INSTRUMENTATION FOR CALIBRATION OF HYPERSONIC WIND TUNNEL

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A research study conducted
under course number AE-900.

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August 1964

ABSTRACT

Instrumentation was designed for the collection of pitot pressure and heat transfer data in the 20 in. test section of the hypersonic, "Hotshot", wind tunnel in the Aircraft Propulsion Laboratory of The University of Michigan. A Schlieren Double-Pass Parallel system coupled with a Fastax camera were used to take pictures of the test runs.

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ACKNOWLEDGMENTS

The first week of the project was spent conferring with Professors J. A. Nicholls and M. Sichel, Mr. Perry Hays and Mr. Kenneth Sivier as to the best way to accomplish the task at hand. Due to their interest, encouragement and guidance, the project got off to a rapid start and through their continuing tutelage throughout the summer it was kept on the right track.

Acknowledgment and gratitude must also be extended to Mr. Steve Crist and Mr. Donald McBride who most willingly came to our assistance in steering us over many obstacles.

Mr. Harry Orr produced some very fine work for the project and through his capable hands machined away many design problems.

Mr. Cletus Iott saved many words in this report by the painstaking care he put into producing the fine photographs of the rake configuration and the HTG model.

Thanks also goes to Mr. Fred Roos for the loan of his 111BF amplifiers which made the use of the HTG's possible, and Mr. Erol Oktay for his assistance in calibrating these amplifiers for our runs.

Finally, if any single entity can be noted in contributing to the success of the project, credit must go to the perseverance, care and interest Mr. Leo Griffin has shown throughout the entire project period.

The general atmosphere of the Aero Lab was found to be most conducive to making our eight week stay at the facility a highly pleasant and fruitful one.

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6. Sample of Heat Probe Data Reduction from Oscillograph Reading to Heat Transfer Rate, $\dot{q}$.

1. INTRODUCTION

One of the problems associated with the use of a hypersonic wind tunnel is pinpointing the extent of the usable inviscid core of hypersonic flow. The free stream velocity depends mainly upon the stagnation enthalpy, and in hypersonic nozzles is unaffected by the boundary layer development[1].

Until June of 1964 no instrumentation had been devised whereby the total enthalpy of the free stream (core) in the University of Michigan's hypersonic "Hotshot" tunnel could be devised. This report describes in detail the instrumentation employed to calibrate the hypersonic tunnel by means of measuring heat transfer rate, $\dot{q}$, and stagnation pressures across the test section of the conical nozzle. Combined knowledge of $\dot{q}$ at a particular station and the corresponding stagnation pressure for the same station will yield the stagnation enthalpy condition from which core conditions can be derived and which will hopefully lead to the knowledge of the boundary layer extent[2].

2. DESCRIPTION OF INSTRUMENTATION

2.1 GENERAL LAYOUT OF THE PROBE RAKE

Figure 1 shows the general layout of the probe rake as employed during the runs on 8, 12 and 14 August 1964. The Heat Transfer Gage Models (HTG models) were mounted so that they could be relocated between runs in such a manner that two runs would allow heat transfer rates, $\dot{q}$'s, to be obtained for the six innermost pressure probe locations. The seventh pressure probe located furthest out from the center of the rake, when positioned in the test section lay too close to the wall to permit a HTG model to be placed for a matched reading.

Figure 2 shows the manner in which the HTG models can be located to match the corresponding pressure probes.

Figure 3 shows the method of 'bookkeeping' developed. The numbers 0-6 represent the station location of the HTG models and pressure probes and the figure shows the distance of each of these stations from the center of the test section. The pressure probes were mounted and permanently wired to the rake. However, since we were limited to three (3) HTG models they were constructed and mounted so that they could readily be relocated on the rake. The dimensions of the HTG models precluded a matching of position with the pressure probe at station '0', therefore, it remained to match six (6) pressure stations with three (3) HTG models which was accomplished in two (2) "Hotshot" runs.

Figures 1 and 2 shows the manner in which the Heat Transfer Models can be located to match the corresponding pressure probes. Also Figure 2 shows a blunt body probe designed and used in the run made 12 August 1964 for the purpose of setting up a normal shock which would be quite strong and easily photographed by the Schlieren System employed.

2. 2 HEAT TRANSFER PROBES[3]

In the initial phase of this project, six (6) Heat Transfer Gages (HTG) designed and built by Arnold Engineering Development Center were found in the Propulsion Lab and the use of these to obtain appropriate data to arrive at the project goal, the boundary layer extent in the test section, was immediately undertaken. Two (2) of the HTG's had been mounted on a one-inch hemisphere-cylinder by AEDC and it remained to mount the other four (4) Heat Transfer Gages in a similar manner. Reference to AEDC-TDR-62-64 describes the manner in which the probes had to be instrumented for readable results. The HTG mounted in the nose of the hemisphere-cylinder model yields the $\dot{q}$ at stagnation conditions behind the normal shock and the shoulder HTG along the cylindrical portion of the model reveals any contamination in the free stream[2].

Since the best results from the Heat Transfer Gages could be effected by grounding the gages at the amplifier rather than at the model itself, a method of attaching the models to the rake using a non-conducting material had to be devised. This requirement resulted in a model configuration as shown in Figure 6. The specifications for the model-to-rake adapter are given in Figure 7. These were locally designed and constructed in the machine shop of the Aero Lab. The design led to a very mobile yet stable anchoring of the model to the rake when positioned and with minimum cost of fabrication both in time and material.

Once the mechanical positioning of the HTG models was effected, the instrumentation had to be devised. Again Ref. 3 supplied the required information, however, the only amplifiers available were the 111BF's located in the subsonic wind tunnel building on North Campus which were used and which indeed rendered readable data. A typical schematic is illustrated in Figure 7.

The oscillograph data may be reduced to yield a $\dot{q}$ for each station where a nose gage is located. The data reduction is as follows:

$$\dot{q} = \frac{1}{K}\frac{de}{dt}$$

where $q = \text{BTU/ft}^2\text{-sec}$

$K = \frac{\text{MV/sec}}{\text{BTU/ft}^2\text{-sec}}$, gage constant

$\frac{de}{dt} = \text{MV/sec}$

Attachment 1 shows the gage constants for the Heat Transfer Gages used and it also contains special handling instructions for these gages.

With the stagnation pressure obtained as outlined in 2. 3 of this section and the corresponding $\dot{q}$'s, stagnation enthalpies may be computed employing the Fay-Riddell Theory (Ref. 4 and 5).

Calibration of the Heat Transfer Gages was accomplished by applying a voltage at the test section wall cannon plug where the leads from the gage would be fed into the amplifying and recording system. Voltages over the anticipated response range were applied and the results are shown in Figures 10 and 10a.

2. 3 PRESSURE PROBES

Seven (7) pressure probes were positioned on the rake as shown in Figures 1, 2 and 3. The instrumentation of the pressure transducers was similar to that in Ref. 6, page 12 and 13. Figure 8 shows a block diagram of the instrumentation.

2. 4 SCHLIEREN SYSTEMS

A Schlieren Double-Pass Parallel System was employed to photograph the flow in the runs made on 12 and 14 August 1964. A description of the Schlieren design considerations may be found in Ref. 6, Appendix D and a schematic of the system may also be found in Ref. 6, Figure D-1.

3. INSTRUMENTATION FOR RUNS MADE 8, 12, AND 14 AUGUST 1964

3. 1 8 AUGUST 1964

This was the first "Hotshot" run that was made where both the pressure probes and Heat Transfer Gages were used simultaneously in the University of Michigan's hypersonic tunnel.

The configuration of the rake was similar to that shown in Figure 1. Figure 9 shows the block schematic of the rake instrumentation for this run.

Figure 10 is the calibration chart for the Heat Transfer Gages.

The results of the pressure transducer calibrations are shown in Figure 11.

The initial conditions in the arc chamber are listed in Chart I for 8, 12 and 14 August 1964. (See Attachment II for more details.)

	Gas	Charge Pressure	Charge Current	Throat Diameter	Switch Pressure	Full Size	Fuze Hole Size	Dump Valve Delay
8 Aug	N_2	900 psia	70,000 amps	.100 in.	1100 psia	5/8 x 3/16	.250 in.	30 msec
12 Aug	N_2	1235 psia	90,000 amps	.100 in.	1100 psia	5/8 x 3/16	.152 in.	30 msec
14 Aug	N_2	1235 psia	90,000 amps	.100 in.	1100 psia	5/8 x 3/16	.152 in.	30 msec

CHART I

3.2 12 AUGUST 1964

The Rake Set-up for this run was similar to that shown in Figure 2. (Note the relocation of the Heat Transfer Models.) The Heat Transfer Models were relocated at Stations 2, 4 and 6 (see Figure 3) and a block wiring diagram for this run is shown in Figure 12.

Initial conditions in the arc chamber set-up are also present in Chart I above. (Attachment II supplies more details.)

The Schlieren Double-pass system was employed to record the flow and the blunt body shape in Figure 2 was inserted in the manner depicted to obtain pictures of a strong shock in the flow.

Heat Transfer Gage Calibrations taken for the 8 August 1964 run were used for this run with the exception of HTG No. 467 which had to be recalibrated due to a change in the amplifier used.

Pressure transducer calibrations from this run are shown in Figure 11a.

3.3 14 AUGUST 1964

The Rake Set-up was similar to that shown in Figure 2 with the exception of the blunt body which was replaced by a 3 in. hemisphere inserted in place of it. The Heat Transfer Models were located at Stations 1, 3 and 5 (see Figure 3). This resulted in the two runs of 12 and 14 August with the same initial conditions producing $\dot{q}$ (heat transfer rate) readings that matched the six (6) inner pressure probe readings. Chart I again contains the initial arc chamber conditions with Attachment 4 showing more details of this information.

The block wiring diagram is shown in Figure 13 and again the Schlieren Douple-pass system was employed.

The data reduction, analyses and conclusions are included in Section 4 of this report for the above three runs.

Attachment 5 shows a typical calculation of the initial conditions in the arc chamber for desired conditions after arcing.

Attachment 6 shows a typical reduction of the heat transfer gage data and a typical oscillograph trace of a good response is shown in Ref. 3, Figure 16.

4. RESULTS

4.1 8 AUGUST 1964

On 8 August 1964, the rake was arranged as shown in Figure 1. Pitot tube 3 at a radius of 5 1/4 in. was inoperative as evidenced by the oscillograph trace in Figure 14.

The Baldwin transducer gauge used to measure arc chamber pressure did not function properly. Consequently, there could be no valid reading of P_0. The nose-mounted heat transfer gauges were operative, but the oscillograph traces were extremely noisy and, thus, difficult to measure. The nose-mounted gauges are labeled A, B, and C on the oscillograph trace in Figure 14. The shoulder-mounted gauges showed no deflection.

4.2 12 AUGUST 1964

On 12 August 1964, the rake was arranged as shown in Figure 2. The heat transfer gauge at radius 3/4 in. was inoperative, but the rest of the tunnel instrumentation operated satisfactorily. The Schlieren-Fastax films of the run clearly showed the blunt body with a strong normal shock at a stand-off distance from the body. This can be seen in Figure 20.

The arc chamber was charged with nitrogen at a pressure of 1235 psig; the arc current was 90,000 amps. The Kistler transducer gauge was operative, and the measured chamber pressure at 10 milliseconds after flow began was 11,450 psia. The stagnation temperature in the chamber was calculated to be 2680°K. The ratio of pitot pressure to total pressure is recorded in the graph in Figure 17.

There was no deflection on the oscillograph traces of the shoulder-mounted heat transfer gauges. The output from the operating nose-mounted gauges is recorded on the graph in Figure 19.

4.3 14 AUGUST 1964

On 14 August 1964, the rake was arranged as shown in Figure 1. All of the instrumentation in the system worked satisfactorily.

An attempt was made to duplicate the arc chamber conditions of the test of 12 August 1964. The arc chamber was charged with nitrogen at a pressure of 1235 psig. The arc current was 90,000 amps. However, the Kistler gauge deflection was greater than in the previous run, and arc chamber pressure was calculated to be 12,450 psia. Stagnation temperature was calculated to be $2920^{0}K$. The ratio of pitot pressure to total pressure is recorded in the graph of Figure 18.

The average heat transfer rates were calculated from the oscillograph traces and recorded in the graph of Figure 19 with the calculated heat transfer rates from the previous test. This was done to provide a composite view of the heat transfer rates at various positions in the tunnel test section under similar conditions.

5. DISCUSSION AND CONCLUSIONS

The run of 8 August 1964 produced no valuable information. The Schlieren-Fastax camera did not photograph the run because of a timing error. The Baldwin transducer gauge did not operate, and chamber pressure could not be calculated because of this malfunction. The experience gained from this test was useful because it served to check the system and permitted the following tests to proceed without the same malfunctions occurring a second time.

The heat transfer gauges used were designed for operation at higher temperatures than those achieved in this series of tests. Because the best inputs were so small, it was necessary to have a high amplification factor to have a sizable galvanometer deflection on the oscillograph. The high gain necessary to produce these deflections also amplified the input noise to high degrees. The oscillograph deflections were of the order of . 05 in. ; therefore, small errors in measurement could produce large errors in the calculation of heat transfer rates. The amplification of noise made these measurements more difficult to make with any degree of accuracy. This noise is evident in the oscillograph traces of nose-mounted gauges A, B, and C in Figures 14, 15, and 16.

To further complicate these measurements, there was a sizable negative deflection in the oscillograph traces of A, B, and C immediately prior to the initiation of flow. It is possible that the field associated with the high current in the arc chamber induced a voltage across the thermocouple gauge, but this is only conjecture. This deflection did complicate the process of making accurate measurements of the oscillograph traces.

The pitot pressure traces began to oscillate at 9 msec and 14 msec for the runs of 12 and 14 August 1964 respectively. An attempt was made to "average-out" these oscillations, but this is a possible source of error in these readings.

The Schlieren-Fastax films taken on 12 August 1964 clearly show the shock wave at a standoff distance from the model. It was not possible to measure the standoff distance accurately because of insufficient resolution of the pictures taken. Because the Schlieren Double-Pass system integrates all of the disturbances along the line of sight, it would be difficult to determine where the leading edge of the shock was.

Of particular interest in the Schlieren-Fastax pictures of the 12 August 1964 test were two which indicate some form of flow instability. The picture in Figure 21 was taken at 5 msec after flow began. The picture in Figure 22 was taken when flow was breaking down. No attempt was made to analyze these pictures because of the lack of specific data correlation.

The Schlieren-Fastax pictures of the 14 August 1964 test showed a shock wave attached to the hemisphere model. This may be seen in the picture in Figure 23.

The shock wave remained in essentially the same configuration for the duration of the run. The resolution of the film was not sufficient to define clearly any standoff distance between the shock wave and the model. There were no instances of instability during the run as there were for the previous run.

On the basis of the data on hand, it appears as if the inviscid core extends to a radius of 6 3/4 in. but does not exceed a radius of 8 1/4 in. The boundary layer accounts for approximately 50% of the test section area. This is in agreement with the theoretical calculations which have been made[1].

6. SUGGESTIONS FOR FURTHER STUDY

Accurate heat transfer rates as a function of time would be more valuable than one average value for the entire test. If a differentiating circuit could be designed into this system, then, the galvanometer outputs would be the rate of change of deflection rather than deflection. It would provide a more valid means of correlating pressure readings with heat transfer rates than is available with the present system.

With accurate heat transfer rates and stagnation pressure behind a normal shock in the test section (i. e., pitot pressure), an iterative solution can be used in conjunction with Fay-Riddell theory to determine stagnation enthalpy[4]. This iterative solution requires many calculations and is well suited to computer solution. Work in this area has been done at AEDC, VKF, and the reader is referred to AEDC-TDR-64-50 for detail on the procedure used in the computer solution.

The heat transfer gauges that were used in these tests were designed to operate at higher temperatures than were encountered in this series of tests. If future tests are to be conducted under similar conditions, it would be advisable to have more sensitive thermocouples. The more sensitive gauges would reduce the need for high gain and tend to minimize the effect of noise because of the greater galvanometer deflections. Small errors in measurement would not result in such large errors in the calculation of heat transfer rates.

7. REFERENCES

1. Sichel, Martin, "The Effect of the Boundary Layer Upon the Flow in a Conical Hypersonic Wind Tunnel Nozzle," Univ. of Mich. Report 02953-2-F, July 1963.
2. Grabau, Smithson, Little, "A Data Reduction Program for Hotshot Tunnels Based on the Fay-Riddell Heat Transfer Rate Using Nitrogen at Stagnation Temperatures from 1500 Degrees to 5000 Degrees," AEDC-TKR-64-50.
3. Ledford, R. L., "A Device for Measuring Heat Transfer Rates in Arc-Discharge Hypervelocity Wind Tunnels," AEDC-TDR-62-64, May 1962.
4. Fay and Riddell, "Theory of Stagnation Point Heat Transfer in Disassociated Air," Journal of the Aeronautical Sciences, Vol. 25, No. 2, p. 73-85, February 1958.
5, Roepke, "Reduction of Fay-Riddell Stagnation Point Heat Transfer Theory," August 1958.
6. Sherman, "Development and Operation of Arc Heated Hypersonic Tunnel," Univ. of Mich. Report 2953-3-F, July 1963.

THERMOCOUPLE HEAT TRANSFER GAGE

A rather complete description of the TCG is given in AEDC-TDR-62-64. However, there are a few things about the transducer that should be doubly emphasized.

1) The 0.003 in. thick disc TCG's are extremely delicate and should be treated with the care given a fine watch without its case. The disc is easily damaged and broken loose from its insulator.

2) The temperature of the disc should be kept below 250°F during the useful part of the run, and never allowed to exceed 400°F.

3) Both the measuring and reference junctions for the chromel-constantan thermocouple are located inside the transducer. There is no need for an external reference junction.

4) Best results are obtained when the output is amplified with a true differential input or a floating input amplifier. The shield is attached at the transducer to the copper disc. The shield can be grounded either at the amplifier or at the model. In any case it should be grounded at only one place. If it is grounded at the amplifier, then the model should be electrically insulated from the tunnel. (Two conductor shielded wire should be used from the transducer to the amplifier.)

The pertinent information about the particular gages you will get is listed below:

Gage No.		Nominal Disc Thickness (in)	Gage Constant (Mv/Sec/Btu/ft^2-sec)
A	474/467	.003/.020	2.65/0.379
B	476/465 476 inoperative (shoulder)	.003/.020	2.86/0.377
C	478/464	.003/.020	2.70/0.380

The data reduction is as follows:

$$\dot{q} = \frac{1}{k} \frac{dE}{dt}$$

$\dot{q}$, BTU/ft^2 - sec

$\frac{dE}{dt}$, $\frac{MV}{sec}$

Attachment 5

Desired Condition: P_o Final 9,000 psia (Max 10,000 psia)

T_o Final 3,000 K

$$P = \rho R T \quad R = 55.2 \text{ for nitrogen } \frac{\text{Ft lb (Force)}}{\text{lb mass } {}^{o}\text{R}}$$

$$\rho = \frac{P_o}{RT} = \frac{9000}{3000\ (55.2)} = \frac{3}{55.2}$$

$$\text{Units: } \frac{\text{psia lb mass } {}^{o}\text{R}}{\text{Ft lb } {}^{o}\text{K x 12 in/Ft}} = \frac{\text{lb mass}}{\text{cu in}}$$

$$\text{K x } \frac{9}{5} = \text{Rankine}$$

$$\text{R x } \frac{5}{9} = \text{Kelvin}$$

$$\frac{9.000}{5.400\ (55.2)\ (12)} = \frac{9.000}{3576.96}$$

$$250\ (12) = 2400$$

$$\boxed{\text{00. 0025 lb 103 lb/cu in.}}$$

Volume = 65 cu. in.

$$65 \text{ x } .002516103 = .163546695 \text{ lb mass}$$

$$\Delta T = T\text{final} - T\text{ initial}$$

$$5400 - 540 = 4860 = \Delta T$$

$$\Delta E = m\ C_v\ \Delta T = C_v = 0.176 \text{ sp. ht BTU/lb mass } {}^{o}\text{R}$$

$\Delta T = 4860{}^{o}$R

$C_v = .176$ BTU/lb m ^{o}R .028776

m = .1635 lb m

Attachment 5 (cont.)

140. 1138 BTU's energy to add.

1054 (140. 1138) = joules of energy

= 147, 679. 9452 joules

1.4768×10^5 joules

ΔE_{coil} energy to gas from coil $= \dfrac{\eta \times I^2 \times 6 \times 10^6 \text{ joules}}{315^2}$

$\eta = .5 \qquad I^2 = \dfrac{1.4768 \times 10^5 \times (315)^2}{6 \times 10^6 (.5)}$

$$= \frac{1.4768 \times 10^5 \times 99225}{3 \times 10^6} = \frac{1.4768 \times 9922.5}{3}$$

$$= \frac{14653.548}{3} = 4884.516 = 69.9 \text{ Kiloamps}$$

70,000 amps.

$P = \rho RT$

$Ti = 540^o$

$R = 55.2$

$\rho = .002516$

12 = factor

$P = .0025 \text{ in}^3.\quad 55.2 \text{ Ft lb.}\quad 540 \quad 12 \text{ in.}$

$= .0025\ (55.2)\ (540)\ (12) = .138\ (540)\ (12) = 7452\ (12) = 894.24$ psia

900 psi

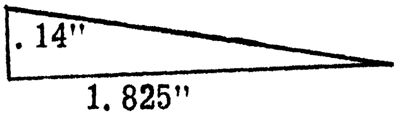
Attachment 6

HTG Data Run - 8 August 1964

Probe Oscillograph:
NP-A

$$\frac{dE}{dT} = \frac{.14 \text{ inches}}{1.825 \text{ inches}}$$

$$\boxed{\frac{1.045''}{10 \text{ m sec}}}$$



1. 825 inches = 17. 45 m sec.

. 14 in. = . 2 n v

. 1045"/m sec

$$\frac{dE}{dT} = \frac{.2 \text{ m v}}{17.45 \text{ m sec.}}$$

$$= .011454 \text{ v/sec.}$$

$$\frac{1.825''}{.1045''/\text{m sec.}} = 17.46$$

NP-B

. 135 inches = dE

$$\frac{.27 \text{ n v}}{17.46 \text{ m sec.}} = .015463$$

Gage constant:

NP-A = . 379

NP-B = . 377

$$\dot{q} = \frac{1}{K}\frac{dE}{dT} = \frac{1}{(\text{MV/SEC/BTU/ft}^2 - \text{sec})} \cdot \frac{\text{MV}}{\text{SEC}}$$

NP-A $\dot{q} = 11.454/.379 = 30.22163$

$\dot{q} = 15.463/.377 = 41.01591$

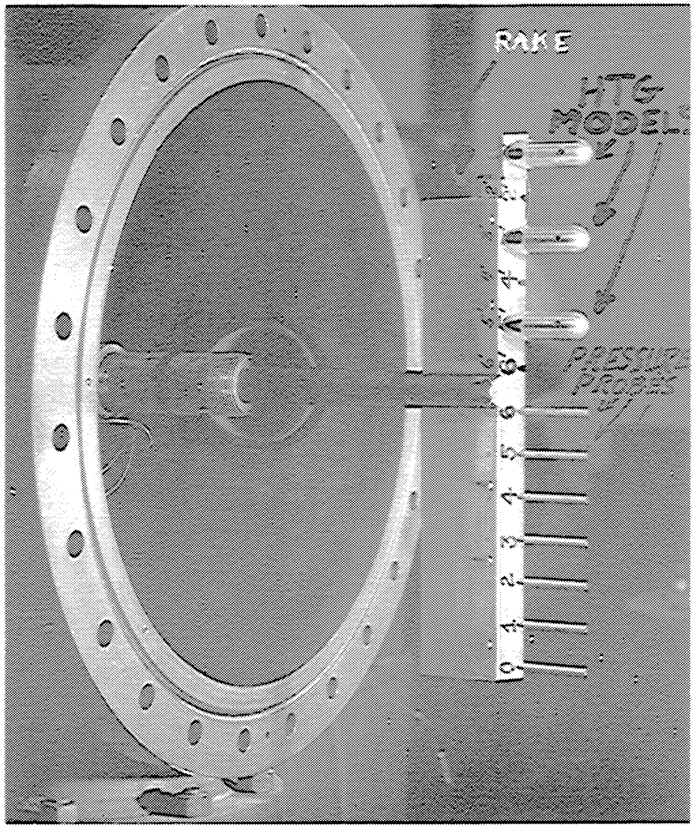


Figure 1. Rake Configuration I

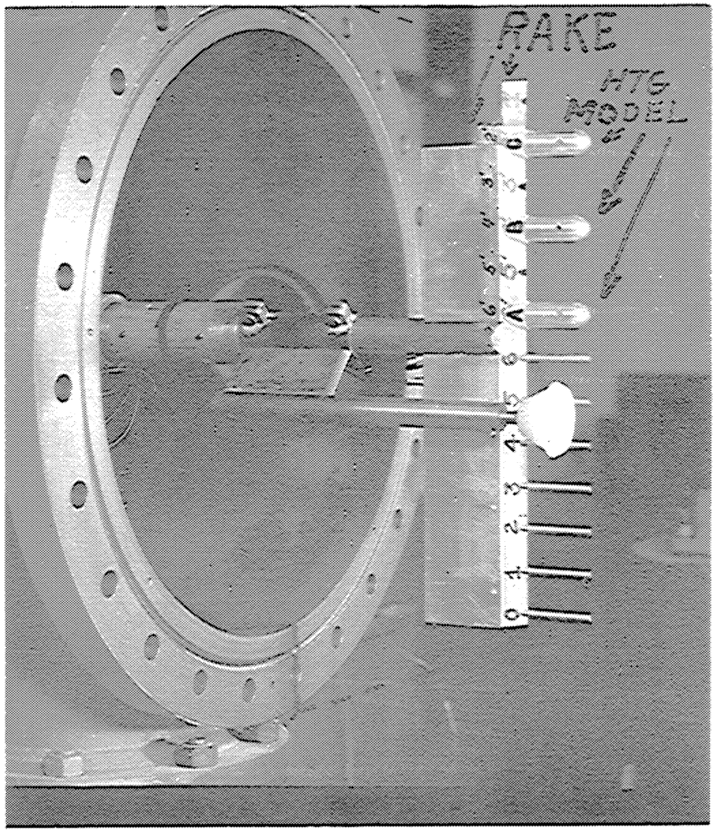


Figure 2. Rake Configuration II

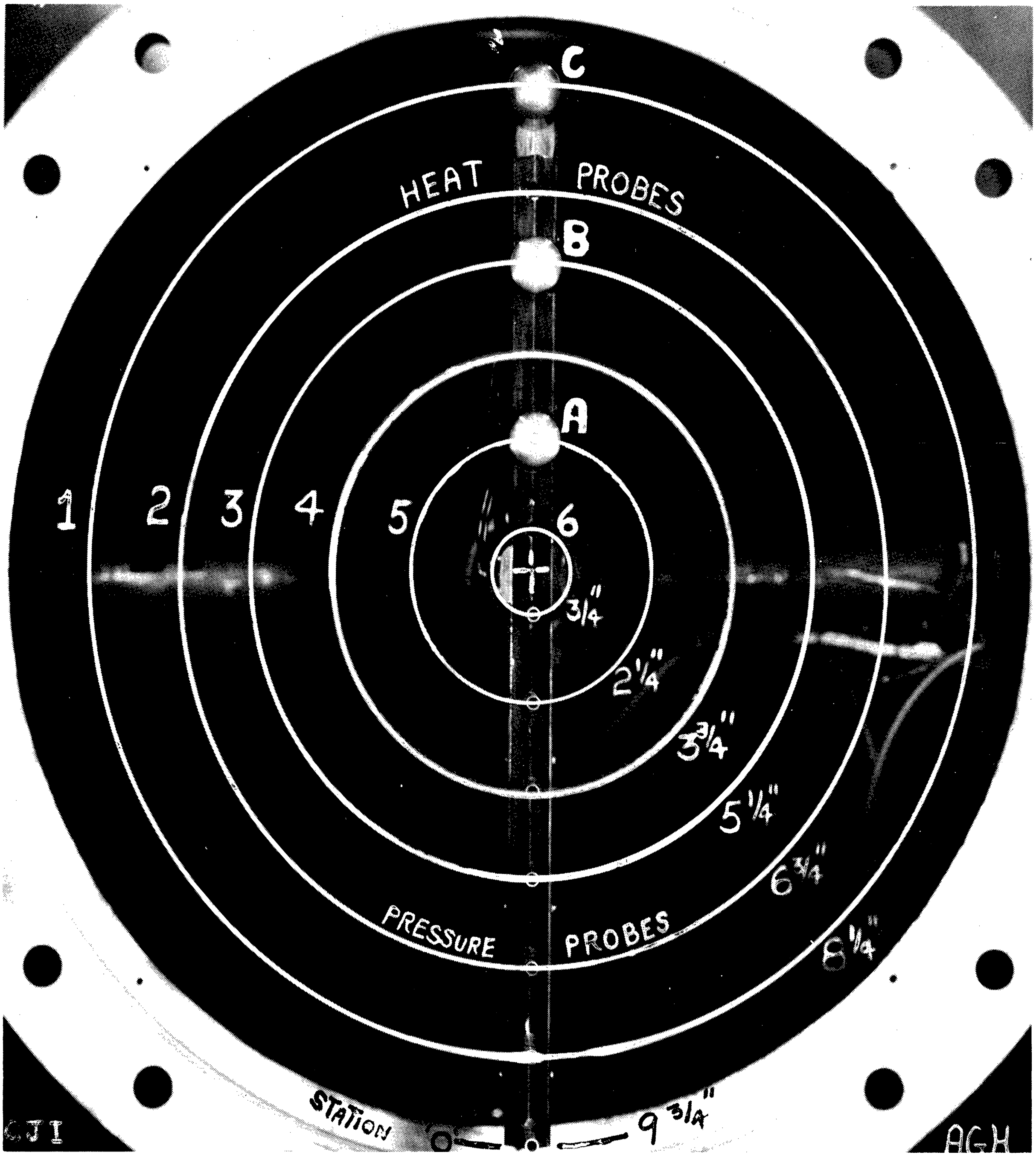

C
HEAT
PROBES
B
A
1
2
3
4
5
6
3/4"
2 1/4"
3 3/4"
5 1/4"
6 3/4"
8 1/4"
PRESSURE
PROBES
STATION
9 3/4"
GJI
AGH

Figure 3

V600- MISC.- 0013

FIG. 4

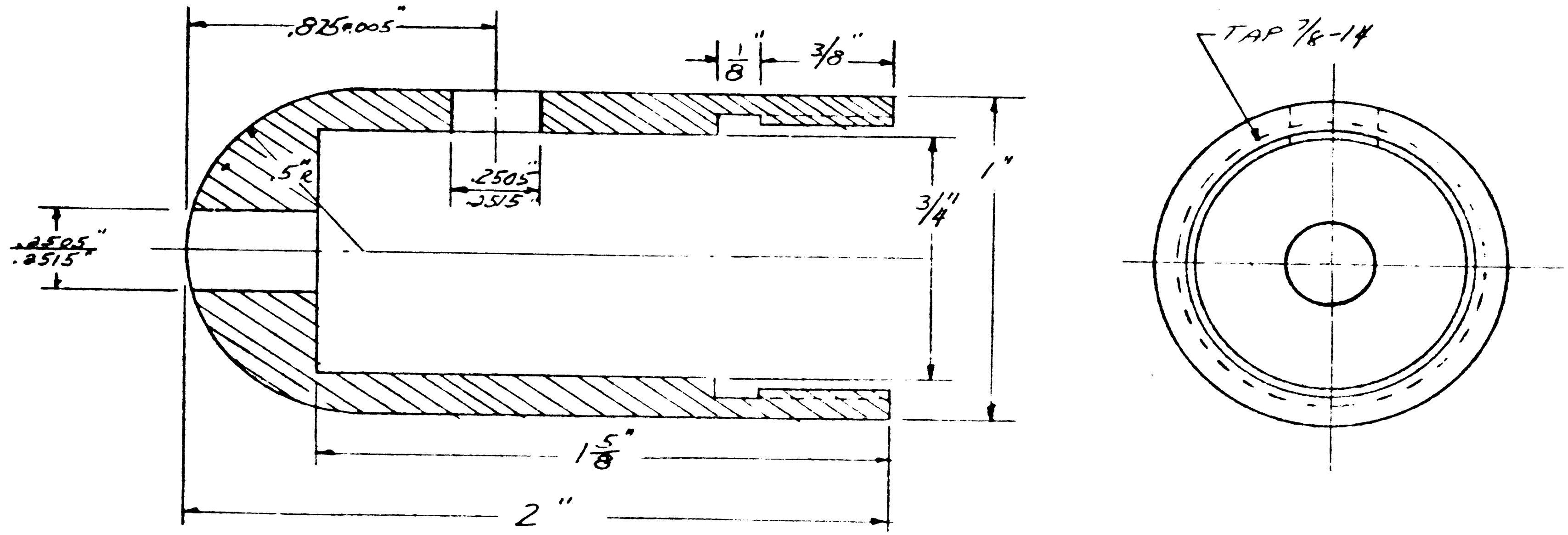


FIG 4

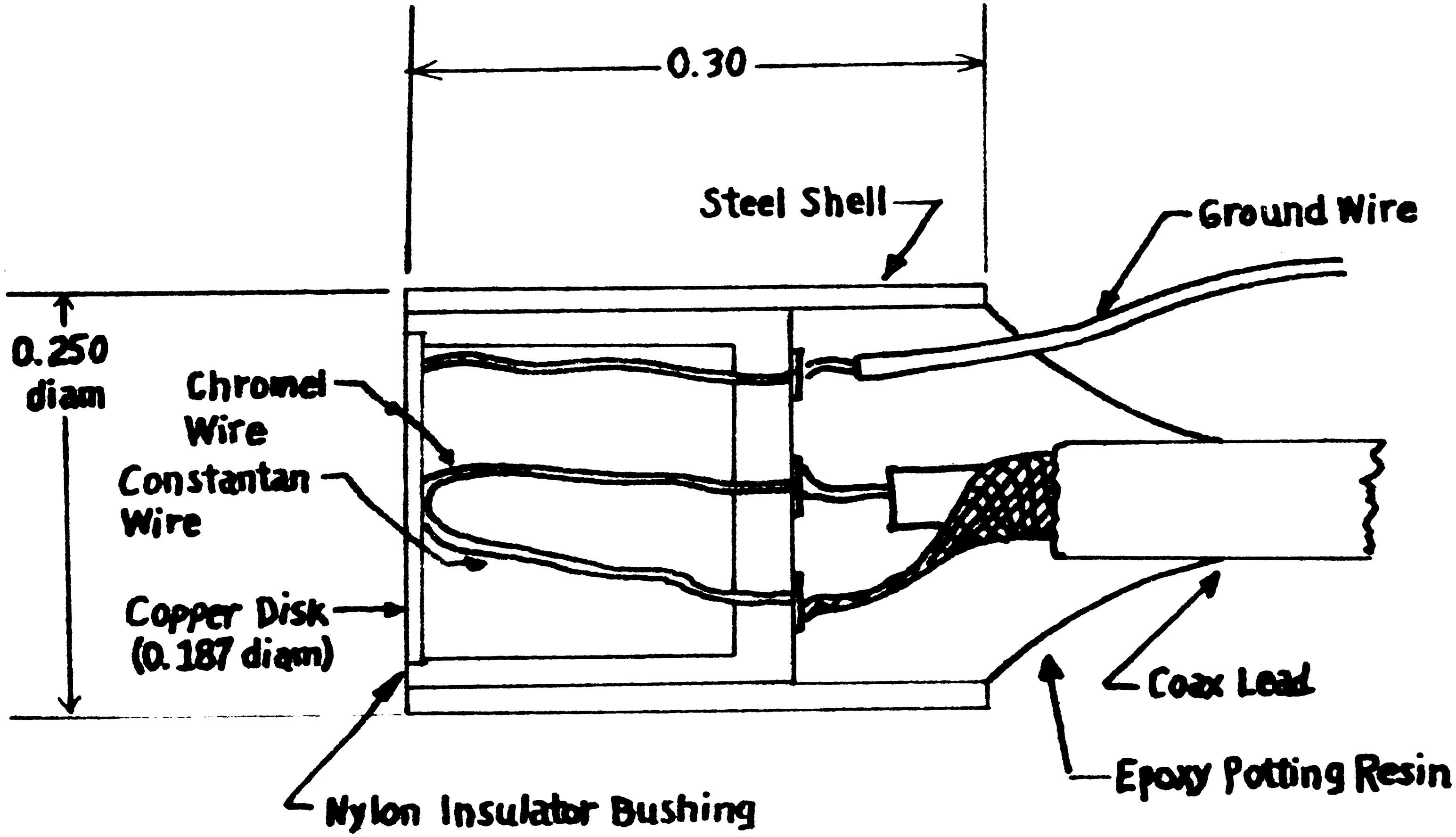
STD HEAT MONITER PROBE $s/r = 2.32$

MAT'L. ALUM.

2X SIZE

SKETCH NO. V600- MISC.- 0013

WNS
12-9-63



Thermocouple HEAT TRANSFER GAGE

FIG. 5

FROM AEDC-TDR 62-64

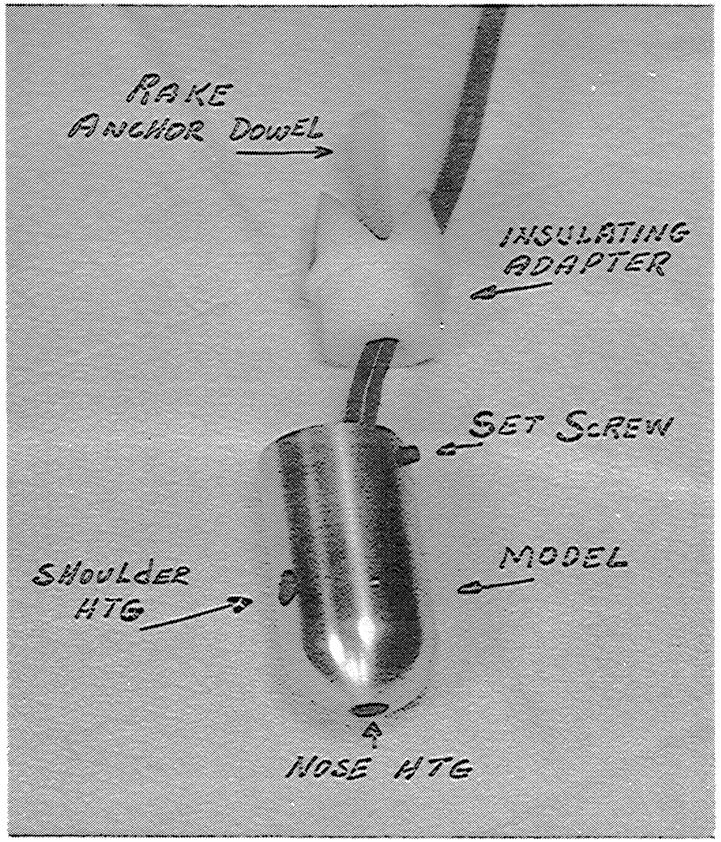


Figure 6. HTG Model and Adapter

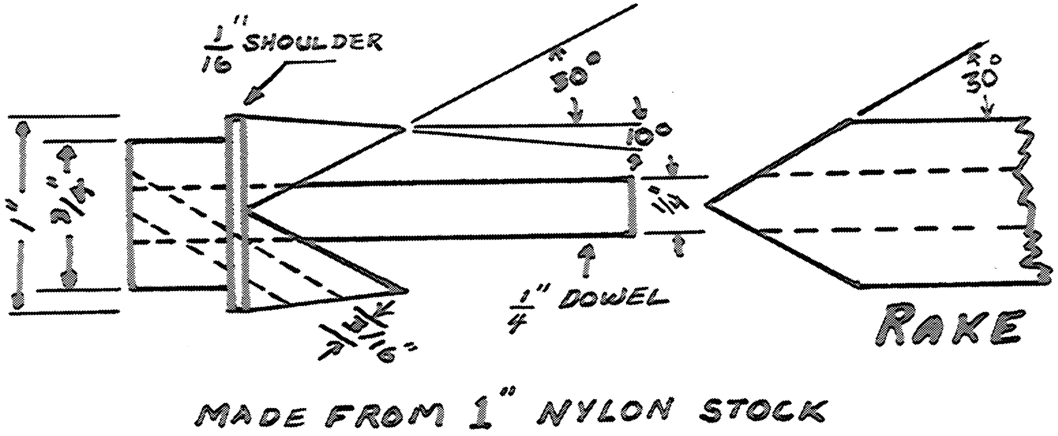


Figure 7. Model-to-Rake Insulative Adapter

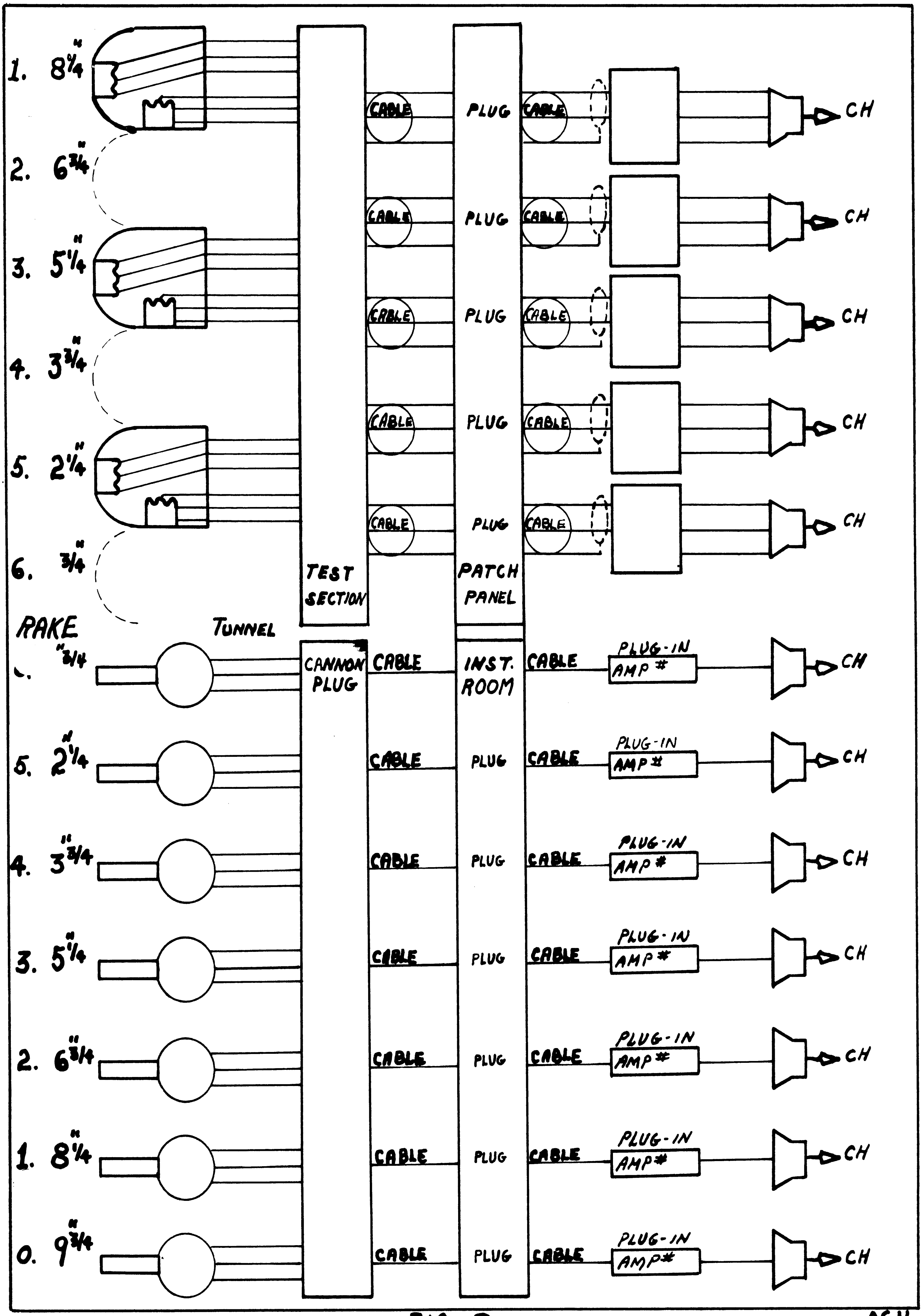

1. 8¼"
2. 6¾"
3. 5¼"
4. 3¾"
5. 2¼"
6. ¾"
RAKE
TUNNEL
CABLE
PLUG
CABLE
CH
CABLE
PLUG
CABLE
CH
CABLE
PLUG
CABLE
CH
CABLE
PLUG
CABLE
CH
CABLE
PLUG
CABLE
CH
TEST SECTION
PATCH PANEL
¾"
CANNON PLUG
CABLE
INST. ROOM
CABLE
PLUG-IN AMP #
CH
5. 2¼"
CABLE
PLUG
CABLE
PLUG-IN AMP #
CH
4. 3¾"
CABLE
PLUG
CABLE
PLUG-IN AMP #
CH
3. 5¼"
CABLE
PLUG
CABLE
PLUG-IN AMP #
CH
2. 6¾"
CABLE
PLUG
CABLE
PLUG-IN AMP #
CH
1. 8¼"
CABLE
PLUG
CABLE
PLUG-IN AMP #
CH
0. 9¾"
CABLE
PLUG
CABLE
PLUG-IN AMP #
CH

FIG. 8

AGH

WIRING FOR RUN - 8 AUG 1964

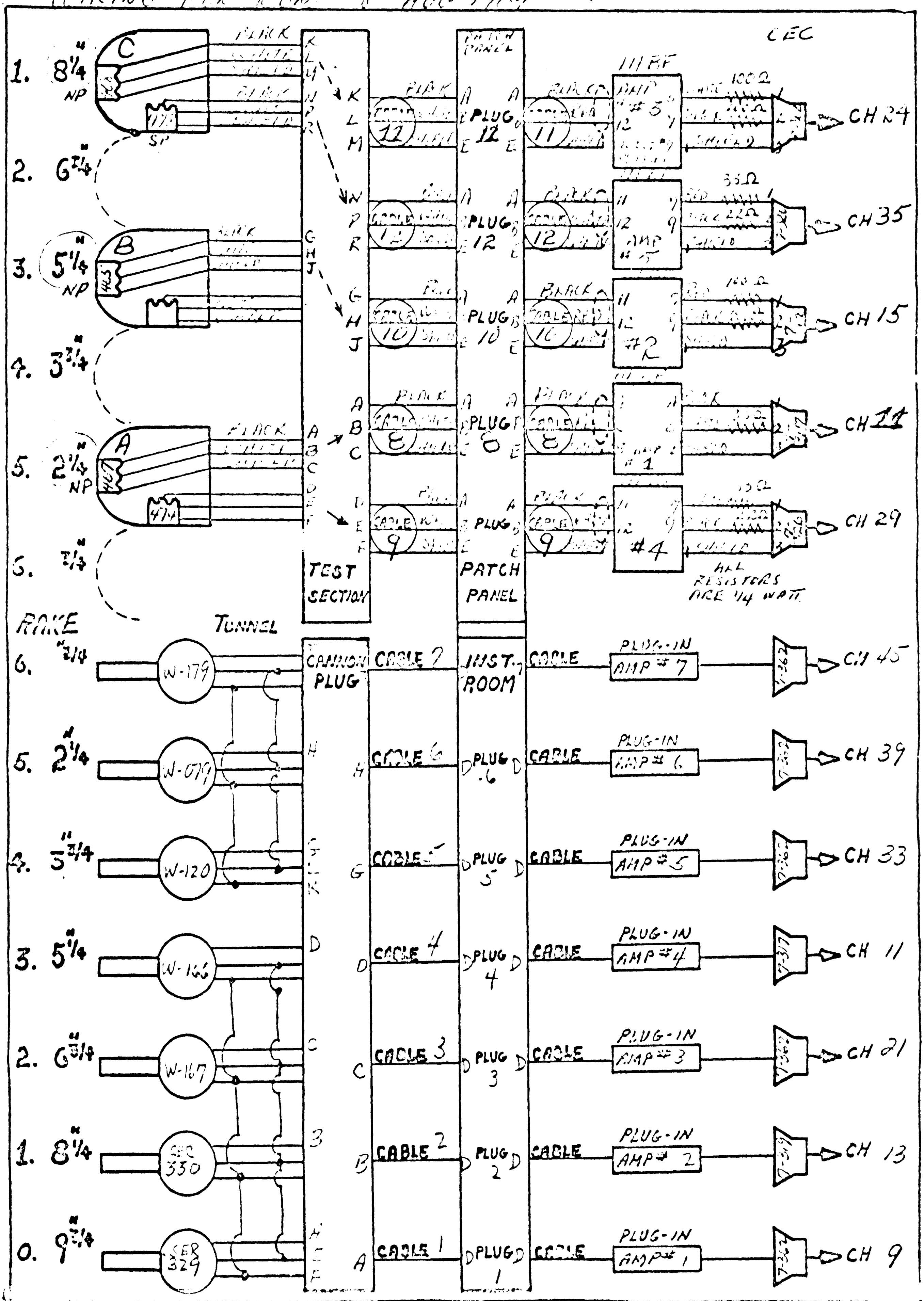


FIG 9

CALIBRATION 111 BF AMP'S
29 JULY 64

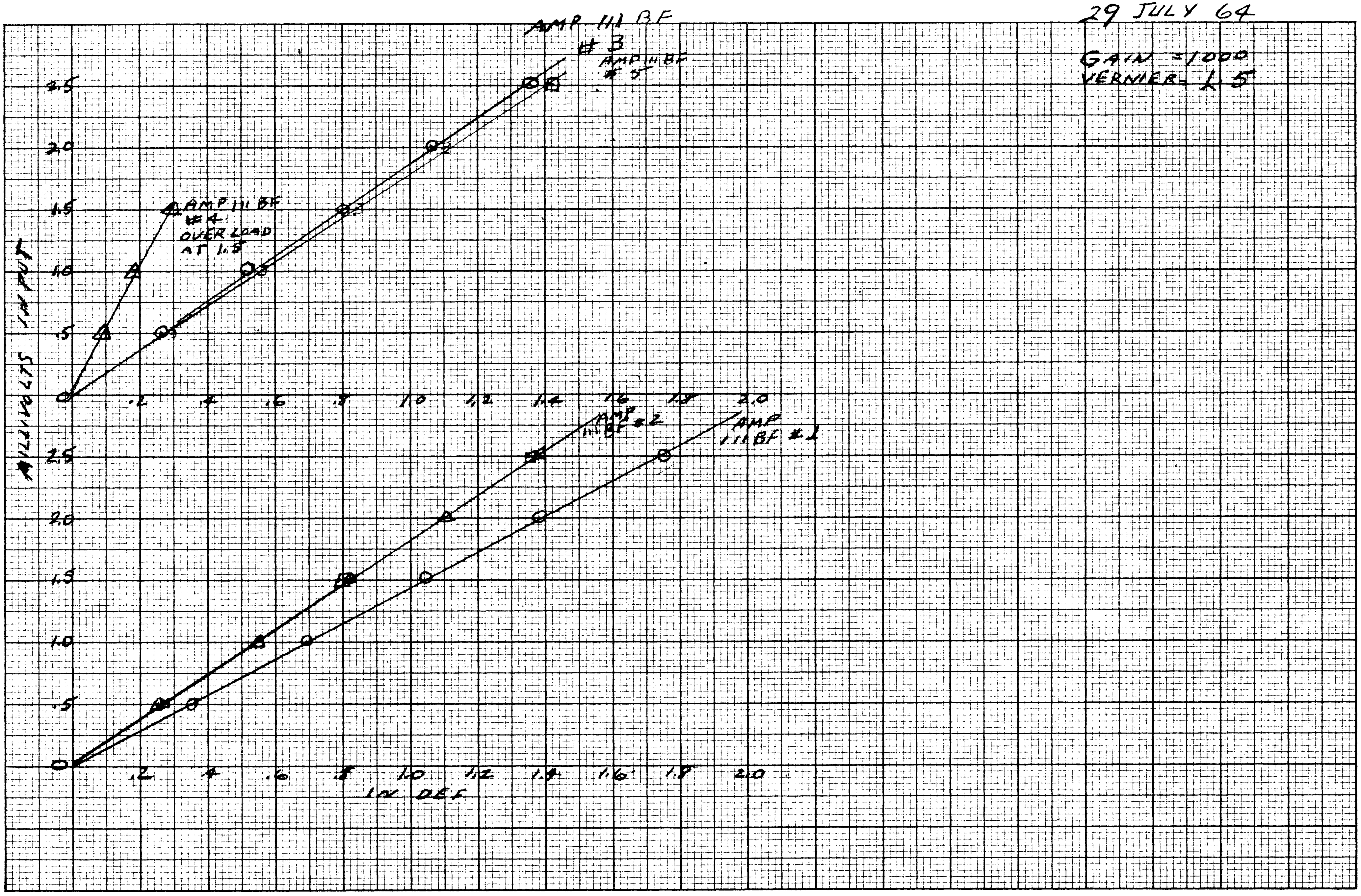


FIG 10

FIG 10

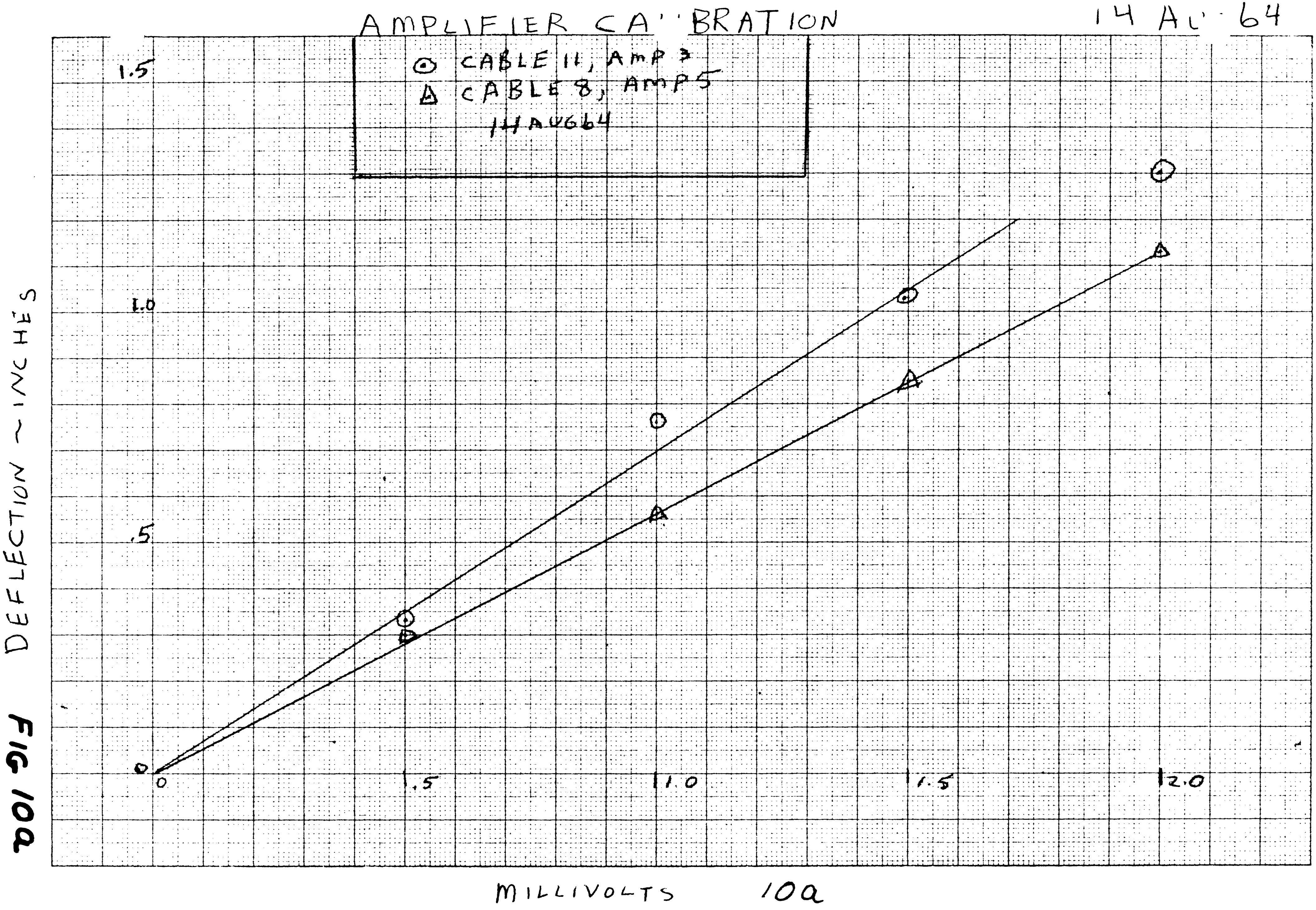

AMPLIFIER CALIBRATION
14 AUG 64
⊙ CABLE 11, AMP 3
△ CABLE 8, AMP 5
14AUG64
DEFLECTION ~ INCHES
1.5
1.0
.5
0
0
.5
1.0
1.5
2.0
MILLIVOLTS
10a

FIG 10a

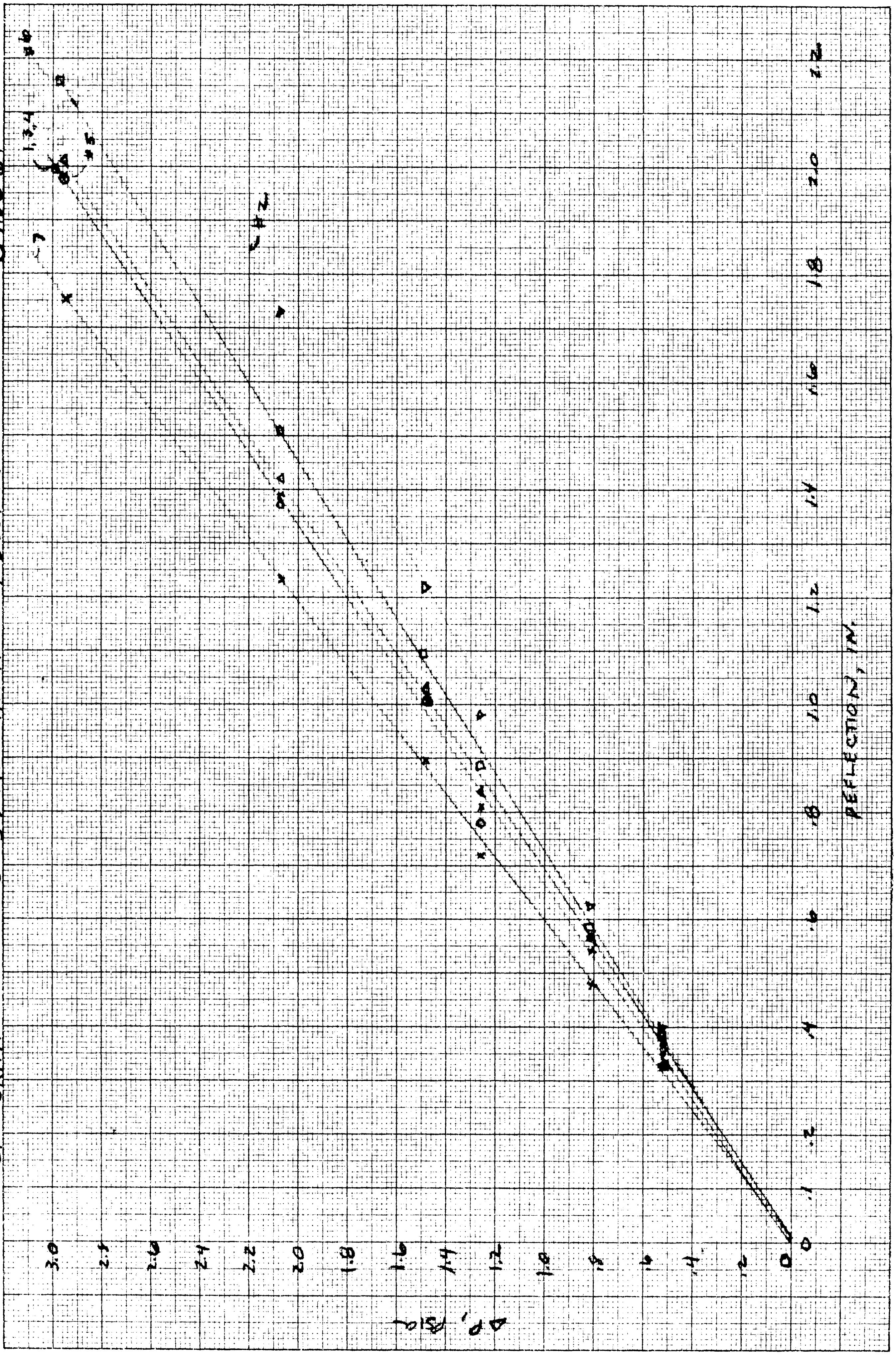


FIGURE 11

FIG 11

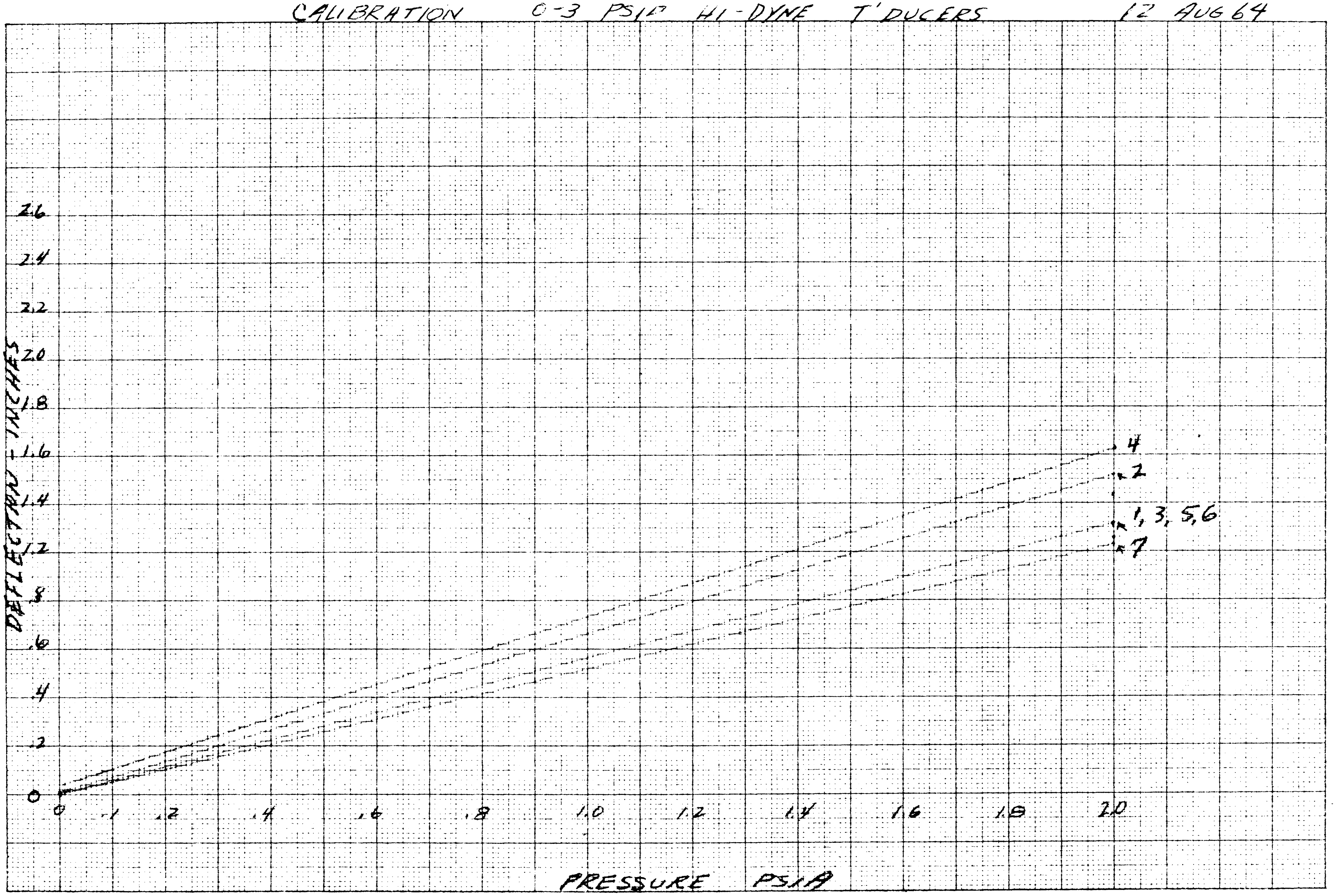

CALIBRATION 0-3 PSIA HI-DYNE T'DUCERS
12 AUG 64
DEFLECTION - INCHES
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
.8
.6
.4
.2
0
4
2
1, 3, 5, 6
7
0
.1
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
PRESSURE PSIA

FIG 11a

CALIBRATION 0-3 PSID HI-DYNE T'DUCERS 14 AUG 64

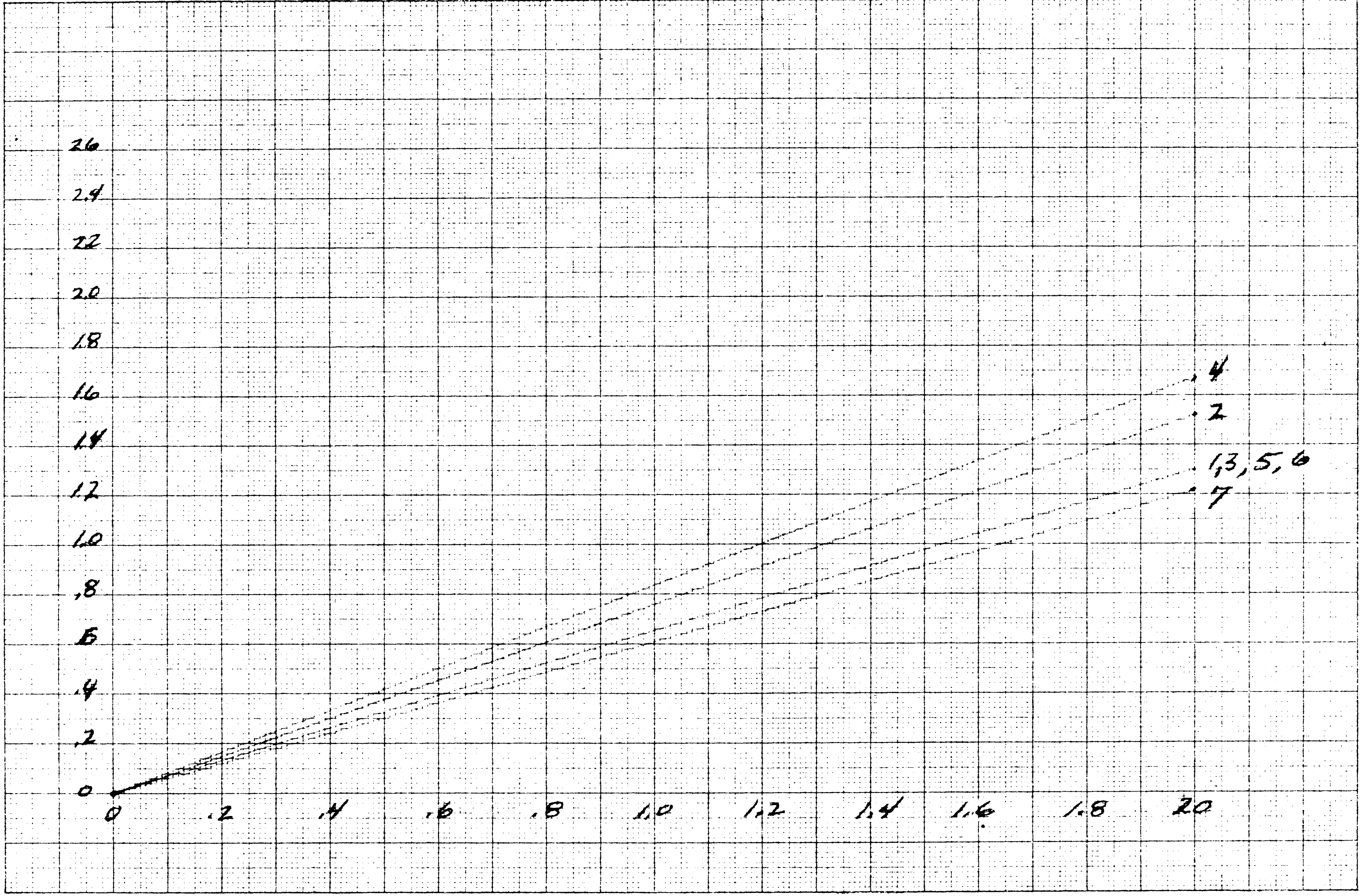


FIG 11b

WIRING FOR 12 AUGUST 1974

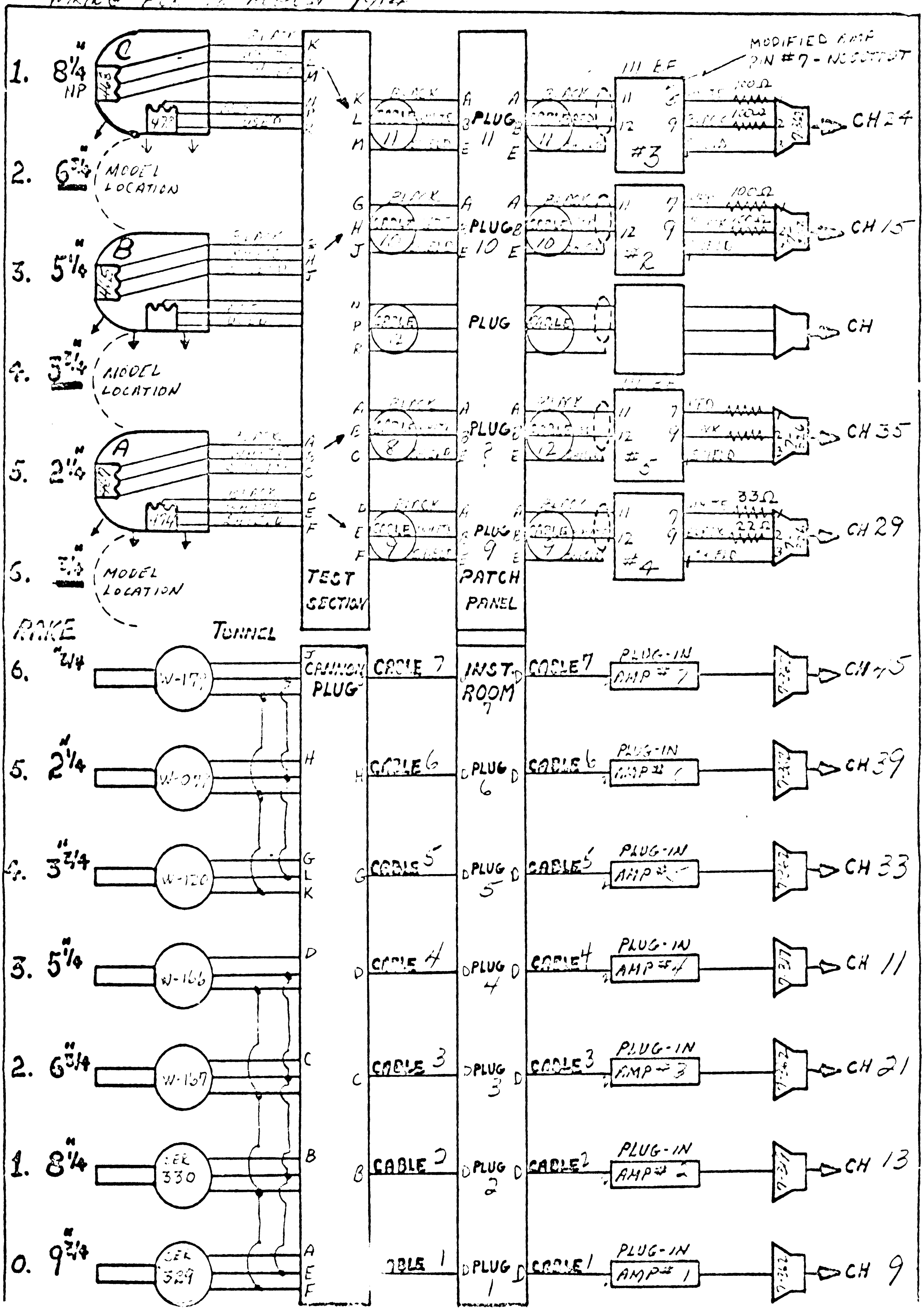


FIG 12

14 Aug 1968

M Hanes

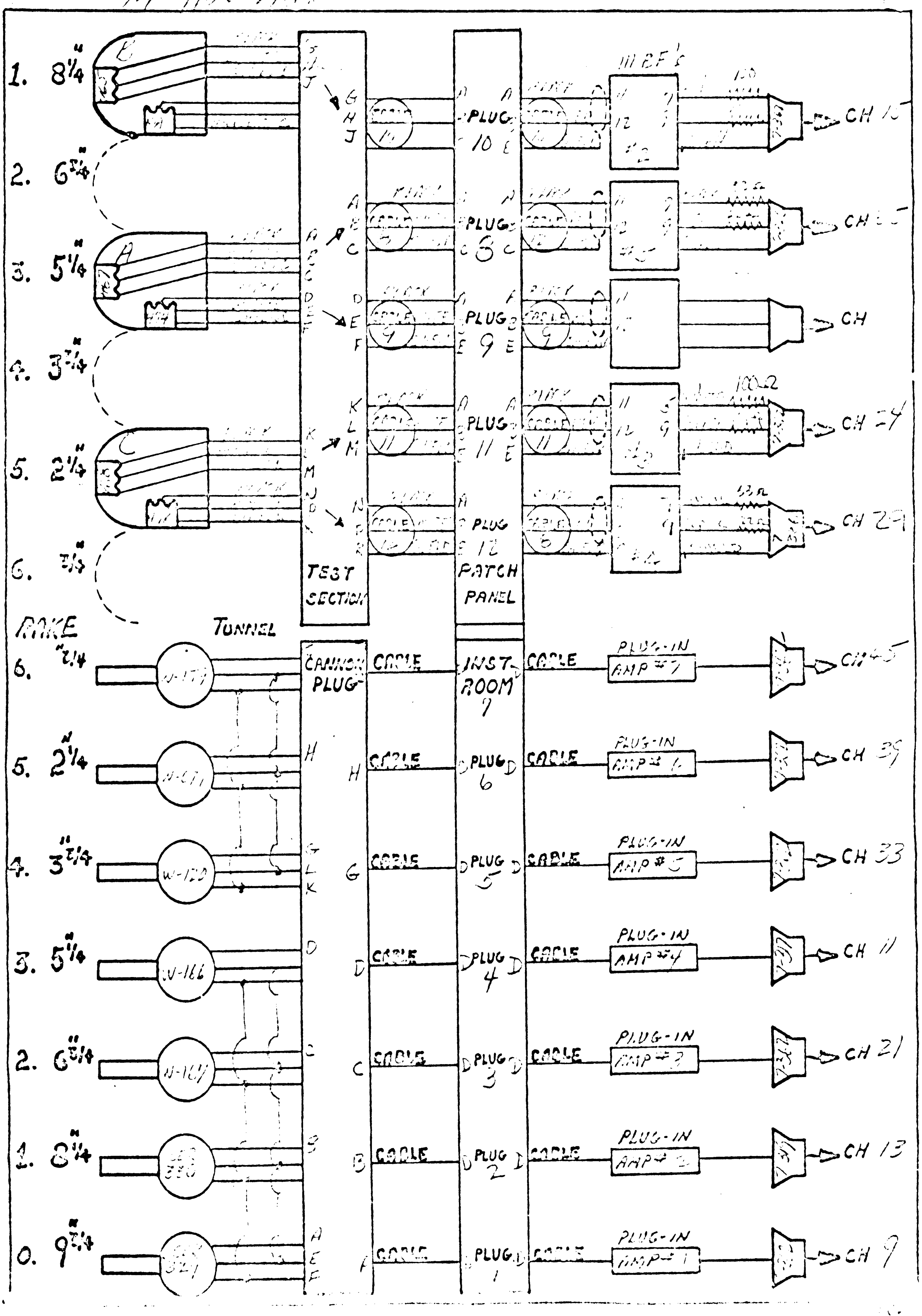


FIG 13

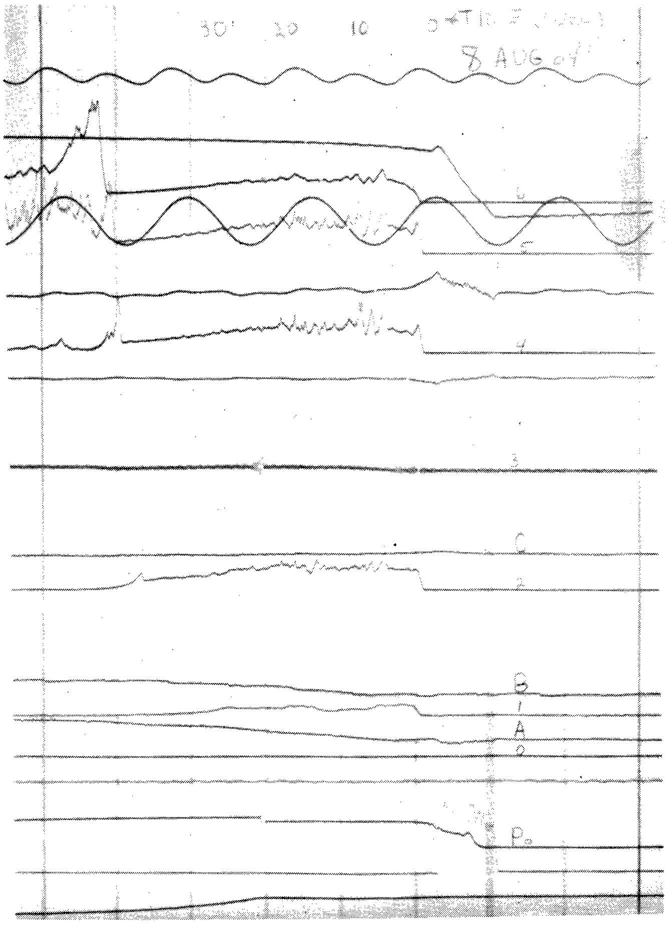


Figure 14

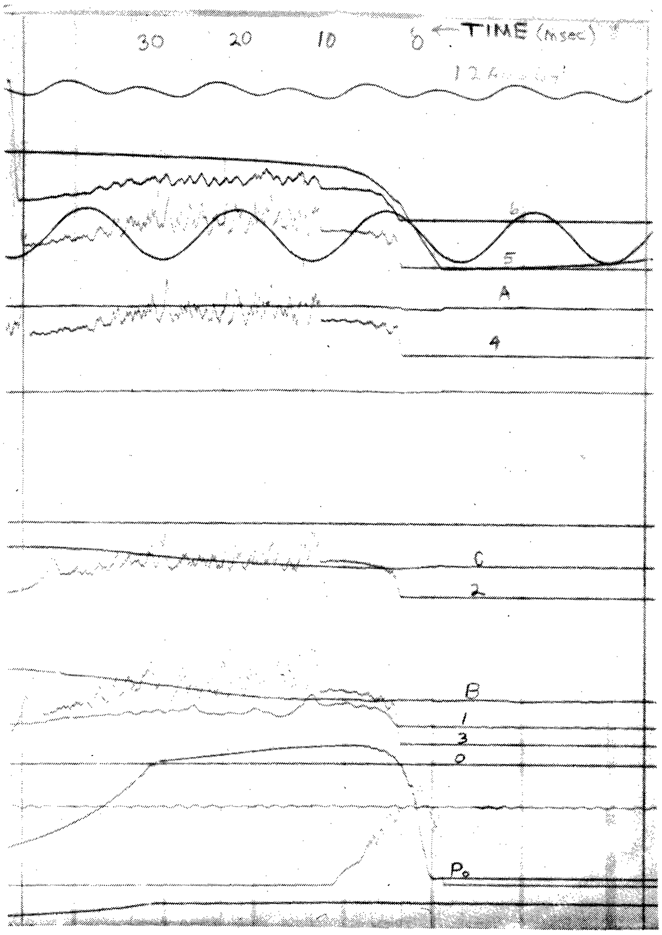


Figure 15

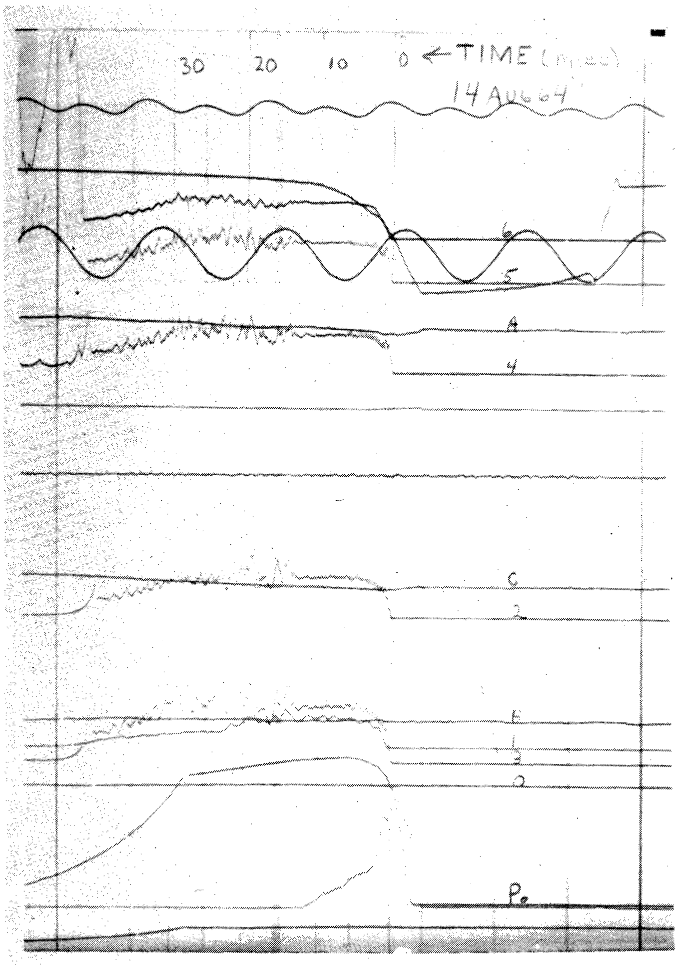


Figure 16

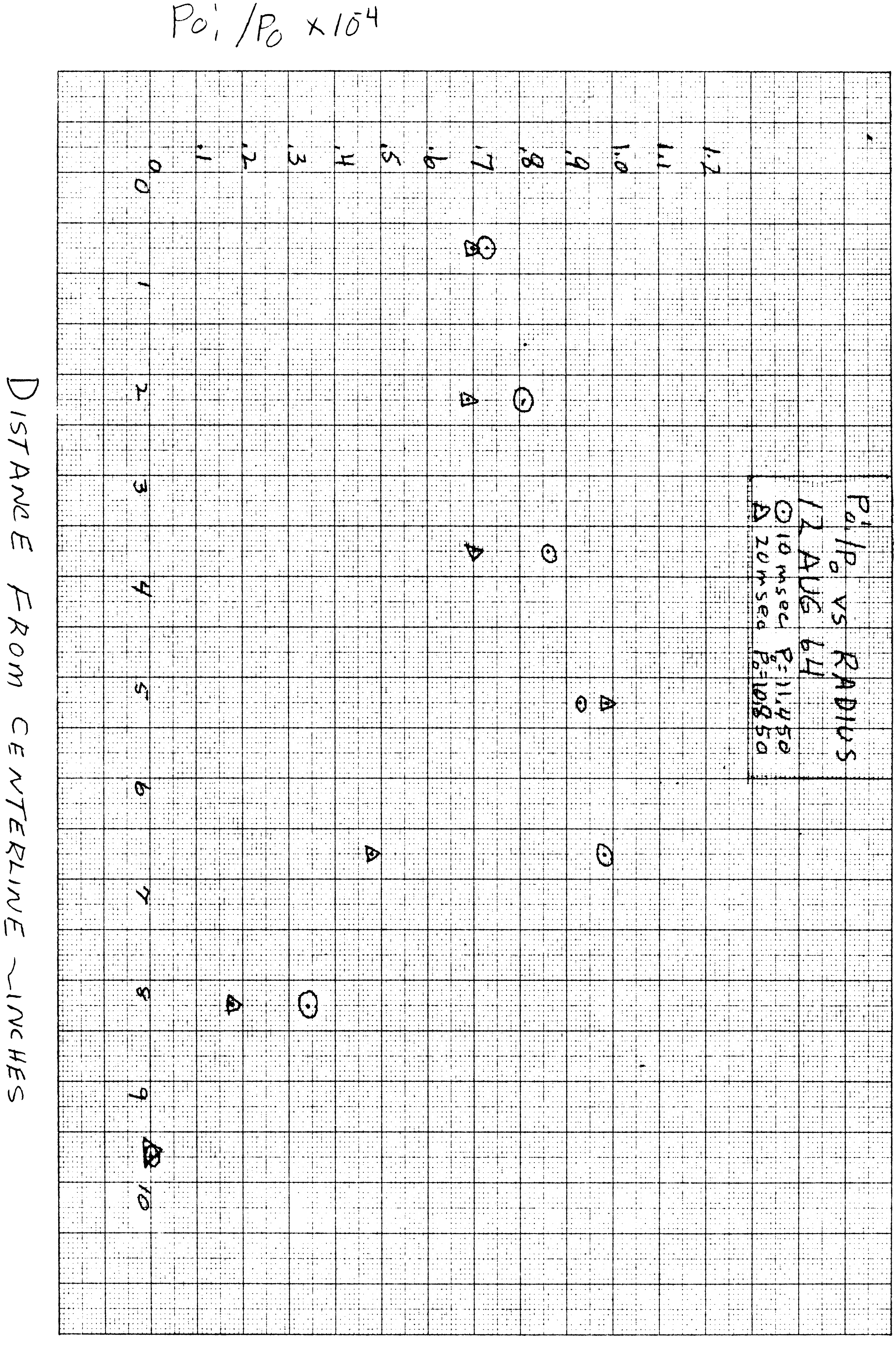

$P_{o_i}/P_o \times 10^{-4}$
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
0
1
2
3
4
5
6
7
8
9
10
DISTANCE FROM CENTERLINE ~ INCHES
P_o'/P_o VS RADIUS
12 AUG 64
⊙ 10 msec P_o=11,450
△ 20 msec P_o=10,850
10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO.

FIGURE 17

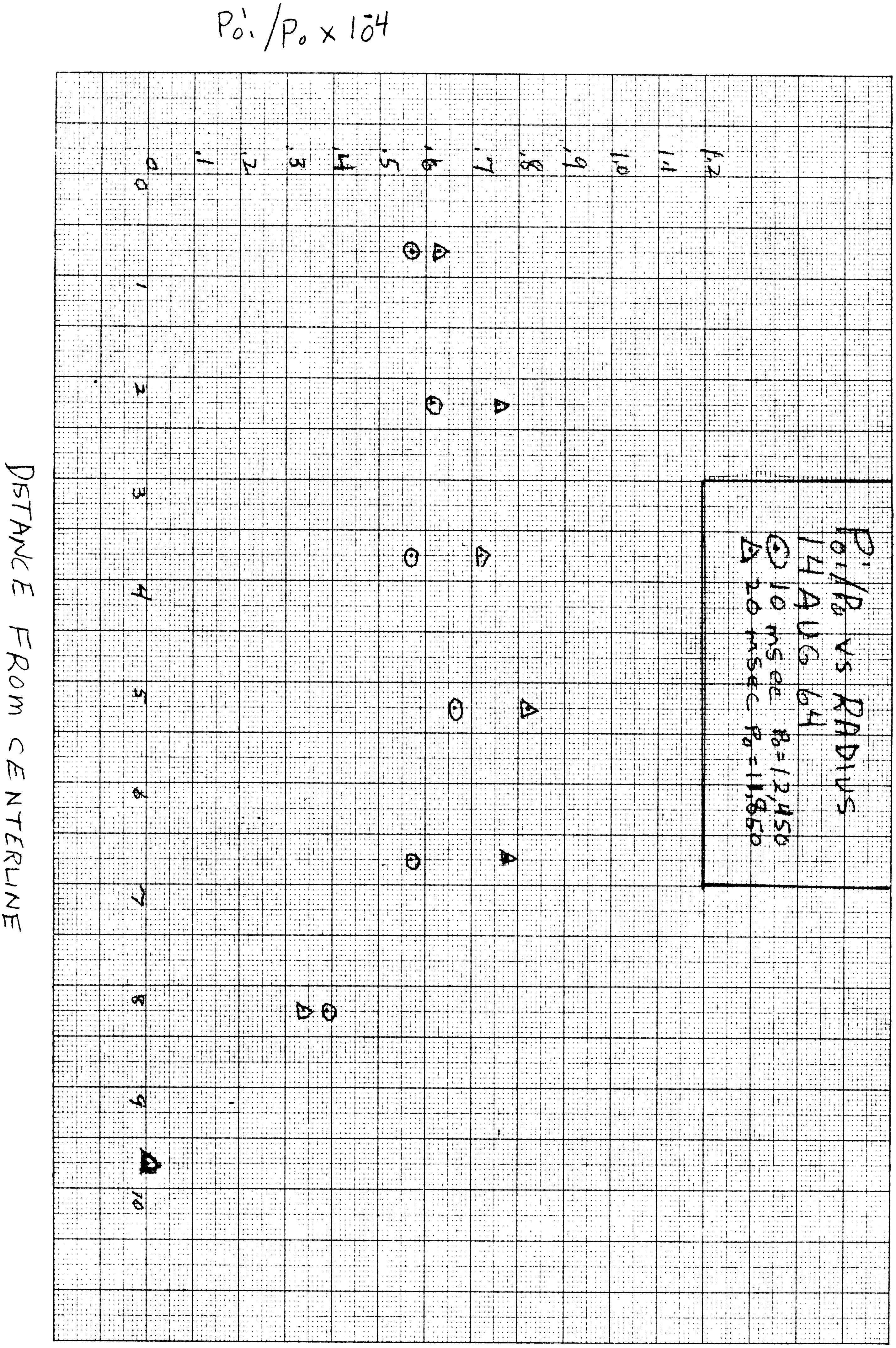

P'o/Po x 10^-4
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
0
1
2
3
4
5
6
7
8
9
10
DISTANCE FROM CENTERLINE
P'o/Po VS RADIUS
14 AUG 64
⊙ 10 msec Po=12,450
△ 20 msec Po=11,950

FIGURE 18

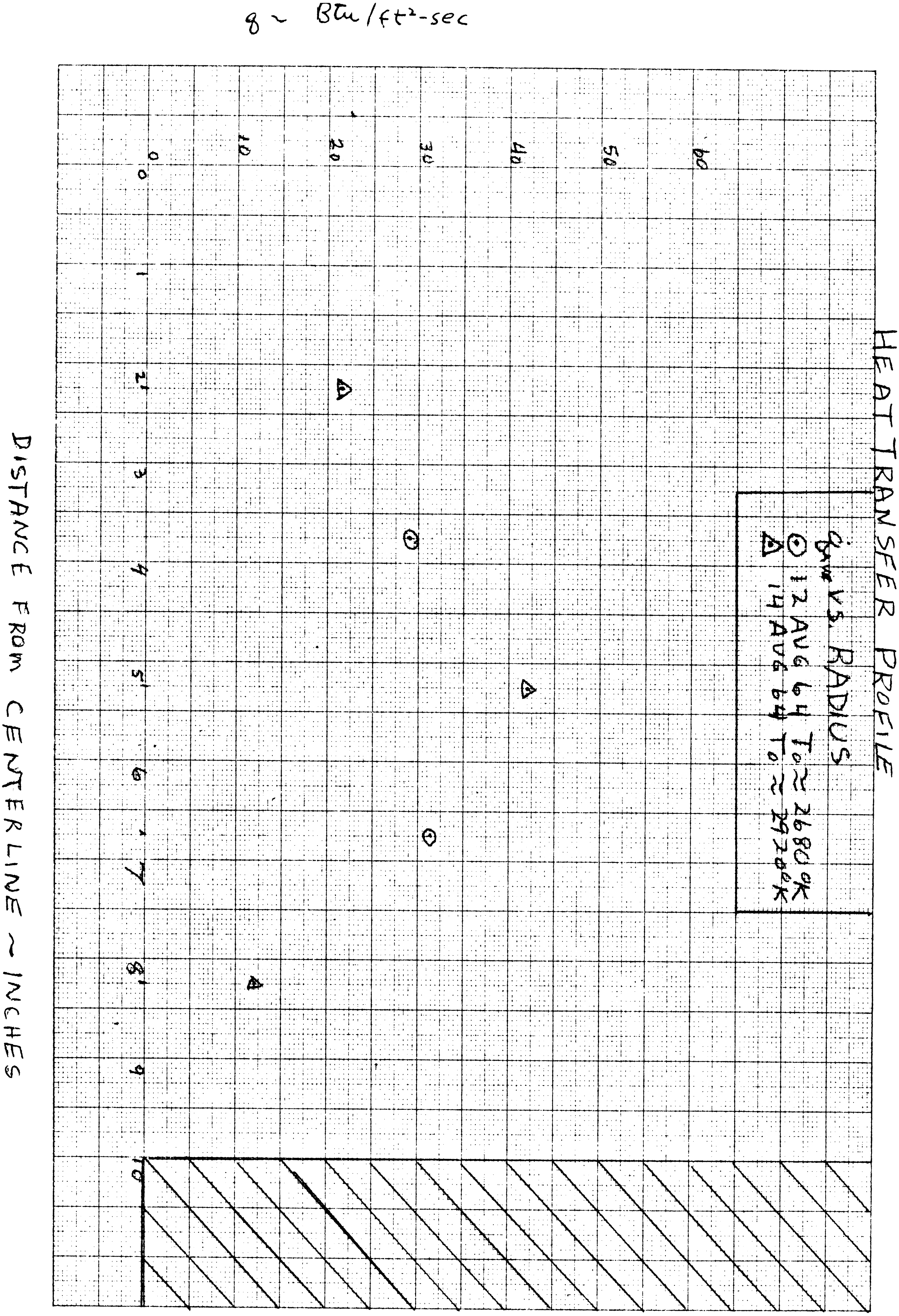

q ~ Btu/ft²-sec
HEAT TRANSFER PROFILE
q_w vs. RADIUS
⊙ 12 AUG 64 T0 ≈ 2680°K
△ 14 AUG 64 T0 ≈ 2920°K
0
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
10
DISTANCE FROM CENTERLINE ~ INCHES

FIGURE 19

Figure 20

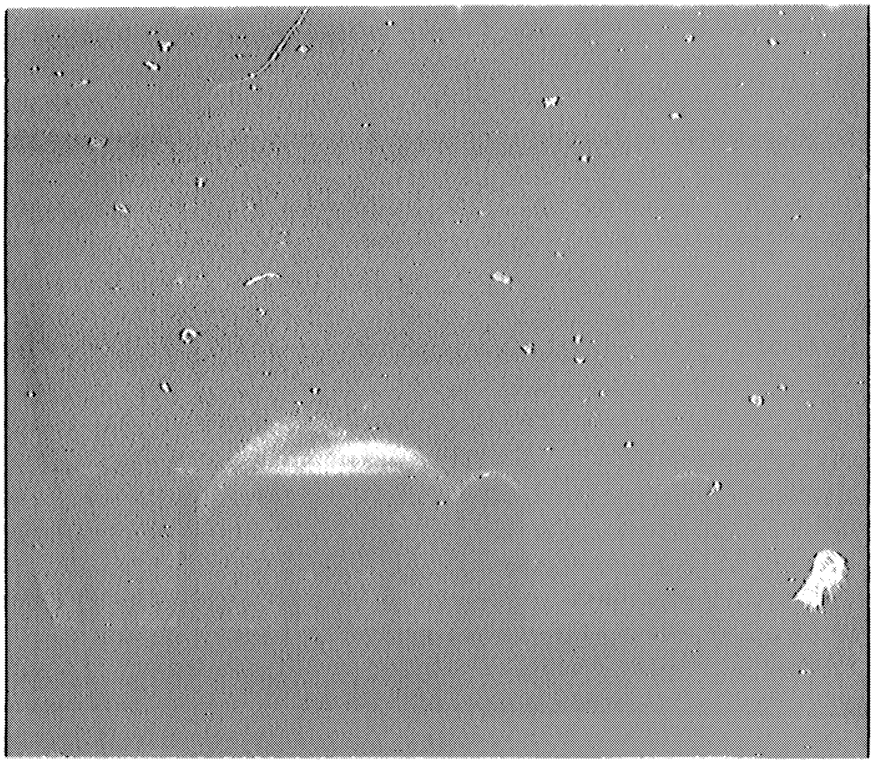


Figure 21

Figure 22

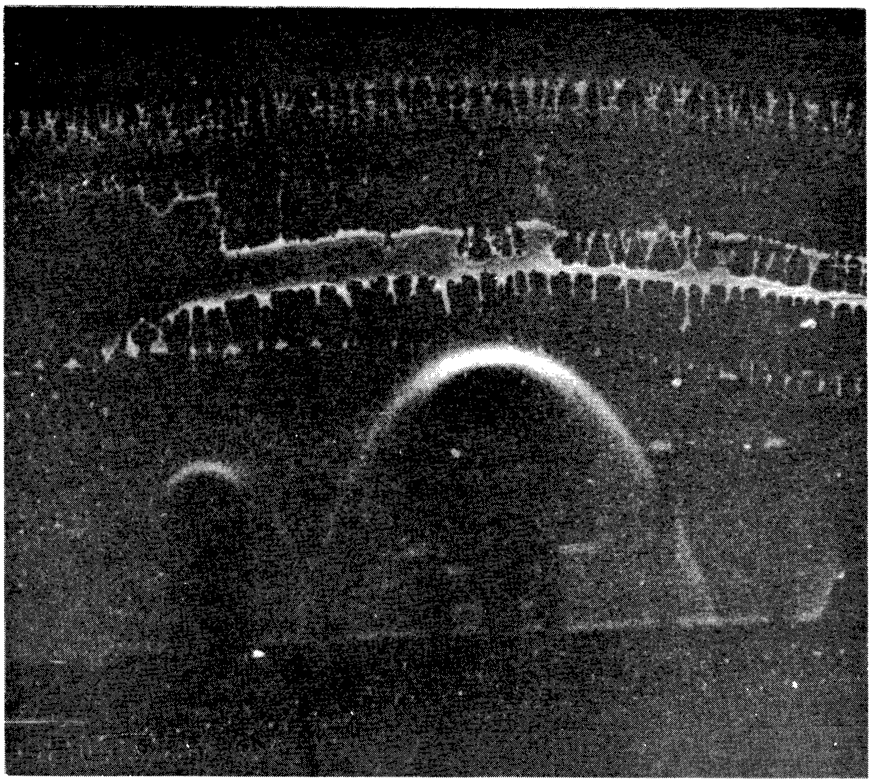


Figure 23