FLUIDYNE ENGINEERING CORPORATION

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MASTER

MHD DIFFUSER MODEL TEST PROGRAM

by

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Conducted for

Argonne National Laboratory
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Approved ______

Owen P. Lamb
Vice President

DISCLAIMER

PREFACE BY

ARGONNE NATIONAL LABORATORY

The magnetohydrodynamic (MHD) diffuser testing program was conducted to establish a satisfactory diffuser design for the U-25 channel project. Consequently, the goals of this testing program were highly mission oriented, that is, determine the correct diffuser design for the U-25 generator channel supplied by the United States for testing in the U-25 Facility at the High Temperature Institute, Moscow, USSR. This program did not include the development of any general analytical methods to predict the performance of MHD diffusers. However, these results may be useful to those embarking on a general program to analytically predict the performance of such diffusers.

The overall performance of an MHD generator is dependent upon several factors, one of which is the diffuser configuration. The configuration establishes the performance of the diffuser, specifically, its pressure recovery coefficient, and its stability relative to the flow field. Because both hydrodynamic and electromagnetic forces affect boundary layer growth, analytically selecting a diffuser is a complicated problem, particularly for diffusers with two dimensional divergence. In addition the configuration and performance of the diffuser must be compatible with the inlet region of the U-25 facility steam generator. The discharge from the diffuser into the steam generator should not produce detrimental effects, either structurally or thermally, on the steam generator. Therefore, within the resource constraints of the project and with consultation with the designer of the MHD channel (Modern Electric Power Products and Service Company - MEPPSCO), the diffuser model/steam generator simulator tests were planned and implemented. Argonne National Laboratory contracted with FluiDyne Engineering Corporation to perform the tests.

Specifically, the purpose of these diffuser tests was to select, from several designs, the best diffuser design, determine the pressure recovery coefficient for this diffuser, to verify that the selected diffuser does not exhibit separated flow or unstable flow, and to assess the pressure loading the selected diffuser imposes on the U-25 steam generator.

This report describes in detail the diffuser configurations tested, the tests performed, the measurements made, and the results of each test.

SUMMARY

Experimental results of the aerodynamic performance of seven candidate diffusers are presented to assist in determining their suitability for joining an MHD channel to a steam generator at minimum spacing. The program was performed at the FluiDyne Engineering Corporation Laboratory for Argonne National Laboratory under ANL Purchase Order No. 31-109-38-3390. The three dimensional diffusers varied in area ratio from 2 to 3.8 and wall half angle from 2 to 5 degrees. The program consisted of five phases: I, tailoring a diffuser inlet nozzle to a 15 percent blockage; II, comparison of isolated diffusers at enthalpy ratios 0.5 to 1.0 with respect to separation characteristics and pressure recovery coefficients; III, recording the optimum diffuser exit flow distribution; IV, recording the internal flow distribution within the steam generator when attached to the diffuser; V, observing isolated diffuser exhaust dynamic characteristics.

The 2 and 2-1/3 degree half angle rectangular diffusers showed recovery coefficients equal to 0.48 with no evidence of flow separation or instability. Diffusion at angles greater than these produced flow instabilities and with angles greater than 3 degrees random flow separation and reattachment.

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DEFINITION OF SYMBOLS

A	Area in^2
A^*	Sonic throat area
B	Blockage
b	Width
C_d	Discharge coefficient
C_p	Pressure Recovery Coefficient
h	Height
M	Mach number
$\overline{m}$	Mass flow parameter, $W\sqrt{T_t}/P_tA$
P	Pressure, psia
Re	Reynolds number
T	Temperature, °R
X	Length
δ	Boundary Layer Thickness
δ^*	Displacement Thickness
ν	Kinematic viscosity

Subscripts

a	Ambient
e	Exit
i	Inlet
t	Total
o	Facility ASME Metering Station
1	Diffuser Nozzle Inlet
2	Diffuser Throat

1.0 INTRODUCTION

The diffuser system employed with an MHD generator channel requires careful consideration of both operating efficiency as established by pressure recovery as well as aerodynamic instability evidenced by flow separation. To assist in defining suitable criteria, the reported test program has been contracted between FluiDyne Engineering Corporation and Argonne National Laboratory. Test hardware designed by MEPPSCO has been furnished by ANL.

The MHD generator channel is of three dimensional rectangular construction with an accelerated subsonic flow choking at the design point. Space limitations between the channel and downstream steam generator impose severe limitations on the intervening diffuser. An optimum diffuser provides maximum pressure recovery in addition to good pressure and velocity distribution. The choices of diffuser geometry encompass shallow to relatively wide wall angle with increasing area ratio. Tradeoffs include higher outlet velocities vs non separating flow.

In this test program, diffuser inlet flow was initially tailored to attain prototype blockage. Pressure recovery coefficients and flow quality were then determined for the seven diffusers. A detailed total pressure survey was then made of the best performing diffuser. Three selected diffusers were then joined to a steam generator simulator and flow and pressures distributions internal to the simulator were measured. Finally detailed exit total pressure time histories of the 2 degree and 5 degree divergence diffusers were charted.

The report describes the test facility and hardware, the data collection and analysis procedures, and summarizes in graphical and tabular form the principal results.

2.0 TEST APPARATUS

The test facility and hardware used to perform the diffuser model evaluation program is shown in the photographs of Figure 1. Ambient temperature compressed air is introduced through a flow conditioning nozzle to the diffuser and exhausted into a steam generator simulator. Hardware furnished by ANL for this study consisted of a single diffuser inlet nozzle, 7 three-dimensional diffusers, and a steam generator simulator with exhaust elbow. The scale (1:10) model was designed by MEPPSCO and fabricated by Evans Industries. Portions of the instrumentation and hardware modifications were done by FluiDyne. The test facility including the air supply and metering system and the instrumentation monitors were furnished by FluiDyne.

2.1 Model Description

A drawing of a typical diffuser joined to the flow conditioning nozzle is shown in Figure 2. The nozzle consists of a two-dimensional contoured inlet adapter joining the 8 inch facility piping to the two by four inch nozzle channel duct. This inlet has straight side walls and the top and bottom walls are contoured from 6.5 inch vertical height to 2 inch height at the exit. The rectangular duct section was originally fabricated to a 42 inch overall length with the intent of reducing this length until a 15 percent boundary layer blockage was attained in testing. The contoured flanged inlet was socketed and joined to the duct with soft solder. Three cutoffs were made to achieve the desired blockage with a final nozzle overall length of 22.4 inches. To accelerate the boundary layer growth, the walls of the rectangular nozzle duct were artificially roughened by milling a diagonal waffle pattern into the surface. The resulting protuberances were 0.080 inch square at 0.205 inch square centers and projected 0.040 inches above the surface. The downstream three inches of the nozzle duct adjoining the diffuser attachment flange were not roughened. A single static pressure tap was placed in this section along the centerline of the 4-inch width and 1-inch upstream of the exit.

Downstream of the nozzle duct, a flanged joint permits attachment of the diffuser to the nozzle. A typical diffuser joined to the nozzle is detailed in Figure 2. The diffusers were tapered rectangular cross-section structures all of a common 15.2 inch length and 2 by 4 inch entrance dimensions varying only in area ratio or diffusion angle and aspect ratio. Comparative photographs of the seven diffusers are shown in Figure 3. Diffuser geometry is tabulated below.

Diffuser Number	Dimensions inches		Divergence Half Angle		Area Ratio	Aspect Ratio
	Entrance	Exit	Top	Side		
1	2 x 4	3.14x5.07	2.1	2.0	1.99	1.61
2	2 x 4	3.77x6.08	3.2	3.8	2.86	1.61
3	2 x 4	2.95x5.27	1.8	2.3	1.95	1.78
4	2 x 4	3.26x5.26	2.3	2.3	2.14	1.61
5	2 x 4	3.45x5.46	2.7	2.7	2.35	1.58
6	2 x 4	3.62x5.63	3.0	3.0	2.55	1.56
7	2 x 4	4.50x6.75	4.6	5.0	3.80	1.50

The diffusers were instrumented with thermocouples and pressure taps spaced in rows along the centerline of the top wall and side wall.

A steel tank shown in Figure 7 was provided to immerse the nozzle and/or the nozzle and diffuser into liquid nitrogen to obtain the desired enthalpy difference across the nozzle or diffuser wall.

The steam generator simulator is detailed in Figure 4. The simulator consists of an outer 14-inch diameter by 34-inch long cylindrical shell surrounding a concentric cylindrical section reducing from 12-1/4 inch to 9 inch diameter. The diffuser exhausts into the forward 12-1/4 inch diameter by 8-inch long cylinder which converges to a 9-inch diameter by 16-inch long cylinder. The intervening reducing section consists of 84 alternating ribs and slots. Figures 12a and 12b provide photographic details of the steam generator simulator internal and external construction. The prototype generator has an outer shell made up of longitudinal water tubes and the inner shell of helically wound tubes. In the reducing section of the inner tube bundle the tubes straighten into a converging grid of 84 longitudinal tubes joining to the reduced diameter downstream helical core section.

The downstream end of the simulator terminates in a 14-inch diameter 3-gore, 90 degree exhaust elbow.

2.2 Instrumentation

Model instrumentation consisted of static pressure orifices and thermocouples installed on the model surfaces and total pressure probes immersed into the flow stream. Total pressures in the model and static pressures on the surfaces were recorded on multiple tube 100-inch mercury manometers graduated at 0.2 inch intervals and readable to 0.05 inch. Manometer boards are photographed on Polaroid film and read with an opaque projector from which computer data tapes are punched for final reduction and tabulation.

In Phase IV recording of pressure and flow distribution within the steam generator simulator, seven static pressure readings were measured with Statham PM822 differential transducers and recorded on a CEC 18 channel oscillograph using CEC 7-319 galvanometers. This same instrumentation provided a chronograph of total pressures in the Phase V study of diffuser dynamics.

The higher stagnation pressure upstream of the 2.062 inch diameter ASME long radius facility flow metering orifice was measured on a Seegars bourdon tube gage accurate to 0.1 percent of full scale.

Temperature measurements are recorded on a Vidar model 502B digital recorder and printer using iron constantan ANSI type J thermocouples.

A single pressure orifice located along the centerline and one inch upstream from the nozzle-diffuser interface was installed to measure the nozzle throat static pressure. Each of the seven diffusers was fitted with twelve static pressure taps divided into two rows equally spaced along the top wall and sidewall centerline. The top row was numbered T1 to T6 and the side row S1 to S6 reading upstream to downstream. Three thermocouples were positioned opposite alternate pressure orifices on the bottom wall. This instrumentation is shown in Figures 2 and 3.

The steam generator simulator was instrumented with six 10-probe total pressure rakes. The rakes lettered A to F axially in the flow direction are located in Figure 4 and are visible in the photograph of the simulator interior in Figure 12b.

Rake A positioned immediately downstream of the diffuser exit has 10 probes equally spaced over a 6-inch length. Rakes B, C and D are identical each having 10 probes equally spaced over a 7-inch length. Rakes E and F are identical and contain 10 probes equally spaced along a 7-inch length except the third and fourth probes are shifted to lie immediately inside and outside the core wall. All survey rake probes are numbered from the wall toward the centerline.

The seven wall static orifice penetrations, numbered 1 to 7, provided to mount transducers are located in Figure 4. Number 1, 2, 3 and 5 measure wall pressures in the inner passage and 4 and 6 in the annulus. The exhaust elbow is fitted with the number 7 transducer located at intersection of the simulator centerline with the elbow wall.

Six additional wall static orifices letter G1 to G6 were added to the simulator following Run IV-26. The first five are located in the outer annulus at 4-inch centers opposite the 9-inch reduced internal cylinder and the last tap is positioned in the core 3 inches upstream of the aft end of this 9 inch cylinder.

3.0 TEST PROCEDURE AND RESULTS

The test program was subdivided into five phases. The first, Phase I, entailed 24 runs numbered I-1 to I-24 to establish the desired 15 percent nozzle blockage. Phase II consisted of 16 runs, II-1 to II-16, and included the measurement of 67 pressure recovery coefficients on the first six diffusers. Phase III, runs III-1 to III-6, provided detailed exit flow surveys for diffuser Number 1, which was selected by ANL as "best". Phase IV entailed the steam generator simulator pressure and flow surveys when coupled with diffusers 1, 4 and 7, Runs IV-9 to IV-52. The final Phase V consisted of diffuser only exit total pressure histories Runs V-1 to V-8 to compare diffuser 1 and 7 exit flow dynamics.

3.1 Phase I-Nozzle Blockage

Phase I of this program entailed tailoring the diffuser inlet flow nozzle to provide the desired 15 percent flow blockage. The nozzle duct was intentionally fabricated with excess length such that the duct length could be reduced sequentially until the desired blockage was attained. Blockage is defined as the ratio of the difference of the geometric and inviscid core flow area to the geometric flow area, or in other words, a measure of the loss of geometric flow area in the displacement boundary layer thickness.

The blockage can be calculated if the mass flow rate is determined independently and the test nozzle free stream static and total pressure measured. The ratio of one-dimensional inviscid flow area calculated for the measured nozzle throat pressure and pressure ratio to the geometric nozzle throat area is the ratio of effective to geometric flow area or the complement of the blockage.

$$B = 1 - A_{eff}/A_{geom}$$

Assigning the subscript, o, to the independent ASME metering station and subscript, 2, to the test nozzle, and writing a continuity statement between the two indicates:

$$\bar{m}_o P_{t_o} C_{d_o} A_o \,/\, \sqrt{T_{t_o}} = \bar{m}_2 P_{t_2} C_{d_2} A_2 \,/\, \sqrt{T_{t_2}}$$

where $\bar{m}$ is the mass flow parameter; P_t and T_t total pressure and temperature; C_d nozzle flow coefficient and A the nozzle geometric flow area. Test nozzle blockage is then:

$$B = 1 - C_{d_2} = 1 - \frac{\bar{m}_o P_{t_o} C_{d_o} A_o}{\bar{m}_2 P_{t_2} A_2} \sqrt{\frac{T_{t_2}}{T_{t_o}}}$$

The flow coefficient C_{d_o} for the 2.062 inch diameter ASME long radius metering nozzle is calculated from a semi empirical boundary layer relationship.

$$C_{d_o} = 1 - .184/Re^{.2}$$

where Re is the Reynolds number based on throat diameter and is of the order 2.8×10^6.

If a uniform boundary layer is assumed on the rectangular test nozzle of width b and height h, the effective flow area can be calculated by subtracting the area defined by the displacement thickness δ^*, from the geometric area.

$$A_{eff} = (b-2\,\delta^*)(h-2\,\delta^*) = bh - 2(b+h)\,\delta^* + 4\,\delta^{*2}$$

or blockage: $$B = 1 - \frac{A_{eff}}{A_{geom}} = \frac{2(b+h)\delta^*}{bh}$$

or the desired: $\delta^* = B\, bh/2(b+h)$

For the 2 by 4 inch test nozzle at 15 percent blockage, the desired displacement thickness is 0.1 inch. Using turbulent flat plate boundary layer analogy, the displacement thickness is proportional to the boundary layer thickness which is proportional to the length and the inverse one-fifth power of the Reynolds number.

Summarizing: $$\frac{\delta}{X} = \frac{K}{Re^{.2}} = K \left(\frac{\nu}{VX}\right)^{.2}$$

and $$\delta^* \simeq \delta \simeq X^{.8}$$

Iterations determined the desired length

$$X_{i+1} = X_i \left(\frac{\delta^*_{i+1}}{\delta^*_i}\right)^{1.25} = X_i \left(\frac{B_{i+1}}{B_i}\right)^{1.25}$$

The actual test procedure required throttling ambient temperature compressed air from the facility 500 psi storage system and exhausting the flow from the test nozzle. When stable flow conditions are attained, both ASME meter and test nozzle pressures and temperatures are simultaneously recorded. Where wall to gas stream enthalpy ratios less than one were desired, the entire nozzle duct was immersed in a liquid nitrogen bath. The tank was similar to that shown in Figure 7, however, of reduced length to accommodate only the nozzle duct.

Phase I test results are tabulated in Figure 5 and can be summarized as follows:

Run Numbers	Nozzle Test Length	Observed Blockage	Displacement Thickness	Desired Length
I-1 to I-11	39.6	.235	.157	22.6
I-12 to I-15	31.0	.207	.138	20.7
I-16 to I-20	24.0	.178	.119	19.3
I-20 to I-24	20.0	.159	.106	18.6

The intermediate steps were taken in the desire to be conservative in cutting off the nozzle length which would require complete refabrication if over shortened. The Reynolds number for the choked duct flow based on the hydraulic diameter of 0.22 ft. was 1.95×10^6. Blockage was observed to be independent of enthalpy ratio over the range 0.48 to 1.0 observed in the tests. Results are plotted in Figure 6.

3.2 Diffuser Recovery

The objective of Phase II was to assist in optimizing diffuser design as indicated by the pressure recovery and absence of flow separation. After the proper inlet nozzle blockage had been established a flange was attached to the nozzle exit to mate with the diffuser flange. The diffuser was attached and diffuser total and static pressures recorded at six flow rates indicated by Mach numbers of 0.6, 0.7, 0.8, 0.9, 0.95 and 1.0 at the nozzle throat. Diffusers Number 1 and 3 were tested both with and without immersion in the liquid nitrogen bath in order that the wall to gas stream enthalpy ratio could be varied over the range 0.3 to 1.0. Diffusers 2, 4, 5 and 6 were tested under ambient conditions only with enthalpy ratios essentially equal to 1. Photographs of a diffuser in the liquid nitrogen bath are shown in Figure 7. After observing that diffuser recovery coefficients were independent of enthalpy ratio, the use of the liquid nitrogen bath was discontinued. The high heat flux rates of the order 25,000 Btu/ft^2-hr resulted in film boiling, a problem alleviated by rotating the nozzle and diffuser to eliminate trapping beneath the horizontal heat transfer surface. Liquid nitrogen consumption was also relatively high requiring approximately 30 gallons per run.

In Phase II, the twelve-wall static pressures, three-wall total temperatures and four diffuser exit total pressures were recorded for each test condition. Diffuser performance was determined by the pressure recovery coefficient defined by:

$$C_p = \frac{P_e - P_i}{P_{t_i} - P_i}$$

where P_e is the diffuser exit static pressure equal to the average of the wall static pressure nearest the exit T_6 and S_6; P_{t_i} and P_i are the inlet total and static pressures at the nozzle throat.

Observed pressures and calculated pressure recovery coefficients for diffusers number 1 through 6 are tabulated in Figure 8. Again, enthalpy ratio did not appear to be a significant parameter either in determining recovery coefficient or nozzle blockage. Mach numbers are calculated from the static pressure at the nozzle exit. Apparent Mach numbers in excess of one result from supersonic expansion in the diffuser which can feed back through the thick (≃ .8 inch) boundary layer a static pressure less than choking. Small total pressure losses in the nozzle duct were observed in Phase I, i.e., between the nozzle inlet, P_{t_1} and the nozzle exit, P_{t_2}. Since no losses were expected in the core flow in the entrance region, a total pressure probe was installed at the diffuser inlet in Runs II-13 and II-14. No pressure loss was observed and it was concluded that P_{t_1} and P_{t_2} were equal. It is noted that P_{t_2} probe interference did effect pressure recovery coefficient repeatability and it was deemed desirable to remove it from the diffuser inlet. Data scatter was also attributed to less than ideal alignment of certain diffuser inlets with the nozzle exit. A further significant observation relative to diffuser 2, 5 and 6 flow instabilities in Runs II-1, II-7, II-8 and II-11 is emphasized. These instabilities were visually observed by the random oscillations of the manometers connected to the four total probes placed at the nozzle exit.

A comparative graph of pressure recovery coefficient vs Mach number for Diffusers 1 to 6 is plotted in Figure 9. Some caution is required in comparing these observations with other data. Uniqueness insofar as the physical placement of the test instrumentation may place some bias in this data.

The recovery coefficient expresses the ratio of static pressure rise in a diffusing passage to the ideal pressure rise that would be obtained in a one-dimensional isentropic diffuser of infinite area ratio with the same centerline velocity. With zero blockage, the ideal recovery is a function solely of the area ratio. The presence of inlet and exit blockage reduce the effective area ratio significantly. In the straight nozzle inlet duct blockage remains essentially constant; however, diffuser exit blockage is a much more variable function of area ratio, aspect ratio, length to width ratio and diffusion angle. For the tested geometry length and entrance dimensions were fixed and diffusers differ only in exit dimension, effecting area ratio, aspect ratio and diffusion angle. Rectangular diffusers with area ratios approximately equal to 2 and wall half angles less than about 2.5 degrees have exit blockage approximately equal to 0.5 and recovery coefficients of the order 0.5. With diffusion angles greater than 3 degrees, separation is very likely to occur and blockage and recovery coefficients are variable and indeterminate. The concluding tabulation summarizes these statements and observations for the first six diffusers.

Diffuser Number	Area Ratio	$C_{p_{ideal}}$ Blockage=0	Observed Inlet Blockage	Estimated Exit Blockage	Estimated Effective A/A*	Estimated Effective C_p	Observed C_p
1	1.99	.868	.16	.50	1.18	.54	.47
2	2.86	.936	.16	--	--	--	.40
3	1.95	.860	.16	.50	1.16	.51	.47
4	2.14	.884	.16	.55	1.15	.49	.48
5	2.35	.906	.16	.60	1.12	.45	.46
6	2.55	.921	.16	--	--	--	.45

NB omitted values divergence too large to estimate.

3.3 Best Diffuser Survey

Phase III was concerned with defining the character of the flow exhausted from the best performing diffuser in Phase II. Detailed total pressure measurements of the diffuser exit flow were made on Diffuser number 1, that selected by ANL as exhibiting the best performance. A ten-probe total pressure rake positioned at six vertical spacings across the exit plane is shown in Figure 10. Probes are spaced at 0.4 inch intervals from the wall on each side leaving a 1.07 inch gap in the center. The initial survey was taken at 0.32 inch from the lower wall and successively raised at 0.50 inch increments resulting in a 60-point matrix defining the pressure distribution. The pressure measurements were recorded at six Mach numbers: 0.6, 0.7, 0.8, 0.9, 0.95 and 1.0.

Isobars and local total to diffuser inlet total pressure ratios are plotted for Runs III-1 to III-6 in Figures 11a to 11f. The plots indicate good total pressure distribution. Maximum observed total pressure ratio decreases from .975 to .966 while Mach number increased from 0.6 to 1.0. The corresponding average total pressure ratioed to inlet total pressure decreases from .913 at M = .6 to .820 at M = 1.0. Although related to the diffuser exit blockage, this is not an adequate estimate of blockage as the very significant deficit in the boundary layer next to the wall is not included.

3.4 Steam Generator Flow Surveys

The objective of Phase IV of the test program was to provide velocity and pressure distribution data with the diffuser coupled to a simulated steam generator. Large rates of diffusion may result in flow separation with resultant dynamic instabilities overstressing heater internals. Lower rates of diffusion lead to undesirable higher inlet velocities. Flow distribution is directly related to heat exchange efficiency. Compromises in diffuser geometry are clearly related to optimizing overall system efficiency.

The model of the steam generator was installed with Diffusers number 1, 4 and 7, to establish the interaction between diffuser and steam generator. Photographs of the test setup are shown in Figures 12a and 12b. Total pressure measurements in the simulator were taken on the six 10-probe rakes shown in Figure 12b. The axial rake position has been defined in Section 2.1 under the test hardware description. To complete a detailed total pressure survey, the rakes were rotated at 30 degree tangential increments to completely traverse the circumference. With Diffuser Number 1, one quadrant was surveyed at 10 degree increments to detect smaller perturbations. Surveys were made at two mass flow rates corresponding to Mach numbers 0.75 and 1.0 at the nozzle throat. Figures 13a and through 13m plot the pressure distributions for Diffuser Number 1; Runs IV-9 to IV-20. Figures 14a through 14m are similar plots for Diffuser Number 4 (Runs IV-21 to IV-40) and Figure 15a through 15m for Diffuser Number 7 (Runs IV-41 to IV-52). The non dimensionalized plots of P_t local to P_{t_1} show a fair symmetry for Diffusers 1 and 4 with centerline pressure ratios slightly less than 1.0 at the entrance to the simulator. Diffuser Number 7 indicates a substantial degree of asymmetry and maximum total pressure ratios of 0.9.

Concurrently with the pressure surveys, static pressure time histories were charted at 7 axial stations along the steam generator simulator. Representative copies of the oscillograph traces are shown for Diffusers 1, 4 and 7 in Figures 16a, 16b and 16c for Runs IV-10, IV-38 and IV-44, respectively. Transducers 1 and 2 were placed upstream of the convergence in the core and transducers 3 and 5 downstream of the convergence in the core region. Transducers 4 and 6 are positioned in the annulus. Comparing Figures 16a and 16b with 16c, indicate a marked increase in amplitude of the pressure fluctuations with Diffuser Number 7. Figures 16a and 16b (Diffusers 1 and 4) show static pressures depressed approximately 0.3 $\pm$ 0.2 psi below ambient in the steam generator simulator at frequences of 150 to 200 HZ in the downstream core and 300 to 400 HZ elsewhere. Figure 16c (Diffuser 7) indicates comparable depressions and frequencies, but fluctuations of roughly twice the amplitude. Oscillograph traces for all runs are similar.

Figure 17 presents two flow visualization photographs comparing the internal boundary layer flow of the simulator coupled to Diffusers 1 and 7. The surface flow is delineated by stippling the walls with a mixture of lampblack dispersed in glycerine which then moves when exposed to the surface velocities encountered in testing. Attention is directed to the flow reversal, i.e., downstream to upstream, which appears in the outer annulus.

In Figure 18, pressure recovery coefficients are tabulated for each of the test points in Phase IV. The average pressure coefficients for Diffusers 1, 4 and 7 are respectively 0.454, 0.478 and 0.270. This tabulation also provides an index of the Phase IV, steam generator pressure survey runs.

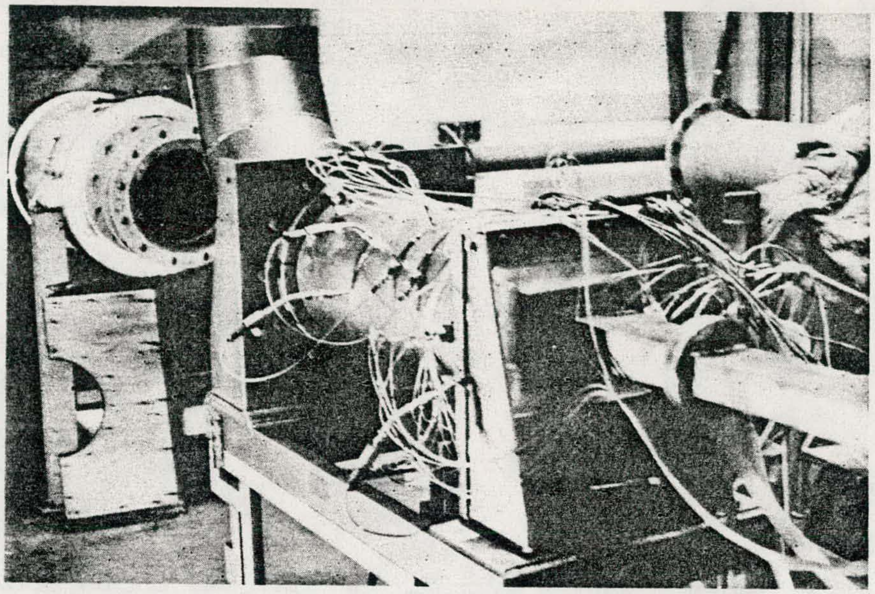
3.5 Diffuser Flow Dynamics

The final Phase V of this program was concerned with verifying the diffuser exit flow dynamics be recording a chronograph of diffuser exit total pressure distributions. Photographs of the diffuser total rakes and their individual probe spacings are shown in Figure 19. Typical traces are presented in Figures 20a and 20b for Diffusers 1 and 7. Probes were designated 6 to 11 reading from left to right as shown in the photographs. Probes were connected to transducers with galvanometers recording the outputs on linagraph paper on an oscillograph. Figure 20a of Diffuser Number 1 (Run V-8) indicates a symmetrical total pressure profile; approximately ambient at the wall (probes 6 and 11), 2.2 psi above ambient on probes 7 and 10, and 4.4 psi above ambient on probes 8 and 9 nearest the centerline. Figure 20b of Run V-4 indicates a marked asymmetry in the exit flow from Diffuser Number 7. A typical shift in pressure level is noted as the flow separates from one wall and reattaches to the opposite wall. A tabulation of exit pressures for all eight Phase V runs is presented in Figure 21. The random separation and reattachment is noted in both Diffuser 7 Runs V-2 and V-4 with Mach numbers of 1.0. Non-symmetrical flow is also evidenced in Runs V-1 and V-3 at Mach .75, but transitory separation and reattachment was not recorded. Diffuser Number 1 shows a non separating uniformly symmetrical flow at both Mach numbers in Runs IV-5 to IV-8. Pressure recovery coefficients for the Phase V testing indicate a value of 0.29 for Diffuser 7 and 0.44 for Diffuser 1.

4.0 CONCLUSIONS

This test program has demonstrated that nozzle blockage can be conveniently established by tailoring the length of a duct of uniform cross section. Both blockage and diffuser performance were observed to be independent of wall to gas stream enthalpy ratio. Rectangular diffusers with area ratios of 2 and diffuser half angles of 2 degrees provide stable flow and pressure recovery coefficients equal to 0.48 (typically Diffuser Number 1). Area ratios greater than 2.5 with diffusion angles greater than 3 degrees exhibited random transitory flow separation. The most rapidly expanding diffuser tested with an area ratio equal to 3.8 and diffusion angles 4.8 degrees (Diffuser Number 7) gave a pressure recovery coefficient equal to 0.27. Good diffuser exit flow distribution was attained in Diffuser Number 1.

Internal pressure surveys of the steam generator simulator when joined with Diffuser Number 1 indicate symmetrical flow distribution, whereas with Diffuser Number 7 poor symmetry and flow separation were observed. With Diffuser Number 1 maximum local total to diffuser inlet total pressure ratios were higher than Diffuser Number 7. Absolute simulator total pressure levels were about the same since Diffuser Number 1 inlet total pressures were lower than with Diffuser Number 7, when maintaining choked flow at the design point. Greater pressure fluctuations were observed with Diffuser Number 7 than with Diffuser Number 1. Flow reversal in the steam generator simulator was recorded with flow visualization techniques.



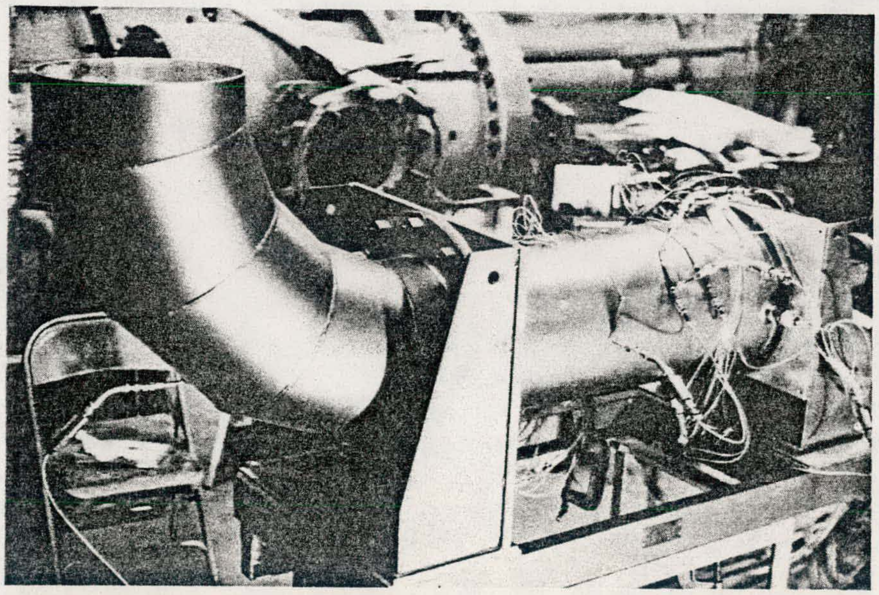


FIGURE 1. TEST FACILITY PHOTOGRAPHS

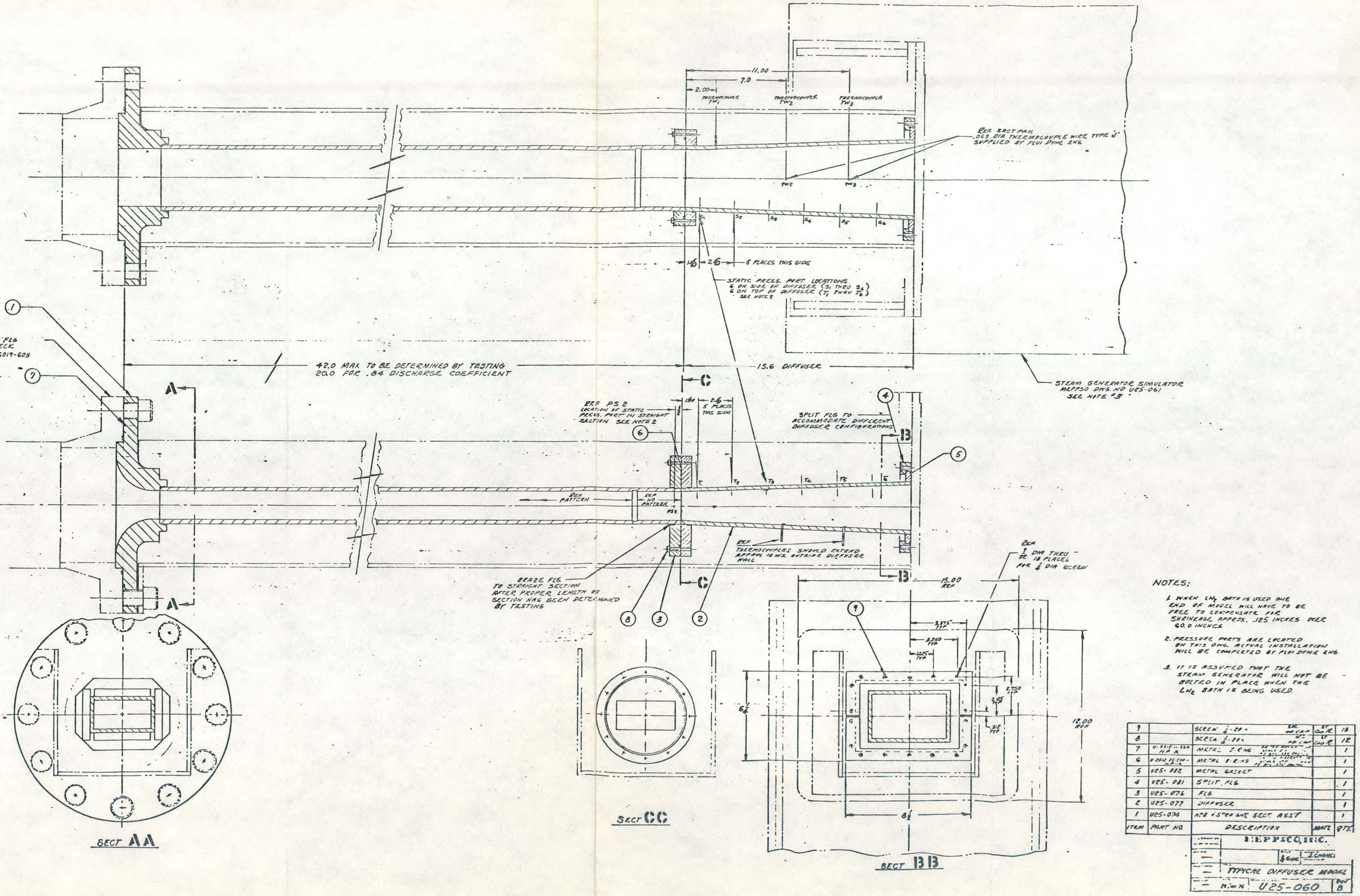
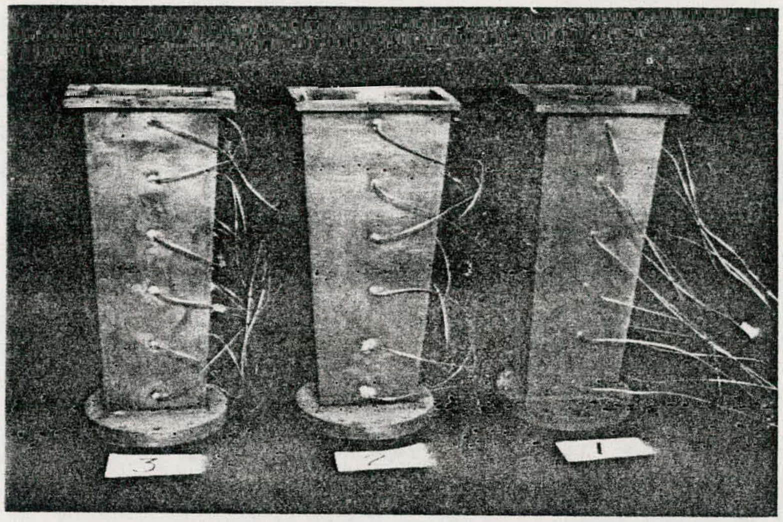


FIGURE 2. NOZZLE DIFFUSER ASSEMBLY



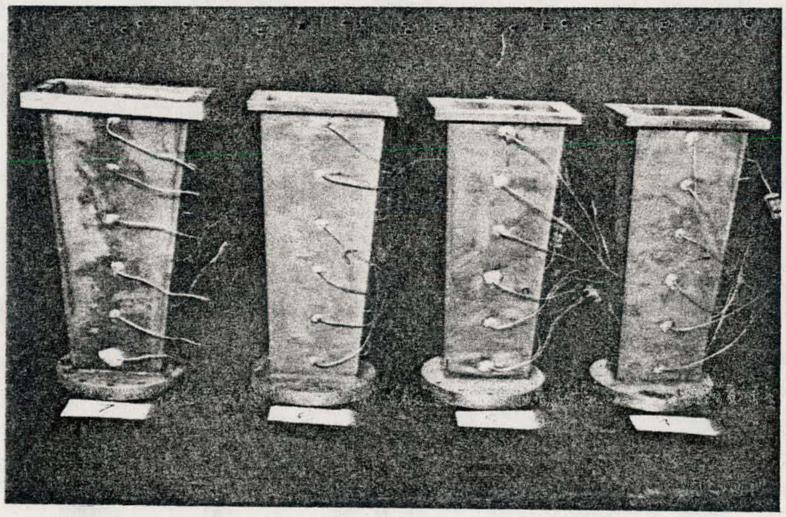
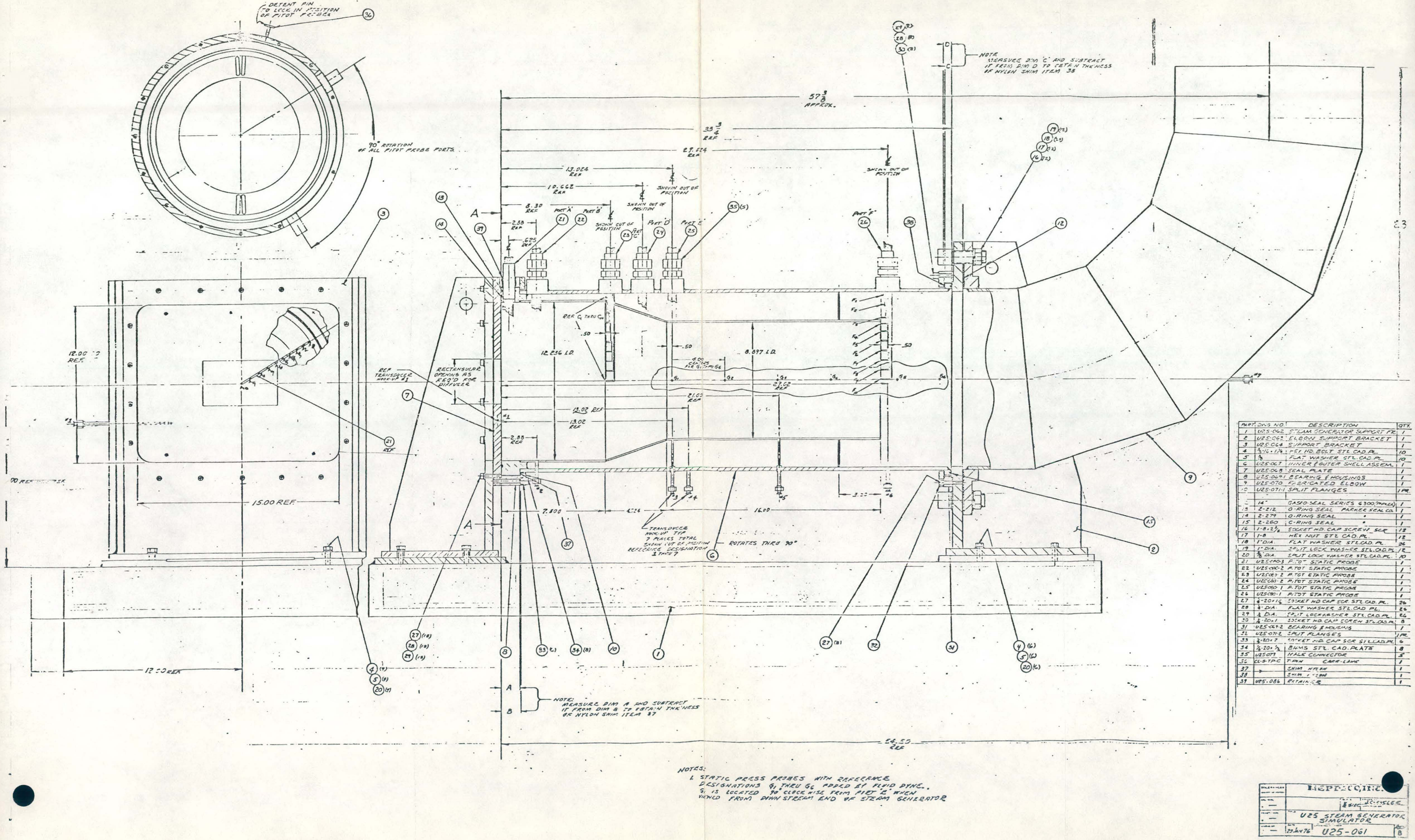


FIGURE 3. DIFFUSERS



PART	DWG NO.	DESCRIPTION	QTY.
1	U25-062	STEAM GENERATOR SUPPORT FR.	1
2	U25-063	ELBOW SUPPORT BRACKET	1
3	U25-064	SUPPORT BRACKET	1
4	3/4-10×1½	HEX HD. BOLT STL CAD. PL	10
5	3/4	FLAT WASHER STL. CAD. PL	10
6	U25-067	INNER & OUTER SHELL ASSEM.	1
7	U25-068	SEAL PLATE	1
8	U25-069-1	BEARING & HOUSINGS	1
9	U25-070	FABRICATED ELBOW	1
10	U25-071-1	SPLIT FLANGES	1 PR.
[illegible]	14"	GASKO-SEAL SERIES 6300 (PARKER)	1
13	2-212	O-RING SEAL PARKER SEAL CO.	1
14	2-279	O-RING SEAL "	1
15	2-260	C-RING SEAL "	1
16	1-8×2¾	SOCKET HD. CAP SCREW SCR	12
17	1-8	HEX NUT STL CAD. PL.	12
18	1" DIA.	FLAT WASHER STL. CAD. PL.	24
19	1" DIA.	SPLIT LOCK WASHER STL. CAD. PL.	12
20	3/8 DIA.	SPLIT LOCK WASHER STL. CAD. PL.	10
21	U25-080-3	PITOT STATIC PROBE	1
22	U25-080-2	PITOT STATIC PROBE	1
23	U25-080-2	PITOT STATIC PROBE	1
24	U25-080-2	PITOT STATIC PROBE	1
25	U25-080-1	PITOT STATIC PROBE	1
26	U25-080-1	PITOT STATIC PROBE	1
27	¼-20×1¼	SOCKET HD CAP SCR. STL. CAD. PL.	26
28	¼ DIA.	FLAT WASHER STL. CAD PL.	26
29	¼ DIA.	SPLIT LOCKWASHER STL. CAD. PL.	26
30	¼-20×1	SOCKET HD. CAP SCREW STL. CAD. PL	8
31	U25-069-2	BEARING & HOUSING	1
32	U25-071-2	SPLIT FLANGES	1 PR.
33	¼-20×?	SOCKET HD CAP SCR STL CAD. PL.	6
34	¼-20×½	BHMS STL. CAD. PLATE	8
35	U25-077	MALE CONNECTOR	5
36	CL-5-TPC	T-PIN CARR-LANE	1
37	→	SHIM NYLON	1
38		SHIM NYLON	1
39	U25-086	RETAINER	1

FIGURE 4. STEAM GENERATOR SIMULATOR

FIGURE 5 - PHASE I TABULATION

NOZZLE BLOCKAGE CALIBRATION

Run Number	Length Inches	P_{T_O} psia	T_{T_O} °R	P_{T_1} psia	P_{T_2} psia	T_{T_2} °R	P/P_{T_2}	T_w/T_g	Blockage
I-1	39.6	50.62	530	27.79	27.01	529	.5366	0.98	.2257
I-2	39.6	51.52	525	28.13	27.33	495	.5276	0.77	.2431
I-3	39.6	52.10	535	28.24	27.46	509	.5218	0.90	.2348
I-4	39.6	51.51	525	27.90	27.11	493	.5239	0.69	.2389
I-5	39.6	52.61	525	27.99	27.06	490	.5239	0.62	.2236
I-6	39.6	52.22	522	28.08	27.23	489	.5393	0.60	.2323
I-7	39.6	51.42	520	27.96	27.23	498	.5393	0.76	.2356
I-8	39.6	51.13	516	28.02	27.34	500	.5349	0.98	.2387
I-9	39.6	52.21	518	28.68	27.99	507	.5275	1.02	.2372
I-10	39.6	53.75	524	29.01	28.16	486	.5563	0.55	.2387
I-11	39.6	53.60	523	29.06	28.18	491	.5575	0.64	.2367
I-12	31.0	58.12	516	30.40	29.86	503	.5055	1.03	.2055
I-13	31.0	60.72	517	31.28	30.70	483	.5468	0.49	.2088
I-14	31.0	60.42	514	31.28	30.70	488	.5508	0.60	.2061
I-15	31.0	60.17	514	31.28	30.70	489	.5508	0.66	.2086
I-16	24.0	62.43	516	31.20	31.00	502	.4826	1.03	.1787
I-17	24.0	61.37	518	30.65	30.48	503	.4874	1.03	.1793
I-18	24.0	69.22	517	34.10	33.88	491	.4905	0.48	.1763
I-19	24.0	67.32	516	33.34	33.14	493	.4895	0.62	.1778
I-20	24.0	67.02	515	33.29	33.12	494	.4854	0.68	.1801
I-21	20.0	62.41	518	30.60	30.45	503	.4957	1.02	.1646
I-22	20.0	68.11	524	32.74	32.60	500	.4870	0.61	.1557
I-23	20.0	67.76	523	32.74	32.60	502	.4900	0.65	.1575
I-24	20.0	67.56	522	32.70	32.57	502	.4911	0.70	.1586

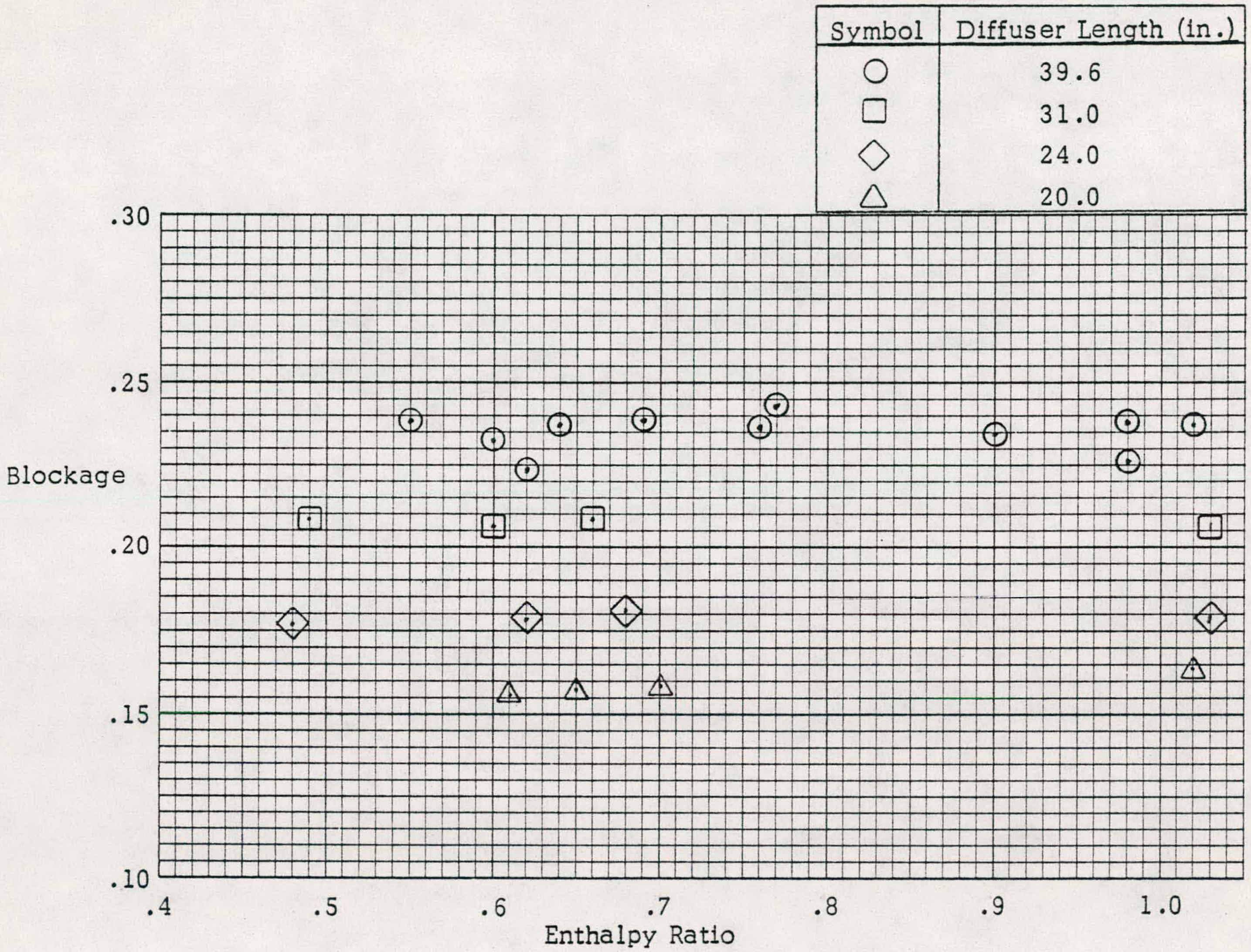
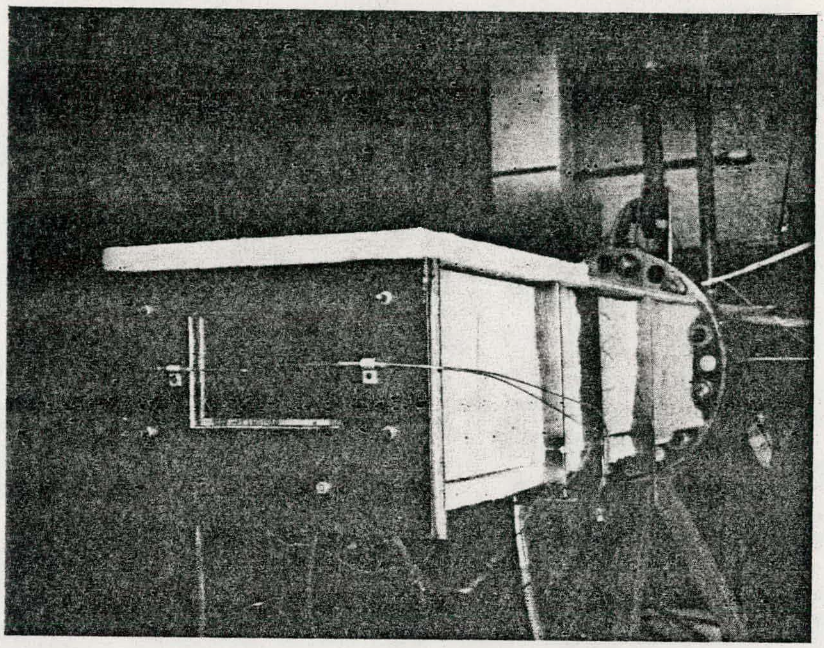


FIGURE 6. BLOCKAGE VS. ENTHALPY RATIO



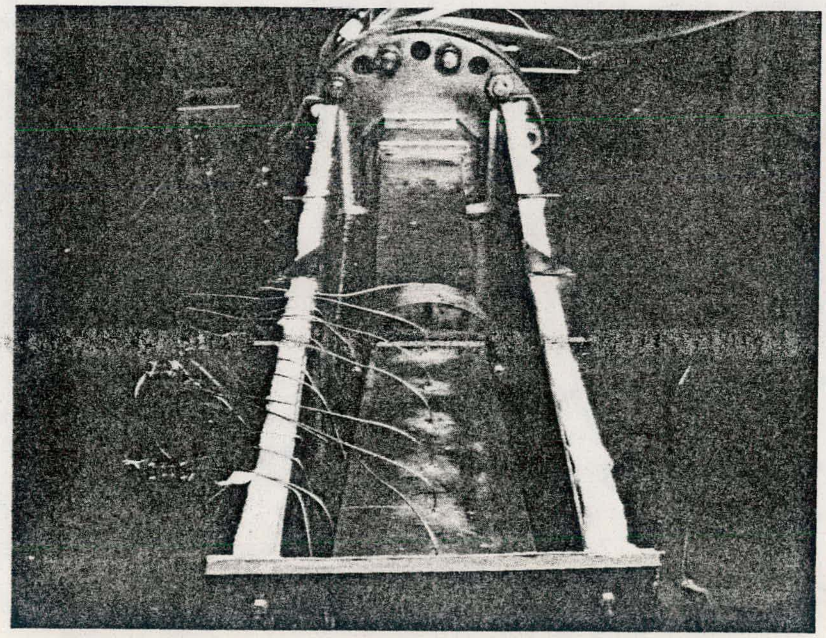


FIGURE 7. PHOTOGRAPHS OF DIFFUSER IN LIQUID NITROGEN BATH

FIGURE 8

PHASE II - DIFFUSER RECOVERY COEFFICIENTS

Run Number	Diffuser	LN_2	T_w/T_g	P_{t_o} psia	P_{t_2} psia	P_2 psia	M	P_e psia	C_p
II-1.1	2	No	1.00	28.55	16.65	12.72	.633	14.36	.416
1.2			1.00	31.56	17.24	12.25	.716	14.36	.422
1.3			1.00	35.31	18.22	11.57	.832	14.31	.412
1.4			1.00	39.76	19.20	11.06	.924	14.28	.396
1.5			1.00	40.15	19.69	10.74	.972	14.28	.396
1.6			1.00	41.64	20.18	10.40	1.021	14.26	.395
II-2.1	1	No	1.00	29.27	16.61	12.41	.659	14.37	.465
2.2			1.00	32.07	17.18	11.92	.742	14.34	.461
2.3			1.00	36.52	18.23	10.89	.890	14.32	.467
2.4			1.00	39.72	19.18	9.72	1.035	14.27	.481
II-3.1	1	Yes	0.35	30.51	16.61	12.21	.678	14.24	.461
3.2			0.42	33.31	17.20	11.62	.770	14.24	.469
3.3			0.53	37.56	18.25	10.45	.929	14.21	.483
3.4			0.60	40.16	19.18	9.13	1.087	14.21	.506
II-4.1	1	No	1.00	27.06	16.22	12.70	.602	14.31	.458
4.2			1.00	30.69	16.86	12.14	.701	14.29	.456
4.3			1.00	34.01	17.59	11.45	.808	14.27	.458
4.4			1.00	37.06	18.40	10.70	.916	14.23	.458
4.5			1.00	38.65	18.84	10.21	.978	14.22	.465
4.6			1.00	40.05	19.37	9.52	1.061	14.22	.476
II-5.1	3	No	1.00	27.05	16.21	12.79	.592	14.30	.443
5.2			1.00	30.62	16.85	12.25	.690	14.28	.442
5.3			1.00	34.00	17.60	11.57	.799	14.25	.445
5.4			1.00	37.00	18.36	10.81	.904	14.21	.450
5.5			1.00	38.54	18.80	10.29	.969	14.21	.460
5.6			1.00	39.84	19.24	9.76	1.035	14.21	.469

FIGURE 8 (Cont.)

Run Number	Diffuser	LN_2	T_w/T_g	P_{t_o} psia	P_{t_2} psia	P_2 psia	M	P_e psia	C_p
II-6.1	3	Yes	0.32	27.10	16.06	12.78	.580	14.27	.455
6.2			0.33	30.62	16.74	12.24	.684	14.27	.451
6.3			0.38	34.05	17.52	11.56	.795	14.25	.451
6.4			0.53	37.00	18.31	10.56	.923	14.20	.471
6.5			0.74	38.44	18.77	10.14	.981	14.20	.470
6.6			0.79	39.79	19.19	9.63	1.044	14.20	.478
II-7.1	5	No	1.00	27.48	16.39	12.74	.609	14.38	.452
7.2			1.00	30.85	16.97	12.22	.701	14.37	.453
7.3			1.00	33.88	17.64	11.64	.799	14.36	.452
7.4			1.00	36.83	18.41	10.88	.900	14.31	.455
7.5			1.00	37.83	18.70	10.57	.941	14.28	.457
7.6			1.00	38.83	19.06	10.25	.985	14.28	.458
II-8	5	No	1.00	39.33	19.18	10.06	1.006	14.25	.460
II-9.1	4	No	1.00	27.44	16.33	12.79	.601	14.36	.445
9.2			1.00	30.83	16.94	12.26	.696	14.36	.447
9.3			1.00	33.86	17.60	11.67	.789	14.35	.452
9.4			1.00	36.76	18.39	10.94	.895	14.33	.455
9.5			1.00	37.81	18.70	10.64	.936	14.31	.456
9.6			1.00	39.20	19.15	10.16	.997	14.31	.462
II-10.1	4	No	1.00	27.36	16.20	12.52	.618	14.18	.452
10.2			1.00	30.83	16.84	11.99	.714	14.18	.451
10.3			1.00	34.03	17.53	11.33	.815	14.17	.457
10.4			1.00	36.93	18.33	10.55	.925	14.15	.464
10.5			1.00	37.74	18.67	10.17	.974	14.15	.469
10.6			1.00	39.12	19.01	9.70	1.029	14.13	.475
II-11.1	6	No	1.00	27.21	16.16	12.54	.614	14.18	.452
11.2			1.00	30.65	16.76	12.00	.708	14.15	.452
11.3			1.00	33.83	17.52	11.39	.809	14.14	.448

FIGURE 8 (Cont.)

Run Number	Diffuser	LN_2	T_w/T_g	P_{t_o} psia	P_{t_2} psia	P_2 psia	M	P_e psia	C_p
II-11.4			1.00	36.70	18.30	10.70	.910	14.13	.450
11.5			1.00	38.02	18.69	10.29	.964	14.09	.452
11.6			1.00	39.02	19.03	9.97	1.007	14.08	.453
II-12.1	4	No	1.00	27.30	16.27	12.64	.611	14.26	.445
12.2			1.00	30.48	16.83	12.15	.698	14.25	.448
12.3			1.00	33.91	17.56	11.47	.804	14.24	.454
12.4			1.00	36.71	18.30	10.73	.907	14.21	.459
12.5			1.00	27.81	18.62	10.34	.956	14.20	.466
12.6			1.00	39.00	19.03	9.85	1.017	14.18	.471
II-13.1	4	No	1.00	27.38	16.34	12.67	.614	14.28	.440
13.2			1.00	30.70	17.01	12.13	.706	14.27	.440
13.3			1.00	33.93	17.71	11.55	.806	14.26	.440
13.4			1.00	36.73	18.49	10.76	.914	14.25	.452
13.5			1.00	37.93	18.88	10.37	.966	14.24	.455
13.6			1.00	39.04	19.27	9.88	1.025	14.22	.461
II-14.1	1	No	1.00	27.25	16.27	12.58	.614	14.17	.436
14.2			1.00	29.64	16.91	12.02	.714	14.16	.439
14.3			1.00	33.82	17.69	11.43	.812	14.15	.438
14.4			1.00	36.62	18.45	10.65	.920	14.11	.447
14.5			1.00	37.82	18.81	10.26	.971	14.10	.451
14.6			1.00	38.91	19.18	9.82	1.027	14.10	.457
II-15.1	1	No	1.00	27.21	16.21	12.59	.612	14.14	.428
15.2			1.00	30.63	16.84	12.03	.710	14.13	.437
15.3			1.00	33.81	17.58	11.39	.812	14.11	.439
15.4			1.00	36.61	18.36	10.64	.919	14.08	.446
15.5			1.00	37.76	18.68	10.24	.967	14.08	.455
15.6			1.00	38.96	19.10	9.76	1.028	14.06	.461

FIGURE 8 (Cont.)

Run Number	Diffuser	LN_2	T_w/T_g	P_{t_o} psia	P_{t_2} psia	P_2 psia	M	P_e psia	C_p
II-16.1	1	No	1.00	27.21	16.19	12.57	.612	14.11	.426
16.2			1.00	30.60	16.82	12.03	.709	14.11	.434
16.3			1.00	33.88	17.51	11.37	.810	14.06	.438
16.4			1.00	36.58	18.24	10.64	.913	14.06	.450
16.5			1.00	37.88	18.63	10.22	.967	14.04	.454
16.6			1.00	38.93	19.00	9.78	1.022	14.03	.462

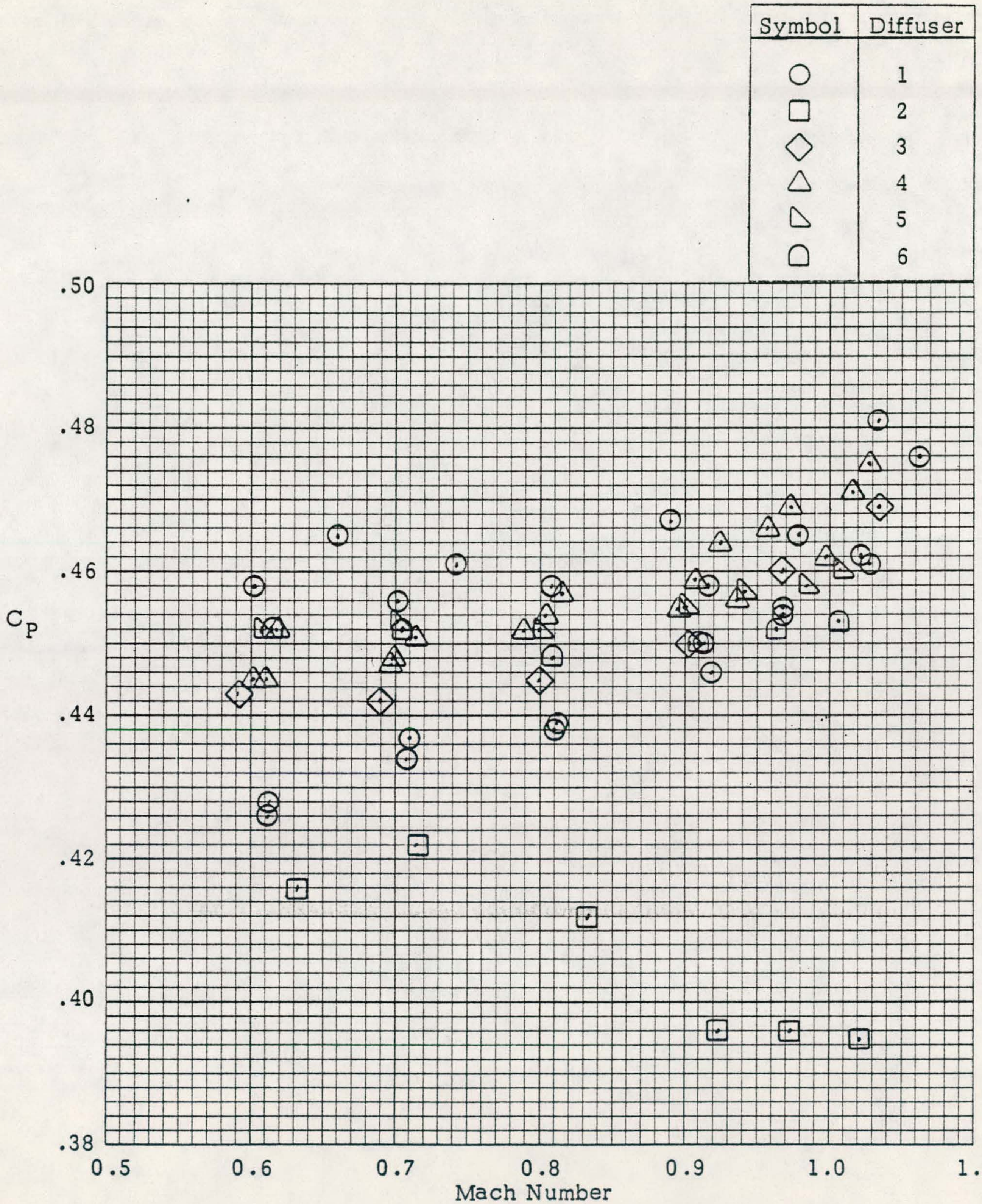
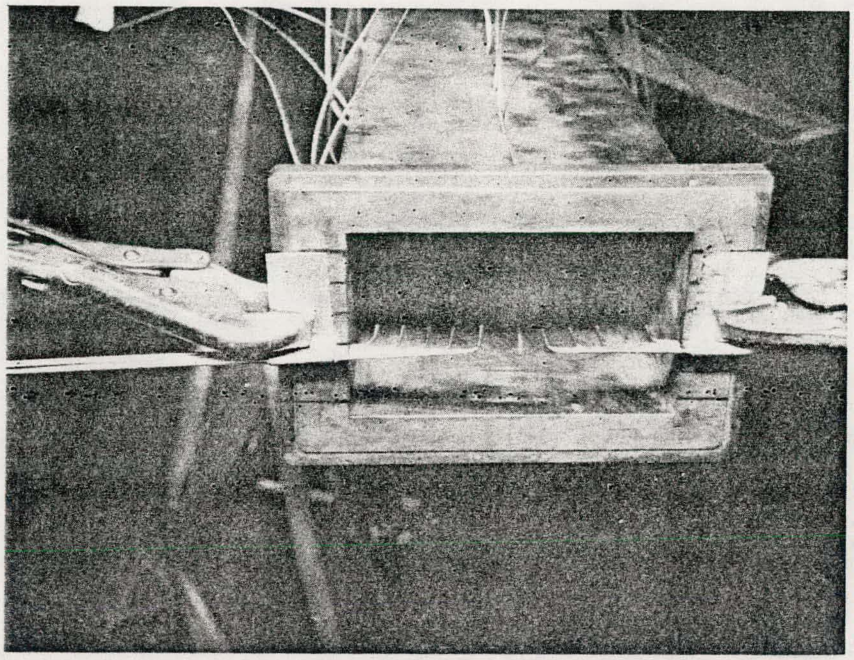


FIGURE 9. DIFFUSER PRESSURE RECOVERY COEFFICIENT VS. MACH NUMBER



Diffuser Number 1 with Exit Survey
Rake Probes Spaced at 0.40 inch Centers
and 0.40 inch from Outer Wall with
1.07 inch Spacing at Center.

FIGURE 10. BEST DIFFUSER EXIT SURVEY

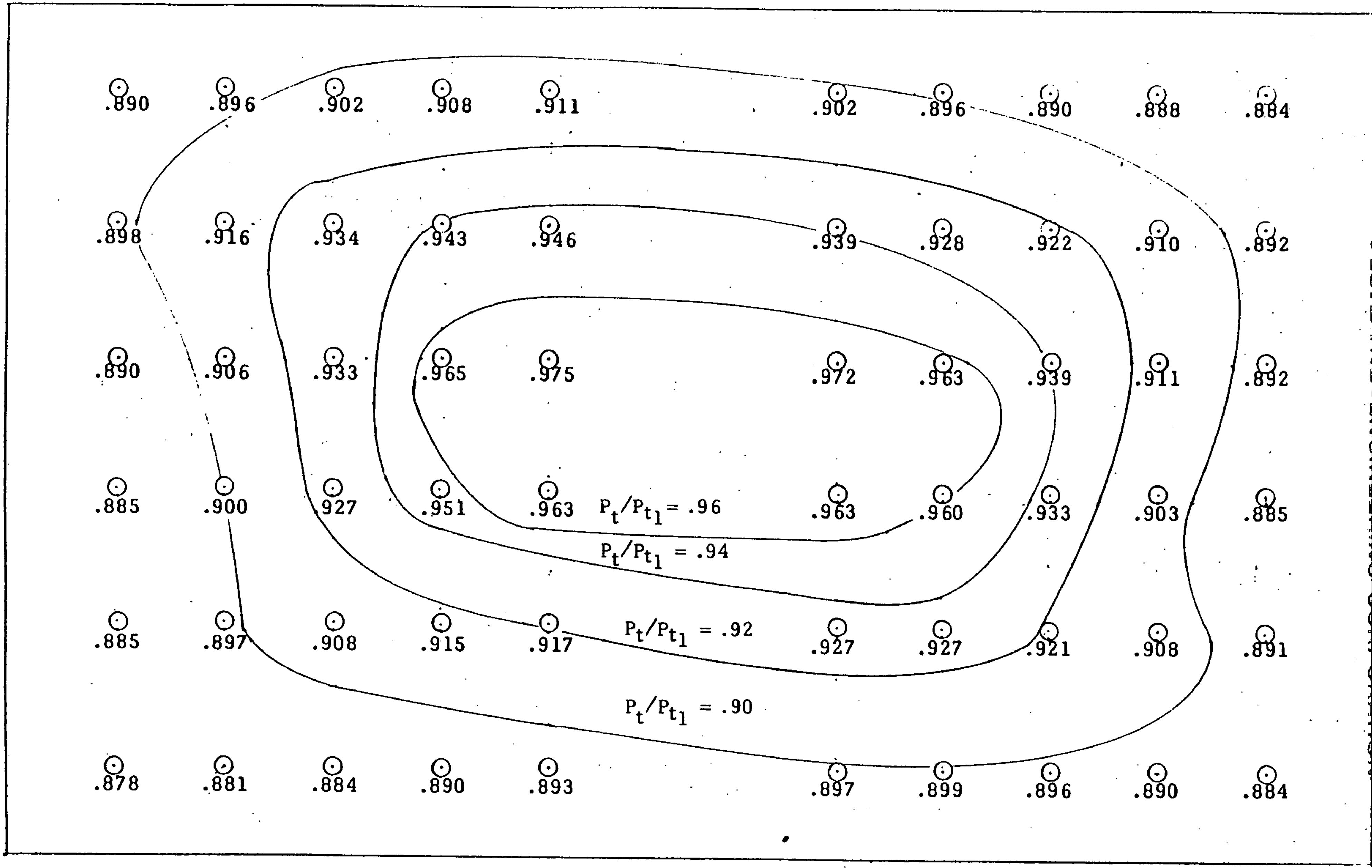


FIGURE 11a. EXIT TOTAL PRESSURE DISTRIBUTION
DIFFUSER NO. 1, M = .60

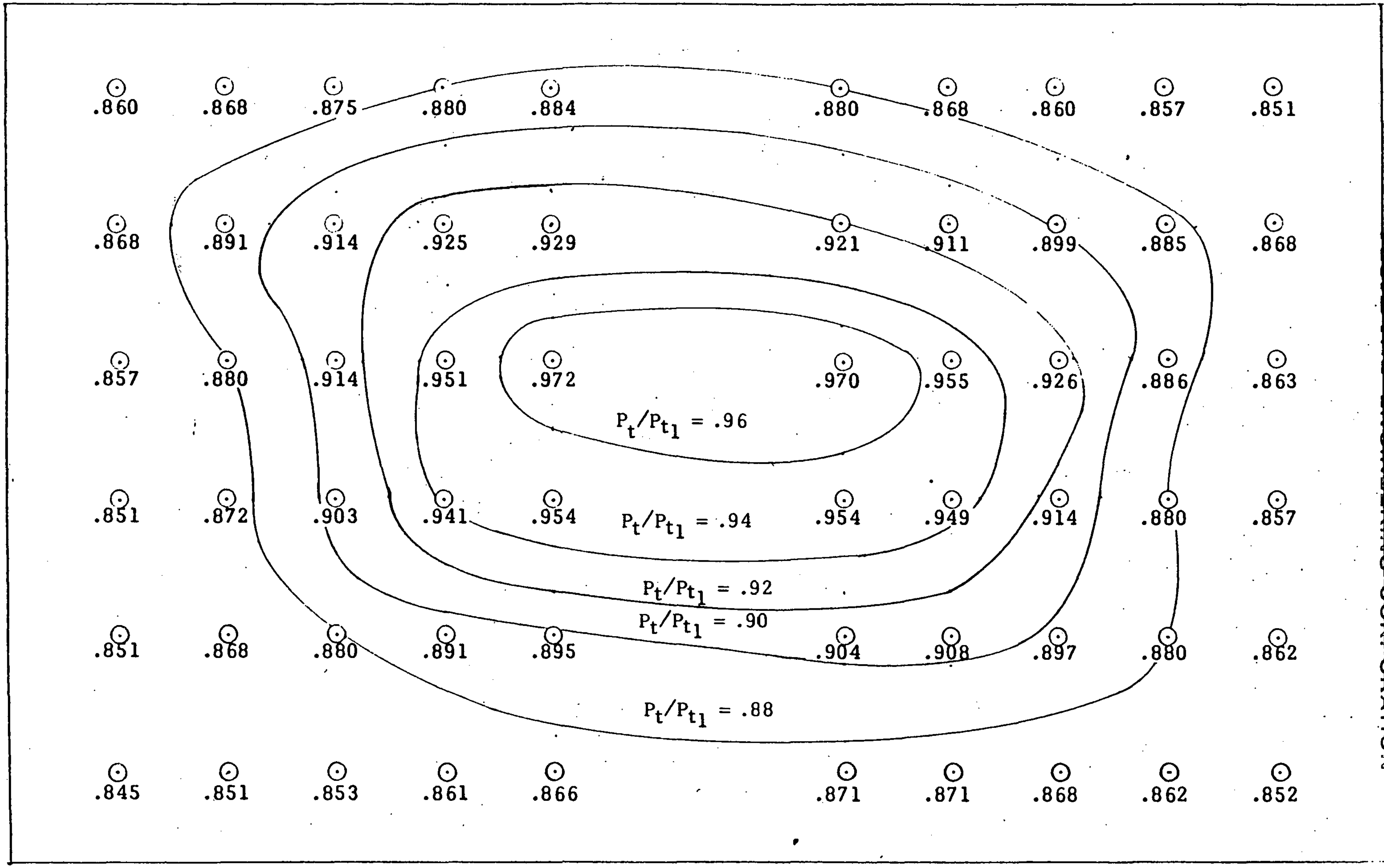


FIGURE 11b. EXIT TOTAL PRESSURE DISTRIBUTION
DIFFUSER NO. 1, M = .70

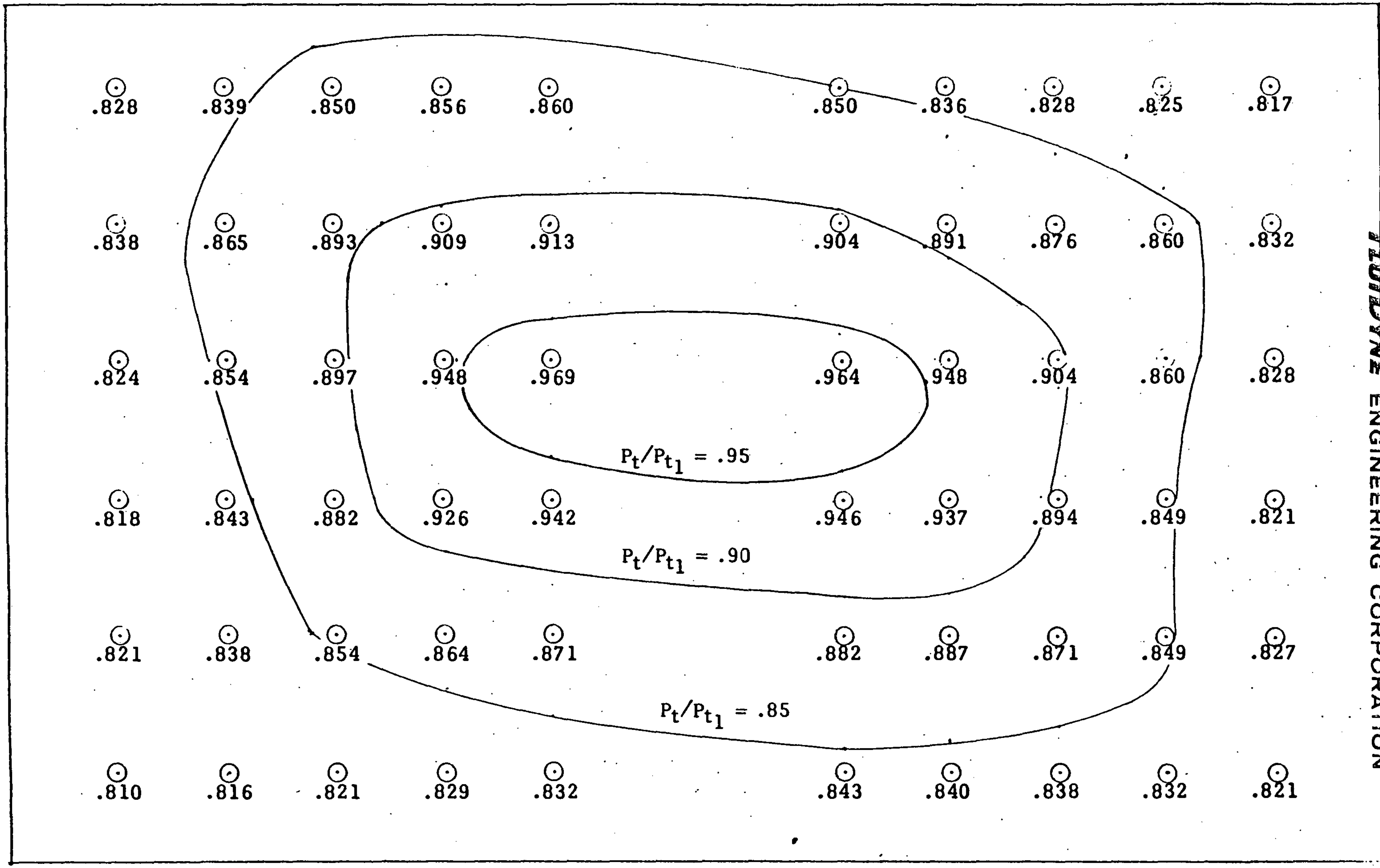


FIGURE 11c. EXIT TOTAL PRESSURE DISTRIBUTION DIFFUSER NO. 1, M = .80

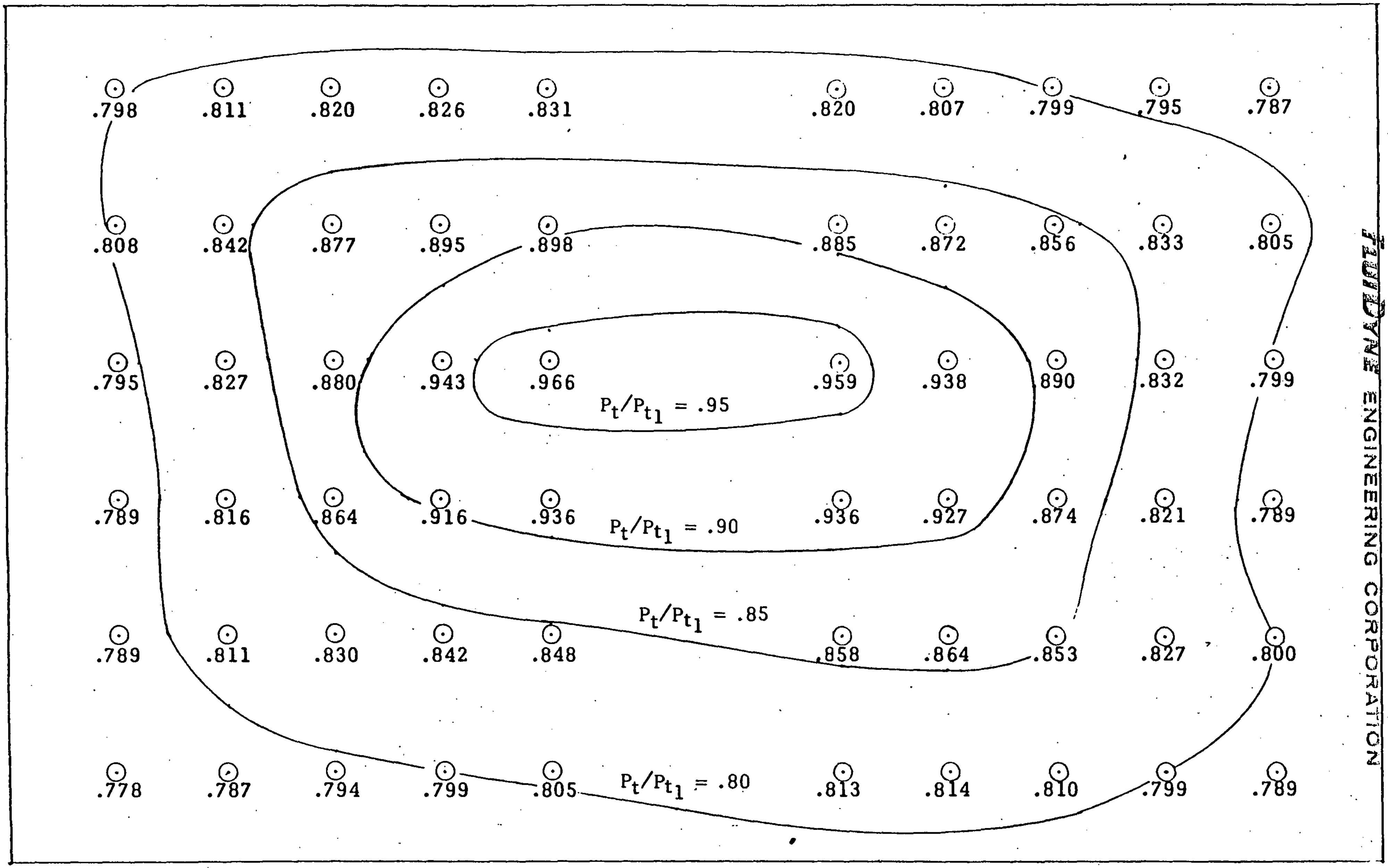


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FIGURE 11d. EXIT TOTAL PRESSURE DISTRIBUTION
DIFFUSER NO. 1, M = .90

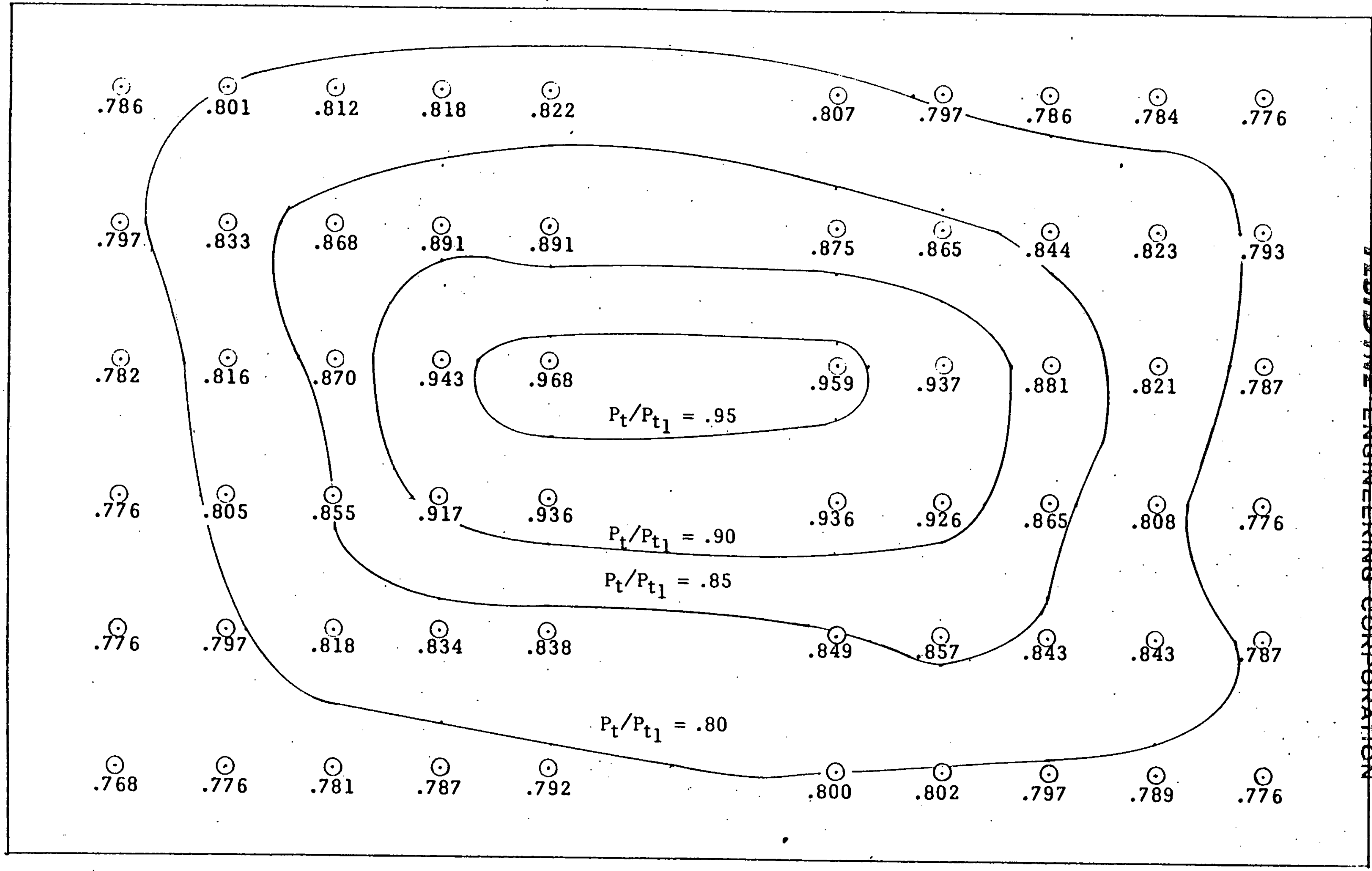


FIGURE 11e. EXIT TOTAL PRESSURE DISTRIBUTION
DIFFUSER NO. 1, M = .95

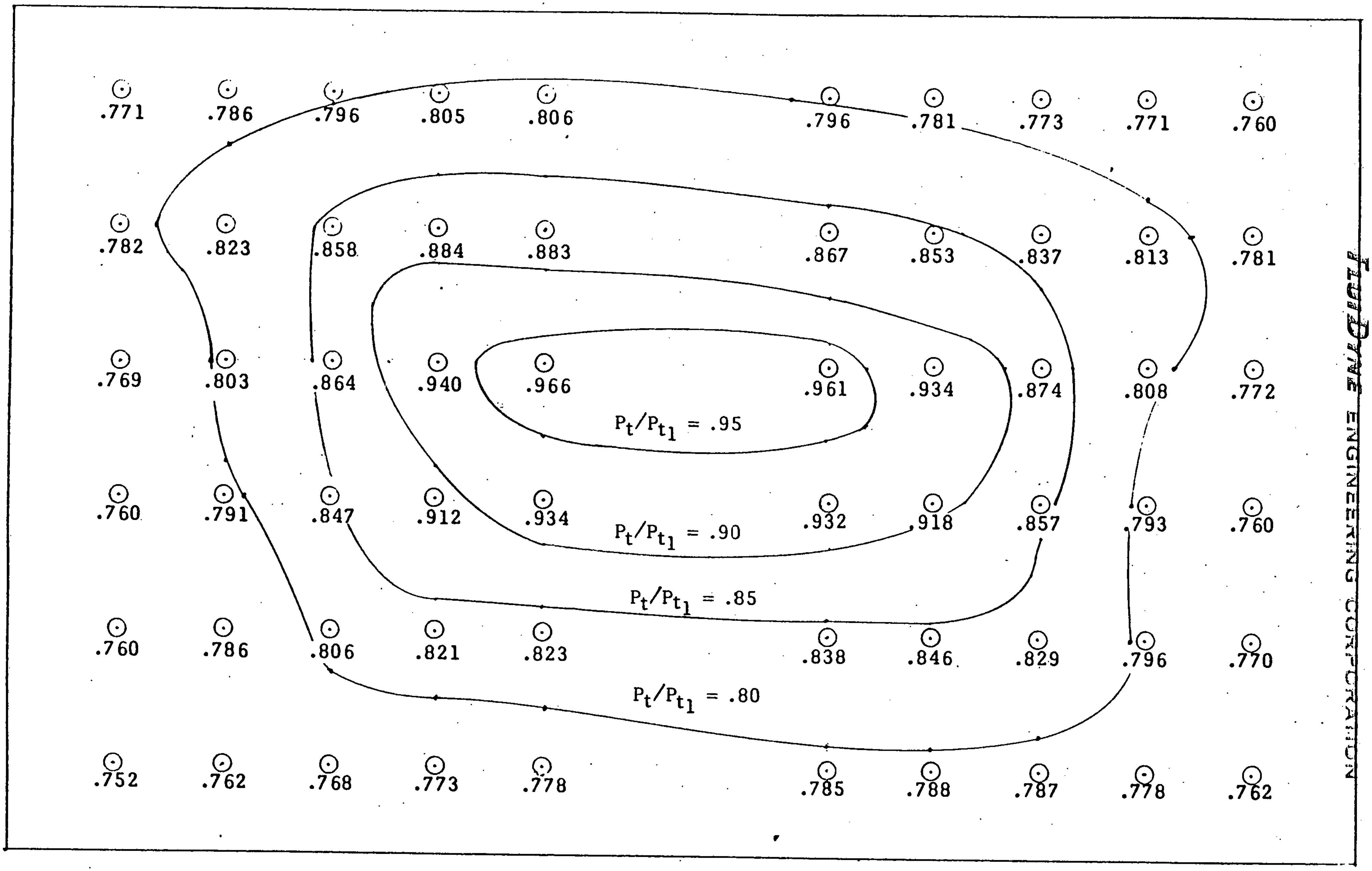
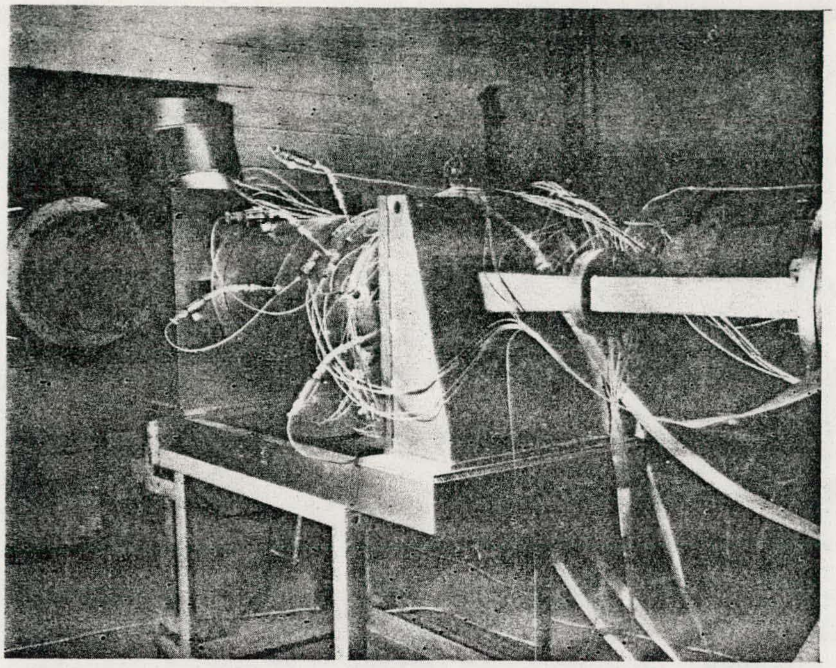


FIGURE 11f. EXIT TOTAL PRESSURE DISTRIBUTION
DIFFUSER NO. 1, M = 1.0



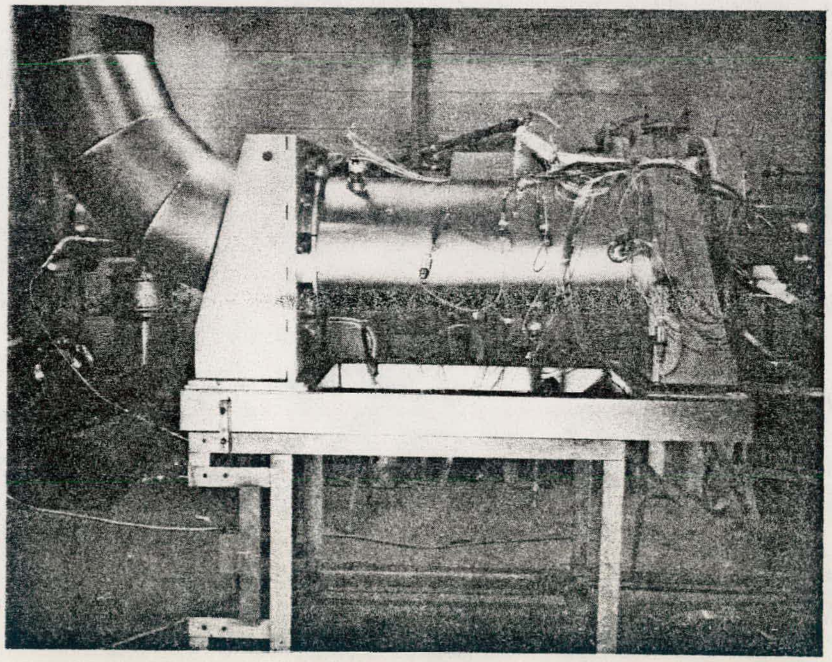
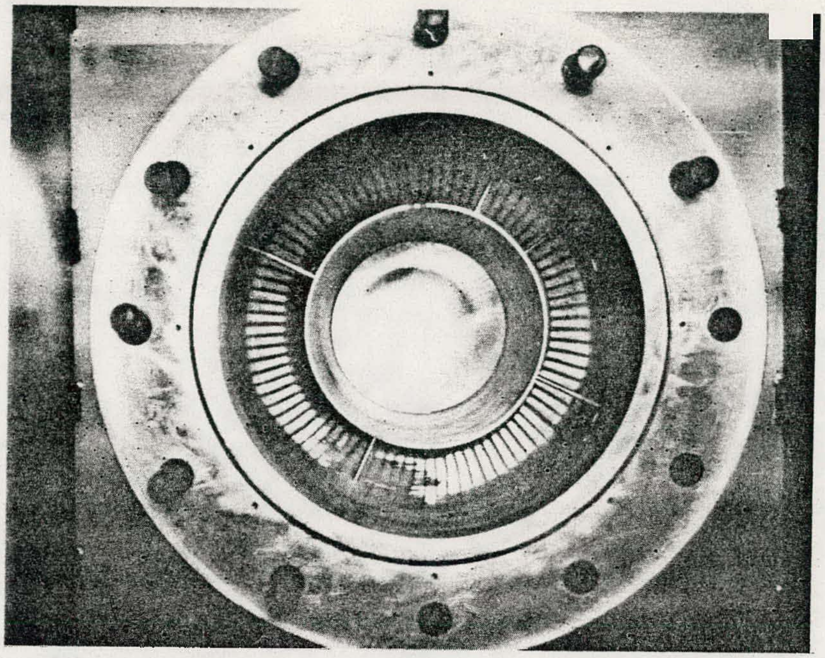
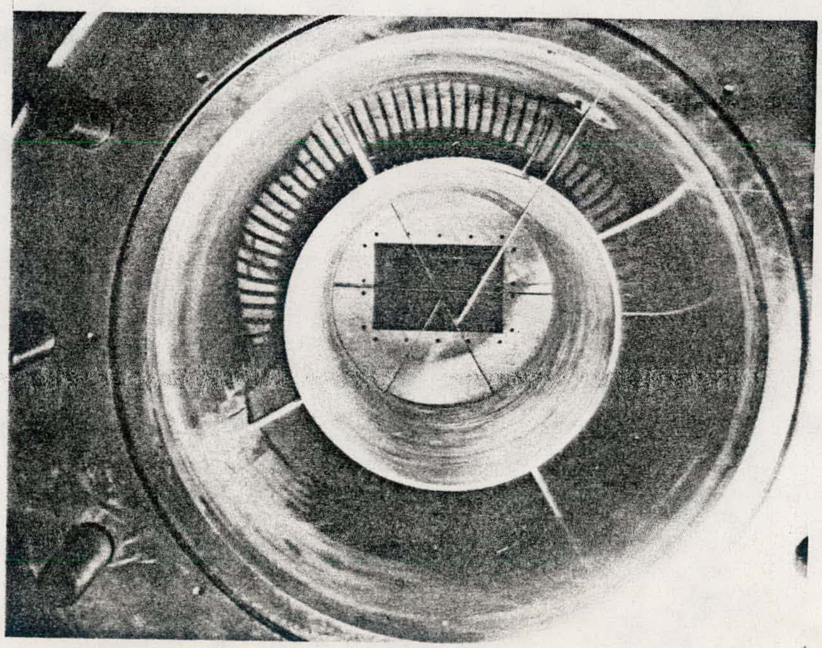


FIGURE 12a. STEAM GENERATOR PHOTOGRAPHS





Viewed from Downstream End of Simulator.

Lower Photograph with Survey Total Rakes Installed.

FIGURE 12b. STEAM GENERATOR PHOTOGRAPHS

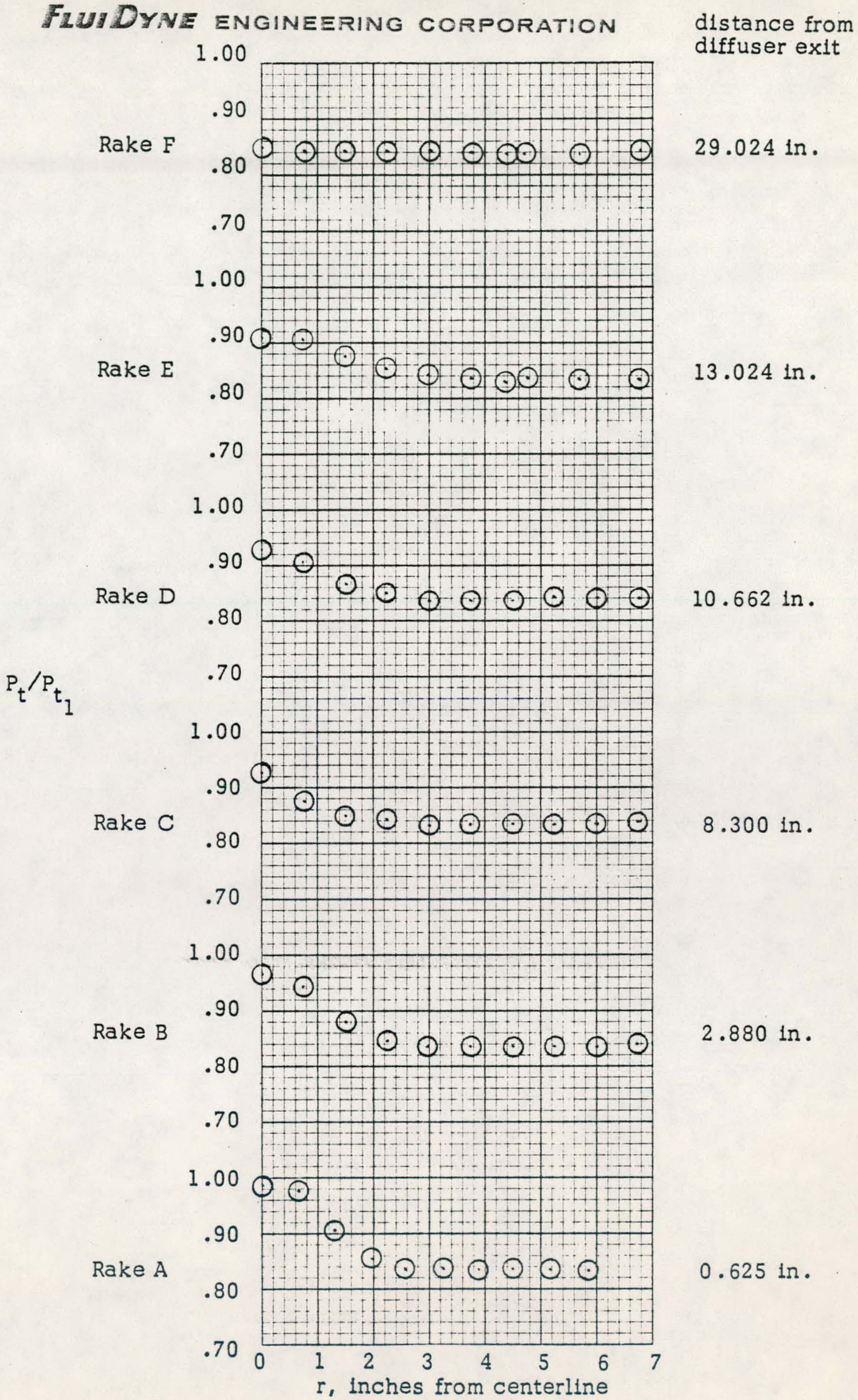


FIGURE 13a. STEAM GENERATOR SURVEY RUN IV-9
DIFFUSER NO. 1, M = .75, $\alpha = 270°$

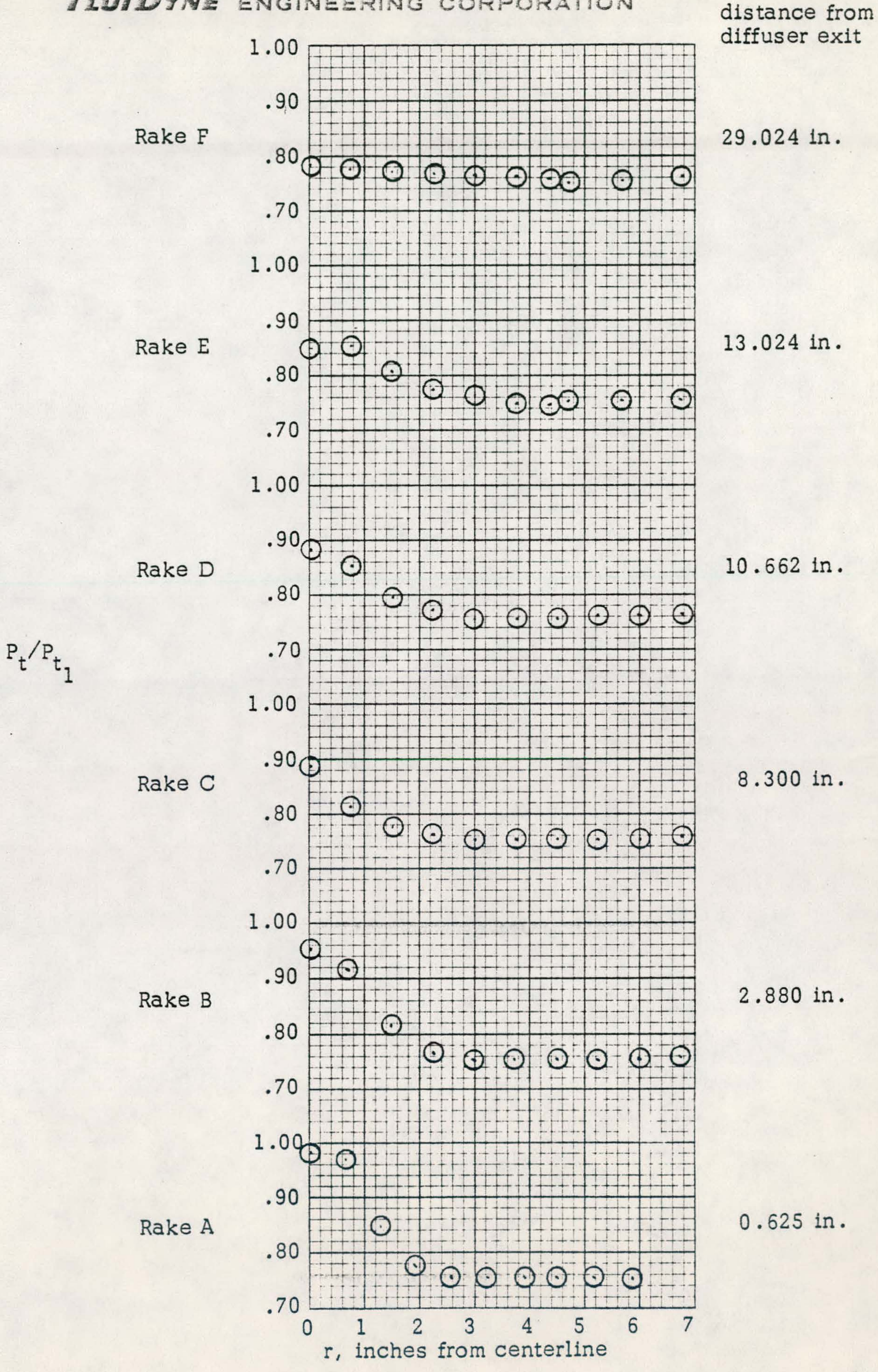


FIGURE 13b. STEAM GENERATOR SURVEY RUN IV-10
DIFFUSER NO. 1, M = 1.0, $\alpha = 270°$

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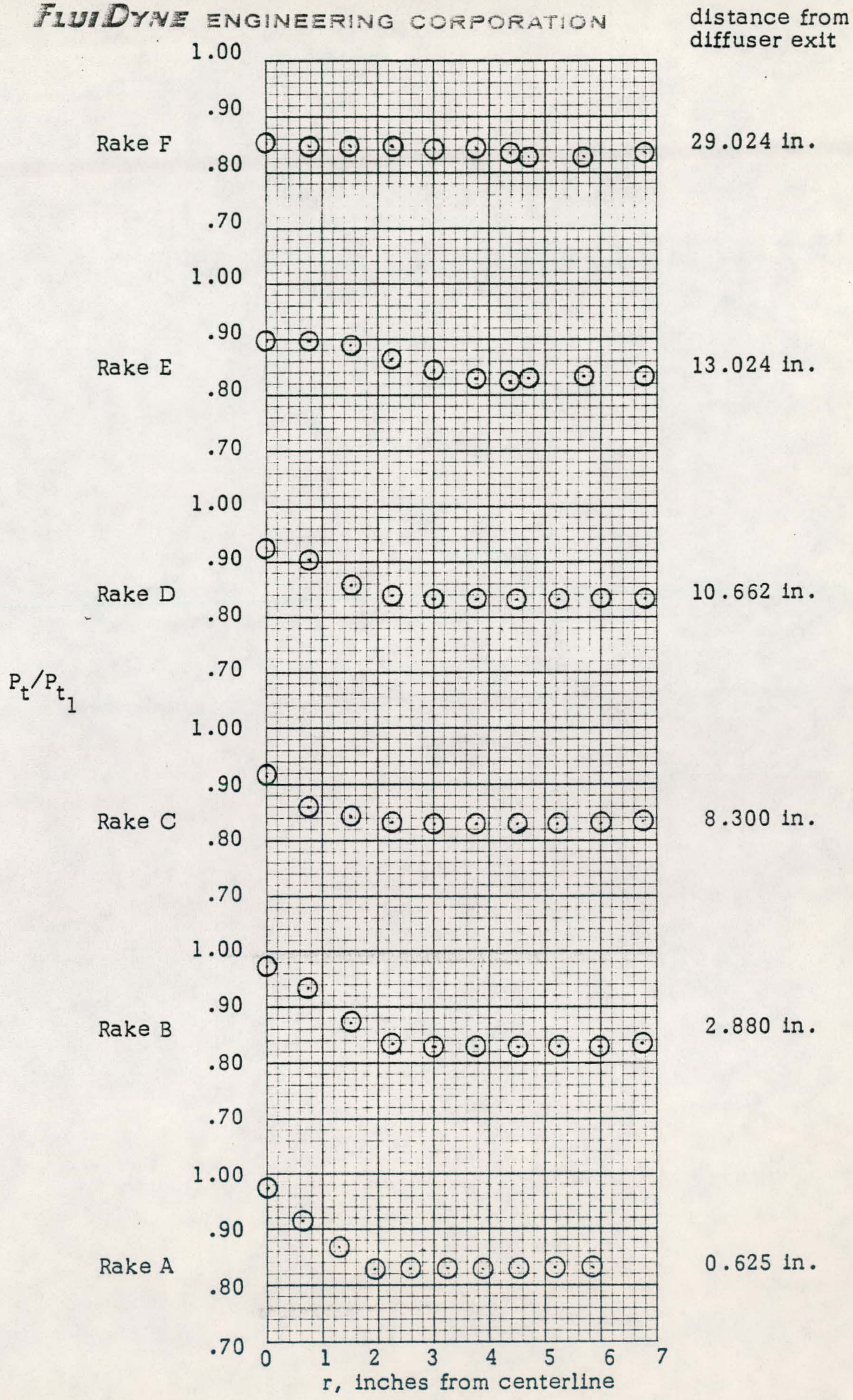

FIGURE 13c. STEAM GENERATOR SURVEY RUN IV-11
DIFFUSER NO. 1, M = .75, $\alpha = 330°$

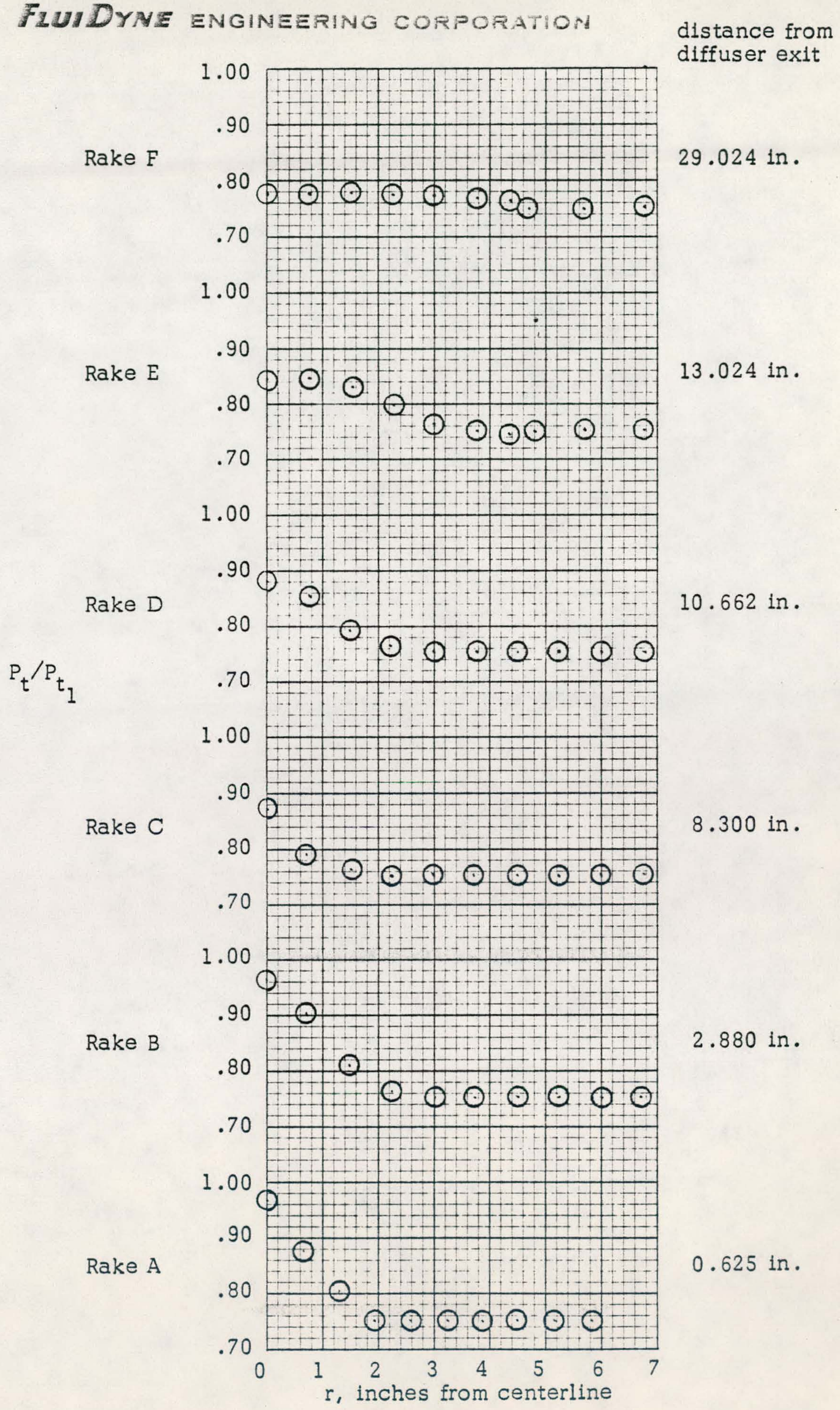

FIGURE 13d. STEAM GENERATOR SURVEY RUN IV-12
DIFFUSER NO. 1, M = 1.0, α = 330°

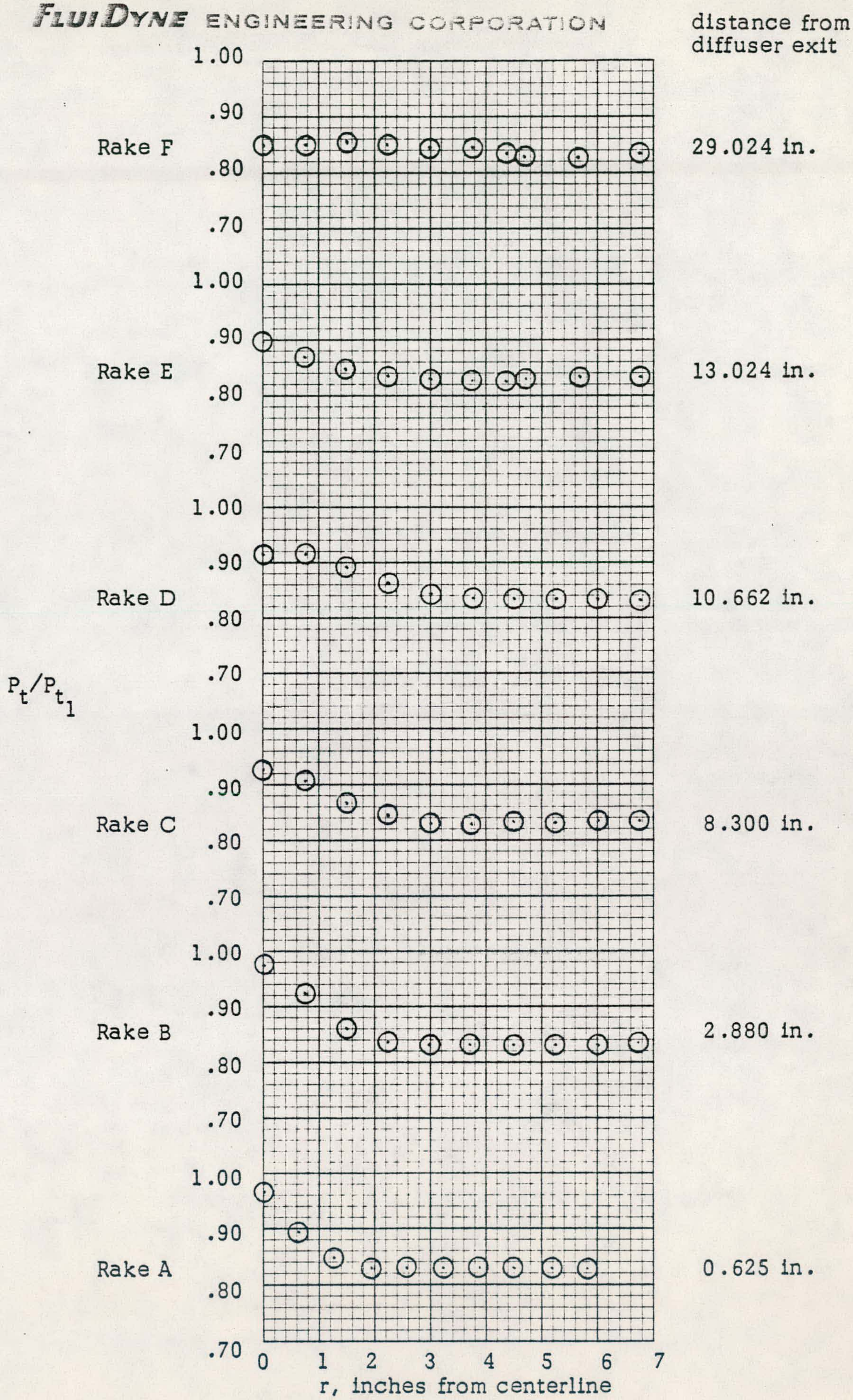

FIGURE 13e. STEAM GENERATOR SURVEY RUN IV-13
DIFFUSER NO. 1, M = .75, $\alpha = 30°$

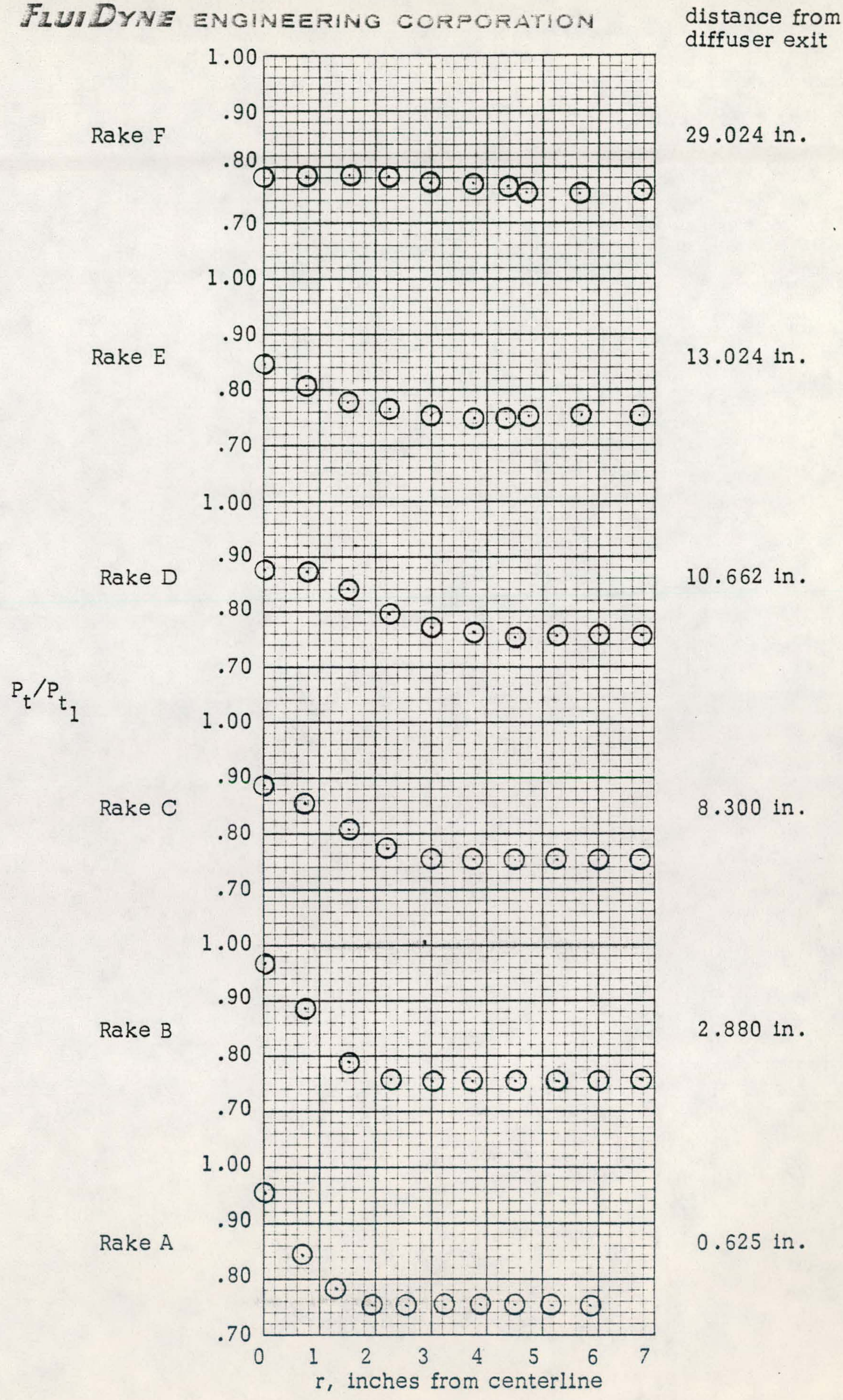

FIGURE 13f. STEAM GENERATOR SURVEY RUN IV-14
DIFFUSER NO. 1, M = 1.0, $\alpha = 30°$

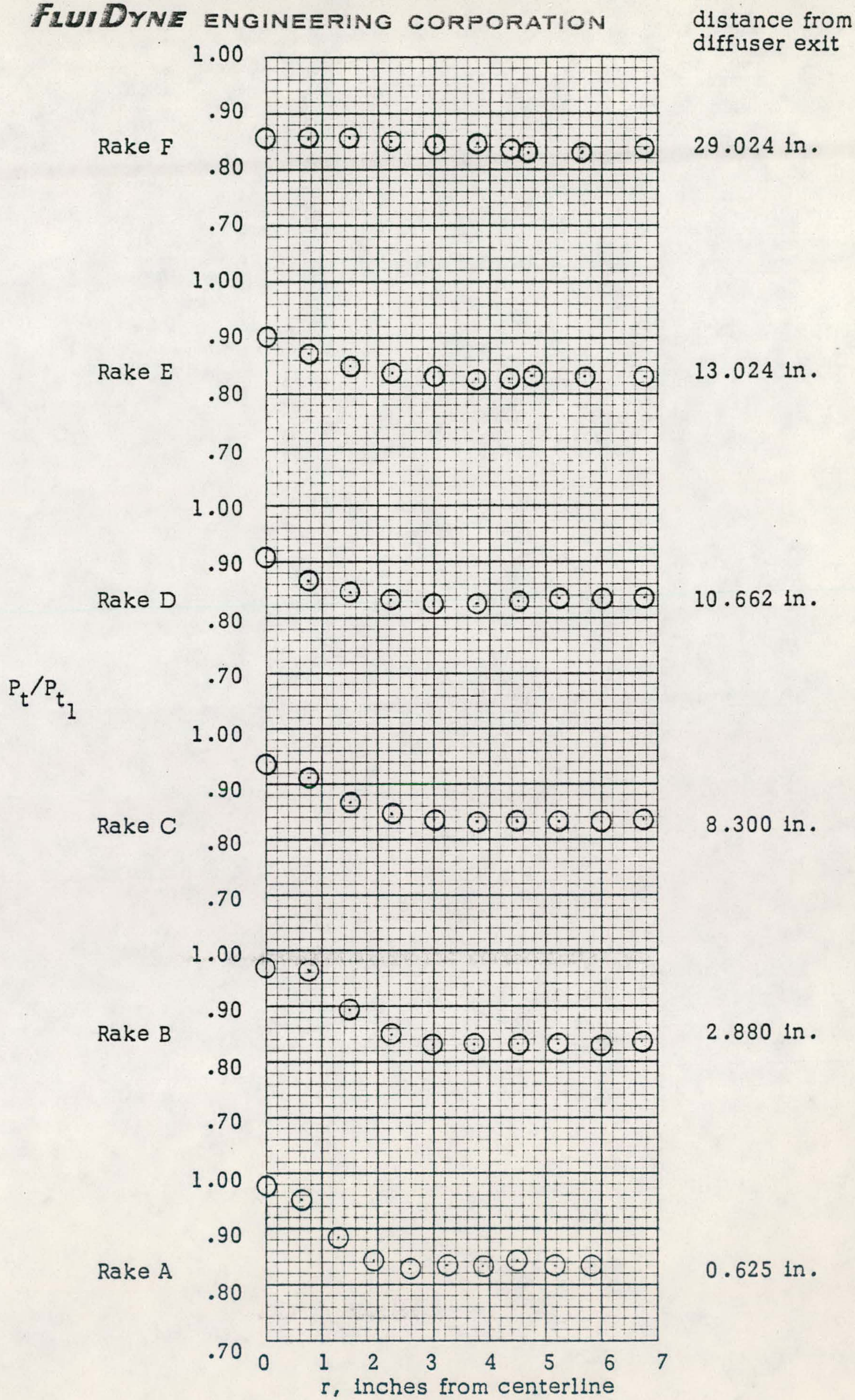

FIGURE 13g. STEAM GENERATOR SURVEY RUN IV-15
DIFFUSER NO. 1, M = .75, $\alpha = 90°$

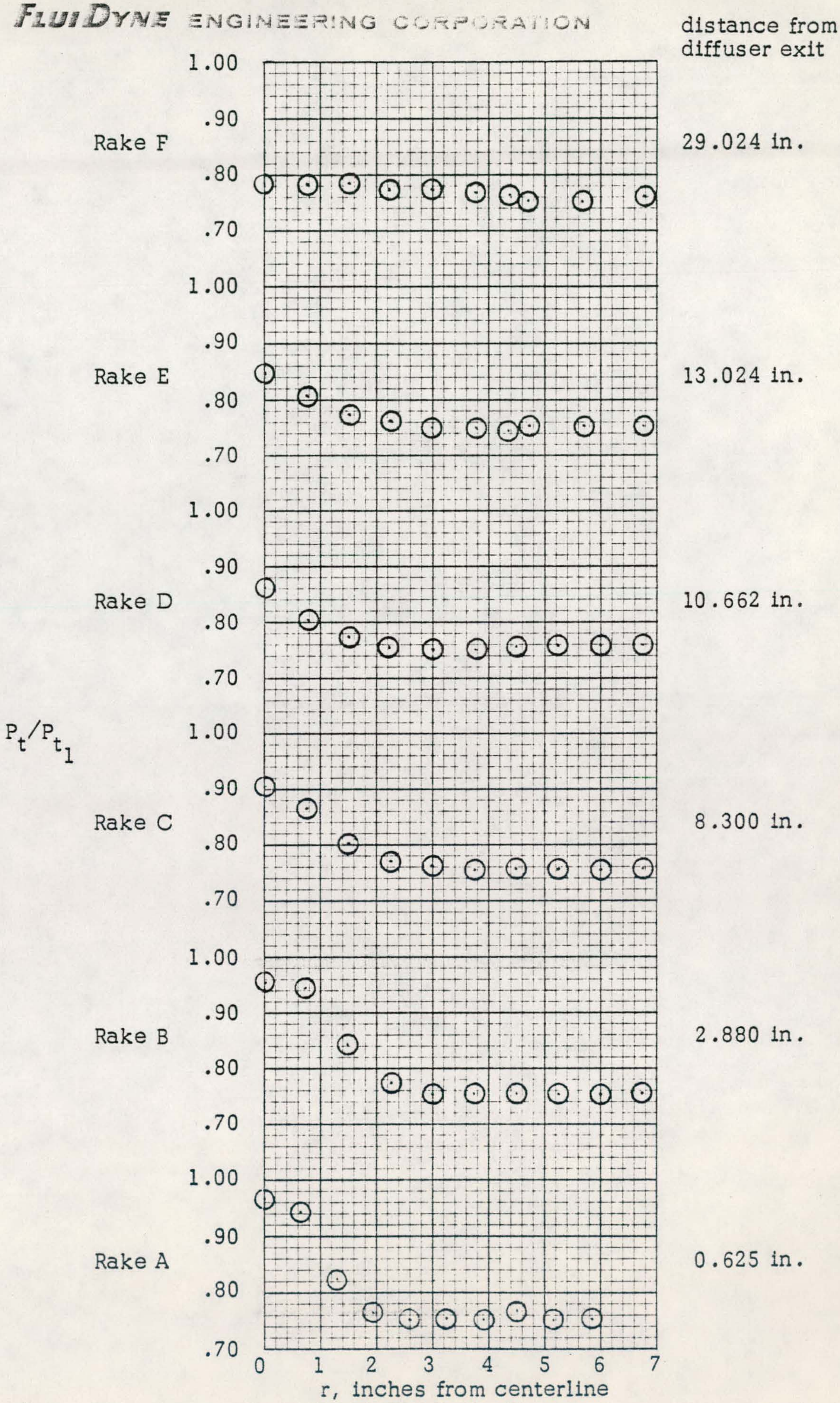

FIGURE 13h. STEAM GENERATOR SURVEY RUN IV-16
DIFFUSER NO. 1, M = 1.0, $\alpha = 90°$

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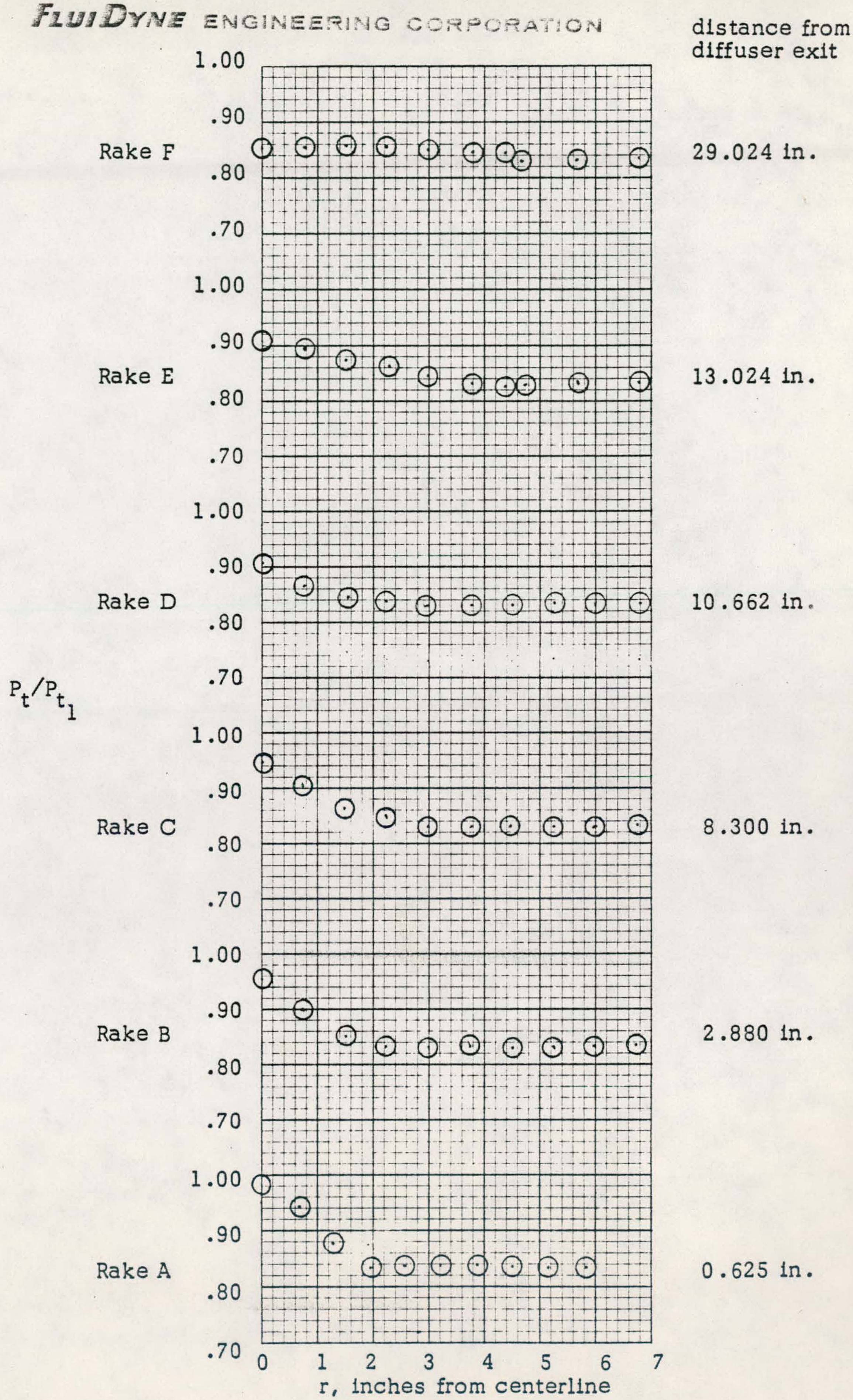

FIGURE 13i. STEAM GENERATOR SURVEY RUN IV-17
DIFFUSER NO. 1, M = .75, $\alpha = 150°$

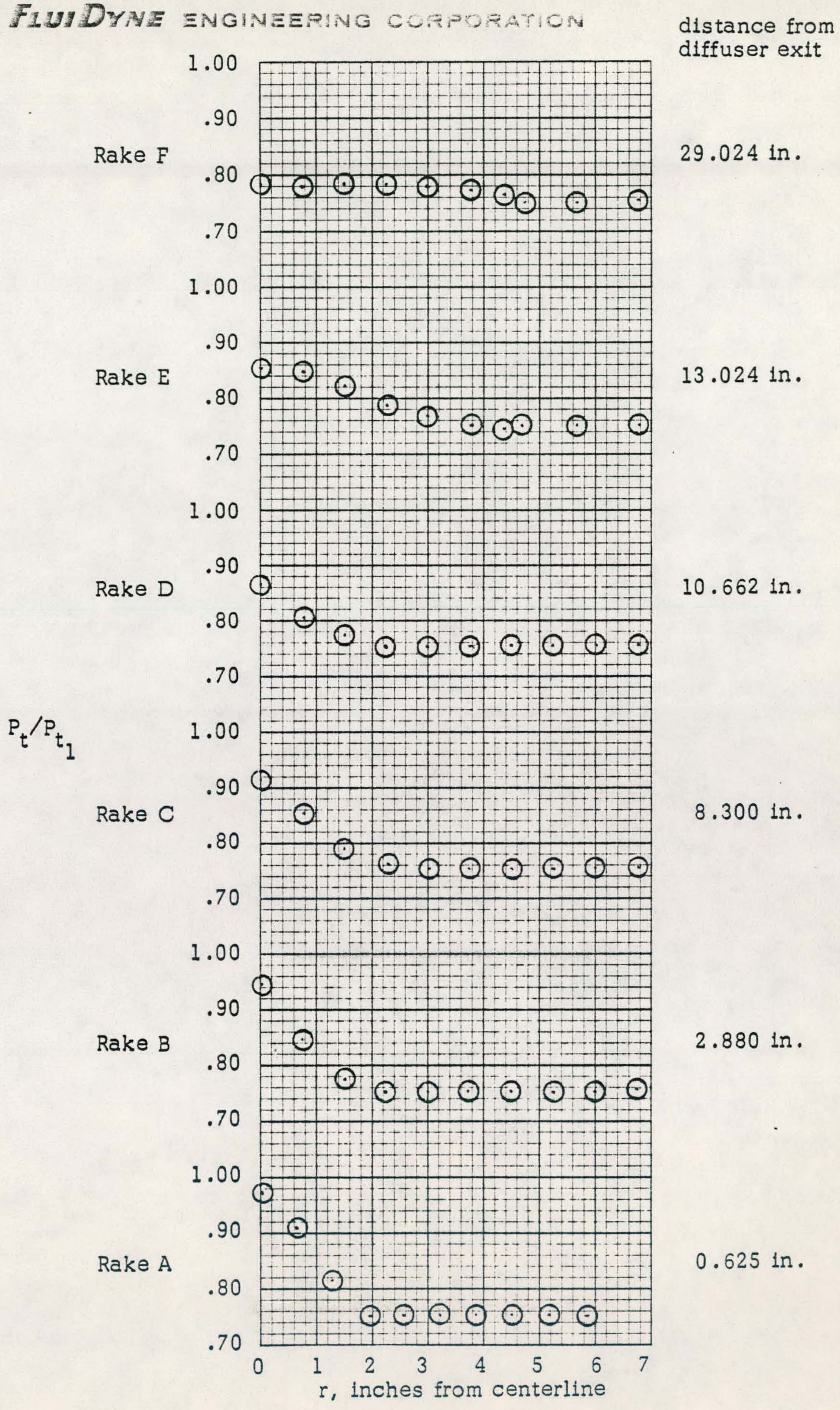

FIGURE 13j. STEAM GENERATOR SURVEY RUN IV-18
DIFFUSER NO. 1, M = 1.0, $\alpha = 150°$

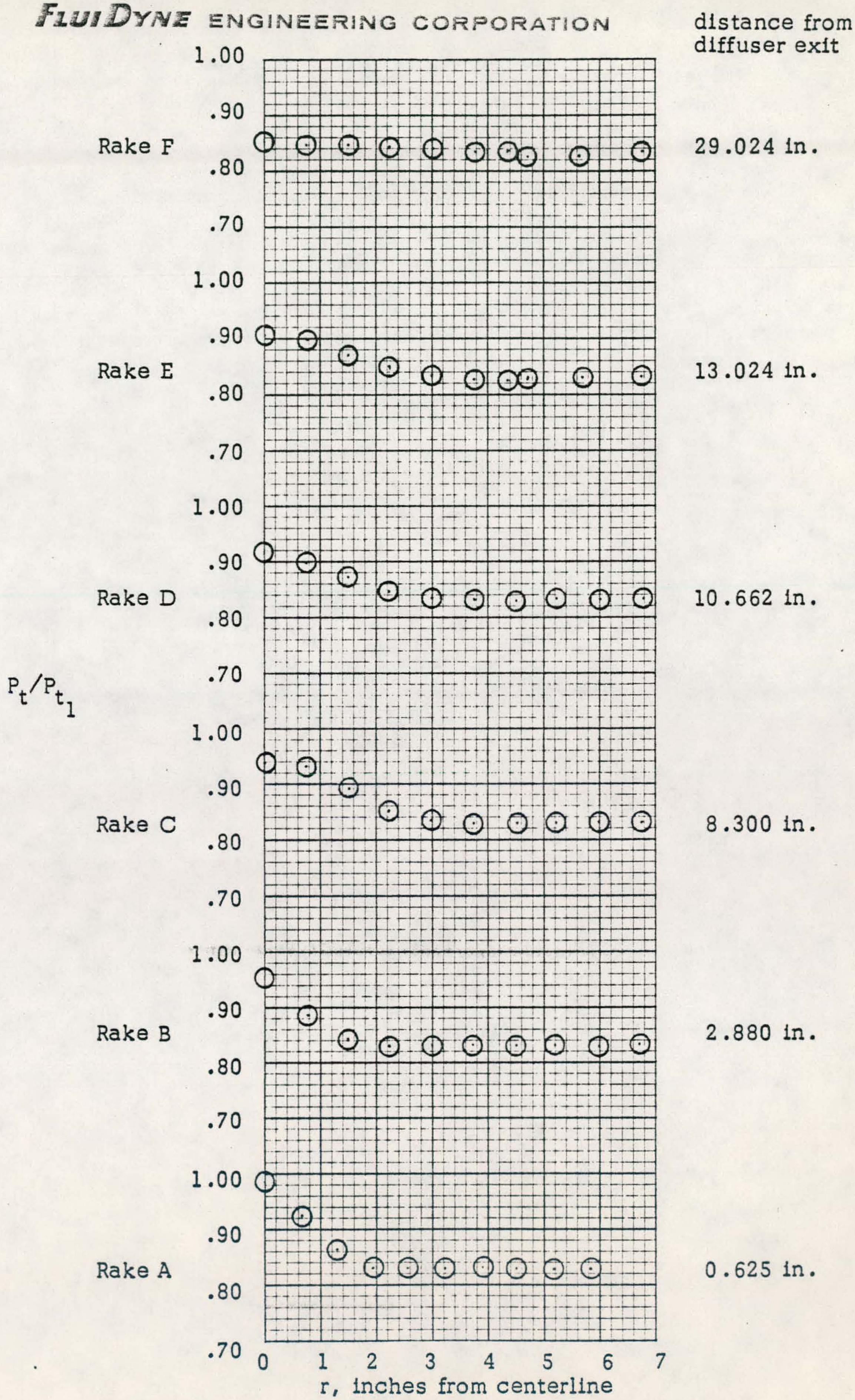

FIGURE 13k. STEAM GENERATOR SURVEY RUN IV-19
DIFFUSER NO. 1, M = .75, $\alpha = 210°$

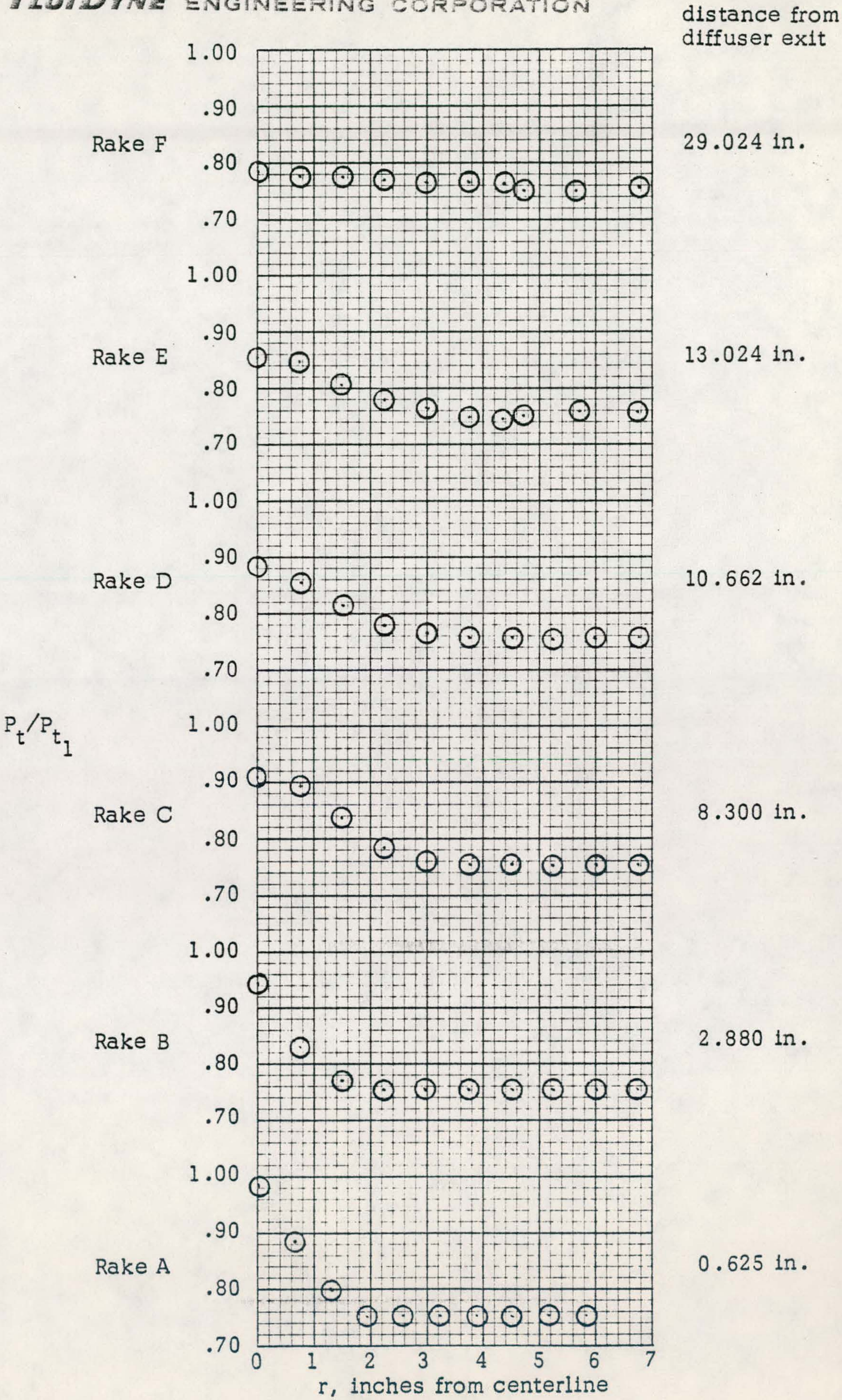

FIGURE 13m. STEAM GENERATOR SURVEY RUN IV-20
DIFFUSER NO. 1, M = 1.0, $\alpha = 210°$

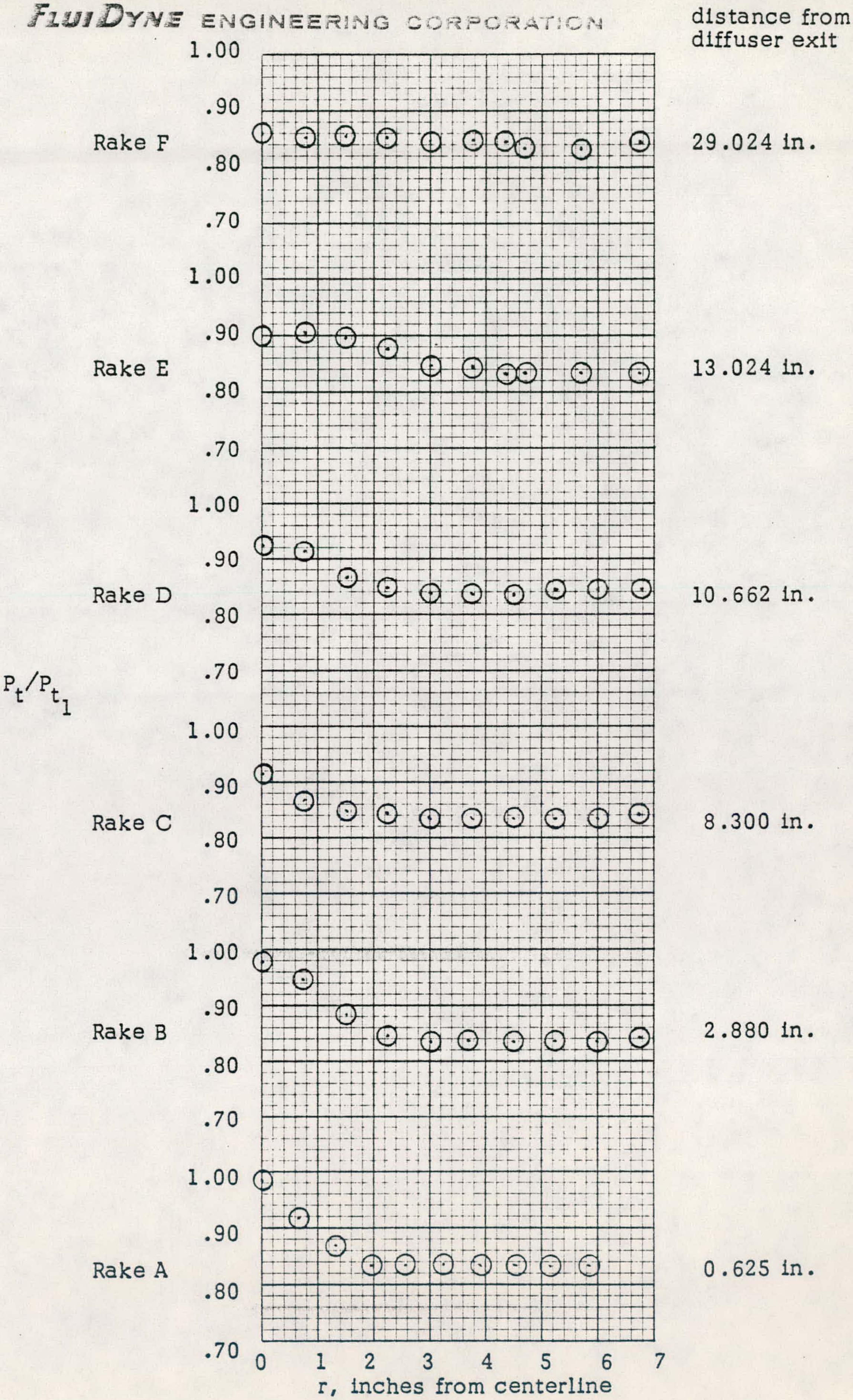

FIGURE 14a. STEAM GENERATOR SURVEY RUN IV-29
DIFFUSER NO. 4, M = .75, $\alpha = 330°$

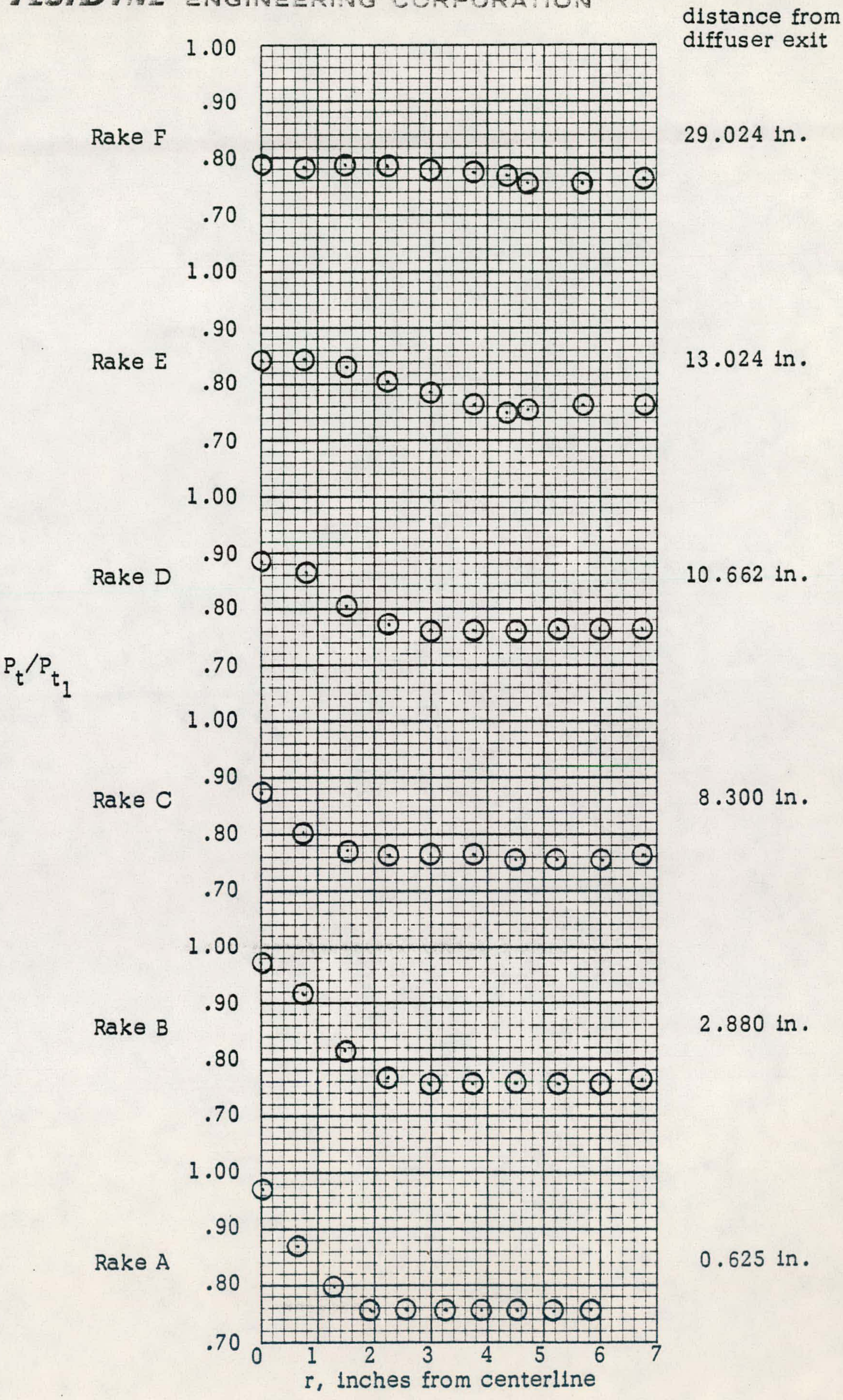

FIGURE 14b. STEAM GENERATOR SURVEY RUN IV-30
DIFFUSER NO. 4, M = 1.0, $\alpha = 330°$

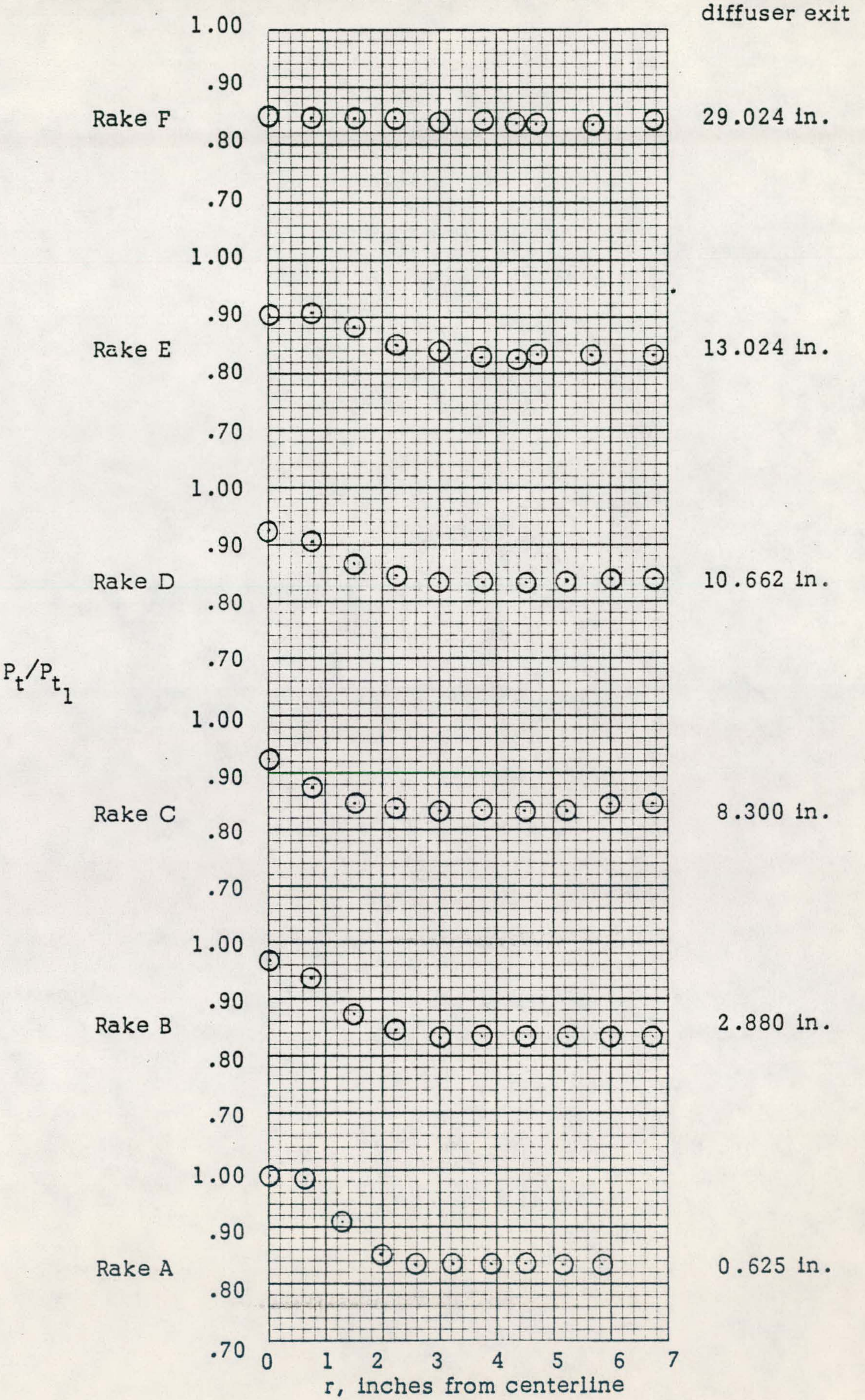

FIGURE 14c. STEAM GENERATOR SURVEY RUN IV-31
DIFFUSER NO. 4, M = .75, $\alpha = 270°$

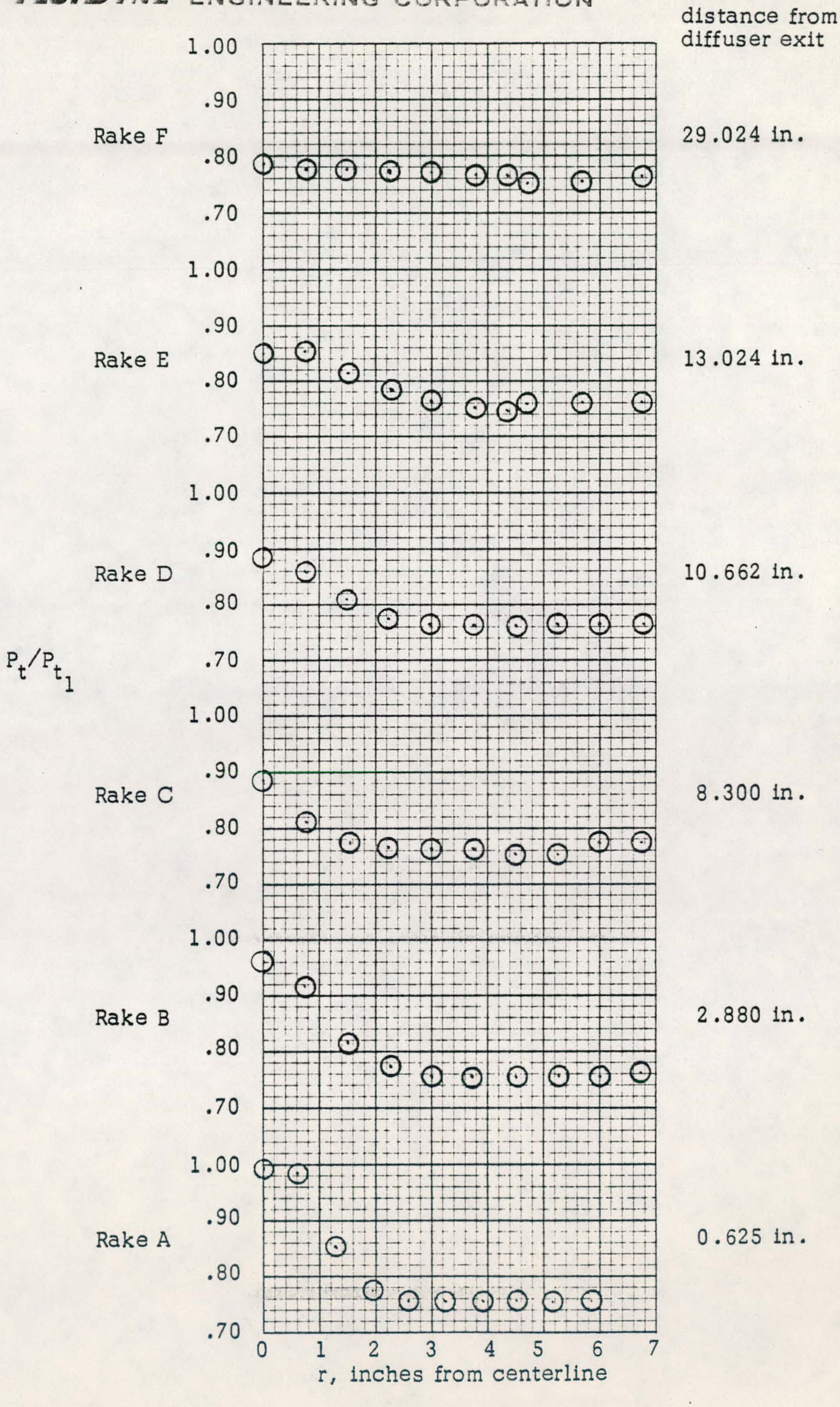

FIGURE 14d. STEAM GENERATOR SURVEY RUN IV-32
DIFFUSER NO. 4, $M = 1.0$, $\alpha = 270°$

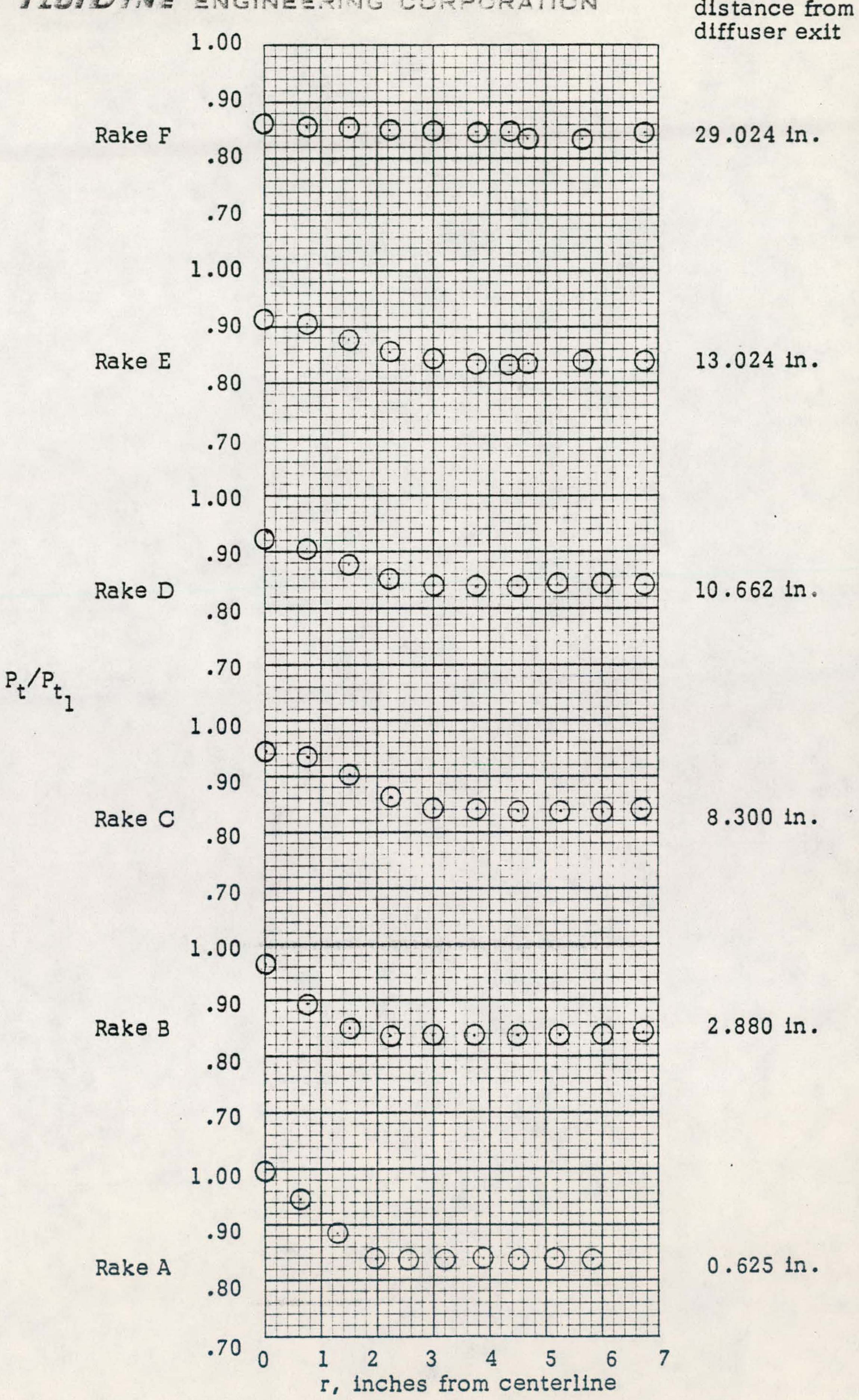

FIGURE 14e. STEAM GENERATOR SURVEY RUN IV-33
DIFFUSER NO. 4, M = .75, $\alpha = 210°$

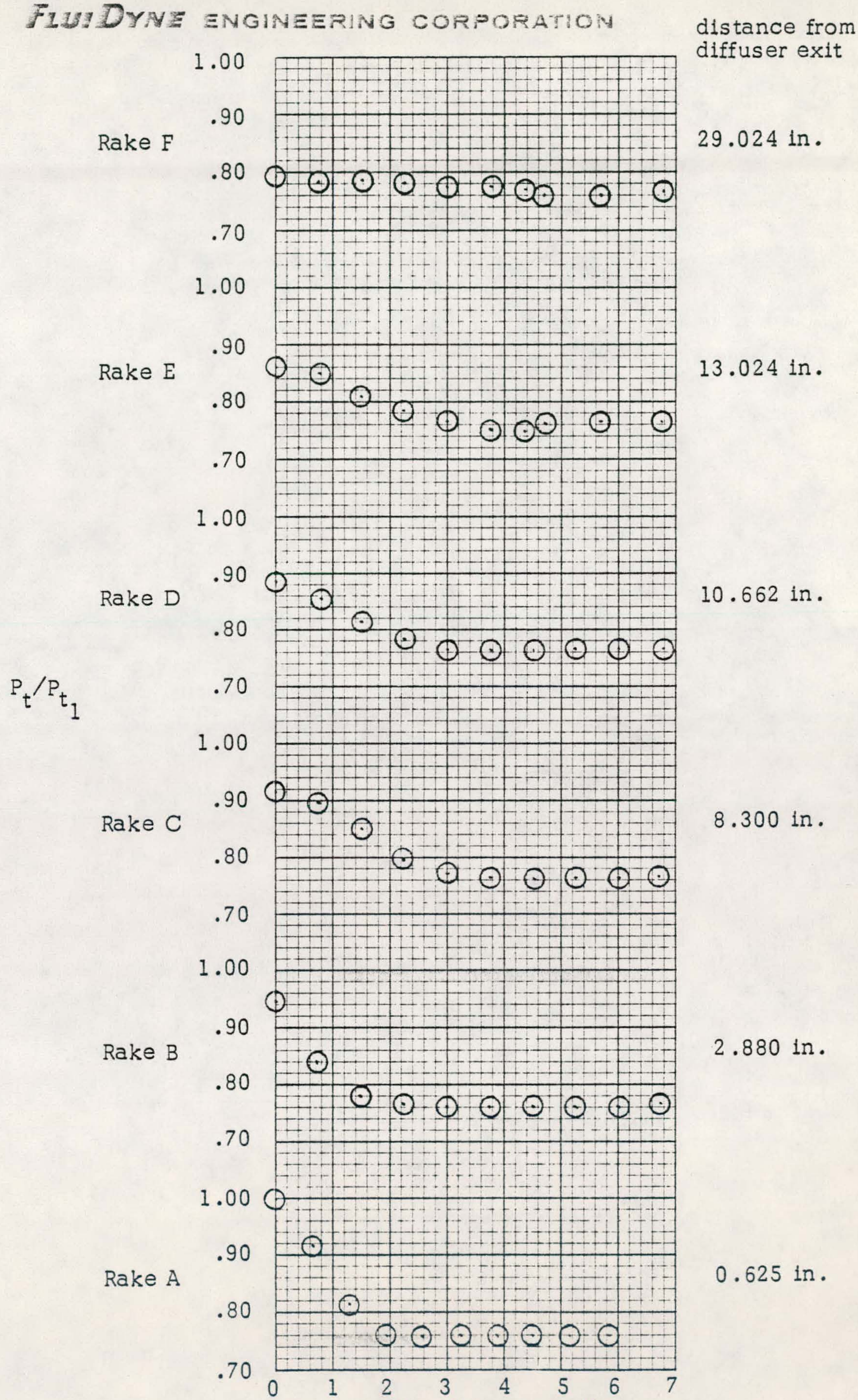

FIGURE 14f. STEAM GENERATOR SURVEY RUN IV-34
DIFFUSER NO. 4, M = 1.0, $\alpha = 210°$

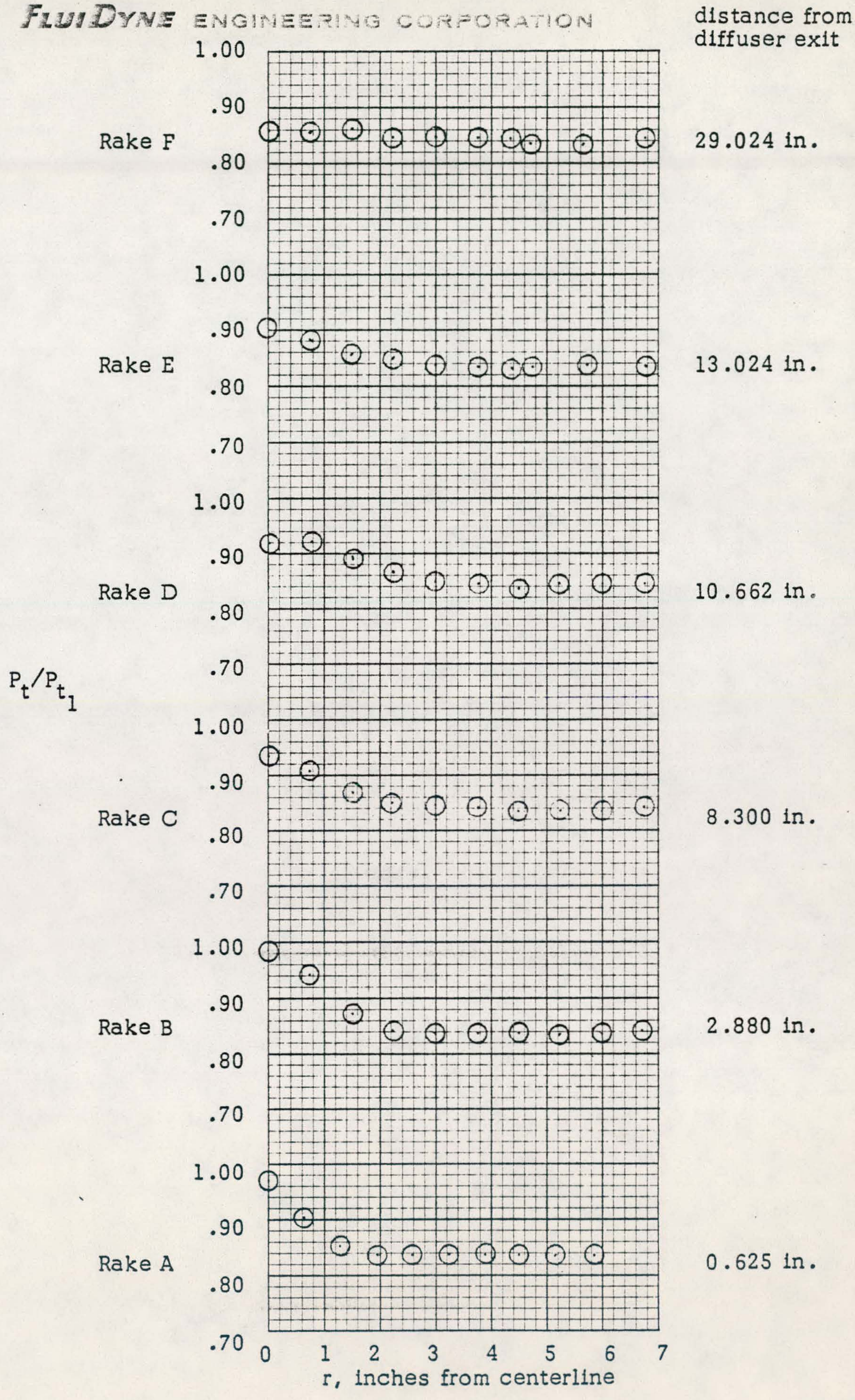

FIGURE 14g. STEAM GENERATOR SURVEY RUN IV-35
DIFFUSER NO. 4, M = .75, $\alpha = 30°$

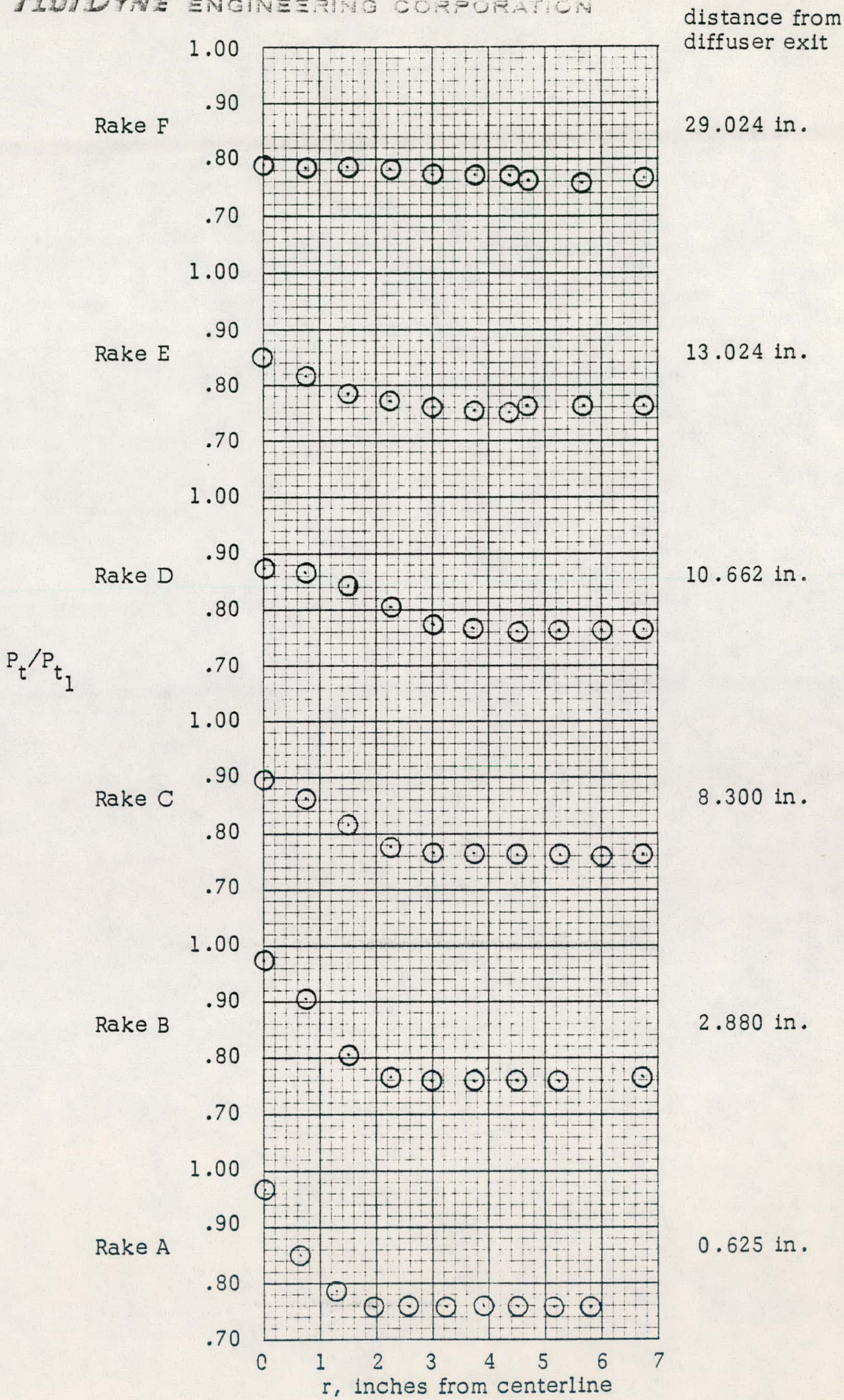

FIGURE 14h. STEAM GENERATOR SURVEY RUN IV-36
DIFFUSER NO. 4, M = 1.0, $\alpha = 30°$

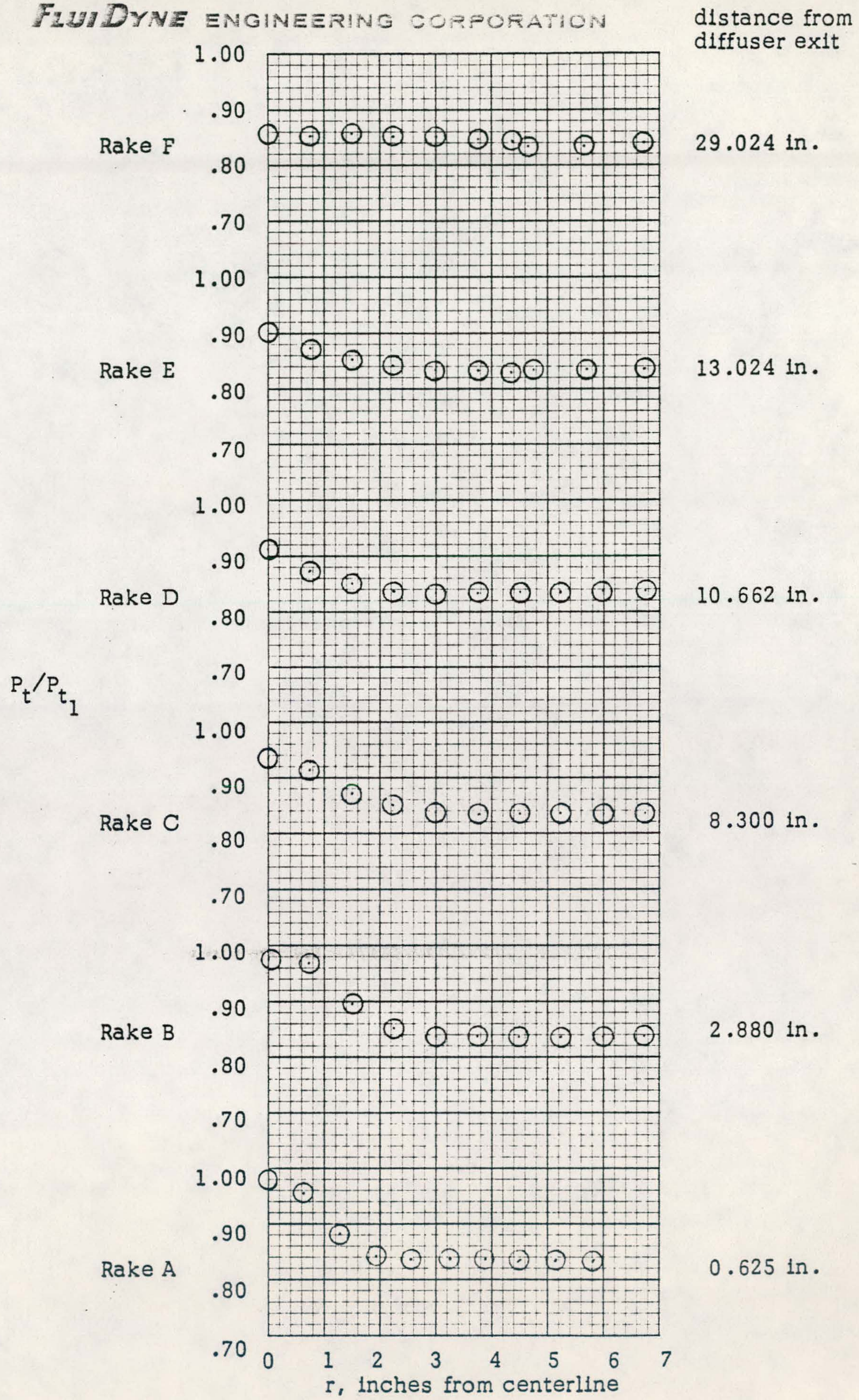

FIGURE 14i. STEAM GENERATOR SURVEY RUN IV-37
DIFFUSER NO. 4, M = .75, $\alpha = 90°$

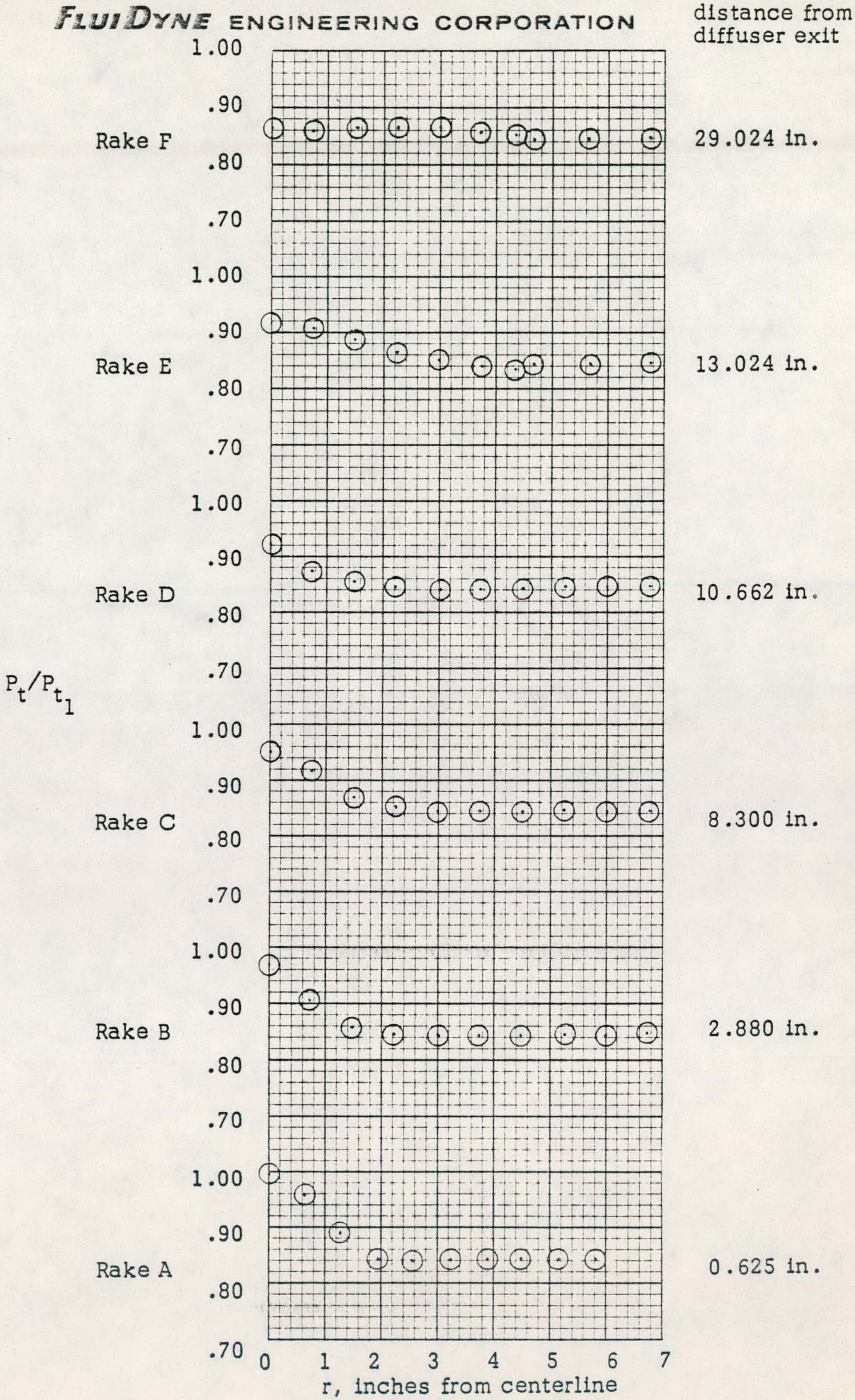

FIGURE 14k. STEAM GENERATOR SURVEY RUN IV-39
DIFFUSER NO. 4, M = .75, $\alpha = 150°$

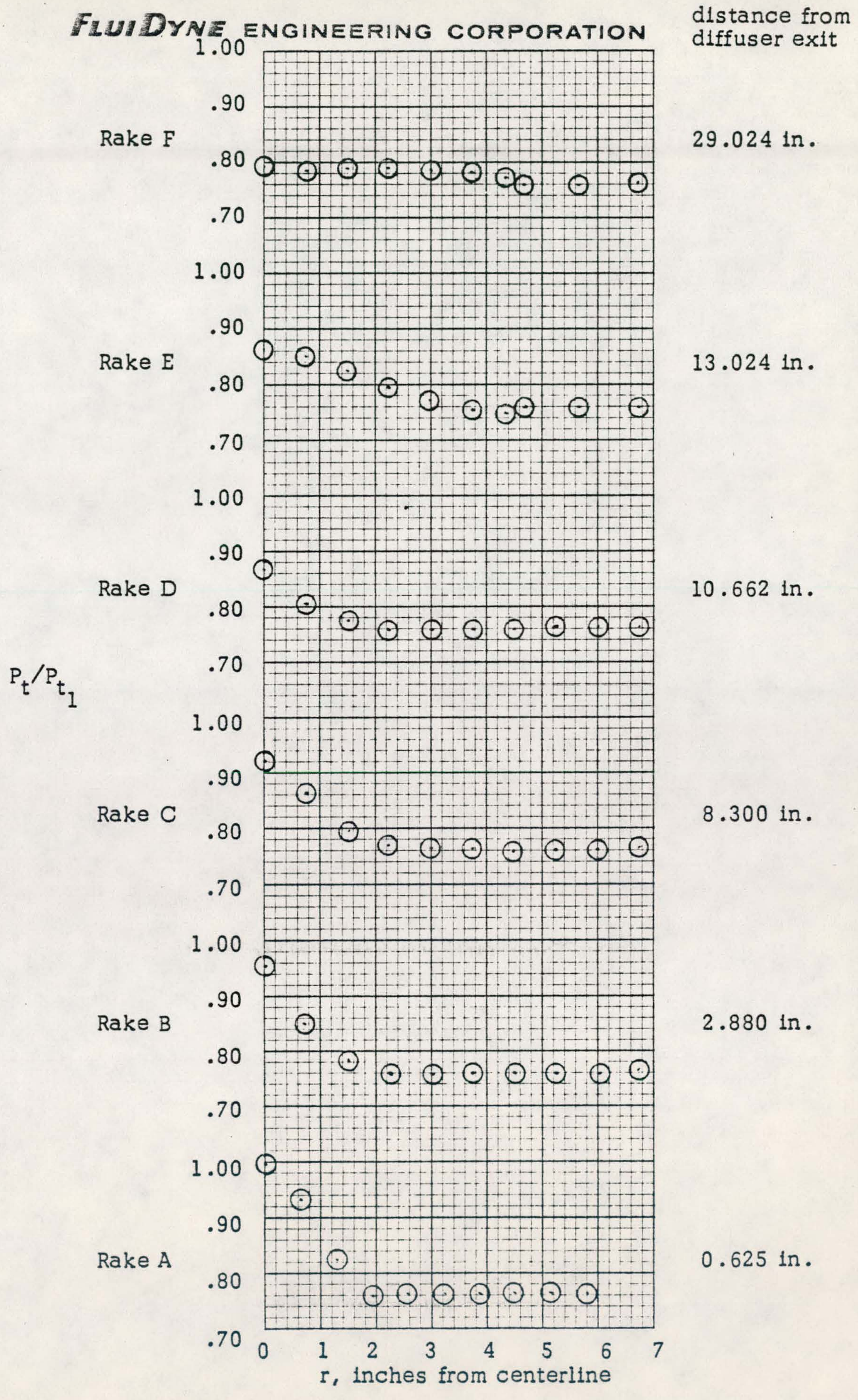

FIGURE 14m. STEAM GENERATOR SURVEY RUN IV-40
DIFFUSER NO. 4, M = 1.0, $\alpha = 150°$

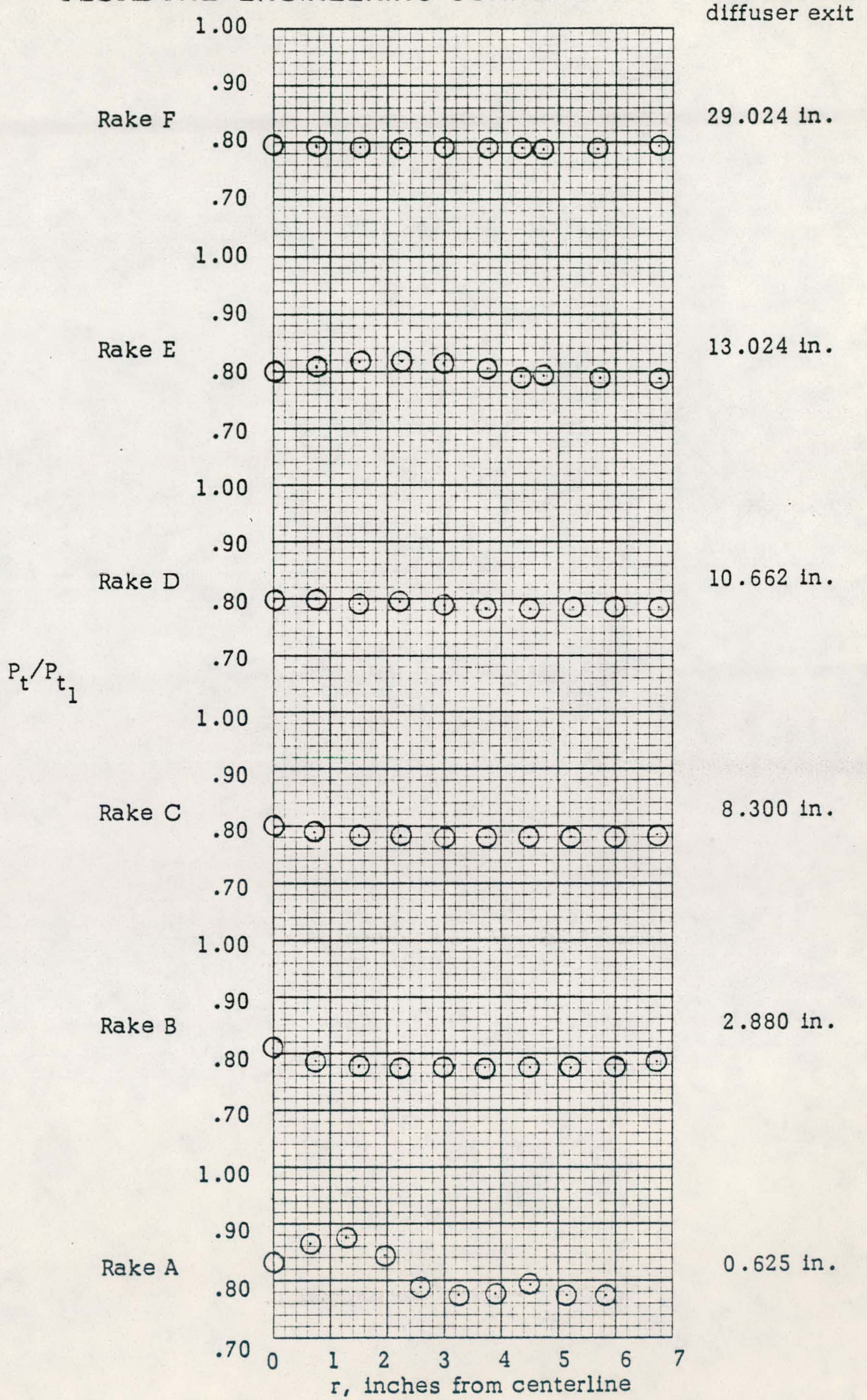

FIGURE 15a. STEAM GENERATOR SURVEY RUN IV-41
DIFFUSER NO. 7, M = .75, $\alpha = 150°$

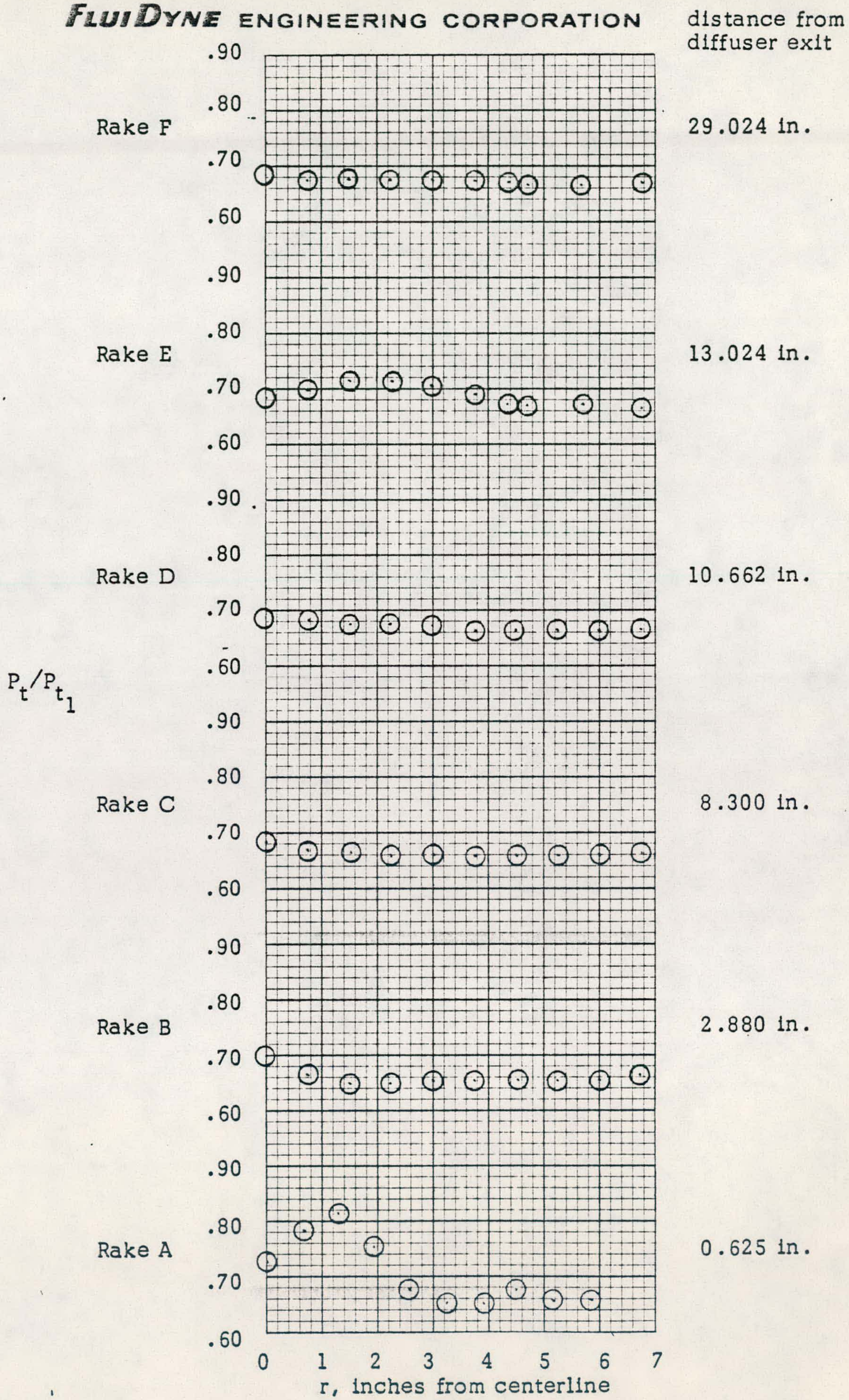

FIGURE 15b. STEAM GENERATOR SURVEY RUN IV-42
DIFFUSER NO. 7, M = 1.0, $\alpha = 150°$

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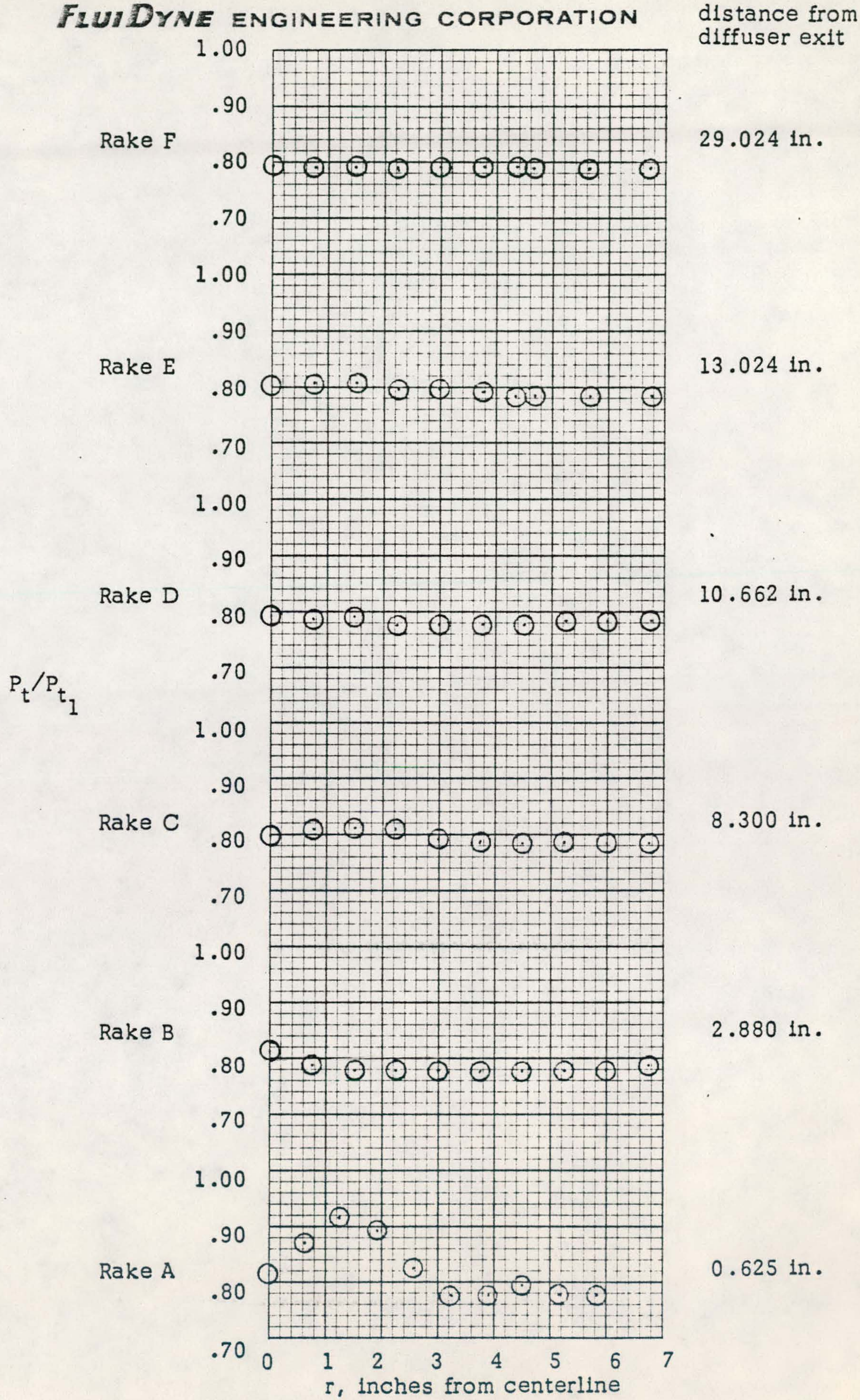

FIGURE 15c. STEAM GENERATOR SURVEY RUN IV-43
DIFFUSER NO. 7, M = .75, $\alpha = 90°$

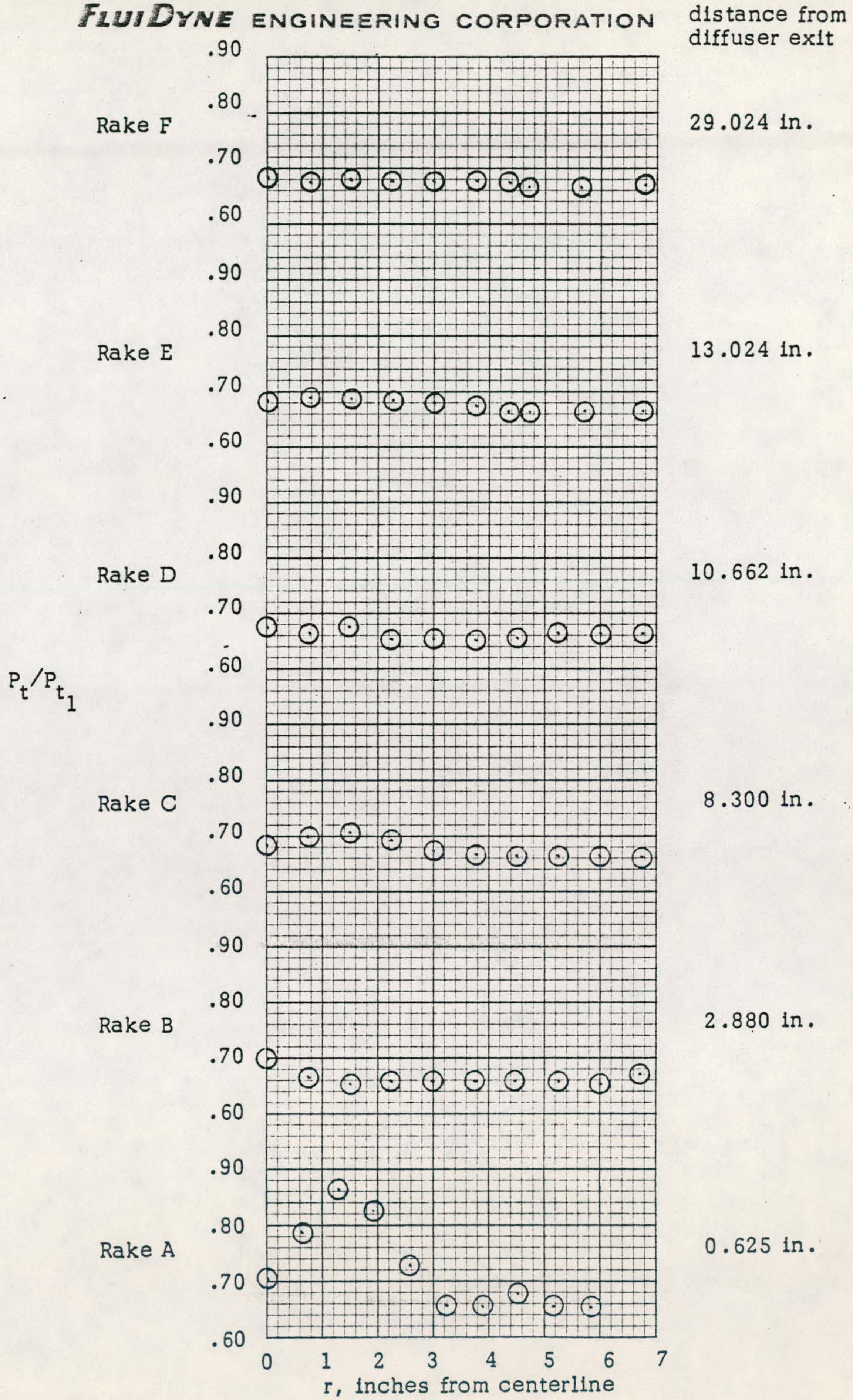

FIGURE 15d. STEAM GENERATOR SURVEY RUN IV-44
DIFFUSER NO. 7, $M = 1.0$, $\alpha = 90°$

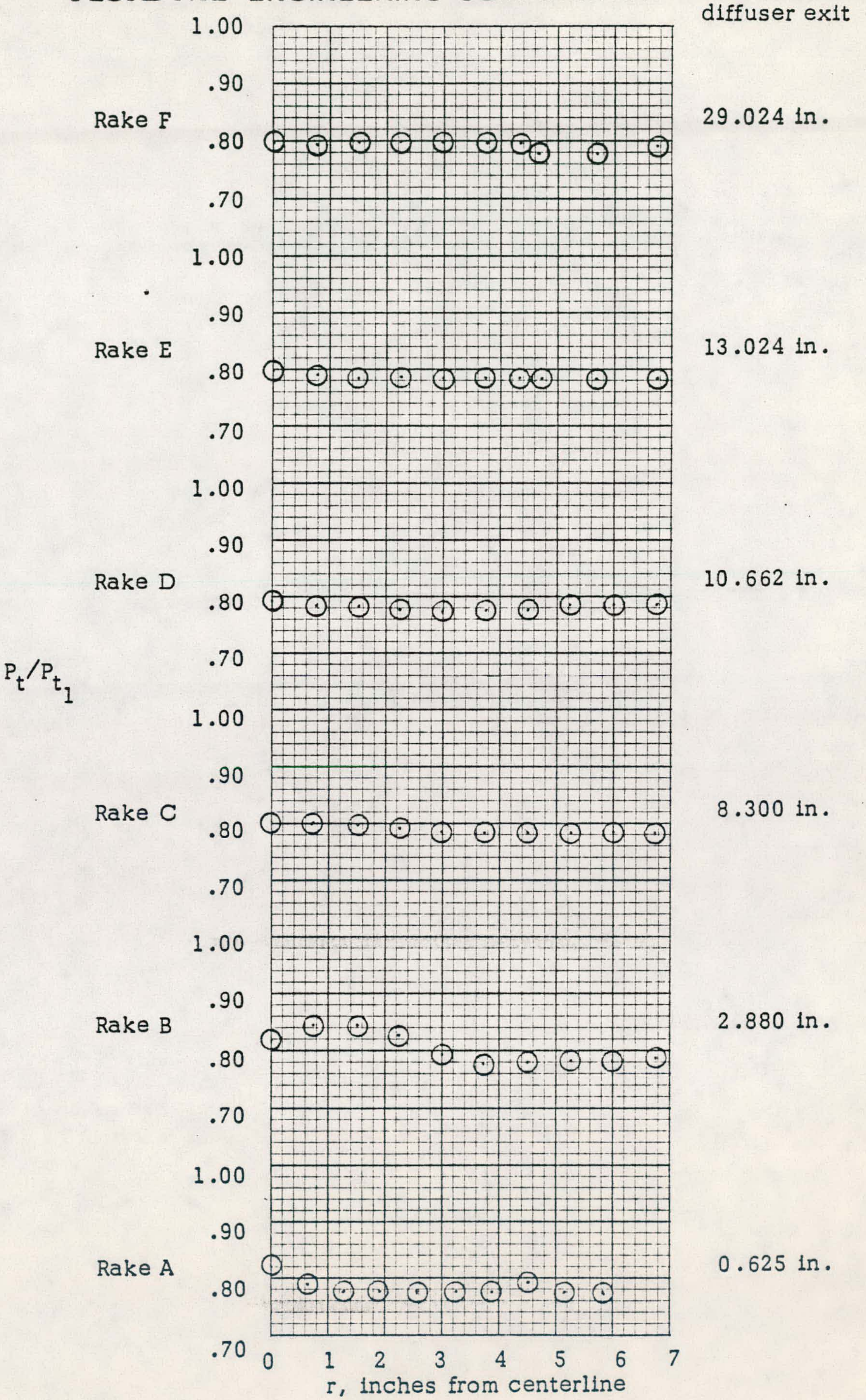

FIGURE 15e. STEAM GENERATOR SURVEY RUN IV-45
DIFFUSER NO. 7, M = .75, $\alpha = 330°$

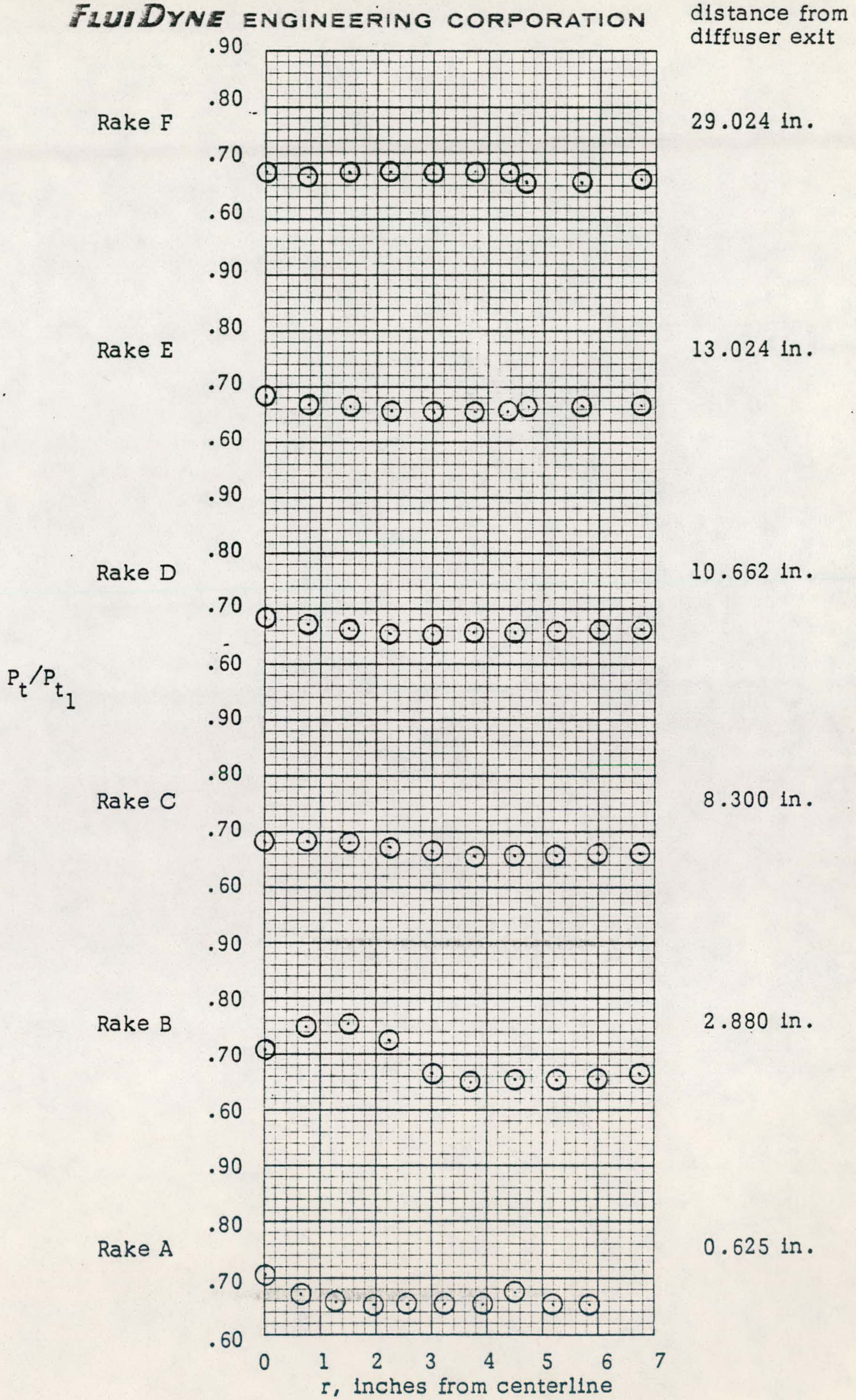

FIGURE 15f. STEAM GENERATOR SURVEY RUN IV-46
DIFFUSER NO. 7, M = 1.0, $\alpha = 330°$

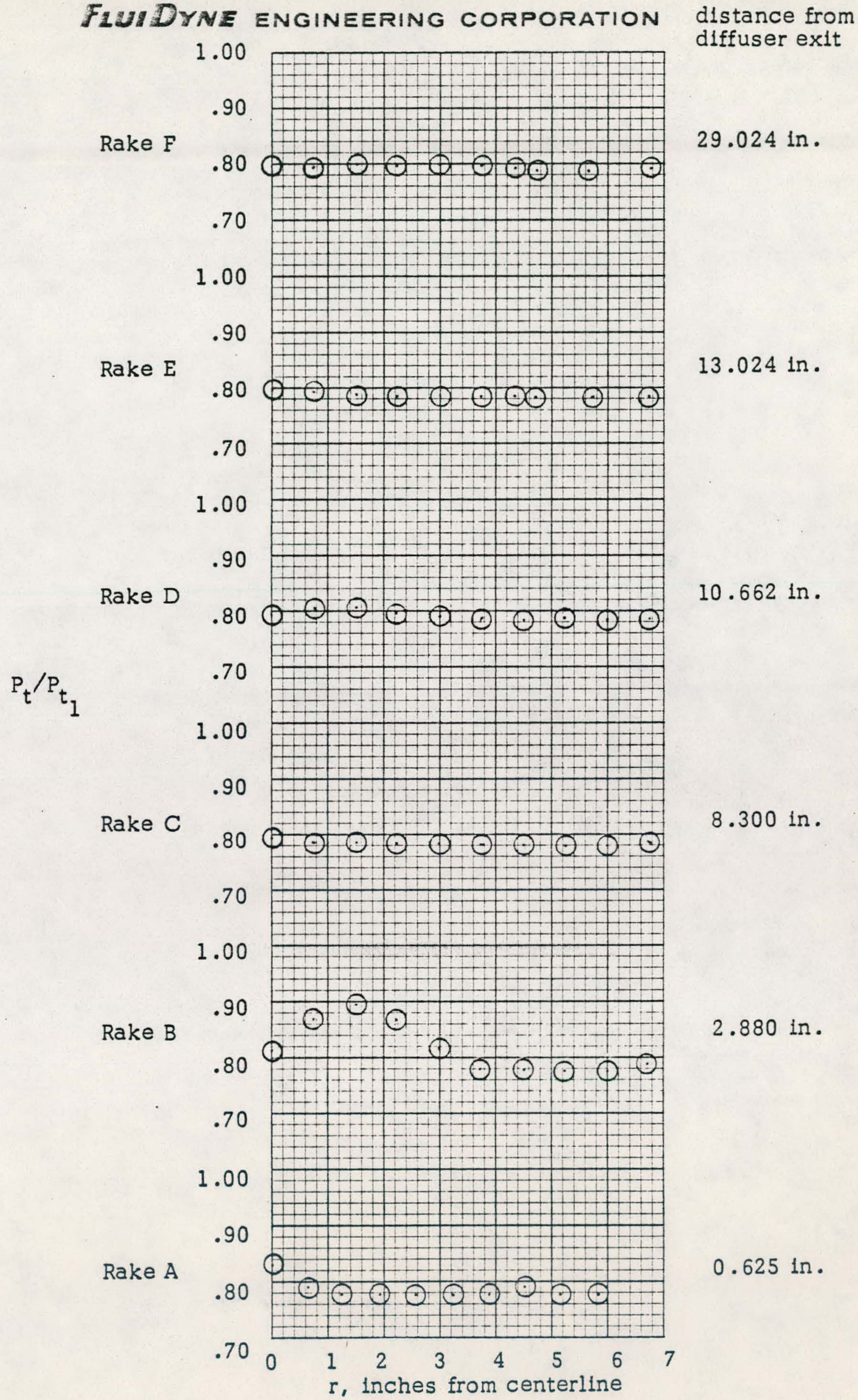

FIGURE 15g. STEAM GENERATOR SURVEY RUN IV-47
DIFFUSER NO. 7, M = .75, $\alpha = 270°$

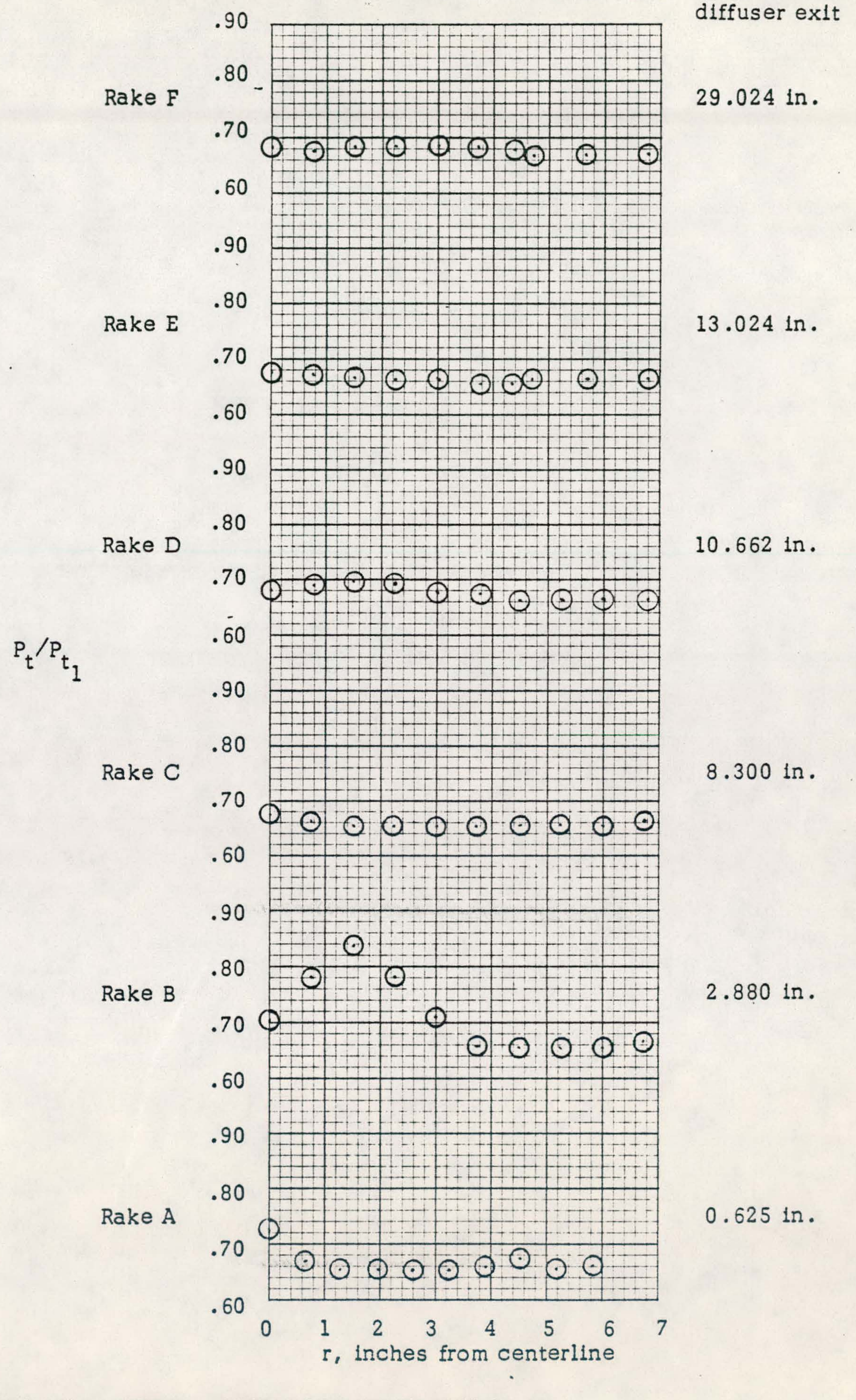

FIGURE 15h. STEAM GENERATOR SURVEY RUN IV-48
DIFFUSER NO. 7, M = 1.0, $\alpha = 270°$

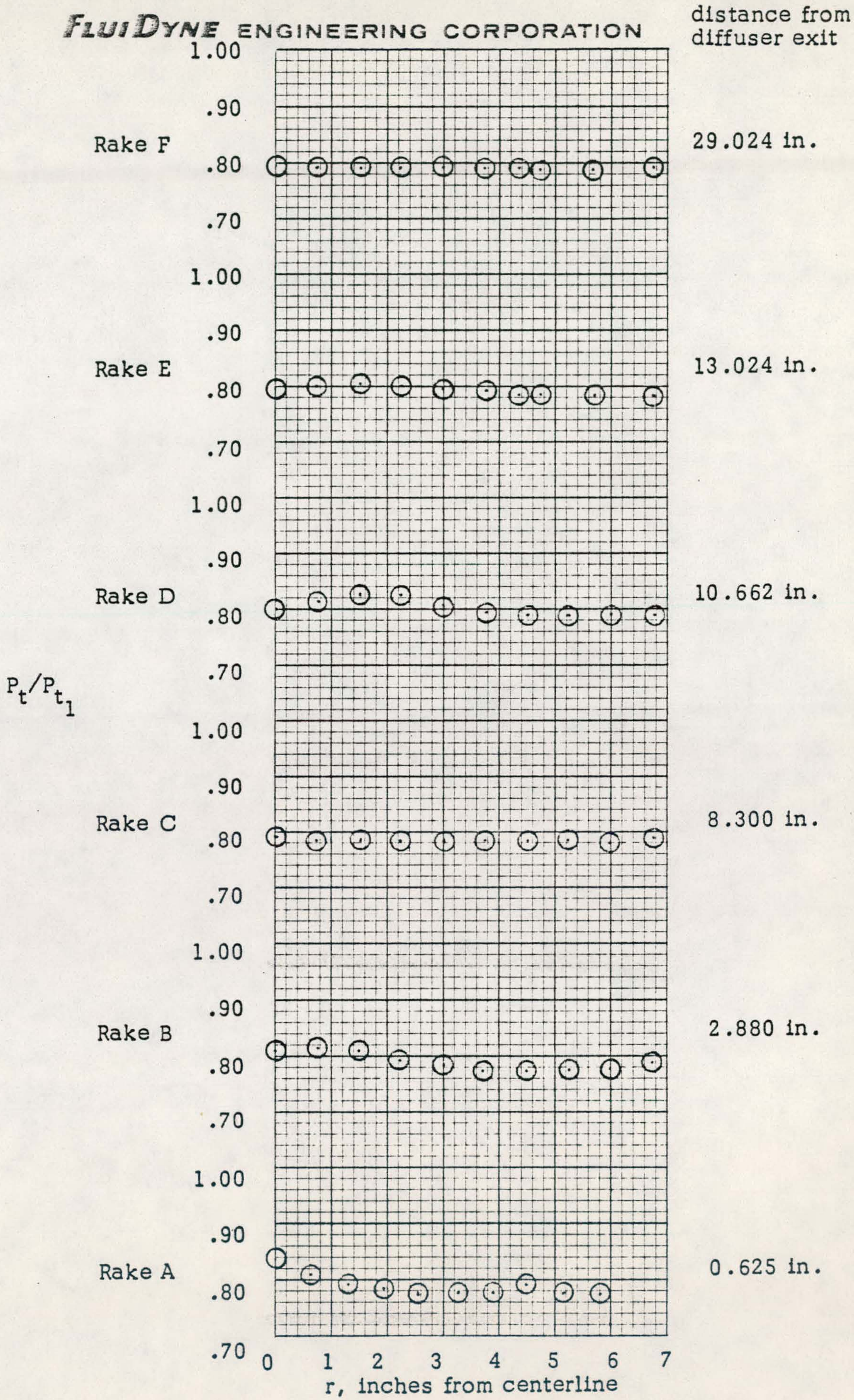

FIGURE 15i. STEAM GENERATOR SURVEY RUN IV-49
DIFFUSER NO. 7, M = .75, $\alpha = 210°$

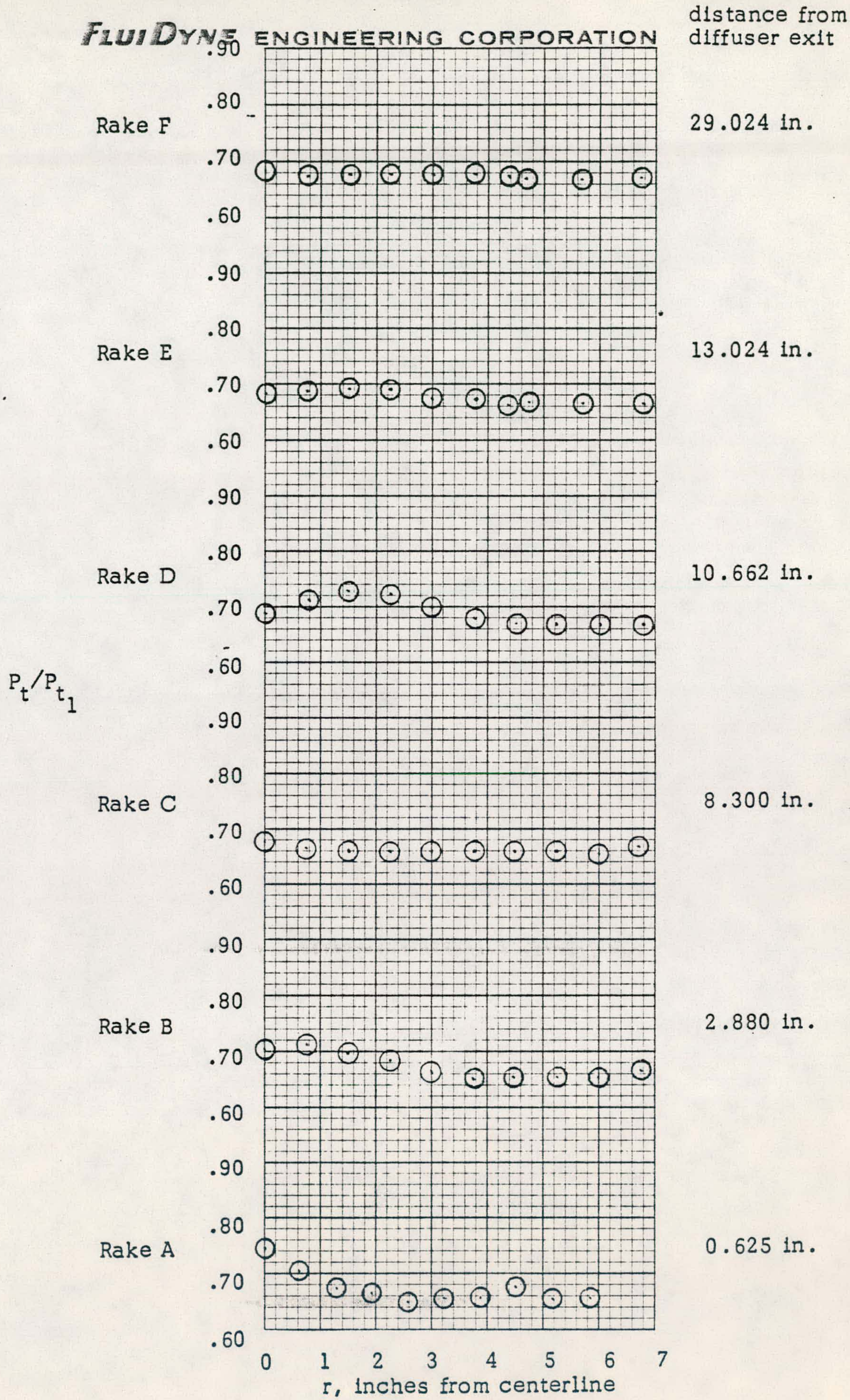

FIGURE 15j. STEAM GENERATOR SURVEY RUN IV-50
DIFFUSER NO. 7, M = 1.0, $\alpha = 210°$

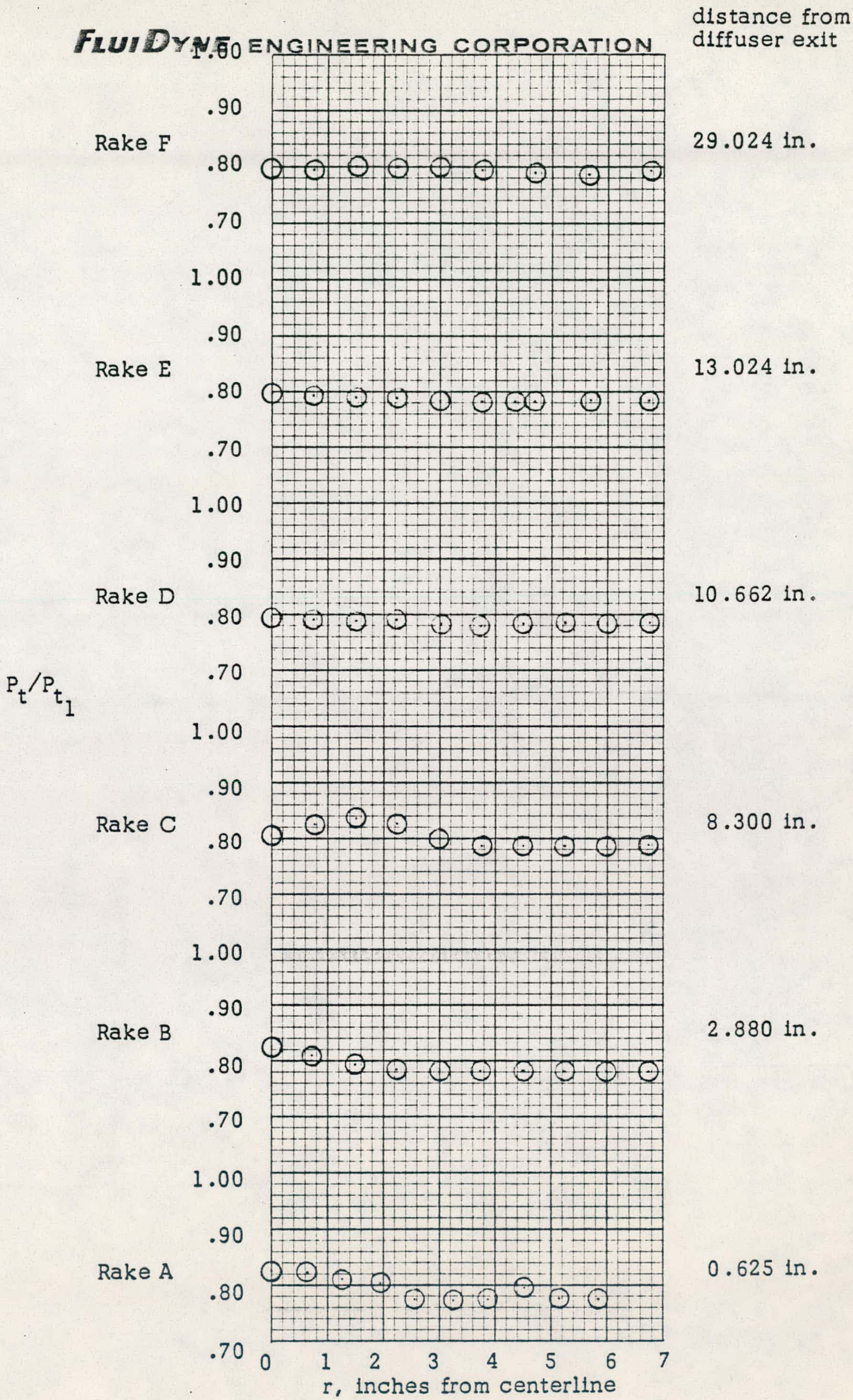

FIGURE 15k. STEAM GENERATOR SURVEY RUN IV-51
DIFFUSER NO. 7, M = .75, $\alpha = 30°$

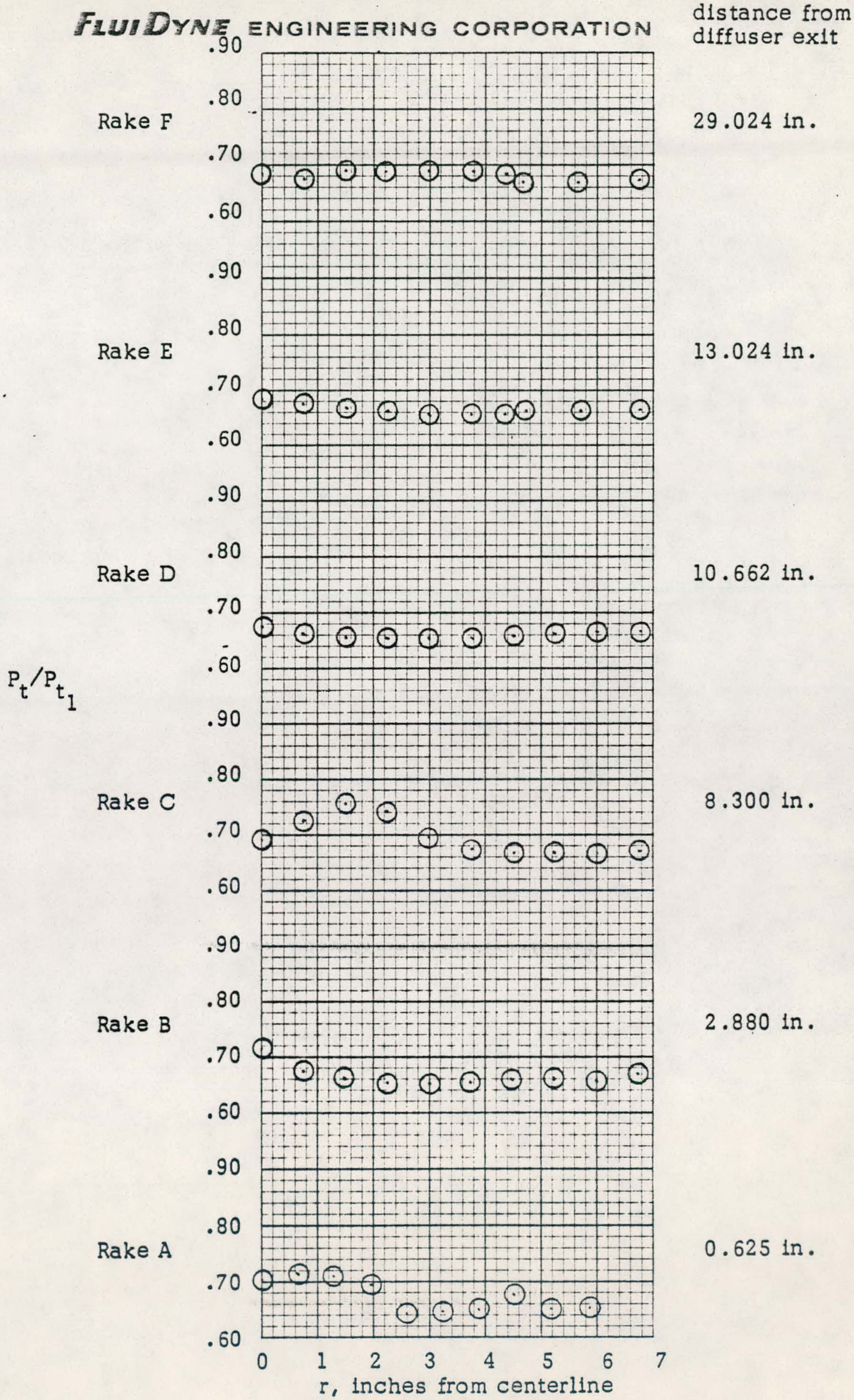

FIGURE 15m. STEAM GENERATOR SURVEY RUN IV-52
DIFFUSER NO. 7, M = 1.0, $\alpha = 30°$

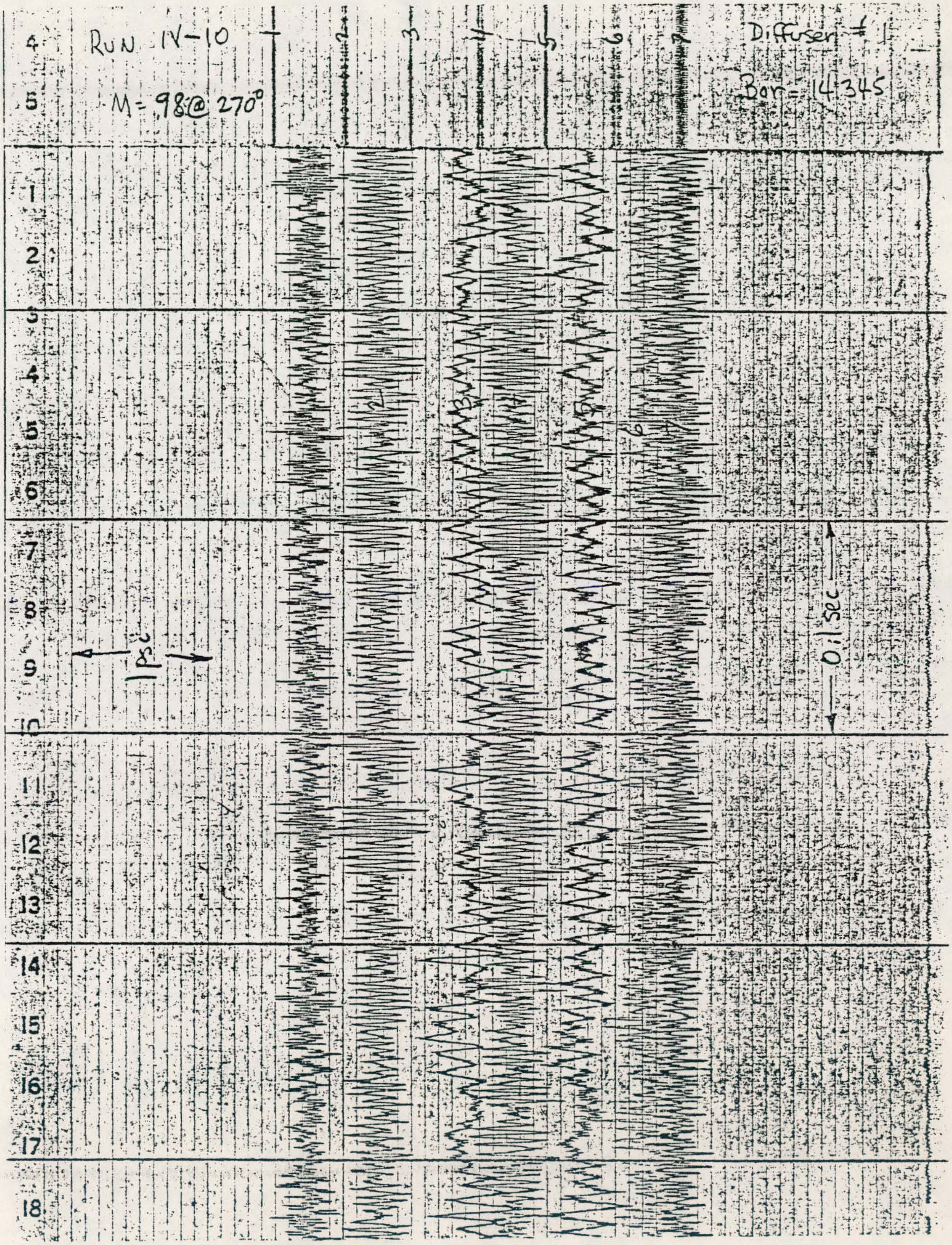

FIGURE 16a. STEAM GENERATOR SIMULATOR STATIC PRESSURE TRACE WITH DIFFUSER NO. 1

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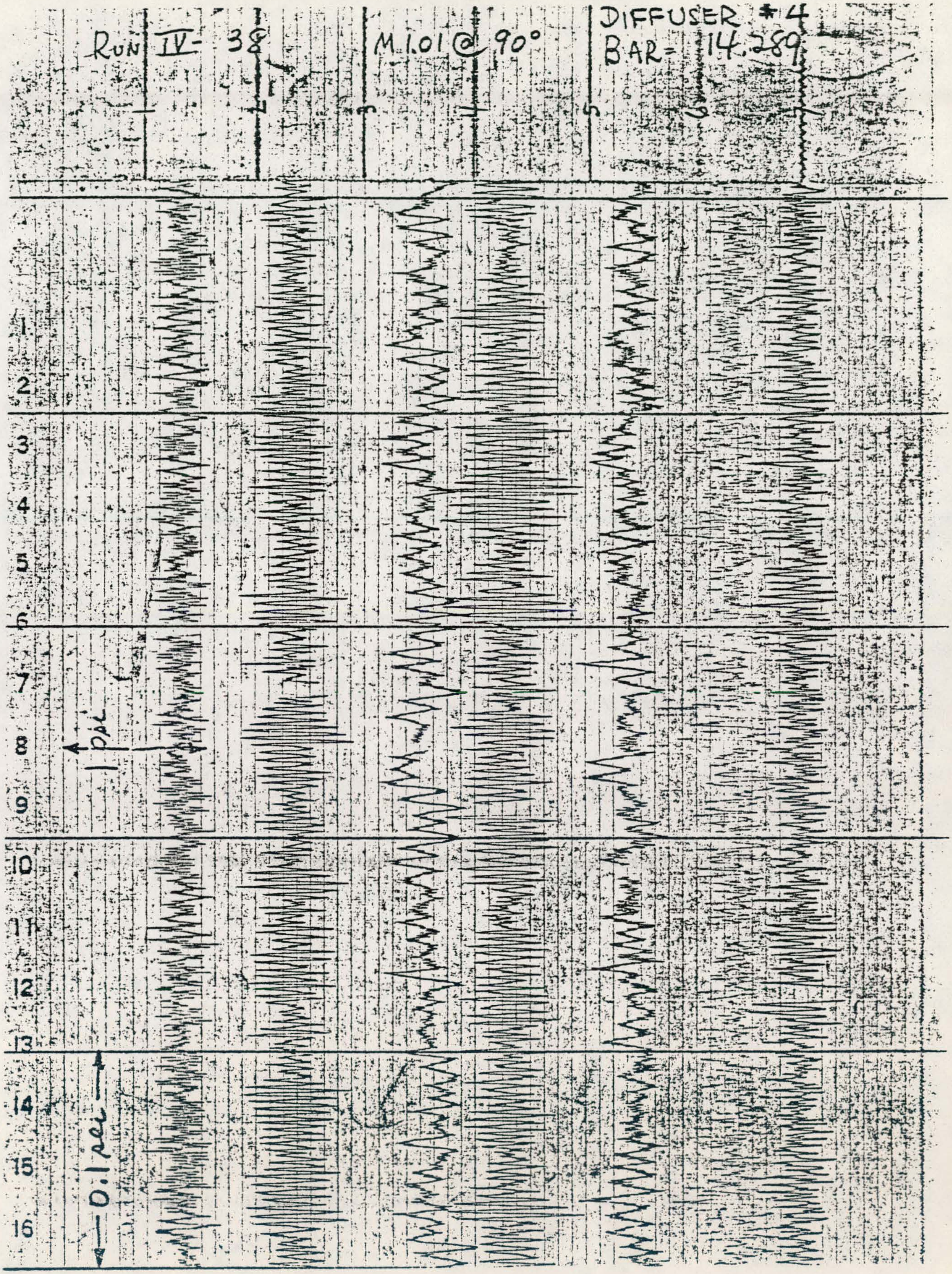


FIGURE 16b. STEAM GENERATOR SIMULATOR STATIC PRESSURE TRACE WITH DIFFUSER NO. 4

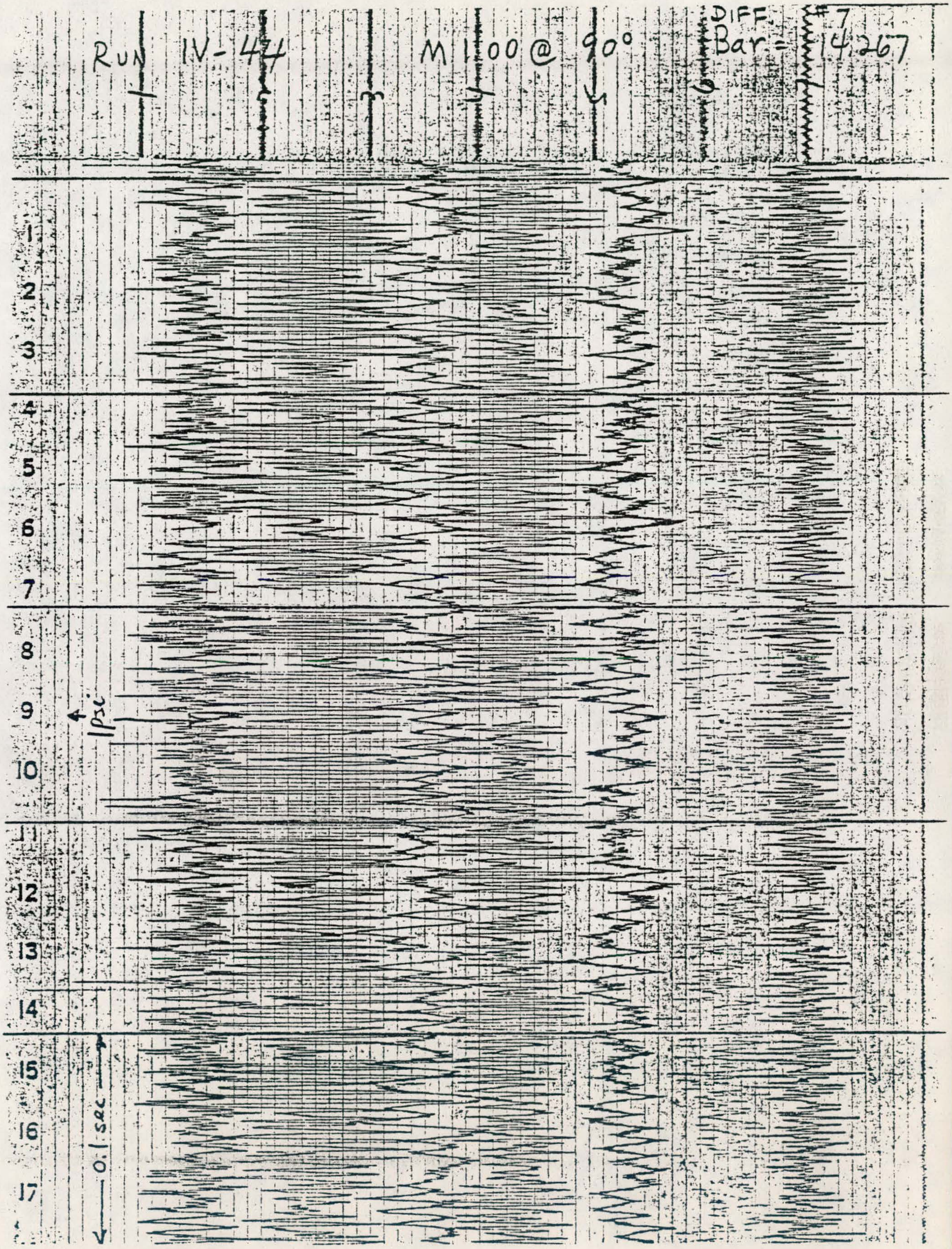
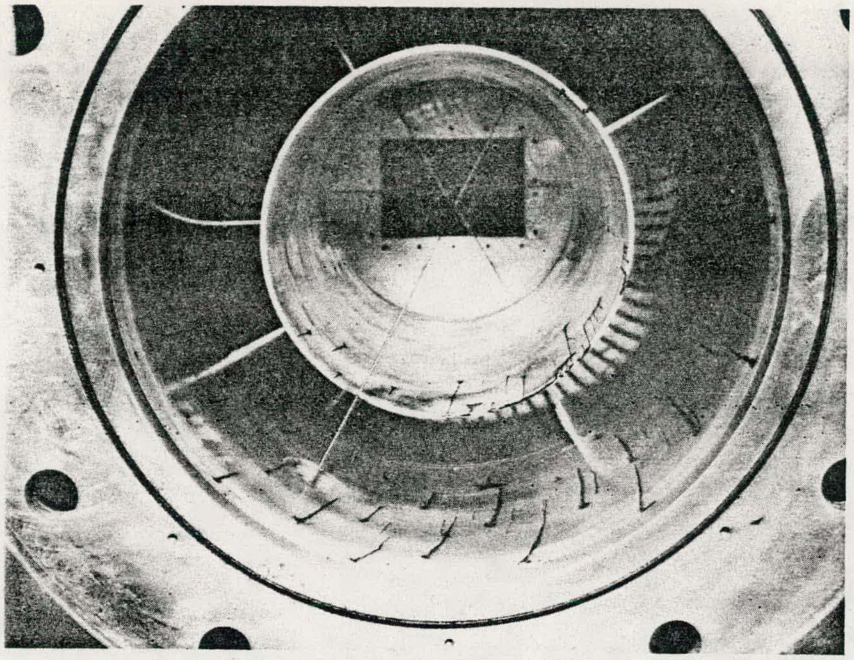
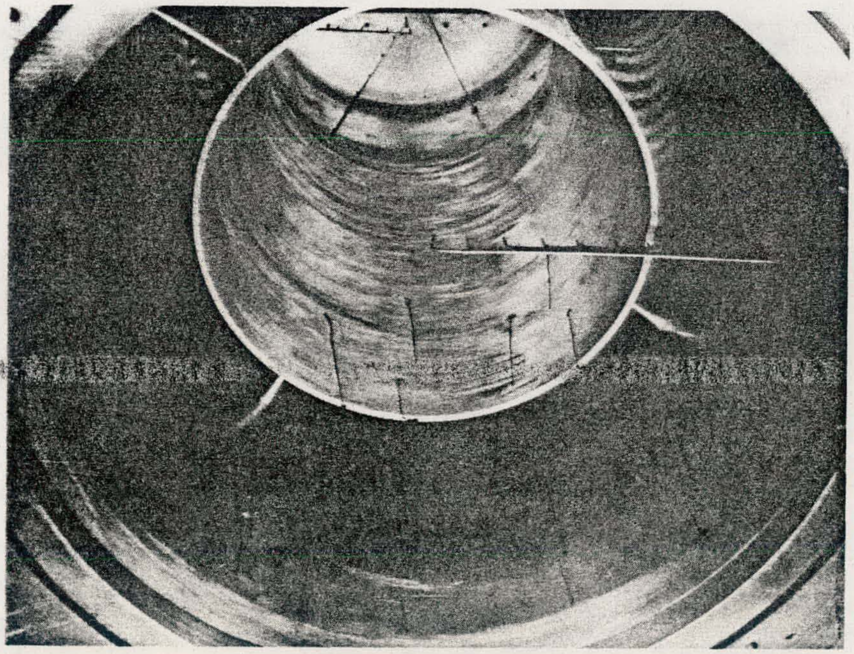


FIGURE 16c. STEAM GENERATOR SIMULATOR STATIC PRESSURE TRACE WITH DIFFUSER NO. 7





Lampblack in Glycerine Streaks at Mach = 1
Upper with Diffuser Number 7
Lower with Diffuser Number 1
Note Flow Reversals in Outer Annulus.

FIGURE 17. STEAM GENERATOR FLOW VISUALIZATION PHOTOGRAPHS

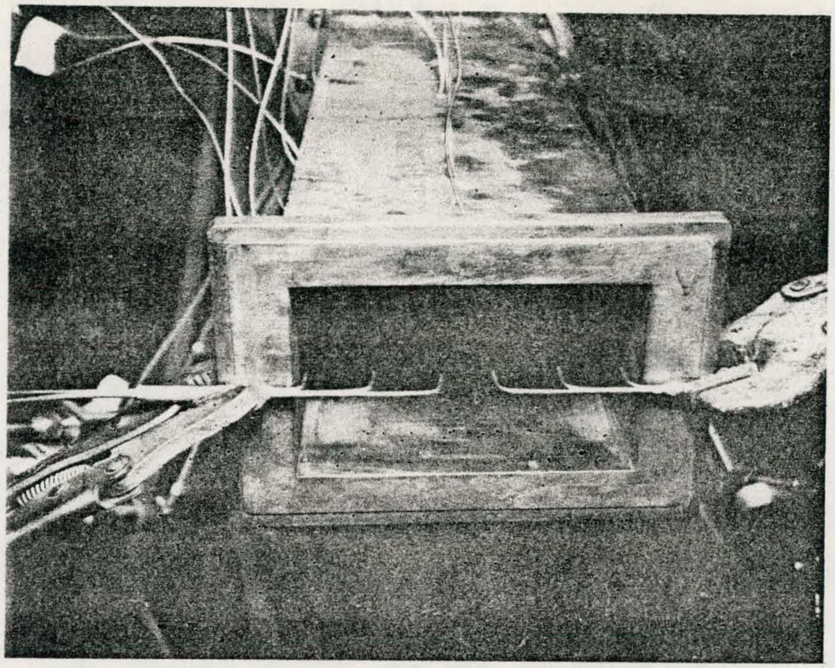
FIGURE 18

PHASE IV - PRESSURE RECOVERY COEFFICIENTS

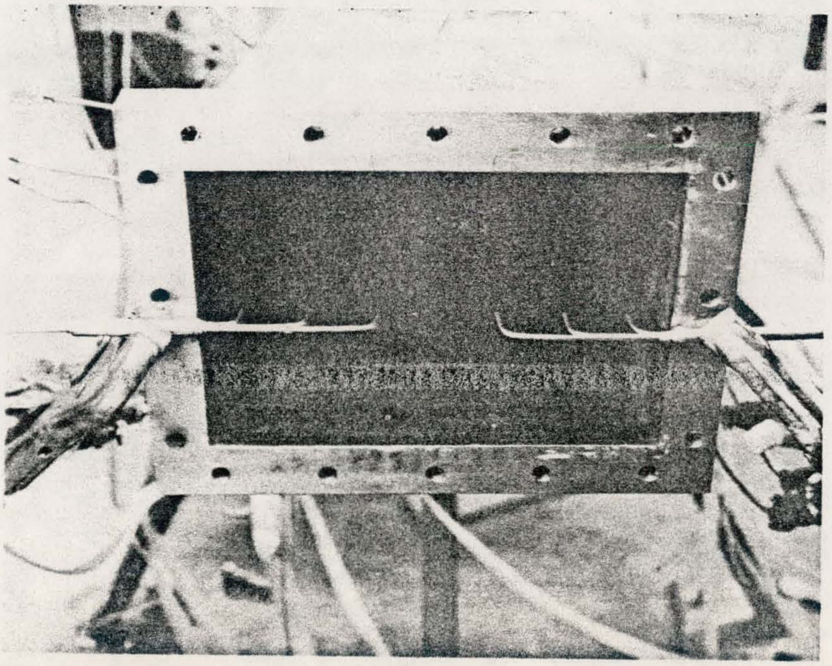
Run Number	Diffuser	Survey Angle	P_{t_o} psia	P_{t_2} psia	P_2 psia	M	P_e psia	C_p
IV-9	1	270	31.86	16.98	11.83	0.74	14.12	.446
-10	1	270	38.20	18.59	10.04	0.98	14.00	.463
-11	1	330	31.98	17.00	11.78	0.74	14.09	.443
-12	1	330	38.21	18.64	9.92	0.99	13.99	.467
-13	1	30	32.13	17.10	11.88	0.74	14.18	.441
-14	1	30	38.51	18.74	10.02	0.99	14.09	.467
-15	1	90	32.18	17.10	11.88	0.74	14.18	.441
-16	1	90	38.41	18.71	10.05	0.99	14.08	.465
-17	1	150	32.11	17.09	11.84	0.74	14.17	.445
-18	1	150	38.50	18.72	10.01	0.99	14.06	.464
-19	1	210	32.26	17.11	11.81	0.75	14.16	.442
-20	1	210	38.44	18.72	10.00	0.99	14.06	.466
-21	1	250	32.26	17.11	11.84	0.75	14.15	.437
-22	1	250	38.39	18.72	10.00	0.99	14.06	.466
-23	1	290	32.25	17.10	11.80	0.75	14.15	.443
-24	1	290	38.48	18.71	9.94	1.00	14.05	.466
-25	1	310	32.30	17.15	11.84	0.75	14.20	.444
-26	1	310	38.48	18.75	10.01	0.99	14.09	.466
-27	1	350	32.32	17.19	11.83	0.75	14.20	.441
-28	1	350	38.48	18.75	10.02	0.99	14.11	.468
-29	4	330	32.44	16.83	11.65	0.74	14.05	.463
-30	4	330	38.74	18.45	9.60	1.01	13.93	.489
-31	4	270	32.44	16.88	11.62	0.75	14.04	.460
-32	4	270	38.74	18.44	9.59	1.01	13.93	.490
-33	4	210	32.39	16.83	11.60	0.75	14.06	.469
-34	4	210	38.74	18.40	9.59	1.01	13.93	.492
-35	4	30	32.44	16.83	11.60	0.75	14.04	.466
-36	4	30	38.74	18.40	9.59	1.01	13.93	.492
-37	4	90	32.34	16.88	11.60	0.75	14.04	.461

FIGURE 18 (Cont.)

Run Number	Diffuser	Survey Angle	P_{t_o} psia	P_{t_2} psia	P_2 psia	M	P_e psia	C_p
IV-38	4	90	38.69	18.45	9.64	1.01	13.93	.486
-39	4	150	32.34	16.73	11.62	0.74	14.04	.474
-40	4	150	38.74	18.40	9.59	1.01	13.96	.496
-41	7	150	33.46	17.98	12.41	0.75	13.96	.278
-42	7	150	42.67	21.06	11.13	1.00	13.81	.270
-43	7	90	33.47	17.98	12.58	0.73	13.99	.260
-44	7	90	42.67	21.06	11.14	1.00	13.79	.267
-45	7	330	33.42	17.98	12.58	0.73	14.00	.262
-46	7	330	42.67	21.09	11.14	1.00	13.82	.269
-47	7	270	33.37	17.98	12.41	0.75	14.00	.285
-48	7	270	42.62	21.01	11.18	0.99	13.80	.267
-49	7	210	33.32	17.98	12.65	0.73	14.00	.252
-50	7	210	42.57	21.02	11.19	0.99	13.83	.269
-51	7	30	33.32	17.98	12.31	0.76	13.96	.291
-52	7	30	42.57	21.02	11.14	1.00	13.78	.267



Diffuser No. 1 Probe Spacing from Left Wall
.15, 1.15, 2.15, 2.94, 3.92,
4.87 in.



Diffuser No. 7 Probe Spacing from Left Wall
.58, 1.58, 2.58, 4.25, 5.23,
6.18 in.

FIGURE 19. DIFFUSER DYNAMICS SURVEY

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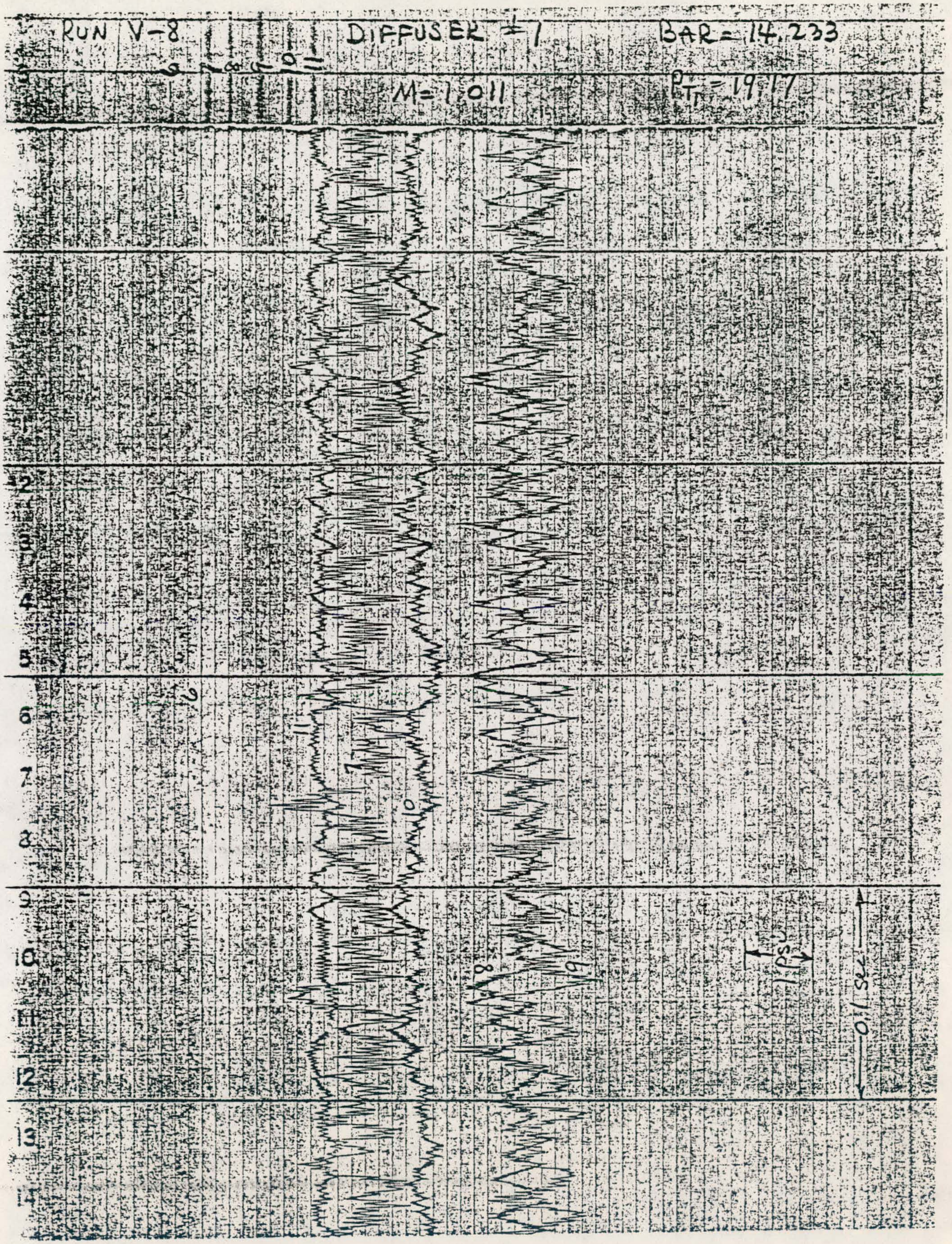

FIGURE 20a. DIFFUSER NO. 1 EXIT TOTAL PRESSURE TRACE