THE EFFECT OF PRESSURE ON PATTERN DISTRIBUTION OF LOW VOLUME SPRAY NOZZLES

By

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PREFACE

The economic and effective use of low volume sprayers for control of crop pests depend upon the uniformity of application of the pesticide. The uniformity of the application will depend to a large extent upon the spray nozzle being used. Low volume spray nozzles can be obtained in various sizes. The angle of spray for these nozzles vary from 65° to 80°. The spacing for these nozzles have been standardized at 20 inches regardless of the spray angle. The author felt that there was a need for comparing the uniformity of the spray pattern of various nozzles at varying pressures.

The author is especially grateful to Professor W. J. Oates for counsel and advice in this study. He is also indebted to Professors James E. Garton and John J. McDow for advice with the various problems involved and especially indebted to Professor E. W. Schroeder, Head of the Department of Agricultural Engineering, for making the facilities of the department available. The author would like to take this opportunity to express his appreciation to the Spraying Systems Company, The Terado Company, and The Monarch Manufacturing Works, Inc. for supplying the nozzles used in the tests.

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I. INTRODUCTION

Spraying has become an accepted practice for defoliation, insect, weed, and plant disease control in many sections of the U. S. The organic chemical industry has developed many new chemicals in the last few years for these purposes. These chemicals are being used every day during the growing season.

The loss in cotton and wheat crops to the farmer has been tremendous. Stiles[20] reported that according to the United States Department of Agriculture last year Oklahoma lost an estimated 41 per cent of its cotton crop to insect damage. The losses were also great in all of the 13 cotton producing states. They amounted to an estimated loss for each state as follows: Virginia, 64%; North Carolina, 56%; Alabama, 35%; South Carolina, 41%; Louisiana, 30%; Georgia, 29%; Arkansas, 29%; Florida, 25%; Mississippi, 25%; Texas, 19%; and Missouri, 7%.

The loss of wheat to greenbug in Western Oklahoma and Kansas has been large. Although final reports on wheat losses to greenbug insect damage are not tabulated, local reports indicate many wheat fields will not be harvested.

In addition to crop losses from insect damage, there is the crop loss resulting from weeds in crops. According to Brown and Carter, the U. S. Chamber of Commerce estimates this loss to be $3,000,000,000 annually.[4] The saving to the farmer for adequate insect and weed control would pay for the cost of using insecticides or herbicides many times.

Since spraying is in its infancy, there are many problems yet to be answered. The engineer has a challenge to meet in designing equipment to do the job properly, because at present the chemist and entomologist are far ahead of the engineer.

There are many variables that enter into the rate of spray application.[12] They are speed of the sprayer, size of orifice, nozzle angle, operating pressure, spacing of the nozzle on the boom, the rate of application of active ingredient desired, spraying height, and wind and climatic conditions. Variations of any one of these items can change the application until effective control is not obtained.

The variable of speed may be held fairly constant on a throttle governed engine. But if spraying is done with a truck mounted sprayer or variable speed governed engine the speed will vary constantly especially in hilly fields. Also, as the speed of the sprayer is increased the rate of application in gallons per acre of spray mix decreases. Therefore, to maintain a uniform application of spray mix the pressure should be increased to obtain a greater discharge from the spray nozzle. The discharge of a nozzle is usually given in tabular form for different nozzles at various speeds and pressures. The following mathematical formula will show the relationship of pressure and speed to the rate of application in gallons per acre.

The formula for the discharge of a sharp edged orifice is:[11]

$$Q = Ca\sqrt{2gh}$$

Where Q is the discharge in cu. ft. per second

C is the product of the coefficient of velocity and the coefficient of contraction.

a is the cross-sectional area of the orifice.

g is the acceleration due to gravity.

h is the head on the orifice in feet.

Therefore, from this formula the discharge is directly proportional to the square root of the pressure. Since the above statement is true, the speed and pressure at which nozzles are rated will be directly proportional to the new speed and pressure in the following manner.

$$\frac{S_2}{S_1} = \sqrt{\frac{P_2}{P_1}}$$

or $$S_2 = S_1 \sqrt{\frac{P_2}{P_1}}$$

The standard rating for nozzles is generally based upon a speed of 4 mph (miles per hour) and a pressure of 30 psi (pounds per square inch).

Using a speed of 4 mph and 30 psi the above formula becomes

$$S_2 = 4 \sqrt{\frac{P_2}{30}}$$

or $$S_2 = \frac{4 \sqrt{P_2}}{5.48}$$

$$S_2 = .73 \sqrt{P_2}$$

or $$P_2 = \frac{S_2^2}{.533}$$

Proper spacing of the nozzles is important to ensure even application. For close growing crops, the spacing must be such that the spray pattern from one nozzle will overlap sufficiently to obtain even application of the insecticide or herbicide. As the spacing is increased or decreased, the spraying height must be increased or decreased to ensure proper overlap of the patterns. The arrangement of the nozzles for row crops will depend upon the size of the crop, and the type of crop being sprayed.

Usually, nozzles with a flat spray are recommended for application of herbicides. They are also recommended for application of insecticides on close growing crops. A common arrangement on the sprayer boom is shown in Figure 1. The spacing for flat spray nozzles has become fairly standardized at 20 inches.

Hollow Cone-nozzles are recommended for application of insecticides for row crops. The manufacturers recommendation for arrangement of these nozzles are shown in Figure 2. They are mounted on drop-pipes from the boom to ensure thorough coverage of the plant with the insecticide. Arrangement of the nozzles will vary with row width and size of plant.

Insecticides can be obtained in one or both of two forms - wettable powder and emulsified concentrate. The wettable powder is formulated by using a carrier that is usually obtained from a source of diatomaceous earths. The purpose of the carrier in a wettable powder is for even coverage of the plant with the insecticide. The wettable powder insecticides are highly abrasive and will cause excessive wear of the spray nozzles. Insecticides in this form are rapidly being replaced by the emulsified concentrates.

The emulsified concentrates are formulated by using a surface active agent in which the concentrated active ingredient is soluble.

The Atlas Powder Company gives the following explanation of surface active agents:[2]

> "Surface active agents are materials which cause variation in the surface forces of a liquid in relation to other liquids, gases or solids. By using these agents, it is possible to intimately mix dissimilar liquids such as oil and water, easily and efficiently. It is also possible to disperse solids or solutions of solids within a liquid or disperse mutually insoluble liquids within another liquid.
>
> Surface active agents performing these functions are known as emulsifiers, dispersing agents or solubilizers.
>
> These same surface phenomena affect the ability of liquids to wet or to spread out in a thin film over surfaces. Surface active agents used for this purpose are called by several names including wetting agents or spreading agents. Other surface active agents are called detergents, antifoaming or foaming agents, penetrants or by other names according to their final functions."

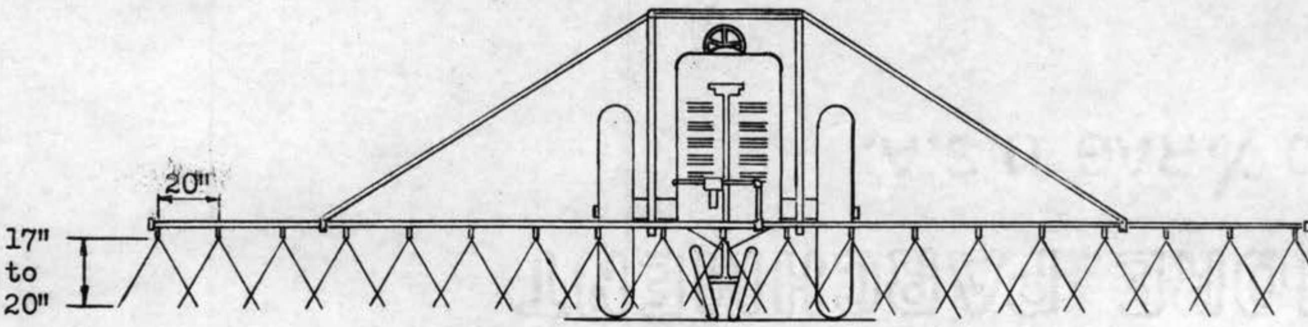

Fig. 1. Manufacturer's recommendation on arrangement of flat spray nozzles.

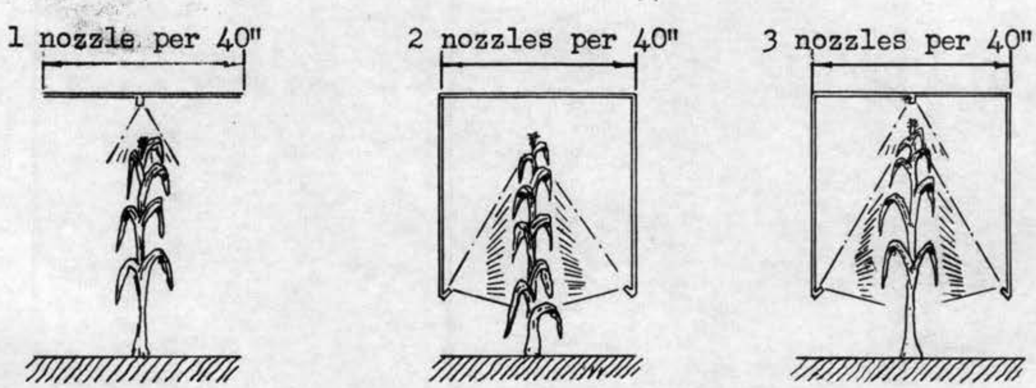

Fig. 2. Manufacturer's recommendation on arrangement of hollow cone nozzles.

The fundamental purpose of an emulsifier is to make oil and water mix thoroughly. The emulsifier that is added will vary for each pesticide. Each formulator does not necessarily use the same emulsifier that his competitor uses.

The emulsifiers used in formulating an emulsified concentrate will change the viscosity and surface tension of the spray mix. The viscosity and surface tension will also be effected by the active ingredient in the spray mix. The discharge of an orifice is directly proportional to the coefficient of discharge. The coefficient of discharge is directly proportional to the Reynolds number, and the Reynolds number is indirectly proportional to the viscosity.[19] But as the Reynolds number becomes larger the less important is the effect of viscosity on discharge. The Reynolds number will become large at high pressures and the effect of viscosity upon discharge will become negligible at these higher pressures. But at lower pressures the effect will be great enough to cause some variation in the discharge of an orifice in comparison to water. Each different spray mix will have a different effect on the discharge of an orifice because of difference in viscosity.

As the surface tension of the spray mix is decreased, the width of the spray pattern will increase at the same pressure. The effect of surface tension will become negligible when the pressure becomes high enough that the resultant force on the spray particle from pressure will be greater than the force due to the surface tension of the liquid.

The rate of application will be affected by the size of the orifice, nozzle spacing, speed, and pressure. The discharge of an orifice varies directly with the cross-sectional area of the nozzles as shown by the mathematical relationships given above. Spray nozzles are rated in gpa (gallons per acre) at a given operating pressure, spraying height, spacing and speed. These are as follows for flat spray nozzles:

Speed	- 4 mph
Operating pressure	- 30 to 40 psi
Spacing	- 20 inches
Spraying height	- 17 to 22 inches.

For hollow cone nozzles these variables are:

Speed	- 4 mph
Operating pressure	- 75 to 80 psi
Spacing	- 1, 2, or 3 nozzles per 40 inch row.

An optimum nozzle angle is set by the manufacturer, but the angle increases with the pressure.

Wind will cause excessive drift of the spray. As the pressure increases the droplet size decreases. Therefore, under windy conditions the pressure should be decreased and the spray mix changed so that the same rate of application of the active ingredient is maintained.

Of the above variables discussed many of the factors in controlling or adjusting them are known. The upper limit of speed of the sprayer is limited by the terrain and by the vehicle being used. Spacing and spraying height are limited by the way the sprayer is built. As for wind effects, the farmer can spray when there is the least wind; and if it is necessary to spray under windy conditions, the pressure can be decreased. The optimum operating pressure is controlled by the insecticide or herbicide being used. Different operating pressures are recommended for applying insecticides or herbicides under different conditions. For example, pressures of 60 to 80 psi are necessary for applying insecticides to cotton late in the season in order that sufficient force is given the spray particle for complete coverage of the cotton plant and low pressures of 30 to 40 psi are sufficient for complete coverage for greenbug control in wheat. But little information is available about the uniformity of the pattern of spray nozzles as the pressure is varied from the manufacturers rated pressure. At present, flat spray nozzles are recommended for weed control and hollow cone nozzles for insect control.

II. OBJECTIVE

The objective of this study was:

1. To find the significant changes that take place in the distribution of the spray pattern of low volume nozzles as pressure is increased.
2. To determine the uniformity of the spray pattern of low volume nozzles at different pressures.
3. To compare the uniformity of the spray pattern of:
    a. Flat spray nozzles with hollow cone nozzles at varying pressures.

    b. Seventy degree flat spray nozzles with 80 degree flat spray nozzles at varying pressures.

    c. Different sizes of low volume nozzles at the same pressures.

III. REVIEW OF LITERATURE

There have been many test procedures for testing spray nozzles. Tests for droplet size, intensity of spray, and several for checking the spray pattern have been devised.

In 1934 French[8] conducted experiments to determine the characteristics of various oil-atomizing sprayers and correlate them with use in leaf hopper control. Studies were made of the droplet size of the oil spray. This was done by using slides that had been coated with lampblack. The slides were quickly exposed to the spray fog. The droplet size was measured by use of a Zeiss Microscope and epi-mirror attachment. With this type of illumination, the impressions made by the oil drops appeared jet black and the portions of the slide light grey. The black impressions were measured with a filar micrometer eyepiece. With this, droplet sizes as small as 5 microns could be measured. This procedure and technique gave fairly good results.

In 1936 French[9] and Crafts did some of the first research work on flat spray nozzles. They found that fan nozzles were not uniform in nature. After experimenting with various shapes and sizes of fan nozzles, they standardized on the ones used in making their tests. These were 60° fan nozzles at 75 psi. After they had made several standard nozzles, tests were conducted to determine the driving force of the spray. The testing apparatus consisted of a sheet of galvanized iron 6 inches wide and 2 ft. long. This sheet of galvanized iron was pivoted in the middle and balanced to hang at an angle of 45°, sloping away from the nozzle. A small container for weights was hung on the lower end of the sheet. When spray was directed horizontally against the sheet, it would spring up toward a horizontal position. Weights were then added to the container hanging from the lower end until the sheet again came to 45^{o}. In these tests some excessively large nozzles that they made were tested. The largest was a 2 1/2 gallon per minute nozzle. This is equivalent to applying 185.5 gallons per acre at 20 inch spacing at 4 mph.

A technique devised by Barger[3], et. al. 1948, is the technique in which the most information about a nozzle can be obtained. The test apparatus consisted of a sheet of 4 ft. by 6 ft. corrugated roofing with 2.7 inch corrugations. This test tray was inclined and at the lower end of the test tray graduated cylinders were mounted. Above the corrugated table was mounted a spray boom that was adjustable in height. In making tests the pump was turned on, then the graduated cylinders were placed under the lower end of the test tray. After sufficient spray mix was obtained, the graduated cylinders were removed quickly and the pump shut off. From this testing procedure, data for any variation of spraying height, nozzle spacing and operating pressure can be obtained.

Shanks and Patterson[21] devised a method of comparing particle size. The equipment consisted of a table mounted on a carriage in such a way that the table could be moved beneath the spray nozzles at varying speeds corresponding to the speed of the sprayer. Paper was fastened on the table and as the table passed beneath the spray nozzle a picture was obtained of the pattern and the droplet size. Ink was used in the spray solution to get the picture of the pattern on the paper.

In 1949 Hudspeth[10] made a comparison of various spray nozzles that are manufactured. He compared the spray patterns by using the techniques devised by Barger and Shanks. Nozzles were tested for general distribution of spray pattern, leakage of the nozzle, ease of assembly and disassembly and numerous other characteristics. All of his tests were conducted at

IV. APPARATUS AND EQUIPMENT

The equipment was essentially the same as used by Barger[3], as shown in Figure 3. The equipment consisted of a corrugated test tray, nozzles selected for testing, pressure gauge and surge tank, 2 horsepower electric motor, 3/4 inch roller pump, adjustable by-pass valves, suction strainer, line strainer, spray boom, container for water, test tube rack and test tubes, graduated cylinder and stop watch.

The corrugated test tray was 3 feet wide by 9 1/2 feet long. The test tray was mounted on a table surface which was inclined at 14 degrees. The distance between the troughs of the corrugations was 1 5/8 inches. A strip of the corrugated material six inches wide, was mounted on the table at the lower end of the test tray to direct the water into the test tubes.

The spray boom was mounted above the test tray. It was supported at each end by a 1 inch pipe that was telescoped in a 1 1/4 inch pipe. Holes were drilled in the supporting pipes at 1 inch intervals to obtain varying heights. Four 1/4 inch pipe couplings were brazed to the spray boom. The pressure gauge and surge tank was fastened to one of the 1/4 inch pipe couplings. The nozzles were mounted on the other 3 pipe couplings. The couplings for mounting the nozzles were mounted on the spray boom 30 inches apart. They were aligned in the same vertical plane and at 90 degrees to the spray boom. One eighth inch holes were drilled in the spray boom so that the liquid could go through the coupling to the nozzle. One quarter inch gas service valves were placed between the nozzle and the spray boom. With this arrangement, a quickly removable test tube rack was not necessary.

The outlet line of the pump was connected to the spray boom. The line strainer and the adjustable by-pass valves were placed in the outlet line. Two by-pass valves were needed to obtain low operating pressures. One of

Fig. 3. Equipment used in testing flat spray nozzle, showing position of nozzles on the spray boom in testing.

the by-pass valves was a 3/4 inch gas service valve and the other one was a 3/4 inch gate valve. A tee was placed in the outlet line and the gas service valve was stubbed into the tee with a return line to the water container from the open side of the gas service valve. The second by-pass valve was placed in the outlet line close to the surge tank and pressure regulator in a similar manner.

A surge tank was needed to obtain accurate pressure readings. A 2 inch pipe, 16 inches long, with caps welded on both ends was used as a surge tank. A hole was drilled and tapped for a 1/4 inch pipe thread in the center of the top plate. The pressure gauge was screwed into this hole. Another hole was drilled and tapped for a 1/4 inch pipe thread near the bottom of the surge tank. The connecting line from the spray boom to the surge tank was screwed in here.

A splashboard of 1 inch by 12 inch lumber was placed around the corrugated test tray as shown in Figure 4 for testing hollow cone nozzles.

The nozzles that were tested are given in Table I.

Fig. 4. Equipment used in testing hollow cone nozzles showing position of nozzle on the spray boom in testing.

TABLE 1

Nozzles Tested

Nozzle	Mfg.	Tradename	Spacing in.	Rated Press. psi	Speed mph	Rated Capacity gpa	Spraying ht. in.	Type	Number Tested
V-5	Terado Co.	Marr	20	30	4	5	18-20	Flat Spray	3
V-10	"	"	20	30	4	10	18-19	" "	3
V-15	"	"	20	30	4	15	18-20	" "	3
8001	Spraying Sys. Co.	Teejet	20	30	4	6.4	17-19	" "	3
80015	"	"	20	30	4	9.6	17-19	" "	3
8002	"	"	20	30	4	20.9	17-19	" "	3
4.6	Monarch Mfg. Works Inc.	-	20	80	4	5.1	-	Hollow Cone	2
9.0	"	-	20	80	4	10.1	-	" "	2
18.0	"	-	20	80	4	20.1	-	" "	2
6	Spraying Sys. Co.	Teejet	40	75	4	5	-	" "	3
12	"	"	40	75	4	10	-	" "	3
18	"	"	40	75	4	15	-	" "	3

V. METHOD OF OBTAINING DATA

The method of obtaining data was planned so that a "picture" could be obtained of the pattern distribution of the flat spray and hollow cone nozzles at 15, 30, 45, 60, 75, and 90 psi.

A. Preliminary Investigations

Preliminary investigations were made to find the best method of obtaining data so that there would be as much accuracy as possible in determining the variations in the pattern distribution at different pressures. These investigations showed the following:

1. Significant difference between data obtained when the test tray was dry and when it was wet.
2. No difference between data obtained for one nozzle when opperating 1, 2, or 3 nozzles at the same time.
3. Significant difference between data obtained when the same nozzle was operated at different positions on the spray boom.
4. No difference in the shape of the pattern above 90 psi.

Therefore, before operating each nozzle it was necessary to wet the test tray. At low pressures, there was no interference between the patterns of adjacent nozzles; so, three nozzles were operated at one time. When the pattern of adjacent nozzles interferred with each other, nozzle number 1 and number 2 were operated at the same time and then nozzle number 3 was operated. The number of the nozzle corresponded to its position on the spray boom as shown in Figure 3 and 4. Each nozzle was kept in the same position for all operating pressures.

B. Adjusting Operating Pressure

The loss in head that results from the flow of a liquid through a closed conduit was accounted for by adjusting the operating pressures so that the final pressure, after the nozzle was in operation, would be the desired pressure.

C. The Effect of Temperature

There was no means provided to control the temperature of the water used in the tests, but the temperature was checked periodically to see if any change occurred. If the water became warmer, the water container was filled with fresh water. The same source of water was always used.

D. Length of Run

All the nozzles were originally intended to be run 1 1/2 minutes at each pressure. This was possible on the smaller nozzles at all operating pressures; but the length of time for operating the larger nozzles, at higher pressures, was shortened to conform to the size of the test tubes used.

E. Spraying Height

The spraying height recommended for flat spray Terado nozzles is 17 to 19 inches for 20 inch spacing. The height for Teejet nozzles is 18 to 20 inches for 20 inch spacing. Since 19 inches is a common spraying height for both of these nozzles, that was the height used throughout the study. The term spraying height is not applicable to hollow cone nozzles because they are used in row crop spraying and are not used in broadcast spraying. In order to have the same basis for comparison with flat spray nozzles, the same spraying height of 19 inches was maintained for testing hollow cone nozzles.

F. Alignment of Nozzles

All flat spray nozzles produce an elliptical spray as shown in Figure 5 - B. Therefore, to obtain uniform coverage, slight overlapping of adjacent sprays is necessary. In field operations, each nozzle is rotated so that the spray pattern is turned slightly from a right angle to the direction of travel to avoid interference of adjacent patterns. In this study all flat spray nozzles were positioned so that the long axis of the ellipse formed by the spray was at right angles to the corrugations of the test tray. They were easily positioned by means of the grooves through the center of the nozzles.

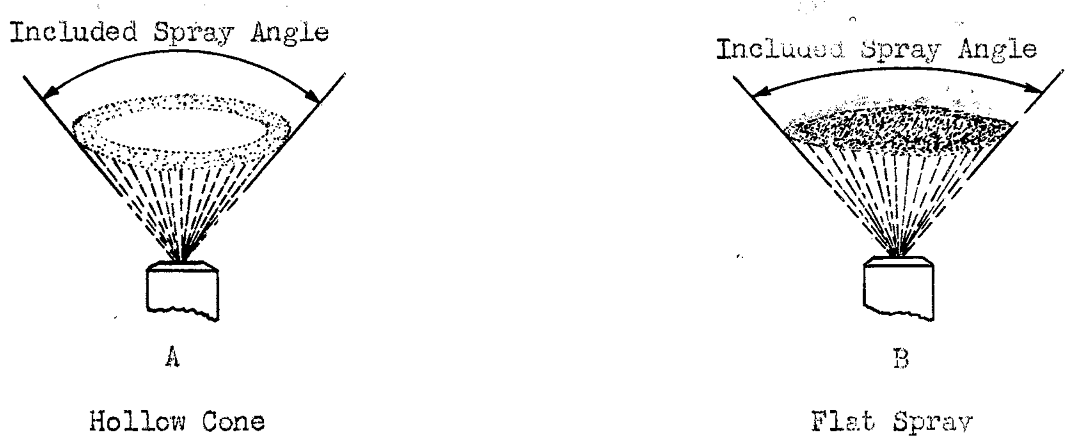

Figure 5. Showing the shape of flat spray and hollow cone sprays.

The hollow cone nozzle did not need to be positioned. These nozzles would show the same pattern distribution no matter which way they were turned about their vertical axis. A perspective of the hollow cone spray is shown in Figure 5 - A.

G. Technique Used

The technique and equipment used in taking data was the same for flat spray and hollow cone nozzles except for the splashboard used in testing hollow cone nozzles. Because of the shape of the hollow cone spray pattern, the spray splashed off the test tray.

The pump was turned on and the pressure regulated to the desired operating pressure. The small valve between the spray boom and the nozzle was opened and at the same time the stop watch started. After the nozzle was operated the proper length of time, the valve was closed and the time was recorded. The center of each nozzle position was previously marked on the test tube rack. In recording data, the amount of water in the center test tube was measured first. Subsequent readings were made from center to left and from center to right. All measurements of liquid were made with a graduated cylinder that was calibrated in cubic centimeters.

Table 1 shows the number of nozzles tested, of each size of nozzle that was selected for testing, from each manufacturer. There were 3 observations made of the pattern distribution of each nozzle tested at each operating pressure.

Figure 6 shows a typical pattern distribution of a flat spray nozzle. Figure 7 shows a typical pattern distribution of a hollow cone nozzle.

Fig. 6. Showing a typical pattern distribution of a flat spray nozzle.

VI. ANALYSIS OF DATA

The method of analyzing the original data for reporting is given in Table 2. Each column represents the observed values for that position in the spray pattern. The columns were totalled and divided by the total number of readings for each nozzle. The average values, as shown, were the values reported.

A. Significant Changes in Pattern Distribution as the Pressure is Increased.

To show the changes that take place in the pattern distribution as pressure is increased, the reported values were plotted for each pressure. The profile of each nozzle at each pressure is shown in Figures 8 through 19.

1. Changes in the Included Spray Angle.

The included spray angle of a nozzle increases, within limits, as the pressure increases. The values of the included spray angle for each nozzle at all test pressures are given in Tables 3 through 6. These values were calculated by the trigonometric relationship of the angle. The spraying height and width of pattern were known. Therefore,

$$\tan 1/2 \text{ included spray angle} = \frac{\text{spraying height}}{1/2 \text{ pattern width}}.$$

2. Changes in Discharge and the Coefficient of Discharge.

The total average discharge was obtained at each pressure by adding the values reported, across the spray pattern. These values are given in Tables 7 through 10.

Also, as the pressure increased, the coefficient of discharge increased. The product of the coefficient of discharge and the cross-sectional area are given in Tables 11 through 14. The values entered in these tables were reported as a product, rather than a true value of the coefficient of discharge, because for each nozzle the cross-sectional area was constant. The values

TABLE 2

Showing the original data of the V-5 Terado nozzle at 15 psi and $1\frac{1}{2}$ minute run. The average values given are the data reported.

No. 1 Nozzle															
		2	7	16	19	22	38	66	46	26	17	17	11	3	
		2	8	18	18	23	39	64	48	28	18	17	8	4	
		2	7	13	19	25	40	60	47	29	20	14	11	5	2
No. 2 Nozzle															
			4	18	21	23	33	55	48	28	20	19	13	3	
			6	18	20	24	32	53	52	32	22	18	16	6	
		2	7	13	18	26	35	51	50	34	25	17	11	6	2
No. 3 Nozzle															
	1	4	9	15	20	28	47	55	36	23	15	10	5	1	
		3	8	14	19	28	45	55	37	23	15	8	3		
		2	8	15	21	31	48	55	36	24	16	10	2		
Total	1	17	66	140	175	230	357	514	400	247	168	130	80	28	4
Average	0.1	1.9	7.1	15.6	19.4	25.6	39.7	57.1	44.4	27.4	18.7	14.4	8.9	3.1	0.4

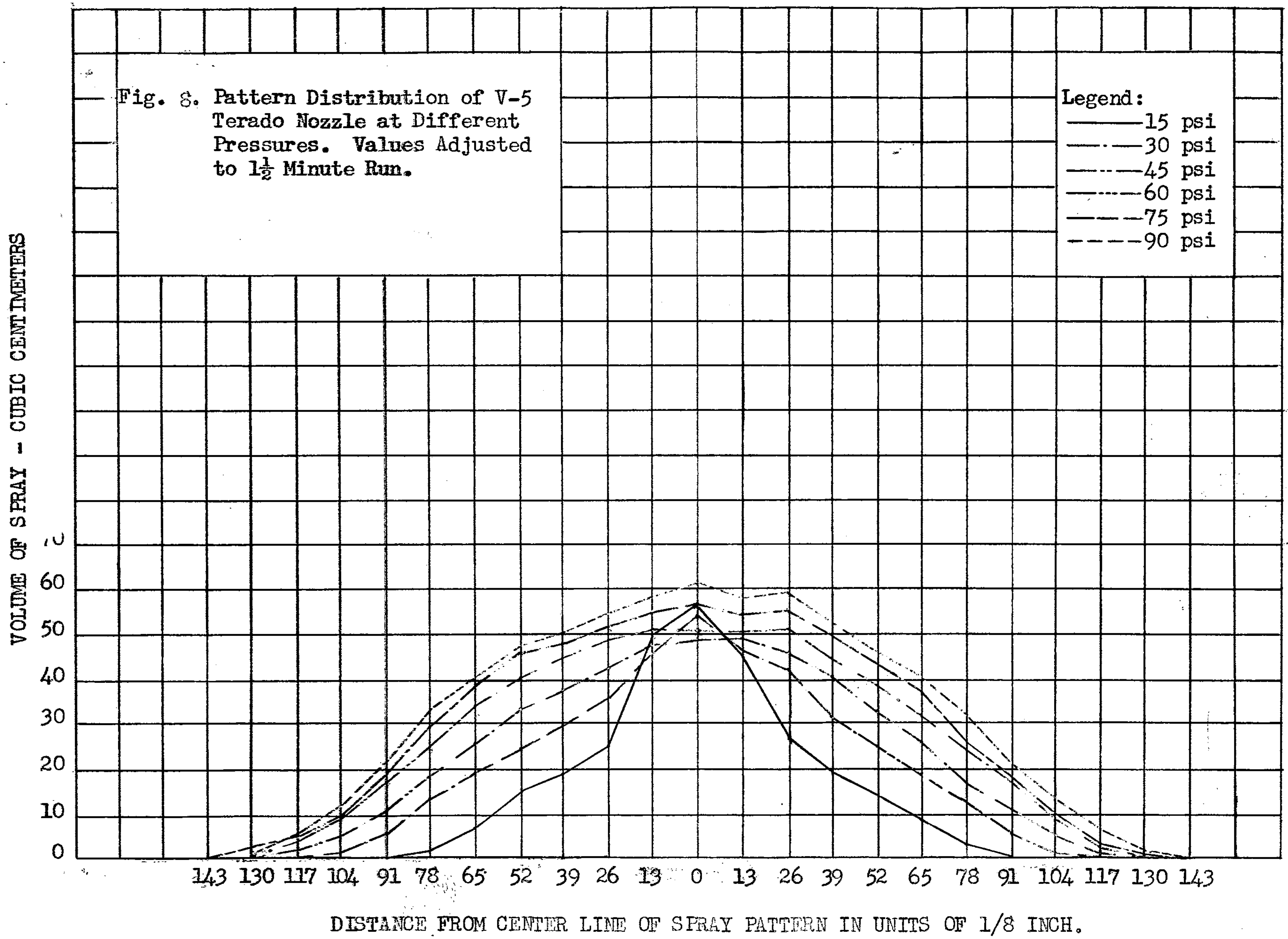

Fig. 8. Pattern Distribution of V-5 Terado Nozzle at Different Pressures. Values Adjusted to $1\frac{1}{2}$ Minute Run.

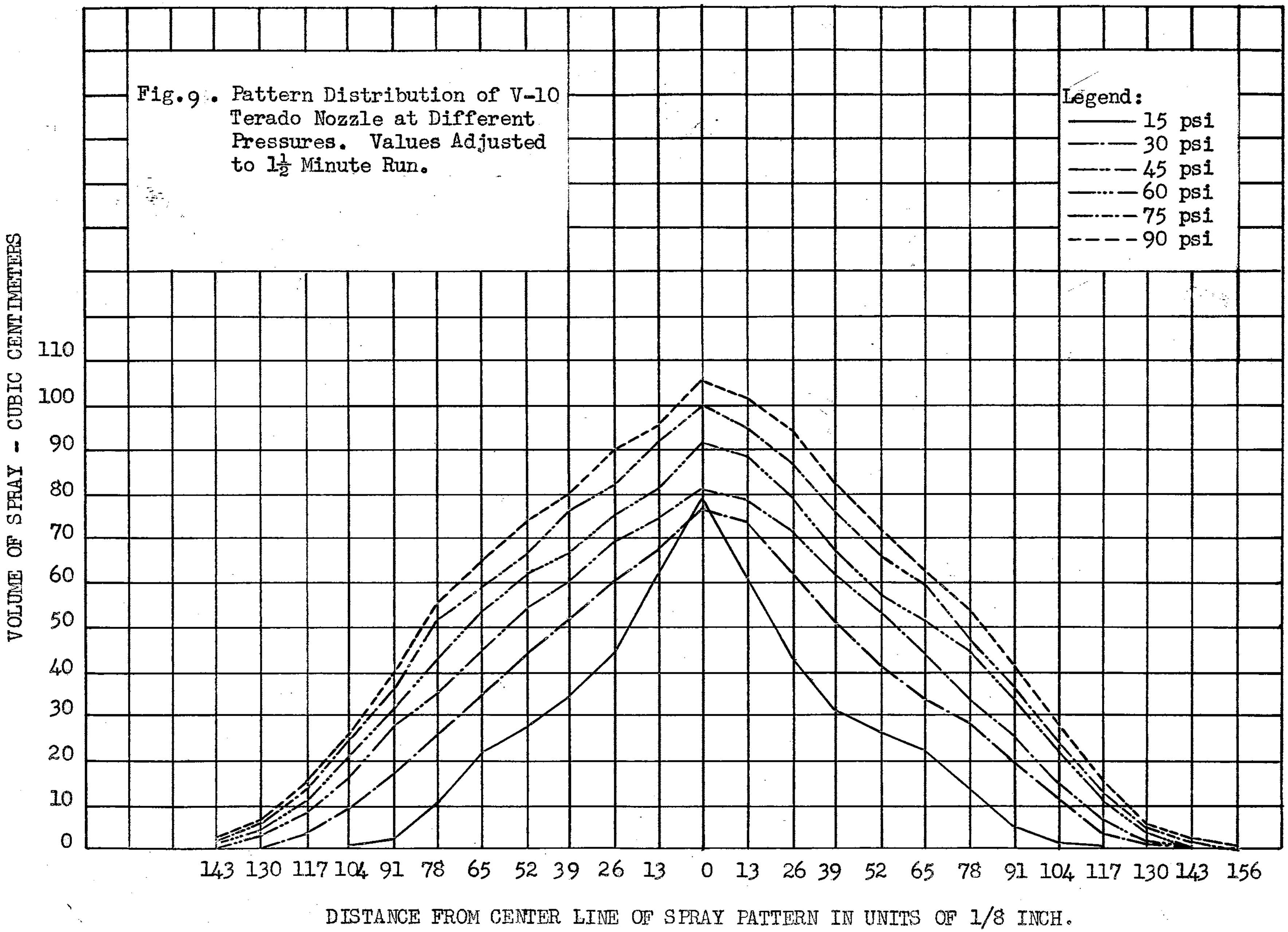
Fig. 9. Pattern Distribution of V-10 Terado Nozzle at Different Pressures. Values Adjusted to $1\frac{1}{2}$ Minute Run.
Legend:
15 psi
30 psi
45 psi
60 psi
75 psi
90 psi
VOLUME OF SPRAY - CUBIC CENTIMETERS
110
100
90
80
70
60
50
40
30
20
10
0
143 130 117 104 91 78 65 52 39 26 13 0 13 26 39 52 65 78 91 104 117 130 143 156
DISTANCE FROM CENTER LINE OF SPRAY PATTERN IN UNITS OF 1/8 INCH.

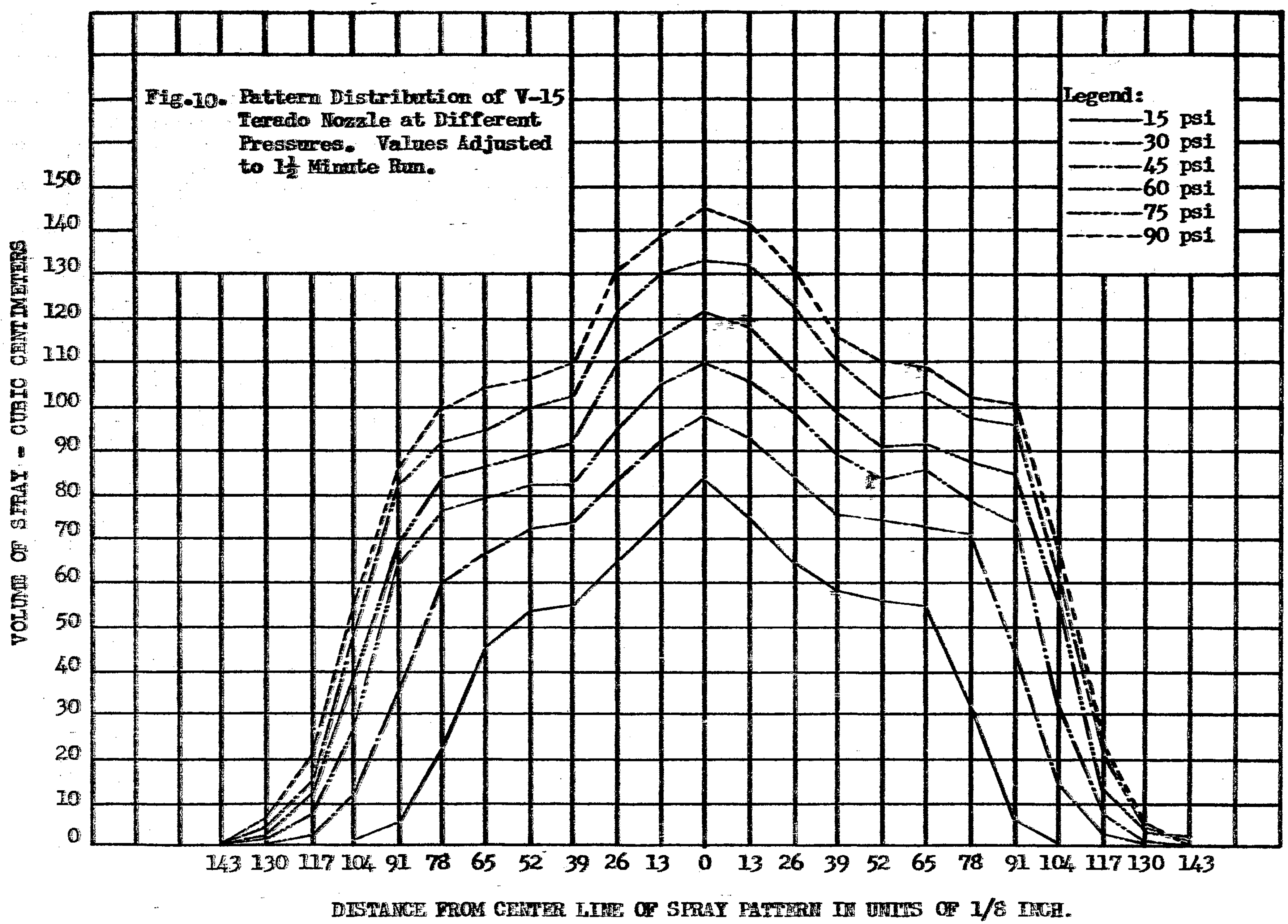

Fig. 10. Pattern Distribution of V-15 Terado Nozzle at Different Pressures. Values Adjusted to 1½ Minute Run.

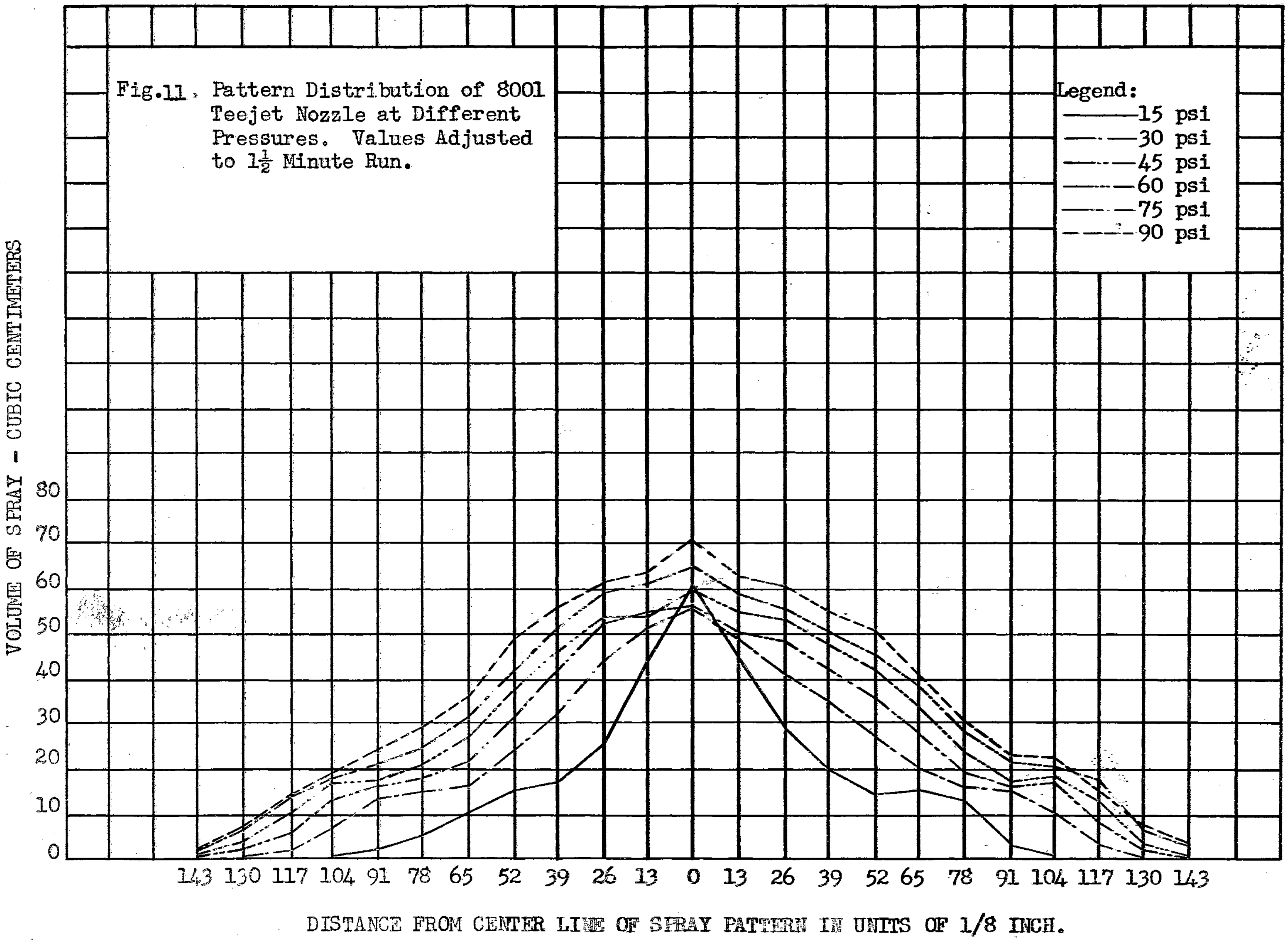

Fig.11. Pattern Distribution of 8001 Teejet Nozzle at Different Pressures. Values Adjusted to 1½ Minute Run.

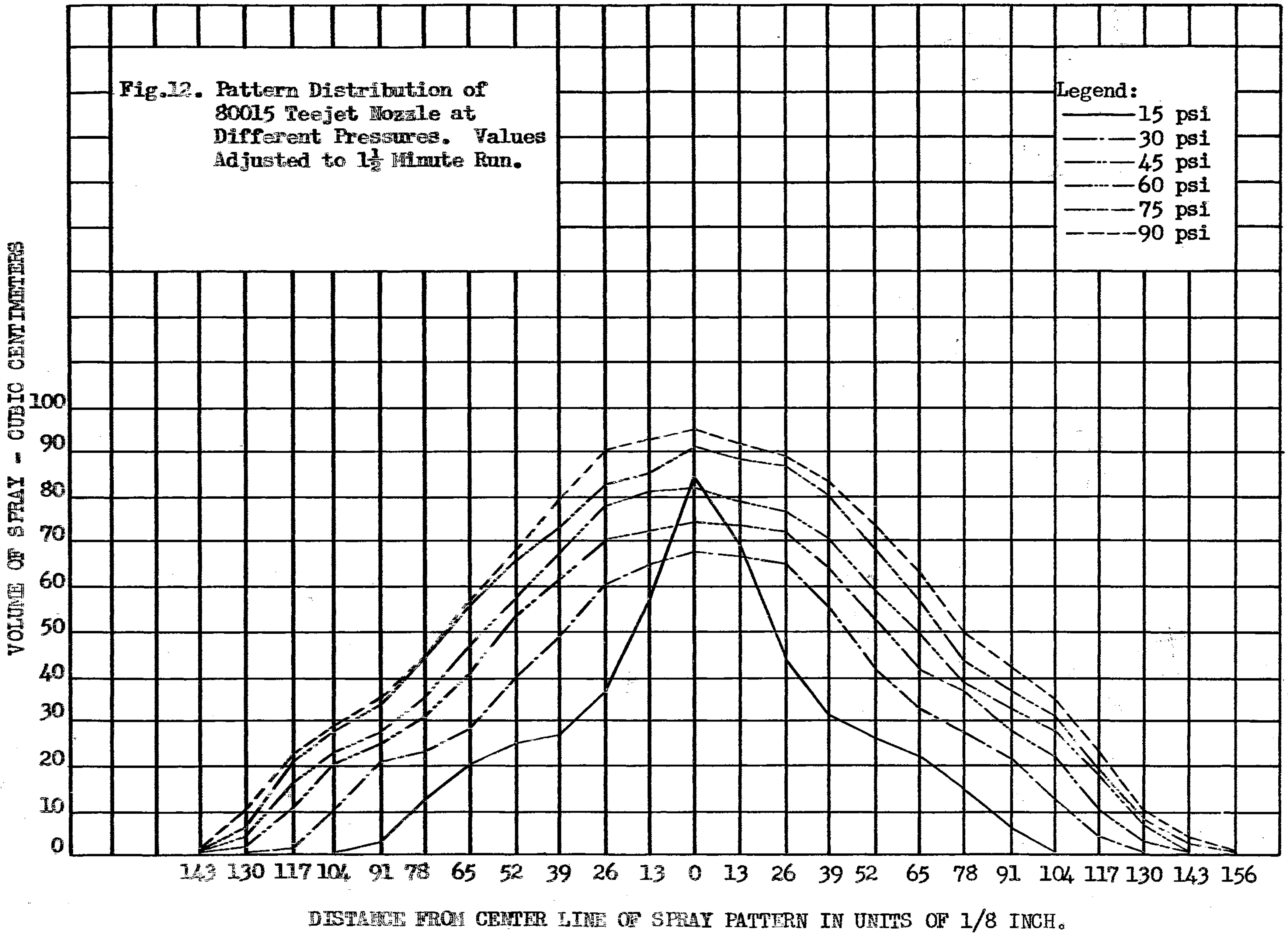

Fig. 12. Pattern Distribution of 80015 Teejet Nozzle at Different Pressures. Values Adjusted to $1\frac{1}{2}$ Minute Run.

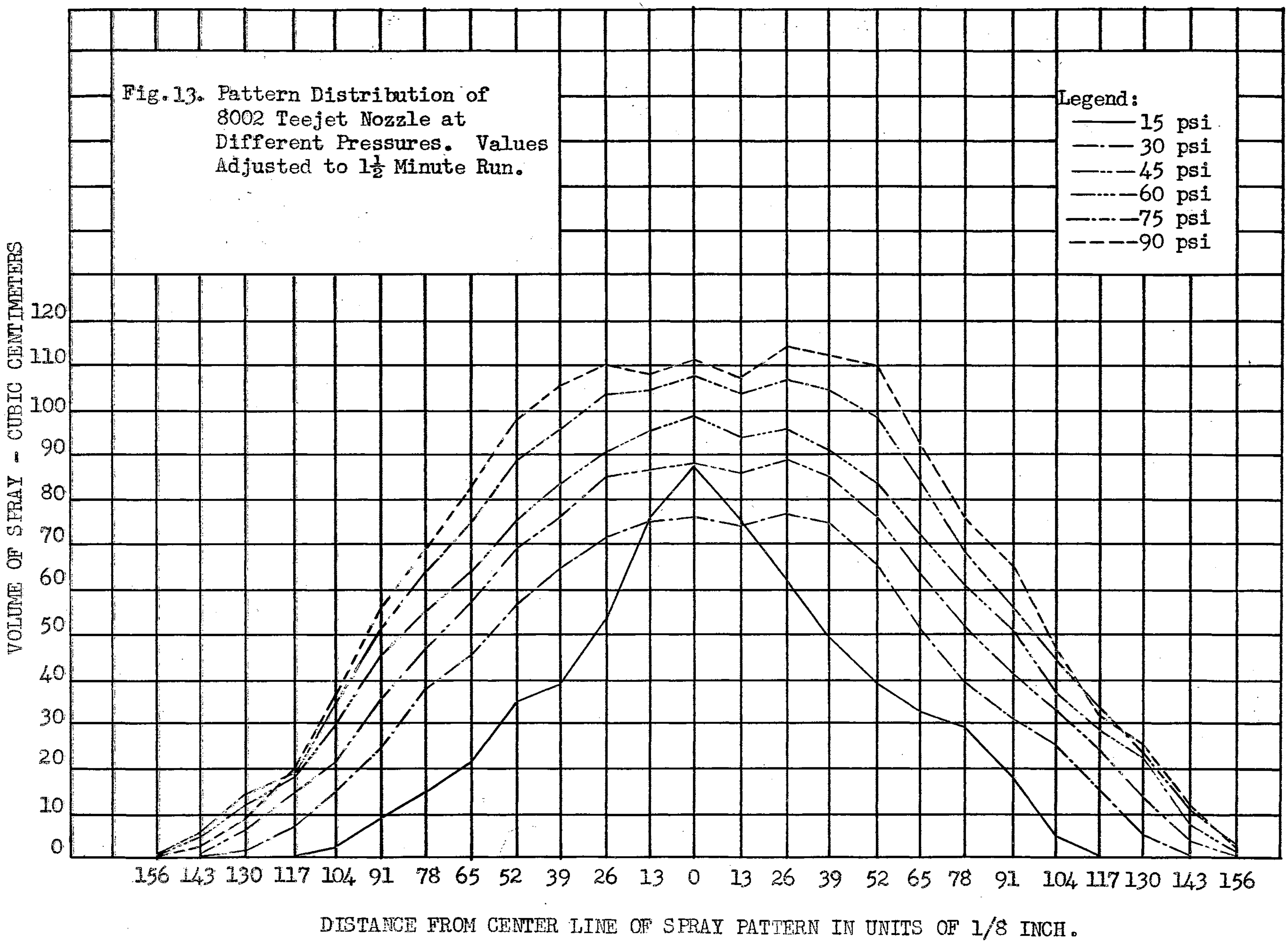

Fig. 13. Pattern Distribution of 8002 Teejet Nozzle at Different Pressures. Values Adjusted to 1½ Minute Run.

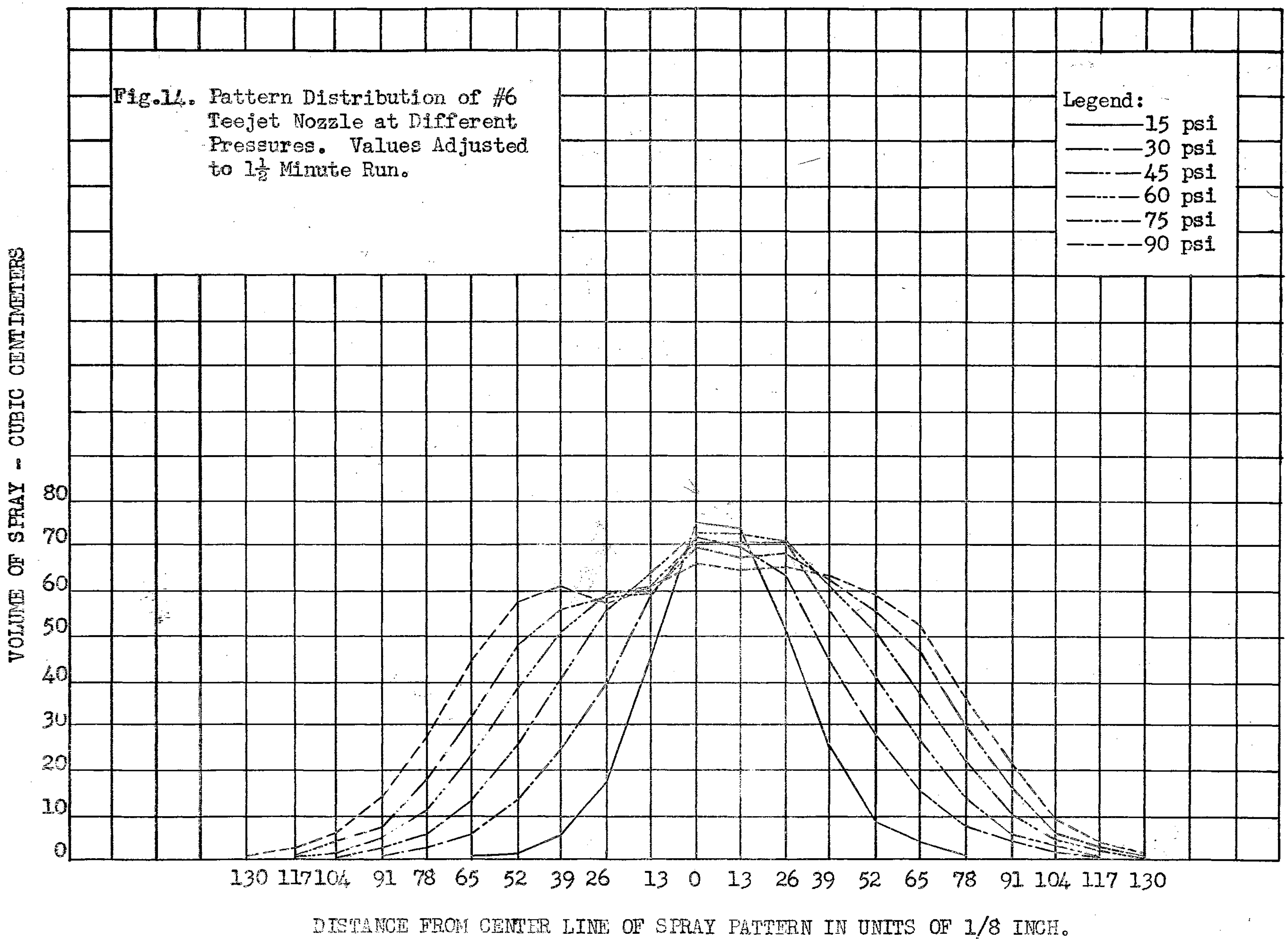

Fig.14. Pattern Distribution of #6 Teejet Nozzle at Different Pressures. Values Adjusted to $1\frac{1}{2}$ Minute Run.

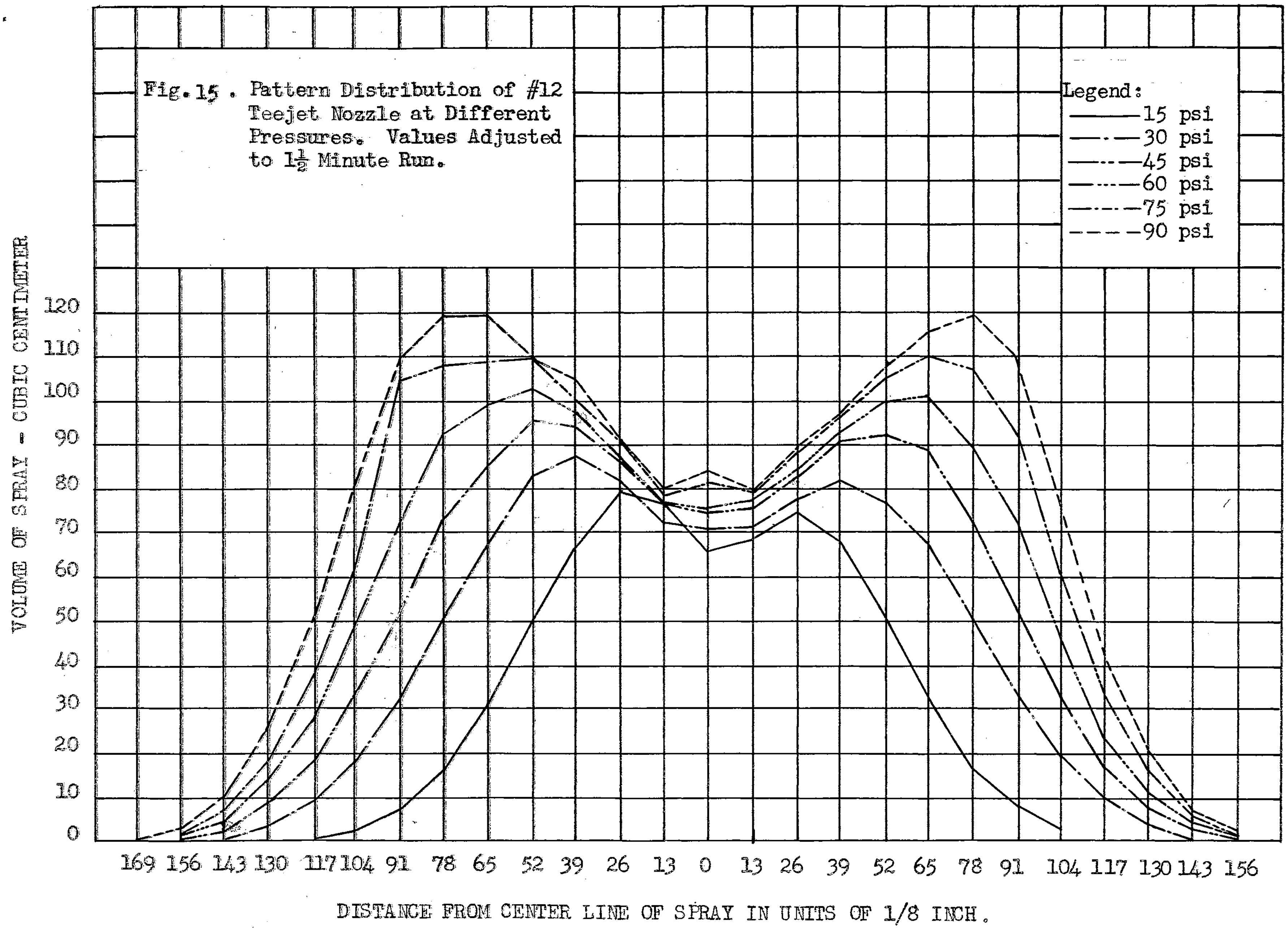

Fig. 15 . Pattern Distribution of #12 Teejet Nozzle at Different Pressures. Values Adjusted to 1½ Minute Run.
Legend:
15 psi
30 psi
45 psi
60 psi
75 psi
90 psi
VOLUME OF SPRAY - CUBIC CENTIMETER
120
110
100
90
80
70
60
50
40
30
20
10
0
169 156 143 130 117 104 91 78 65 52 39 26 13 0 13 26 39 52 65 78 91 104 117 130 143 156
DISTANCE FROM CENTER LINE OF SPRAY IN UNITS OF 1/8 INCH.

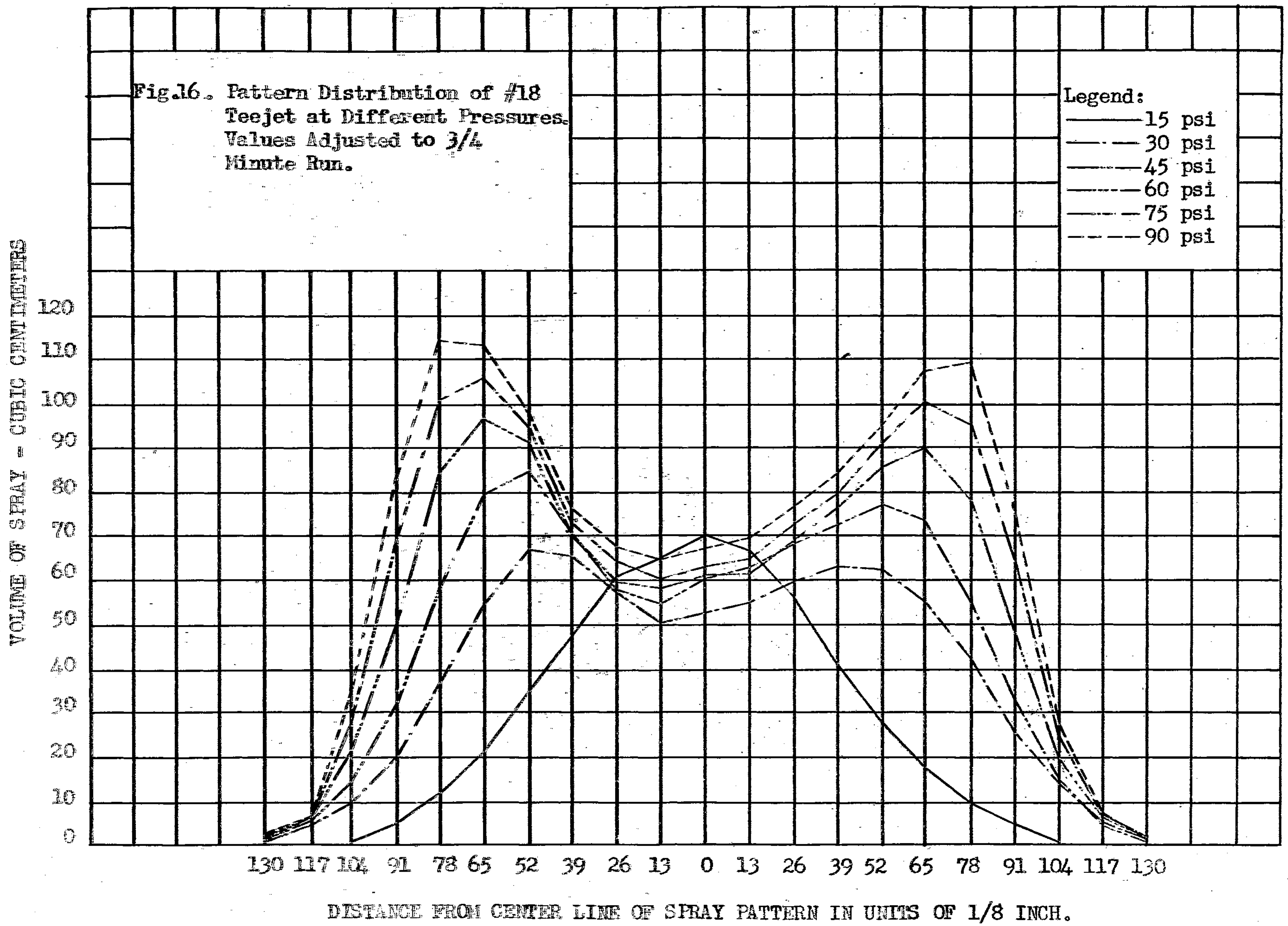
Fig.16. Pattern Distribution of #18 Teejet at Different Pressures. Values Adjusted to 3/4 Minute Run.
Legend:
15 psi
30 psi
45 psi
60 psi
75 psi
90 psi
VOLUME OF SPRAY - CUBIC CENTIMETERS
120
110
100
90
80
70
60
50
40
30
20
10
0
130 117 104 91 78 65 52 39 26 13 0 13 26 39 52 65 78 91 104 117 130
DISTANCE FROM CENTER LINE OF SPRAY PATTERN IN UNITS OF 1/8 INCH.

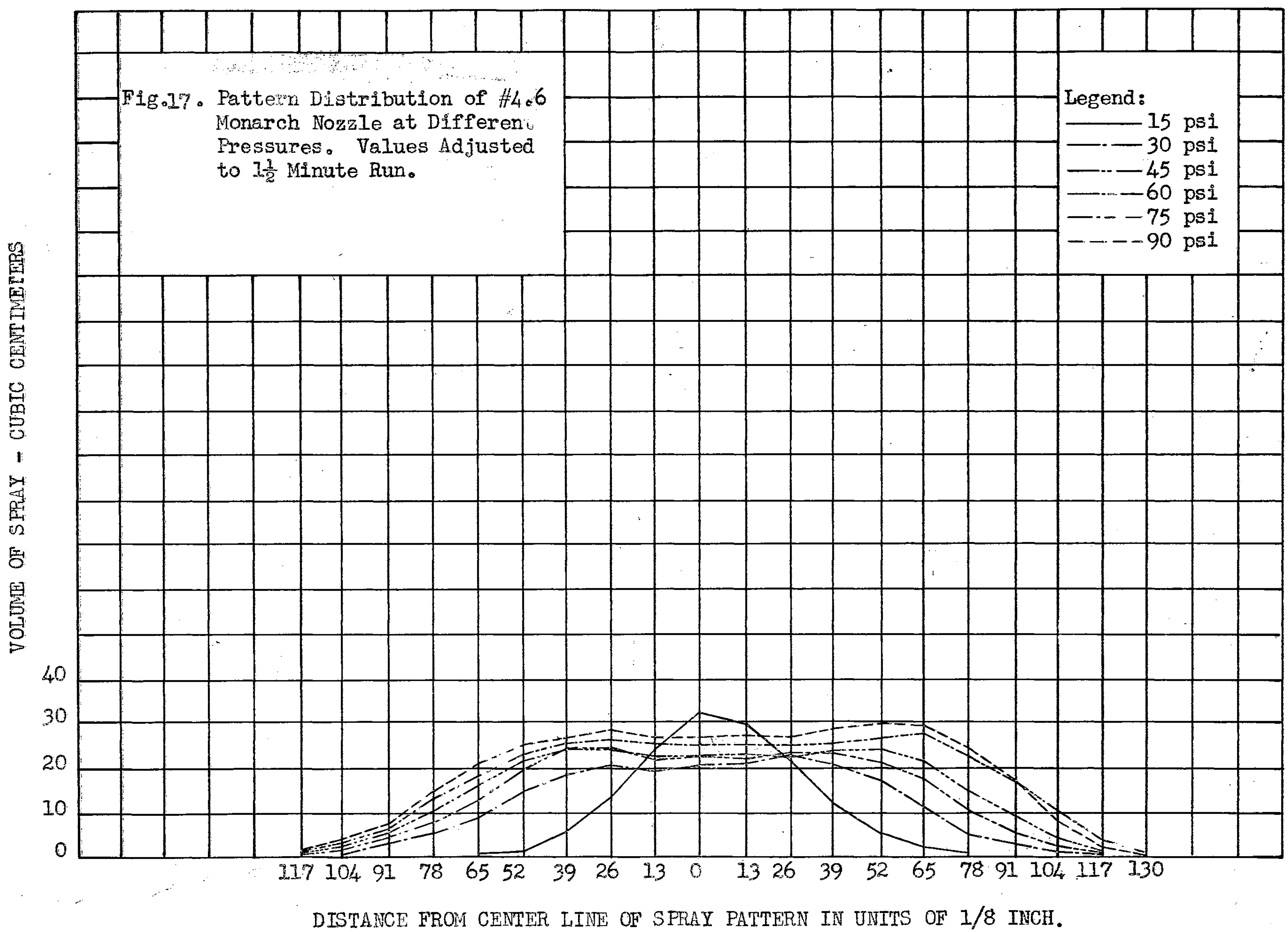

Fig. 17. Pattern Distribution of #4.6 Monarch Nozzle at Different Pressures. Values Adjusted to 1½ Minute Run.

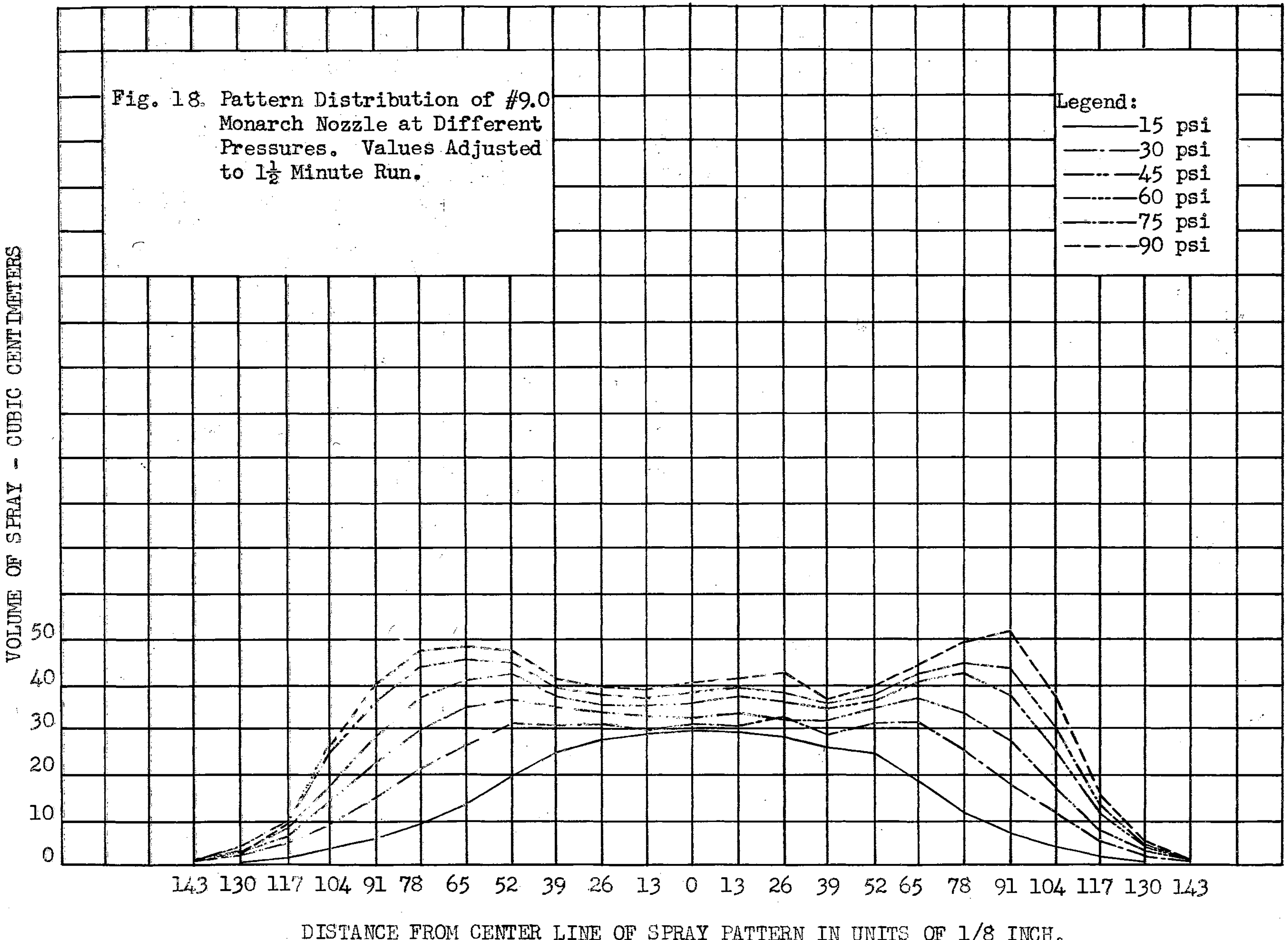

Fig. 18. Pattern Distribution of #9.0 Monarch Nozzle at Different Pressures. Values Adjusted to 1½ Minute Run.

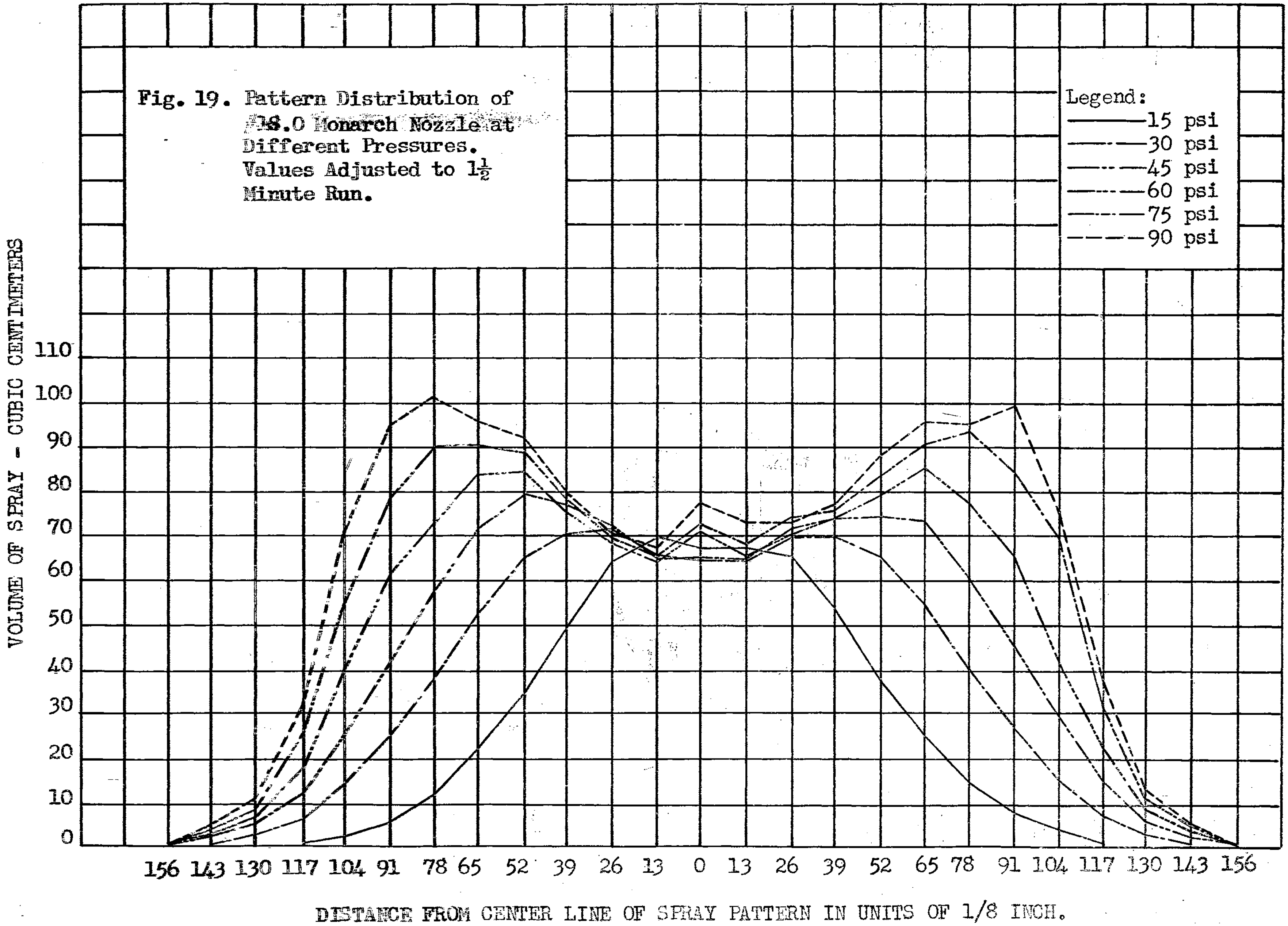

Fig. 19. Pattern Distribution of #18.0 Monarch Nozzle at Different Pressures. Values Adjusted to 1½ Minute Run.

TABLE 3

The Effect of Pressure on the Included Spray Angle of Terado Flat Spray Nozzles.

	Test Pressure					
Nozzle	15	30	45	60	75	90
V-5	62	75	80	80	80	80
V-10	69	75	80	86	86	86
V-15	69	75	80	86	86	86

TABLE 4

The Effect of Pressure on the Included Spray Angle of Teejet Flat Spray Nozzles.

	Test Pressure					
Nozzle	15	30	45	60	75	90
8001	69	80	80	86	86	86
80015	69	80	86	86	86	86
8002	69	86	91	91	91	91

TABLE 5

The Effect of Pressure on the Included Spray Angle of Teejet Hollow Cone Nozzles.

	Test Pressure					
Nozzle	15	30	45	60	75	90
6	54	69	75	75	80	80
12	75	86	91	91	91	96
18	69	80	80	80	80	80

TABLE 6

The Effect of Pressure on the Included Spray Angle of Monarch Hollow Cone Nozzles.

	Test Pressure					
Nozzle	15	30	45	60	75	90
4.6	54	69	75	75	75	75
9.0	75	80	80	80	80	80
18.0	75	86	86	86	86	86

TABLE 7

The Effect of Pressure on the Discharge of Terado Nozzles. Discharge Given in Cubic Centimeters. Values Adjusted to 1 1/2 Minute Run.

	Test Pressure					
Nozzle	15	30	45	60	75	90
V-5	283	422	508	597	661	716
V-10	492	715	874	1003	1122	1228
V-15	758	1129	1398	1564	1778	1908

TABLE 8

The Effect of Pressure on the Discharge of Teejet Flat Spray Nozzles. Discharge Given in Cubic Centimeters. Values Adjusted to 1 1/2 Minute Run.

	Test Pressure					
Nozzle	15	30	45	60	75	90
8001	325	477	583	654	738	794
80015	483	696	864	984	1113	1188
8002	652	947	1163	1315	1490	1590

TABLE 9

The Effect of Pressure on the Discharge of Monarch Nozzles.
Discharge Given in Cubic Centimeters
Values Adjusted to 1 1/2 Minute Run.

	Test Pressure					
Nozzle	15	30	45	60	75	90
4.6	150	214	263	291	345	366
9.0	313	442	530	625	688	741
18.0	608	896	1088	1239	1399	1521

TABLE 10

The Effect of Pressure on the Discharge of Teejet Hollow
Cone Nozzles. Discharge Given in Cubic Centimeters.
Values Adjusted to 1 1/2 Minute Run.

	Test Pressure					
Nozzle	15	30	45	60	75	90
6	310	452	570	650	708	776
12	724	1080	1325	1525	1690	1865
18	1082	1600	1955	2260	2525	2740

TABLE 11

The Effect of Pressure on Coefficient of Discharge of Terado Nozzles. Values are Product of Coefficient of Discharge And Cross-sectional Area Times 10^{-6}.

	Test Pressure					
Nozzle	15	30	45	60	75	90
V-5	2.5	2.6	2.6	2.6	2.6	2.6
V-10	4.3	4.4	4.4	4.4	4.4	4.4
V-15	6.5	6.9	7.0	6.9	6.9	6.8

TABLE 12

The Effect of Pressure on Coefficient of Discharge of Teejet Flat Spray Nozzles. Values are Product of Coefficient Of Discharge and Cross-sectional Area Times 10^{-6}.

	Test Pressure					
Nozzle	15	30	45	60	75	90
8001	2.8	2.9	2.9	2.8	2.9	2.8
80015	4.2	4.3	4.3	4.3	4.3	4.2
8002	5.7	5.8	5.8	5.7	5.8	5.6

TABLE 13

The Effect of Pressure on Coefficient of Discharge of Monarch Nozzles. Values are Product of Coefficient of Discharge And Cross-sectional Area Times 10^{-}[illegible].

	Test Pressure					
Nozzle	15	30	45	60	75	90
4.6	1.3	1.3	1.3	1.3	1.3	1.3
9.0	2.7	2.7	2.7	2.7	2.7	2.6
18.0	5.3	5.5	5.5	5.4	5.4	5.4

TABLE 14

The Effect of Pressure on Coefficient of Discharge of Teejet Hollow Cone Nozzles. Values are Product of Coefficient of Discharge and Cross-sectional Area Times 10^{-6}.

	Test Presure					
Nozzle	15	30	45	60	75	90
6	2.7	2.9	2.9	2.8	2.8	2.8
12	6.5	6.6	6.6	6.6	6.6	6.6
18	9.4	9.8	9.8	9.8	9.8	9.7

were obtained by converting the discharge to cubic feet per second and dividing this value by the square root of the pressure. The following relationships give the method used.

$Q = Ca \sqrt{2gh}$ (Explanation of terms given on page 2).

16.4 cubic centimeters = 1 cubic inch

1728 cubic inches = 1 cubic foot

Therefore,

$$Ca = \frac{Q}{\sqrt{2gh} \times 1728 \times 16.4 \times 90 \text{ secs. per } 1\ 1/2 \text{ min.}}$$

B. Determination of the Coefficient of Uniformity.

A numerical value was needed to best show the uniformity of the pattern distribution of the nozzles. An expression devised by Christiansen[5] was used for showing this. The uniformity coefficient expressed as an equation is,

$$C. U. = 100 \left(1 - \frac{|Sx|}{mn}\right)$$

where $|Sx|$ is the summation of the deviations of the individual observations from the mean, m is the mean value of the observations and n is the number of observations. A perfectly uniform pattern is then represented by 100 per cent.

When the intensity of application at any number of equally spaced points across the entire spray pattern is determined, the coefficient of uniformity can be determined. If the individual observations made of the spray pattern were interpreted as the intensity of application for the area covered in each 1 5/8 inches, Christiansens's equation could be used. Therefore, the use of the above formula was based on the assumption that these observations were representative of the pattern distribution for each 1 5/8 inches.

1. Flat Spray Nozzles at 20 Inch Spacing.

Figure 20 shows the method used in plotting the flat nozzlea at 20 inch spacing for the determination of the coefficient of uniformity. The values used for the individual observations were the averages of corresponding values on the opposite side of the spray pattern. These average values represent the pattern distribution for an infinite number of observations at all possible positions of the nozzle on the spray boom. The composite pattern of two nozzles at 20 inch spacing is represented as shown.

To obtain the average coefficient of uniformity at 20 inch spacing, thirteen readings were taken from the profile of the composite pattern. The mean value of the readings was determined by summing these values and dividing by thirteen. The deviations from the mean were determined and totalled. Then the equation for the uniformity coefficient was applied. The average uniformity coefficients, of the flat spray nozzles at 20 inch spacing, are given in Tables 15 and 16 for all test pressures. The graphs of the coefficient of uniformity versus pressure for these nozzles are shown in Figure 21.

2. Flat Spray and Hollow Cone Nozzles.

So that a comparision of the uniformity of hollow cone and flat spray nozzles could be made, the uniformity coefficient was determined for each individual nozzle. These values are given in Tables 17 through 20. The graphs of the average coefficient of uniformity versus pressure are given in Figures 22 and 23.

The average values for computing these uniformity coefficients were obtained in a similar manner to flat spray nozzles at 20 inch spacing. The mean value of the observations were obtained by adding the individual observations of the pattern and dividing by the total number of observations.

Then the deviations from the mean were obtained and totalled and the equation for the uniformity coefficient was applied.

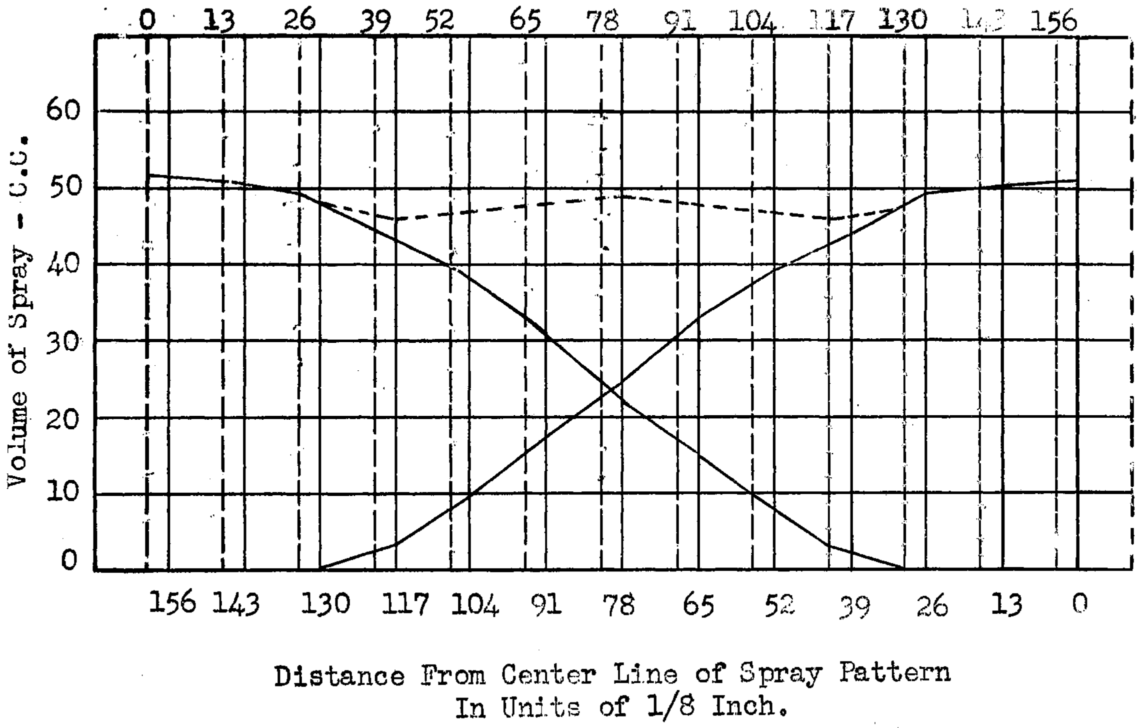

Fig.20. Shows values which are the average of corresponding values on opposite sides of the spray pattern. The solid lines represent the discharge of the individual nozzles. The dashed line represents the composite pattern of two nozzles on 20 inch spacing.

TABLE 15

The Effect of Pressure on the Average Coefficient of Uniformity of Terado Flat Spray Nozzles at 20 Inch Spacing.

	Test Pressure					
Nozzle	15	30	45	60	75	90
V-5	44	74	89	97	97	97
V-10	59	85	94	96	96	96
V-15	84	88	86	85	86	86

TABLE 16

The Effect of Pressure on the Average Coefficient of Uniformity of Teejet Flat Spray Nozzles at 20 Inch Spacing.

	Test Pressure					
Nozzle	15	30	45	60	75	90
8001	50	81	94	92	96	95
80015	57	87	96	97	97	98
8002	71	98	96	95	94	92

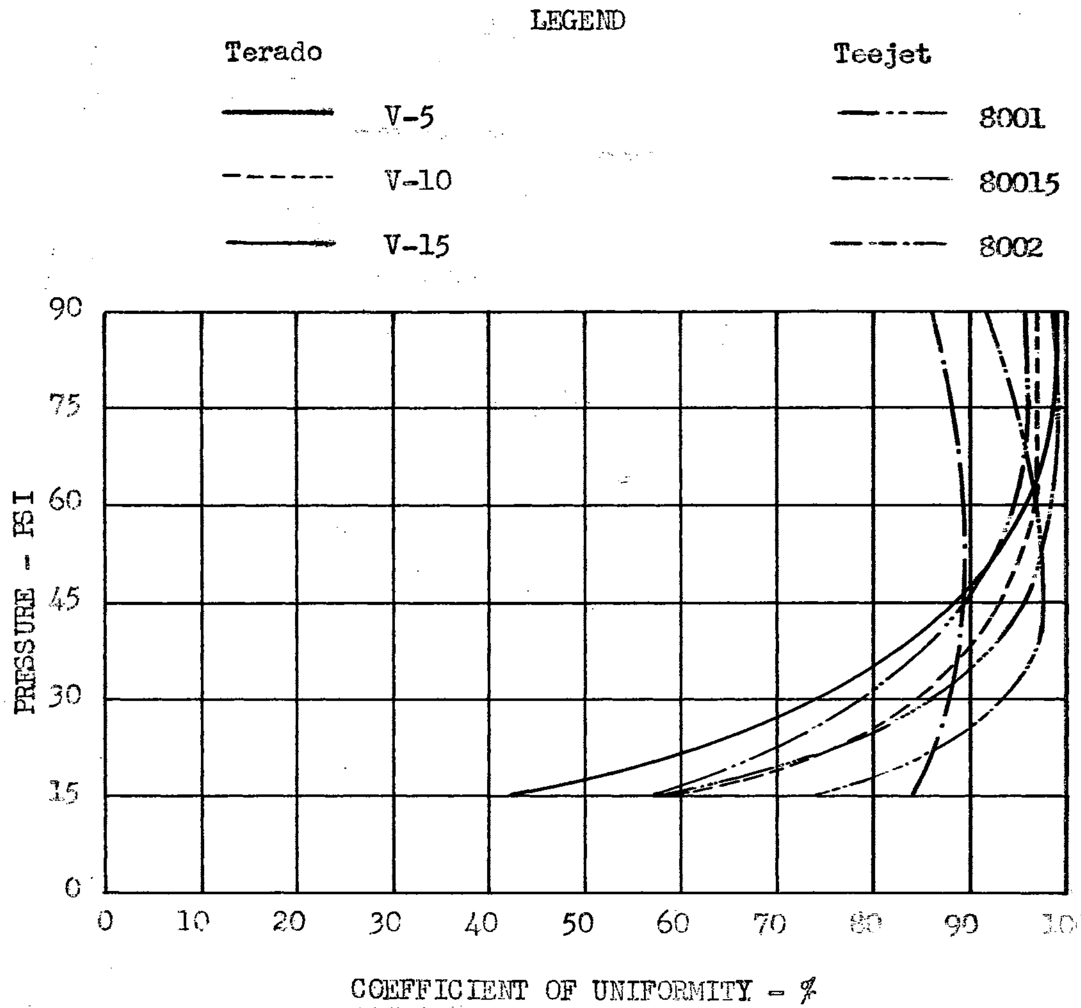

Fig. 21. The Graph of the Coefficient of Uniformity Versus Pressure of the Flat Spray Nozzles Tested at 20 inch spacing.

TABLE 17

The Effect of Pressure on the Average Coefficient of Uniformity of Teejet Hollow Cone Nozzles.

	Test Pressure					
Nozzle	15	30	45	60	75	90
6	6	17	20	30	39	37
12	28	38	39	45	55	44
18	38	44	45	51	66	54

TABLE 18

The Effect of Pressure on the Average Coefficient of Uniformity of Monarch Hollow Cone Nozzles.

	Test Pressure					
Nozzle	15	30	45	60	75	90
4.6	15	42	52	61	59	56
9.0	41	54	61	63	67	68
18.0	26	36	47	53	58	63

TABLE 19

The Effect of Pressure on the Average Coefficient of Uniformity of Terado Flat Spray Nozzles.

	Test Pressure					
Nozzle	15	30	45	60	75	90
V-5	33	44	45	53	42	47
V-10	38	47	45	41	42	35
V-15	47	57	54	45	48	49

TABLE 20

The Effect of Pressure on the Average Coefficient of Uniformity of Teejet Flat Spray Nozzles.

	Test Pressure					
Nozzle	15	30	45	60	75	90
8001	32	37	44	40	44	44
80015	37	39	39	43	46	39
8002	46	48	47	52	52	50

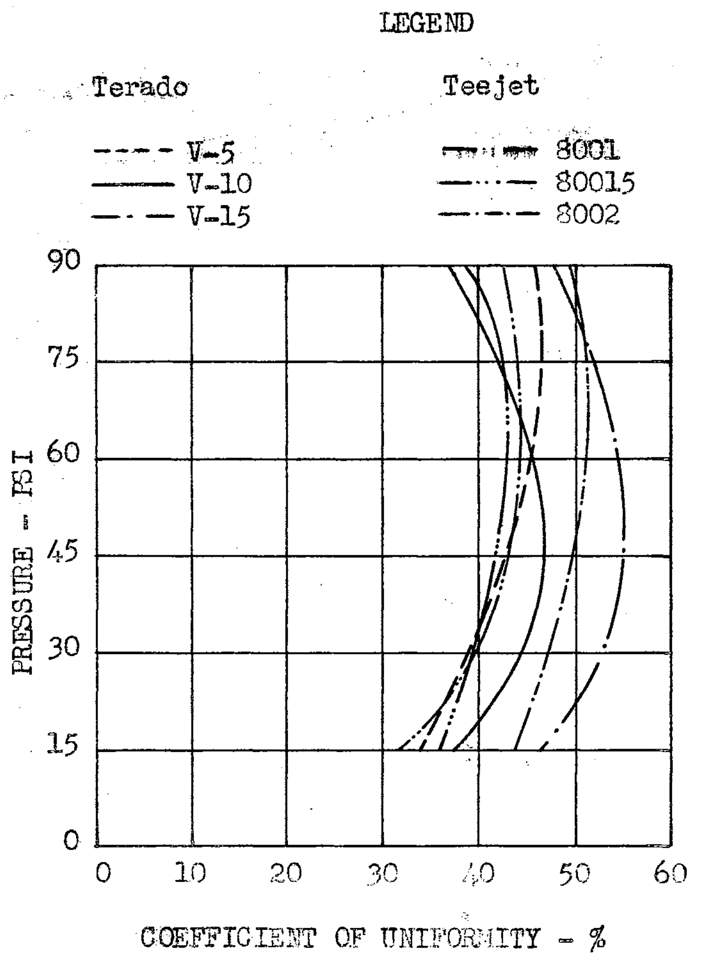

Fig. 22. The Graph of the Coefficient of Uniformity Versus Pressure of Flat Spray Nozzles.

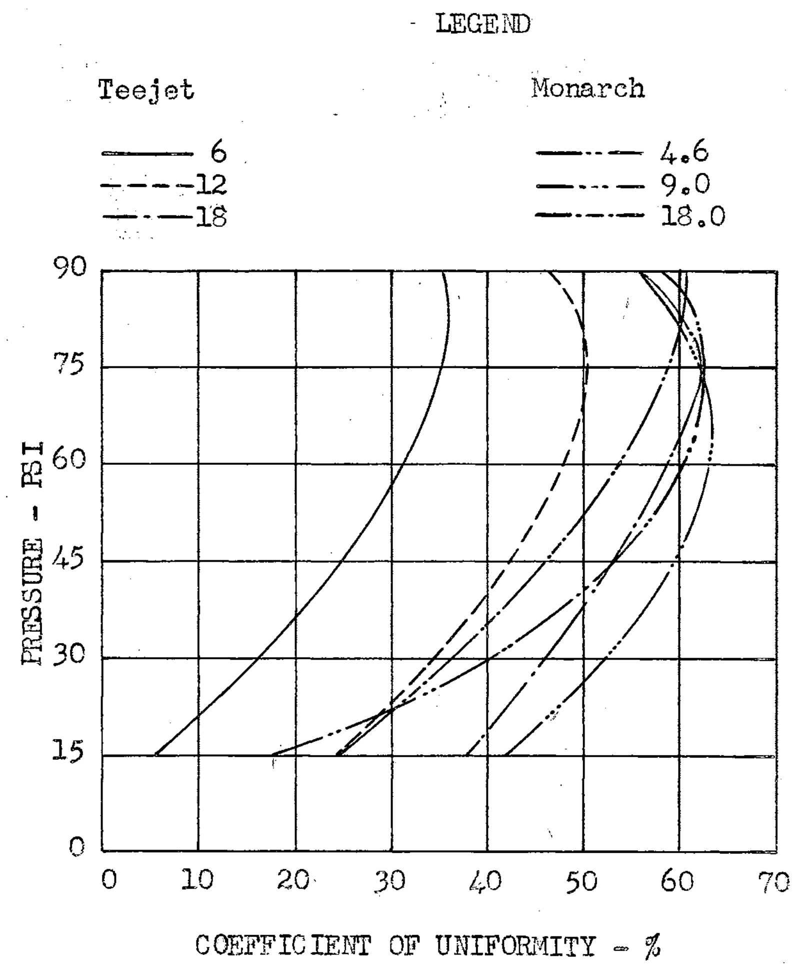

Fig. 23. The Graph of the Coefficient of Uniformity Versus Pressure of Hollow Cone Nozzles.

VII. DISCUSSION OF RESULTS

The effect of pressure on the coefficient of discharge is shown in Tables 11 through 14. They are included in this discussion as a measure of the accuracy of the reported observations. A study of these results shows that the greatest error in the reported values is 4 per cent.

A. Significant Changes in Pattern Distribution at different pressures.

1. Flat Spray Nozzles.

Figures 8 through 13 show the profile of each flat spray nozzle at each pressure. Tables 3 and 4 show the effect of pressure on the included spray angle and Tables 7 and 8 show the effect of pressure on the discharge. A study of these results shows that the included spray angle reaches a maximum value for the smaller flat spray nozzles at 30 to 45 psi. As the size of the nozzle increases, the included spray angle reaches a maximum at lower pressures.

With the exception of lower operating pressures, the pattern is similar throughout the range of pressures; but the profile increases in height as the pressure and discharge increase. At low pressures the pattern distribution is not as uniform as it is at higher pressures. The patterns for the larger nozzles were more nearly the same shape throughout the range of pressures. In general, the most uniform pattern is obtained at 45 psi for all nozzle sizes.

2. Hollow Cone Nozzles.

Figures 14 through 19 show the profile of each hollow cone nozzle at each pressure. Tables 9 and 10 show the effect of pressure on the discharge and Tables 5 and 6 show the effect of pressure on the included spray angle. These results show that the smaller nozzles reach a maximum included spray angle at 75 psi. As the size of the nozzle increases, the included spray angle reaches a maximum at lower pressures.

The patterns are similar to each other above 45 psi. The profiles of the patterns were more nearly the same shape throughout the range of pressures for the larger nozzles. In general the most uniform pattern was obtained at 60 psi.

B. A Comparison of the Uniformity Coefficient of Hollow Cone Nozzles to Flat Spray Nozzles.

The average coefficient of uniformity of the hollow cone and flat spray nozzles is given in Tables 17 through 20. The graphs of coefficient of uniformity versus pressure are given in Figures 22 and 23. These results show that the range of the coefficients of uniformity is greater for hollow cone than flat spray nozzles. The hollow cone nozzles have a higher coefficient of uniformity than the flat spray nozzles at high pressures. Generally, the flat spray nozzles have a higher coefficient of uniformity at low pressures than the hollow cone nozzles. The greatest uniformity, for flat spray nozzles, is from 30 to 45 psi. The greatest uniformity for hollow cone nozzles is from 60 to 75 psi.

C. A Comparison of 70° Flat Spray Nozzles to 80° Flat Spray Nozzles.

Tables 15 and 16 show the values for the average coefficient of uniformity of flat spray nozzles at 20 inch spacing. The graphs of coefficient of uniformity versus pressure for flat spray nozzles at 20 inch spacing are shown in Figure 21. The spray angle of the Terado nozzles was 70° and the Teejet 80°, according to the manufacturer.

The V-5 Terado compares in size to the 8001 Teejet. At lower pressures, the 8001 Teejet, or 80° nozzle, is more uniform than the V-5 Terado, or 70° nozzle. The 80015 Teejet and the V-10 Terado show no difference in uniformity. The 8002 Teejet is more uniform at higher pressures than the V-15 Terado. There is very little difference between the uniformity of 70° and 80° nozzles.

D. A Comparison of Different Sizes of Nozzles.

1. Terado Flat Spray Nozzles.

The average coefficients of uniformity values at 20 inch spacing are given in Table 15. From these results the V-5 nozzle has the highest uniformity at high pressures. The least variation in the uniformity was shown in the V-15 nozzle. The uniformity of the V-10 nozzle compared favorably with the V-5 at higher pressures and was higher in uniformity than the V-5 at lower pressures.

2. Teejet Flat Spray Nozzles.

Table 16 gives the average coefficient of uniformity for Teejet flat spray nozzles at 20 inch spacing. There is the least variation in the uniformity of the 8002 nozzle. The 80015 and the 8002 are more uniform at lower pressures than the 8001. There is very little change in the coefficient of uniformity above 45 psi.

3. Teejet Hollow Cone Nozzles.

The average coefficients of uniformity of these nozzles are given in Table 17. The uniformity for them is the highest at 60 to 75 psi. The uniformity of the #6 nozzle is extremely low at low pressures. The #18 has the least variation in uniformity and also the highest uniformity of either of the other two nozzles.

4. Monarch Hollow Cone Nozzles.

The values for the average coefficients of uniformity of Monarch hollow cone nozzles are given in Table 18. The #9.0 nozzle has the highest uniformity at all pressures. The highest uniformity for the #4.6 nozzle is obtained at 45 psi and above. These nozzles have the highest uniformity from 45 to 90 psi.

VIII. SUMMARY AND CONCLUSIONS

The following conclusions are drawn from the information obtained in this study:

A. Operating pressure

1. Operating pressures of 45 to 75 psi give the greatest uniformity of pattern distribution, when flat spray nozzles are used at 20 inch spacing.

2. Operating pressures of 30 to 45 psi give the greatest uniformity of pattern distribution, when flat spray nozzles are used individually.

3. Operating pressures of 60 to 75 psi give the greatest uniformity of pattern distribution for hollow cone nozzles.

4. Hollow cone and flat spray nozzles should not be operated below 30 psi.

B. Type of nozzle

1. Flat spray nozzles have higher uniformity of patter distribution at low pressures than hollow cone nozzles.

2. Hollow cone nozzles have higher uniformity of pattern distribution at high pressures than flat spray nozzles.

3. There is no essential difference between the uniformity of the pattern distribution of 70° and 80° flat spray nozzles.

C. Size of nozzle

1. The uniformity of the pattern distribution for flat spray nozzles that will apply 10 gpa at 4 mph, 20 inch spacing, and 30 to 40 psi has the most desirable characteristics throughout the pressure range.

2. The uniformity of the pattern distribution for hollow cone nozzles that will apply 10 gpa at 4 mph, 75 to 80 psi and 2 nozzles per row has the most desirable characteristics throughout the pressure range.

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APPENDIX

DATA SHEET 1. V-5 Terado. Average values of the spray pattern of 3 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi 1½ min. run	30 psi 1½ min. run	45 psi 1½ min. run	60 psi 1½ min. run	75 psi 1½ min. run	90 psi 1½ min. run
		0.3	0.4	1.0	1.7
		1.0	2.8	4.1	7.7
	1.9	5.5	9.2	9.9	12.8
0.4	6.6	13.0	17.0	18.5	21.6
3.1	13.4	18.5	24.3	26.9	31.2
8.9	19.6	25.9	33.1	38.0	40.4
14.4	25.2	33.4	39.6	44.0	46.1
18.7	32.1	40.3	44.8	50.0	52.7
27.4	42.9	47.4	51.3	56.0	58.4
44.4	47.6	48.2	50.7	55.0	57.9
57.1	54.3	49.2	51.7	56.3	60.4
39.7	46.3	47.3	51.0	55.0	58.1
25.6	37.4	43.0	48.2	52.2	54.7
19.4	30.3	38.3	43.6	46.8	50.3
15.6	25.1	33.3	40.2	46.2	47.1
7.1	19.8	26.1	33.6	39.4	40.5
1.9	12.6	19.4	25.1	29.3	32.4
0.1	5.4	11.6	17.7	19.3	21.9
	1.9	5.1	9.4	9.9	12.2
	0.4	1.4	3.9	4.3	6.0
		0.3		1.0	1.3
				0.3	

DATA SHEET 2. V-10 Terado. Average values of the spray pattern of 3 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi 1½ min. run	30 psi 1½ min. run	45 psi 1½ min. run	60 psi 1½ min. run	75 psi 1 min. run	90 psi 1 min. run
					0.3
	0.3	0.3	0.8	0.9	1.0
	0.8	2.3	4.2	4.4	3.9
0.2	2.7	8.1	11.0	8.3	10.2
1.9	10.7	16.1	21.2	16.0	18.6
5.9	19.8	25.8	34.0	24.4	28.8
13.7	28.0	32.4	43.4	32.9	36.3
23.0	34.4	44.6	51.7	40.0	41.7
26.8	41.2	53.7	58.8	44.5	47.4
30.9	50.2	62.1	67.6	51.0	54.2
42.3	62.7	71.9	79.2	58.7	62.8
62.3	73.4	79.4	88.9	64.0	67.9
79.1	76.8	82.2	91.0	66.4	70.7
62.4	67.2	74.1	80.8	60.2	63.6
45.3	61.0	69.3	75.9	54.4	60.1
34.3	50.6	59.2	67.3	49.1	53.3
27.9	43.9	54.1	61.8	44.8	49.0
21.1	34.2	45.5	54.2	39.2	43.7
11.6	26.0	36.6	43.4	33.9	36.8
3.3	17.8	27.8	31.2	25.2	26.3
0.3	9.8	17.5	20.7	17.0	17.8
	4.2	8.1	10.4	9.1	9.6
		2.8	4.3	3.9	4.0
			0.8	0.7	0.4

DATA SHEET 3. V-15 Terado. Average values of the spray pattern of 3 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi 1½ min. run	30 psi 1 min. run	45 psi 1 min. run	60 psi 1 min. run	75 psi 1 min. run	90 psi 3/4 min. run
			0.2	0.3	0.4
		0.5	2.3	3.2	2.7
	1.6	5.3	8.7	13.7	10.9
0.2	9.4	22.0	31.4	40.7	34.3
6.3	30.3	49.3	57.1	65.2	50.5
31.1	47.3	56.1	59.1	65.3	51.2
54.8	49.3	57.3	60.9	68.6	54.4
57.4	49.9	55.6	60.8	68.3	54.9
58.0	50.6	59.3	65.0	73.5	58.7
64.8	56.0	65.9	72.2	82.0	65.2
75.3	61.6	71.7	79.6	88.5	70.9
84.5	65.2	73.3	81.1	88.7	72.0
75.4	61.1	70.7	78.2	86.5	69.1
64.7	55.7	63.9	72.6	81.1	65.1
54.6	48.7	55.0	61.0	68.3	54.9
54.2	47.8	54.9	59.6	65.9	53.7
45.5	44.4	52.9	57.9	62.7	51.9
22.3	39.9	51.0	56.0	61.0	49.7
5.9	23.7	43.1	46.4	55.1	43.1
0.8	7.8	18.5	25.2	32.9	27.3
	1.4	4.9	8.3	10.1	10.3
		1.0	1.6	2.5	3.2
				0.2	

DATA SHEET 4. 8001 Teejet. Average values of the spray pattern of 3 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi 1½ min. run	30 psi 1½ min. run	45 psi 1½ min. run	60 psi 1½ min run	75 psi 1½ min. run	90 psi 1½ min. run
			0.2	0.9	1.1
	0.2	1.7	3.6	6.0	7.0
	3.4	8.6	13.6	18.0	15.1
0.3	10.8	17.6	18.8	20.8	22.3
2.9	16.2	16.9	17.9	21.7	22.6
12.2	16.6	19.2	22.8	28.2	29.9
17.0	19.9	27.3	33.0	38.6	40.4
15.3	27.4	36.6	41.7	46.2	50.2
19.9	34.7	42.1	47.7	50.4	55.2
28.3	41.0	48.4	53.3	56.4	60.7
45.9	48.0	50.1	55.1	58.9	62.0
61.3	55.6	56.6	60.0	65.1	70.2
44.8	50.7	55.1	54.3	60.7	63.4
25.9	43.0	52.3	52.9	59.4	61.1
17.7	31.1	41.4	45.8	50.8	56.3
16.8	22.9	30.8	37.8	41.7	48.4
10.1	16.8	21.7	26.7	30.4	35.7
5.0	15.9	17.8	20.7	24.8	28.4
1.6	13.9	16.1	17.0	20.2	23.3
	6.8	13.9	16.2	17.6	18.8
	1.1	6.6	10.3	13.1	13.8
		1.4	3.6	6.4	7.1
			0.4	0.9	

DATA SHEET 5. 80015 Teejet. Average values of the spray pattern of 3 nozzles of the same size and 3 readings of each nozzles at different pressures

15 psi 1½ min. run	30 psi 1½ min. run	45 psi 1½ min. run	60 psi 1½ min. run	75 psi 1½ min. run	90 psi 1½ min. run
				0.3	0.9
		0.6	0.8	2.6	3.6
	0.4	3.0	7.0	7.9	10.1
	3.9	10.3	17.9	19.7	22.9
0.6	13.1	22.1	28.2	31.7	35.3
6.3	21.1	28.0	32.9	37.2	41.6
15.0	27.7	32.6	39.8	44.6	50.0
21.8	33.1	42.0	50.0	57.3	62.7
26.2	42.6	53.4	59.9	68.8	73.1
31.1	55.1	64.4	70.4	80.1	83.3
43.9	65.8	72.3	77.1	87.1	89.6
69.4	66.9	74.2	79.2	88.4	91.2
84.2	67.4	74.7	82.2	90.7	95.0
57.0	64.6	72.1	81.4	85.0	92.3
37.7	60.3	70.1	78.4	82.9	90.1
27.6	49.1	60.9	67.2	72.9	79.0
25.2	40.1	53.3	58.1	65.9	68.1
20.4	28.9	41.0	46.6	56.1	56.6
12.8	23.2	30.7	35.2	44.9	44.8
3.6	20.6	25.0	27.4	33.6	34.8
	10.0	20.2	23.8	28.6	29.3
	1.4	10.3	16.3	20.2	22.7
		1.9	3.8	6.1	10.3
				0.4	1.1

DATA SHEET 6. 8002 Teejet. Average values of the spray pattern of 3 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi 1½ min. run	30 psi 1½ min. run	45 psi 1½ min. run	60 psi 1½ min. run	75 psi 1 min. run	90 psi 1 min. run
			0.6	1.3	1.1
	0.6	3.9	4.8	7.1	7.2
	5.1	13.6	14.1	14.9	15.7
0.2	15.9	24.1	18.8	21.8	20.9
3.9	25.2	32.6	24.7	29.2	30.7
18.4	30.7	41.7	34.1	37.1	43.2
29.1	39.8	51.6	40.6	45.1	50.8
32.6	51.1	63.6	48.1	55.4	61.6
39.2	65.6	76.7	56.4	65.9	73.6
49.6	75.2	85.0	60.7	69.2	74.9
62.2	77.7	89.2	64.1	70.7	76.2
75.7	74.7	86.2	62.2	68.4	71.0
88.1	76.7	88.6	65.9	72.0	74.4
75.9	75.4	87.7	63.3	69.8	72.3
53.9	71.3	85.1	60.6	69.4	73.4
39.6	64.3	76.0	55.4	64.3	69.7
35.2	57.1	69.4	50.4	59.3	65.2
21.1	45.9	57.1	42.3	49.3	54.4
15.9	37.9	48.1	36.9	42.0	46.0
9.6	23.0	36.4	30.1	34.2	36.9
1.9	15.0	21.0	19.9	22.8	23.8
	7.1	14.4	11.8	11.9	12.0
	1.2	6.8	8.6	9.6	5.3
		0.9	2.8	2.9	1.4
			0.2	0.3	

DATA SHEET 7. #6 Teejet. Average values of the spray pattern of 3 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi 1½ min. run	30 psi 1½ min. run	45 psi 1½ min. run	60 psi 1½ min. run	75 psi 1½ min. run	90 psi 1½ min. run
				0.9	1.3
		0.6	1.7	2.2	3.9
	1.1	2.4	4.2	6.2	9.7
	3.1	5.9	10.0	15.8	21.4
0.6	7.7	14.1	21.4	29.0	36.4
3.2	16.1	27.1	38.0	47.3	52.1
9.1	28.4	41.1	50.9	56.6	59.7
26.1	45.6	56.2	60.8	62.4	62.7
51.7	62.8	70.8	70.9	68.1	65.0
73.8	69.9	72.8	70.2	67.0	64.2
74.6	72.0	72.9	70.7	69.7	66.3
45.7	59.0	63.4	61.6	59.8	60.9
17.8	39.9	55.7	59.6	59.3	58.3
5.4	24.2	40.4	50.8	56.9	61.3
1.4	13.3	26.1	38.9	48.1	58.1
0.3	5.3	12.7	22.2	31.8	43.6
	2.0	5.3	10.8	18.0	28.0
	0.6	2.0	4.7	7.8	13.8
		0.6	1.1	3.1	6.0
			0.6	0.6	2.2
					0.8

DATA SHEET 8. 12 Teejet. Average values of the spray pattern of 3 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi 1½ min. run	30 psi 1½ min. run	45 psi 1 min. run	60 psi 1 min. run	75 psi 1 min. run	90 psi 1 min. run
		0.2	0.4	0.6	1.2
	0.7	2.0	2.6	3.4	4.4
	4.0	5.1	7.4	9.9	12.8
	10.0	11.2	16.2	21.6	27.8
2.8	19.4	21.8	31.0	40.8	51.4
8.2	33.8	35.6	48.8	61.4	73.3
17.6	50.3	48.8	60.0	71.1	79.1
32.6	67.8	59.3	66.9	73.1	77.4
51.1	78.2	61.6	66.6	70.3	72.3
68.1	82.2	60.6	61.9	64.0	64.3
75.1	78.3	55.3	55.3	58.6	59.4
68.6	71.1	50.8	51.6	52.3	53.4
66.6	70.4	50.1	51.0	54.9	56.0
77.1	72.5	50.7	50.3	52.3	53.1
79.9	82.7	58.0	58.6	60.5	60.0
67.1	87.8	63.1	65.1	66.7	69.6
50.1	84.1	64.2	69.0	73.3	72.8
31.0	68.4	57.4	66.1	72.9	79.9
16.9	50.7	48.7	62.3	72.6	79.9
7.8	33.2	34.7	48.7	71.0	73.6
2.6	19.3	21.9	32.7	42.7	55.6
0.4	9.9	12.2	19.0	25.3	33.9
	4.4	6.2	9.7	13.0	19.2
	1.1	2.4	4.0	5.3	7.4
	0.4	0.7	1.7	1.3	3.1
					0.6

DATA SHEET 9. 18 Teejet. Average values of the spray pattern of 3 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi 1 min. run	30 psi 1 min. run	45 psi 3/4 min. run	60 psi ½ min. run	75 psi ½ min. run	90 psi ½ min. run
	1.7	0.6	0.4	0.4	0.7
	6.7	4.0	3.9	3.0	3.3
0.6	17.3	13.7	12.9	15.6	17.8
3.9	34.3	32.1	32.3	42.4	50.2
12.3	55.9	55.0	51.8	64.3	72.7
23.7	73.9	73.3	60.0	67.1	72.3
37.6	83.3	77.2	57.3	60.6	64.3
54.8	83.9	72.3	51.0	53.4	56.2
75.6	79.1	68.4	46.4	48.7	51.7
89.4	73.2	62.4	41.1	43.3	46.0
93.2	70.3	60.0	40.3	42.3	44.6
87.3	67.2	55.2	38.1	39.9	42.6
80.8	76.1	57.9	39.3	42.1	44.7
64.2	87.6	70.4	46.8	48.0	51.1
47.0	89.0	85.3	60.6	63.1	65.3
28.9	71.8	79.4	64.8	71.3	75.4
16.0	49.6	58.0	55.2	67.1	76.2
6.0	27.8	32.6	34.0	45.3	56.0
1.0	13.4	14.3	14.3	18.1	21.7
	4.9	5.0	4.1	4.1	4.1
	1.0	1.0	0.8	0.8	0.7

DATA SHEET 10. 4.6 Monarch. Average values of spray pattern of 2 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi ½ min. run	30 psi 1½ min. run	45 psi 1½ min. run	60 psi 1½ min. run	75 psi 1½ min. run	90 psi 1½ min. run
				1.0	
	0.2	0.5	0.3	4.2	1.3
	1.0	2.3	3.5	10.5	7.3
	2.7	5.8	9.5	17.3	17.3
0.5	5.8	10.2	15.5	23.5	23.7
2.0	11.2	17.2	22.3	27.5	28.0
5.8	17.0	21.5	24.5	26.8	29.3
12.3	21.0	23.2	23.7	25.2	27.2
21.7	22.7	23.3	22.3	24.8	26.3
29.7	21.3	22.2	23.0	25.0	26.7
32.3	20.7	22.7	22.7	24.5	26.2
24.2	19.7	22.5	22.0	24.8	26.2
13.5	20.3	24.0	23.8	25.7	27.0
5.8	18.5	23.2	23.2	24.7	26.2
1.8	14.8	19.7	21.7	23.3	25.5
0.5	9.0	12.5	16.0	17.5	20.5
	5.2	7.3	10.3	11.5	14.5
	2.7	3.5	4.8	5.8	7.3
	0.7	1.0	1.5	2.0	2.2
		0.1		0.2	0.2

DATA SHEET 11. 9.0 Monarch. Average values of spray pattern of 2 nozzles of the same size and 3 readings of each nozzle at different pressures.

15 psi 1½ min. run	30 psi 1½ min. run	45 psi 1½ min. run	60 psi 1½ min. run	75 psi 1½ min. run	90 psi 1½ min. run
	0.3	0.5			0.3
0.2	1.5	2.2	2.7	2.7	3.0
1.5	5.5	7.8	11.0	12.7	15.8
3.3	11.5	17.3	25.0	30.3	38.2
7.0	18.7	27.7	38.3	44.2	52.0
11.8	25.3	34.3	42.0	45.2	49.3
18.5	30.5	36.8	40.5	41.2	43.8
24.5	30.2	33.3	35.8	37.5	39.2
26.8	29.0	31.0	33.8	35.0	36.7
27.8	32.5	32.3	36.3	38.5	42.7
29.2	30.3	33.2	37.5	39.5	41.3
29.7	30.2	31.2	36.3	38.7	40.5
28.8	29.8	31.5	35.0	36.8	39.0
27.2	30.7	32.2	36.2	37.8	39.8
23.7	30.5	34.0	38.2	39.7	41.0
19.3	30.8	37.3	42.2	44.8	47.5
13.5	26.5	35.2	41.2	45.7	48.2
9.2	20.7	29.3	37.7	44.3	47.5
5.8	14.5	21.5	28.0	36.0	40.0
3.3	9.3	14.8	16.8	24.8	25.2
1.5	4.5	5.3	7.0	9.8	8.7
	1.5	1.7	1.5	2.0	1.3
	0.2	0.3			

DATA SHEET 12. 18.0 Monarch. Average values of the spray pattern of 2 nozzles of the same size and 3 readings of each at different pressures.

15 psi 1½ min. run	30 psi 1½ min. run	45 psi 1½ min. run	60 psi 1½ min. run	75 psi 1½ min. run	90 psi 1 min. run
	0.2	1.7	2.1	3.1	2.5
	2.7	5.7	8.6	11.3	8.6
0.8	7.5	15.0	22.5	30.0	25.0
3.2	16.3	29.3	41.5	59.5	50.3
8.0	27.8	45.7	66.3	84.5	66.0
14.7	40.7	60.5	77.6	93.3	62.8
25.2	56.2	73.1	86.6	91.1	63.6
38.7	65.5	74.3	79.1	83.5	58.0
54.2	70.0	73.0	73.0	74.3	50.8
66.2	69.2	71.8	71.0	73.8	48.8
67.3	63.0	63.5	65.3	68.6	48.8
67.0	63.0	65.3	71.3	72.5	51.8
69.8	65.2	65.0	63.8	63.5	44.3
64.2	71.2	71.9	68.1	69.3	46.8
49.5	70.8	77.1	75.6	78.1	53.1
35.3	66.3	79.5	83.5	89.0	61.0
21.7	52.5	71.3	82.8	90.6	64.2
12.5	38.3	58.2	71.8	90.6	67.5
6.2	25.3	41.9	60.6	78.8	63.1
2.2	14.5	25.7	39.6	55.0	46.6
0.5	6.8	12.5	18.6	25.8	21.0
	2.3	5.0	6.8	9.3	7.0
		2.2	2.1	2.6	2.2

THESIS TITLE: THE EFFECT OF PRESSURE ON PATTERN DISTRIBUTION OF LOW VOLUME SPRAY NOZZLES.

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