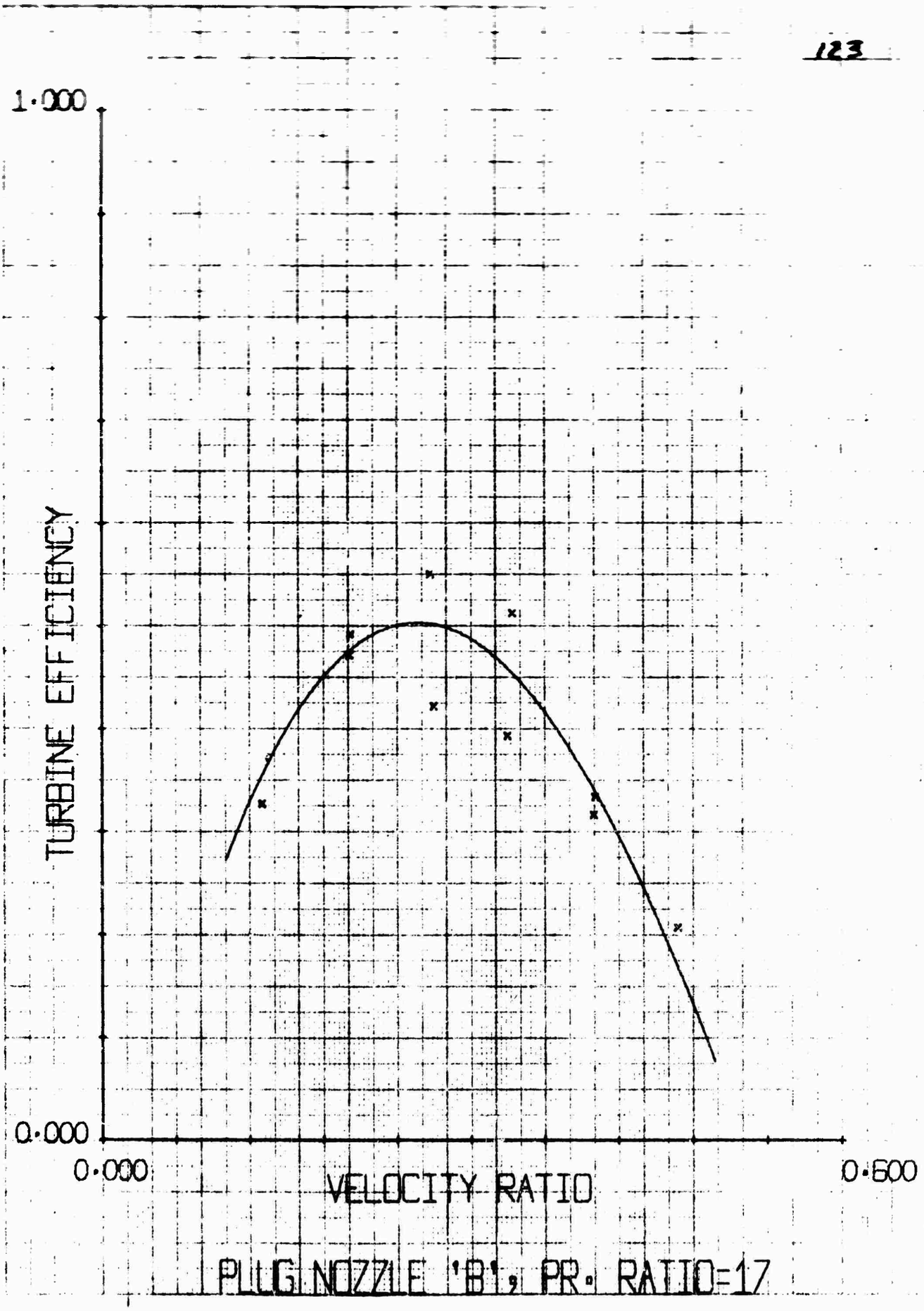


PLUG NOZZLE 'A', PR. RATIO=12

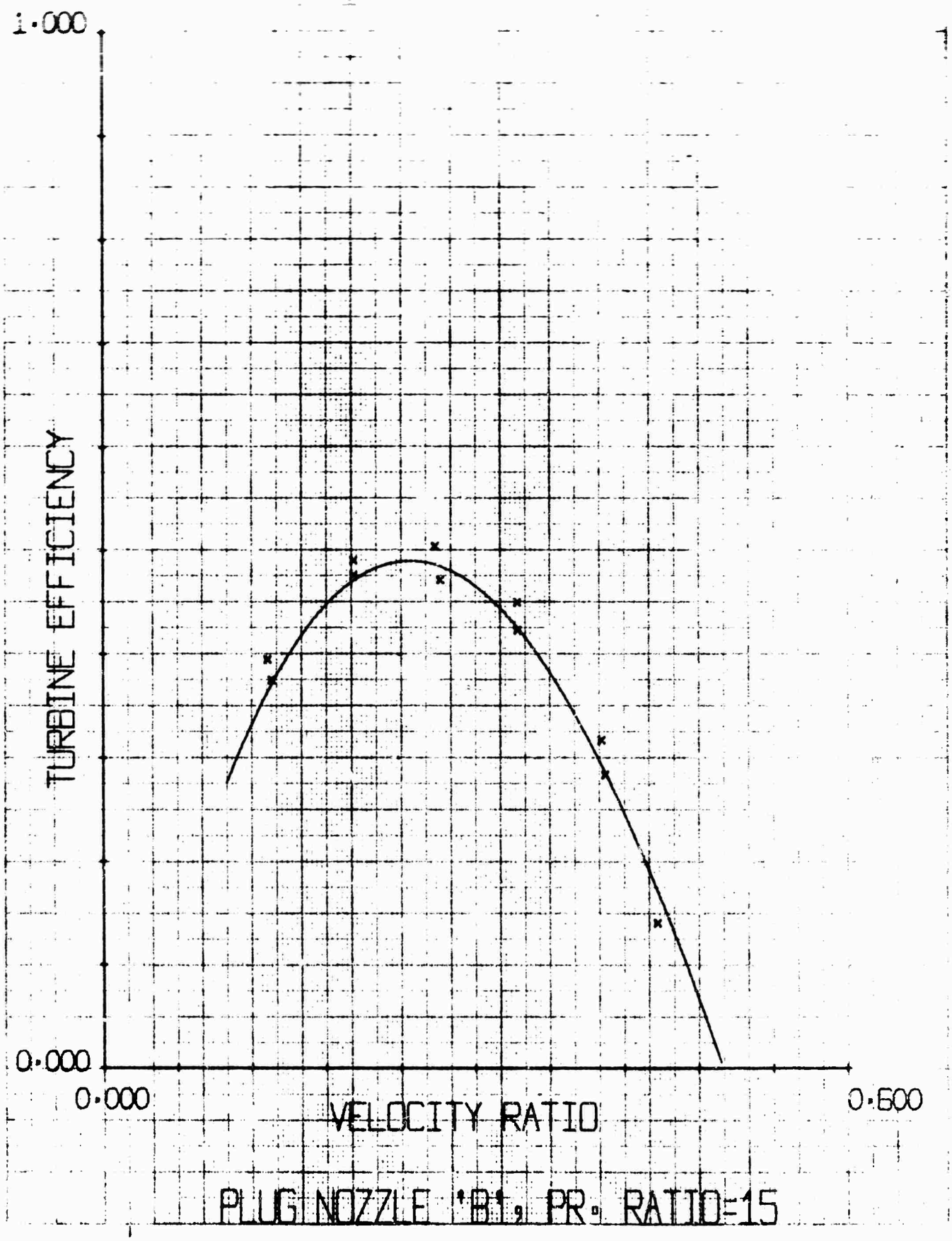


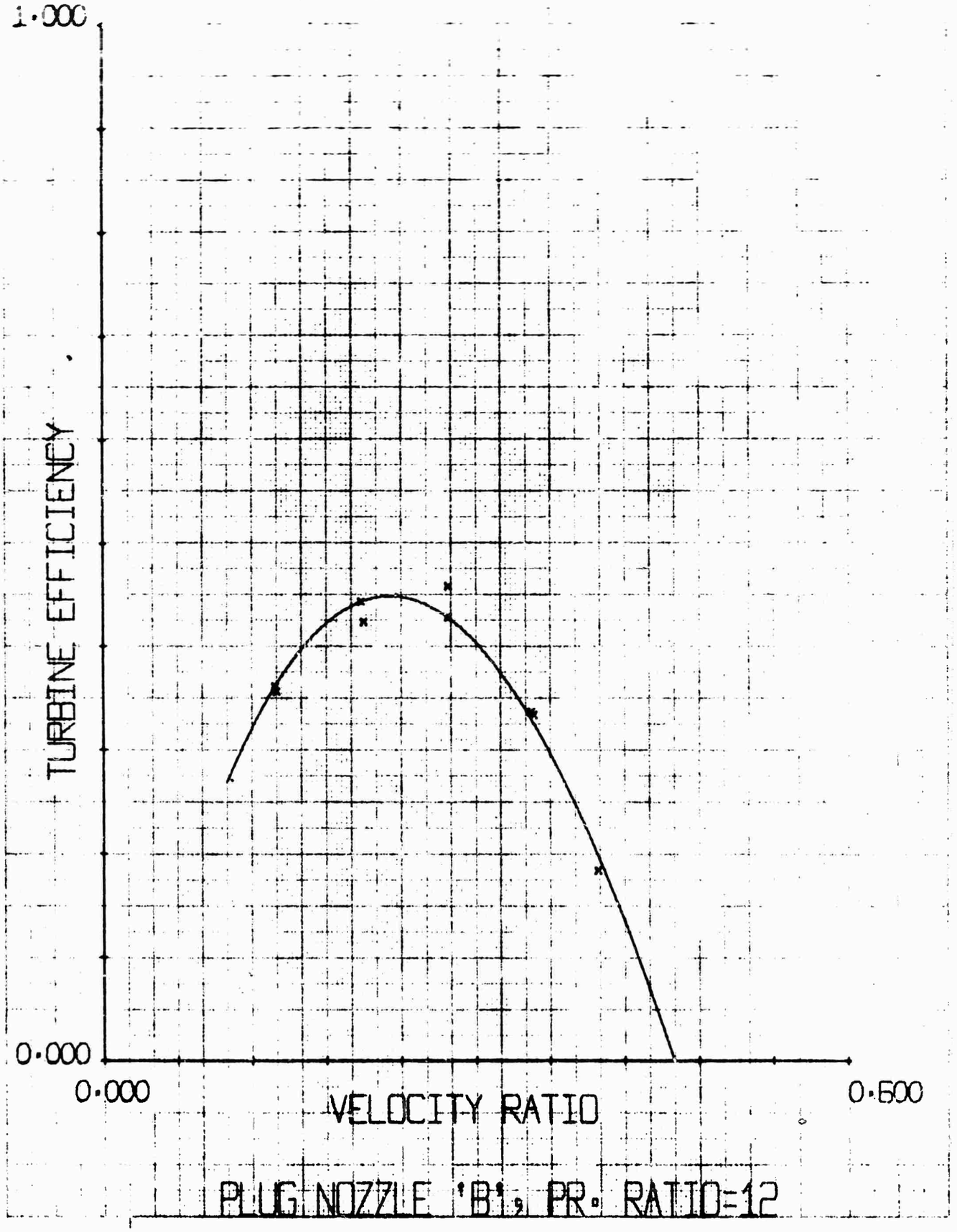
PLUG NOZZLE 'B', PR. RATIO=2·5

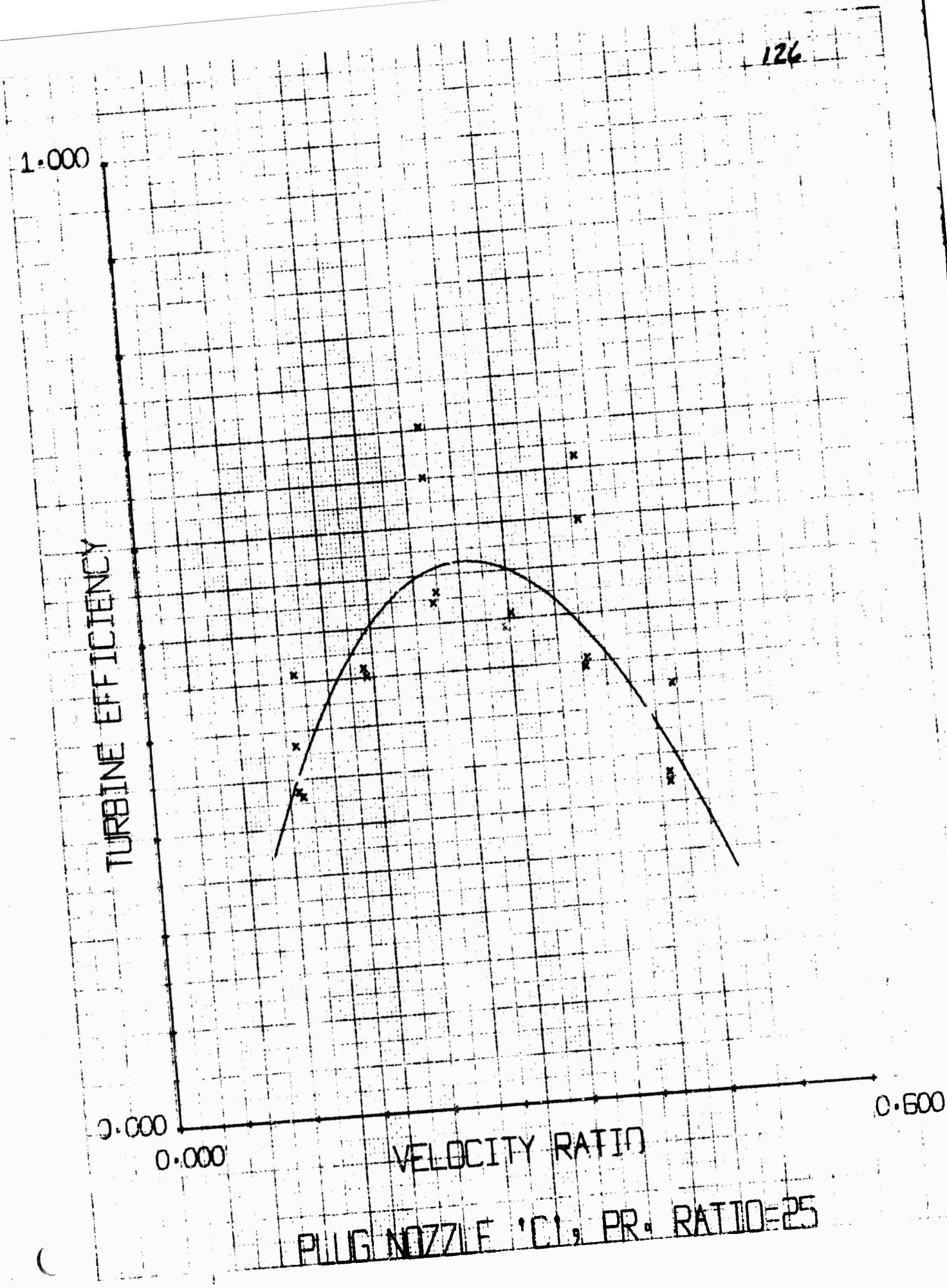

1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
PLUG NOZZLE 'B', PR. RATIO=20

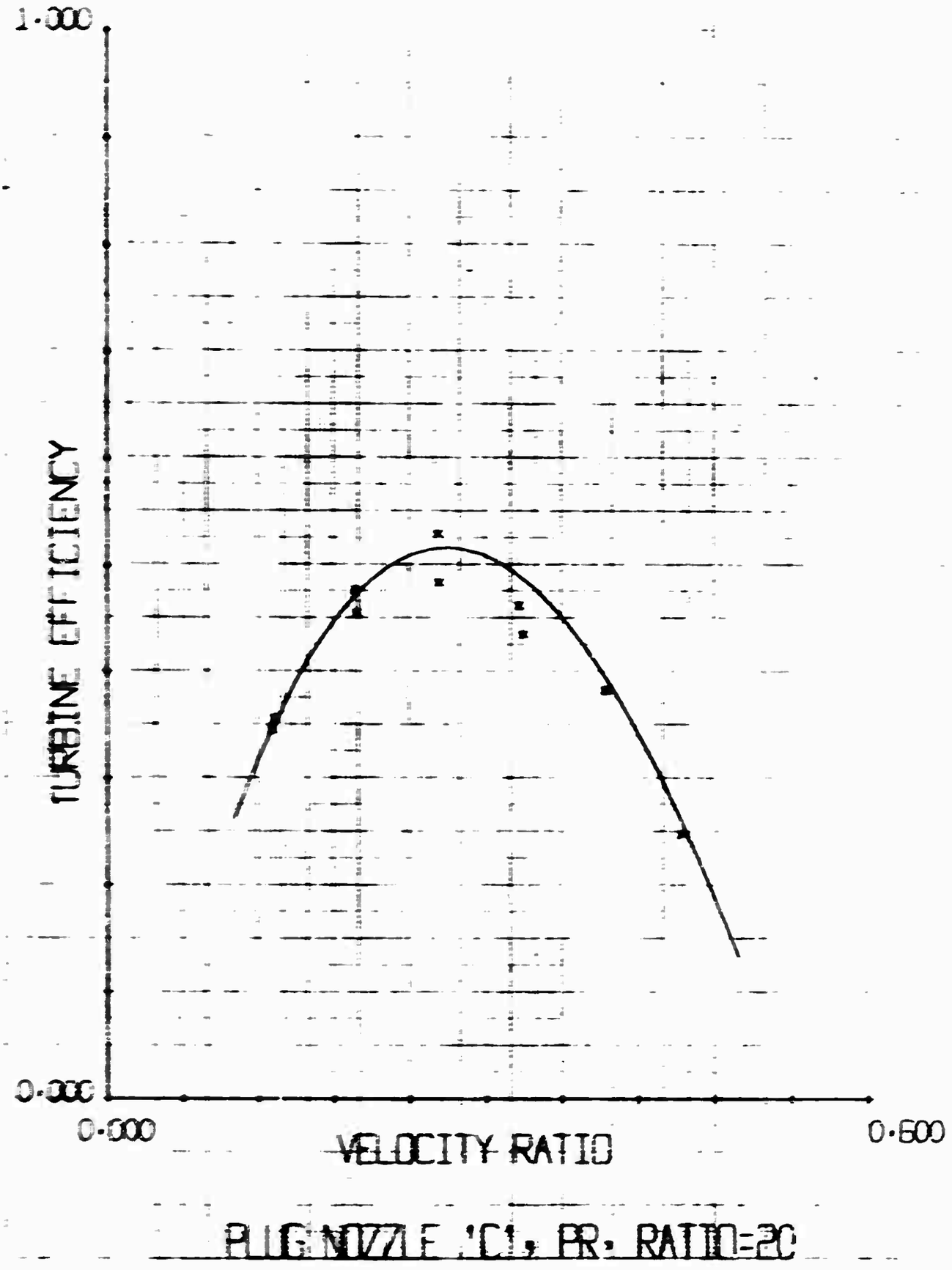


PLUG NOZZLE 'B', PR. RATIO=17

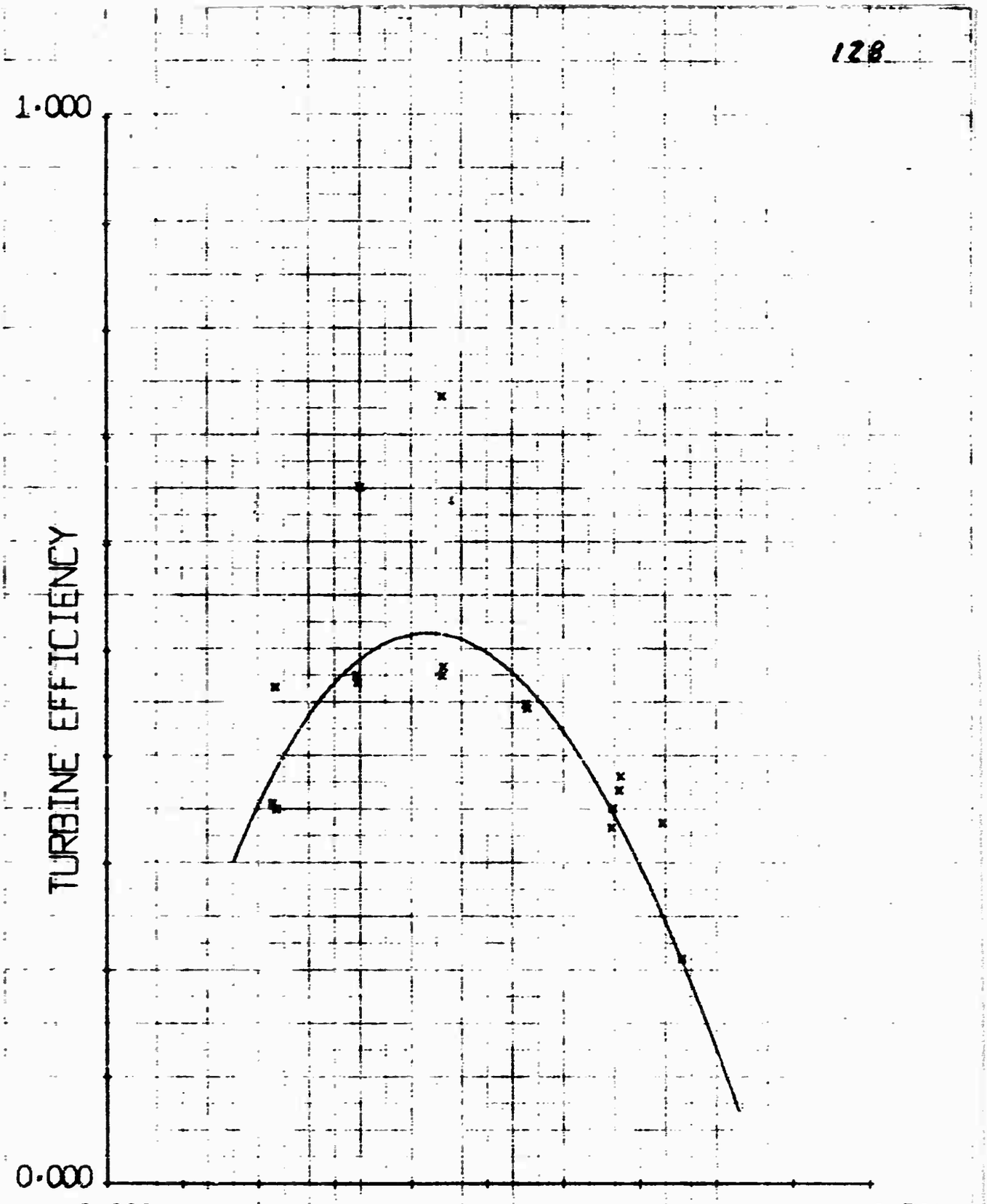

1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
PLUG NOZZLE 'B', PR. RATIO=15


1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
PLUG NOZZLE 'B', PR. RATIO=12

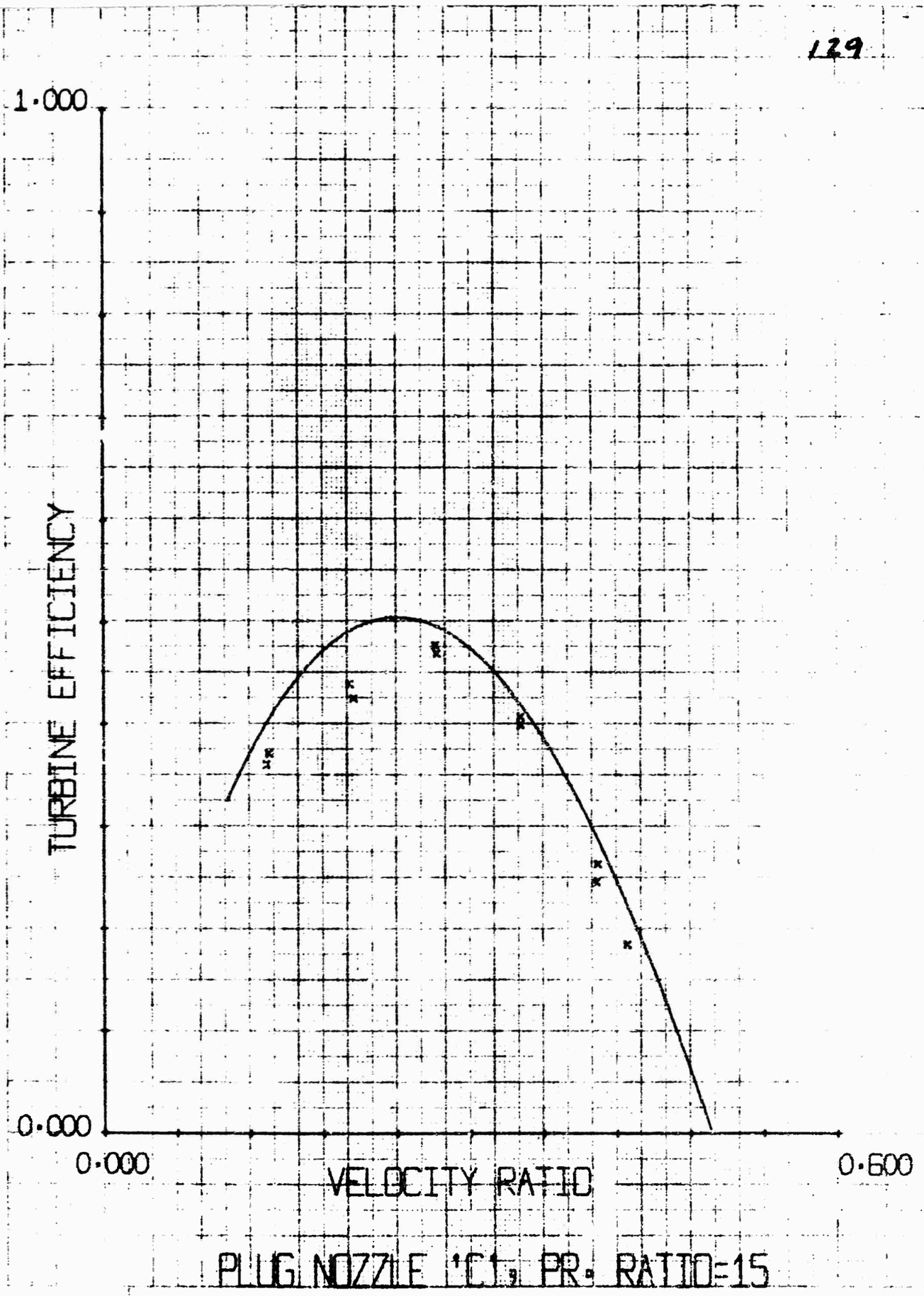

1.000
TURBINE EFFICIENCY
0.000
0.000
VELOCITY RATIO
0.600
PLUG NOZZLE 'C', PR. RATIO=25



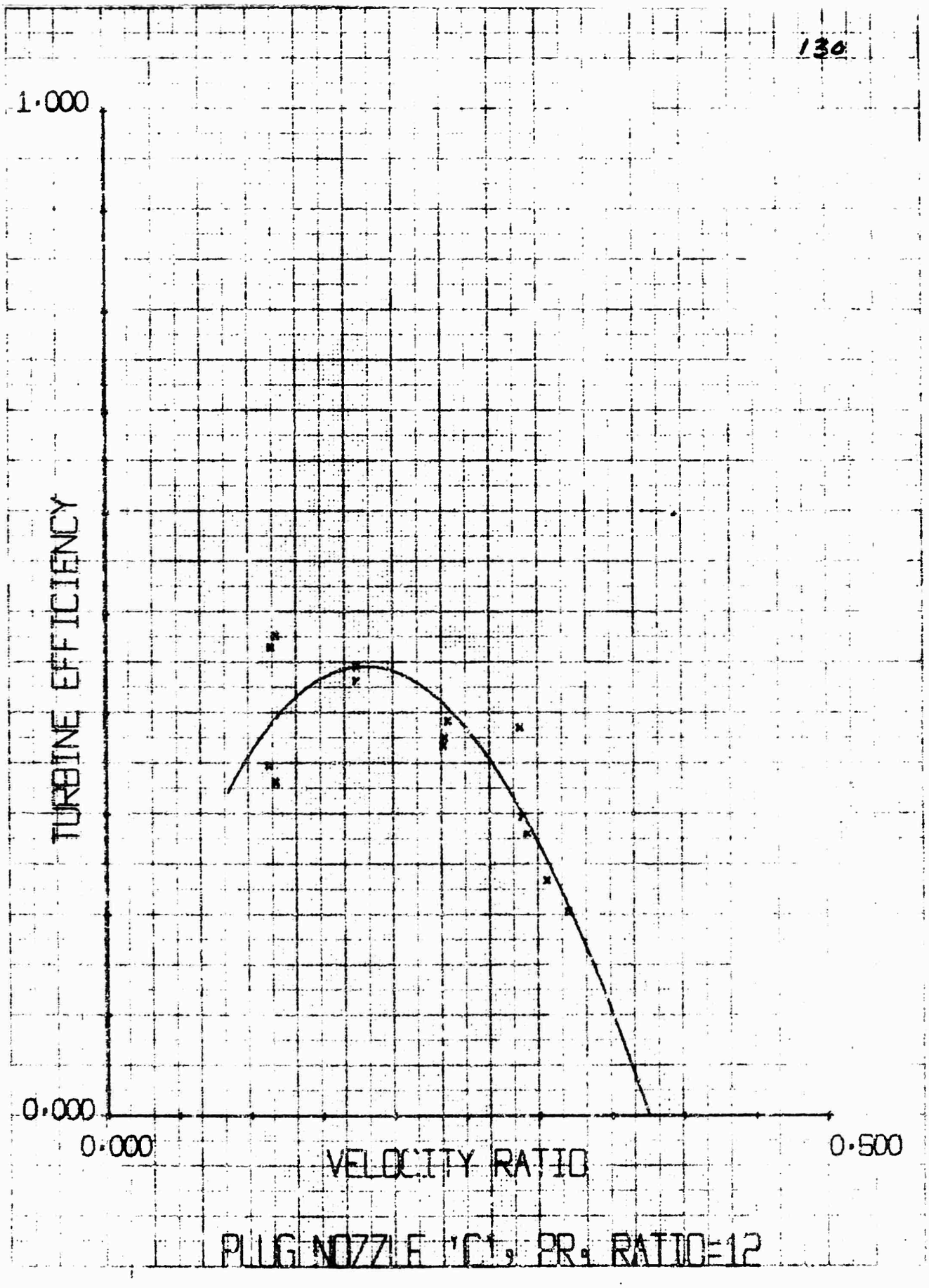
PLUG NOZZLE, PR. RATIO=2.0



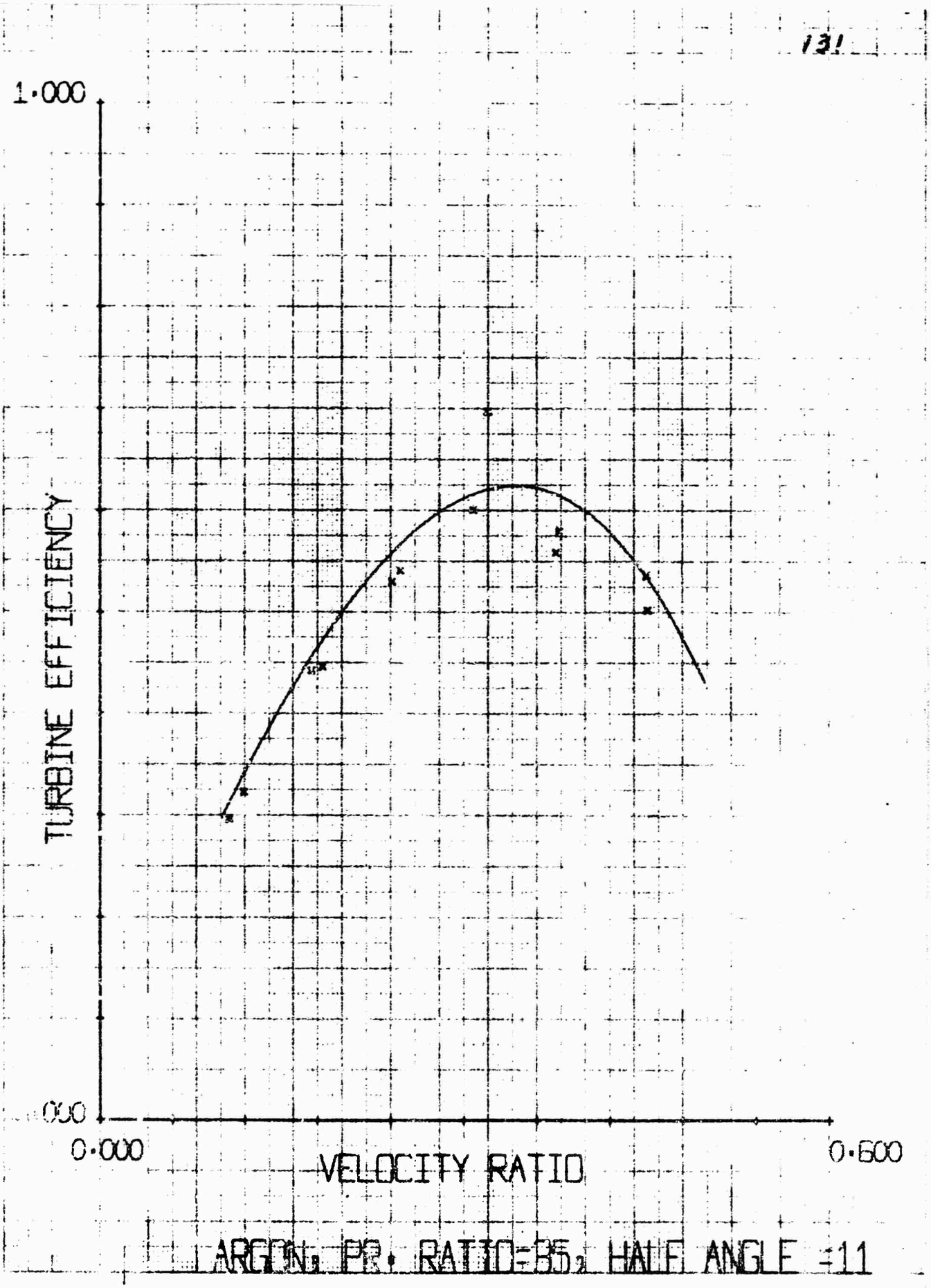
PLUG NOZZLE 'C', PR. RATIO=17



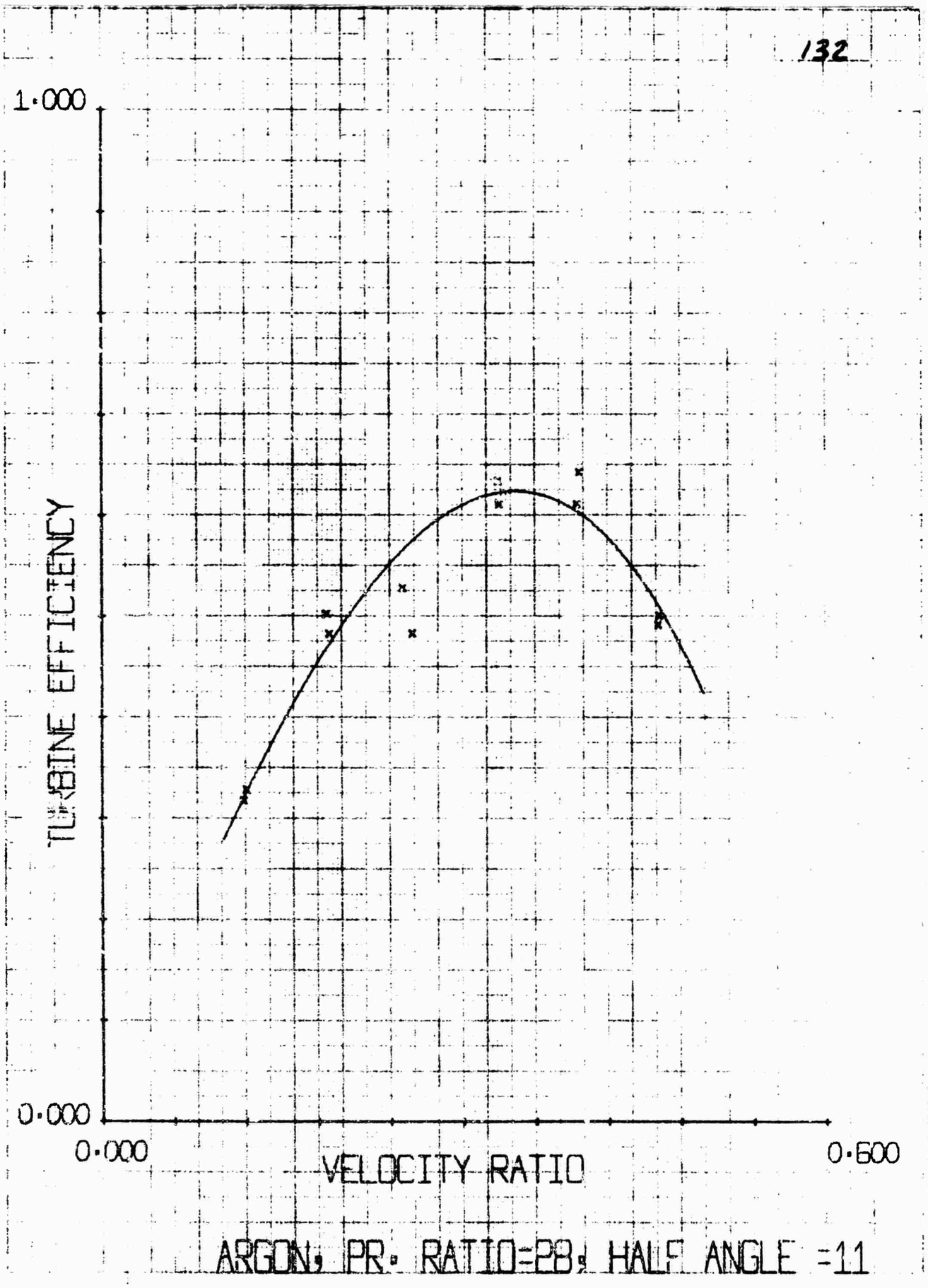
PLUG NOZZLE 'C1', PR. RATIO=15

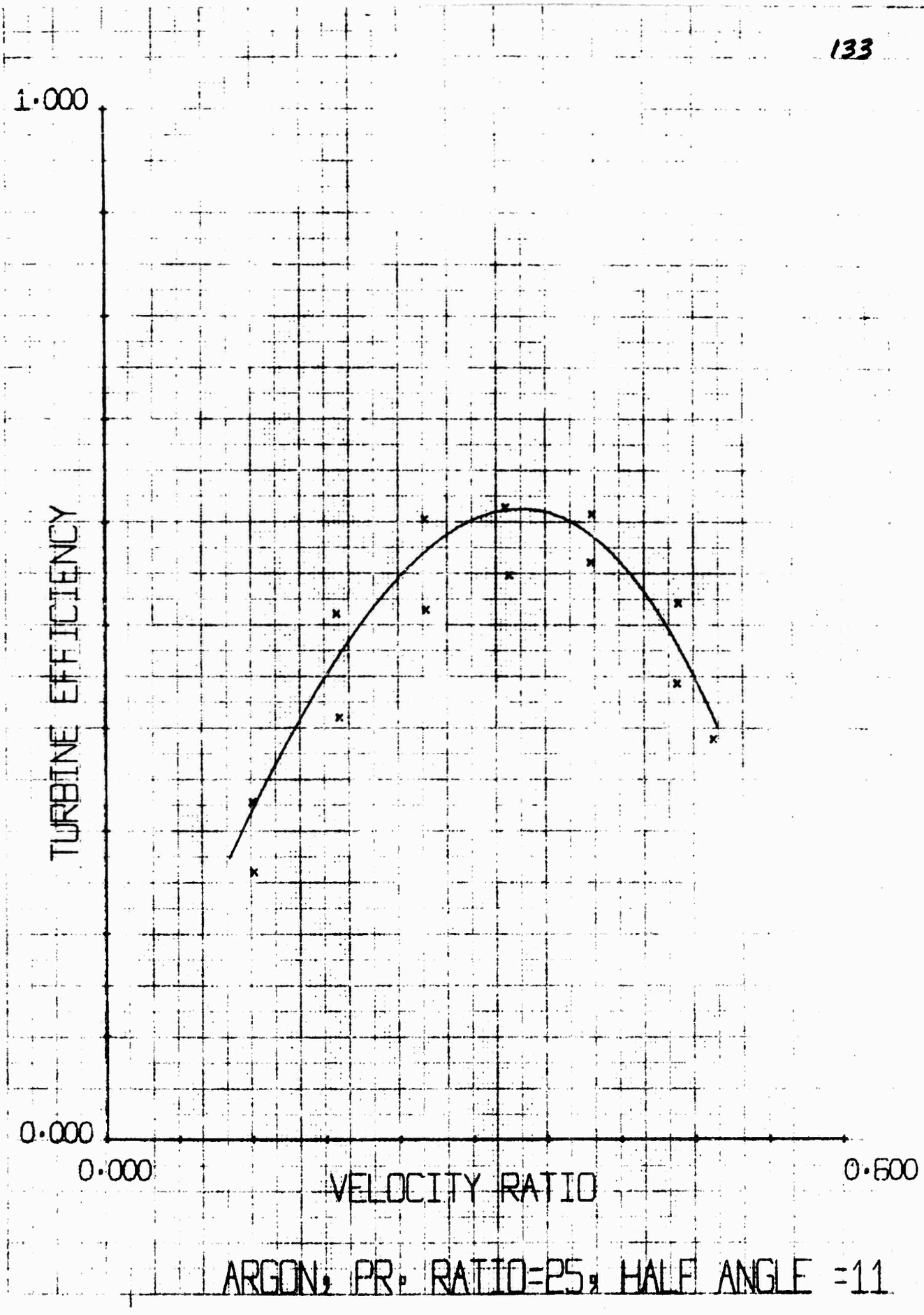


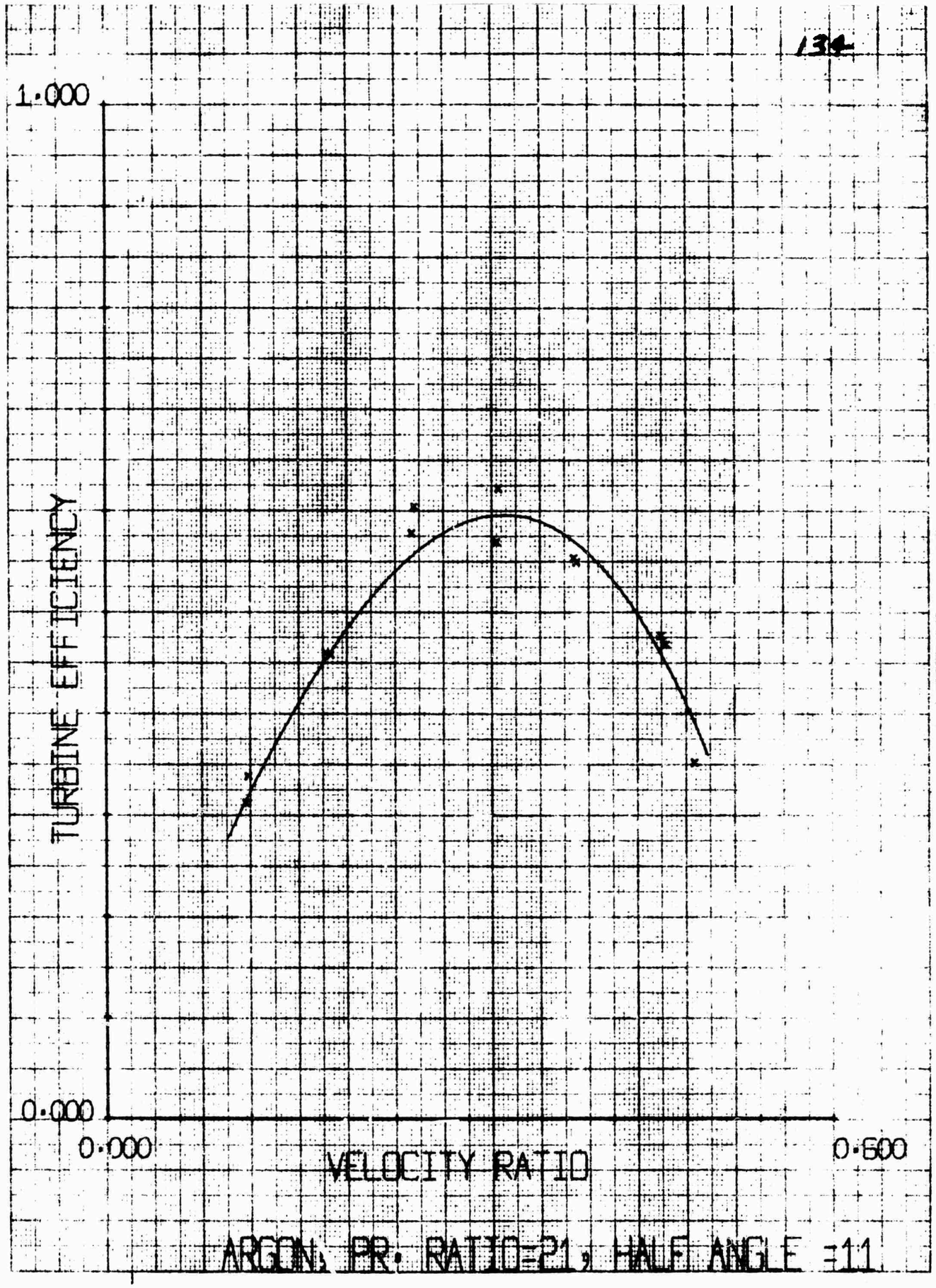
PLUG NOZZLE 'C', PR. RATIO=12

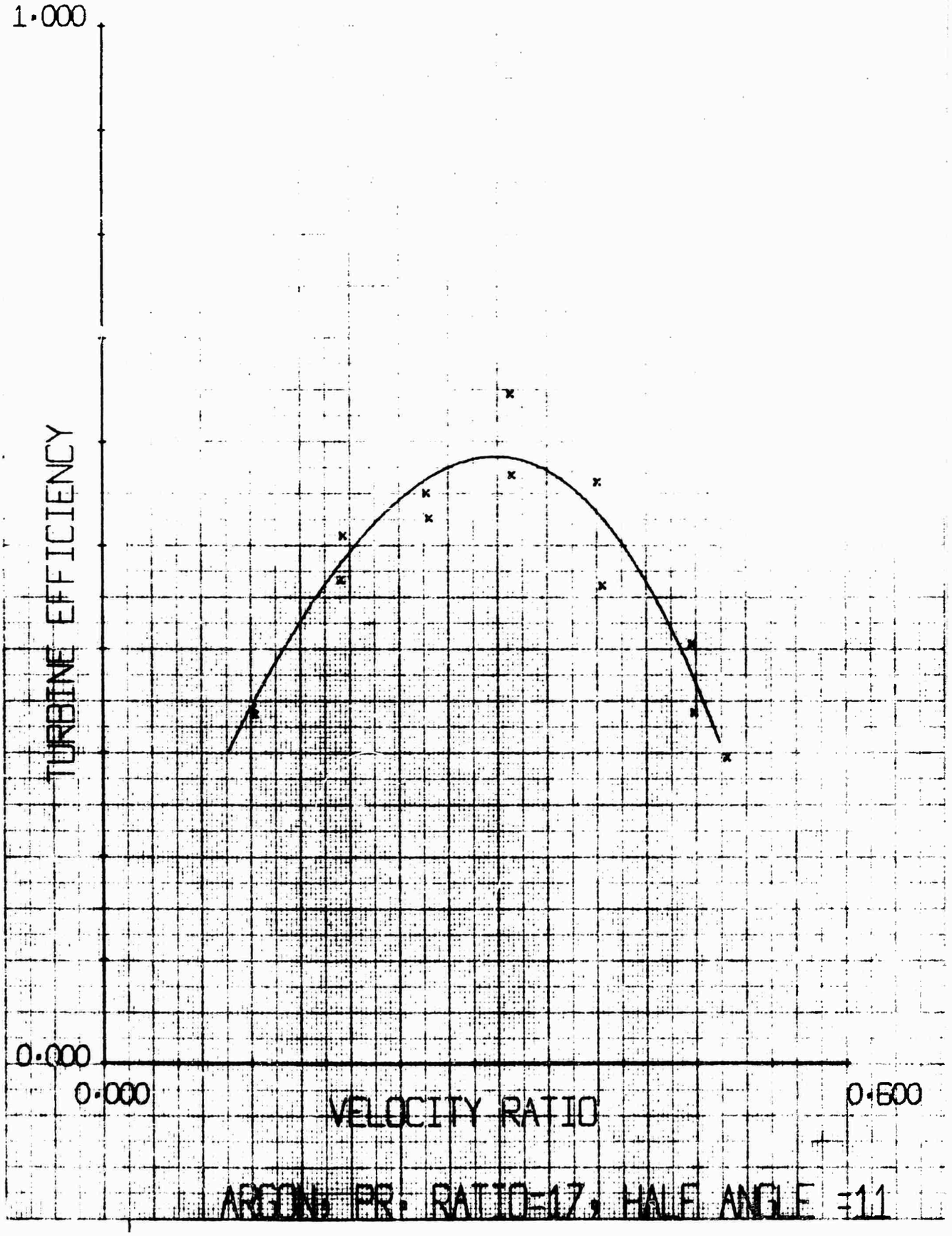


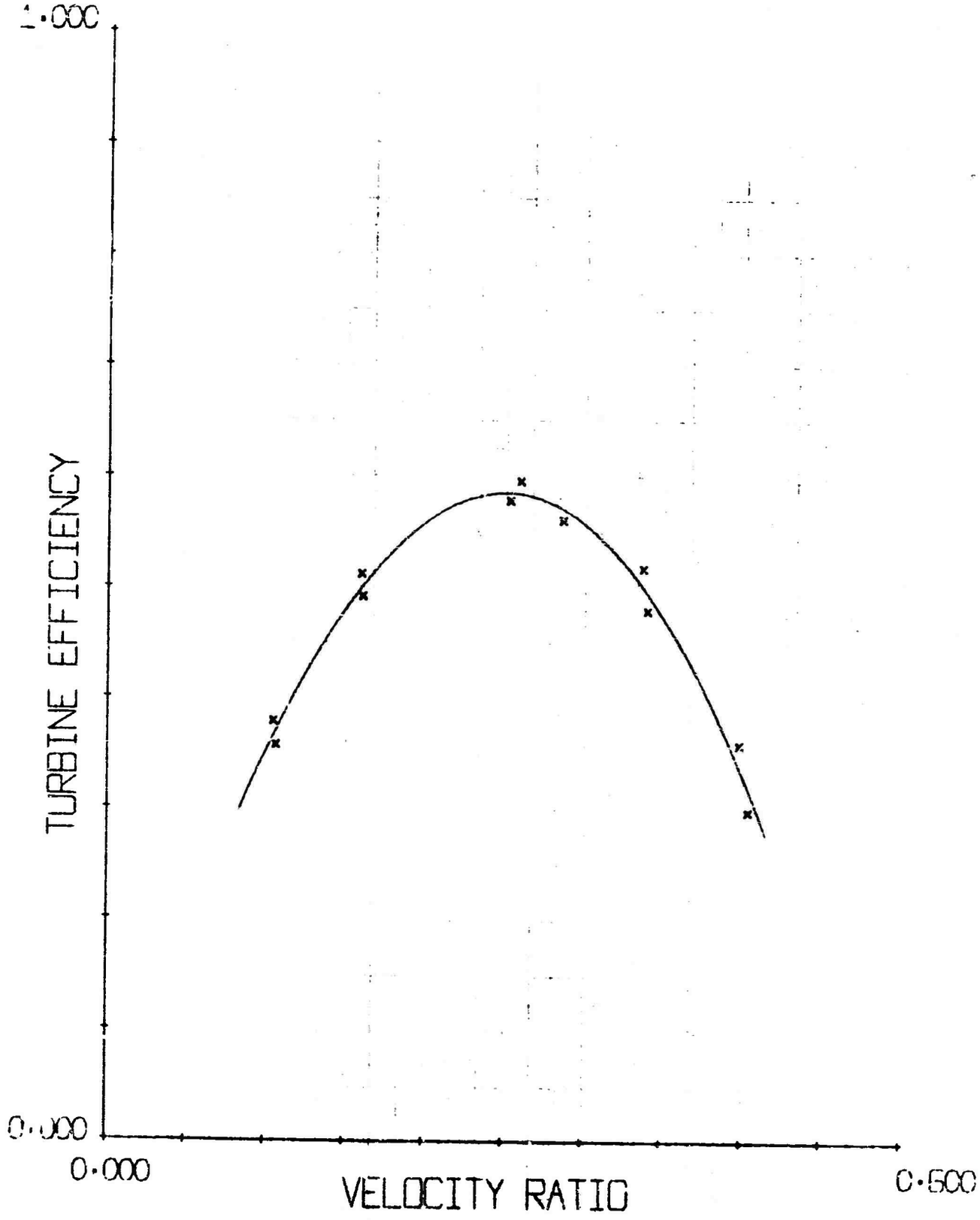
ARGON, PR. RATIO=55, HALF ANGLE =11


1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
ARGON, PR. RATIO=2B; HALF ANGLE =11


1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
ARGON, PR. RATIO=2·5, HALF ANGLE =11


1.000
TURBINE EFFICIENCY
0.000
0.000
VELOCITY RATIO
0.600
ARGON, PR. RATIO=21, HALF ANGLE =11


1·000
TURBINE EFFICIENCY
0·000
0·000
VELOCITY RATIO
0·600
ARGON, PR. RATIO=17, HALF ANGLE =11



FREON, PR. RATIO=13, HALF ANGLE=11

APPENDIX B

LIST OF DATA POINTS

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.515	0.190000	0.464000	0.090819
24.660003		0.463091	0.195731
2.515	0.256000	0.519000	1.207018
24.660003		0.531070	2.325661
2.515	0.322000	0.563000	1.095366
24.660003		0.552046	1.945589
2.515	0.391000	0.504000	2.280843
24.660003		0.526808	4.525483
2.515	0.440000	0.492000	1.063806
24.660003		0.481361	2.162207
2.515	0.196000	0.496000	2.471137
23.680000		0.471288	4.982131
2.515	0.262000	0.538000	0.312376
23.680000		0.534876	0.580624
2.515	0.326000	0.549000	0.287044
23.680000		0.551870	0.522849
2.515	0.396000	0.548000	2.480865
23.560001		0.523191	4.527125
2.515	0.439000	0.476000	0.650864
23.560001		0.482508	1.367363

THE NUMBER OF DATA POINTS IS 10
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.194
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.313

U.S.N.P. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.515	0.204000	0.461000	1.116198
19.470001		0.449838	2.421255
2.515	0.271000	0.519000	0.609932
19.630001		0.525099	1.175302
2.515	0.332000	0.565000	2.113438
19.310001		0.543865	3.740598
2.515	0.404000	0.516000	0.560343
19.240001		0.510396	1.085936
2.515	0.440000	0.460000	1.293379
19.180000		0.472933	2.811694

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.138
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.246

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.515	0.192000	0.471000	0.381523
16.910003		0.467184	0.810028
2.515	0.263000	0.534000	0.248885
16.910003		0.536488	0.466077
2.515	0.331000	0.531000	0.164985
16.810001		0.529350	0.310707
2.515	0.394000	0.502000	2.049082
16.910003		0.481509	4.081837
2.515	0.450000	0.414000	0.885683
16.910003		0.422856	2.139331

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.746
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 1.561

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.515	0.203000	0.516000	5.277378
14.800001		0.463226	10.227478
2.515	0.270000	0.521000	0.168738
14.800001		0.522687	0.323970
2.515	0.335000	0.453000	6.419540
14.920000		0.517195	14.171171
2.515	0.405000	0.450000	0.410604
15.030000		0.445894	0.912454
2.515	0.444000	0.406000	2.761865
14.800001		0.378381	6.802623

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.007
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 6.487

J.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION / PRESSURE RATIO	VELOCITY RATIO	EMPIRICAL DATA POINT / SMOOTHED DATA POINT	SCATTER PER CENT EFF. / SCATTER PER CENT VAL.
2.515 / 11.820001	0.207000	0.472000 / 0.445499	2.650094 / 5.614606
2.515 / 11.820001	0.236000	0.479000 / 0.516038	3.703821 / 7.732402
2.515 / 11.820001	0.346000	0.449000 / 0.481361	3.238106 / 7.211818
2.515 / 11.820001	0.415000	0.362000 / 0.361551	0.044900 / 0.124033

THE NUMBER OF DATA POINTS IS 4
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.409
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.170

D.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.513	0.124000	0.359000	0.998467
24.730003		0.366984	2.761246
2.513	0.153000	0.423000	1.256388
24.730003		0.425573	2.970185
2.513	0.189000	0.480000	1.560145
24.730003		0.503601	3.197020
2.513	0.219000	0.541000	0.724554
24.730003		0.540245	1.339287
2.513	0.251000	0.568000	1.610732
24.730003		0.584107	2.835796
2.513	0.288000	0.596000	1.485979
24.730003		0.610859	2.493254
2.513	0.319000	0.624000	0.252664
24.730003		0.621473	0.404910
2.513	0.348000	0.610000	1.193952
24.730003		0.621939	1.957299
2.513	0.384000	0.606000	0.416278
24.730003		0.610162	0.686928
2.513	0.418000	0.559000	2.786291
24.730003		0.536862	4.984429

THE NUMBER OF DATA POINTS IS 10
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.228
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.365

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION / PRESSURE RATIO	VELOCITY RATIO	EMPIRICAL DATA POINT / SMOOTHED DATA POINT	SCATTER PER CENT EFF. / SCATTER PER CENT VAL.
2.513 / 19.780002	0.129000	0.378000 / 0.382604	0.460422 / 1.218047
2.513 / 19.780002	0.161000	0.442000 / 0.458203	1.620376 / 3.666009
2.513 / 19.780002	0.196000	0.515000 / 0.523959	0.895905 / 1.739622
2.513 / 19.780002	0.231000	0.593000 / 0.572729	2.027011 / 3.418231
2.513 / 19.780002	0.262000	0.589000 / 0.602326	1.332617 / 2.262507
2.513 / 19.780002	0.293000	0.586000 / 0.619672	3.367209 / 5.746091
2.513 / 19.780002	0.331000	0.644000 / 0.624962	1.903784 / 2.956187
2.513 / 19.780002	0.363000	0.588000 / 0.616409	2.840948 / 4.831545
2.513 / 19.780002	0.395000	0.573000 / 0.596554	2.355421 / 4.110682
2.513 / 19.780002	0.431000	0.582000 / 0.561396	2.060306 / 3.540045
2.513 / 19.780002	0.465000	0.511000 / 0.516414	0.541424 / 1.059540

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.764
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.140

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.513	0.136000	0.432000	2.987462
16.490001		0.402125	6.915422
2.513	0.171000	0.462000	3.510731
16.490001		0.497107	7.598986
2.513	0.200000	0.541000	1.275992
16.490001		0.553759	2.358582
2.513	0.234000	0.566000	3.162575
16.490001		0.597625	5.587588
2.513	0.269000	0.656000	3.538561
16.490001		0.620614	5.394148
2.513	0.304000	0.636000	1.137769
16.490001		0.624622	1.788945
2.513	0.337000	0.612000	0.220036
16.490001		0.614200	0.359536
2.513	0.371000	0.587000	0.524652
16.490001		0.592246	0.893785
2.513	0.405000	0.531000	3.112650
16.490001		0.562126	5.861866
2.513	0.438000	0.514000	1.415682
16.490001		0.528156	2.754245

THE NUMBER OF DATA POINTS IS 10
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.088
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.951

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.513	0.132000	0.404000	2.205318
14.960001		0.426053	5.458708
2.513	0.170000	0.493000	1.667517
14.960001		0.509675	3.382388
2.513	0.203000	0.536000	2.881014
14.840000		0.564810	5.375028
2.513	0.240000	0.612000	0.408184
14.840000		0.607918	0.666968
2.513	0.260000	0.619000	0.421035
14.960001		0.623210	0.680186
2.513	0.273000	0.650000	1.979816
14.960001		0.630201	3.045871
2.513	0.307000	0.636000	0.174152
14.960001		0.637741	0.273825
2.513	0.339000	0.625000	0.600087
14.960001		0.631000	0.960140
2.513	0.377000	0.596000	1.017964
14.960001		0.606179	1.707993
2.513	0.406000	0.571000	0.437700
14.960001		0.575377	0.766551
2.513	0.449000	0.506000	0.555145
14.960001		0.511551	1.097126

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.122
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.128

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION / PRESSURE RATIO	VELOCITY RATIO	EMPIRICAL DATA POINT / SMOOTHED DATA POINT	SCATTER PER CENT EFF. / SCATTER PER CENT VAL.
2.513 / 11.970001	0.138000	0.405000 / 0.394147	1.085239 / 2.679604
2.513 / 11.970001	0.172000	0.487000 / 0.491073	0.407379 / 0.836508
2.513 / 12.070001	0.209000	0.568000 / 0.563251	0.474858 / 0.836018
2.513 / 12.070001	0.249000	0.594000 / 0.605506	1.150679 / 1.937171
2.513 / 12.070001	0.278000	0.643000 / 0.614919	2.808022 / 4.367065
2.513 / 12.070001	0.317000	0.627000 / 0.602187	2.481270 / 3.957368
2.513 / 12.070001	0.351000	0.569000 / 0.569738	0.073862 / 0.129810
2.513 / 12.070001	0.386000	0.556000 / 0.516048	3.795147 / 6.825804
2.513 / 12.070001	0.428000	0.501000 / 0.434959	6.604076 / 13.181789
2.513 / 12.070001	0.462000	0.362000 / 0.353602	0.839769 / 2.319806

THE NUMBER OF DATA POINTS IS 10
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.972
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.707

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.511	0.127000	0.370000	0.371420
25.000003		0.366285	1.003839
2.511	0.188000	0.541000	3.841484
25.000003		0.502585	7.100710
2.511	0.157000	0.453000	1.355666
25.000003		0.439443	2.992640
2.511	0.222000	0.583000	2.537203
25.080001		0.557628	4.351978
2.511	0.255000	0.584000	1.319372
24.870002		0.597193	2.259200
2.511	0.281000	0.632000	1.301360
25.210002		0.618986	2.059114
2.511	0.317000	0.660000	2.413666
23.250003		0.635863	3.657070
2.511	0.353000	0.598000	3.971648
22.730003		0.637716	6.641553
2.511	0.288000	0.634000	1.053345
24.680000		0.623466	1.661427
2.511	0.322000	0.639000	0.199115
24.580001		0.637008	0.311604
2.511	0.358000	0.636000	0.081145
24.080001		0.636811	0.127587

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.511	0.393000	0.683000	5.488360
23.800003		0.628116	8.035667
2.511	0.418000	0.626000	2.150857
23.600002		0.604491	3.435874

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.006
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.356

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.511	0.387000	0.652000	3.877270
22.370002		0.613227	5.946734
2.511	0.424000	0.631000	5.231548
22.200000		0.578684	8.290885
2.511	0.446000	0.574000	2.232778
21.960002		0.551672	3.889858
2.511	0.132000	0.436000	2.201760
19.660003		0.413982	5.049908
2.511	0.165000	0.460000	2.814639
19.730003		0.488146	6.118780
2.511	0.198000	0.554000	0.723362
19.830001		0.546766	1.305707
2.511	0.233000	0.648000	5.536938
19.900001		0.592630	8.544658
2.511	0.264000	0.600000	1.980567
19.830001		0.619805	3.300945
2.511	0.295000	0.628000	0.687360
19.830001		0.634873	1.094523
2.511	0.331000	0.672000	3.415453
19.630001		0.637845	5.082521
2.511	0.394000	0.589000	1.877045
19.630001		0.607770	3.186834

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.511	0.432000	0.587000	1.759374
19.630001		0.569406	2.997231
2.511	0.462000	0.504000	2.512324
19.250003		0.529123	4.984770

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.680
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.599

D.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.511	0.134000	0.363000	2.336228
17.140003		0.386362	6.435890
2.511	0.167000	0.474000	0.721204
17.050003		0.481212	1.521528
2.511	0.201000	0.574000	2.287066
17.050003		0.551129	3.984436
2.511	0.234000	0.668000	7.295239
17.000003		0.595047	10.921016
2.511	0.267000	0.588000	3.037953
17.140003		0.618379	5.166588
2.511	0.301000	0.588000	3.602445
16.860000		0.624024	6.126608
2.511	0.332000	0.644000	2.837849
17.000003		0.615621	4.406598
2.511	0.367000	0.564000	2.978086
16.810001		0.593780	5.280296
2.511	0.402000	0.617000	5.475259
16.870002		0.562247	8.874002
2.511	0.436000	0.508000	1.769340
16.750003		0.525693	3.482953
2.511	0.471000	0.536000	5.057186
16.660003		0.485428	9.435049

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.399
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.966

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.511	0.135000	0.446000	2.376252
14.870000		0.422237	5.327919
2.511	0.168000	0.480000	0.924533
14.870000		0.489245	1.926111
2.511	0.203000	0.545000	0.108611
15.230001		0.543913	0.199287
2.511	0.238000	0.627000	4.474688
15.150001		0.582253	7.136663
2.511	0.274000	0.598000	0.724959
15.030000		0.605249	1.212306
2.511	0.305000	0.569000	4.315960
15.110000		0.612139	7.585168
2.511	0.337000	0.627000	1.978123
14.920000		0.607218	3.154901
2.511	0.376000	0.660000	7.476736
15.000001		0.585232	11.328388
2.511	0.410000	0.577000	2.467048
15.000001		0.552329	4.275648
2.511	0.439000	0.530000	1.543593
15.000001		0.514564	2.912440
2.511	0.477000	0.421000	3.112632
15.070001		0.452126	7.393425

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.682
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.768

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
2.511	0.139000	0.365000	2.790737
12.000001		0.392907	7.645856
2.511	0.175000	0.467000	1.129633
11.940000		0.478296	2.418915
2.511	0.211000	0.565000	3.091228
12.000001		0.534087	5.471200
2.511	0.237000	0.503000	5.448008
12.100000		0.557480	10.831031
2.511	0.279000	0.567000	0.115907
12.040000		0.568159	0.204421
2.511	0.318000	0.538000	1.331329
11.900001		0.551313	2.474590
2.511	0.354000	0.519000	0.309634
11.900001		0.515903	0.596597
2.511	0.385000	0.468000	0.423467
11.900001		0.472234	0.904844
2.511	0.421000	0.289000	11.958862
12.000001		0.408588	41.380149
2.511	0.458000	0.302000	2.937353
11.940000		0.331373	9.726335
2.511	0.492000	0.230000	2.233228
11.950000		0.252332	9.709686

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.888
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.305

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.59	0.191000	0.449000	3.536767
25.370002		0.484367	7.876987
2.59	0.256000	0.556000	2.023733
24.850002		0.576237	3.639807
2.59	0.318000	0.617000	0.395596
25.080001		0.613044	0.641160
2.59	0.385000	0.542000	5.779684
25.080001		0.599736	10.663623
2.59	0.450000	0.528000	0.905478
25.080001		0.537054	1.714920

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.528
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.907

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.59	0.197000	0.540000	1.697480
20.230003		0.523025	3.143483
2.59	0.263000	0.580000	1.301777
20.230003		0.593017	2.244444
2.59	0.328000	0.565000	4.370964
20.400001		0.608709	7.736219
2.59	0.396000	0.559000	1.465440
20.400001		0.573654	2.621538
2.59	0.434000	0.513000	2.008426
20.400001		0.533084	3.915061

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.168
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.932

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.59	0.199000	0.524000	1.095748
16.900001		0.513042	2.091122
2.59	0.265000	0.584000	0.353264
16.900001		0.580467	0.604905
2.59	0.332000	0.565000	0.892090
16.670002		0.573920	1.578922
2.59	0.400000	0.480000	3.543263
16.850002		0.515432	7.381799
2.59	0.443000	0.437000	2.619391
16.530002		0.463193	5.994031

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.700
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.530

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.59	0.205000	0.475000	2.501100
14.550001		0.500011	5.265474
2.59	0.271000	0.543000	0.142324
14.420000		0.544423	0.262106
2.59	0.340000	0.557000	1.869201
14.240001		0.538308	3.355838
2.59	0.413000	0.449000	2.910608
14.300001		0.478106	6.482423
2.59	0.451000	0.388000	3.857440
14.050001		0.426574	9.941856

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.256
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.061

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.59	0.210000	0.512000	3.137570
11.340000		0.480624	6.128067
2.59	0.279000	0.534000	3.261185
11.340000		0.501388	6.107089
2.59	0.354000	0.422000	2.433574
11.230001		0.446335	5.766763
2.59	0.418000	0.434000	8.092798
12.230001		0.353072	18.646999
2.59	0.443000	0.354000	4.545605
12.140001		0.308543	12.840692

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 4.294
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 9.897

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.57	0.196000	0.472000	1.077711
24.870002		0.461222	2.283288
2.57	0.251000	0.530000	0.471222
25.910003		0.534712	0.889099
2.57	0.318000	0.572000	0.339651
25.700000		0.568603	0.593795
2.57	0.378000	0.568000	1.862168
25.290000		0.549378	3.278465
2.57	0.449000	0.471000	0.184631
25.290000		0.469153	0.391998

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.787
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 1.487

D.M.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT E.V.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.57	0.195000	0.461000	2.000297
20.360000		0.481803	4.512577
2.57	0.263000	0.563000	1.296854
20.400001		0.550431	2.232432
2.57	0.328600	0.585000	2.257013
20.230003		0.562429	3.858143
2.57	0.397000	0.529000	0.589311
20.560001		0.523106	1.114009
2.57	0.461000	0.442000	0.144150
20.560001		0.463461	0.320657

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.265
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.405

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.57	0.200000	0.493000	0.445854
17.480003		0.497458	0.904370
2.57	0.270000	0.552000	0.493061
17.620002		0.556930	0.893227
2.57	0.334000	0.548000	1.014173
17.480003		0.537858	1.850690
2.57	0.846000	0.483000	0.051182
17.620002		0.483511	0.105967
2.57	0.470000	0.380000	1.446962
17.620002		0.365530	3.807796

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.690
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 1.512

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.57	0.203000	0.542000	1.803934
15.300001		0.523960	3.328293
2.57	0.274000	0.544000	0.394892
15.620000		0.547948	0.725905
2.57	0.341000	0.489000	3.472388
15.420000		0.523723	7.100998
2.57	0.409000	0.472000	1.523089
15.420000		0.456769	3.226884
2.57	0.478000	0.374000	2.455646
15.420000		0.349443	6.565898

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.929
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.189

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
2.57	0.208000	0.543000	1.122284
12.210001		0.531777	2.066821
2.57	0.279000	0.521000	1.877308
12.340000		0.539773	3.603279
2.57	0.348000	0.464000	2.495688
12.340000		0.488956	5.378633
2.57	0.423000	0.376000	1.437229
12.360000		0.390372	3.822417
2.57	0.458000	0.341000	0.551337
12.210001		0.335486	1.616824

THE NUMBER OF DATA POINTS IS 5
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.496
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.297

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.112000	0.286000	0.027829
208.000030		0.285721	0.097305
4.15	0.167000	0.400000	0.374382
208.000030		0.403743	0.935956
4.15	0.221000	0.480000	0.840860
208.000030		0.488408	1.751793
4.15	0.111000	0.291000	0.774049
209.000030		0.283259	2.659965
4.15	0.167000	0.393000	1.074385
209.000030		0.403743	2.733806
4.15	0.224000	0.481000	1.126533
208.000030		0.492265	2.342066
4.15	0.289000	0.564000	0.836074
208.000030		0.555639	1.482401
4.15	0.339000	0.585000	0.475204
208.000030		0.580247	0.812314
4.15	0.392000	0.604000	1.770770
217.000030		0.586292	2.931739
4.15	0.421000	0.582000	0.014567
217.000030		0.581854	0.025029
4.15	0.397000	0.580000	0.589645
216.000030		0.585898	1.0.0629

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.342000	0.582000	0.088405
216.000030		0.581115	0.151899
4.15	0.284000	0.525000	2.707541
216.000030		0.552075	5.157221
4.15	0.230000	0.497000	0.272238
216.000030		0.499722	0.547763
4.15	0.175000	0.447000	2.883470
216.000030		0.418165	6.450716
4.15	0.113000	0.289000	0.082784
216.000030		0.288172	0.286452

THE NUMBER OF DATA POINTS IS 16
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.871
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 1.836

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.116000	0.301000	0.314468
141.400024		0.304144	1.044744
4.15	0.175000	0.441000	2.061587
141.400024		0.420384	4.674801
4.15	0.229000	0.487000	0.741279
136.500030		0.494412	1.522133
4.15	0.290000	0.526000	1.910031
140.600018		0.545100	3.631238
4.15	0.349000	0.550000	1.518821
140.800018		0.565188	2.761494
4.15	0.407000	0.567000	0.558006
132.500030		0.561419	0.984139
4.15	0.350000	0.573000	0.769126
136.500030		0.565306	1.342280
4.15	0.292000	0.580000	3.377753
140.800018		0.546222	5.823765
4.15	0.231000	0.453000	4.360563
135.900024		0.496605	9.625967
4.15	0.177000	0.461000	3.734463
135.900024		0.423655	8.100790
4.15	0.119000	0.295000	1.601076
140.100006		0.311010	5.427377

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.904
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.085

D.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.119000	0.296000	0.620871
95.400009		0.302208	2.097560
4.15	0.173000	0.319000	8.012140
97.500015		0.399121	25.116428
4.15	0.234000	0.532000	5.190057
95.400009		0.460049	9.765146
4.15	0.297000	0.547000	2.408433
95.000015		0.522915	4.402986
4.15	0.356000	0.545000	2.790964
93.000015		0.517090	5.121035
4.15	0.398000	0.465000	1.638734
93.000015		0.481387	3.524183
4.15	0.353000	0.500000	1.858783
94.600006		0.518587	3.717566
4.15	0.297000	0.503000	1.991570
93.400009		0.522915	3.959384
4.15	0.234000	0.479000	0.104939
94.600006		0.480049	0.219087
4.15	0.175000	0.404000	0.170276
94.600006		0.402297	0.421481
4.15	0.118000	0.337000	3.676875
93.200012		0.300731	10.918625

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.588
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.295

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.120000	0.294000	1.473248
47.200004		0.308732	5.011048
4.15	0.190000	0.400000	0.446838
47.100006		0.395531	1.117095
4.15	0.244000	0.391000	1.253372
47.000007		0.403533	3.205556
4.15	0.309000	0.357000	0.441426
46.900001		0.361414	1.236467
4.15	0.370000	0.280000	0.594043
46.900001		0.285940	2.121585
4.15	0.348000	0.316000	0.017482
46.900001		0.316174	0.055322
4.15	0.305000	0.361000	0.432503
46.800003		0.365325	1.198070
4.15	0.245000	0.426000	2.272552
46.300003		0.403274	5.334630
4.15	0.186000	0.418000	2.493227
46.300003		0.393067	5.964657
4.15	0.122000	0.303000	0.959563
45.800003		0.312595	3.166875

THE NUMBER OF DATA POINTS IS 10
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.038
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.041

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.15	0.127000	0.273000	0.000321
23.000003		0.272996	0.001178
4.15	0.195000	0.344000	0.000774
22.900001		0.343992	0.002252

THE NUMBER OF DATA POINTS IS 2
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.000
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 0.001

U.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.107000	0.282000	1.958072
197.000030		0.301580	6.943520
4.11	0.165000	0.413000	0.640213
198.700012		0.419402	1.550153
4.11	0.225000	0.485000	1.922172
197.000030		0.504221	3.963242
4.11	0.282000	0.573000	1.945114
197.000030		0.553548	3.394615
4.11	0.340000	0.559000	1.714730
199.500030		0.576147	3.067496
4.11	0.401000	0.578000	0.410723
199.500030		0.573892	0.710594
4.11	0.401000	0.549000	2.489281
199.500030		0.573892	4.534210
4.11	0.342000	0.582000	0.552570
199.700012		0.576474	0.949434
4.11	0.284000	0.578000	2.322936
197.800018		0.554770	4.018920
4.11	0.227000	0.533000	2.655351
199.500030		0.506446	4.981897
4.11	0.155000	0.418000	1.629358
198.700012		0.401706	3.8[illegible]7987

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.115000	0.312000	0.806403
197.800018		0.320064	2.584625

THE NUMBER OF DATA POINTS IS 12
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.587
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.383

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EXP.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.111000	0.290000	3.984233
149.600006		0.299842	3.393994
4.11	0.166000	0.401000	0.261116
149.600006		0.403611	0.451162
4.11	0.231000	0.494000	1.076901
149.600005		0.483231	2.179981
4.11	0.298000	0.516000	0.300193
146.300018		0.519301	0.501653
4.11	0.348000	0.555000	2.825499
149.600006		0.526745	5.390989
4.11	0.403000	0.488000	2.269727
149.600006		0.510697	4.651080
4.11	0.419000	0.507000	3.460875
149.600006		0.502391	0.909823
4.11	0.405000	0.489000	2.074301
149.600006		0.509743	4.741925
4.11	0.397000	0.537000	2.358618
149.600006		0.513411	4.392585
4.11	0.335000	0.542000	1.455140
149.600006		0.527448	2.684761
4.11	0.294000	0.492000	2.908444
147.700012		0.521084	5.911473

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.234000	0.476000	0.986832
149.600006		0.485868	2.073177
4.11	0.173000	0.424000	0.966328
149.600006		0.414336	2.279076
4.11	0.118000	0.322000	0.696498
150.200012		0.315035	2.163038

THE NUMBER OF DATA POINTS IS 14
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.401
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.943

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
4.11	0.234000	0.476000	0.986832
149.600006		0.485868	2.073177
4.11	0.173000	0.424000	0.966328
149.600006		0.414336	2.279076
4.11	0.118000	0.322000	0.696498
150.200012		0.315035	2.163038

THE NUMBER OF DATA POINTS IS 14
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.401
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.943

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.351000	0.518000	0.819242
100.500015		0.526192	1.581548
4.11	0.296000	0.506000	1.933098
100.100006		0.525331	0.820352
4.11	0.232000	0.499000	2.[illegible]61856
100.500015		0.478381	[illegible]3197[illegible]
4.11	0.176000	0.385000	1.930701
100.500015		0.404307	5.014810
4.11	0.120000	0.293000	1.352310
100.500015		0.306523	4.615393
4.11	0.113000	0.300000	0.703013
99.700012		0.292969	2.343377
4.11	0.168000	0.411000	1.936835
99.700012		0.391631	4.712494
4.11	0.231000	0.500000	2.269423
99.700012		0.477305	4.538846
4.11	0.289000	0.501000	2.144420
99.700012		0.522444	4.280281
4.11	0.348000	0.517000	1.020241
95.700012		0.527202	1.973386
4.11	0.411000	0.491000	1.342273
99.700012		0.477577	2.733753

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.426000	0.464000	0.759470
100.100006		0.456405	1.636790
4.11	0.411000	0.479000	0.142270
96.120010		0.477577	0.297015

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.416
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.206

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION / PRESSURE RATIO	VELOCITY RATIO	EMPIRICAL DATA POINT / SMOOTHED DATA POINT	SCATTER PER CENT EFF. / SCATTER PER CENT VAL.
4.11 / 80.100006	0.115000	0.271000 / 0.248134	2.286502 / 8.437280
4.11 / 77.200012	0.173000	0.316000 / 0.304963	1.103657 / 3.492587
4.11 / 72.500015	0.237000	0.368000 / 0.344059	2.394062 / 6.505604
4.11 / 76.500015	0.310000	0.317000 / 0.348048	3.104883 / 9.794586
4.11 / 74.200012	0.352000	0.345000 / 0.326141	1.885903 / 5.466385
4.11 / 76.900009	0.420000	0.233000 / 0.245916	1.291632 / 5.543488
4.11 / 79.100006	0.408000	0.276000 / 0.264444	1.155573 / 4.186860
4.11 / 74.200012	0.354000	0.328000 / 0.324602	0.339782 / 1.035921
4.11 / 76.900009	0.314000	0.344000 / 0.346786	0.278616 / 0.809930
4.11 / 77.200012	0.238000	0.338000 / 0.344431	0.643116 / 1.902710
4.11 / 74.800003	0.179000	0.298000 / 0.309799	1.179933 / 3.959508

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
4.11	0.120000	0.227000	2.667051
74.800003		0.253670	11.749126

THE NUMBER OF DATA POINTS IS 12
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.527
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.240

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
4.11	0.121000	0.245000	2.045956
59.800003		0.224540	8.350843
4.11	0.179000	0.289000	2.309406
59.800003		0.312094	7.991024
4.11	0.242000	0.374000	3.489309
59.800003		0.339106	9.329706
4.11	0.303000	0.304000	0.905364
59.800003		0.313053	2.978174
4.11	0.365000	0.268000	1.824370
59.800003		0.249756	6.807352
4.11	0.420000	0.165000	1.031234
59.800003		0.175312	6.249908
4.11	0.429000	0.170000	0.769722
59.800003		0.162302	4.527779
4.11	0.363000	0.243000	0.921547
59.800003		0.252215	3.792377
4.11	0.299000	0.301000	1.503062
59.800003		0.316030	4.993562
4.11	0.237000	0.338000	0.117814
59.800003		0.339178	0.348563
4.11	0.182000	0.316000	0.113433
59.800003		0.314865	0.358967

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.121000	0.210000	1.454043
59.800003		0.224540	6.924016

THE NUMBER OF DATA POINTS IS 12
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.373
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.221

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION / PRESSURE RATIO	VELOCITY RATIO	EMPIRICAL DATA POINT / SMOOTHED DATA POINT	SCATTER PER CENT EFF. / SCATTER PER CENT VAL.
4.11 / 50.100006	0.124000	0.324000 / 0.308433	1.556653 / 4.804485
4.11 / 50.100006	0.184000	0.302000 / 0.399730	9.773004 / 32.360939
4.11 / 50.100006	0.247000	0.401000 / 0.423267	2.226770 / 5.553043
4.11 / 49.900001	0.305000	0.339000 / 0.393646	5.464679 / 16.119998
4.11 / 49.900001	0.371000	0.305000 / 0.317247	1.224780 / 4.015673
4.11 / 50.100006	0.426000	0.242000 / 0.232192	0.980717 / 4.052550
4.11 / 49.900001	0.442000	0.202000 / 0.205539	0.353980 / 1.752376
4.11 / 49.900001	0.429000	0.243000 / 0.227236	1.576388 / 6.487194
4.11 / 49.900001	0.369000	0.317000 / 0.320055	0.305581 / 0.963978
4.11 / 49.900001	0.303000	0.438000 / 0.395337	4.266232 / 9.740257
4.11 / 49.900001	0.242000	0.482000 / 0.423723	5.827659 / 12.090580

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.184000	0.421000	2.126992
50.100006		0.399730	5.052238
4.11	0.123000	0.337000	3.074205
50.300003		0.306257	9.122272

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.981
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.624

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.11	0.123000	0.249000	0.567817
39.900001		0.243321	2.280392
4.11	0.189000	0.291000	1.092630
39.900001		0.280073	3.754745
4.11	0.247000	0.304000	3.844291
39.900001		0.265557	12.645696
4.11	0.306000	0.207000	0.370919
39.900001		0.210709	1.791882
4.11	0.371000	0.123000	1.388141
39.900001		0.109118	11.285703
4.11	0.426000	0.000000	0.601351
39.900001		-0.006013	0.601351
4.11	0.378000	0.072000	2.385756
39.900001		0.095857	33.135505
4.11	0.308000	0.209000	0.080266
39.900001		0.208197	0.384050
4.11	0.249000	0.247000	1.733345
39.900001		0.264333	7.017591
4.11	0.185000	0.248000	3.151962
39.900001		0.279519	12.709524
4.11	0.123000	0.244000	0.067818
39.900001		0.243321	0.277943

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.389
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 7.807

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
4.11	0.128000	0.253000	0.670069
25.200000		0.259700	2.648496
4.11	0.192000	0.332000	1.819664
24.900001		0.313803	5.480917
4.11	0.256000	0.263000	1.012605
25.200000		0.273126	3.850211
4.11	0.297000	0.179600	1.292356
25.200000		0.191923	7.219870
4.11	0.314000	0.140000	0.474229
25.200000		0.144742	3.387353
4.11	0.322000	0.119000	0.070174
25.100002		0.119701	0.589697
4.11	0.336000	0.078000	0.657673
25.200000		0.071423	8.431707
4.11	0.288000	0.229000	1.535990
24.900001		0.213640	6.707384
4.11	0.258000	0.271000	0.079822
25.000003		0.270201	0.294548
4.11	0.193000	0.305000	0.892663
24.900001		0.313926	2.926764
4.11	0.128000	0.263000	0.329929
25.000003		0.259700	1.254485

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 0.803
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.890

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.7	0.175000	0.461000	3.085804
203.200012		0.430141	6.693718
4.7	0.114000	0.323000	1.559639
199.800018		0.307403	4.828604

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.288
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.782

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.7	0.116000	0.315000	0.145942
153.700012		0.316459	0.463307
4.7	0.175000	0.413000	2.531719
153.700012		0.438317	6.130071
4.7	0.231000	0.498000	1.968461
152.100006		0.517684	3.952734
4.7	0.293000	0.565000	0.384855
150.200012		0.568848	0.681159
4.7	0.349000	0.538000	4.792440
152.400024		0.585924	8.907880
4.7	0.408000	0.514000	6.419397
152.100006		0.578194	12.489101
4.7	0.438000	0.554000	1.149404
152.400024		0.565494	2.074737
4.7	0.408000	0.565000	8.680606
152.400024		0.578194	13.053543
4.7	0.349000	0.615000	2.907550
152.400024		0.585924	4.727725
4.7	0.291000	0.588000	2.024853
155.400024		0.567751	3.443628
4.7	0.235000	0.531000	0.889897
152.400024		0.522101	1.675889

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION / PRESSURE RATIO	VELOCITY RATIO	EMPIRICAL DATA POINT / SMOOTHED DATA POINT	SCATTER PER CENT EFF. / SCATTER PER CENT VAL.
4.7 / 152.400024	0.175000	0.462000 / 0.438317	2.368277 / 5.126141
4.7 / 160.200012	0.116000	0.322000 / 0.316459	0.554055 / 1.720667

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.678
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.957

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.7	0.118000	0.331000	0.209218
100.100006		0.333092	0.632079
4.7	0.175000	0.395000	3.140968
101.000015		0.426409	7.951818
4.7	0.237000	0.483000	1.915711
99.900009		0.502157	3.966276
4.7	0.294000	0.549000	0.854468
100.100006		0.540455	1.556409
4.7	0.357000	0.533000	0.602245
101.000015		0.539022	1.129916
4.7	0.412000	0.482000	1.091420
100.100006		0.492914	2.264358
4.7	0.412000	0.498000	0.508576
100.100006		0.492914	1.021238
4.7	0.359000	0.544000	0.587725
99.300003		0.538122	1.080378
4.7	0.297000	0.551000	0.950169
100.100006		0.541498	1.724445
4.7	0.18000	0.476000	4.237342
100.300003		0.433626	8.901981
4.7	0.120000	0.335000	0.166773
100.300003		0.336667	0.497832

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.296
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 2.793

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION / PRESSURE RATIO	VELOCITY RATIO	EMPIRICAL DATA POINT / SMOOTHED DATA POINT	SCATTER PER CENT EFF. / SCATTER PER CENT VAL.
4.7	0.123000	0.345000	0.877082
50.300003		0.336229	2.542268
4.7	0.186000	0.365000	6.587649
50.500007		0.430876	18.048355
4.7	0.246000	0.443000	0.515461
50.300003		0.448154	1.163548
4.7	0.306000	0.372000	3.708797
50.200004		0.409088	9.969886
4.7	0.371000	0.283000	3.699714
50.300003		0.319997	13.073194
4.7	0.428000	0.201000	1.500275
50.800003		0.216002	7.464058
4.7	0.433000	0.220000	1.383292
50.800003		0.206167	6.287694
4.7	0.365000	0.342000	1.221227
50.300003		0.329787	3.570841
4.7	0.306000	0.467000	5.791199
50.500007		0.409088	12.400856
4.7	0.247000	0.502000	5.407494
50.300003		0.447925	10.771900
4.7	0.185000	0.444000	1.397150
50.200004		0.430028	3.146736

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.7	0.123000	0.336000	0.022917
50.200004		0.336229	0.068208

THE NUMBER OF DATA POINTS IS 12
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.676
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 7.375

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
4.7	0.128000	0.274000	1.261413
25.000003		0.286614	4.603697
4.7	0.194000	0.310000	3.246861
25.100002		0.342468	10.473749
4.7	0.255000	0.294000	1.774305
25.100002		0.311743	6.035052
4.7	0.322000	0.165000	0.963401
25.200000		0.174634	5.838799
4.7	0.337000	0.153000	2.517599
25.100002		0.127824	16.454895
4.7	0.321000	0.145000	3.253743
25.100002		0.177537	22.439609
4.7	0.256000	0.364000	5.347783
25.100002		0.310522	14.691711
4.7	0.194000	0.349000	0.653141
25.100002		0.342468	1.871466
4.7	0.129000	0.308000	1.990872
25.100002		0.288091	6.463872

THE NUMBER OF DATA POINTS IS 9
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.334
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 9.874

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.194000	0.469000	1.522112
23.720001		0.453778	3.745441
PLUG 'A'	0.191000	0.484000	3.433180
23.470001		0.449668	7.093347
PLUG 'A'	0.190000	0.458000	0.973266
23.400001		0.448267	2.125036
PLUG 'A'	0.259000	0.526000	0.598847
23.580001		0.520011	1.138494
PLUG 'A'	0.259000	0.525000	0.495266
23.540000		0.520047	0.943365
PLUG 'A'	0.322000	0.568000	3.363895
24.250003		0.534361	5.922351
PLUG 'A'	0.324000	0.574000	3.973877
24.550003		0.534261	6.923132
PLUG 'A'	0.390000	0.505000	0.034439
24.850002		0.505344	0.068197
PLUG 'A'	0.390000	0.511000	0.624299
24.480003		0.504757	1.221720
PLUG 'A'	0.456000	0.447000	0.827282
24.290000		0.438727	1.850744
PLUG 'A'	0.457000	0.466000	2.843857
24.310001		0.437561	6.102698

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
PLUG 'A'	0.389000	0.582000	7.705677
24.110000		0.504943	13.239995
PLUG 'A'	0.325000	0.488000	4.596287
24.210002		0.533962	9.418621
PLUG 'A'	0.260000	0.565000	4.470742
24.830001		0.520292	7.912817
PLUG 'A'	0.195000	0.505000	5.003578
24.000003		0.454964	9.908075
PLUG 'A'	0.130000	0.296000	3.352022
24.480003		0.329520	11.224401
PLUG 'A'	0.129000	0.331000	0.389099
24.530002		0.327109	1.175526
PLUG 'A'	0.127000	0.322000	0.028473
24.660003		0.322284	0.088425
PLUG 'A'	0.126000	0.320000	0.019997
24.660003		0.319800	0.062491
PLUG 'A'	0.192000	0.467000	1.660502
24.580001		0.450394	3.555679
PLUG 'A'	0.191000	0.446000	0.290006
24.580001		0.448900	0.650238
PLUG 'A'	0.257000	0.515000	0.337910
24.450000		0.518379	0.656137

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.257000	0.516000	0.240528
24.660003		0.518405	0.466140
PLUG 'A'	0.325000	0.489000	4.507041
24.450000		0.534070	9.216854
PLUG 'A'	0.324000	0.489000	4.533053
24.660003		0.534330	9.270048
PLUG 'A'	0.389000	0.511000	0.52 52
24.660003		0.505771	1.023193
PLUG 'A'	0.390000	0.505000	0.006961
24.680000		0.505069	0.013785
PLUG 'A'	0.458000	0.421000	1.671159
24.760002		0.437711	3.969500
PLUG 'A'	0.445000	0.450000	0.231963
24.470001		0.452319	0.515474
PLUG 'A'	0.383000	0.516000	0.614619
24.560001		0.509853	1.191123
PLUG 'A'	0.326000	0.539000	0.506401
24.470001		0.533936	0.939519
PLUG 'A'	0.258000	0.519000	0.000250
24.370002		0.519002	0.000482
PLUG 'A'	0.196000	0.449000	0.723064
24.370002		0.456230	1.610387

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.129000	0.339000	1.186532
24.570003		0.327134	3.500093
PLUG 'A'	0.124000	0.332000	1.736718
24.450000		0.314632	5.231081
PLUG 'A'	0.191000	0.428000	2.092606
24.250003		0.448926	4.889266
PLUG 'A'	0.254000	0.507000	0.949645
24.740001		0.516496	1.873067
PLUG 'A'	0.323000	0.536000	0.172448
24.330001		0.534275	0.321731
PLUG 'A'	0.384000	0.527000	1.787507
24.530002		0.509124	3.391855
PLUG 'A'	0.449000	0.430000	1.873964
24.850002		0.448739	4.358057
PLUG 'A'	0.448000	0.429000	2.001017
24.530002		0.449010	4.664376
PLUG 'A'	0.389000	0.523000	1.719701
24.680000		0.505802	3.288148
PLUG 'A'	0.256000	0.539000	2.124917
24.530002		0.517750	3.942333
PLUG 'A'	0.194000	0.405000	4.833120
24.450000		0.453331	11.933630

THE NUMBER OF DATA POINTS IS 44
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.831
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.869

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.131000	0.341000	0.361967
20.160003		0.344619	1.061487
PLUG 'A'	0.199000	0.445000	2.438575
20.430000		0.469385	5.479944
PLUG 'A'	0.265000	0.549000	2.108252
20.060001		0.527917	3.840163
PLUG 'A'	0.332000	0.477000	5.374253
20.330001		0.530742	11.266777
PLUG 'A'	0.402000	0.574000	9.159368
20.060001		0.482406	15.957088
PLUG 'A'	0.464000	0.388000	1.731258
20.060001		0.405312	4.462007
PLUG 'A'	0.465000	0.393000	1.120615
20.100002		0.404206	2.851438
PLUG 'A'	0.401000	0.539000	5.538088
20.100002		0.483619	10.274747
PLUG 'A'	0.332000	0.476000	5.457426
20.230003		0.530574	11.465181
PLUG 'A'	0.264000	0.468000	5.941206
20.130001		0.527412	12.694885
PLUG 'A'	0.199000	0.504000	3.323591
20.000003		0.470764	6.594427

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.132000	0.377000	2.920168
20.000003		0.347798	7.745805
PLUG 'A'	0.130000	0.373000	3.132599
20.270000		0.341674	8.398391
PLUG 'A'	0.130000	0.344000	0.097137
20.000003		0.343028	0.282377
PLUG 'A'	0.196000	0.461000	0.407439
20.500003		0.465074	0.883816
PLUG 'A'	0.132000	0.329000	2.117413
19.530002		0.350174	6.435906
PLUG 'A'	0.328000	0.584000	5.358148
19.530002		0.530418	9.174911
PLUG 'A'	0.198000	0.450000	2.101832
19.490001		0.471018	4.670739
PLUG 'A'	0.400000	0.478000	0.329911
19.530002		0.481299	0.690191
PLUG 'A'	0.456000	0.406000	0.616729
19.550003		0.412167	1.519037
PLUG 'A'	0.401000	0.461000	1.842957
19.400001		0.479429	3.997739
PLUG 'A'	0.329000	0.516000	1.374972
19.400001		0.529749	2.664674

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.265000	0.517000	1.132023
19.400001		0.528320	2.189600
PLUG 'A'	0.130000	0.366000	1.954347
19.330001		0.346456	5.339746
PLUG 'A'	0.263000	0.593000	6.559122
19.560001		0.527408	11.060915
PLUG 'A'	0.198000	0.453000	1.828706
19.400001		0.471287	4.036880

THE NUMBER OF DATA POINTS IS 26
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.858
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.963

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.132000	0.350000	1.091307
17.280002		0.360913	3.118021
PLUG 'A'	0.201000	0.499000	1.965391
17.280002		0.479346	3.938661
PLUG 'A'	0.268000	0.529000	0.319147
16.980003		0.525808	0.603302
PLUG 'A'	0.336000	0.458000	5.755139
17.170002		0.515551	12.565807
PLUG 'A'	0.406000	0.459000	0.577128
17.220001		0.453228	1.257359
PLUG 'A'	0.480000	0.326000	1.191914
17.040000		0.337919	3.656178
PLUG 'A'	0.472000	0.363000	0.662118
17.280002		0.356378	1.824017
PLUG 'A'	0.408000	0.453000	0.899112
16.720001		0.444008	1.984795
PLUG 'A'	0.337000	0.547000	3.254867
17.100002		0.514451	5.950397
PLUG 'A'	0.268000	0.483000	4.280847
16.980003		0.525808	8.863037
PLUG 'A'	0.203000	0.535000	5.324441
17.140003		0.481755	9.952228

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.134000	0.359000	0.698167
17.140003		0.365981	1.944755
PLUG 'A'	0.129000	0.358000	0.225794
16.850002		0.355742	0.630710
PLUG 'A'	0.196000	0.456000	1.755070
16.850002		0.473550	3.848839
PLUG 'A'	0.261000	0.514000	1.012695
17.080001		0.524127	1.970223
PLUG 'A'	0.329000	0.489000	2.841163
16.940002		0.517411	5.810149
PLUG 'A'	0.396000	0.454000	1.053422
17.180000		0.464534	2.320314
PLUG 'A'	0.464000	0.341000	2.719653
17.180000		0.368196	7.975522
PLUG 'A'	0.462000	0.350000	1.730555
16.940002		0.367305	4.944444
PLUG 'A'	0.399000	0.451000	0.746005
16.970001		0.458460	1.654114
PLUG 'A'	0.331000	0.499000	1.959336
17.230003		0.518593	3.926525
PLUG 'A'	0.265000	0.507000	1.911366
17.330001		0.526113	3.769953

THE NUMBER OF DATA POINTS IS 22
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.907
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.204

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.137000	0.373000	0.461655
14.870000		0.377616	1.237683
PLUG 'A'	0.137000	0.384000	0.638342
14.870000		0.377616	1.662348
PLUG 'A'	0.138000	0.376000	0.360971
15.020000		0.379609	0.960031
PLUG 'A'	0.206000	0.520000	3.854447
15.000001		0.481455	7.412399
PLUG 'A'	0.275000	0.555000	4.244709
14.810001		0.512552	7.648125
PLUG 'A'	0.344000	0.485000	0.169694
14.810001		0.483303	0.349885
PLUG 'A'	0.412000	0.463000	5.315703
15.070001		0.409843	11.480999
PLUG 'A'	0.480000	0.330000	3.250551
15.260000		0.297494	9.850156
PLUG 'A'	0.414000	0.442000	3.655714
15.000001		0.405442	8.270847
PLUG 'A'	0.343000	0.479000	1.058453
15.180000		0.489584	2.209714
PLUG 'A'	0.207000	0.501000	1.858461
15.000001		0.482415	3.709503

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.140000	0.342000	4.172021
14.760000		0.383720	12.198894

THE NUMBER OF DATA POINTS IS 12
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.420
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.582

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'A'	0.139000	0.372000	0.010406
11.960001		0.371895	0.027975
PLUG 'A'	0.211000	0.471000	1.130092
12.000001		0.459699	2.399346
PLUG 'A'	0.280000	0.490000	2.006334
12.000001		0.469936	4.094559
PLUG 'A'	0.351000	0.411000	0.767797
12.100000		0.418677	1.868120
PLUG 'A'	0.423000	0.250000	5.592239
12.020000		0.305922	22.368957
PLUG 'A'	0.491000	0.154000	0.243106
11.940000		0.156431	1.578613
PLUG 'A'	0.422000	0.353000	4.520828
12.020000		0.307791	12.806877
PLUG 'A'	0.350000	0.374000	4.361433
12.020000		0.417614	11.661584
PLUG 'A'	0.211000	0.471000	1.130092
12.000001		0.459699	2.399346
PLUG 'A'	0.140000	0.365000	0.914609
12.020000		0.374146	2.505779

THE NUMBER OF DATA POINTS IS 10
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.067
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 6.171

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'B'	0.125000	0.345000	1.333141
24.950000		0.358331	3.864178
PLUG 'B'	0.189000	0.469000	1.109820
24.850002		0.480098	2.366355
PLUG 'B'	0.256000	0.574000	4.051411
24.870002		0.533485	7.058208
PLUG 'B'	0.316000	0.518000	0.539076
24.850002		0.523390	1.040688
PLUG 'B'	0.393000	0.455000	1.084596
24.950000		0.444154	2.383727
PLUG 'B'	0.456000	0.351000	1.752341
25.060001		0.333478	4.992424
PLUG 'B'	0.453000	0.325000	1.024371
24.750003		0.335243	3.151912
PLUG 'B'	0.390000	0.488000	3.946513
24.950000		0.448534	8.087118
PLUG 'B'	0.323000	0.509000	0.908124
24.750003		0.518081	1.784134
PLUG 'B'	0.318000	0.521000	0.392043
25.120002		0.524920	0.752483
PLUG 'B'	0.253000	0.595000	6.312991
24.790000		0.531870	10.610069

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
PLUG 'B'	0.192000	0.509000	2.595603
24.750003		0.483043	5.099418
PLUG 'B'	0.130000	0.387000	1.881230
24.750003		0.368187	4.861060

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.071
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.311

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'B'	0.130000	0.392000	4.378623
20.350002		0.348213	11.169956
PLUG 'B'	0.197000	0.488000	1.588589
20.400001		0.472114	3.255305
PLUG 'B'	0.254000	0.515000	0.290215
20.160003		0.512097	0.563524
PLUG 'B'	0.324000	0.501000	1.263445
20.100002		0.488365	2.521848
PLUG 'B'	0.392000	0.400000	0.237554
20.440002		0.402375	0.593885
PLUG 'B'	0.455000	0.248000	1.836320
20.060001		0.266363	7.404519
PLUG 'B'	0.456000	0.299000	3.189665
20.260002		0.267103	10.667778
PLUG 'B'	0.400000	0.439000	5.765301
19.800003		0.381347	13.112806
PLUG 'B'	0.326000	0.484000	0.315880
20.200000		0.487158	0.652646
PLUG 'B'	0.265000	0.481000	3.174210
19.830001		0.512742	6.599189
PLUG 'B'	0.194000	0.470000	0.160455
20.400001		0.468395	0.341395

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'B'	0.129000	0.345000	0.106358
20.000003		0.346063	0.308285

THE NUMBER OF DATA POINTS IS 12
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.858
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.767

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'B'	0.130000	0.327000	2.909088
16.550003		0.356090	8.896295
PLUG 'B'	0.201000	0.472000	0.439053
16.730003		0.476390	0.930198
PLUG 'B'	0.270000	0.422000	7.801348
16.630001		0.500013	18.486606
PLUG 'B'	0.330000	0.393000	6.875635
17.270000		0.461756	17.495258
PLUG 'B'	0.400000	0.316000	1.857513
16.640003		0.334575	5.878207
PLUG 'B'	0.468000	0.207000	2.532193
17.520000		0.181678	12.232816
PLUG 'B'	0.401000	0.334000	0.398695
16.520000		0.330013	1.193699
PLUG 'B'	0.334000	0.513000	6.379097
16.590000		0.449208	12.434890
PLUG 'B'	0.267000	0.551000	5.020010
16.640003		0.500800	9.110727
PLUG 'B'	0.202000	0.492000	1.496321
16.540000		0.477036	3.041303
PLUG 'B'	0.132000	0.372000	1.112526
16.570003		0.360874	2.990663

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.347
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.426

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'B'	0.133000	0.395000	3.083402
14.920000		0.364166	7.806080
PLUG 'B'	0.202000	0.491000	2.013522
14.850000		0.470864	4.100860
PLUG 'B'	0.266000	0.505000	1.765382
15.070001		0.487346	3.495806
PLUG 'B'	0.334000	0.450000	2.744418
14.850000		0.422555	6.098707
PLUG 'B'	0.405000	0.284000	0.113880
14.910001		0.282861	0.400988
PLUG 'B'	0.447000	0.140000	2.910027
14.940000		0.169100	20.785907
PLUG 'B'	0.402000	0.317000	2.977103
14.800001		0.287229	9.391492
PLUG 'B'	0.334000	0.423000	0.229418
15.000001		0.425294	0.542360
PLUG 'B'	0.272000	0.472000	1.248479
14.960001		0.484484	2.645082
PLUG 'B'	0.202000	0.476000	0.496524
14.880001		0.471034	1.043119
PLUG 'B'	0.136000	0.375000	0.415414
14.850000		0.370845	1.107772

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.636
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.219

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'B'	0.139000	0.361000	0.161898
12.040000		0.362618	0.448471
PLUG 'B'	0.208000	0.444000	0.066715
11.970001		0.443332	0.150260
PLUG 'B'	0.278000	0.459000	3.138119
12.000001		0.427618	6.836860
PLUG 'B'	0.345000	0.336000	0.542932
12.040000		0.330570	1.615871
PLUG 'B'	0.399000	0.184000	1.552516
12.040000		0.199525	8.437589
PLUG 'B'	0.347000	0.334000	0.749468
12.040000		0.326505	2.243918
PLUG 'B'	0.278000	0.429000	0.037205
12.070001		0.429372	0.086725
PLUG 'B'	0.210000	0.424000	2.071047
12.000001		0.444710	4.884545
PLUG 'B'	0.140000	0.356000	0.834715
12.020000		0.364347	2.344706

THE NUMBER OF DATA POINTS IS 9
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.017
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.005

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'C'	0.129000	0.460000	10.589921
24.580001		0.354100	23.021568
PLUG 'C'	0.253000	0.706000	14.959146
24.910003		0.556408	21.188591
PLUG 'C'	0.385000	0.665000	17.418785
25.310001		0.490812	26.193660
PLUG 'C'	0.454000	0.423000	8.479583
24.700000		0.338204	20.046295
PLUG 'C'	0.384000	0.599000	10.888463
25.230003		0.490115	18.177734
PLUG 'C'	0.253000	0.654000	7.278371
25.820003		0.581216	11.129009
PLUG 'C'	0.126000	0.386000	2.622807
25.230003		0.359771	6.794837
PLUG 'C'	0.126000	0.339000	1.101422
24.800003		0.350014	3.249033
PLUG 'C'	0.190000	0.462000	3.002083
24.880001		0.492020	6.498017
PLUG 'C'	0.254000	0.524000	3.892970
25.160003		0.562929	7.429333
PLUG 'C'	0.315000	0.494000	6.174255
25.000003		0.555742	12.498493

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
PLUG 'C'	0.381000	0.447000	4.571336
25.160003		0.492713	10.226703
PLUG 'C'	0.446000	0.322000	5.980683
25.590000		0.381806	18.573551
PLUG 'C'	0.446000	0.332000	4.496091
25.430000		0.376960	13.542444
PLUG 'C'	0.383000	0.456000	3.729129
25.290000		0.493291	8.177915
PLUG 'C'	0.320000	0.508000	4.689133
25.080001		0.554891	9.230579
PLUG 'C'	0.257000	0.535000	2.524257
25.000003		0.560242	4.718237
PLUG 'C'	0.192000	0.453000	5.122066
25.260002		0.504220	11.306980
PLUG 'C'	0.129000	0.333000	3.224855
25.110000		0.365248	9.684253

THE NUMBER OF DATA POINTS IS 19
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 6.355
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 12.720

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'C'	0.130000	0.346000	0.212663
19.930000		0.348126	0.614634
PLUG 'C'	0.198000	0.456000	1.954239
19.970001		0.475542	4.285614
PLUG 'C'	0.263000	0.485000	3.242659
20.000003		0.517626	6.727152
PLUG 'C'	0.326000	0.463000	2.858704
20.150001		0.491587	6.174307
PLUG 'C'	0.395000	0.383000	0.769657
19.730003		0.390696	2.009548
PLUG 'C'	0.454000	0.248000	1.356163
20.150001		0.261561	5.468401
PLUG 'C'	0.394000	0.384000	1.087337
19.970001		0.394873	2.831609
PLUG 'C'	0.329000	0.436000	5.280167
20.150001		0.488001	12.110475
PLUG 'C'	0.262000	0.531000	1.347244
20.060001		0.517527	2.537182
PLUG 'C'	0.196000	0.478000	0.509590
20.000003		0.472904	1.066087
PLUG 'C'	0.132000	0.357000	0.500071
20.060001		0.351999	1.400759

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.739
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.111

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'C'	0.133000	0.466000	7.796574
16.910003		0.388034	16.730846
PLUG 'C'	0.265000	0.739000	22.361507
16.910003		0.515385	30.259143
PLUG 'C'	0.404000	0.369000	3.257489
17.000003		0.336425	8.827886
PLUG 'C'	0.438000	0.338000	8.656908
17.000003		0.251430	25.612152
PLUG 'C'	0.405000	0.382000	4.551387
17.130001		0.336486	11.914627
PLUG 'C'	0.200000	0.654000	16.088707
16.880001		0.493112	24.600467
PLUG 'C'	0.271000	0.642000	12.855411
16.840000		0.513445	20.024005
PLUG 'C'	0.198000	0.470000	2.003950
17.210002		0.490039	4.263723
PLUG 'C'	0.131000	0.357000	2.166325
17.370002		0.378663	6.068137
PLUG 'C'	0.266000	0.485000	3.102642
17.160003		0.516026	6.397201
PLUG 'C'	0.331000	0.450000	1.830017
17.170002		0.468300	4.066706

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'C'	0.398000	0.334000	1.982045
17.230003		0.353820	5.934268
PLUG 'C'	0.453000	0.211000	0.234463
17.170002		0.213344	1.111202
PLUG 'C'	0.399000	0.352000	0.086802
17.200000		0.351132	0.246597
PLUG 'C'	0.332000	0.446000	2.095282
17.160003		0.466952	4.697942
PLUG 'C'	0.265000	0.477000	3.951013
17.260002		0.516510	8.283046
PLUG 'C'	0.197000	0.477000	1.117140
17.410003		0.488171	2.342012
PLUG 'C'	0.134000	0.351000	3.588658
17.240001		0.386886	10.224100

THE NUMBER OF DATA POINTS IS 18
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 5.429
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 10.644

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'C'	0.133000	0.361000	4.082983
15.000001		0.401829	11.310205
PLUG 'C'	0.204000	0.426000	6.755239
14.790000		0.493552	15.857368
PLUG 'C'	0.272000	0.470000	2.655023
15.000001		0.496550	5.648985
PLUG 'C'	0.341000	0.400000	1.743388
14.900001		0.417433	4.358470
PLUG 'C'	0.403000	0.246000	4.133994
14.900001		0.287339	16.804851
PLUG 'C'	0.428000	0.185000	3.524923
14.900001		0.220249	19.053646
PLUG 'C'	0.404000	0.264000	2.144837
14.920000		0.285448	8.124385
PLUG 'C'	0.341000	0.408000	0.990551
14.920000		0.417905	2.427823
PLUG 'C'	0.271000	0.478000	1.992607
15.060001		0.497926	4.168634
PLUG 'C'	0.201000	0.440000	5.307341
15.050001		0.493073	12.062139
PLUG 'C'	0.135000	0.372000	3.441351
14.780000		0.406413	9.250946

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.342
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 9.915

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'C'	0.137000	0.467000	7.735431
11.960001		0.389645	16.564094
PLUG 'C'	0.366000	0.235000	0.893777
11.800001		0.243937	3.803309
PLUG 'C'	0.344000	0.387000	9.034675
11.830001		0.296653	23.345413
PLUG 'C'	0.284000	0.393000	0.597596
11.840000		0.398975	1.520601
PLUG 'C'	0.141000	0.478000	8.390171
11.890001		0.394098	17.552658
PLUG 'C'	0.135000	0.349000	3.574800
11.860000		0.384748	10.242982
PLUG 'C'	0.208000	0.448000	0.641673
11.810001		0.441583	1.432307
PLUG 'C'	0.281000	0.376000	2.699619
11.850000		0.402996	7.179839
PLUG 'C'	0.346000	0.298000	0.515157
11.840000		0.292848	1.728714
PLUG 'C'	0.384000	0.204000	0.577893
11.820001		0.198221	2.832813
PLUG 'C'	0.350000	0.282000	0.089669
11.820001		0.282896	0.317976

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
PLUG 'C'	0.280000	0.369000	3.386760
11.820001		0.402867	9.178213
PLUG 'C'	0.208000	0.433000	0.858324
11.810001		0.441583	1.982274
PLUG 'C'	0.141000	0.332000	6.109506
11.840000		0.393095	18.402130

THE NUMBER OF DATA POINTS IS 14
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.221
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.291

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
ARGON 2.511	0.107000	0.297000	1.607114
34.570007		0.313071	5.411159
ARGON 2.511	0.175000	0.443000	1.428288
34.470001		0.457282	3.224127
ARGON 2.511	0.241000	0.531000	3.009033
34.470001		0.561090	5.666730
ARGON 2.511	0.308000	0.602000	1.759469
34.360000		0.619594	2.922707
ARGON 2.511	0.376000	0.560000	5.960489
34.290001		0.619604	10.643732
ARGON 2.511	0.450000	0.537000	0.146019
34.290001		0.538460	0.271917
ARGON 2.511	0.451000	0.503000	3.372335
34.290001		0.536723	6.704445
ARGON 2.511	0.379000	0.581000	3.641820
34.470001		0.617418	6.268193
ARGON 2.511	0.320000	0.698000	7.294810
34.030006		0.625051	10.451017
ARGON 2.511	0.248000	0.542000	2.757549
34.470001		0.569575	5.087730
ARGON 2.511	0.184000	0.447000	2.665943
33.850006		0.473659	5.964078

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
ARGON 2.511	0.119000	0.323000	1.761663
34.470001		0.340616	5.454066

THE NUMBER OF DATA POINTS IS 12
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.950
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.672

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
ARGON 2.511	0.118000	0.318000	0.915259
30.090000		0.327152	2.878173
ARGON 2.511	0.187000	0.503000	3.430015
27.510002		0.468699	6.819116
ARGON 2.511	0.258000	0.484000	8.923114
26.800003		0.573231	18.436187
ARGON 2.511	0.330000	0.612000	1.305246
28.470001		0.625052	2.132755
ARGON 2.511	0.394000	0.612000	1.077425
27.260002		0.601225	1.760499
ARGON 2.511	0.462000	0.501000	0.867414
28.050003		0.509674	1.731366
ARGON 2.511	0.461000	0.492000	1.308751
26.910003		0.505087	2.660063
ARGON 2.511	0.396000	0.644000	3.907847
28.610000		0.604921	6.068087
ARGON 2.511	0.329000	0.635000	1.363229
27.310001		0.621367	2.146818
ARGON 2.511	0.250000	0.529000	3.810275
28.080001		0.567102	7.202789
ARGON 2.511	0.189000	0.483000	1.022172
27.690002		0.472778	2.116298

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
ARGON 2.511	0.120000	0.329000	0.327789
27.690002		0.325722	0.996321

THE NUMBER OF DATA POINTS IS 12
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.354
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.579

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL,
ARGON 2.511	0.120000	0.328000	0.710207
24.570003		0.320897	2.165266
ARGON 2.511	0.189000	0.511000	4.398156
24.570003		0.467018	8.606960
ARGON 2.511	0.262000	0.515000	5.680085
24.620002		0.571800	11.029291
ARGON 2.511	0.330000	0.549000	6.216026
24.570003		0.611160	11.322452
ARGON 2.511	0.396000	0.561000	2.353096
24.450000		0.584531	4.194467
ARGON 2.511	0.466000	0.443000	3.680545
24.880001		0.479805	8.308729
ARGON 2.511	0.495000	0.389000	1.642686
24.570003		0.405426	4.222844
ARGON 2.511	0.467000	0.521000	4.596043
24.570003		0.475039	8.821580
ARGON 2.511	0.397000	0.608000	2.367985
24.570003		0.584320	3.894713
ARGON 2.511	0.327000	0.615000	0.424456
24.570003		0.610755	0.690173
ARGON 2.511	0.261000	0.603000	3.265953
24.450000		0.570340	5.416175

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION / PRESSURE RATIO	VELOCITY RATIO	EMPIRICAL DATA POINT / SMOOTHED DATA POINT	SCATTER PER CENT EFF. / SCATTER PER CENT VAL,
ARGON 2.511 / 24.370002	0.191000	0.410000 / 0.470361	6.036174 / 14.722377
ARGON 2.511 / 24.450000	0.121000	0.260000 / 0.323217	6.321710 / 24.314270

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 3.668
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 8.285

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
ARGON 2.511	0.116000	0.312000	0.244516
21.120002		0.314445	0.783705
ARGON 2.511	0.182000	0.460000	0.670397
21.180000		0.453296	1.457385
ARGON 2.511	0.254000	0.579000	2.256894
20.870002		0.556431	3.897917
ARGON 2.511	0.324000	0.570000	2.749586
21.320003		0.597495	4.823836
ARGON 2.511	0.388000	0.554000	1.848554
21.360000		0.572485	3.336741
ARGON 2.511	0.464000	0.468000	1.812249
21.130001		0.449877	3.872328
ARGON 2.511	0.487000	0.351000	4.318983
21.360000		0.394189	12.304794
ARGON 2.511	0.460000	0.477000	1.584267
21.360000		0.461157	3.321316
ARGON 2.511	0.390000	0.550000	2.063429
21.360000		0.570634	3.751690
ARGON 2.51.	0.326000	0.623000	2.500188
21.410003		0.597998	4.013144
ARGON 2.511	0.256000	0.605000	4.590523
21.430000		0.559094	7.587642

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
ARGON 2.511	0.186000	0.458000	0.228595
21.410003		0.460285	0.499117
ARGON 2.511	0.118000	0.338000	1.958525
21.430000		0.318414	5.794453

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.063
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 4.264

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
ARGON 2.511	0.123000	0.337000	1.418161
17.120002		0.351181	4.208194
ARGON 2.511	0.192000	0.467000	1.524383
17.120002		0.482243	3.264203
ARGON 2.511	0.264000	0.527000	3.934562
17.150001		0.566345	7.465963
ARGON 2.511	0.331000	0.569000	1.623404
17.200000		0.585234	2.853083
ARGON 2.511	0.404000	0.461000	6.535507
16.960002		0.526355	14.176805
ARGON 2.511	0.476000	0.405000	2.874029
17.000003		0.376259	7.096367
ARGON 2.511	0.504000	0.295000	0.862121
16.710002		0.286378	2.922446
ARGON 2.511	0.478000	0.339000	2.892905
16.750003		0.367929	8.533645
ARGON 2.511	0.400000	0.562000	3.152978
16.710002		0.530470	5.610282
ARGON 2.511	0.330000	0.647000	6.208992
16.890003		0.584910	9.596588
ARGON 2.511	0.262000	0.551000	1.413095
17.000003		0.565131	2.564600

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
ARGON 2.511	0.194000	0.510000	2.256346
16.730003		0.487436	4.424207
ARGON 2.511	0.121000	0.343000	0.565761
16.890003		0.348657	1.649450

THE NUMBER OF DATA POINTS IS 13
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 2.712
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 5.720

O.N.R. NOZZLE RESEARCH PROGRAM

NOZZLE DESIGNATION	VELOCITY RATIO	EMPIRICAL DATA POINT	SCATTER PER CENT EFF.
PRESSURE RATIO		SMOOTHED DATA POINT	SCATTER PER CENT VAL.
FREON 2.511	0.128000	0.357000	1.383626
13.100000		0.370836	3.875704
FREON 2.511	0.193000	0.492000	0.930023
13.000001		0.501300	1.890291
FREON 2.511	0.304000	0.579000	0.662744
12.890001		0.585627	1.144635
FREON 2.511	0.344000	0.561000	1.005268
12.890001		0.571052	1.791921
FREON 2.511	0.408500	0.480000	1.497721
12.950000		0.494977	3.120254
FREON 2.511	0.485000	0.298000	1.939237
13.000001		0.317392	6.507508
FREON 2.511	0.478000	0.359000	2.131051
13.050001		0.337689	5.936075
FREON 2.511	0.405000	0.518000	1.719379
13.200000		0.500806	3.319266
FREON 2.511	0.312000	0.596000	1.133156
13.200000		0.584668	1.901268
FREON 2.511	0.192000	0.512000	1.226508
13.500001		0.499734	2.395524
FREON 2.511	0.126000	0.378000	1.208842
13.620000		0.365911	3.197994

THE NUMBER OF DATA POINTS IS 11
THE AVERAGE ERROR IN PER CENT EFFICIENCY IS 1.348
THE AVERAGE ERROR IN PER CENT OF EMPIRICAL DATA VALUE IS 3.189

APPENDIX C

TURBINE TEST SCHEMATIC DIAGRAM

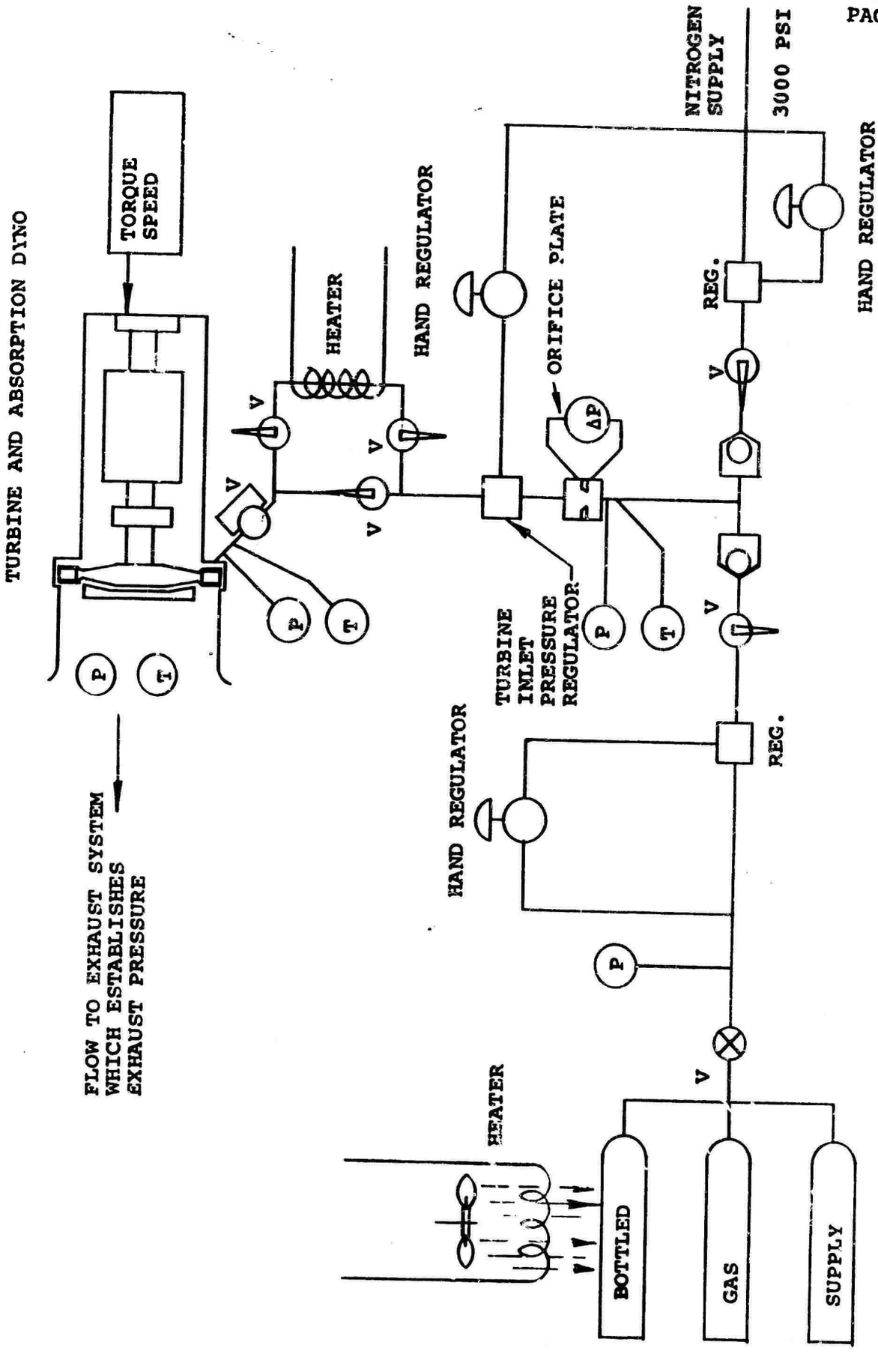


Figure 46. TURBINE TEST SCHEMATIC DIAGRAM

APPENDIX D

SAMPLE DATA SHEET

Table V

Sample Data Sheet

FREON 13 NOZZLE 2.511 BAR. 29.4
RUN 1 28 MAY '71 ORIFICE PLATE .296

DATA PT.#	P.R. NOM.	TQ CORR.	NS TR. / COUNT	NS RPM	TTE °F	PTI PSIG	TQ PSID.	TVI °F	TTI °F	PTE PSIA	PVI PSIG	PTI PSIA	PTI PSIA	ΔPVP IN H2O	ΔPVP PSI
733	12.8	102.95	5K / 171	5130	29.	78.5	105.	40.	50.	7.1	232.	92.9	246.4	41.0	1.480
734	12.8	92.0	7K / 257	7710	22.	78.	95.	43.	48.	7.1	235.	92.4	249.4	39.7	1.434
735	12.8	68.08	12K / 401	12030	16.	77.	73.	49.	43.	7.1	242.	91.4	256.4	38.2	1.379
736	12.8	56.65	13K / 450	13500.	-5.	76.2	62.5	58.	39.	7.05	246.	90.6	260.4	37.8	1.365
737	12.8	40.85	16K / 538	16140.	0.	76.2	48.	68.	38.	7.0	250.	90.6	264.4	38.2	1.365
738	12.8	21.24	19K / 640	19200.	17.	76.5	30.	76.	38.	7.0	254.	90.9	268.4	38.6	1.394
739	12.8	25.60	14K / 627	18810.	27.	77.0	34.	85.	40.	7.0	255.	91.4	269.4	39.0	1.401
740	12.8	44.12	16K / 533	15770.	13.	78.0	51.	94.	42.	7.0	259.	92.4	272.4	40.2	1.452
741	12.8	67.0	12K / 413	12390.	16.	78.	72.	107.	44.	7.0	262.	92.4	276.4	41.4	1.495
742	12.8	94.33	7K / 256	7680.	18.	80.	97.	123.	48.	7.0	265.	94.4	279.4	43.0	1.553
743	12.8	106.21	5K / 169	5070.	32.	81.	108.	135.	52.	7.0	269.	95.4	283.4	44.0	1.581

DATA PT.#	Δh_{is} BTU/lb	J_{v_1} ft³/lb	$\dot{W}$ lb/sec	$J\dot{W}\Delta h_{is}$ ft lb/sec	P_{SWAT} ft lb/sec	P.R.	η/η_T	T/T_2	U	C_o	U/C_o
733	20.3 [illegible]	.16	.0899	1419.8	507.3	13.10	.357		129.3	1008.3	.128
734	20.1 68.2-48.1	.16	.0885	1383.9	681.3	13.0	.492		194.3	1003.3	.193
735	19.8 67.3-47.5	.155	.0852	1358.6	786.7	12.89	.579		303.2	995.8	.304
736	19.5 66.7-47.2	.160	.0863	1309.2	734.65	12.89	.561		340.2	988.2	.344
737	19.8 66.5-46.7	.165	.0855	1317.0	633.35	12.95	.480		406.8	995.8	.4085
738	19.9 66.5-46.7	.168	.0852	1312.4	391.7	13.00	.298		483.9	995.8	.485
739	19.6 66.8-47.2	.173	.0844	1286.9	462.5	13.05	.359		474.1	990.8	.478
740	19.7 67.2-47.5	.175	.0852	1305.8	677.6	13.20	.518		403.0	913.3	.405
741	20.0 67.5-47.5	.177	.0859	1336.6	799.1	13.20	.596		312.3	1000.8	.312
742	20.1 68.0-47.7	.180	.0868	1357.3	695.18	13.50	.512		193.5	1003.3	.192
743	20.3 68.6-48.3	.185	.0866	1367.7	517.27	13.62	.378		127.7	1008.3	.126

Sundstrand Aviation
division of Sundstrand Corporation

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July 14, 1971
L7-ONR-190

ONR
Chief of Naval Research
Department of the Navy
Washington, D.C. 20360

Attention: Mr. J. R. Patton, Jr., Code 473

Subject: Contract No. 00014-68-C-0406
"Final Technical Report on an Analytical and Experimental Research Program to Optimize Turbine Nozzle for Off Design Performance of Partial Admission Turbines"

Reference: Sundstrand Letter L6-ONR-184, dated 6/24/71
Same Subject

Gentlemen:

Please find enclosed ~~two~~ (1/2) ~~sets~~ of illustrations, photos, etc. to replace the Xerox copies as transmitted with the original reports per the reference letter.

Very truly yours,

SUNDSTRAND AVIATION
Division of Sundstrand Corporation

J. G. Buell
Contract Program Manager

JGB:dlr

Enclosure

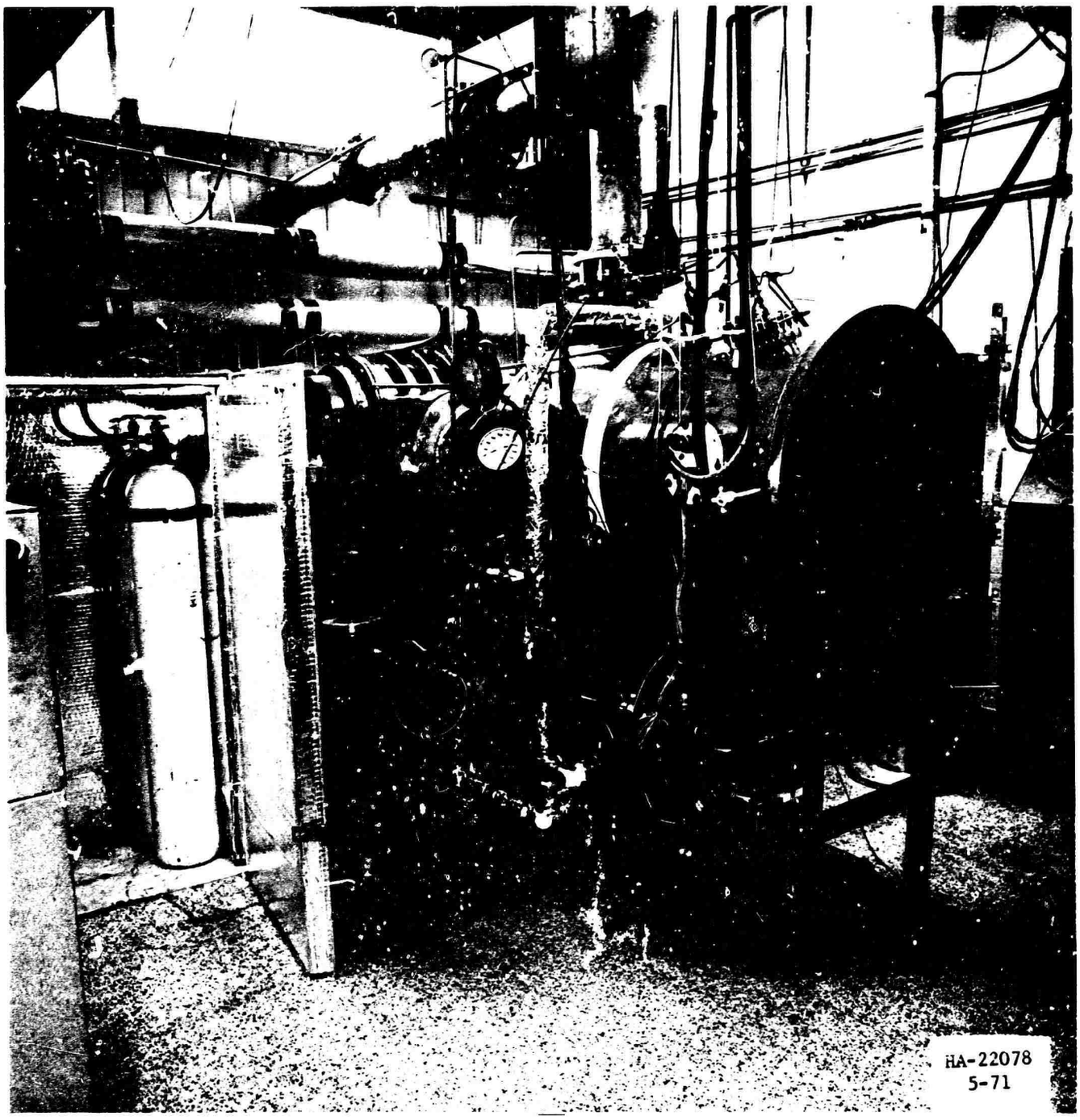


FIGURE 1 TURBINE TEST CHAMBER AND APPARATUS.

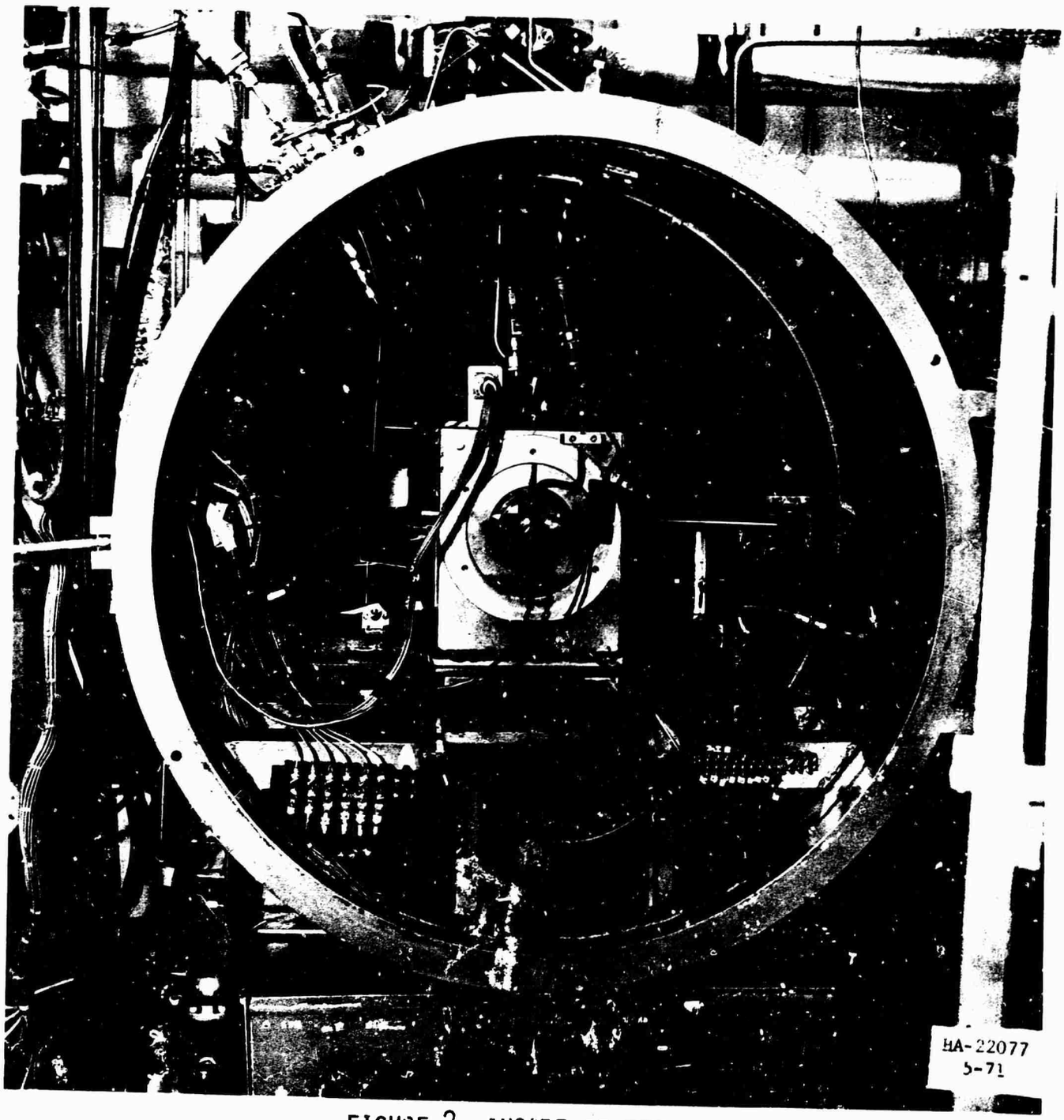


FIGURE 2 INSIDE OF TEST CHAMBER WITH RIG INSTALLED

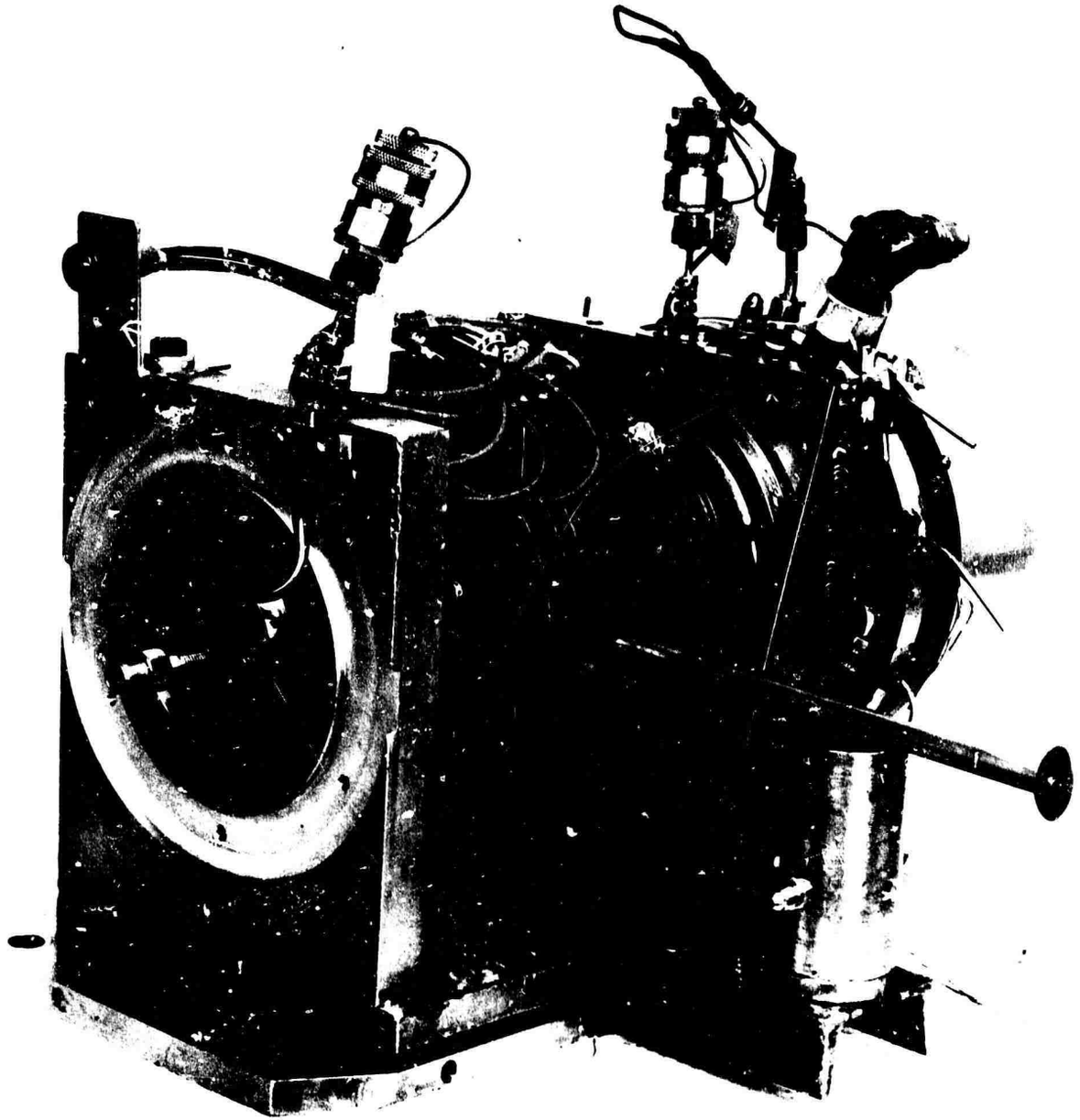
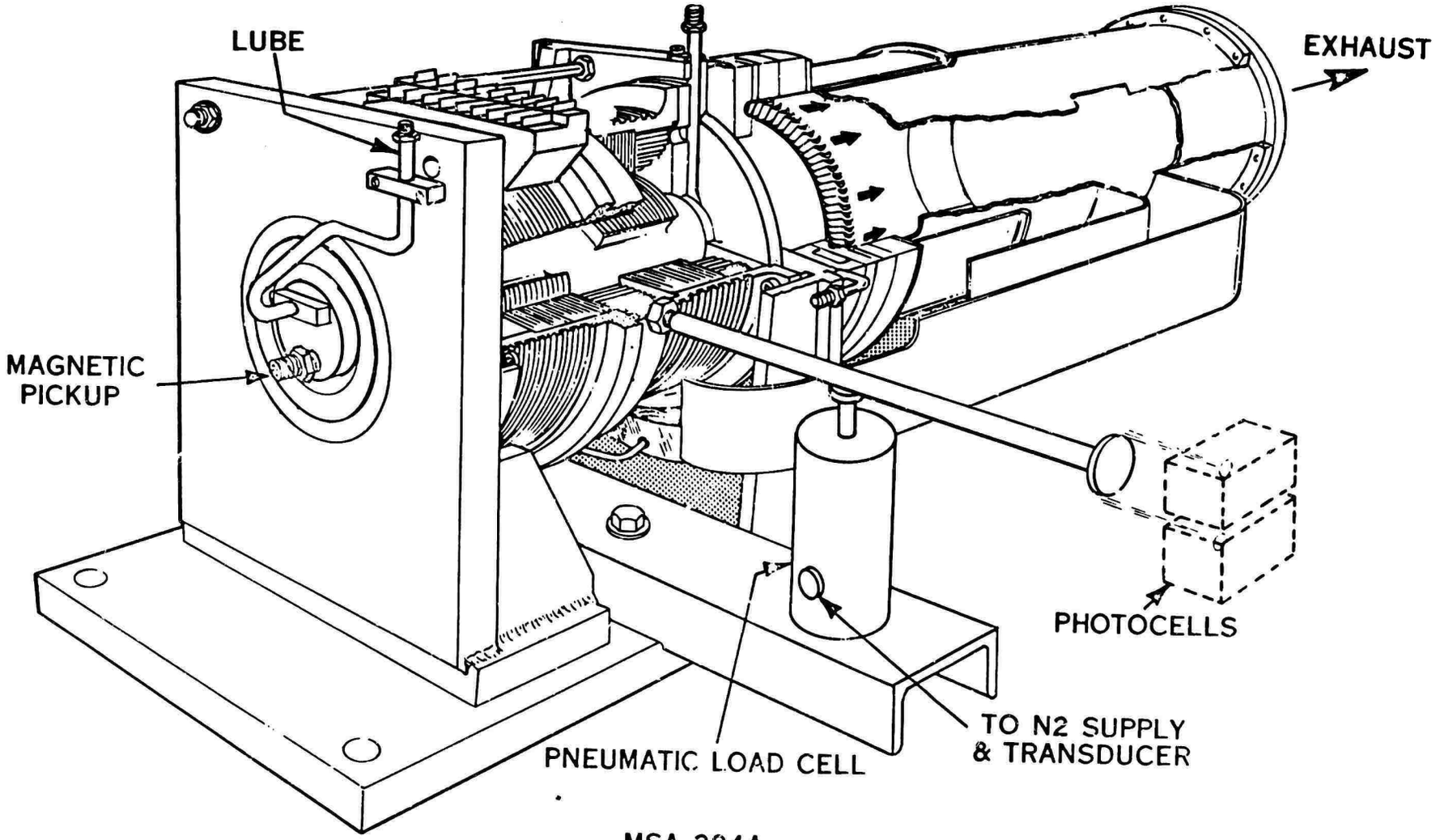


FIGURE 3 TURBINE TEST RIG



MSA 394A

FIGURE 4 TURBINE TEST RIG-DIAGRAM

HA-22125
6-71

FIGURE 5 TEST RIG AND COMPONENTS