JET PROPULSION EXPERIMENTS

A THESIS

Submitted in partial fulfillment
of the requirements for the Degree
of Master of Science in Aeronautical Engineering

by

John J. Harper

Georgia School of Technology
Atlanta, Georgia
1942

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Approved:

Date Approved by Chairman May 13th, 1942

ACKNOWLEDGMENTS

The author wishes to thank Professor Montgomery Knight who suggested the investigation and made many helpful criticisms during its development; and Mr. W. C. Slocum who aided in the construction of the apparatus used.

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SUMMARY

An investigation was made to determine the extent to which an air jet could be augmented by the use of a "thrust augmentor", and thus give some indication as to the feasibility of using the jet as a prime mover. The augmentation was to be effected by inducing a flow of air through the jet, thereby increasing the mass rate of flow of air, and consequently the thrust.

Specifically, the purpose of the tests was to determine (1) if a simple, practical augmented jet could be developed, (2) the amount of augmentation, (3) the effect upon the augmentation of the following variables: (a) diffuser expansion ratio, (b) nozzle area, (c) ratio of induced flow inlet area and nozzle area.

The results show that the augmentation is rather small, but is substantially constant over the range of pressures used. Also the jet developed is simpler than other augmented jets tested by the National Advisory Committee for Aeronautics. The variables mentioned in (3), above, definitely affect the augmentation.

INTRODUCTION

The term jet propulsion, in particular, refers to propulsion by means of a high speed jet issuing from a properly shaped nozzle under high pressures. In its broadest sense, it is that type of propulsion which is characteristic of prime movers designed to work in a fluid medium such as air or water, or in space. In a fluid, the jet may be composed of the medium itself set in motion by some external mechanical means such as a screw. In space, the fluid must necessarily come from within the vehicle itself (Reference 8). The type of jet tested is known as an "air burning" rocket when a fuel is burned in the pressure chamber. Although the fuel may be contained within the rocket itself, the air necessary for combustion must be taken in from the atmosphere, hence the term "air burning" rocket.

The rocket is equivalent in function to a combination of heat engine and propeller. It would be hard to imagine a less complicated system than the rocket which, in its simplest form, consists of a hollow cylinder with one end closed, thrust being exerted on the closed end by gases exhausted from a fuel burned within the cylinder. It would seem, therefore, that propulsion by means of a jet of burned gases is the simplest method of propelling vehicles through air or water. However, the application of jet propulsion to airplanes as they exist today has been shown by Roy, Reference 7, and Buckingham, Reference 8, to be unsatisfactory because the screw propeller is vastly superior insofar as fuel consumption and thrust are concerned. Roy found that an airplane must fly at a speed of 800 miles per hour in order to be propelled as efficiently by a jet as by a screw propeller. This speed is out of the question at the present.

However, if the thrust of the jet could be increased or augmented sufficiently without increasing the power required, the jet might be used efficiently as a prime mover at the higher speeds now possible to aircraft. It is known that the propulsive efficiency of a jet increases as the speed of the vehicle approaches that of the jet. Therefore, if some device were used which would increase the thrust, and at the same time decrease the jet velocity, then this velocity would approach more closely that of the vehicle. Any jet of burned gases ejected under pressure has a high velocity, and therefore simplification of the problem requires that this velocity be reduced without a great loss of energy. Only if the propulsive efficiency of the jet were equal to that of the screw propeller would the jet assume importance. The propulsive efficiency is defined by Campini, Reference 3, as the ratio of the work done by the thrust and the mechanical equivalent of heat energy absorbed per unit time. Jet augmentation becomes a necessity if the jet is to be used efficiently as a prime mover for propelling air, land or water vehicles.

At high speeds, as encountered in jet propulsion, Lord Kelvin, Reference 8, pictures the jet boundary as that of a turbulent sheath which separates the jet from the surrounding medium. This sheath, according to his point of view, consists of ring vortices which follow one another in rapid succession and tend to act as rollers between the jet and the surrounding medium. The picture cannot be so orderly, for there is no definite surface of separation because of a certain amount of mixing between the jet and its surrounding medium. The fluid issuing from the nozzle is termed the "core stream" and the induced flow in the medium is called the "jacket stream". A free jet is one whose reaction is a "core reaction", and an augmented jet is one used with devices to change its momentum. All the energy given to the air must come from the energy of the jet.

It would seem that the most apparent motion given to the core by the pressure in the nozzle is an axial one. Other motions, however, do exist. There is the rotary motion of eddies which make up the turbulent sheath, and the inflow of air normal to the jet which replaces that carried downstream. This energy can be utilized to secure augmentation only by devices which direct these induced motions parallel to the jet axis and at the same time distribute the energy through as large a mass of fluid as possible. It would be difficult to devise a system of guide vanes, and venturis, which would break up the vortices and convert their angular momentum to linear momentum. One other possibility of augmentation is that of directing axially the inflow of fluid, normal to the axis of the jet, which replaces that carried downstream. Thus all that is required is suitable guide vanes such that the normal inflow is directed axially. The Melot augmentor is of this type.

The American Rocket Society, Reference 9, has done a great deal of work on jet propulsion, but unfortunately this has dealt with true rockets burning liquid fuels, and no attempts were made with an augmented jet of any sort. Due to extremely high exhaust temperatures encountered in all of these rocket tests, a very good heat resistant material or a massive structure would have to be employed, consequently a light weight,simple,thrust augmentor is out of the question. Actually, only a few attempts have been made to increase the thrust of a simple jet by the use of auxiliary devices. As mentioned previously, Roy, Reference 7, in his mathematical treatment of "Propulsion by Reaction", used a combination of jet and screw propeller, and hence takes advantage of the higher efficiency of the propeller. His idea was to place nozzles at the propeller tips and have the jet directed tangentially to the helical path. By the use of this scheme, the advantage of highest obtainable nozzle speed is realized. This scheme, as far as is known, was never tried experimentally. However, this type of apparatus belongs more to the gas turbine field than to true jet propulsion.

There is still the possibility of using auxiliary devices along with the jet. As previously stated, owing to the high jet velocities associated with burned gases ejected from a nozzle, the efficiency of the jet is poor, and only a comparatively small amount of thrust is obtained for a given amount of kinetic energy in the jet. It is easily seen that if some of this kinetic energy could be transmitted to the surrounding air so as to increase the momentum of the jet and decrease its velocity by inducing a greater mass flow of air, the mechanical efficiency of the jet and its thrust would be increased. It is a fortunate fact that any changes in the jet after it leaves the nozzle do not affect the thrust arising on the interior of the nozzle. Hence, as stated previously, additional force may be obtained by the action of fluid set in motion by the jet on auxiliary devices. This may be done without impairing the original reaction. Most augmentors tried by the National Advisory Committee for Aeronautics were constructed with this fact in mind.

The scheme most often tried or suggested is that used some years ago by Melot at the French Laboratoire du Conservatoire des Arts et Metiers. This device consists of a series of annular guides of curved profile surrounding the jet, the last such ring (also the largest) having a long diverging cone attached, thus forming a large Venturi tube. As stated previously, the action of the jet is supposed to create a low pressure region near the mouth of the Venturi thus causing the surrounding air to be drawn through it.(Reference 4) This induced flow increases the mass rate of flow and decreases the velocity. In this manner, the thrust of the jet is increased or augmented. This method and the one suggested by Roy seem to be the only two such schemes of augmentation. However, since the Melot type merely induces an additional flow of air, it was thought that a simpler method of inducing the flow could be devised. The type of jet used in the development of the high speed wind tunnel at the National Physical Laboratory, References 1 and 2, although not yet used for jet propulsion, seemed to be one answer to the problem at hand since this device directs the normal inflow of air parallel to the axis of the jet, increasing its momentum, without the use of several bulky guide vanes as in the Melot type.

In the proposed systems of jet propulsion, the jet is composed of the products of combustion at a high temperature, but it was believed that the augmentation would not depend greatly upon the temperature and nature of the gases in the jet. Inasmuch as a supply of compressed air at ordinary temperatures was available, no attempts were made to burn a mixture of combustibles in the pressure chamber.

APPARATUS

The experiments were carried out in the laboratory of the Daniel Guggenheim School of Aeronautics at the Georgia School of Technology where a supply of compressed air was available. The supply line was a standard one and one-half inch pipe. The range of chamber pressures used was from 0 to 45 pounds per square inch gage.

Figure 1 shows a view of the plain jet. This jet was used as the basis of comparison in determining the augmentation. Figure 2 is a cross section of the same jet (not to scale) and the nozzles tested. The chamber was turned from steel, as was the end cap. This jet has two air inlets as shown in Figure 2. It was originally designed to burn air and gasoline; hence, one inlet is inclined at 45°. A pressure gage tap is at 90° to the air inlets.

Figure 3 is a view of the augmented jet showing the small stand upon which the jet was mounted. Figure 4 is a disassembled view of this jet, showing the component parts which consist of the chamber, nozzle, inlet flare, and diffuser cone. The annular chamber was constructed from two sections of different diameter steel tubing placed one inside the other. Two end plates were welded on thus forming the pressure chamber. The diffuser was formed from terneplate and was made to screw into the top of the chamber. The inlet flare was turned from solid wood. The nozzle was machined from solid round steel stock and screwed into the bottom of the chamber. Three such nozzles were made; these are designated as 1, 2, and 3. Their areas are 0.1093, 0.177, and 0.0658 square inches, respectively. Figure 5 is a full size drawing of the jet and nozzles tested, and clearly shows how the jet was constructed and also shows the path of the air.

In operation, the high pressure air issuing from the annular nozzle exhausts the air from inside the throat of the jet and thus creates a region of low pressure. This low pressure region induces an additional flow of air which mixes with the high pressure air, thereby increasing the mass rate of flow through the jet.

Figure 6 is a schematic diagram of the entire set up. Attached to the end of the supply pipe is a "T" connection to which are fastened two flexible rubber supply hose. These hose are attached to the jet being tested. The jet itself sits on the platform scales which measure the reaction. In the supply pipe is a static orifice and a total head tube as shown. Flexible hose connect these to a water manometer, which reads the dynamic head only. A pressure gage is placed in the supply line for recording static pressures. The mass rate of flow is determined by means of the manometer and pressure gage reading. Figure 7 is a general view of the equipment with the plain jet in place; Figure 8 is the same except that the augmented jet is shown in position for testing.

PROCEDURE

The procedure for one nozzle setting will be given. The same testing procedure was followed for each nozzle tested.

It was first necessary to find the pipe factor or coefficient of discharge. This was accomplished by making a survey across the pipe with a total head tube in conjunction with a static orifice. A special total head tube was constructed for making the survey. It was made of hypodermic tubing and fitted into a brass housing where it was free to slide up and down. A reference mark was scribed on the tube for proper positioning in the pipe. When in the proper position the tube was soldered in place. Five stations were taken across the pipe. Runs were made at constant static pressure. Two such runs, one at 20 pounds per square inch gage and one at 35 pounds per square inch gage, were made. For each station, the dynamic head was calculated from the manometer reading. The square root of this head was plotted against pipe stations and the average determined by taking the average of a number of heads taken at the mean radii of equal concentric annular areas. This average divided by the center line head gave the coefficient. This was done for both runs and the average of the two taken as the overall pipe coefficient. This coefficient "C" was combined with the area of the pipe, "A", to give a constant "K" = CA.

In order to compute the amount of augmentation it was necessary to use some jet as a basis of comparison. The thrust of a plain, simple convergent nozzle was decided upon since the nozzles used in the augmented jet were all convergent. A small convergent nozzle of the same area as nozzle No. 1 was machined; this was used only to find the nozzle coefficient. A test was made on this nozzle, the actual jet velocity,

V_a , being determined from

$$V_a = \frac{T_h}{m}$$

where T_h = thrust in pounds as measured by scales

m = mass rate of flow in slugs per second

The nozzle coefficient $\sqrt{e_n}$ is determined from

$$\sqrt{e_n} = \frac{V_a}{V_{th}}$$

where V_{th} = theoretical jet velocity in feet per second. V_{th} is calculated from

$$V_{th} = 109.7\sqrt{T^o\left[1 - \left(\frac{P_o}{P_c}\right)^{.286}\right]} \quad \text{(Reference 5)}$$

where T^o = absolute chamber temperature, degrees F.

P_c = absolute chamber pressure, pounds per square inch.

P_o = absolute atmospheric pressure, pounds per square inch.

Having determined the nozzle coefficient, the actual velocity for any chamber temperature and pressure can be found from

$$V_a = C_v\,109.7\sqrt{T^o\left[1 - \left(\frac{P_o}{P_c}\right)^{.286}\right]}$$

where $C_v = \sqrt{e_n}$

By assuming an average value for T^o and P_o , the velocity for any chamber pressure may be found. For any mass rate of flow the thrust can be calculated from

$$T_h = m\,V_a$$

where T_h = thrust in pounds as before

V_a = actual jet velocity, feet per second

m = mass rate of flow, slugs per second

Hence, if the thrust as determined above is plotted against chamber pressure the resulting curve will be the basic thrust curve, and values can be read at any desired pressure within the range plotted. The degree of augmentation is obtained by dividing the actual thrust by that obtained from the basic thrust curve at a given chamber pressure.

The augmented jet was then mounted in place for testing on the platform scales, and readings were taken at 5 pounds per square inch intervals of chamber pressure. The thrust reaction, static line pressure and manometer reading were recorded for each different chamber pressure. Since all thrust curves were plotted for a constant rate of flow, M, of 100 pounds per hour, it was necessary to get the thrust for this rate of flow. The actual mass rate of flow was calculated from

$$m = \rho K V_{a_p}$$

where m = mass rate of flow, slugs per second

ρ = mass density of air, slugs per cubic foot

K = CA = pipe constant

V_{a_p} = supply pipe velocity, feet per second.

The mass density, ρ, was corrected for temperature and pressure in all cases. The velocity, V_{a_p}, was determined from

$$V_{a_p} = \sqrt{2 \frac{q}{\rho}}$$

where q = dynamic pressure in pounds per square feet

ρ = mass density of air in the supply pipe, slugs per cubic foot.

The thrust for a rate of flow of 100 pounds per hour was obtained in the following manner

$$M = m \times 116{,}000 = \text{actual weight of air, pounds per hour}$$

$$\frac{T_h}{m \times 116{,}000} = \text{thrust per pound per hour}$$

$$T_h \times 100 = \text{thrust for } M = 100 \text{ pounds per hour}$$

These values were plotted against chamber pressure for all runs. It is to be clearly understood that for different chamber pressures, a change in nozzle area is necessary if the rate of flow is to be kept constant. The results presented are, therefore, for geometrically similar jets of the type tested. The significance of these results is that as the pressure ratio increases, the dimensions of the jet system decreases.

The amount of augmentation was determined from

$$\text{augmentation} = \frac{T_h}{T_{h_b}}$$

where T_{h_b} = basic thrust in pounds, from Figure 9.

A curve of augmentation versus chamber pressure was plotted for each nozzle tested.

RESULTS

Tables I through XI show the results obtained from the tests. These results are plotted in Figures 9 through 20.

Figure 9 shows the thrust plotted against $\frac{P_c}{P_o}$ atmospheres for the simple convergent nozzle. This is the basic thrust curve and is used for determining the amount of augmentation.

Figure 10 shows the thrust curve for the augmented jet with nozzle No. 1. Figure 11 is the augmentation curve for this nozzle. The augmentation curve obtained by the National Advisory Committee for Aeronautics, Reference 5, is plotted on this same sheet for the sake of comparison.

Figure 12 shows three different thrust curves for nozzle No. 1. Three tapered plugs designed to reduce the induced flow inlet area to three-fourths, one-half, and one-fourth of its original value were placed in the jet throat. Figure 13 shows the augmentation curves for nozzle No. 1 for these three different plugs.

Figure 14 is the thrust curve for nozzle No. 2. This nozzle had a slightly larger area than either 1 or 3 as shown in Figure 5. Figure 15 is the augmentation curve for nozzle No. 2.

Figures 16 and 17 show thrust and augmentation versus chamber pressure for nozzle No. 3.

Figure 18 is the thrust curve obtained from a convergent-divergent nozzle. This nozzle, shown in Figure 2, had a three-eights inch throat and an expansion ratio of 1.6 with a total included angle of divergence of about 6°. This curve is included in order to compare this nozzle with the augmented jet.

Figure 19 shows three different thrust curves for nozzle No.1. Three diffuser expansion ratios were tried, 2, 1.75, and 1.5 besides that of the original diffuser which had a ratio of 2.4. Figure 20 shows the augmentation curves obtained for the various expansion ratios.

Where different tests were made on the same nozzle, the nozzle setting was kept constant. All values of thrust and augmentation were plotted for a constant rate of flow of 100 pounds per hour.

DISCUSSION

The nozzle coefficient for the basic jet was determined experimentally and was found to be very nearly 1.0 (0.99 actual value). The thrust was determined by assuming a constant rate of flow and calculating the theoretical velocity. The nozzle coefficient was applied to the theoretical velocity to determine the actual jet velocity. The product of the rate of flow and the velocity gave the thrust, which, when plotted against chamber pressure, gave the basic thrust curve as shown in Figure 9.

A test was made, along with these, with the induced flow inlet completely plugged, the plug being flush with the edge of the nozzle. This was done because it was thought that the thrust obtained in this manner might be used as the basic thrust. The results were so poor that they were not even recorded. The reason for such poor thrust was due to the large amount of turbulence set up by the action of the jet. The action of the high pressure air issuing from the annular nozzle is to exhaust any air in the throat. After exhausting the air from the jet throat, a low pressure region existed in the throat and the air issuing from the nozzle tended to "spill over" into the center of the jet thus creating the turbulence mentioned above. The final result was that the velocity of the air coming out of the diffuser was practically zero. The thrust was consequently small.

Figure 10, the thrust curve for nozzle No. 1, has the same general shape as Figure 9, which is to be expected; however, the thrust for any given chamber pressure is greater. This is due to the additional mass of air induced through the jet. In the British reports on high speed wind tunnels, References 1 and 2, the velocity in the working portion became practically constant at 45 pounds per square inch gage pressure. This could have been an indication of the thrust, and, if so, the thrust curve would flatten out. Examination of Figure 10 shows that this curve has no tendency to reach a maximum although the chamber pressure was carried up to 40 pounds per square inch gage. This, then, would seem to indicate that the thrust will continue to increase up to a certain limit.

Figure 11 shows the variation in augmentation with chamber pressure for nozzle No. 1. The most prominent characteristic is that the augmentation is practically constant throughout the range of pressures used. The slight "hump" between $\frac{P_c}{P_o}$ of 1.4 and 1.6 is probably due to the fact that at low pressures the calculated results are slightly in error because the manometer and gage readings were probably inaccurate. Plotted on this same sheet is the augmentation curve as obtained by the National Advisory Committee for Aeronautics from their tests on the Melot type augmentor. The difference between the two curves can easily be seen; the curve of the National Advisory Committee for Aeronautics reached the same value of augmentatien but at a pressure of 90 pounds per square inch gage, after which the curve immediately falls off. The authors of the report make no attempt to explain why the augmentation curve peaked as it did.

Figure 12 shows three thrust curves for nozzle No. 1 with plugs inserted. This was done because it was believed that varying the ratio of induced flow inlet area and nozzle area, R, might give higher augmentation. The ratio for the augmented jet was found to be 26.9, so it was decided to reduce this by inserting turned wooden plugs in the center of the jet. These plugs were the same length as that of the jet. Examination of Figure 5 will show how the plugs were inserted. Plug No. 1 reduced the inlet area to three-fourths of its original value, No. 2 to one-half, and No. 3 to one-fourth. These were centered in the jet and held in place by small pieces of rod. The results were not encouraging, for even the smallest plug gave a thrust much less than the basic thrust. The other two plugs gave even worse results as shown by the curves in Figure 13. Although there is probably an optimum ratio of areas, this is not the method to use to determine the particular ratio as the increased surface area due to adding the plugs created an additional amount of skin drag resulting in poor thrust.

Figure 14 is the thrust curve for nozzle No. 2 which had an area of 0.177 square inches. Comparison with Figure 10 shows that the thrust obtained at the lower pressures is somewhat less than that for nozzle No.1, but it is greater at higher chamber pressures. The fact that the ratio of areas, R, was changed when nozzle No. 2 was used might have contributed to the increase in thrust.

The augmentation, shown in Figure 15, reaches a maximum value of 1.4 at about 3.6 atmospheres, but it is rather poor at the lower pressures. This curve is not as constant as that given by nozzle No. 1 since the augmentation at the lower pressures is not as high.

It is interesting to note that nozzle No. 3, the thrust curve for which is shown in Figure 16, gave even less thrust than No. 1. The area of this nozzle was 0.0658 square inches which made the ratio of areas, R, greater than that for No. 1. The ratio is about 44.8 for No. 3. Recalling that it was stated that the ratio of areas for nozzle No. 2 was less than that for No. 1, it would seem that still smaller ratios would give better results. The augmentation curve, Figure 17, is constant except for the "hump" at 1.2 atmospheres. It was thought that this was probably due to inaccurate data, but since it appears consistently in nearly all the curves, this can hardly be true. No logical answer which would clarify this point could be found.

Figure 18 was plotted only for comparison purposes. It is the thrust for a convergent-divergent nozzle. Note that it gave smaller thrust values than the simple convergent nozzle. This is probably due to poor nozzle efficiency caused by too much divergence which made the flow turbulent. For the jet temperatures encountered, the divergence was too great; however, for high jet temperatures a greater divergence would probably be needed.

Figure 19 shows the effect of varying the diffuser expansion ratio. The original expansion ratio was 2.4 with about 6^{o} divergence. As the expansion ratio was decreased, the thrust decreased, possibly because of too rapid expansion. Had the taper started at the nozzle instead of at the diffuser, the effect would probably not have been as great. As it was, the flow followed the chamber walls which were straight and then suddenly diverged, and this effect is more noticeable for the shorter diffusers.

The augmentation curves are shown in Figure 20. The expansion ratio of 2 gave approximately the same values as the original except at the lower pressures where the effect is marked. For all three, the augmentation is fairly constant above 1.6 atmospheres. For comparison the augmentation curve for the original diffuser is dotted in, since the same nozzle and nozzle setting were used.

Very few experimental data could be found with which to compare the results obtained in these tests. The only two published sources discovered were National Advisory Committee for Aeronautics Technical Note No. 431, Reference 4, and Technical Note No. 442, Reference 8. The results given in Technical Note No. 431 were obtained from tests made on a Melot type augmentor. The maximum augmentation was about 1.37 at 6.1 atmospheres. A portion of the National Advisory Committee for Aeronautics curve is plotted in Figure 11. Note that the values obtained are not constant for any portion of the curve. The results of a great number of tests are given in Technical Note No. 442. Many different arrangements were tested but the results were poor; the best results were obtained with the Melot type of augmentor. Montgomery

Knight, Reference 6, in unpublished tests made at Georgia School of Technology, obtained values as high as 1.29 using a simple Venturi arrangement.

From the results obtained, several suggestions for improving the experimental jet set-up are apparent. First, a two dimensional jet would be more convenient, for the parameters affecting the thrust could easily be varied. With this arrangement the nozzle area, angle of divergence, expansion ratio, ratio of induced flow inlet area and nozzle area could be varied and the best combination determined. Second, Figures 19 and 20 indicate that slightly higher expansion ratios with less divergence would be beneficial. The fact that the flow could be heard to pulsate as though the air were breaking away from the jet walls indicates that the diffuser used on the experimental set-up had too much divergence. Some of this turbulence, however, was attributed to the jet walls not being smooth enough. Third, it would be interesting to determine the effect of "ram" or initial velocity on the thrust, and to compare this with the static thrust. This could be done by mounting the jet in a wind tunnel, although the ram effect would probably be small due to the low tunnel velocities. Time did not permit further development of the jet, and these suggestions are made for future study.

CONCLUSIONS

Within the limits of the results obtained, the following conclusions can be made:

(1) It is possible to obtain substantially constant augmentation over a range of pressures with a suitably designed jet.

(2) Values of augmentation as high as 1.4 are possible with the annular jet tested.

(3) The annular jet compares favorably with other types of augmented jets tested by the National Advisory Committee for Aeronautics.

(4) Unless appreciably higher values of augmentation can be obtained the jet will never be satisfactory as a prime mover for propelling air, land or water vehicles at low speeds.

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TABLES

All results for constant rate of flow of 100 lbs. per hour

Table I
Simple Convergent Nozzle

$\frac{P_c}{P_o}$	T_h
1.00	0.0
1.35	0.622
1.70	0.815
2.05	0.940
2.40	1.022
2.75	1.09
3.1	1.142
3.45	1.19
3.8	1.225
4.15	1.257
4.5	1.287

Table II
Augmented Jet, Nozzle No.1

$\frac{P_c}{P_o}$	T_h	Augmentation
1.0	0.	0.
1.5	1.00	1.39
2.0	1.26	1.37
2.5	1.43	1.373
3.0	1.565	1.38
4.0	1.65	1.375
4.5	1.70	1.372

Table III
Augmented Jet, Nozzle No. 1, .97" Diameter Plug

$\frac{P_c}{P_o}$	T_h	Augmentation
1.0	0.	0.
1.35	0.82	0.965
1.70	1.69	0.960
2.05	2.57	0.960
2.40	3.32	0.960
2.75	3.94	0.945
3.10	4.82	0.935
3.45	5.50	0.930
3.80	6.19	0.940

Table IV

Augmented Jet, Nozzle No. 1, 1.37" Diameter Plug

$\frac{P_c}{P_o}$	T_h	Augmentation
1.0	0.	0
1.35	0.62	0.63
1.70	1.12	0.63
2.05	1.69	0.63
2.40	2.18	0.62
2.75	2.69	0.62
3.10	3.17	0.615
3.41	3.56	0.605
3.80	4.00	0.59

Table V

Augmented Jet, Nozzle No. 1, 1.68" Diameter Plug

$\frac{P_c}{P_o}$	T_h	Augmentation
1.0	0	0
1.35	0.44	0.46
1.70	0.94	0.52
2.05	1.31	0.52
2.40	1.69	0.50
2.75	2.06	0.46
3.10	2.12	0.41
3.41	2.25	0.37

Table VI

Augmented Jet, Nozzle No. 2

$\frac{P_c}{P_o}$	T_h	Augmentation
1.2	0.60	1.225
1.4	0.78	1.165
1.6	0.90	1.17
1.8	1.0	1.17
2.0	1.1	1.195
2.5	1.32	1.27
3.0	1.52	1.35
3.4	1.63	1.38
3.8	1.70	1.393

Table VII
Augmented Jet, Nozzle No. 3.

$\frac{P_c}{P_o}$	T_h	Augmentation
1.2	0.72	1.4
1.4	0.92	1.394
1.6	1.02	1.325
1.8	1.11	1.30
2.0	1.18	1.282
2.5	1.34	1.29
3.0	1.45	1.29
3.4	1.52	1.29

Table VIII
Plain Jet, Simple Convergent-Divergent Nozzle

$\frac{P_c}{P_o}$	T_h
1.0	0
1.35	0.68
1.70	1.25
2.045	2.06
2.39	2.81
2.745	3.5
3.09	4.31
3.44	5.00
3.79	5.87
4.13	6.50

Table IX
Augmented Jet, Nozzle No.1, Diffuser Expansion Ratio = 2

$\frac{P_c}{P_o}$	T_h	Augmentation
1.0	0	0
1.35	0.84	1.32
1.695	1.00	1.24
2.04	1.19	1.25
2.39	1.402	1.315
2.735	1.473	1.35
3.08	1.52	1.37
3.43	1.63	1.375
3.78	1.585	1.375

Table X

Augmented Jet, Nozzle No. 1, Diffuser Expansion Ratio = 1.75

$\frac{P_c}{P_o}$	T_h	Augmentation
1.0	0	0
1.2	0.45	0.918
1.4	0.75	1.136
1.6	0.94	1.22
1.8	1.06	1.24
2.0	1.16	1.26
2.5	1.35	1.298
3.0	1.49	1.325
3.4	1.58	1.34
3.8	1.64	1.344

Table XI

Augmented Jet, Nozzle No. 1, Diffuser Expansion Ratio = 1.5

$\frac{P_c}{P_o}$	T_h	Augmentation
1.0	0	0
1.2	0.50	1.02
1.4	0.78	1.18
1.6	0.93	1.208
1.8	1.04	1.218
2.0	1.13	1.229
2.5	1.28	1.23
3.0	1.39	1.235
3.4	1.45	1.23
3.8	1.51	1.238

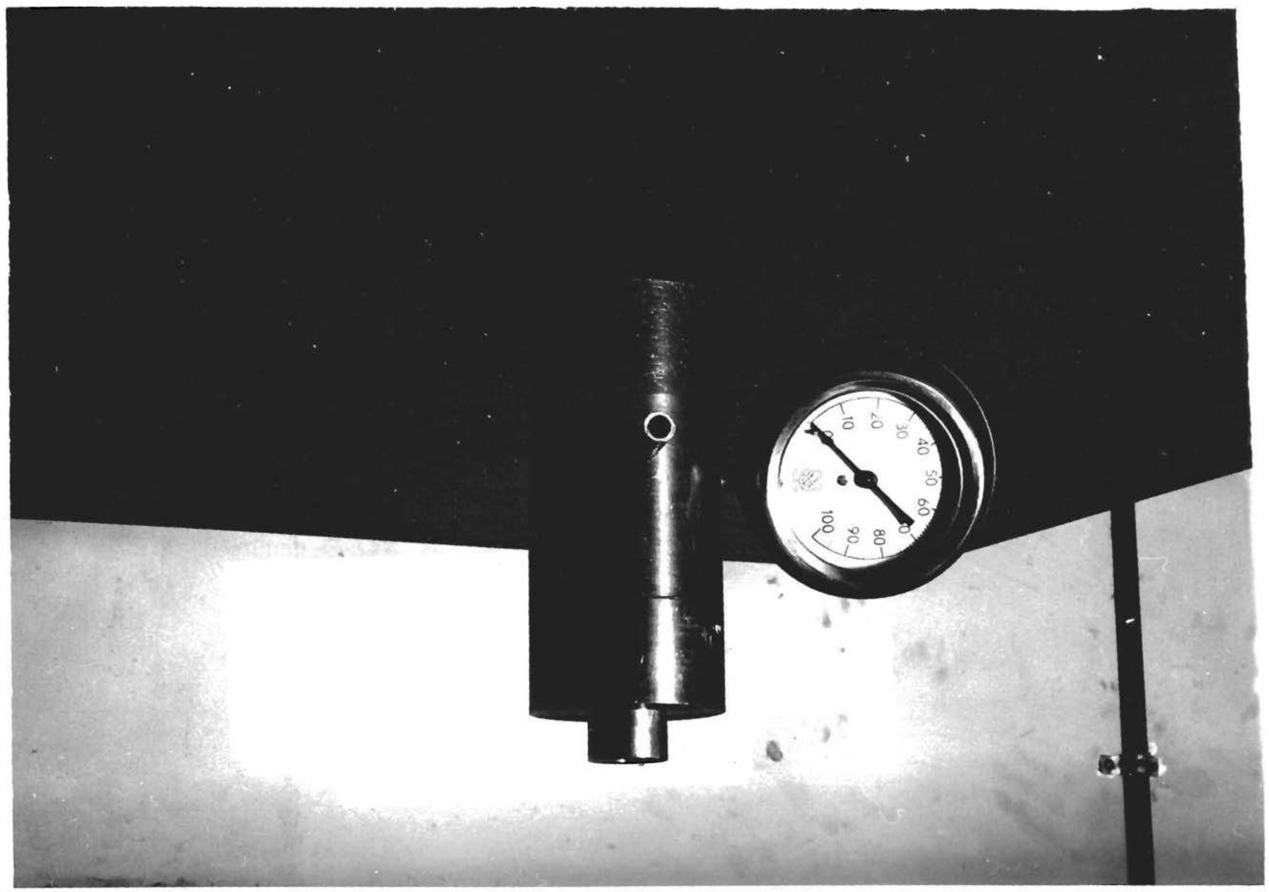

Fig. 1

View of Plain Jet

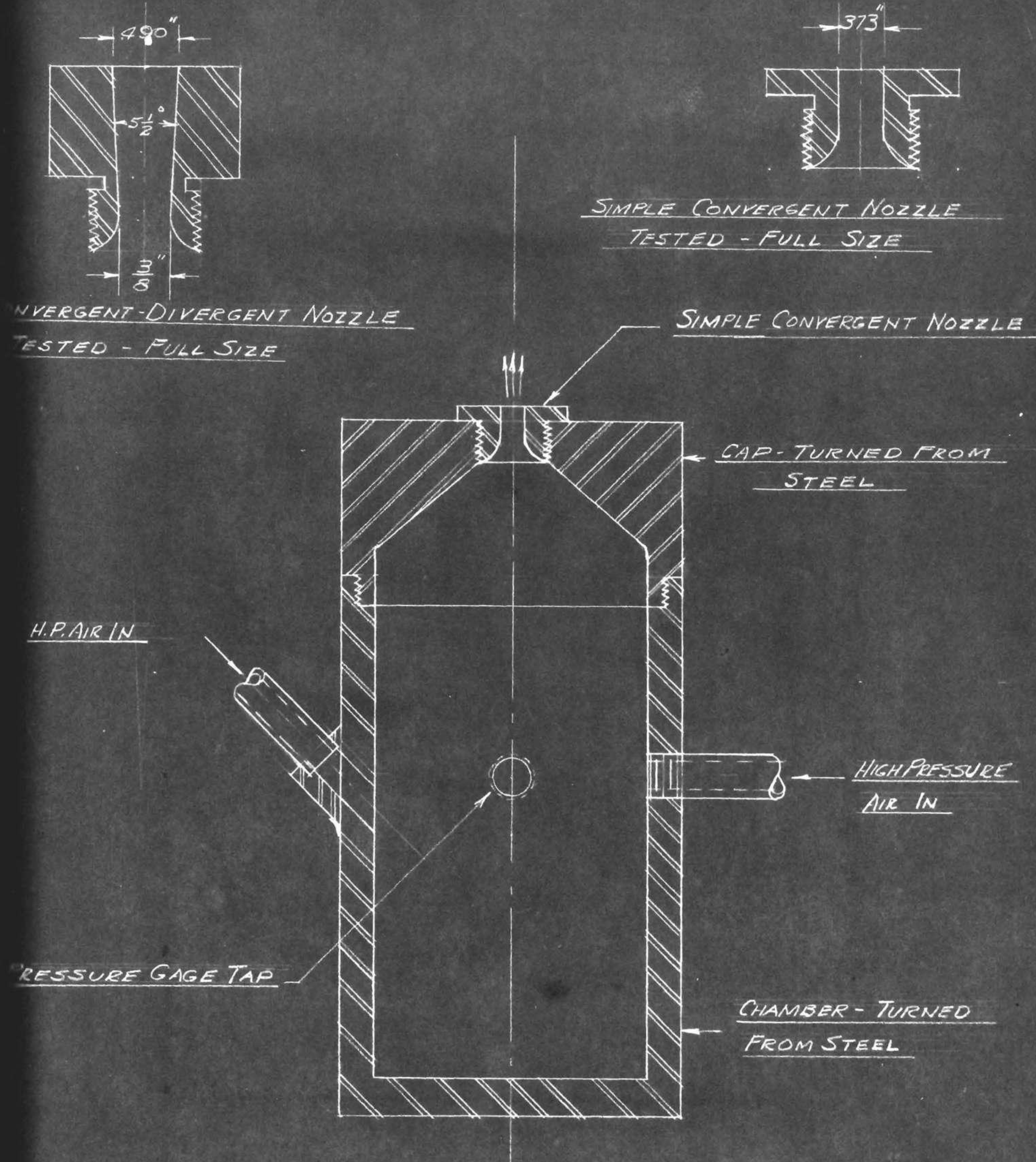

FIG. 2

SKETCH SHOWING CONSTRUCTION OF PLAIN JET

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Fig. 3

View of Augmented Jet

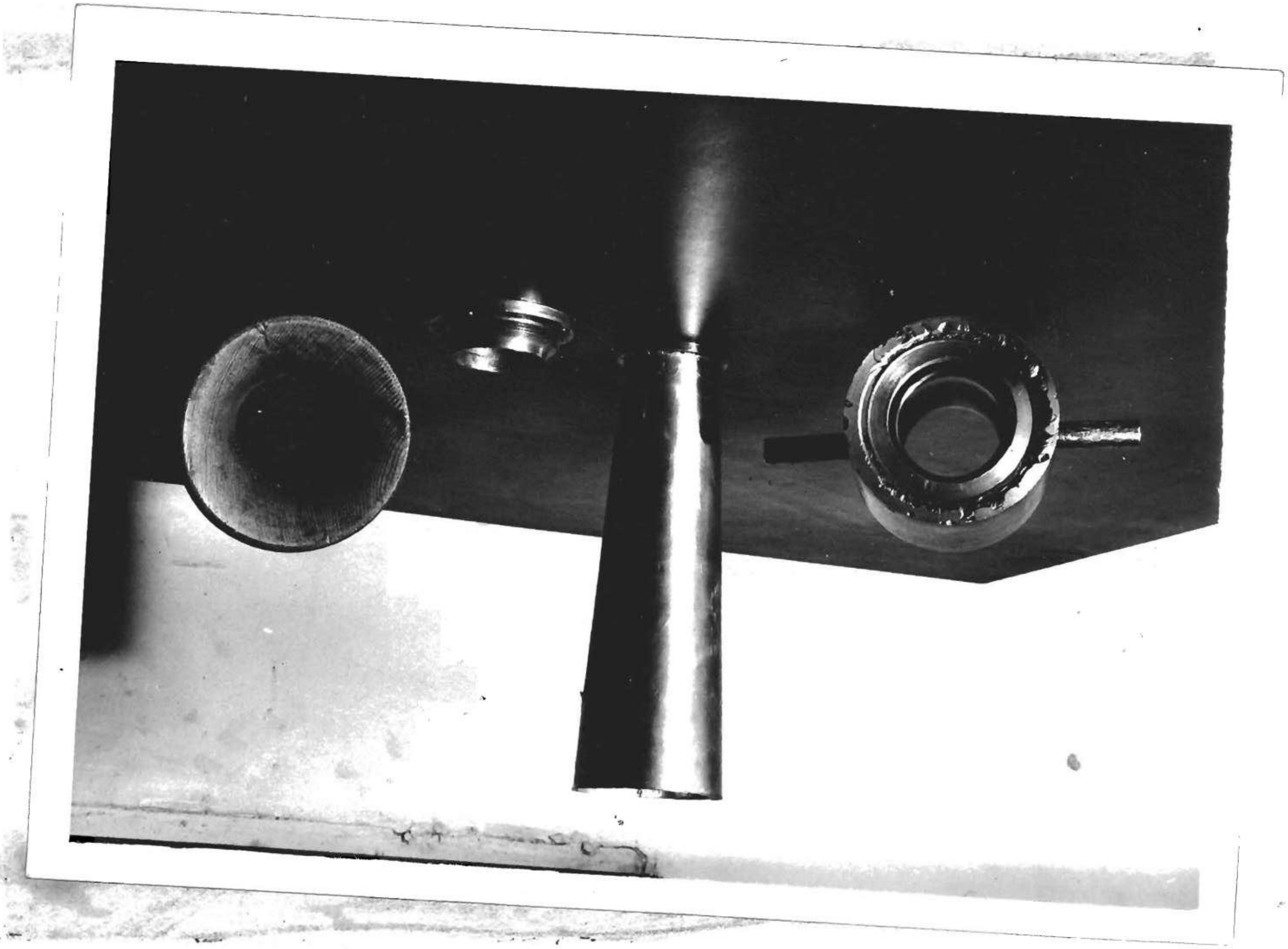

Fig. 4

Disassembled View of Augmented Jet Showing Component Parts

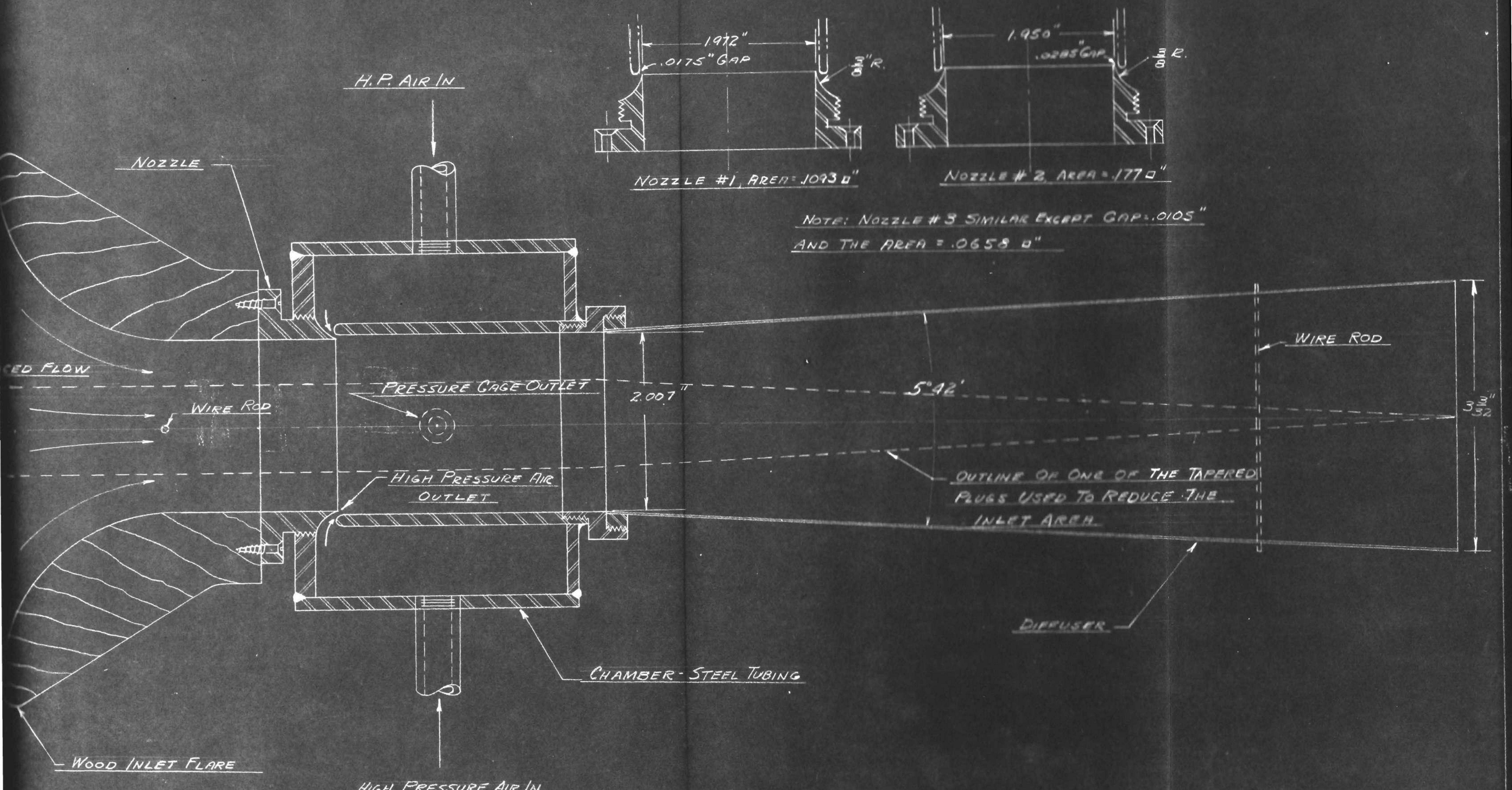

FIG. 5

FULL SIZE SECTION OF AUGMENTED JET

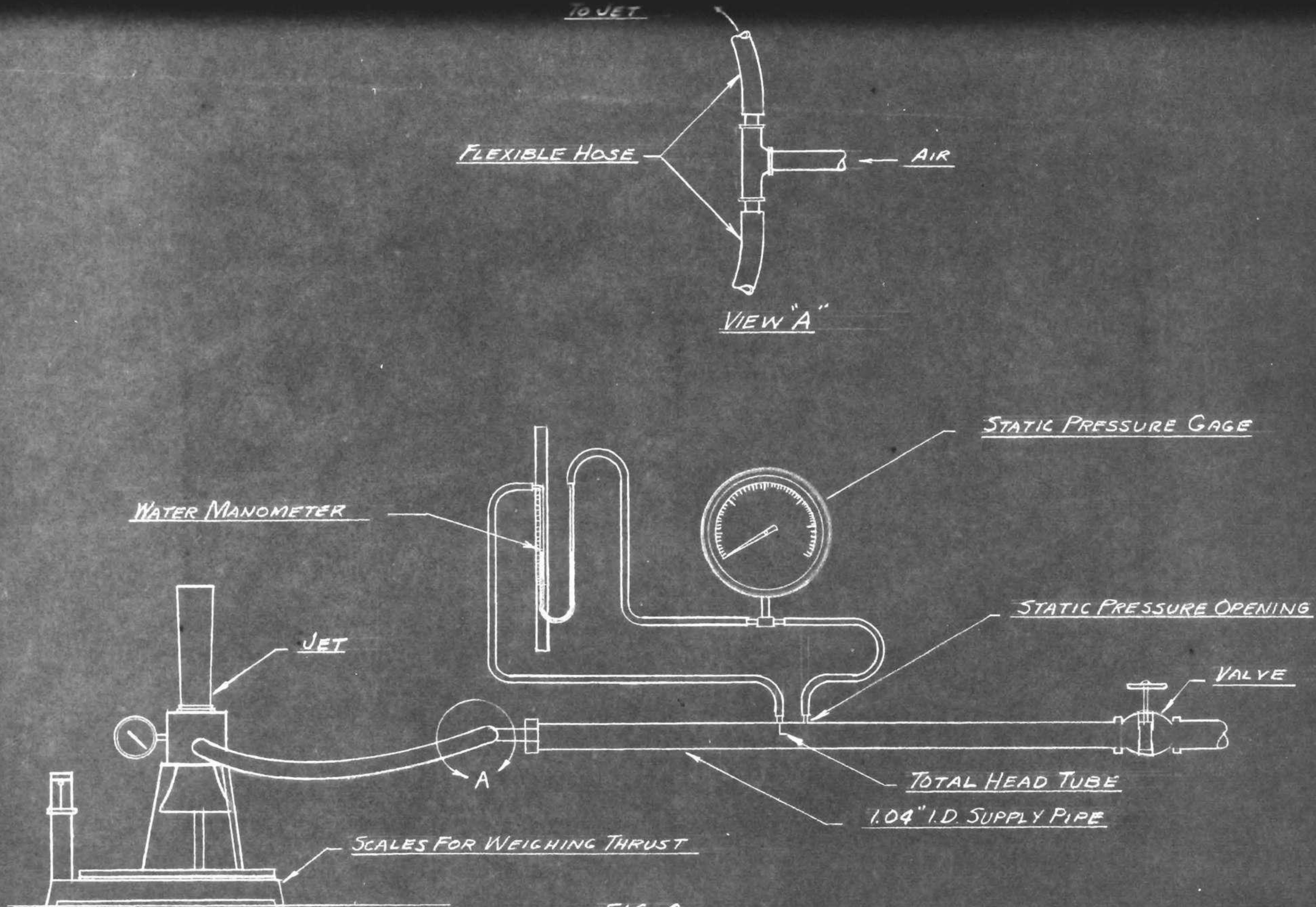

FIG. 6

SCHEMATIC DIAGRAM OF APPARATUS

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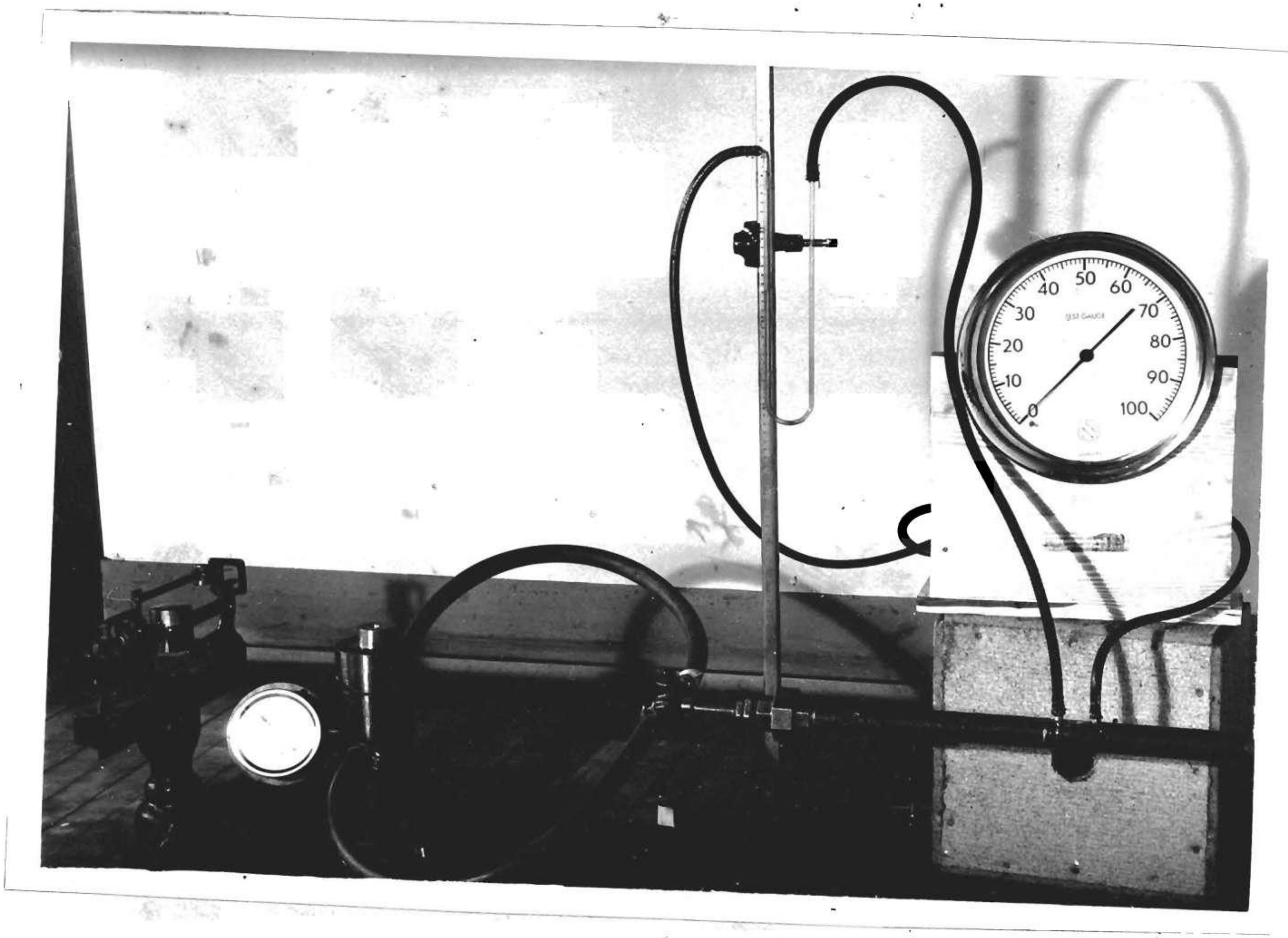

Fig. 7

General View of Apparatus with Plain Jet in Place

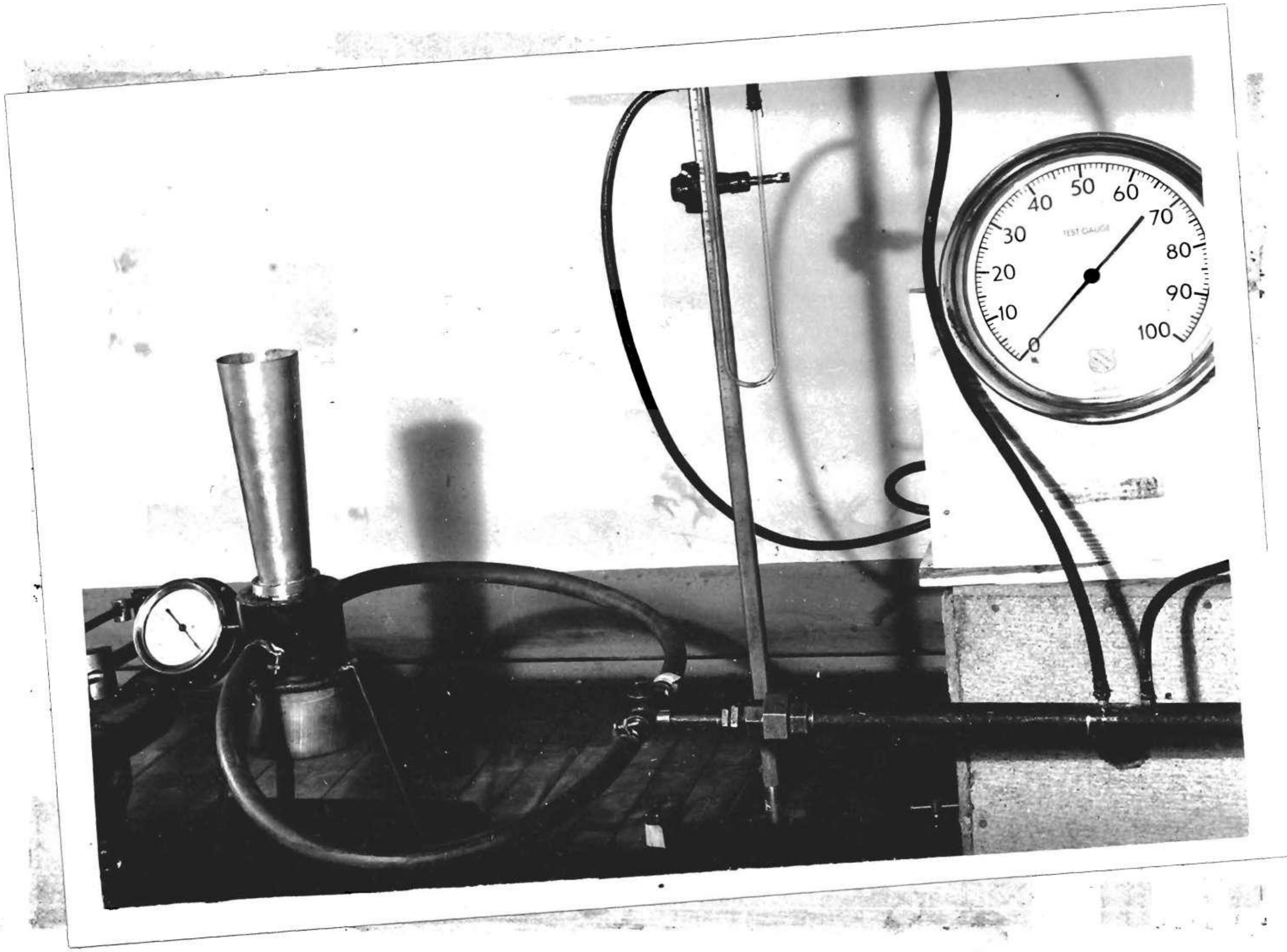

Fig. 8

General View of Apparatus with Augmented Jet in Place

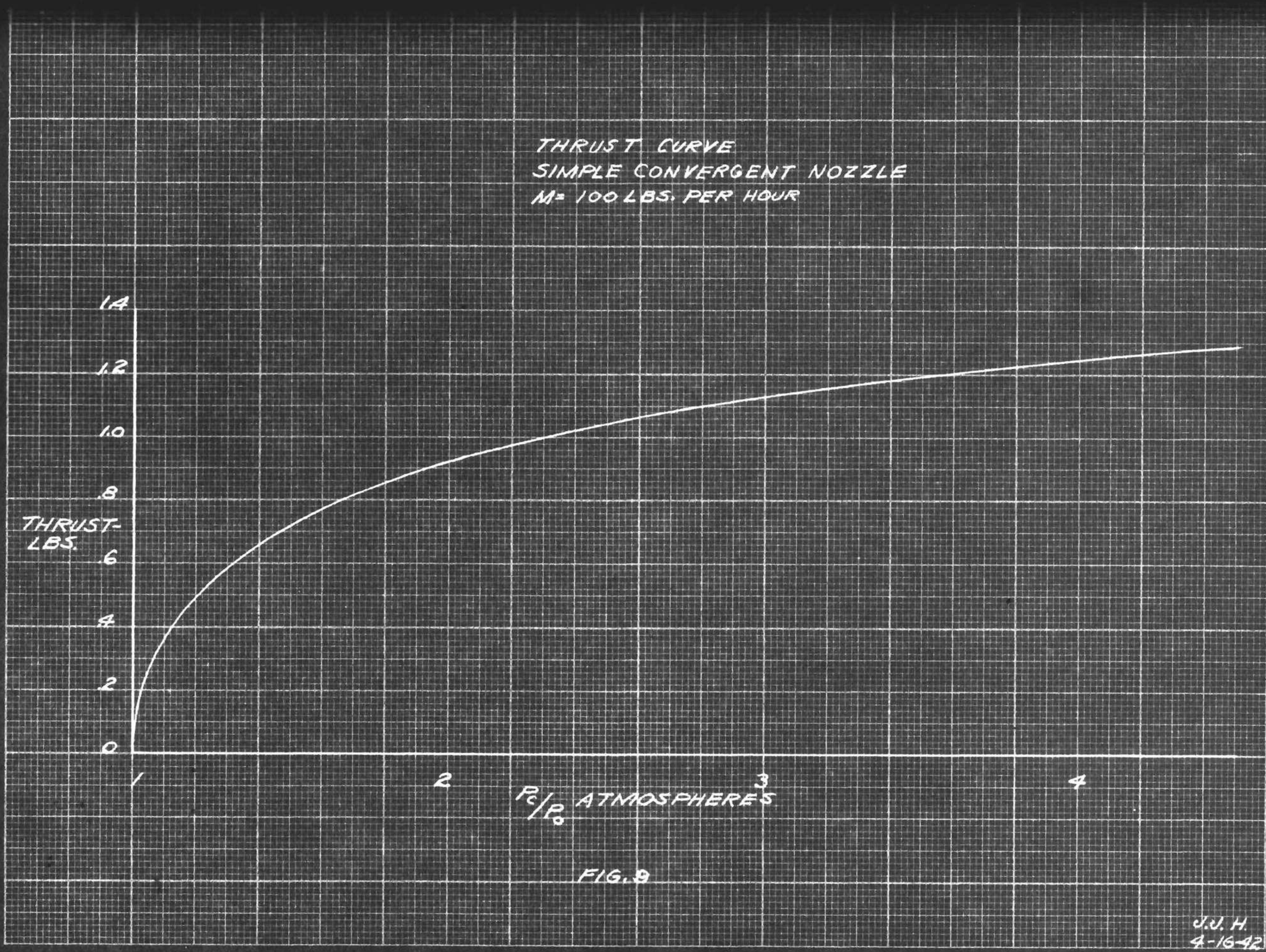
THRUST CURVE
SIMPLE CONVERGENT NOZZLE
M= 100 LBS. PER HOUR
1.4
1.2
1.0
.8
THRUST-
LBS.
.6
.4
.2
0
1
2
3
4
Pc/Po ATMOSPHERES
J.J. H.
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FIG. 9

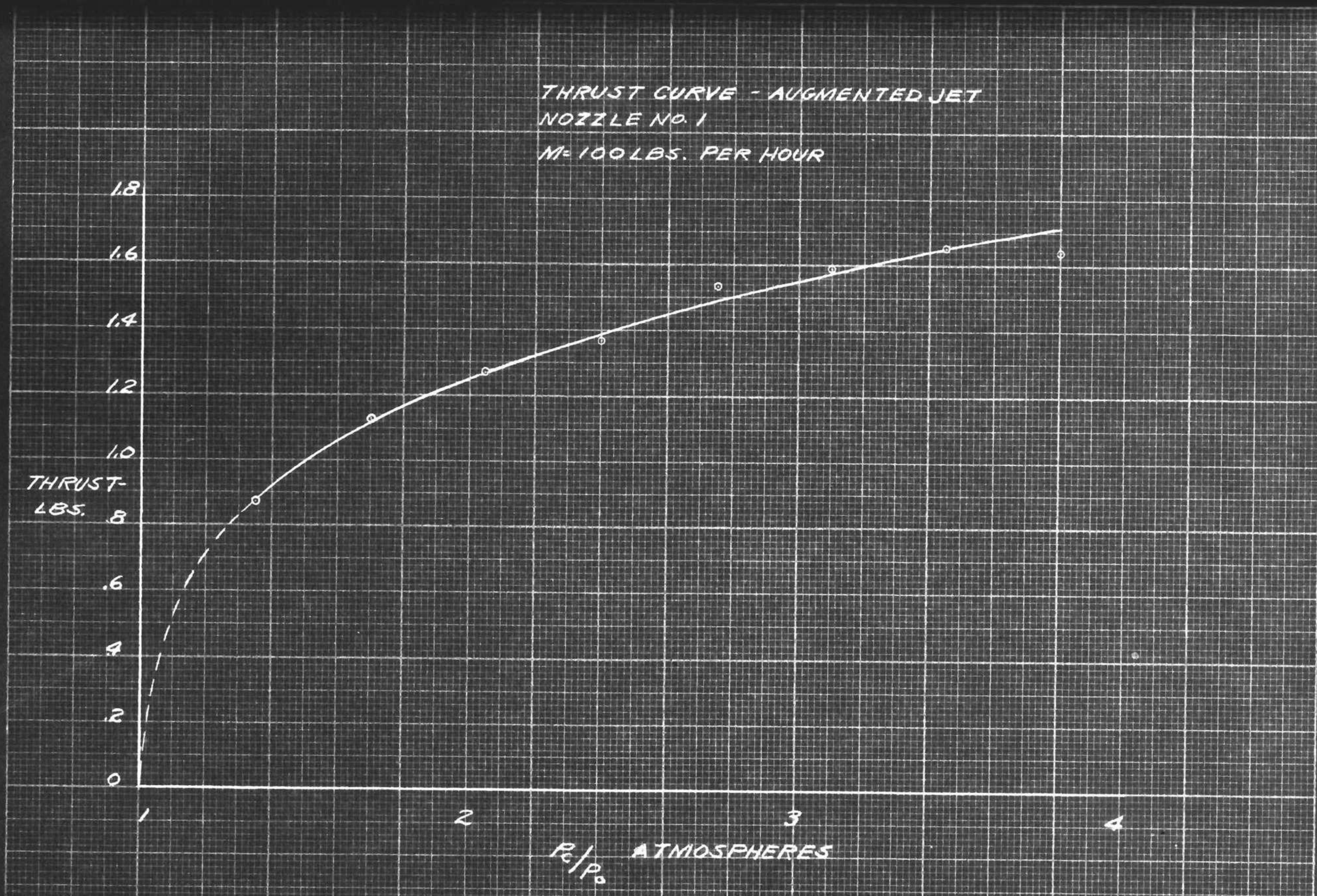

FIG. 10

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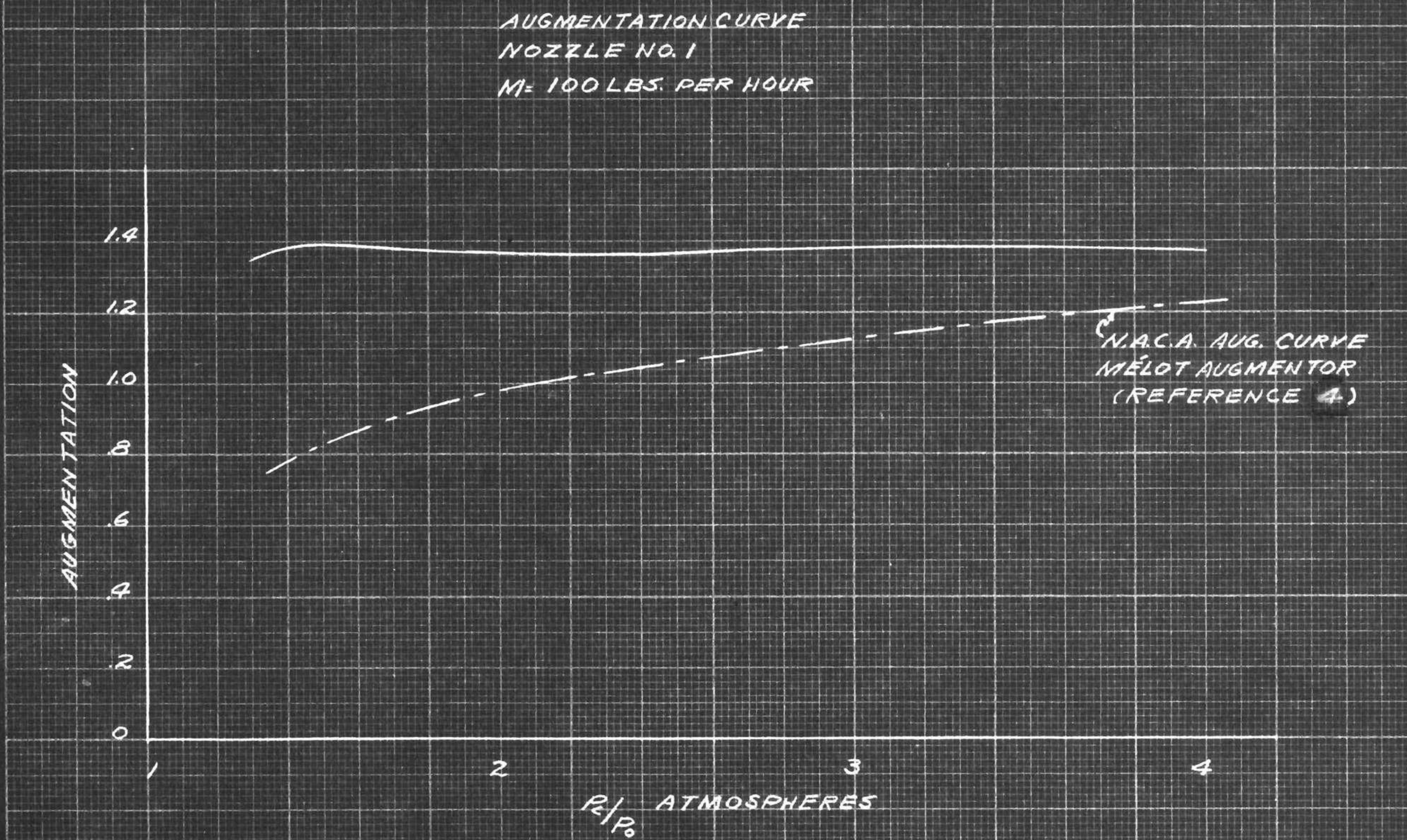

FIG. 11

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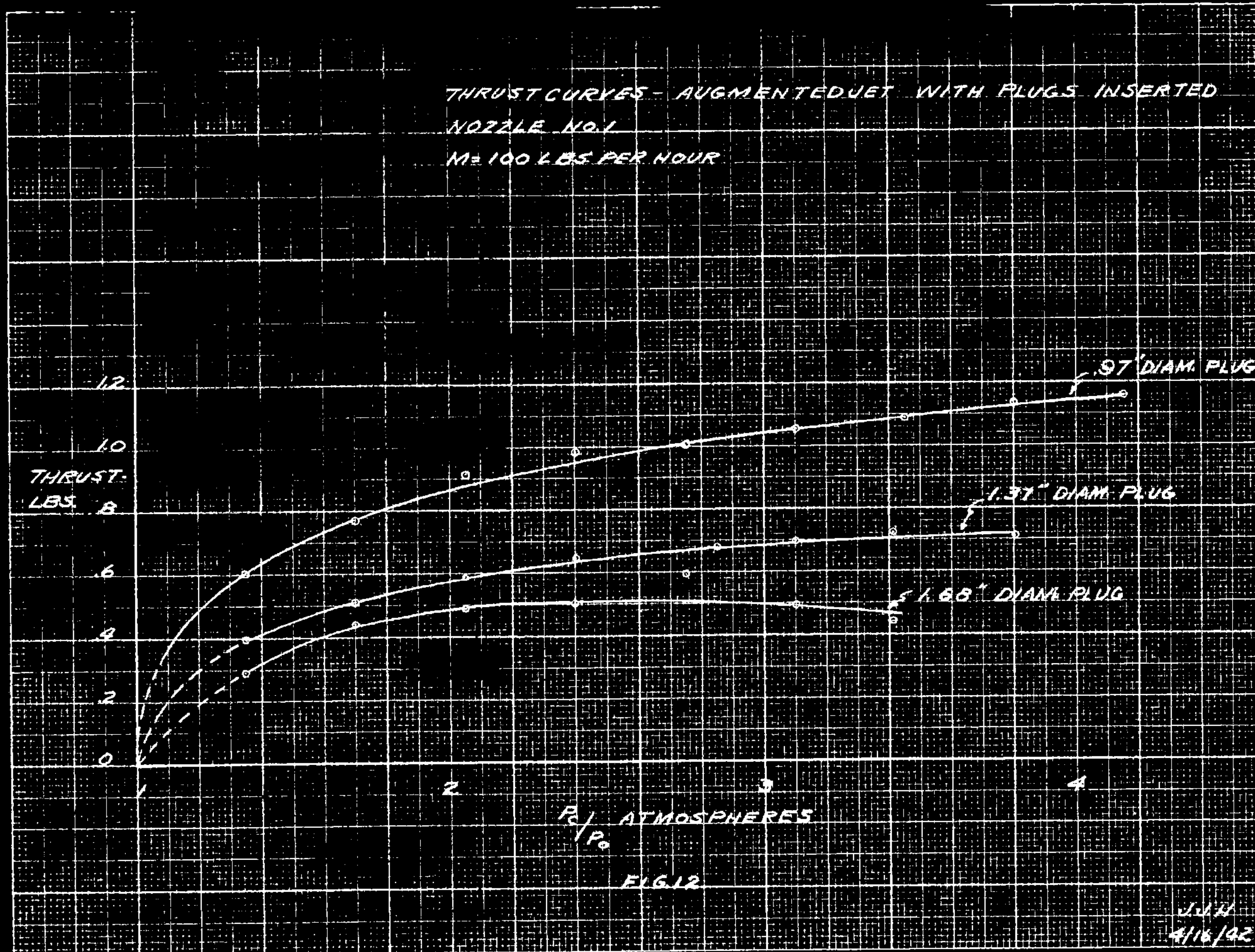
THRUST CURVES - AUGMENTED JET WITH PLUGS INSERTED
NOZZLE NO. 1
M= 100 LBS PER HOUR
.97" DIAM. PLUG
1.37" DIAM. PLUG
1.68" DIAM. PLUG
THRUST-LBS.
1.2
1.0
.8
.6
.4
.2
0
1
2
3
4
P_c/P_o ATMOSPHERES
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FIG. 12

AUGMENTATION CURVES

NOZZLE No. 1 WITH PLUGS INSERTED

M = 100 LBS. / HOUR

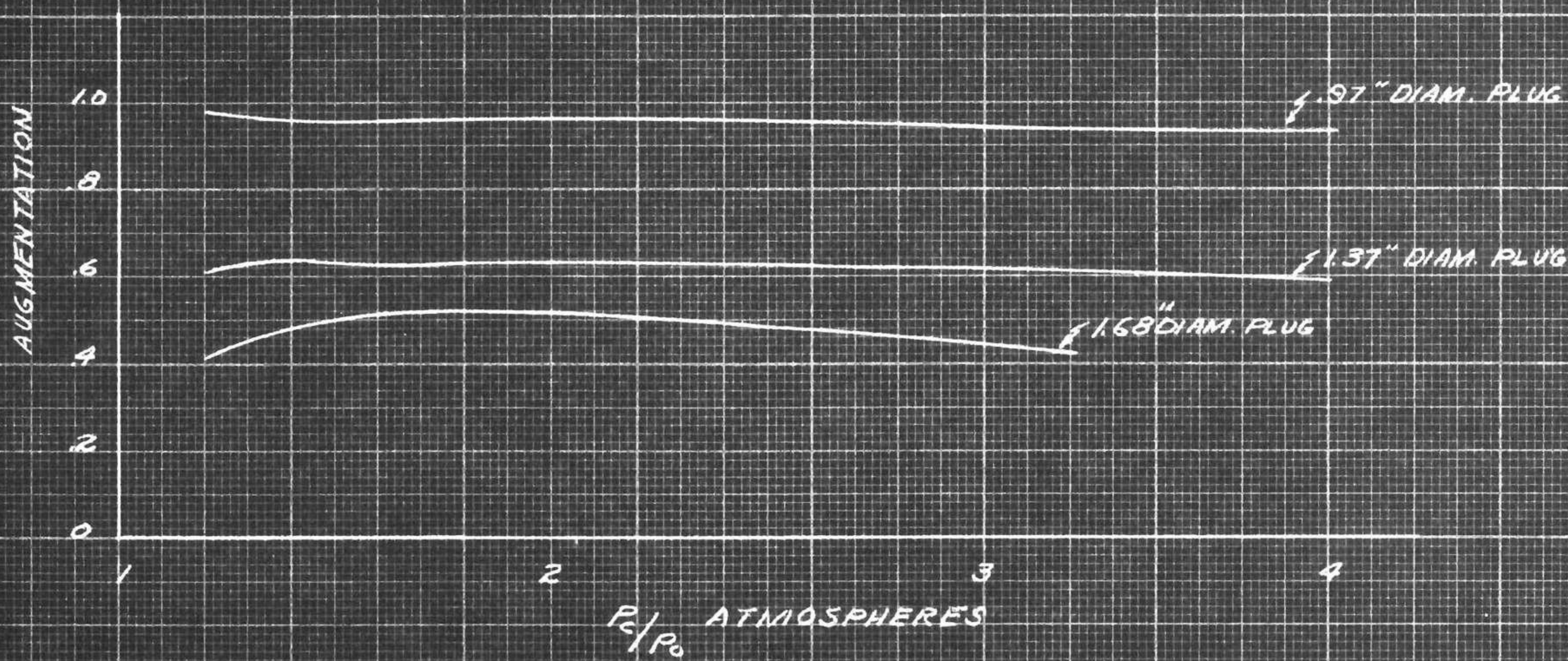

FIG. 13

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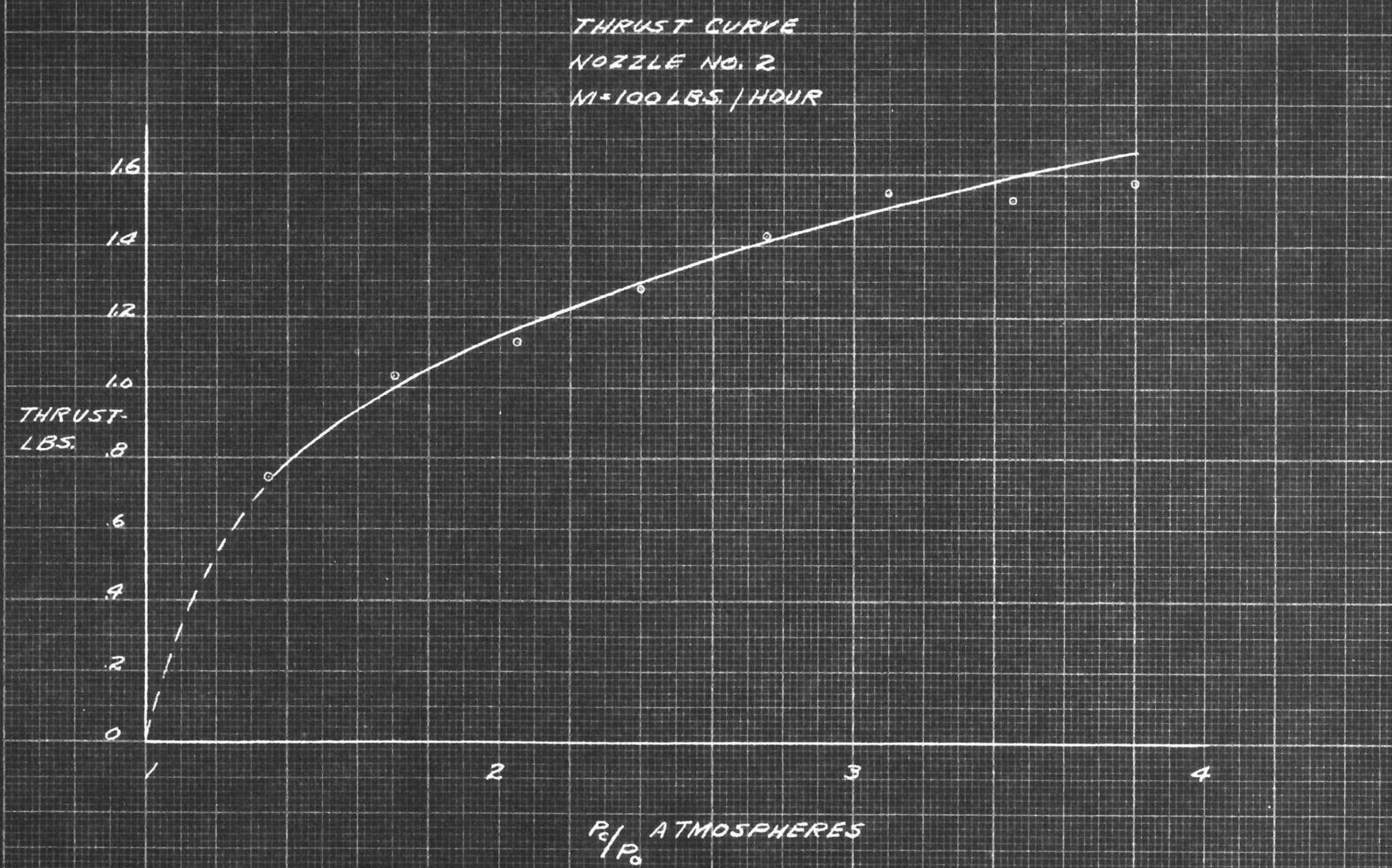

FIG. 14

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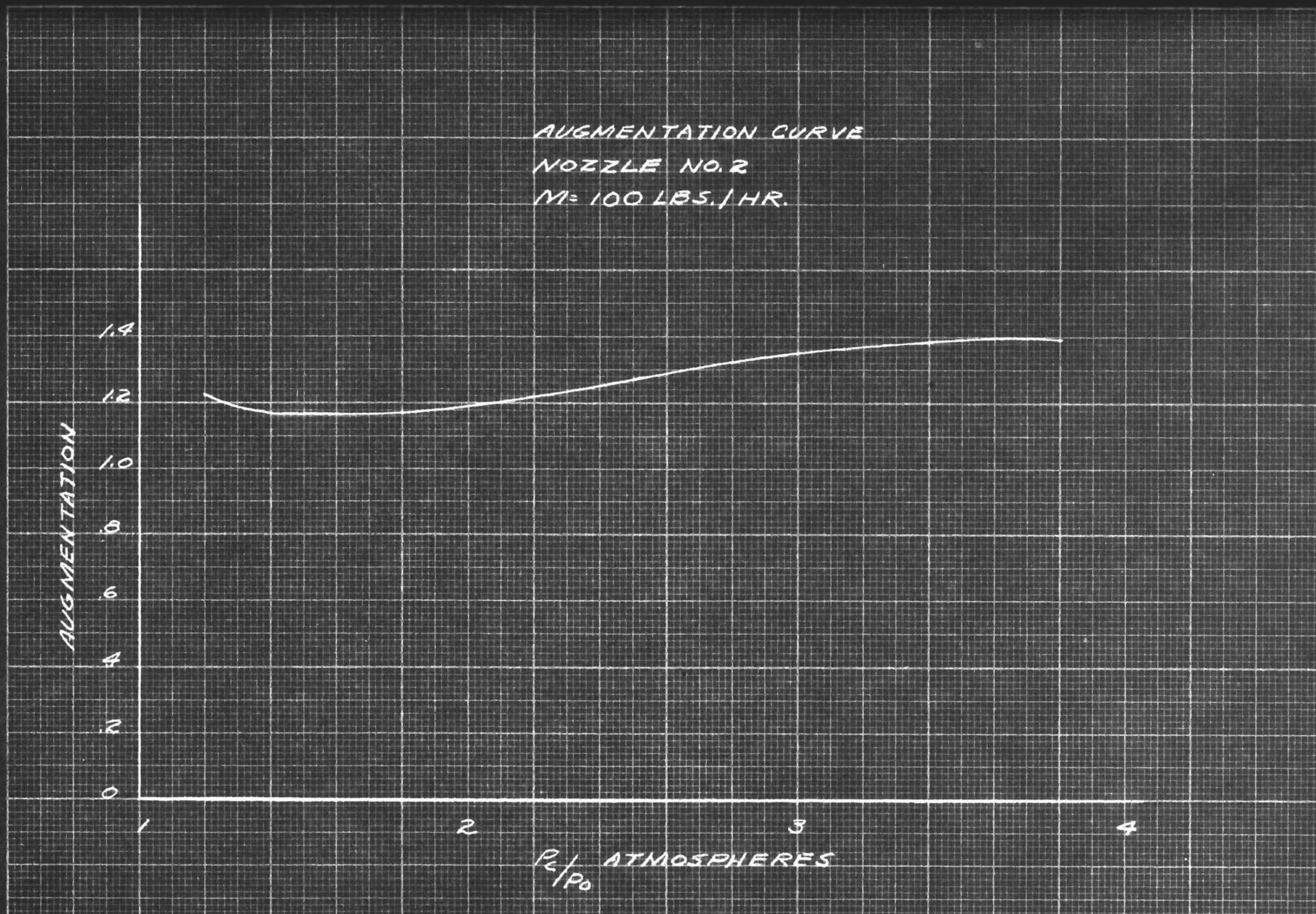
AUGMENTATION CURVE
NOZZLE NO. 2
M= 100 LBS./HR.
AUGMENTATION
1.4
1.2
1.0
.8
.6
.4
.2
0
1
2
3
4
Pc/Po ATMOSPHERES
J.J.H.
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FIG. 15

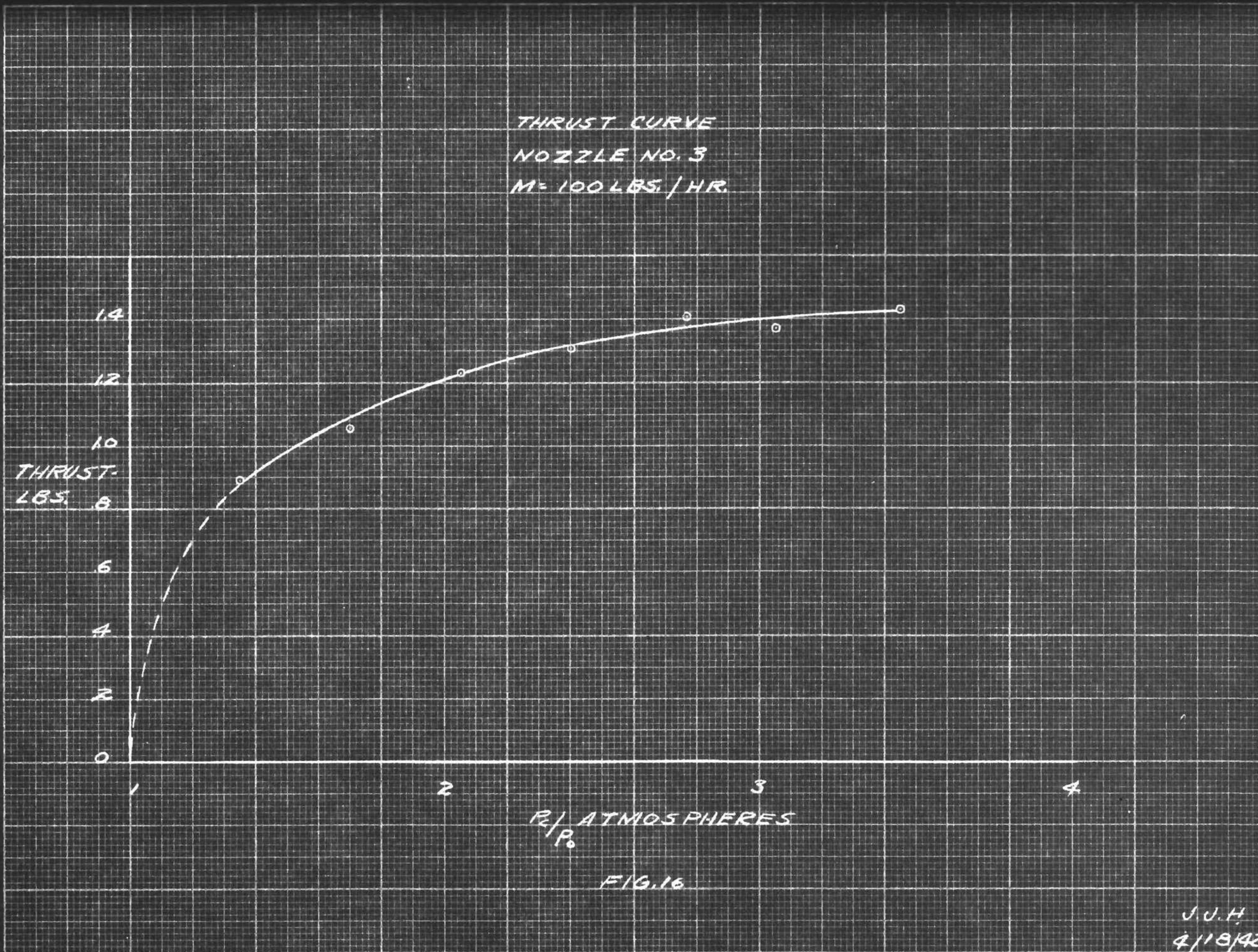
THRUST CURVE
NOZZLE NO. 3
M = 100 LBS./HR.
THRUST-LBS.
1.4
1.2
1.0
.8
.6
.4
.2
0
1
2
3
4
P_2/P_0 ATMOSPHERES
J.U.H.
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FIG. 16

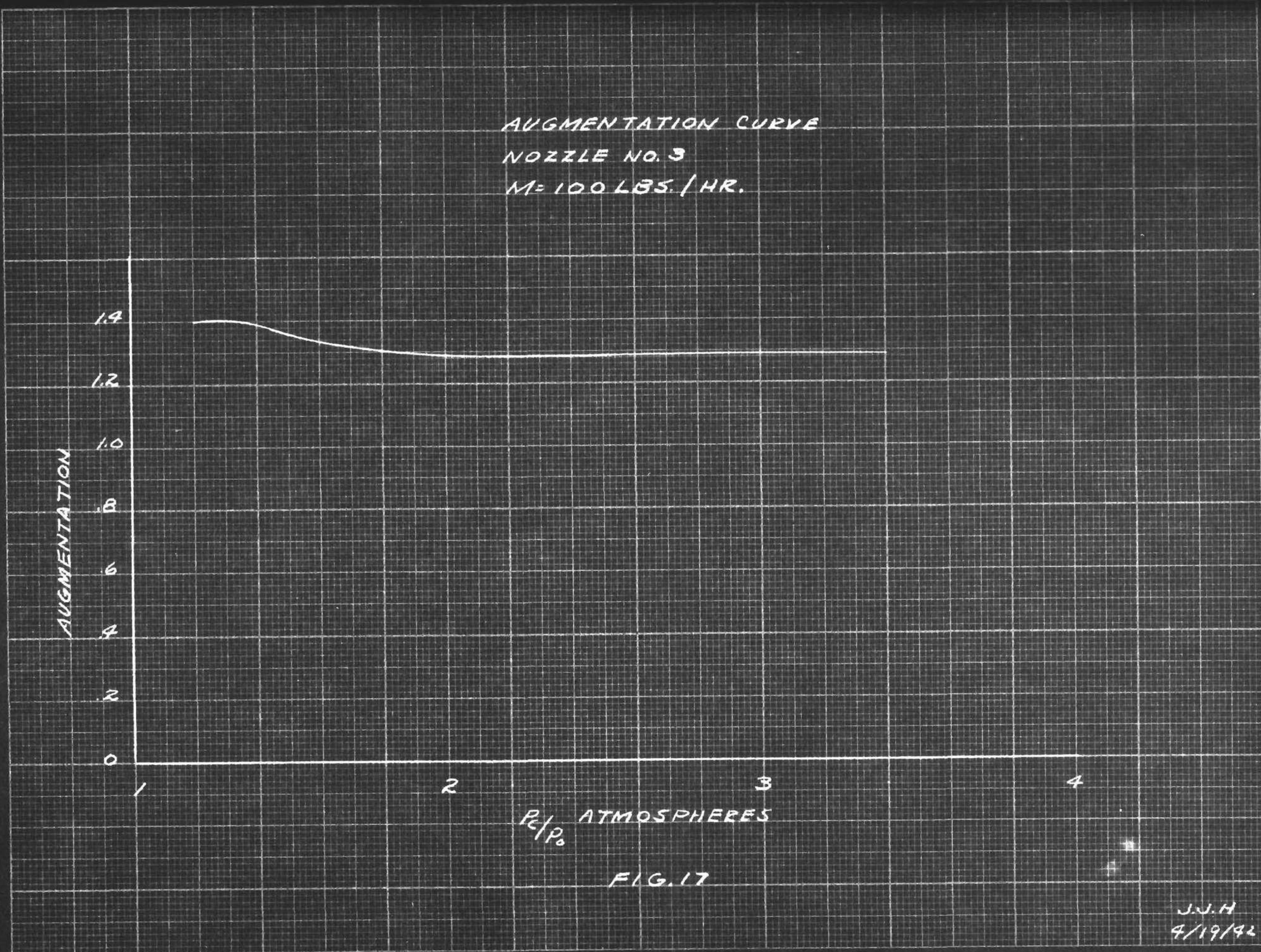
AUGMENTATION CURVE
NOZZLE NO. 3
M= 100 LBS./HR.
AUGMENTATION
1.4
1.2
1.0
.8
.6
.4
.2
0
1
2
3
4
Pc/Po ATMOSPHERES
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FIG. 17

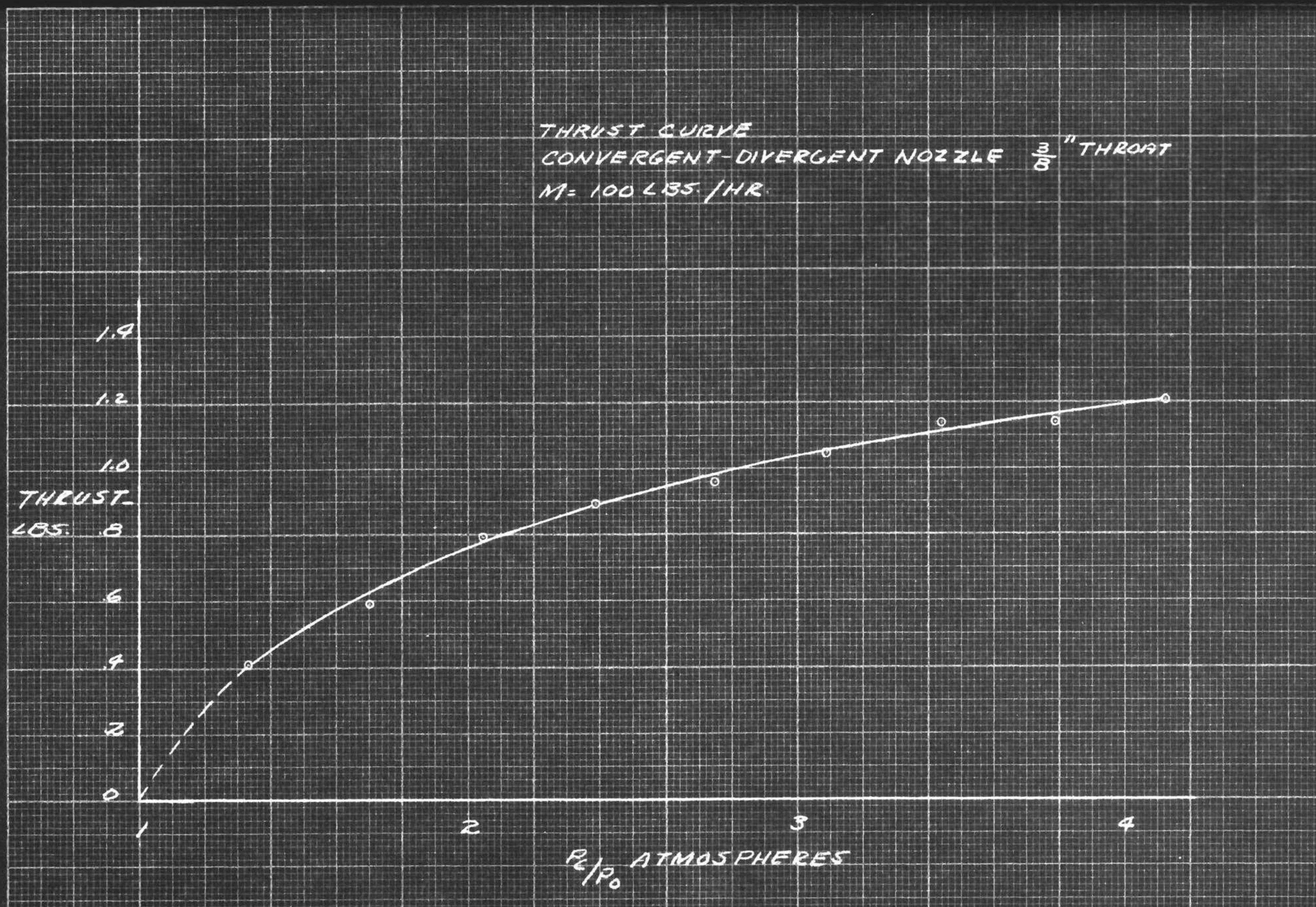
THRUST CURVE
CONVERGENT-DIVERGENT NOZZLE 3/8" THROAT
M= 100 LBS./HR.
1.4
1.2
1.0
THRUST-
LBS.
.8
.6
.4
.2
0
1
2
3
4
Pc/Po ATMOSPHERES
J.J.H
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FIG. 18

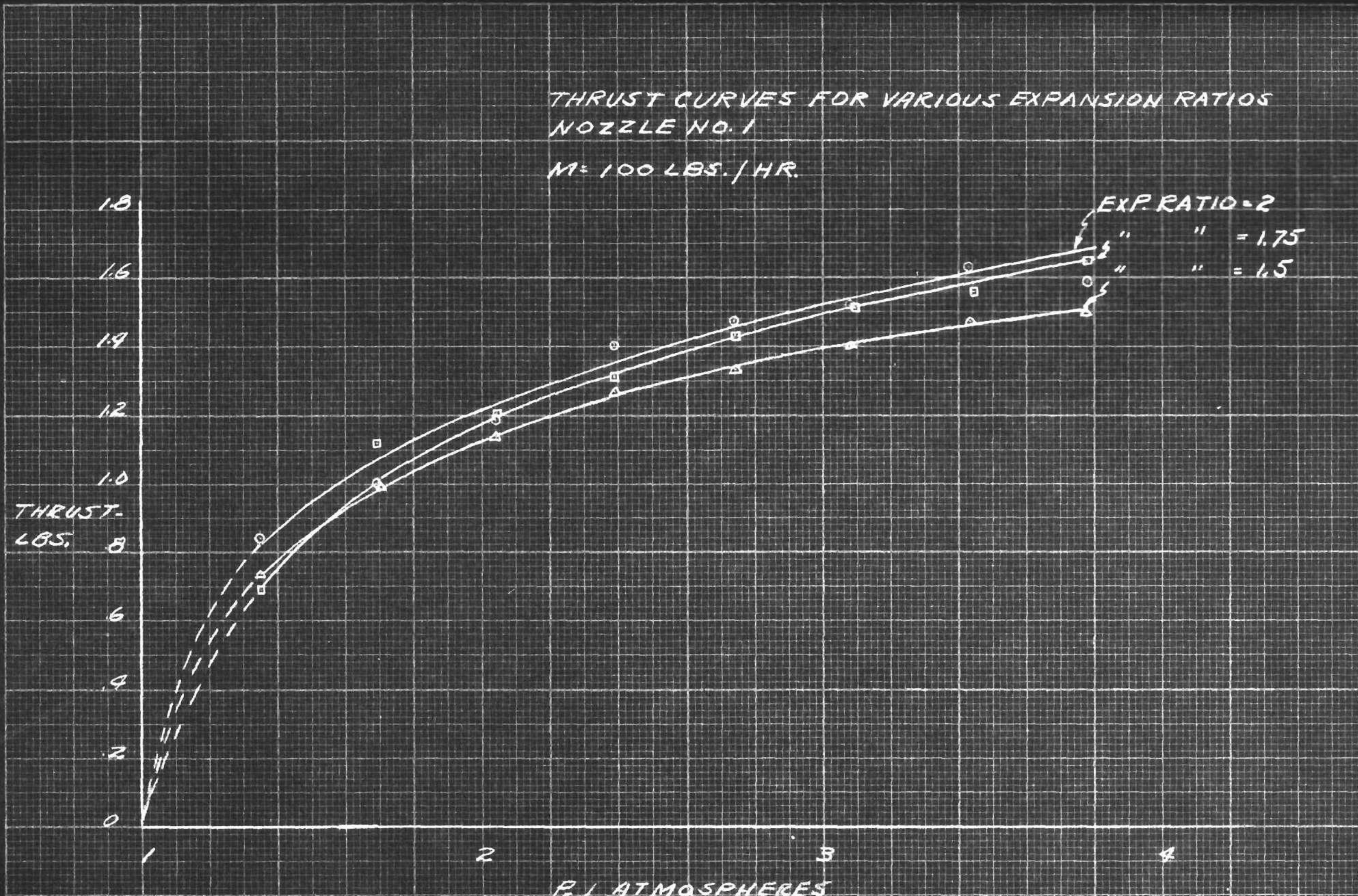
THRUST CURVES FOR VARIOUS EXPANSION RATIOS
NOZZLE NO. 1
M = 100 LBS./HR.
EXP. RATIO = 2
" " = 1.75
" " = 1.5
THRUST-LBS.
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
1
2
3
4
Pc/Po ATMOSPHERES
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FIG. 19

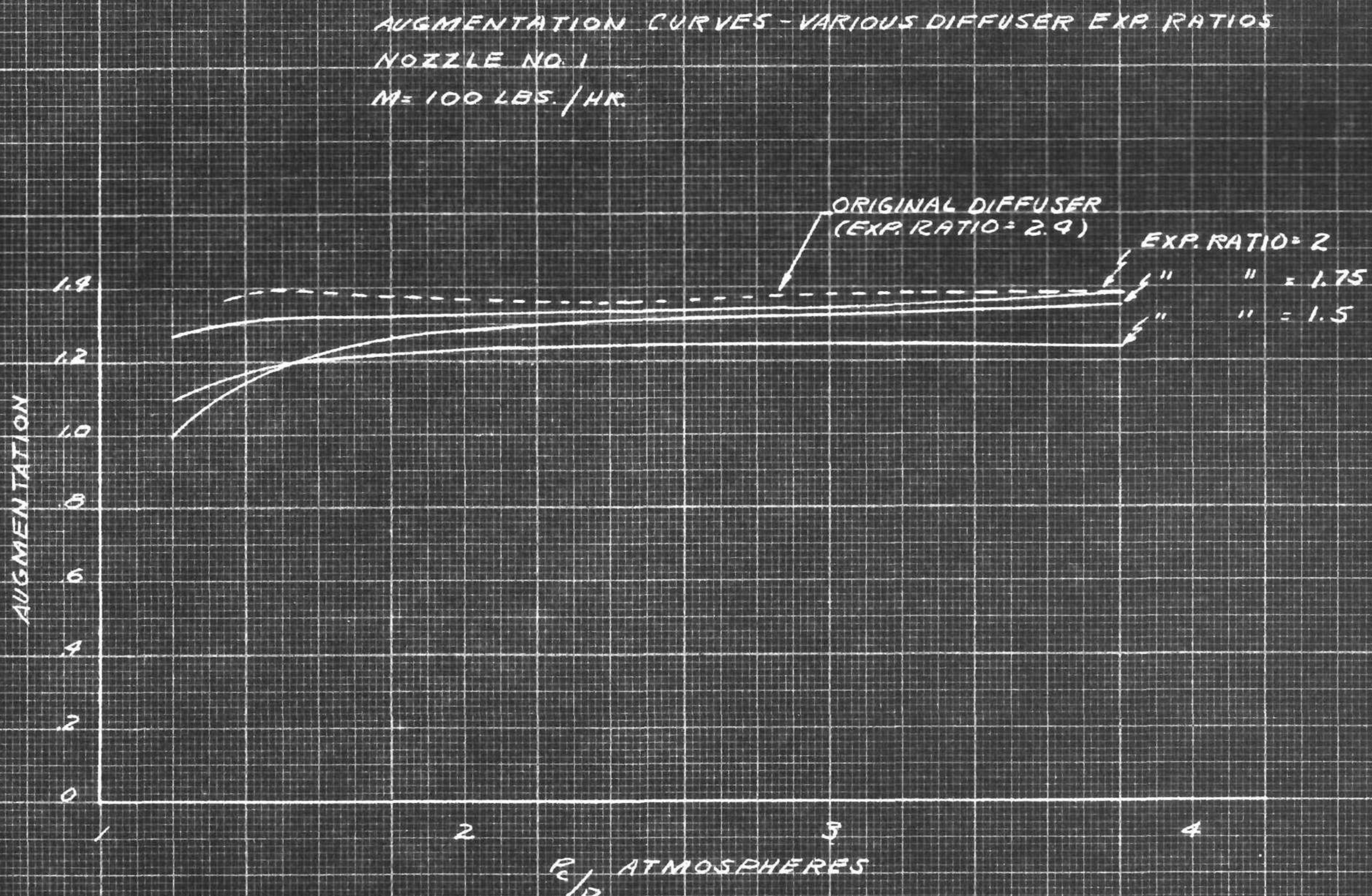

FIG. 20

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