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Final Report

INITIAL DEVELOPMENT AND ANALYSIS OF PAINT SPRAY GENERATORS

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TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

Some of the performance variables of a turbine-type spray generator were studied. Water was sprayed in the early stages and paint in the later stages of the project. The effect of varying air-paint mass ratio was explored superficially to search out any gross effects, and the rotational speed was varied to seek an optimum speed.

The influence of air-paint mass ratio was minor; large changes were permitted without affecting the drop-size distribution in the center of the pattern. No study of the effect of the air-paint ratio on the overall spray or on the stability of operation of the generator has been made on a quantitative basis.

The influence of the rotational speed was also minor, except that speed higher than about 15,000 rpm appeared to increase the drop size slightly in the center of the pattern. No quantitative study of the speed influence on the overall pattern has been made yet.

The drop-size distribution shows that the mode, or "peak," of the curve occurs at 30 to 50 microns on a numerical distribution, and at 40 to 80 microns on a mass distribution. The drop sizes range from less than 10 microns to larger than 200 microns, in a distribution only slightly skewed.

Changing the liquid from water to paint makes only a slight change in the drop-size distribution. This indicates either a minor influence of physical properties of the liquid on the spray over a wide range of values, or a mechanical mechanism of drop formation which is substantially independent of liquid properties. The latter appears most likely, but there is insufficient knowledge of paint spray processes to disprove the former.

The turbine-type generator appears feasible as a possible spray device, although considerable work is still needed to reduce it to a routine commercial device.

An impinging-sheet spray generator was also evaluated briefly with both water and paint. It also showed a relative insensitivity to wide variations in air-paint ratio. Further work was suspended because it produced slightly larger drops with slightly higher air rates than the turbine type, and the original objectives had been changed to development of a working device.

AIMS AND BACKGROUND

A need to overcome certain technical and patent problems, involved in the current use of the rotating concentric-cup generator, led to this research program aimed at developing a special paint spray generator to be used in an electrostatic painting process. The idea for the device originated with the faculty at The University of Michigan. The basic idea had been successfully used for spray lubrication of antifriction bearings prior to the inception of this program. During a project conference concerning the multi-color paint-selector valve being designed at the University (Project 2464), Mr. A. J. Slatkin of the Ford Motor Company, Dearborn, Michigan, discussed the complete electrostatic painting process with Professors York, Carrick, Hall, and Edmonson, and Mr. Westervelt of the University. This discussion included the general problems that exist in the process and its use. Several portions of the process were examined for the effect they might have on each other. It was generally understood that accurate knowledge of certain items was at hand, for example, that the size of paint particles which would produce a quality surface was known. Although no direct comment concerning the effectiveness of the electrostatic transport mechanism was made, it was tacitly assumed that this portion of the process should not be a part of the research problem at the University. Based upon this discussion, the research project on spray generators was developed.

Since no final conclusion can be drawn either from the data presented or from other information which will be reported, a "Summary Statement" follows this section of the report to give the reader a limited knowledge of the relationship of the spray generator and the complete painting system.

I. SUMMARY STATEMENT

Spray painting of components in mass production employs the same basic operations as are found in custom painting. To avoid excessive costs, however, the production process must continuously provide a uniform quality of coated surface at a rate consistent with production schedules. Variations, such as changes in paint consistency and in thinner volatility, require immediate adjustment of the process equipment if quality is to be maintained. Process adjustments may be based upon accurate knowledge of the effect each has on the total system and on product quality, or upon experience from trial and error. Trial-and-error experience is remarkably successful, but the basic information required in the understanding of this system is rarely an outgrowth of this method. Misapplication of a process frequently is a direct result of information gathered from the trial-and-error system. A basic understanding must be available if any complete process is to survive successive changes as required in the production and sale of an item to the public.

This report indicates that there has not been a complete development or evaluation of either spray-generating device considered. The data indicate that the turbine spray generator delivers a spray in the particle-size range recommended by Mr. Slatkin. We believe that this device can be improved to overcome such problems as were present in the research unit, which was the first and only unit to be constructed. Additional research and evaluation is required to complete the understanding of the mechanism of paint spray generation.

The following pages will show that orientation of procedures initially decided upon for research and evaluation was altered frequently. These changes, planned to provide additional information required to understand the application of the spray generator under development to the painting process, were decided upon through information and cooperation from the representatives of the Ford Motor Company.

It became apparent that the action of the electrostatic field could not be predicted. In view of the great importance of this field in the process, however, it is fair to say that we believe that there is a serious lack of understanding of the electrostatic transport mechanism. Further, we believe that the spray-generator performance, the role of paint thinner, and the quality of the painted surface cannot be correlated until the transport mechanism is understood. We urge that the research program be continued so that those people charged with the responsibility of specification, design, and operation of the process may be provided with information which will permit them to exploit it to its maximum potentiality.

II. THE RESEARCH PROGRAM

Two types of spray generators were studied during this project. A turbine-type generator as initially proposed was first studied. Careful first consideration of this unit indicated that such problems as corrosion and erosion would require attention before it would become a reliable component for the production painting process. As a result, an alternate spray generator was proposed. This unit gave promise, when successfully developed, of reducing the anticipated problems of the high-speed turbine spray generator. A research model of the impinging-sheet spray generator was designed and built.

A. HIGH-SPEED TURBINE SPRAY GENERATOR

Detailed design and construction of the turbine-driven spray generator immediately followed the initiation of this project. Figure 1 is a sketch of this device. The initial design of the unit was intended only to prove or negate the idea of impact spray formation. Primary emphasis was placed upon the impeller, its surrounding casing and the outlet slot. A minimum amount of thought was given to the secondary parts. Decisions concerning clearance and width and angle of the opening of the outlet slot to produce a fan-shaped spray were arbitrary. A standard, off-the-shelf, tool-maker's air turbine with collet was selected. The lack of concentricity of this rather inexpensive power source was expected. Steel was selected for minimum shaping expense, with very little consideration given to longevity of performance. The unit was arranged for research adjustments, not for production-type adjustments. This design did perform its intended function. The shape of the spray generator and its casing, the number and depth of vanes in the impeller, the end outside diameter clearances, the location of liquid and air inlets, the position and shape of the discharge slot, and the speed of rotation are all variables which require research study. For any one set of mechanical conditions, the research program required a planned investigation of the liquid-air flow ratio at varying rotative speeds. A detailed description, including drawings, of the high-speed turbine spray generator is presented in Appendix A.

B. THE IMPINGING-SHEET SPRAY GENERATOR

During the time required for construction of the high-speed spray generator, Professor Hall and Mr. Westervelt proposed a device for spray generation that was markedly different from known paint spray units. A simple mock-up demonstrated that it should be investigated. A decision was made to build a research unit. Figure 2 is a sketch of this spray generator. The unit is basically a floating "poppet" valve (A) around which one fluid emerges in an expanding cone. The confining surface for that fluid opposite to the valve surface is a concentric ring (B) which is also free to float in the outer confining casing. The second fluid emerges between the ring and the concentric fixed casing (C) into a focusing cone. The two fluids make contact immediately in front of the generator at the sharp edge of the concentric ring. The fluid-flow rates and pressures control the po-

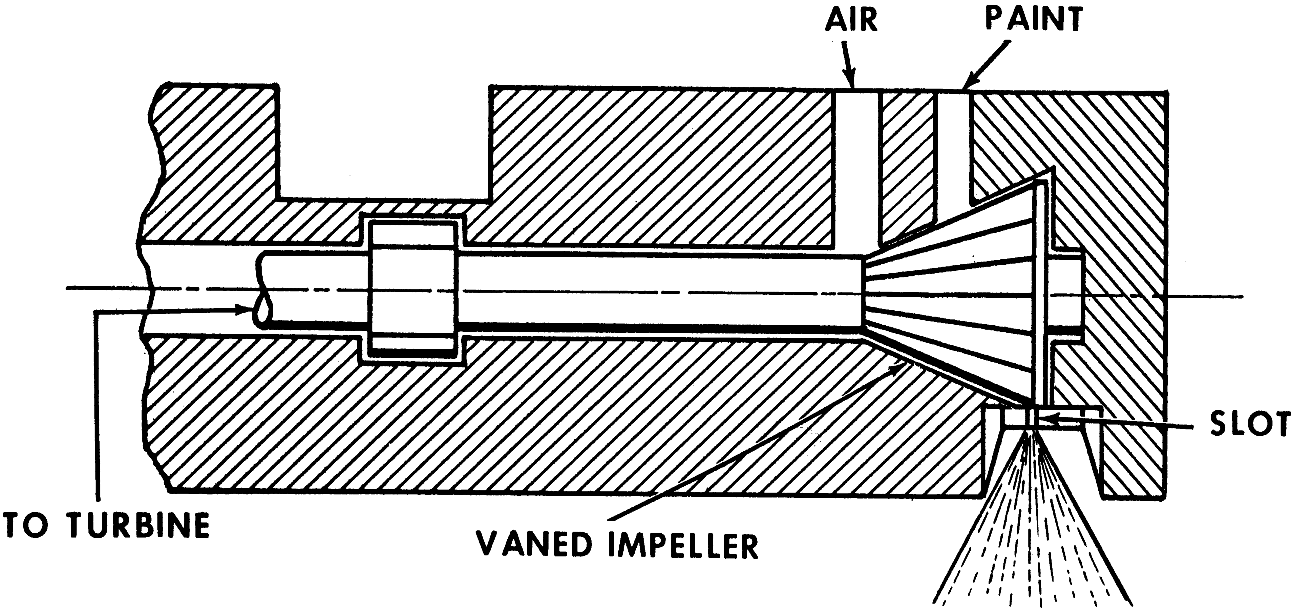


Fig. 1. Schematic diagram of turbine-type spray generator. (Not to scale.)

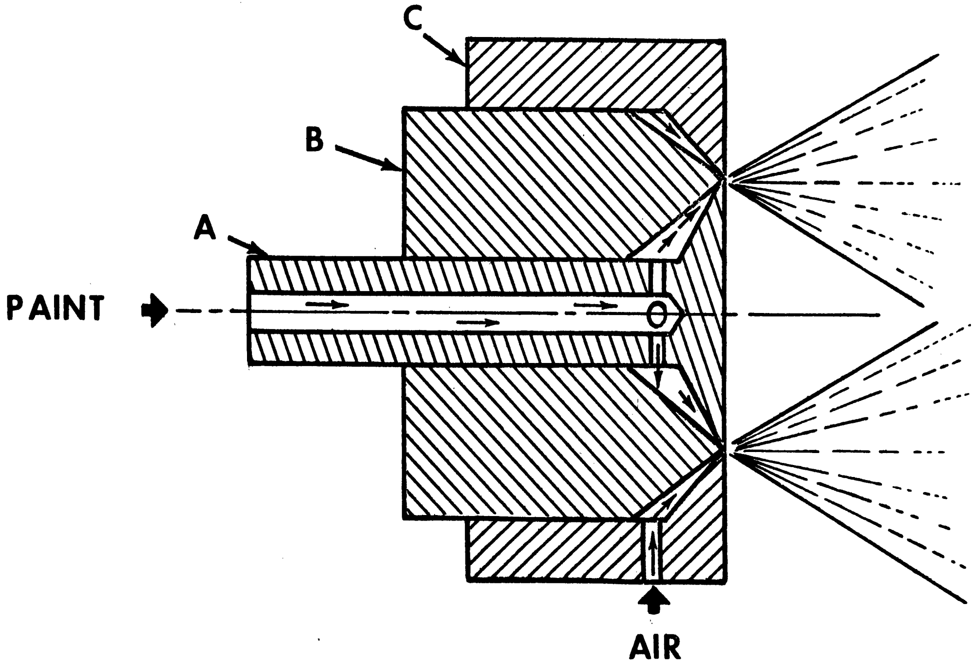


Fig. 2. Schematic diagram of impinging-sheet spray generator.

sition of the two floating parts which actually move only a slight distance along the axis. When the fluid sheet is formed by equal-momentum streams, the spray thus formed was expected to be a two-phase stream emerging into the electrostatic transport zone along the axis of the generator.

A planned analytical program for this unit included a series of liquid-air flow ratios including both water and paint as a liquid. A detailed description of the experimental unit and proposed units which were not built is presented in Appendix B.

III. INSTRUMENTATION

Instrumentation selection for any research project is based upon a prior study which is intended to establish a program. The kind of equipment selected will measure, and record where necessary, the parameters which are anticipated to provide an understanding of the physical phenomena in the research problem and, at the same time, permit evaluation of the equipment being developed.

Instrumentation was selected to measure the fluid-flow rates, to establish the mechanical variables, to record photographically the spray-generator performance, and to analyze the photographs.

A. FLUID FLOW

Flow measurements of air, water, and paint were required. The schematic arrangement of instrumentation is shown in Fig. 3a, b, c.

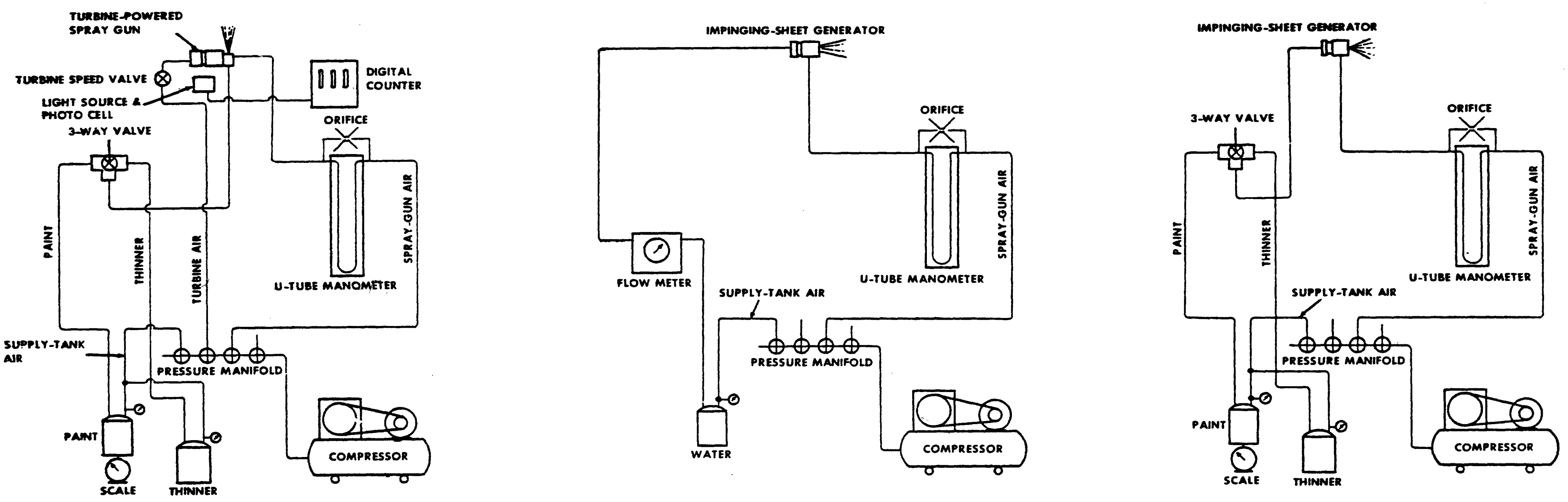
Air-flow measurement were made through use of a calibrated flat-plate orifice having a 5/32-in. diameter installed in a 3/8-in. diameter straight length of tubing. The pressure difference, across the orifice plate was measured by a mercury-filled differential manometer. The orifice was calibrated using a displacement-type gas meter.

Water-flow rates were read directly from a weight-calibrated rotameter.

The rate of paint flow to the spray generating apparatus was measured by the change in weight of a pressurized paint can during a known time interval.

B. MECHANICAL VARIABLES

Speed measurements were made using a pre-set interval digital counter. The input pulses to the counter were generated by a photoelectric cell which was energized by reflected light from one flat of the hexagon collet nut on the air turbine. Mechanical fits of component parts were measured by micrometer, micrometer differences,



a. Turbine-powered spray gun.

b. Impinging-sheet generator spraying water.

c. Impinging-sheet generator spraying paint.

Fig. 3. Schematic diagrams of instrumentation for process variables.

rule measurements, and protractor readings.

C. PHOTOGRAPHIC EQUIPMENT

Two photographic processes were employed in this project. The high-speed-flash photography technique was used in conjunction with statistical analysis to establish the performance of the spray generators. Late in the program high-speed motion pictures were made to study certain characteristics of the spray generators.

1. <u>High-Speed-Flash Equipment</u>.—The high-speed-flash photographic technique is a portion of a successful analytical procedure applied to droplet study which was developed at The University of Michigan several years ago. The analytical procedure involves photographing the spray as formed by the spray generator and statistically analyzing the images on the developed photographic film.

The camera is a specially constructed unit with a 3.0-in. focal length lens. The depth of focus is designed so that a 0.40- x 0.50-in. rectangular sample zone approximately 0.050 - 0.10 in. thick is recorded. The magnification is 10X. The film resolution exceeds 100 lines per millimeter. The minimum drop size that can be photographed is thus in the order of 10 microns.

The flash equipment is arranged so that the camera records a silhouette of liquid drops on the film. The duration of a single flash is in the order of one microsecond. By combining two flashes with a controlled time interval between them, thus producing a double exposure of the drop, its velocity in the plane of the sample zone may be calculated.

The arrangement of the camera, spray generator, and lights is sketched in Fig. 4. A parallel light beam passes through the spray zone to be sampled. The distinct advantage inherent in the technique is that the sample is not taken physically with the attendant errors and sampling bias, but is accomplished optically without disturbing the spray pattern or drops. The resulting flash photograph is a sample whose dimensions are controlled by the film size, magnification of the camera, and the depth of field of the lens.

The camera equipment employed on this project is the same as originally developed except for certain modifications required to prevent damage to the camera lens and lighting equipment that might result from the handling of paints.

Complete details of the photographic process are presented in Appendix C.

2. <u>High-Speed Motion-Picture Equipment</u>.—An Eastman high-speed motion-picture camera was used late in the program in an attempt to find the cause of certain random large paint droplets. The probability of finding these in the analytical technique was low because of the very short duration of the light flash. The film which is part of this report was taken at 3000 frames per second. Motion pictures were taken from both the profile of the fan-shaped spray and from above the spray. The

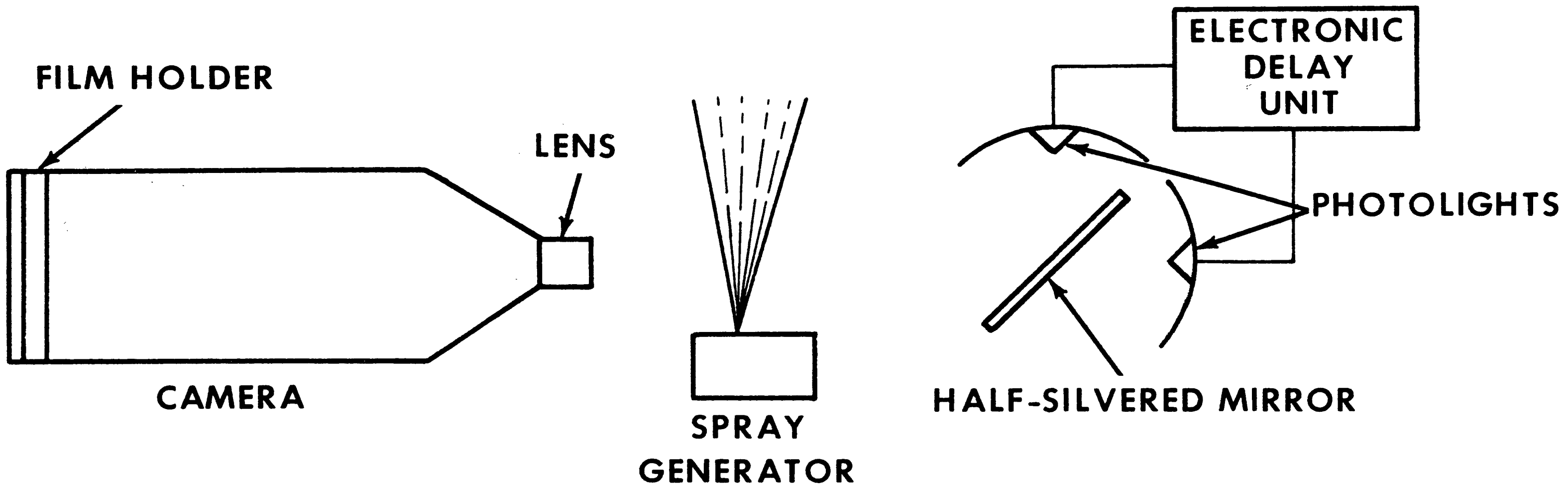


Fig. 4. Schematic diagram of photographic setup.

motion-picture technique aided understanding, but did not add to the statistical analysis necessary to the research problem. Its use was intended to provide a continuing view of the spray.

D. EQUIPMENT FOR COUNTING AND MEASURING LIQUID DROPS

Liquid-drop diameter and velocity were measured from a projected image of the drop and its successive locations as recorded on the developed film were used in the high-speed-flash photographic technique. A Jones and Lamson bench comparator adjusted to magnify the negative image 10X was used in the counting, sizing, and velocity determinations. The total magnifications of the actual drop size was 100X. The drops of liquid were measured in size ranges rather than as incividual sizes. A simple comparator scale gave both drop size and the displacement of the drop in the double image. A detailed discussion of the procedure is presented in Appendix C.

IV. EXPERIMENTAL PROCEDURE

The original programs of experimental work required a systematic study of known variables in the process of spray formation, first using water as a liquid and then attempting to correlate this information with results when using paint as the liquid. It was hoped and cautiously anticipated that such a correlation would be found that the effect of any future design changes in the spray generator could be measured by using the cheaper and simpler study of water sprays. As previously mentioned, this program was altered several times because of the immediate need for transferring promising developments to the production process with less than complete knowledge of its behavior.

A. ADJUSTMENT OF PROCESS VARIABLES

Generally, any one set of data reported herein was taken after the value of the process variables was chosen, that is, mass flow of water or paint, mass flow of air, speed of turbine, etc. After stabilization of all variables was completed, the drop-size information was obtained photographically. Each set of photographs was developed and analyzed while mechanical changes in equipment were completed for the next step in the procedure.

B. PHOTOGRAPHIC TECHNIQUE

As is shown in Fig. 4, a camera is aimed at the zone of the spray to be sampled and a short-duration flash unit is placed on the opposite side of the sample zone and directed into the camera lens. The flash must be of a time and intensity to give sharp images in the sample zone. This requirement is a matter of experience in exposing the particular film being used. The double exposure results in a double image of the same droplet.

The photographic technique is so rapid in sampling that normal fluctuations in performance of any spray generator are not averaged in each picture. Each set of data, therefore, is taken from at least six photographs taken several seconds apart while operating conditions are held as constant as possible. The number of photographs was decided upon from past experience; however, the statistical procedures were continually checked to determine the need for fewer or more representative photographic samples.

C. STATISTICAL ANALYSIS

Mass and size of each drop in the spray cannot be measured in such a research program; not even the total number of drops issuing from a generator could be determined. Because of these obvious problems, statistical analyses and interpretations were employed.

All drop-size analyses and velocity measurements were made on a routine basis. A direct measurement of each individual drop was not made, but the drops were scaled into size groups, the range of sizes in each group increasing by a geometric ratio of $\sqrt{2}$. Past experience has shown that this is fully adequate for the information desired, and smooths the data in such a way as to permit employing a minimum size of sample. If the number of drops per picture was small, all drops were sized and counted; if the number was large, random sampling procedures were instituted to eliminate bias without requiring measurement of an excessive number of drops. At least 200 drops are needed to assure adequate sampling; 400 will usually guarantee representative analysis.

The sampling procedures have made possible a variety of presentations which help to understand the merits of the spray generator.

D. HIGH-SPEED MOTION-PICTURE PHOTOGRAPHY

A series of high-speed motion pictures was taken in an attempt to learn more about the mechanism of drop formation in the case of the turbine-type spray generator. The spray generator and its spray formation were photographed from several "close-up" locations using negative film and flood-light illumination. The turbine was operated in both clockwise and counterclockwise rotation (with respect to the observer) at 20,000 rpm and at two air-water ratios. A portion of the total film also includes the pictures of the spray using paint and air combination.

E. APPLICATION OF SPRAY GENERATOR TO THE ELECTROSTATIC FIELD

During the study of the spray generators, it was decided to determine their performance while spraying paint in an electrostatic field. Each unit was transported to Detroit along with sufficient instrumentation to determine that the flow rates would be maintained in a favorable range.

The camera equipment was not used on these occasions. Although the camera and its flash equipment was not installed in the electrostatic transport field, there is reason to believe that such analysis can be carried on successfully in the field with consistent results.

V. RESULTS

The following discussion is presented with full knowledge that the research program as initially decided upon was not completed. The program as presented includes only a cursory exploration of the speed range in the case of the turbine-type generator and only limited conditions of fluid-air mass ratios in both spray generators.

Other limitations should be pointed out. All samples except a special series were taken at the center of the fan-shaped spray in the case of the turbine-type generator. A similar situation exists in the case of the impinging-sheet spray generator. In each case, however, there is considerable basis for certain recommendations.

A. THE HIGH-SPEED TURBINE-TYPE SPRAY GENERATOR

Performance data were obtained on the turbine spray generator at rotational speeds ranging from zero to 25,000 rpm while spraying paint. The paint flow rates ranged from 0.06 to 0.45 pound per minute and the air rates from 0.05 to 0.085 pound per minute. These were combined to give mass ratios of air-to-paint of 0.13 to 1.2, although not all rates or ratios are represented at each rotation speed.

The data obtained are not tabulated in this report but are shown as normalized size-distribution curves. Appendix D includes direct size-distribution curves which show the percentage of drops per unit size range as a function of the diameter (see Figs. 12-29 inclusive). These are distributions which "weight" each drop the same, regardless of size.

The data can be calculated further to give "mass-distribution curves," which show the percentage of volume (or mass) per unit size range as a function of the diameter (see Figs. 30-35 inclusive). This type of distribution shifts the distribution curve to larger sizes, because it "weights" each drop according to its volume or mass.

One additional type of plot is sometimes of value, the cumulative distribution curves. Figures 36-38 show Figs. 14, 16, and 20, respectively, replotted as cumulative probability curves. The deviation from a straight line on such a plot indicates to some degree the deviation of the distribution from a normal probability curve, and therefore indicates the selectivity of the process. The slope of the curve indicates the sharpness of the peak of the distribution curve, or the approach to uniformity of the drops.

An examination of the direct size-distribution curves shows that a numerical distribution gives peaks or modes of the curves between 30 and 50 microns. This is so common that the few curves falling outside this range can almost be written off as freaks. The distribution also shows a mode which is fairly broad, the size class with the maximum number of drops usually having a close second in an adjacent size class. The "shoulders" of the curve fall off rapidly, but almost all curves include drops from less than 10 to 200 microns. No bimodal curves appear (except at zero rotation), although a few plateaus appear.

The mass-distribution curves have modes shifted to the sizes of 40 to 80 microns, and usually the mode is much sharper than for the direct size-distribution curves. The extension of the calculations gives smooth data for these curves, thus indicating a good self-consistency of the data.

The arithmetic average diameter of drops, computed by averaging the total count of drops in the various size ranges, is a simple way of summarizing and comparing these sets of data. Figure 5 includes the average diameters of each set of data presented individually in Appendix D with curves faired-in to indicate apparent trends in the data for each rotational speed. The 5000-rpm data are the only ones which show a significant change with air-liquid ratio. Speeds of 10,000 rpm to 15,000 rpm appear to develop the smallest average drop diameter.

All data presented above were taken at a single location near the center of the fan-shaped spray pattern of the turbine-type generator. Near the end of the program reported herein, a series of samples was taken across the fan, giving direct size-distribution curves in Figs. 39-46 in Appendix D. These curves show larger drops in the sample near the outside of the spray pattern, with the greatest effect on the "near" side of the rotating impeller. Figure 6 shows the shift in the average diameter with location across the fan pattern.

The effect of the variation in drop size across the fan is more significant than any variation shown in Fig. 5 for the effect of process variables. For comparison, a point for 20,000 rpm is shown on Fig. 5 taken from a composite of locations 2 and 3 in the center of the fan. The points for locations 1 and 4 are much higher than all other data points shown and an average for the entire spray would be higher also.

Analyses using both water and paint indicate that speeds of rotation in excess of 15,000 rpm do not affect the particle sizes significantly. The sizes appear to increase slightly with increasing speed. This appearance might well be deceiving, however, for the analysis of the entire spray pattern and combination of velocity measurements to give temporal distribution could give a different interpretation

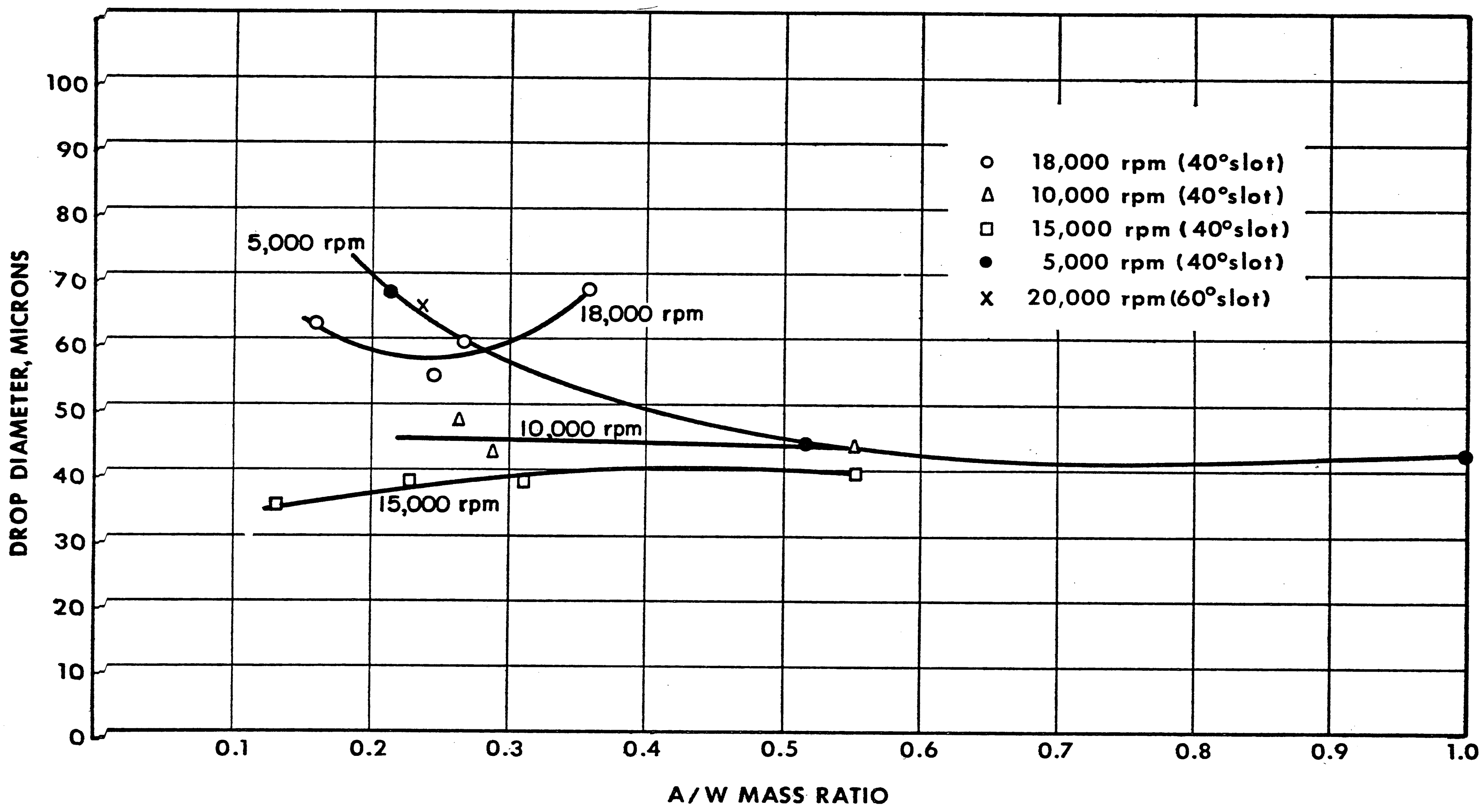


Fig. 5. Arithmetic average diameters of paint drops in center of spray fan of turbine-type spray generator.

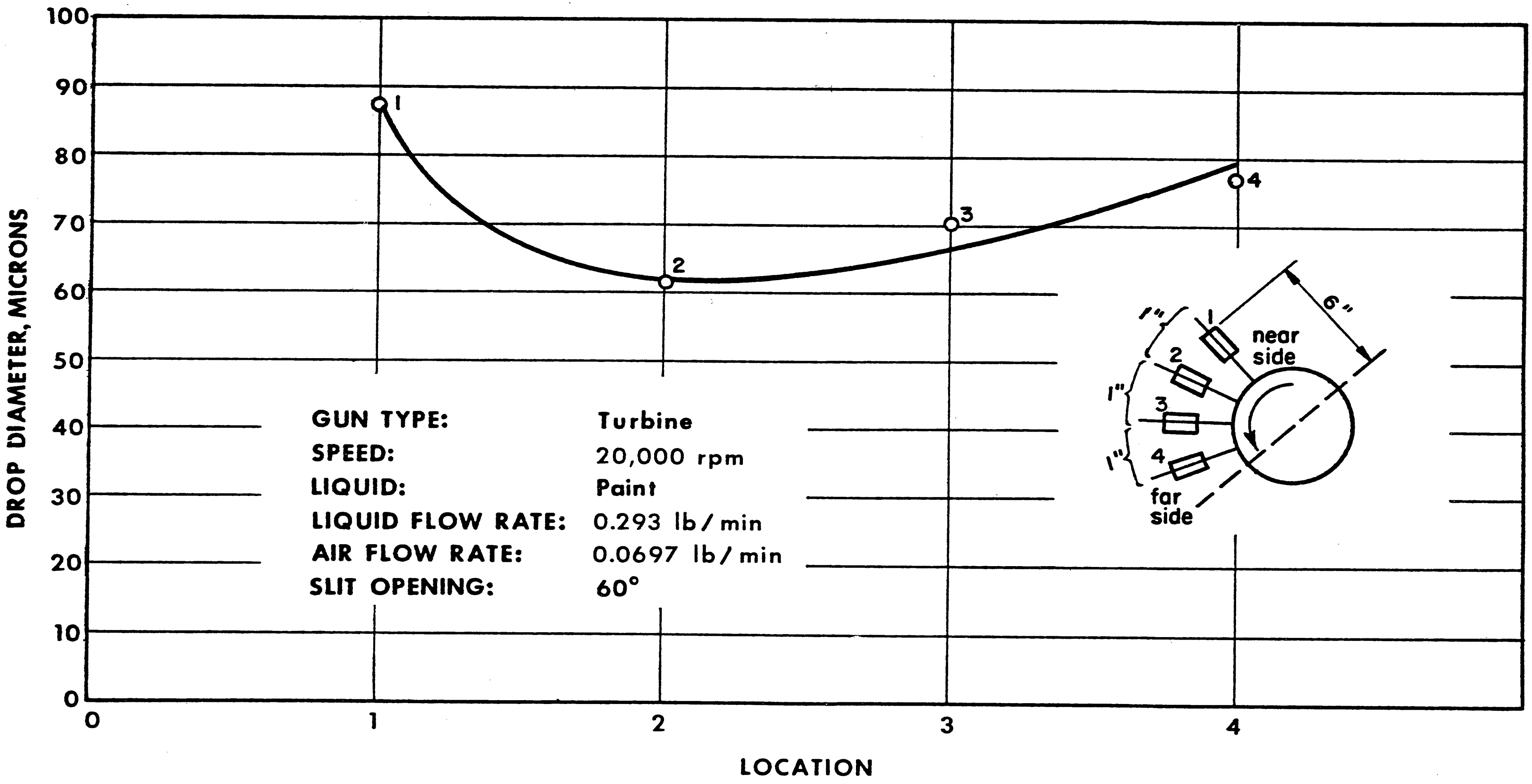


Fig. 6. Arithmetic average diameters of paint drops in different zones of spray fan from turbine-type spray generator.

from the spatial distribution shown here.* Since the data were incomplete, no effort was made to compute such analyses.

Another way to make the point of the preceding paragraph would be to point out that the nonuniformity of drop sizes across the spray fan was not measured at other speeds. Increasing the speed also increases the velocities of the drops somewhat, and this increase might be selective, giving a different spatial and temporal trend. The mechanism of drop formation by the turbine-type generator is far from clear from the survey type of information reported here. The insensitiveness of the spatial distribution to speed, to air-liquid ratio, and to the shift from water to paint, all seem to support a theory of mechanical impact in the impeller as the major energy source for drop formation. The one pulse per revolution revealed by the motion pictures must be superimposed on that concept, for mechanical impact appears to be a function of vane frequency and not rpm.

Figure 7 shows a plot of arithmetic average diameter for water frops generated by the turbine-type unit at 25,000 rpm. The direct size-distribution curves and the size ranges appear the same as those for paint. They are shown as Figs. 48 and 49 in Appendix D.

An important item to be noted from the data and from the project experience is that the difference in performance with water and paint is not nearly as great as would be expected from the difference in physical properties of the fluids. This is true for both the turbine-type and the impinging-sheet spray generators. This observation is worthy of investigation from the viewpoint of the painting process, for if minor variations in paint properties do not result in variation in drop sizes, then the difference in product quality with different thinners can be explained only by events transpiring during the period of transport to the surface and the spreading on the surface. As indicated in the introduction to this report, our efforts were restricted to the drop-generation phase of the integrated process.

The idea of average diameters must be regarded with caution, for the averages are of the sizes appearing simultaneously in the photographs, sometimes called a "spatial" average. An average for the spray produced per unit of time, a "temporal" average, must incorporate the velocities of the drops. All the distribution curves are subject to this modification before they can be said to represent the spray approaching the painted surface, for this is strictly a temporal average.

The velocities of most of the drops were measured, but the restriction of the samples to the center portions of the patterns reduces their significance to simple orders of magnitude. In any one size classification, the velocity of liquid drops at the sampling location varied over a wide range. The variation could readily

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*A simple analogy may be given by visualizing an aerial photograph of a busy arterial highway. The proportion of the cars to trucks in the instantaneous photograph would be a spatial distribution. The different average velocities of the cars and trucks would give a different proportion passing a single intersection per hour. This is a temporal distribution.

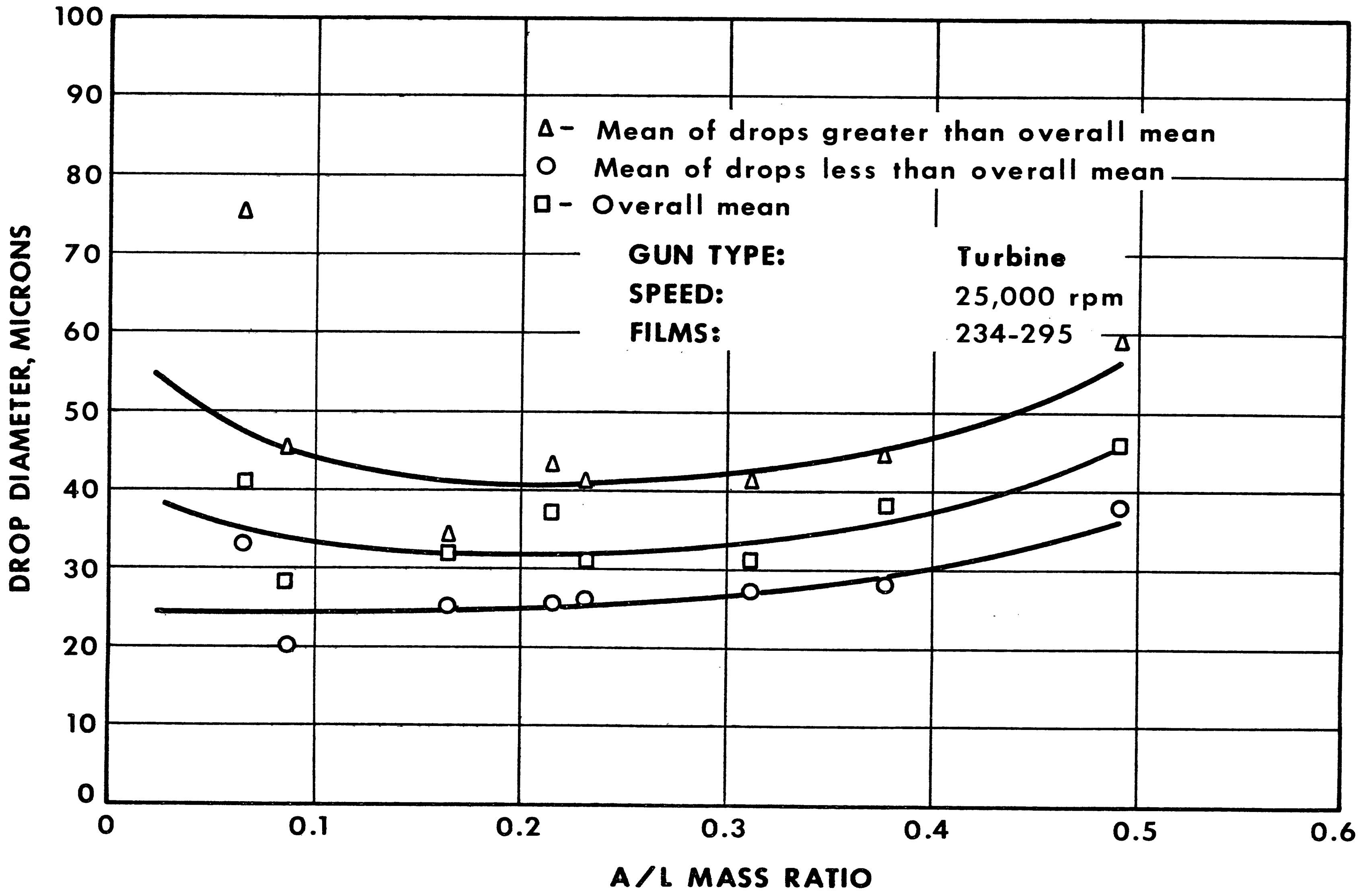


Fig. 7. Arithmetic average diameters of water drops in center of spray fan from turbine-type spray generator.

be attributed to momentum exchanges rather than any unusual feature of the spray generator. With a turbine speed of 20,000 rpm, the mean drop velocity in the 56-80 micron range was 55 ft/sec; in the 80-113 micron range, 85 ft/sec; in the 40-56 micron range, 35 ft/sec; and in the 28-40 micron range, 35 ft/sec. This distribution is shown in Fig. 8. It is of particular interest to note that the rate of change of velocity was high, apparently due to the low air-liquid ratio at which this unit performed. There are no data to support this point.

B. THE IMPINGING-SHEET GENERATOR

A series of test runs was made with different ratios of air to water, the sample zone being the same for all runs. The samples were taken at a point slightly more than three inches from the face of the generator and at the point of apparent greatest drop population (number of drops per unit volume). Figure 9 shows the arithmetic average diameter as a function of the air-water ratio (see Figs. 50 and 51). The average drop size decreases slightly as the air-water ratio increases.

This spray is essentially uniform all around the generator axis; therefore, the velocity distribution could be of more value. It is shown in Fig. 10, where each curve corresponds to a drop-size range (see Figs. 52 and 53). The fraction of the drops of any given size range found at each velocity shows some regularity. The bulk of the drops at the sample location have low velocities, with a spectrum of velocities apparent for the smaller drops. The larger drops divide sharply into velocities below 15 or above 40 ft/sec. Probably the higher velocity corresponds to the exit velocity from the generator, and the lower velocity is that of the entrained mass of liquid drops and air which forms quickly after emergence from the annular slits. Most of the energy given up by the faster drops is probably to to found in air entrained from the outside, not the air emerging from the generator.

The impinging-sheet generator was also run with paint, and at the same time a study was made of the variation of drop size as the sample zone was moved to each side of the zone of highest drop population. Figure 11 shows the direct size distribution at the centerline. The solid curves were made with a metal fluid diaphragm, and the dashed curves with a Teflon diaphragm; all were at an air-paint mass ratio of 1.5. The considerably larger drops obtained with the Teflon diaphragm may be the result of difference in wettability of paint for that surface, but unfortunately this experimental model might also have been operated with slightly different centering of the floating parts, which could also explain the variation.

Work was suspended on the impinging-sheet spray generator after initial trials indicated that it produced slightly larger drop sizes while requiring higher airflow rates. This decision was based on a short-range objective, however, and does not suggest that the idea lacks merit. The only unit built included only the first consideration of design parameters. This unit proved to be difficult to adjust; therefore much of the information that was initially gathered must be viewed accordingly.

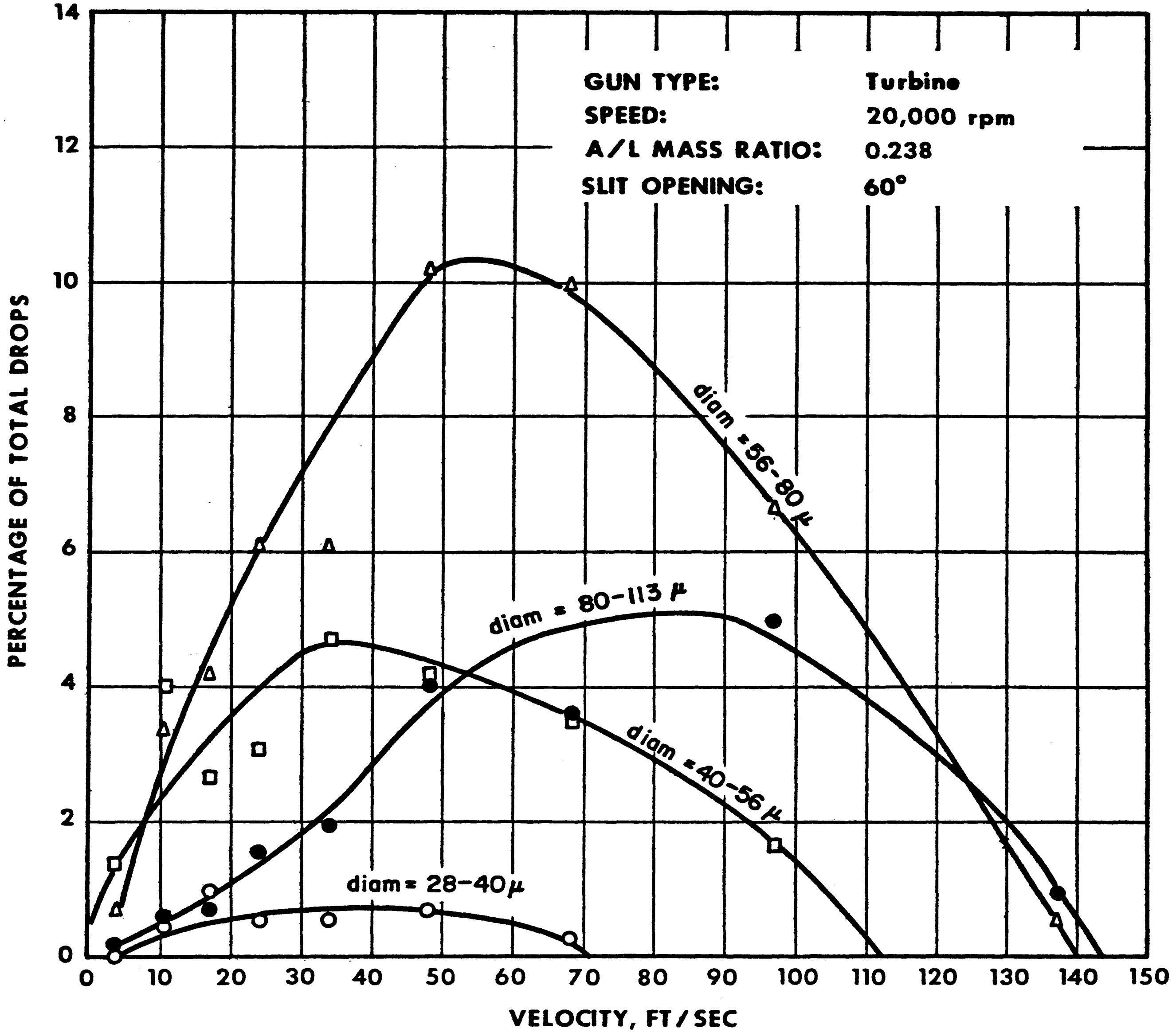


Fig. 8. Percentage of total drops in the entire spray plotted vs. velocity, ft/sec.

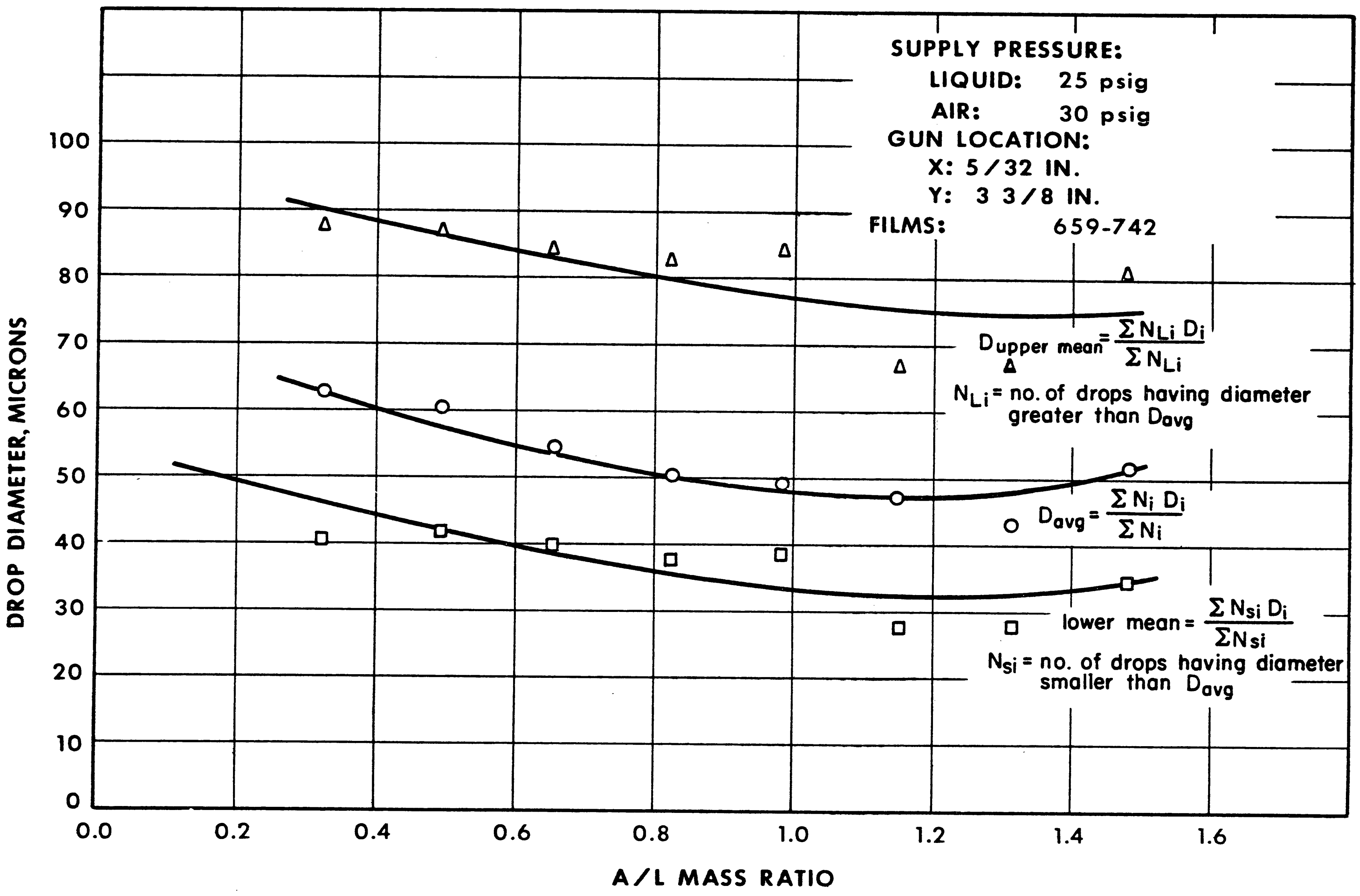


Fig. 9. Arithmetic average diameters of water drops at zone of maximum drop population from impinging-sheet spray generator.

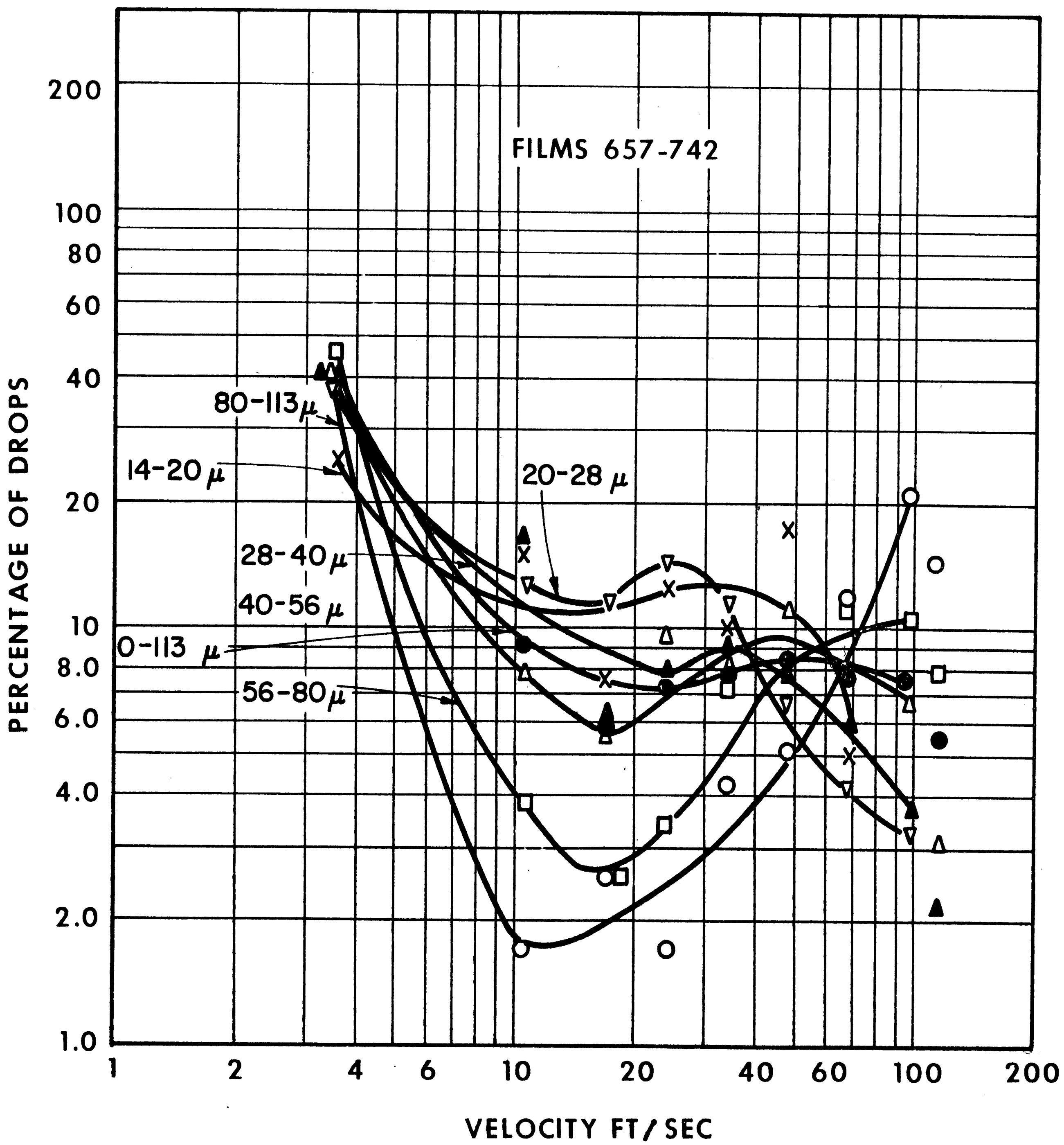


Fig. 10. Velocity distribution of water drops in zone of maximum drop population from impinging-sheet spray generator.

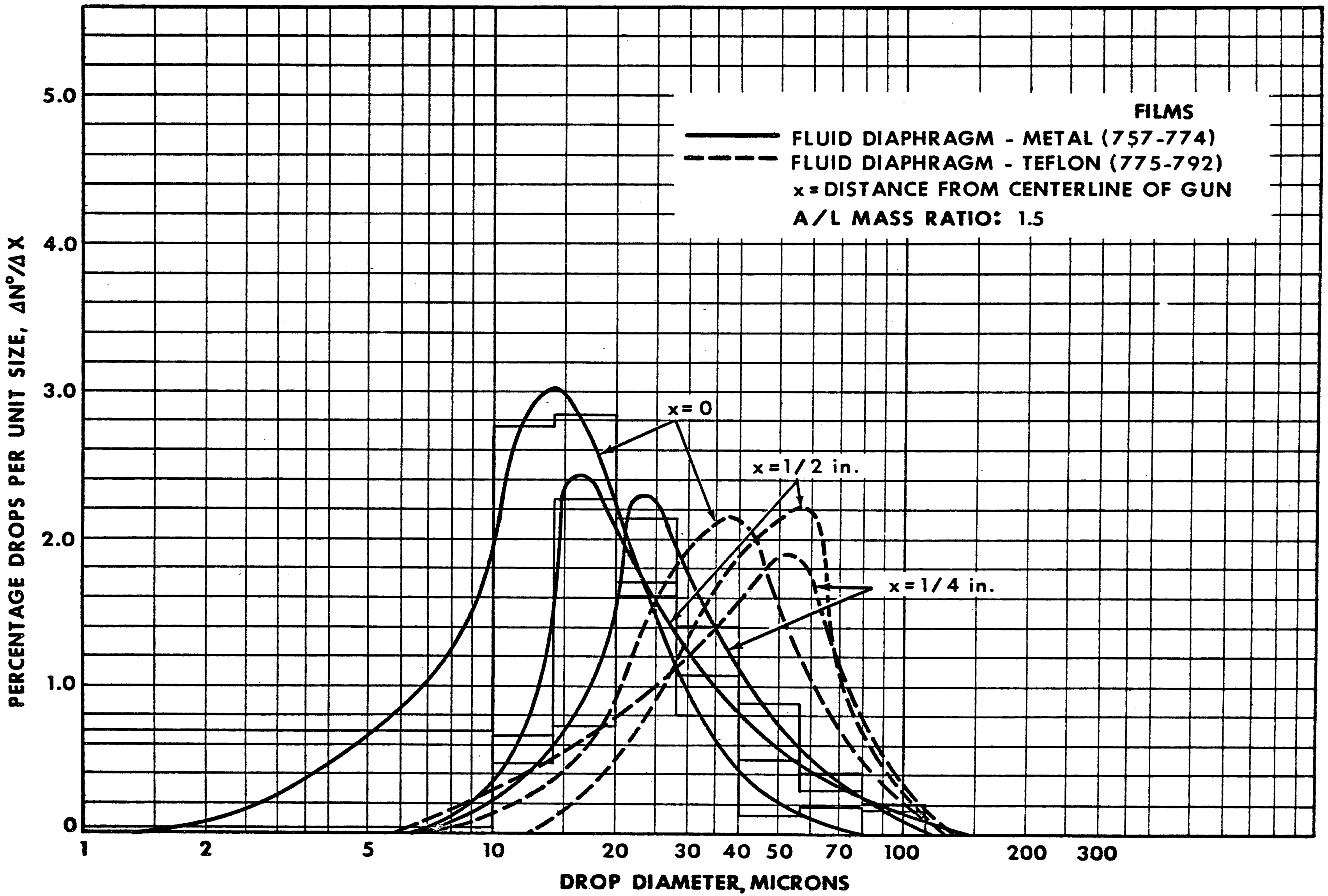


Fig. 11. Direct size distribution of paint drops at various points in spray from impinging-sheet spray generator.

C. INSTALLATION OF SPRAY GENERATORS IN THE ELECTROSTATIC TRANSPORT FIELD

Since the observations of the spray generators in the electrostatic field were made without the aid of measuring instrumentation, the results are necessarily confined to visual observations and comparisons that can be made by a person who has considerable experience with the overall painting process.

Both the impinging-sheet spray generator and the turbine-type spray generator were installed and operated in the electrostatic field. The spray generated by both units showed a marked tendency to be insensitive to action of the field. It might be assumed that a large percentage of the paint drops were electrically neutral.

The paint pattern on the panel to be coated at 38 in. from the spray generators was narrower than the pattern produced by the present rotating-cup generator. The spray from the impinging-sheet spray generator concentrated in a relatively smaller area than anticipated under action of the field and demonstrated a tendency to deposit paint at a velocity higher than anticipated. The test was further complicated by the problem of adjustment of the air and liquid streams.

The spray from the turbine-type generator was fan-shaped and, therefore, concentrated on a narrow vertical portion of the panel to be coated. This feature was planned for in the initial design. As in the case of the impinging-sheet spray generator, the issuing spray seemed to be only slightly affected by the electrostatic field. It was observed that the spray generator collected paint on itself more rapidly when charged than grounded.

Several theories for the above observations could be advanced, but confirmation of these theories would require carefully controlled experimental work before the design of additional spray apparatus should proceed.

D. RESULTS OF HIGH-SPEED MOTION-PICTURE PHOTOGRAPHY

An edited film showing the action of the turbine-type spray generator is a portion of this report. Several items of importance are contributed by these pictures. It will be noted that there is a periodic growth and decay of the volume of the issuing spray. We believe that a portion of this periodic performance is due to the method used in this first unit for regulating the liquid volume to the high-speed rotor. The regulating orifice was not installed in the best location. It is further observed that this periodic action can be correlated to the speed of the rotor, thus suggesting the possibility of a resonant system. Measurements sufficient to pursue this thought are not available.

Visual observations of the coated panel showed that an occasional large drop issued from the spray generator. The film shows that, when a large volume of drops issues from the generator, an accumulation of liquid seems to issue in large drops from the cone side of the rotor housing. We believe that a more uniform flow rate to the rotor and a knowledge of the possible resonant condition will make it possible to eliminate this source of large drops. It will also be observed that a liquid accumulation occurs on an exterior surface and breaks loose at irregular intervals. Relief of these projecting edges would stop the accumulation.

VI. CONCLUSIONS AND RECOMMENDATIONS

The discussion in the preceding section emphasizes the partial information available at this time; therefore specific answers have not been arrived at. However, recommendations can be made.

The turbine-type spray appears feasible as a device for producing a paint spray in the drop-size range now accepted for production painting. Although the single research model studied is hardly capable of leading to a commercial model without changes, these changes can be determined by systematic investigation as soon as a desired drop-size spectrum can be specified.

Because of an unfavorable visual evaluation of the impinging-sheet spray generator in the electrostatic field, further development work was halted. This unit still holds promise. Indicated changes of design parameters and greater ease of adjustment could easily alter the performance of this unit, so that its initial promise of providing a relatively trouble-free unit would be realized. Again, knowing the drop-size spectrum which will produce a quality product in a known transport mechanism, changes can be contemplated with some degree of certainty of success.

The information which has been presented leads to one predominant conclusion. The functioning of various component parts of the process must be understood and correlated if consistant results are to be achieved. We do not believe the process has reached this final goal.

We recommend that a systematic study of the process of production painting should be undertaken, with the objective of determining the key variables to be specified and controlled to achieve a desired result. This involves all three major phases: namely, drop generation, drop transport, and drop deposition.

Until such a study is undertaken, it is not possible to state the requirements for a drop generator or any other component of the process. It is possible only to experiment by trial and error.

APPENDICES

APPENDIX A

DETAILED DESCRIPTION AND DRAWINGS OF HIGH-SPEED TURBINE

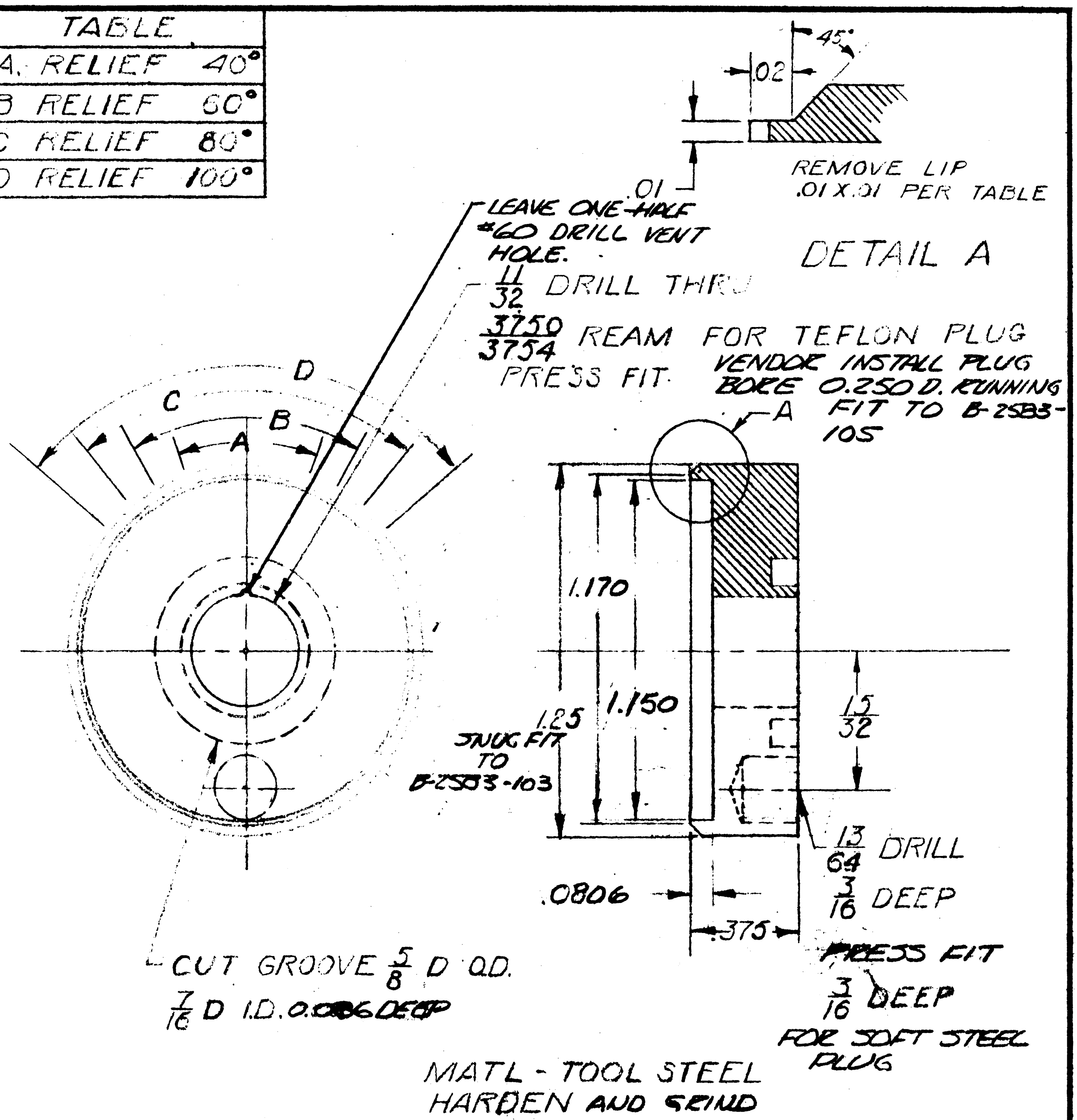
Drawings 2583-100 to 2583-107 inclusive are the detailed drawings and assembly of the experimental turbine-type spray generator. The air turbine was purchased from Onsrud Machine Co., Chicago, Illinois. All parts were made in local machine shops. The unit was assembled by the research mechanics.

Several items gave trouble on this assembly. The outside of the turbine housing was eccentric with the turbine shaft. This problem was partially solved by re-work. The collet which was used to hold the shaft of the turbine rotor was reasonably good but not good enough to prevent eccentric action of the rotor in its housing. The life of the outboard bearing was therefore limited. The bearing was required, however, to prevent out-of-balance vibration and interference with the cone-shaped housing.

It must be remembered that this unit was assembled for one purpose, to explore the possibility of impact spray generation.

There are several design features, clearances, speeds, and liquid and air feed locations, which undoubtedly have an effect on the performance of the turbine unit. A thorough knowledge of the effect of these changes would lead to a device that would perform consistently to advantage in the overall process.

TABLE	
A. RELIEF	40°
B RELIEF	60°
C RELIEF	80°
D RELIEF	100°



REMOVE LIP
.01 X .01 PER TABLE

DETAIL A

LEAVE ONE-HALF
#60 DRILL VENT
HOLE.

11/32 DRILL THRU

3750/3754 REAM FOR TEFLON PLUG
PRESS FIT

VENDOR INSTALL PLUG
BORE 0.250 D. RUNNING
FIT TO B-2583-
105

SNUG FIT
TO
B-2583-103

13/64 DRILL
3/16 DEEP

PRESS FIT
3/16 DEEP
FOR SOFT STEEL
PLUG

CUT GROOVE 5/8 D O.D.
7/16 D I.D. 0.0086 DEEP

MATL - TOOL STEEL
HARDEN AND GRIND

MAKE 4 PARTS
1 EACH AS PER. TABLE

HOLD BOTH ENDS OF CYLINDER AND .0841 RECESS ∥ AND
⊥ TO CYLINDER AXIS T.I.R. 0.0002
1.250; 1.170; 1.150 AND 0.250 D. CONCENTRIC T.I.R. 0.0001

ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR MICHIGAN

PROJECT 2583

CLASSIFICATION

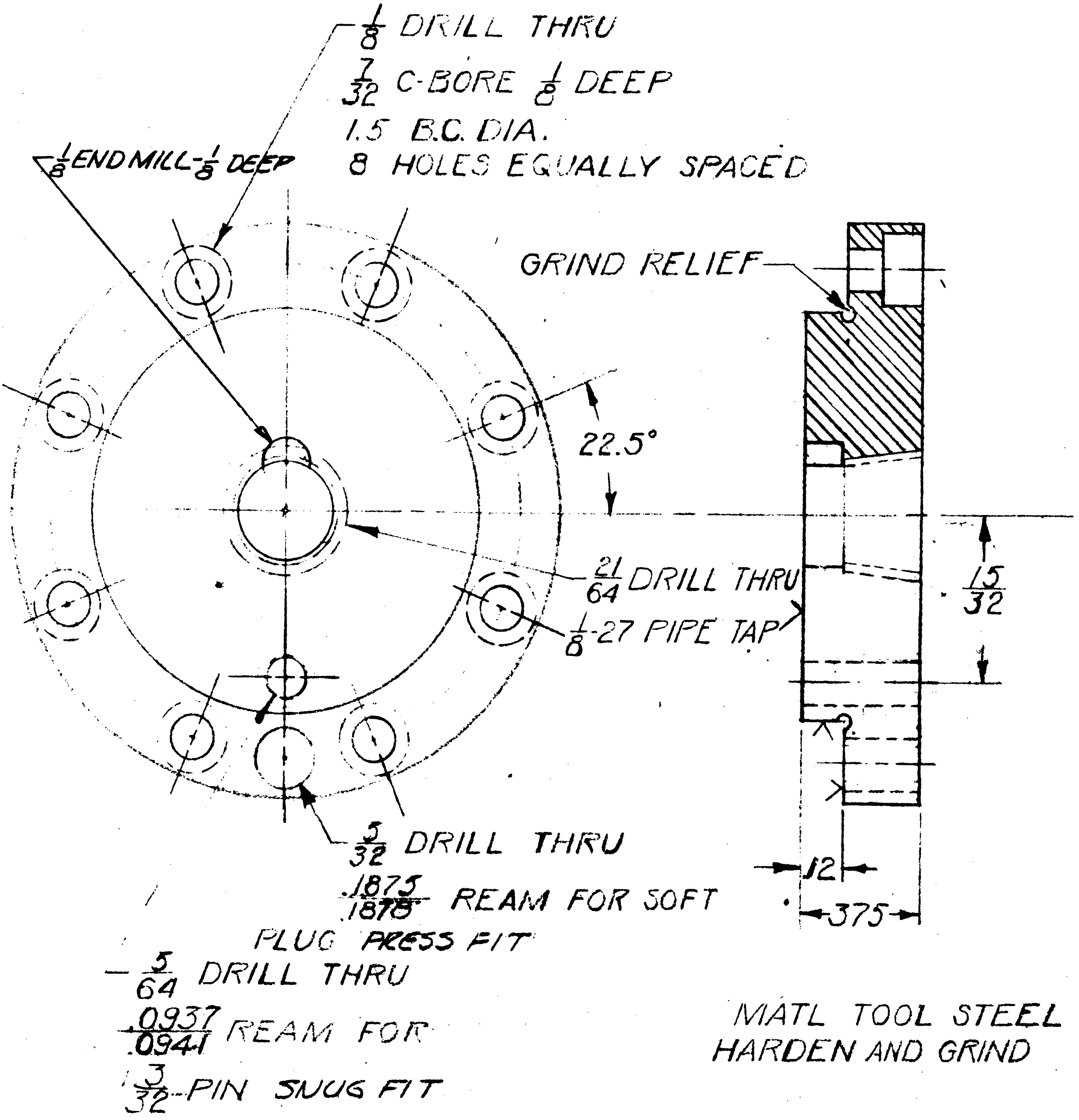
ISSUE | DATE

DESIGNED BY
DRAWN BY R.C. SCOTT
CHECKED BY
APPROVED BY
SCALE 2" TO 1"
DATE JAN 30-1957

TITLE PAINT SPRAY NOZZLE
PLATE

DWG. NO. A- 2583 -106

1000 5-53 DETROIT BLUE PRINT & SUPPLY CO.



MATL TOOL STEEL
HARDEN AND GRIND

ISSUE	DATE

ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR MICHIGAN

PROJECT 2583

CLASSIFICATION

DESIGNED BY
DRAWN BY R.C. SCOTT
CHECKED BY
APPROVED BY
SCALE 2 TO 1
DATE JAN. 30-1957

TITLE PAINT SPRAY NOZZLE PLATE - RETAINER

DWG. NO. A- 2583 -107

1000 6-55 DETROIT BLUE PRINT & SUPPLY CO.

APPENDIX B

DETAILED DESCRIPTION AND DRAWINGS OF IMPINGING-SHEET GENERATOR

Drawings 2583-200 and 2583-201 show the detailed drawings and assembly of the first and only impinging-sheet spray generator. Although considerable performance data were taken on this unit, such details as the area of openings were not obtained due to the uncertainty of the action of the spring adjustments. The component concentric parts of the assembly did not stay in location; therefore adjustment to provide a visually suitable spray was required on each occasion after an experimental test run was started.

As a result of the difficulties with the first unit, a self-regulating, more readily adjusted generator for both single-color and multi-color operation was designed. Neither the Single Line or the Dual Line impinging-sheet generator was built. These design drawings are included in the report for possible future consideration since it is the opinion of the research group that further work on this unit might be highly desirable. Thorough knowledge of a number of design and process variables must be known before this unit can be successfully used on the expected variation of processes.

APPENDIX C

DETAILS OF PHOTOGRAPHIC PROCESS

The experimental procedures attempted to analyze optically a spray either on a quantitative or a qualitative basis. The quantitative procedure results in still pictures which are then analyzed for drop-size and drop-velocity data. The essential elements for this procedure are a low-magnification camera, a high-contrast film, twin high-intensity, short-duration light flashes, and a Jones and Lamson bench comparator. The qualitative analysis was done through the study of films taken with a high-speed camera about a foot from the spray gun.

QUANTITATIVE ANALYSIS, METHOD, AND EQUIPMENT

By using a proven photographic technique, small pictorial samples of the "living" spray are taken and then analyzed. To produce the picture, a simple photographic setup is used having a light source, a subject, a lens, and a camera.

CAMERA AND LENS

The still camera used was a simple black light-tight box, with a film-plate holder mounted opposite a threaded lens mounting. A 100-mm Argus, F:4.5, Tele-Sandmar lens was used as it allowed 6-1/4 in. from the lens to the subject. This distance kept the lens from becoming wet by water or paint. Also a ten-fold magnification of the subject was produced with this setup. The camera was 44-1/16 in. long as measured from the film surface to the outermost extension of the lens.

FILM AND DEVELOPMENT

The film was 4- x 5-in. Kodak Contrast Process Orthochromatic sheets. This film has a high-contrast characteristic and high-resolution ability. These properties enhance the detection and analysis of small drops.

After exposure, the film was developed in twelve-sheet capacity, light-tight development tanks. The negatives were developed to an optimum where the small drops were clearly visible and the large drops slightly fuzzy. D-11 developer and F-5 fixer were used throughout.

ILLUMINATION

Since a shutterless camera was used in all photographs, the light source served the dual purpose of illumination and lens shutter. For this purpose, a General Electric Photolight Unit* was used which produces light by the discharge of a capacitor through an arc. The duration of the flash is about 1 microsecond. All exposures were double so that the drop velocity could be determined. For this, a half-silvered mirror was set so as to bend the light beams together. An electronic delay unit fired the two photolights consecutively, 23 microseconds apart.

COUNTING AND MEASURING DROPS

The drop diameter and velocity were measured from a projected image of the negative. A Jones and Lamson bench comparator was set up to magnify the negative image ten times. The measured image was therefore 100 times the size of the actual drop.

The drop diameters were not measured exactly in microns, but were compared to an arbitrarily chosen scale. The divisions of the scale were selected approximately by starting with ten microns and multiplying by a factor of $\sqrt{2}$. The micron ranges used were: 0-10, 10-14, 14-20, 20-28, 28-40, 40-56, 56-80, 80-113, and 113-160.

The drop velocities were measured using the same selected scale, but the ranges were proportional to velocity in feet per second.

A clear cellulose-acetate sheet scratched with the necessary markings served as a gauge in each case.

QUALITATIVE ANALYSIS METHOD AND EQUIPMENT

This analytic procedure attempted to get an overall view of the spray with a high-speed motion-picture technique. This is a gross technique compared to the still picture method, but was more quantitative than an actual visual observation. Professional photographers used a Kodak high-speed camera capable of film speeds of 3000 frames per second. Cine-Kodak, Tri-X negative film was decided upon so that pictures similar to the still negatives would be obtained. Standard flood lamps illuminated the spray and the gun. The surface of the gun was dulled with black paint so that it would blend with the surroundings; thus the spray would be emphasized. All the exposed film was developed commercially.

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*General Electric Photolight, Catalog 9364688G1.

SAMPLE CALCULATIONS FROM ORIGINAL DATA

The data collected are material for a long series of calculations to determine in various forms spray characteristics, such as size distribution, mass distribution, and velocity distribution. These calculations fall into two major groups, those performed on the data for each individual location in the spray and those performed to combine data from each location into results for the entire spray. For individual locations in sprays, a wide variety of data was taken. But in only one case were data taken over several locations in one spray. A series of calculations for one location are detailed below for the turbine gun with paint as a liquid. The paint rate was 0.293 lb/min; the air rate, 0.0697 lb/min; and the impeller speed was 20,000 rpm. This set is the second of a series of four taken of a traverse of the spray from a 60° slot, negatives 959-964.

CALCULATIONS FOR ONE LOCATION IN A SPRAY

The characteristics which can be computed from a single table of original data for one location in a spray include the size distribution, mass distribution, various "average" diameters and velocity of drops. Of these only the size distribution, usually converted into some average diameter, and the mass concentration are important in themselves.

The size distribution may be expressed as a cumulative or a direct curve. For purposes of comparison of either type of curve, all numbers are first converted to percentages, or rather to a spray consisting of exactly 100 drops. The summation of all six photographs taken at the location selected gives actual numbers of drops, designated in Table I by ΔN, for each size range, ΔX. The total number of drops is 271. Reducing this to 100 reduces proportionally the values for each size range, giving the percentages, ΔN°, for each size range, ΔX. The values of ΔN° can be summed successively to give the values of the total percentage of drops smaller than the upper limit of each size range. These successive sums can be plotted as a function of size, giving the cumulative curve in Fig. 47.

The direct distribution curve is more sensitive and shows more sharply the sizes which include the majority of the drops. For this curve the percentage of drops in a size range is assumed to be evenly distributed over the size range. Then the ratio $\Delta N^\circ/\Delta X$ is the percentage of drops per unit size; which might be called the numerical intensity. The values in Table I under that heading are plotted against size in Fig. 40. The stepped curve corresponds to the actual values given by the assumed distribution. The smoothed curve is an estimate of the probable distribution which would be obtained if the increments of size range were decreased to infinitesimal values. A maximum numerical intensity is found at a size of 40-56 microns.

An average diameter with respect to number of drops can be computed as that diameter for 100 identical drops which gives a total of diameters equal to the actual total for the 100 drops of varied sizes. For the data in Table I, this diameter is 61.5 microns.

TABLE I

Size Range, microns	Size Difference ΔX, microns	Total No. of Drops per Size Range ΔN	% per Size Range $\Delta N°$	Cumulative Percent	% per Size Range $\Delta N°/\Delta X$	Total Volume per Size Range ΔV, ft^3	% Volume per Size Range $\Delta V°/\Delta X$
0-10	10	0	0	0	0	0	0
10-14	4	0	0	0	0	0	0
14-20	6	0	0	0	0	0	0
20-28	8	1	.4	.4	.05	$9.6x10^{-16}$	$2.17x10^{-3}$
28-40	12	16	5.9	6.3	.49	$427x10^{-14}$	$6.58x10^{-2}$
40-56	16	105	38.8	45.1	2.42	$7910x10^{-14}$	.914
56-80	24	119	43.9	89.	1.83	$25500x10^{-14}$	1.96
80-113	33	28	10.3	99.3	.31	$16800x10^{-14}$	.933
113-160	47	2	.07	100.	.02	$3450x10^{-14}$	.136

For

Gun type: turbine	Air rate: .0697 lb/min
Speed: 20,000 rpm	Air-liquid mass ratio: .238
Liquid: paint	Films: 959-964
Liquid rate: .293 lb/min	Slit opening: 60°

The mass of the representative 100 drops can be calculated by simple geometric relations, since the drops are generally spherical. This calculation must be made size range by size range, resulting in the mass for each size range, ΔM, which can be calculated in percentages, ΔM°. The percentage of mass per unit size, $\Delta M^{\circ}/\Delta X$, which might be called the mass intensity, is analogous to the numerical intensity. Being a function of the cube of the diameter, the values of the mass intensity reflect any irregularities in the numerical distribution curve. The stepped and smoothed curves for the data in Table I are shown in Fig. 44. The maximum occurs at a size of 56 to 80 microns.

The velocity of the drop perpendicular to the axis of the camera may be estimated from the distance between drop images, if the interval between light flashes is not so short as to "stop" all drops. The effective interval between flashes must be known and the distance between drop images must be measured. The interval between flashes was known to be 23 microseconds. The measured velocities were anywhere between slightly greater than zero to greater than 113 feet per second.

APPENDIX D

REPRESENTATION OF ALL DATA

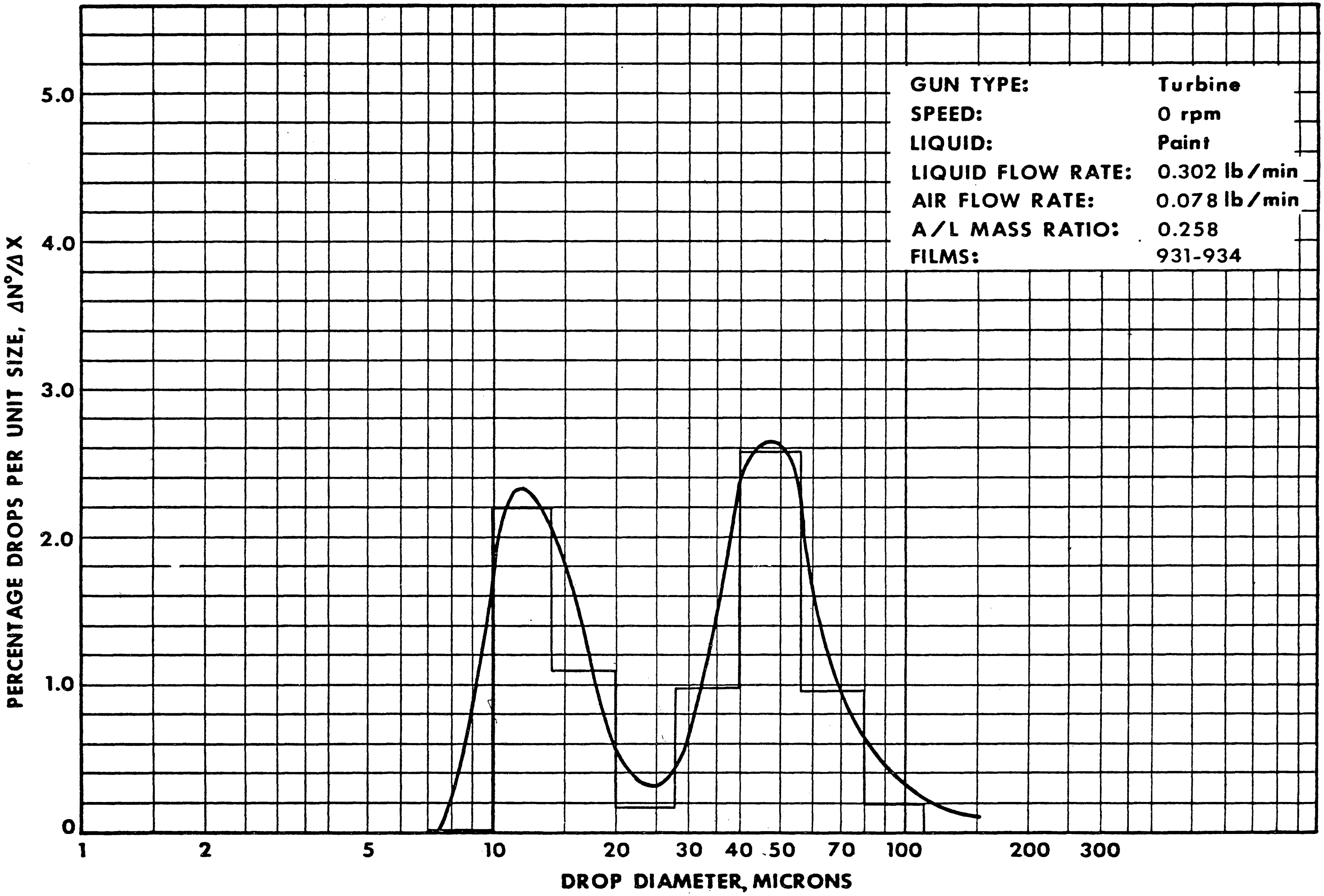

Fig. 12. Direct size distribution.

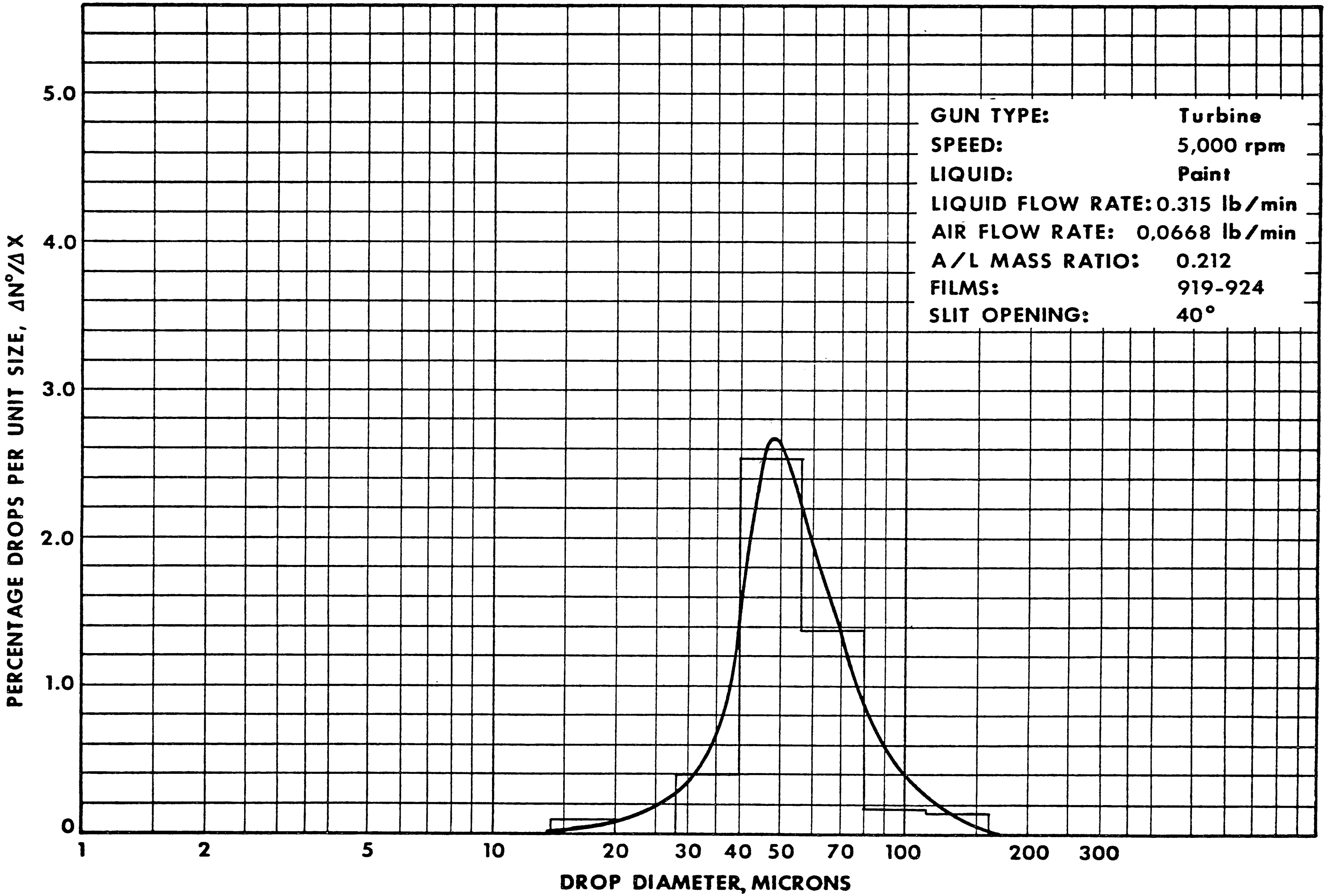

Fig. 13. Direct size distribution.

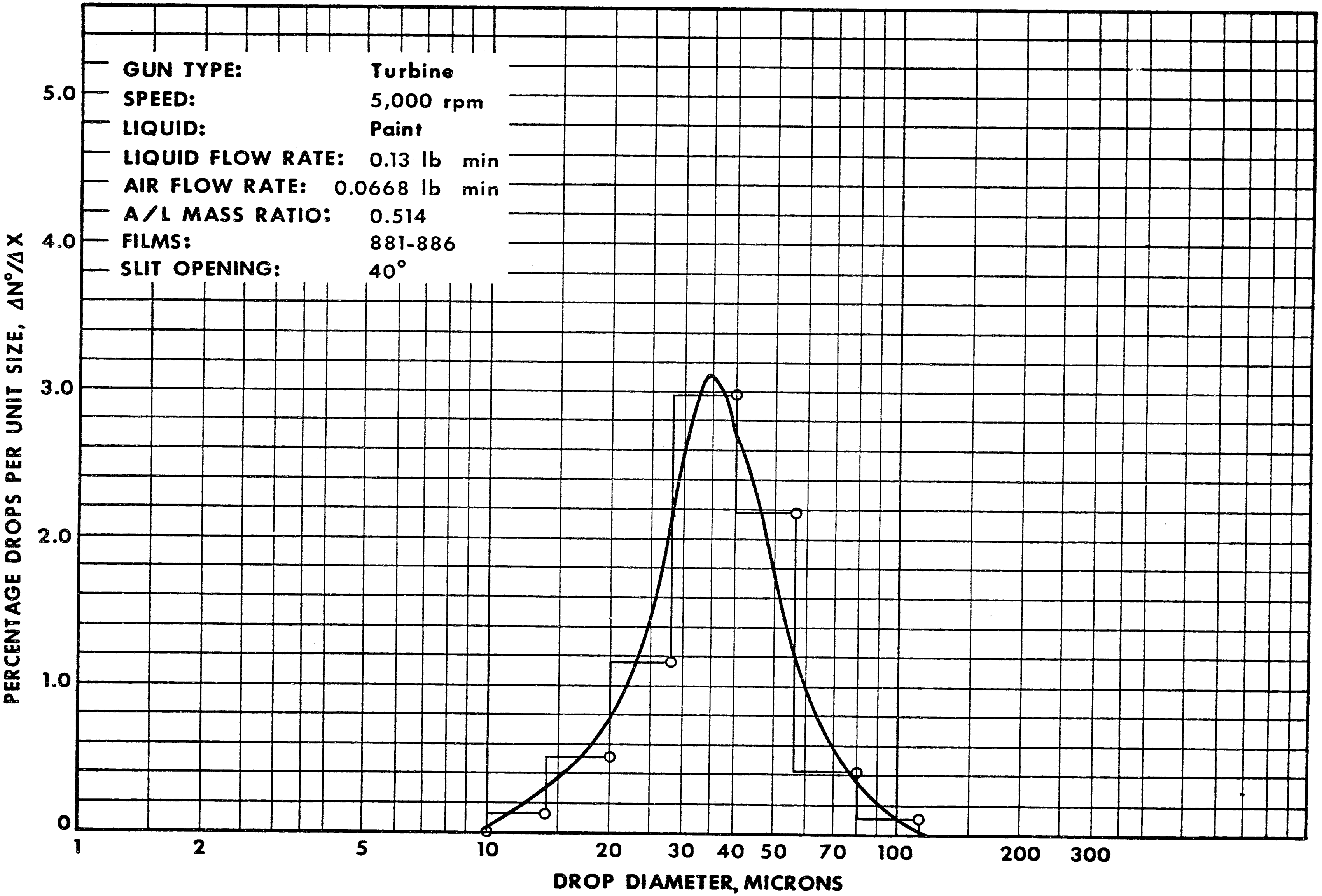

Fig. 14. Direct size distribution.

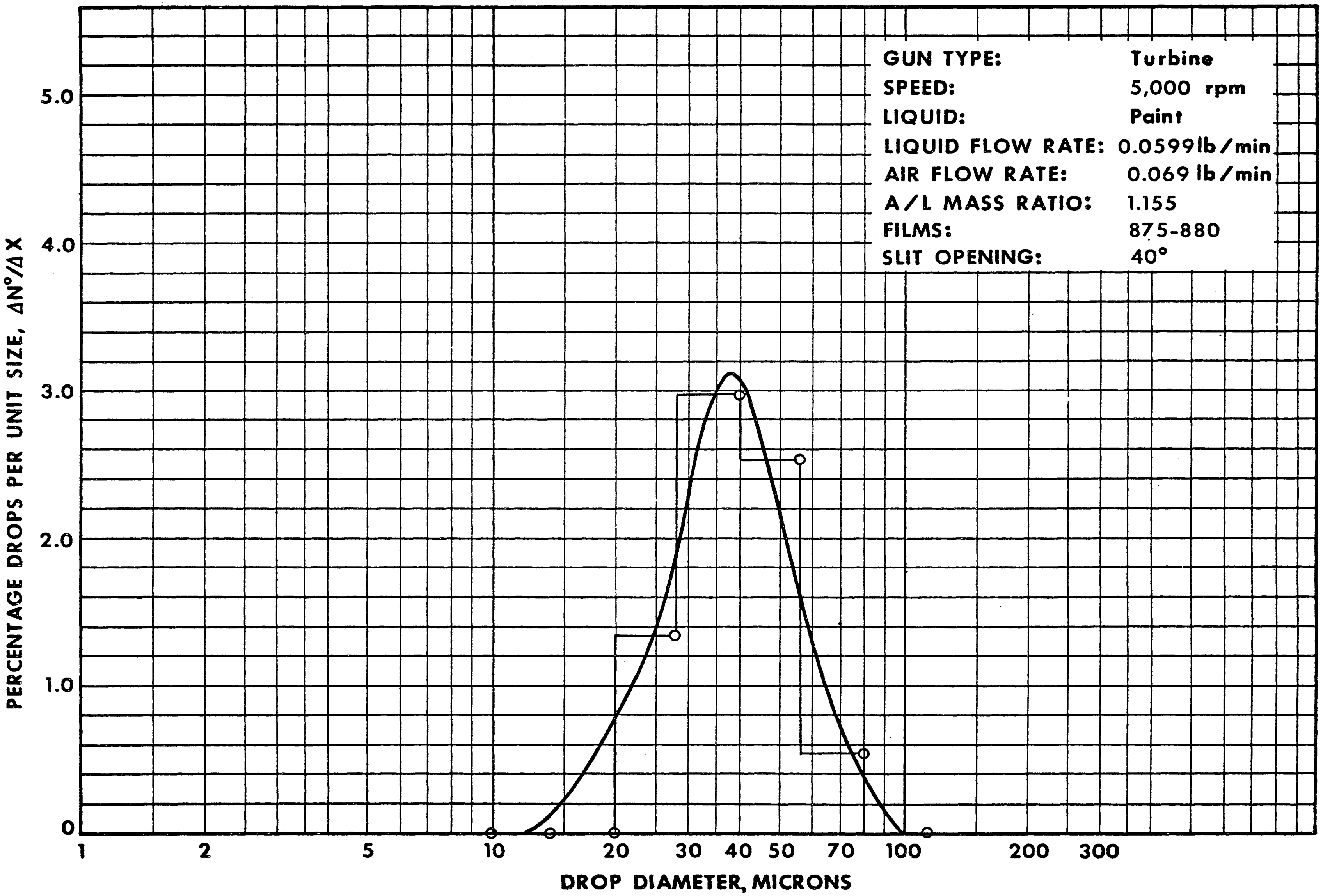

Fig. 15. Direct size distribution.

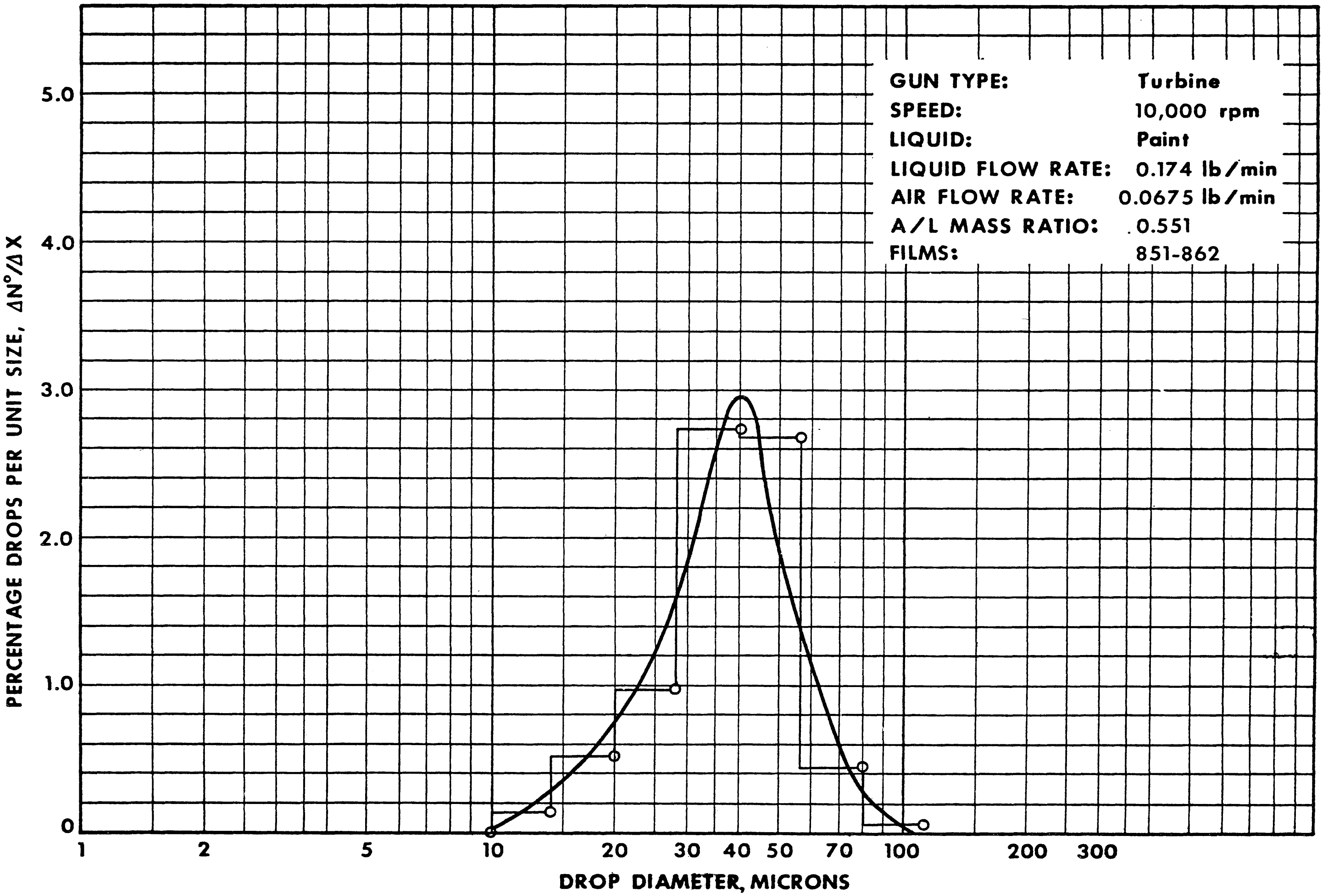

Fig. 16. Direct size distribution.

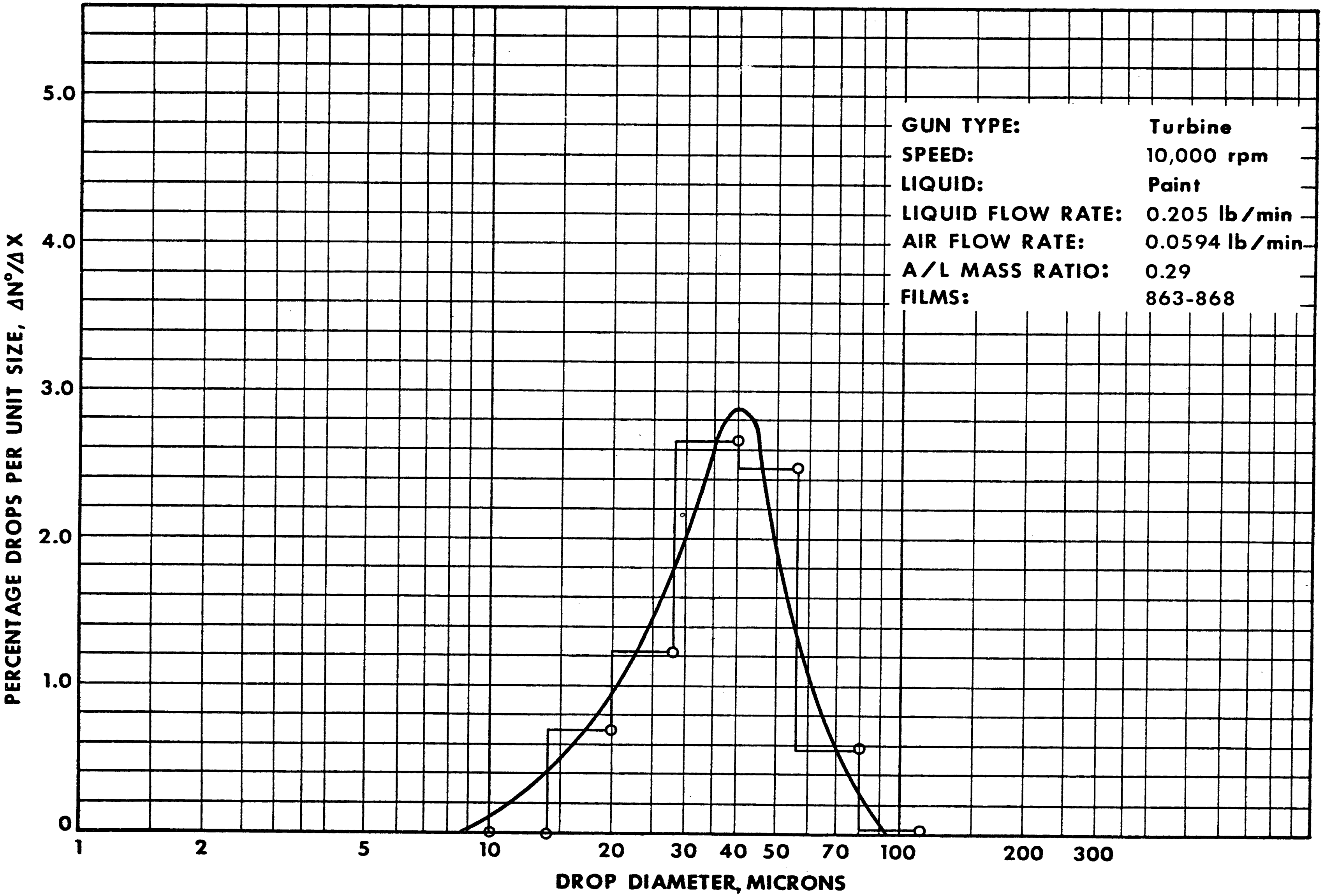

Fig. 17. Direct size distribution.

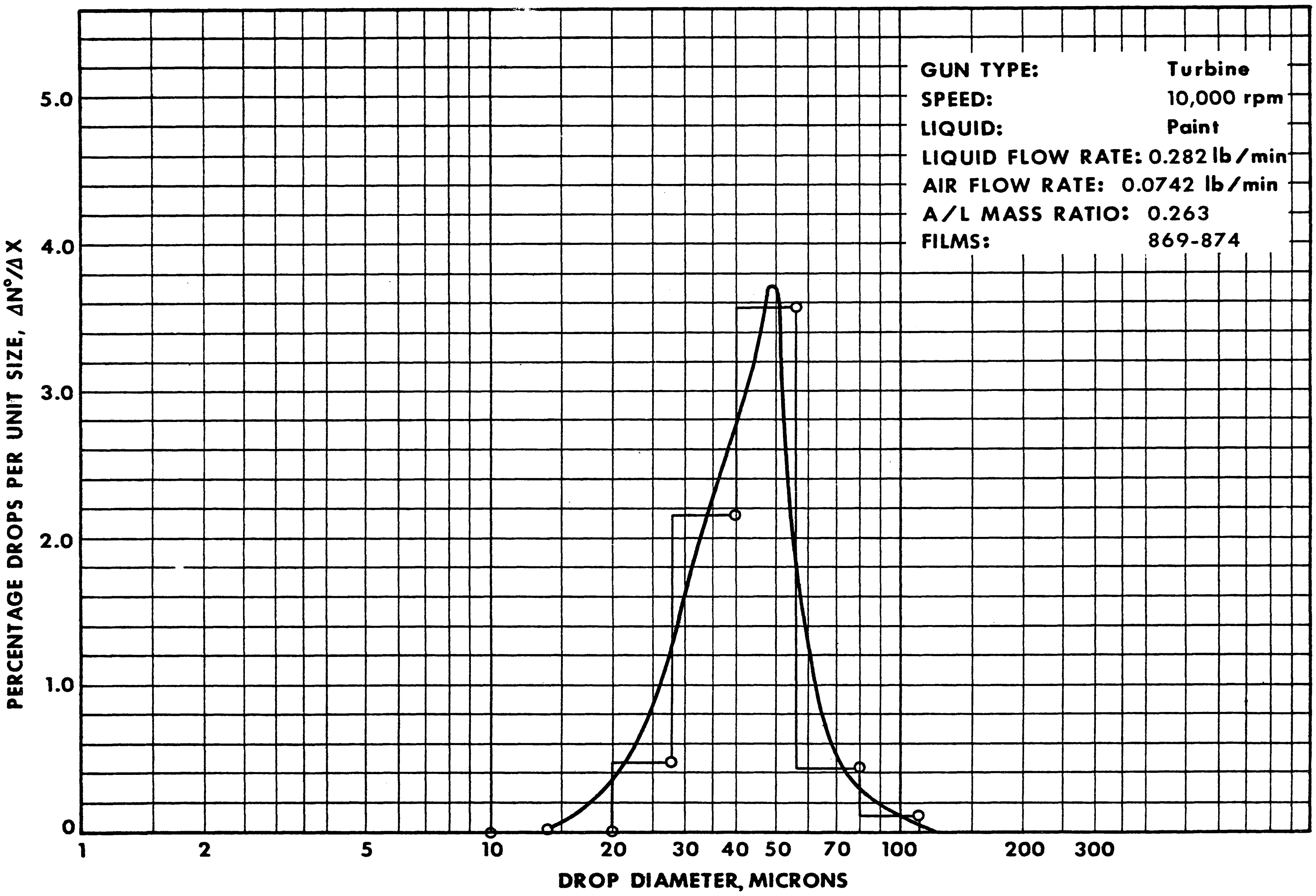

Fig. 18. Direct size distribution.

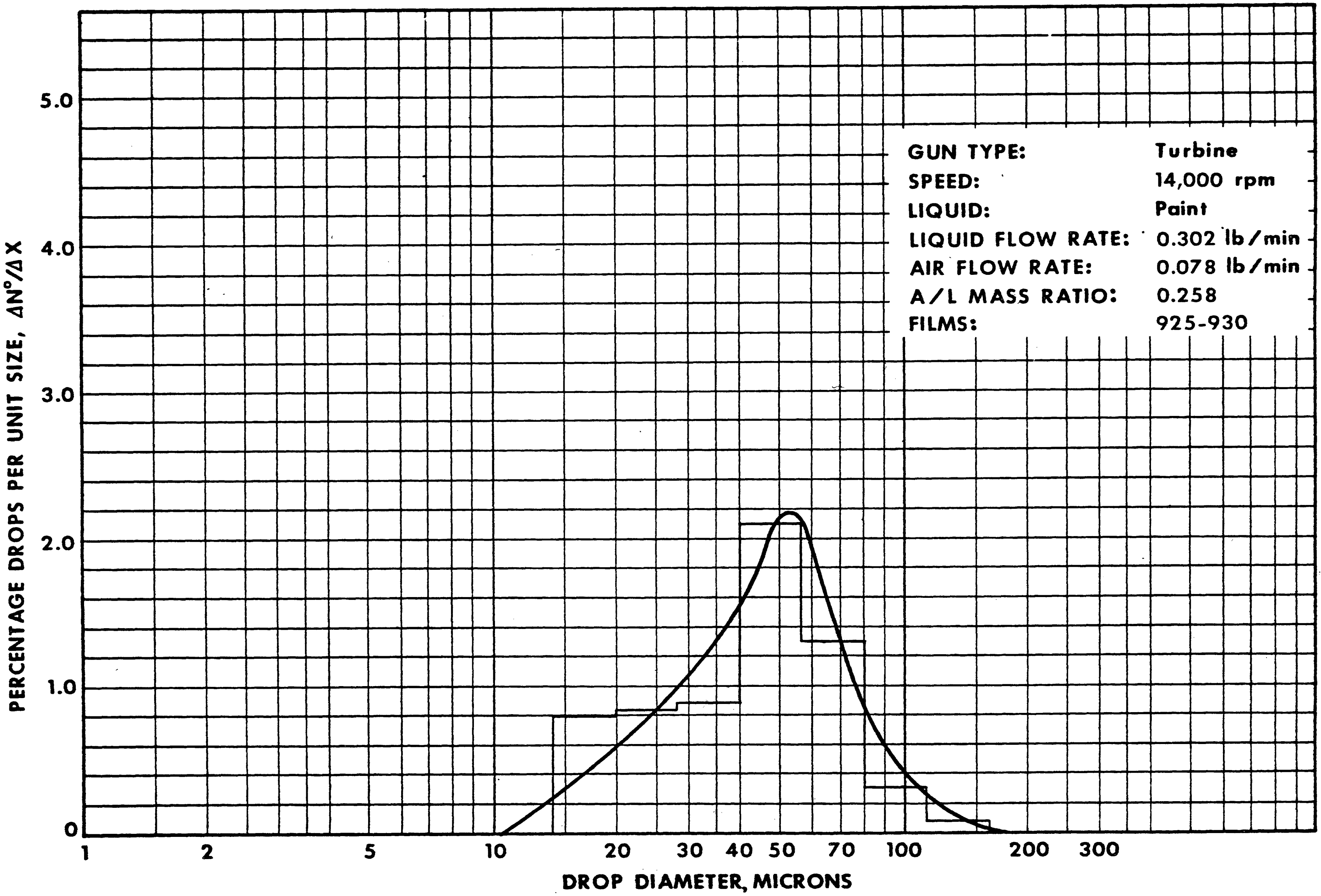

Fig. 19. Direct size distribution.

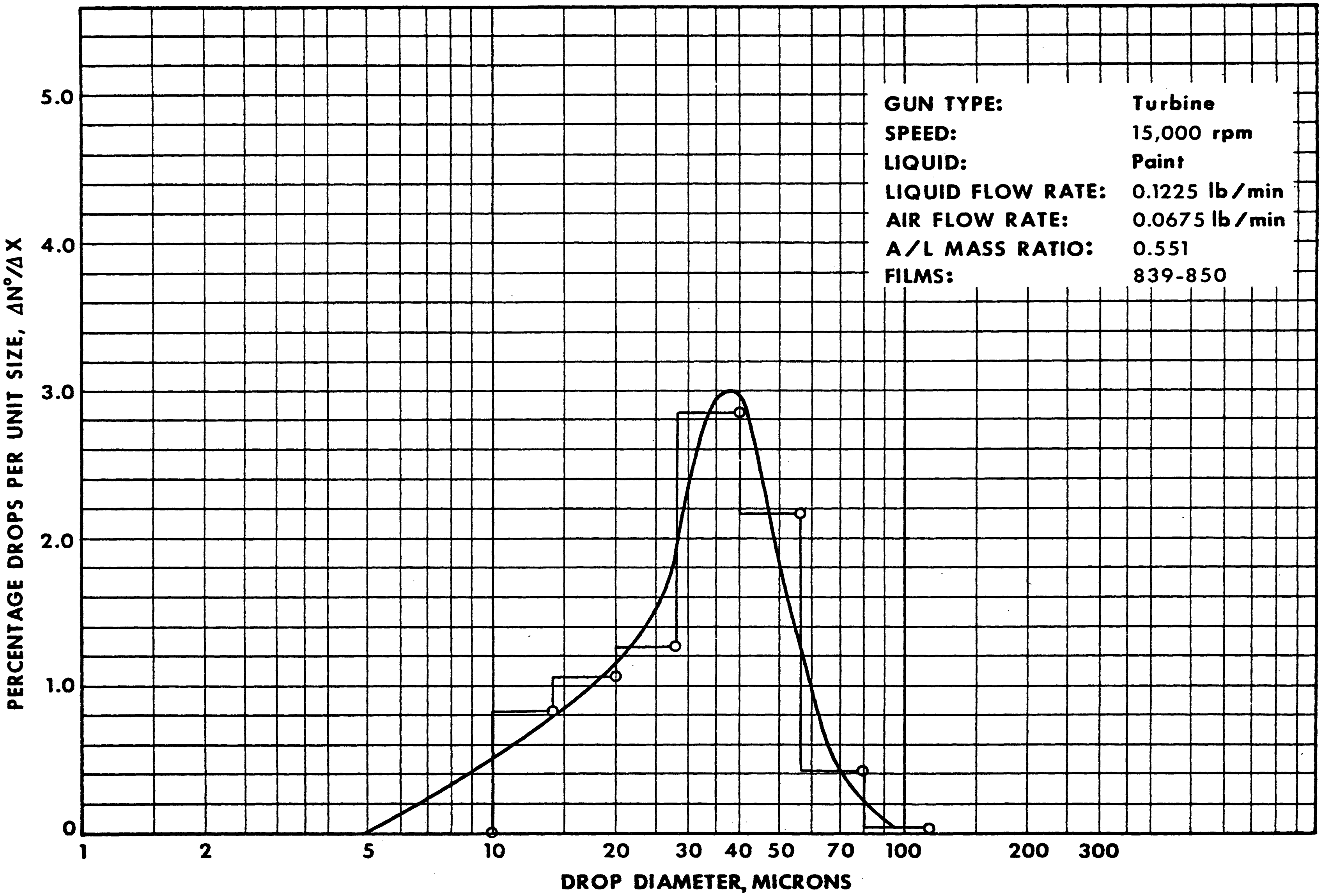

Fig. 20. Direct size distribution.

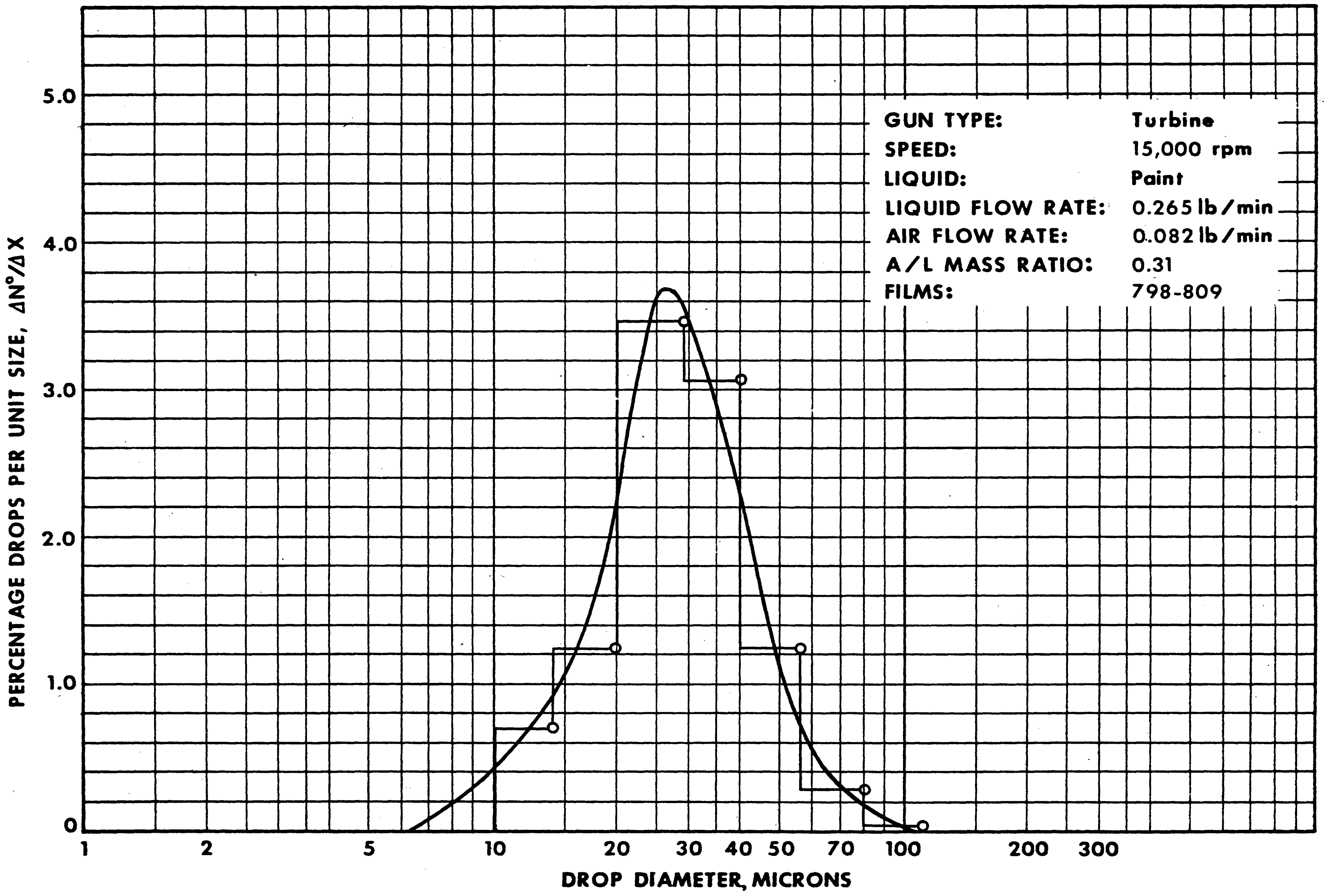

Fig. 21. Direct size distribution.

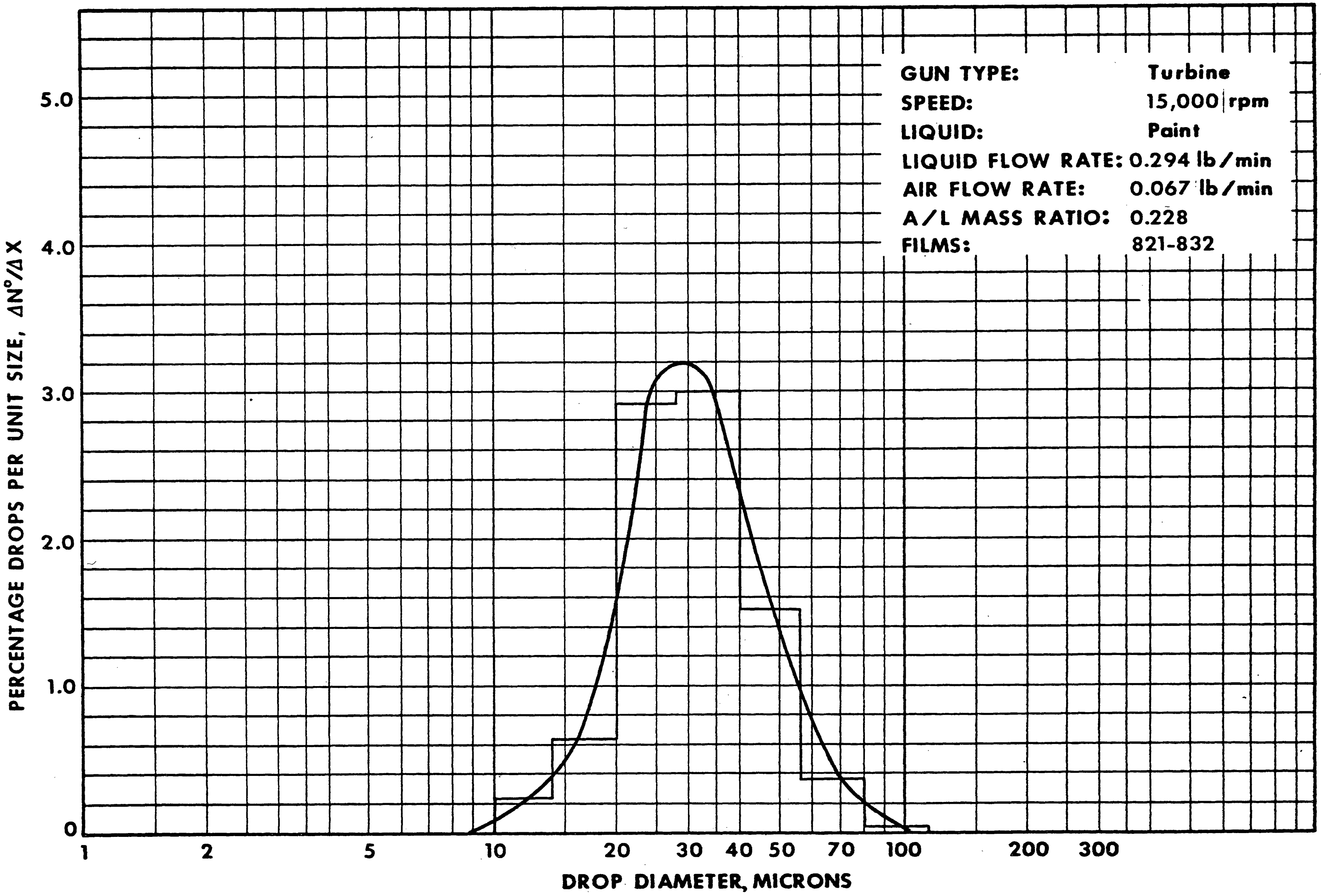

Fig. 22. Direct size distribution.

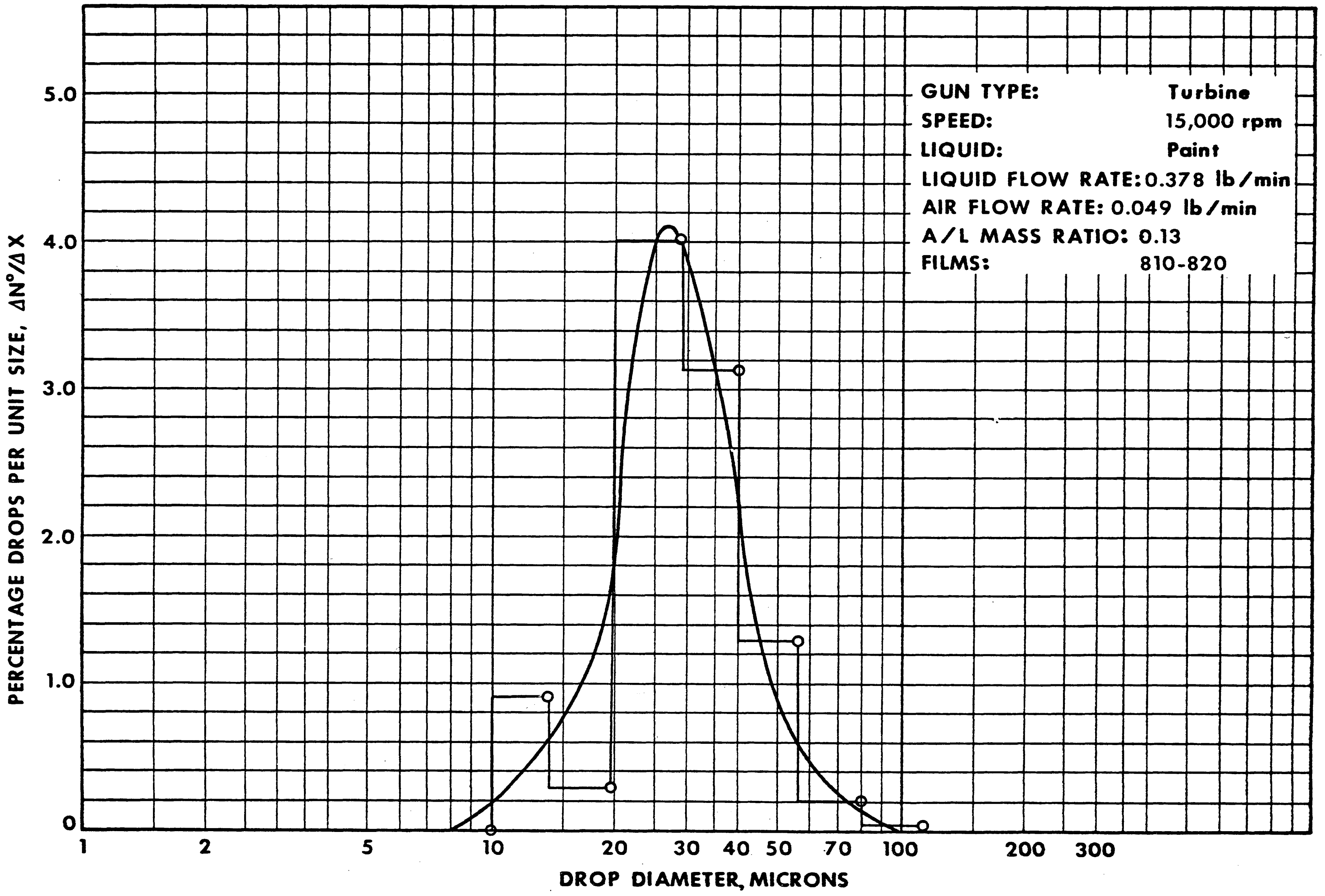

Fig. 23. Direct size distribution.

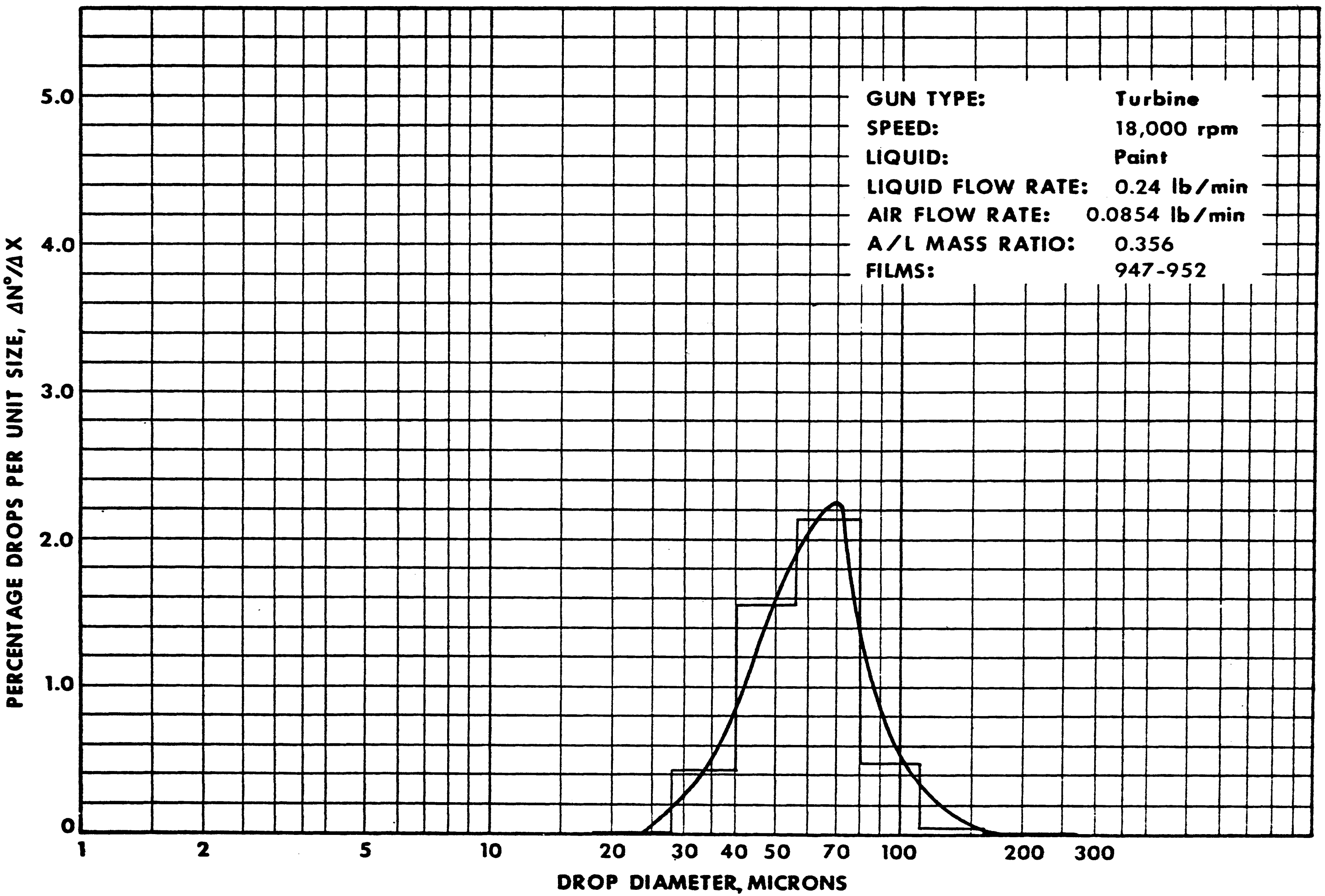

Fig. 24. Direct size distribution.

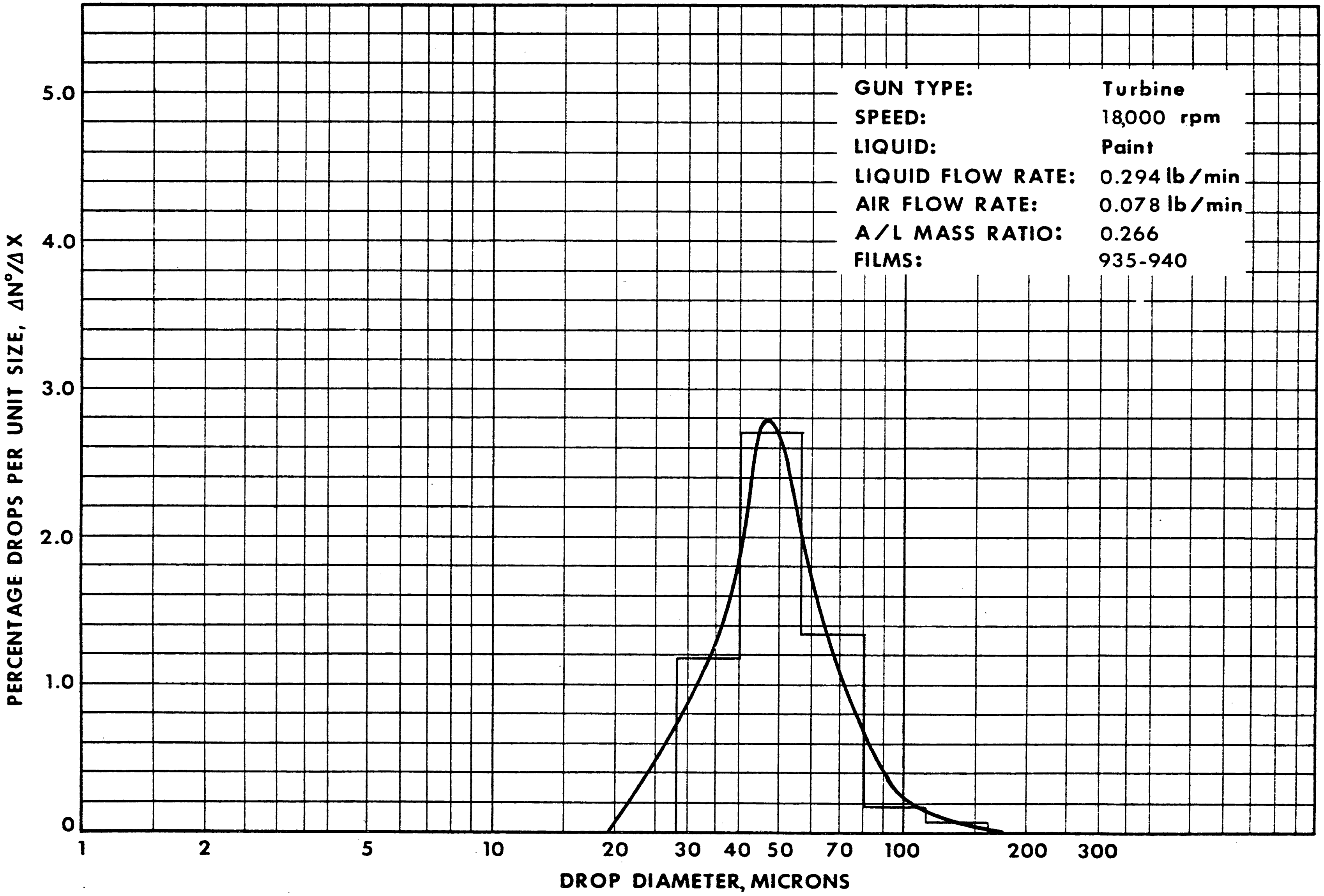

Fig. 25. Direct size distribution.

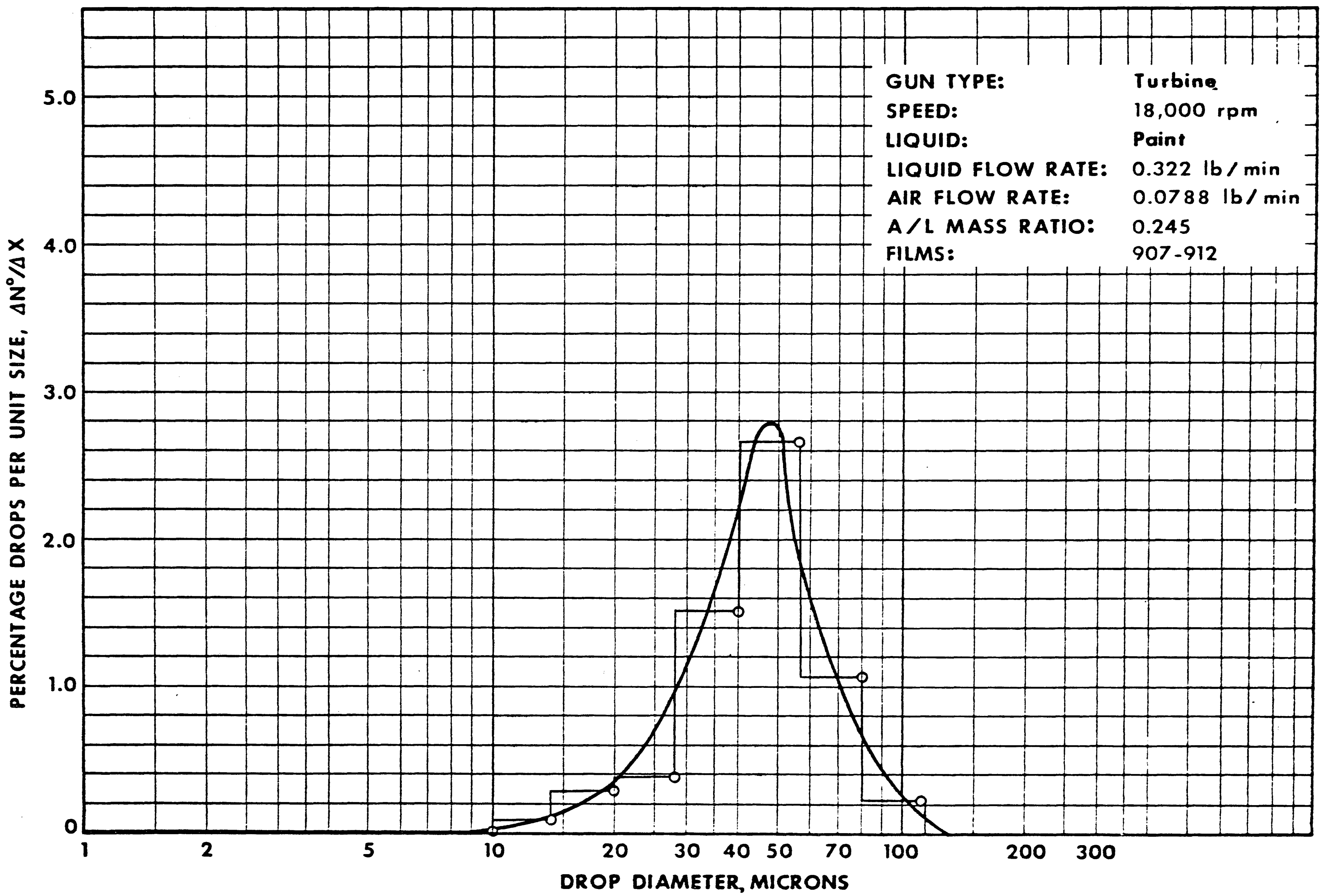

Fig. 26. Direct size distribution.

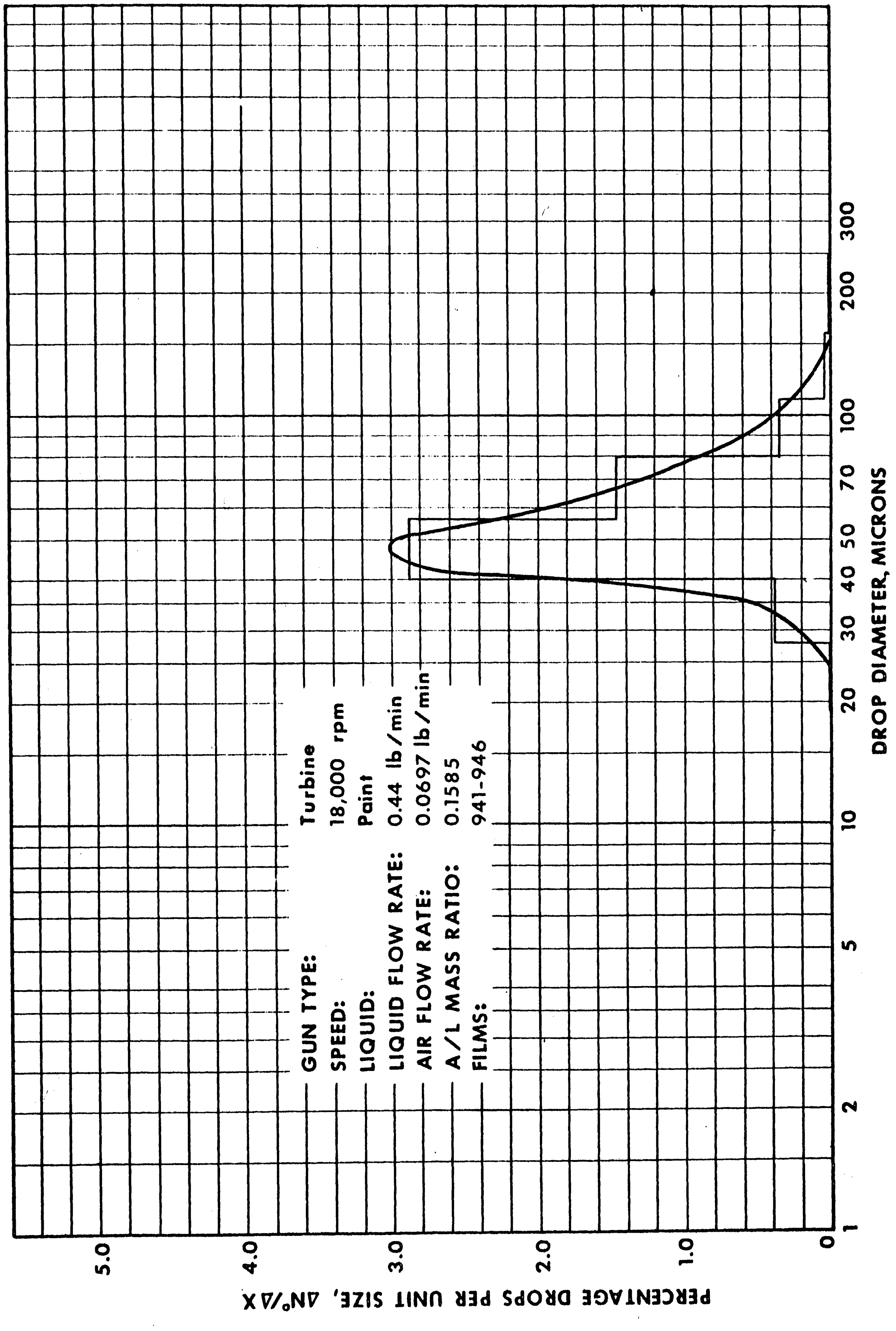

Fig. 27. Direct size distribution.

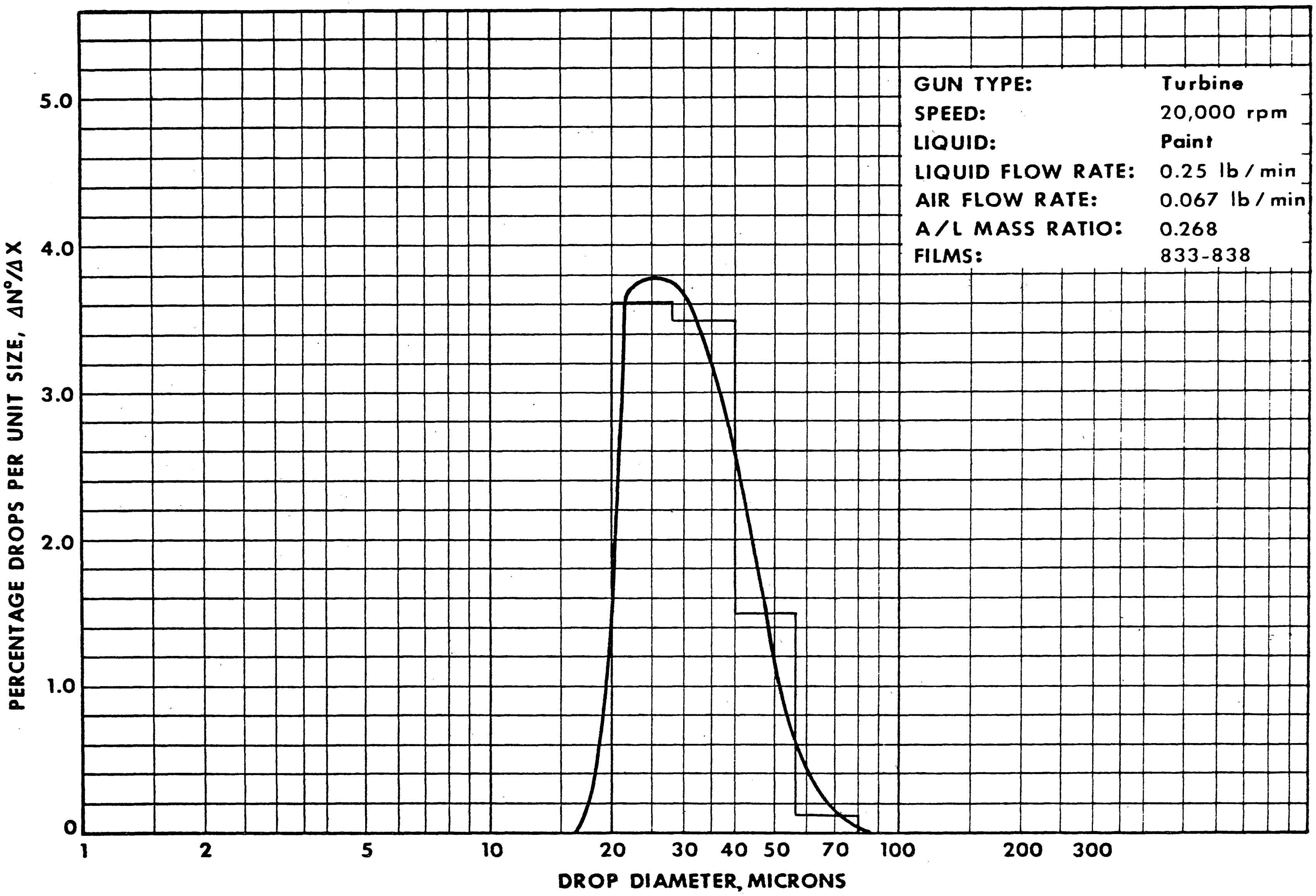

Fig. 28. Direct size distribution.

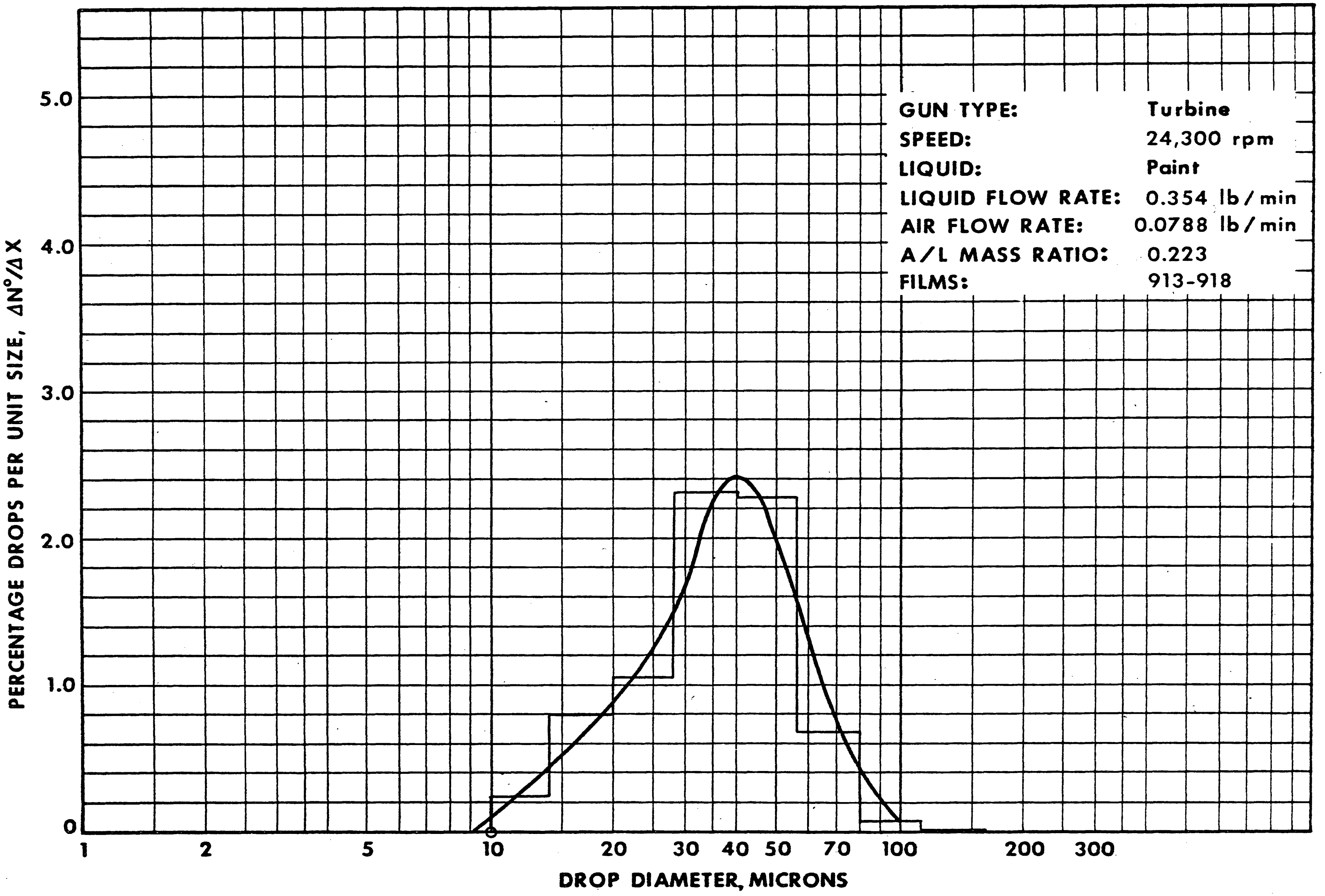

Fig. 29. Direct size distribution.

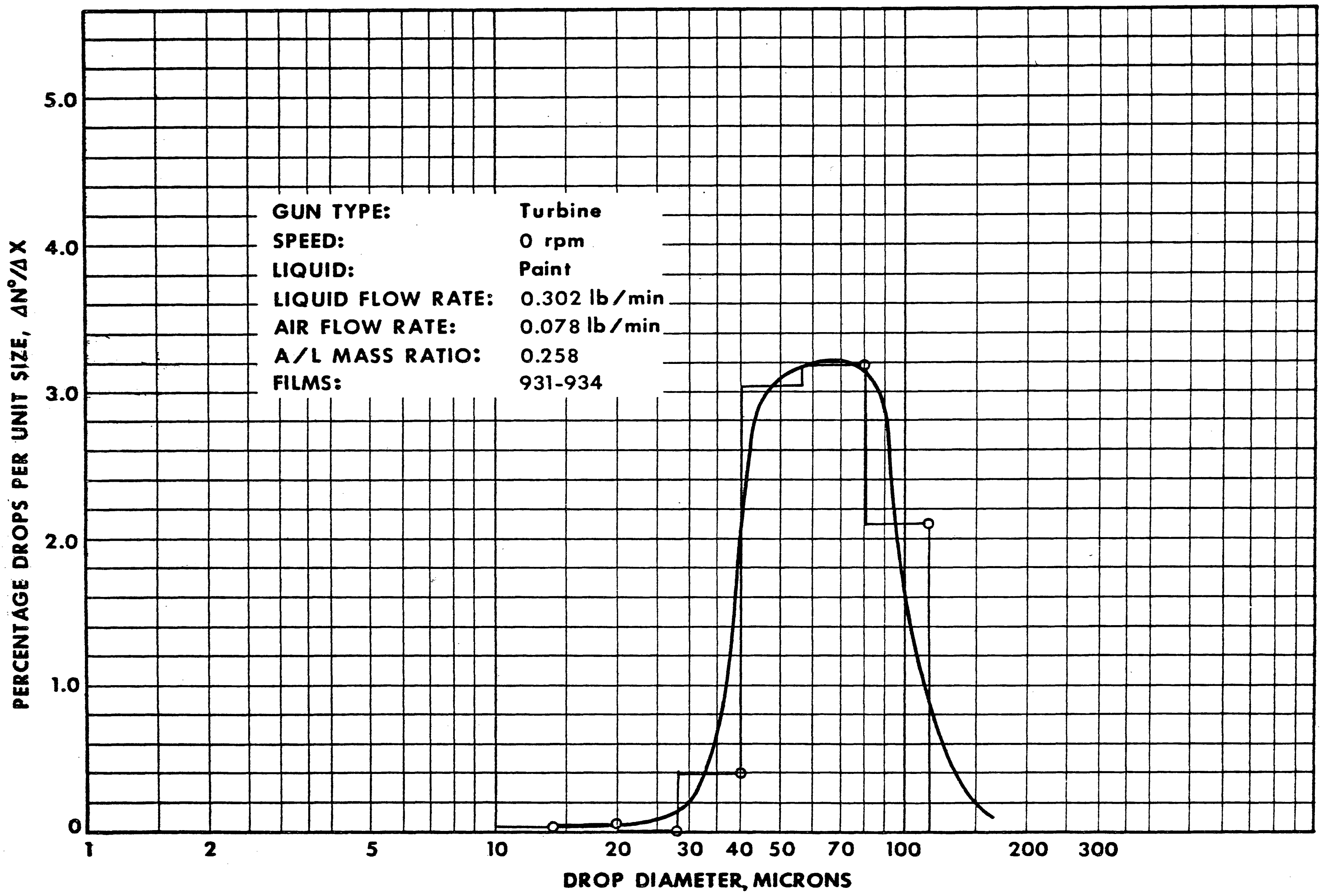

Fig. 30. Mass distribution.

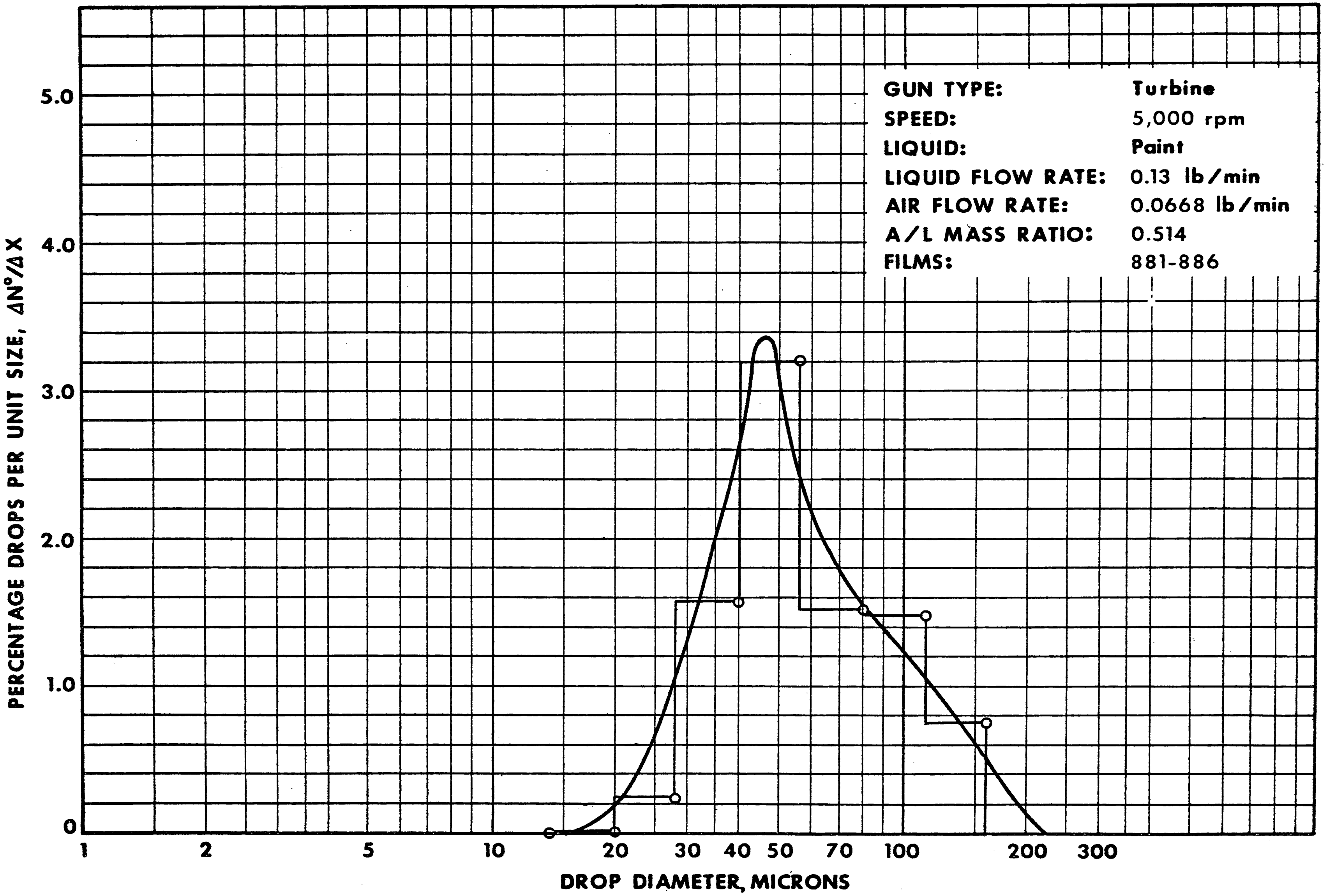

Fig. 31. Mass distribution.

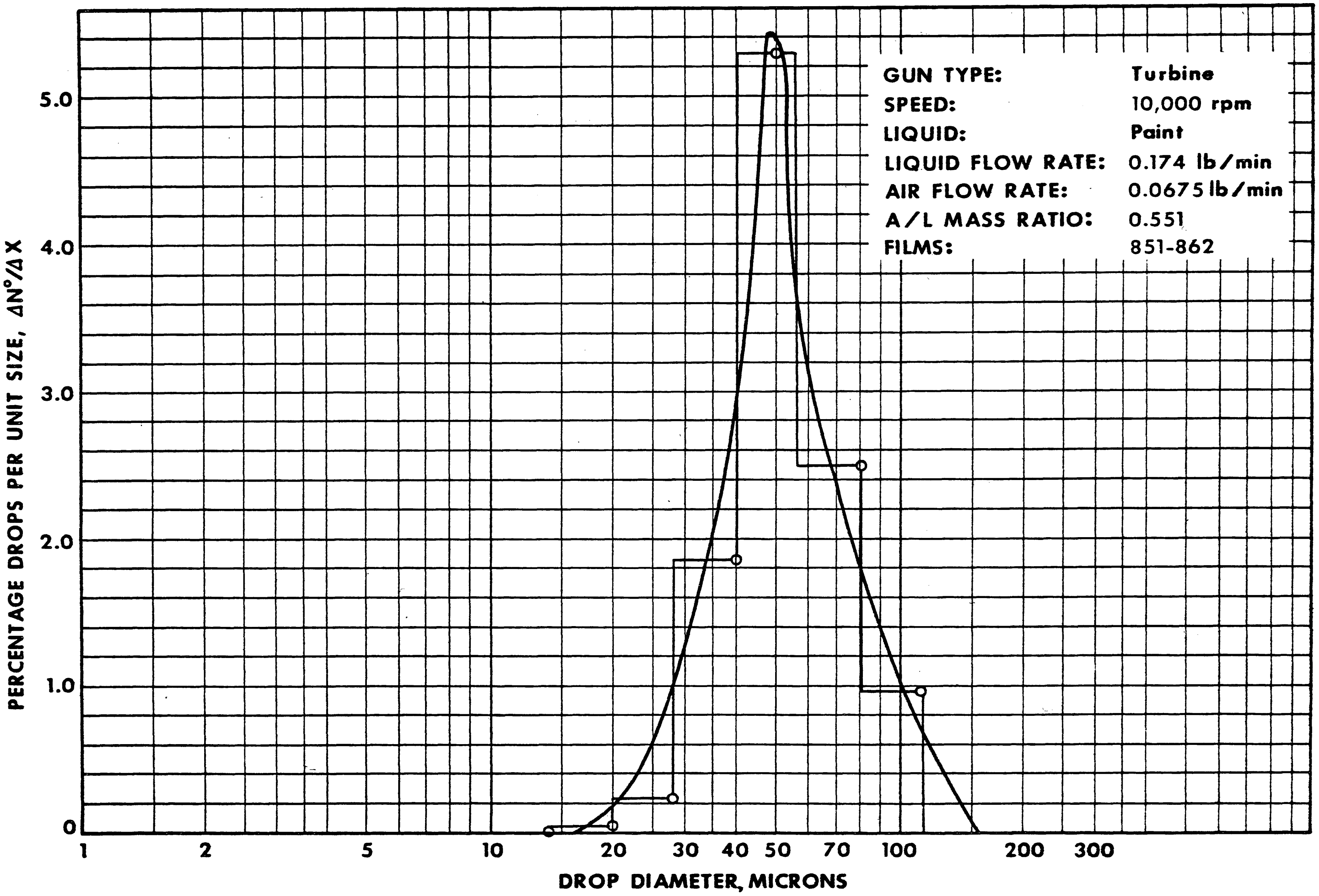

Fig. 32. Mass distribution.

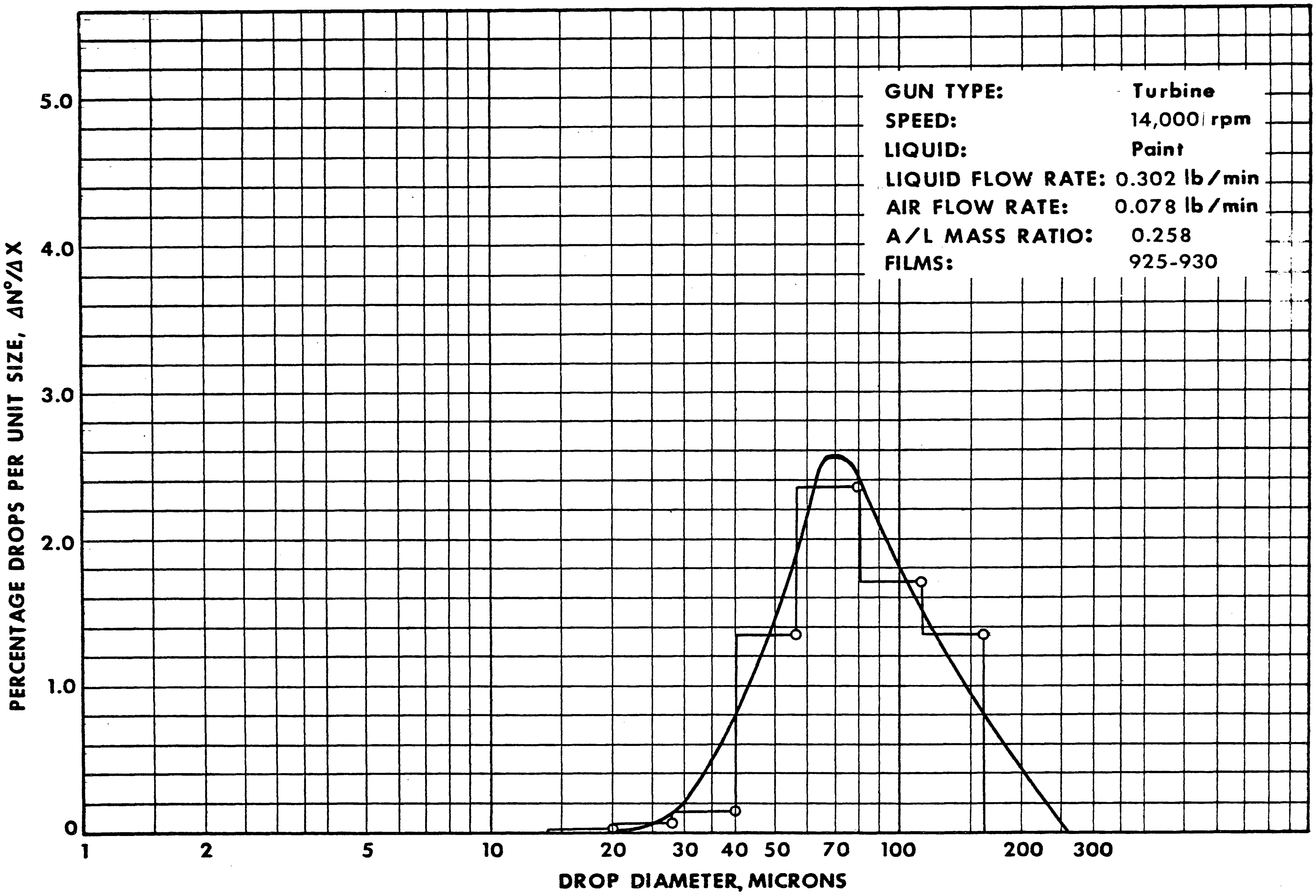

Fig. 33. Mass distribution.

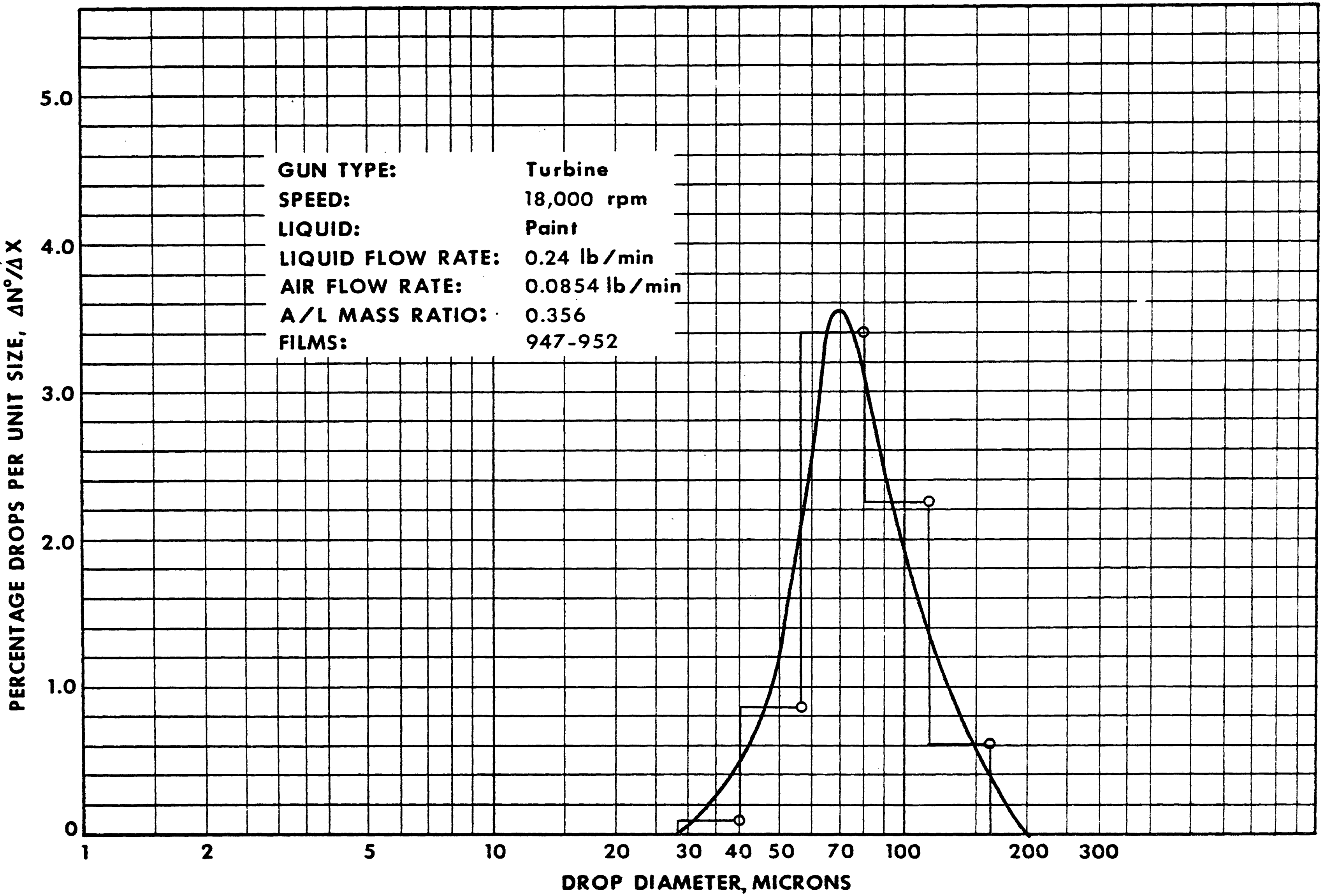

Fig. 34. Mass distribution.

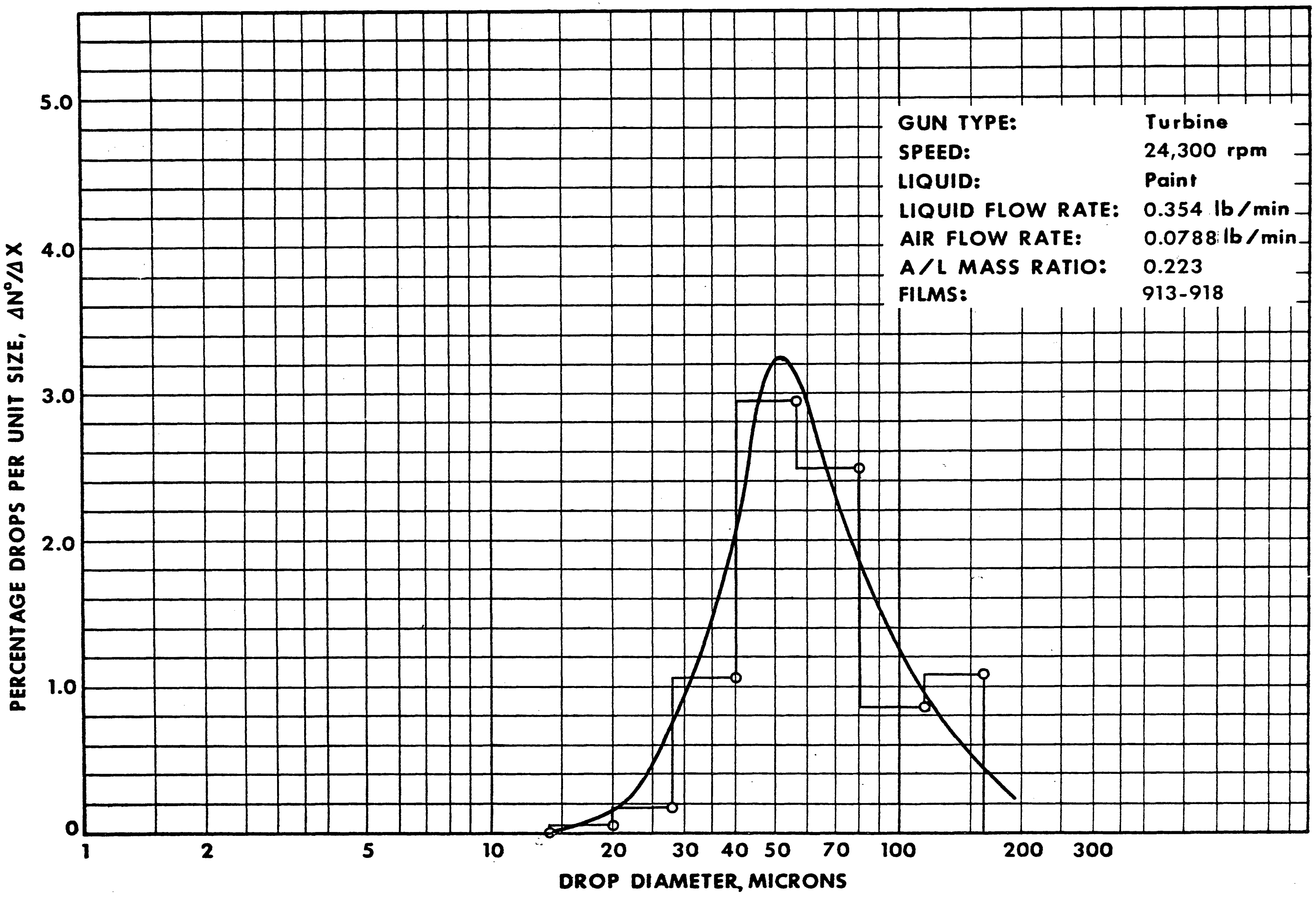

Fig. 35. Mass distribution.

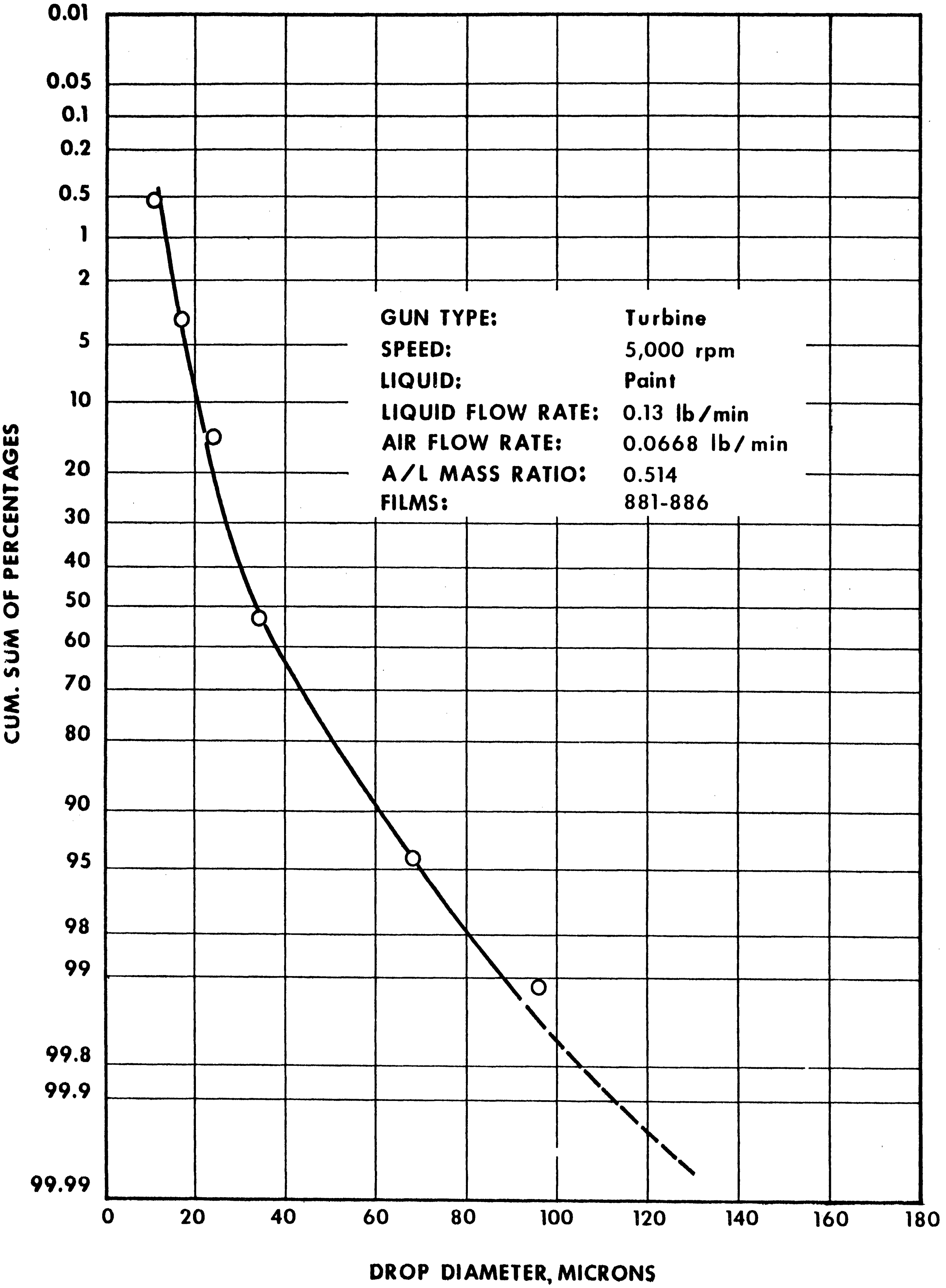

Fig. 36. Cumulative drop-size distribution.

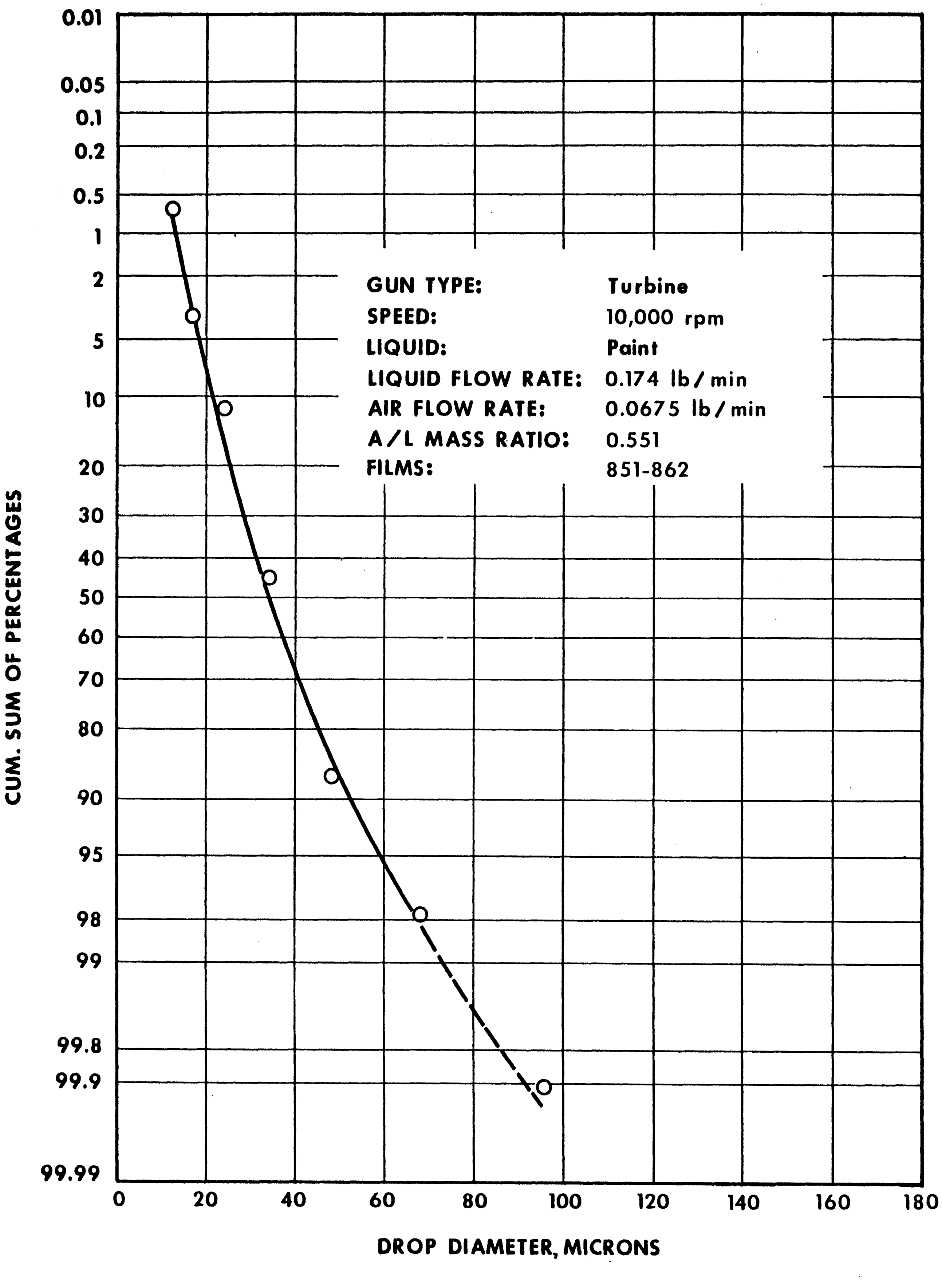

Fig. 37. Cumulative drop-size distribution.

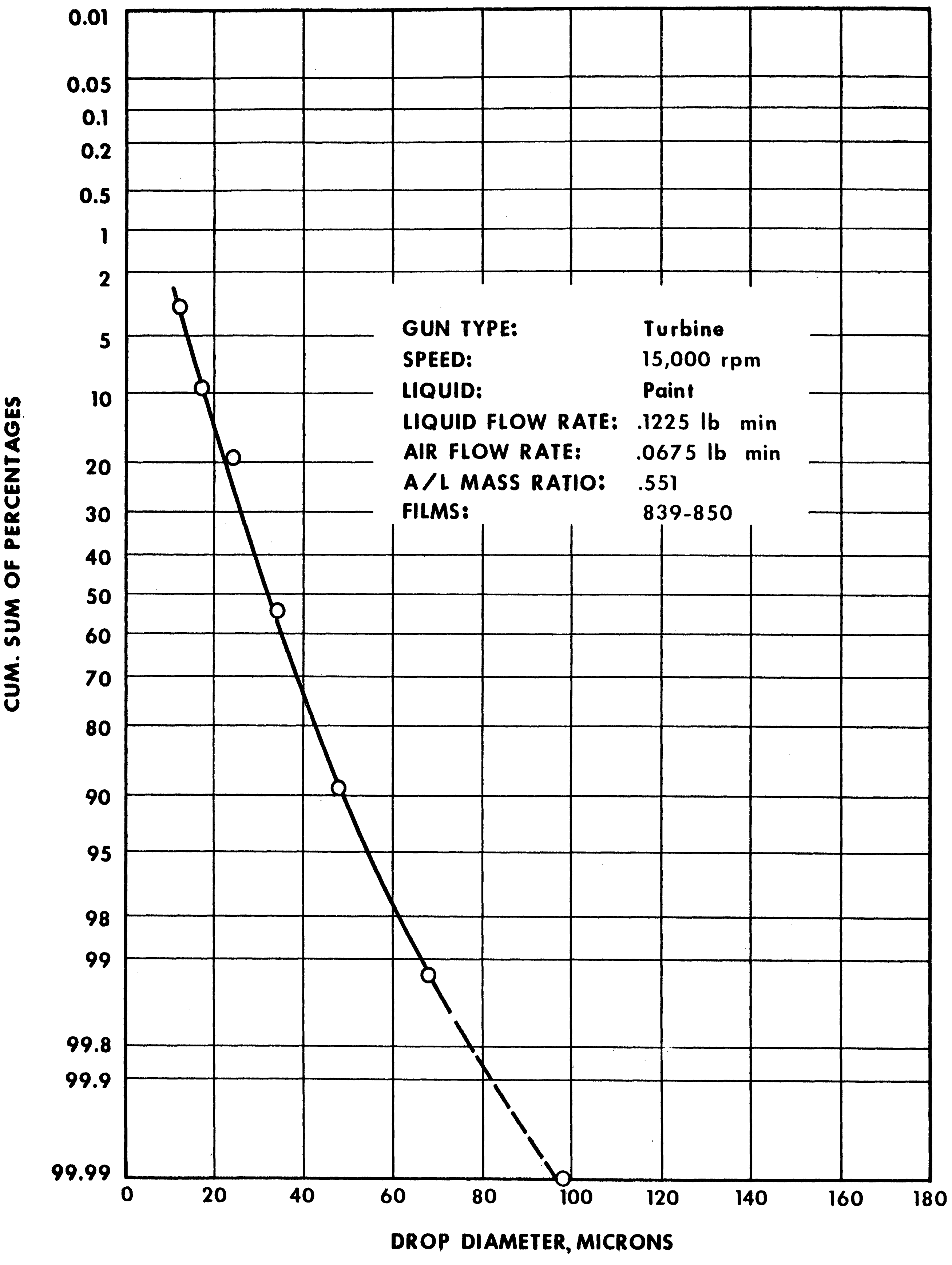

Fig. 38. Cumulative drop-size distribution.

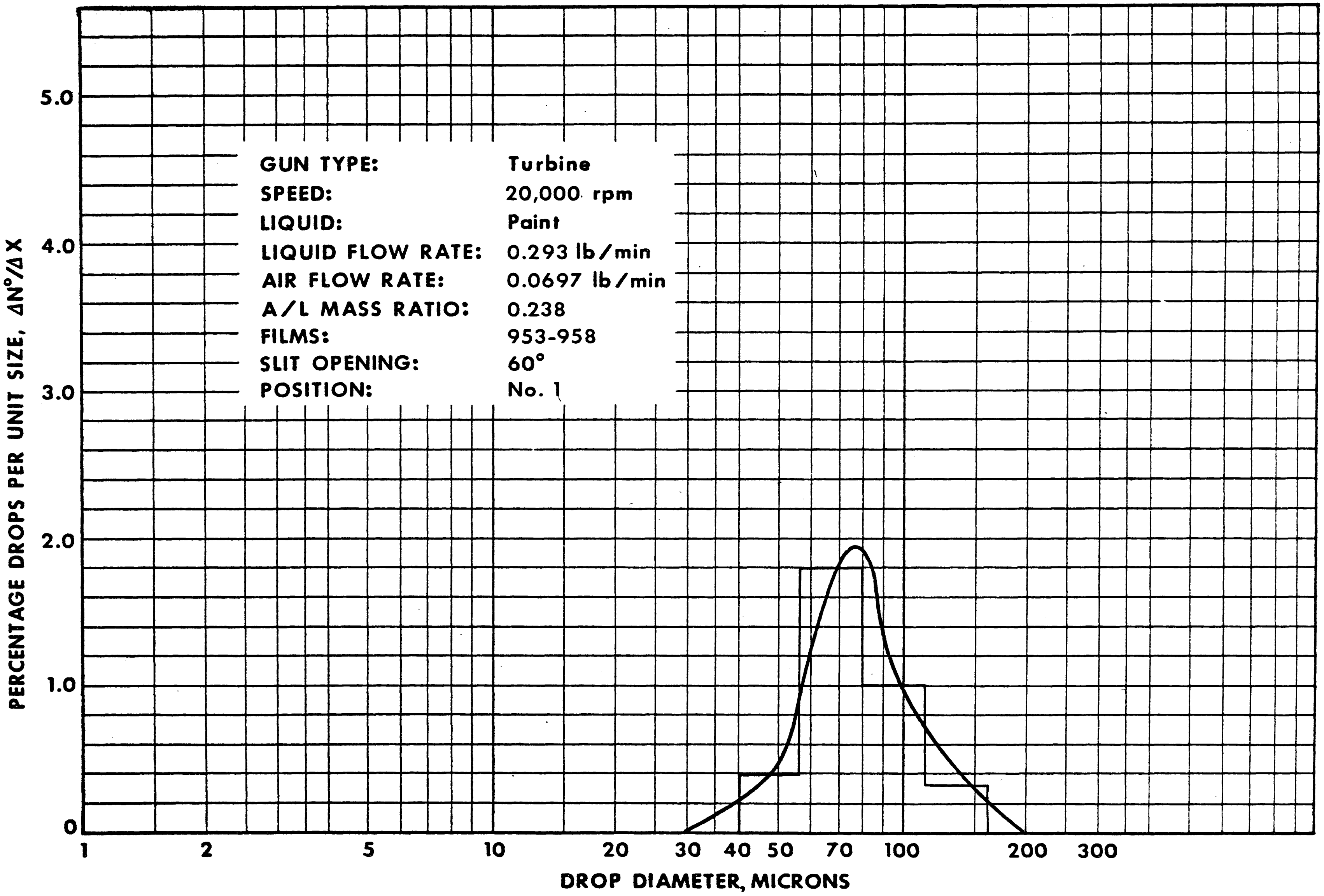

Fig. 39. Direct size distribution.

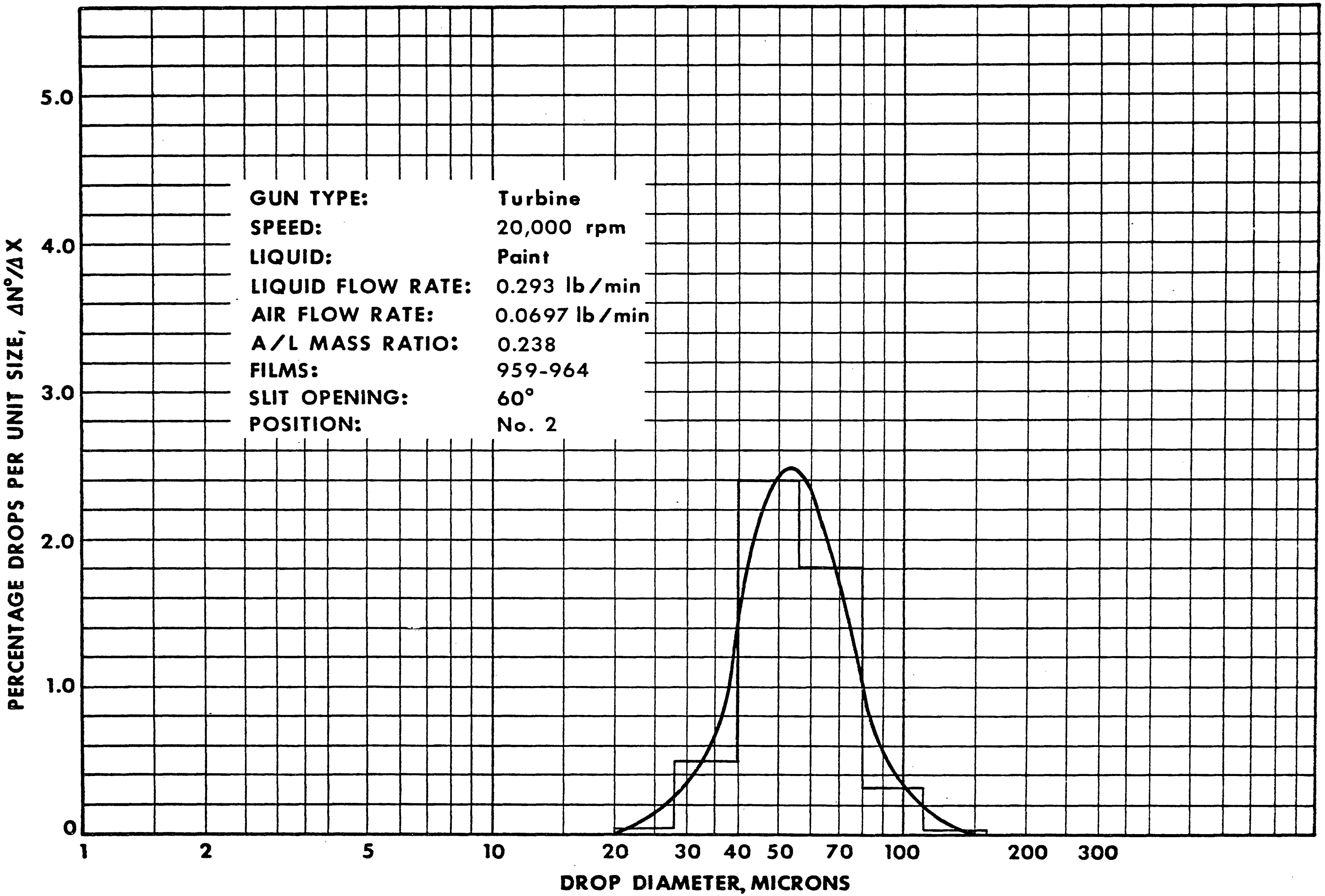

Fig. 40. Direct size distribution.

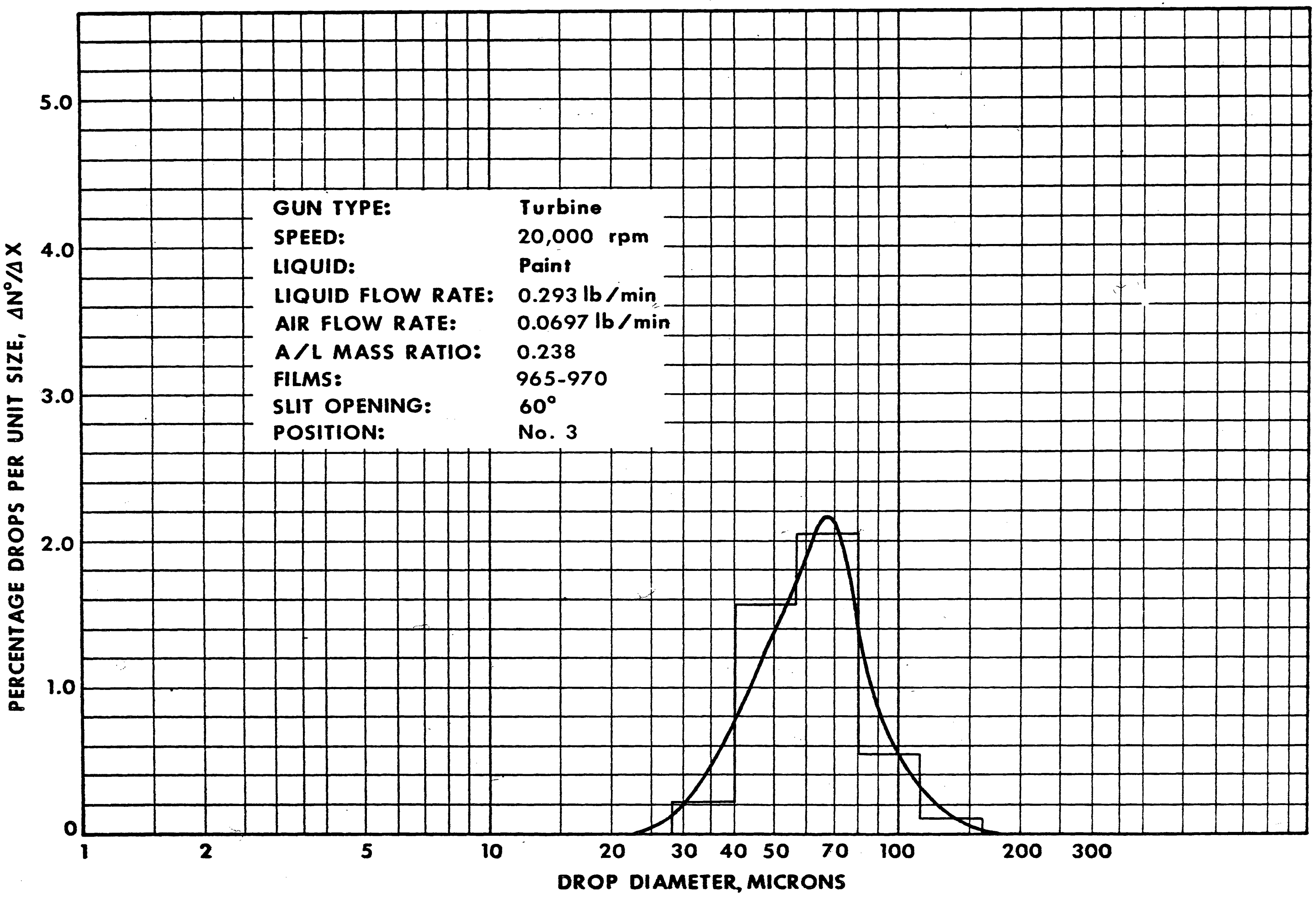

Fig. 41. Direct size distribution.

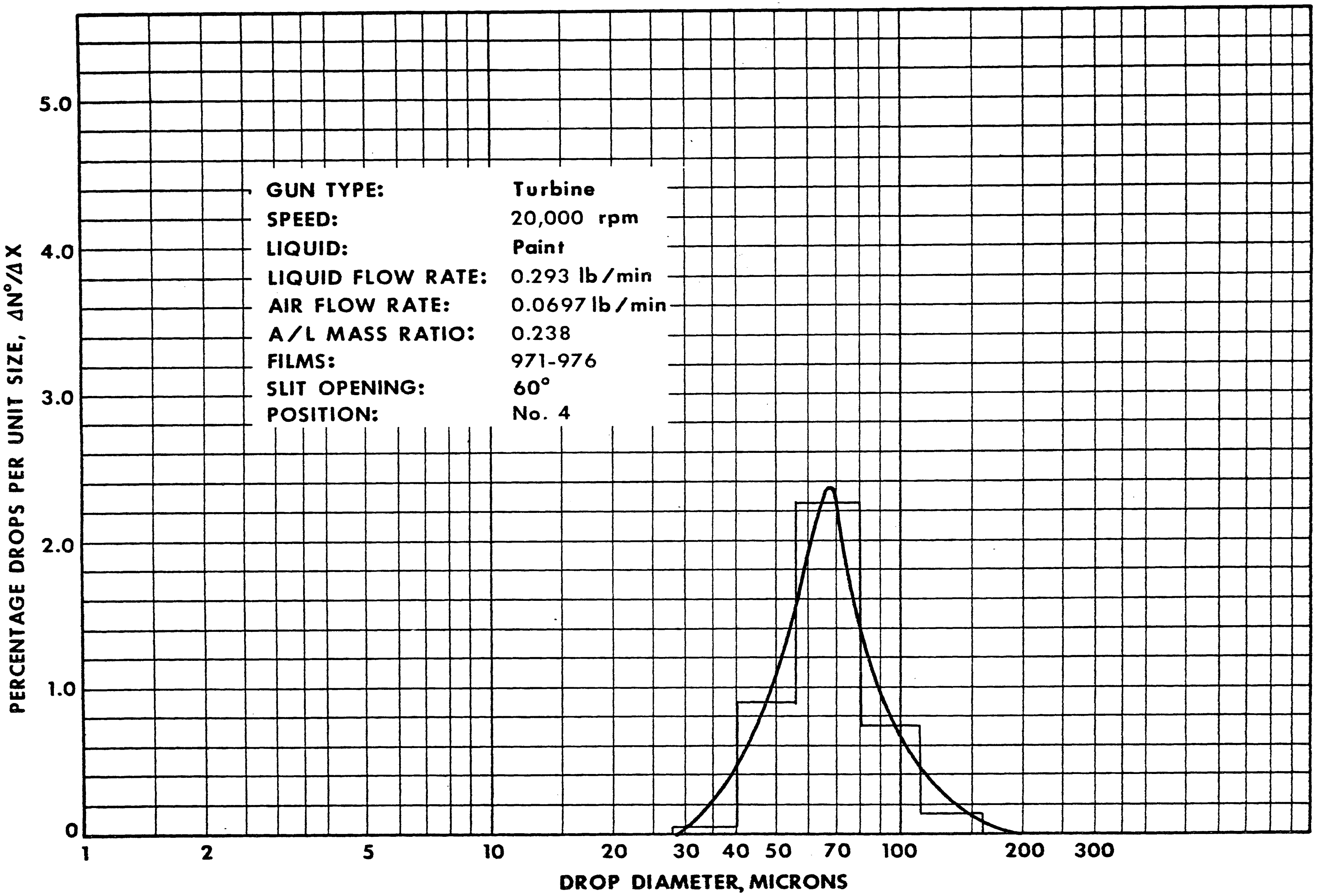

Fig. 42. Direct size distribution.

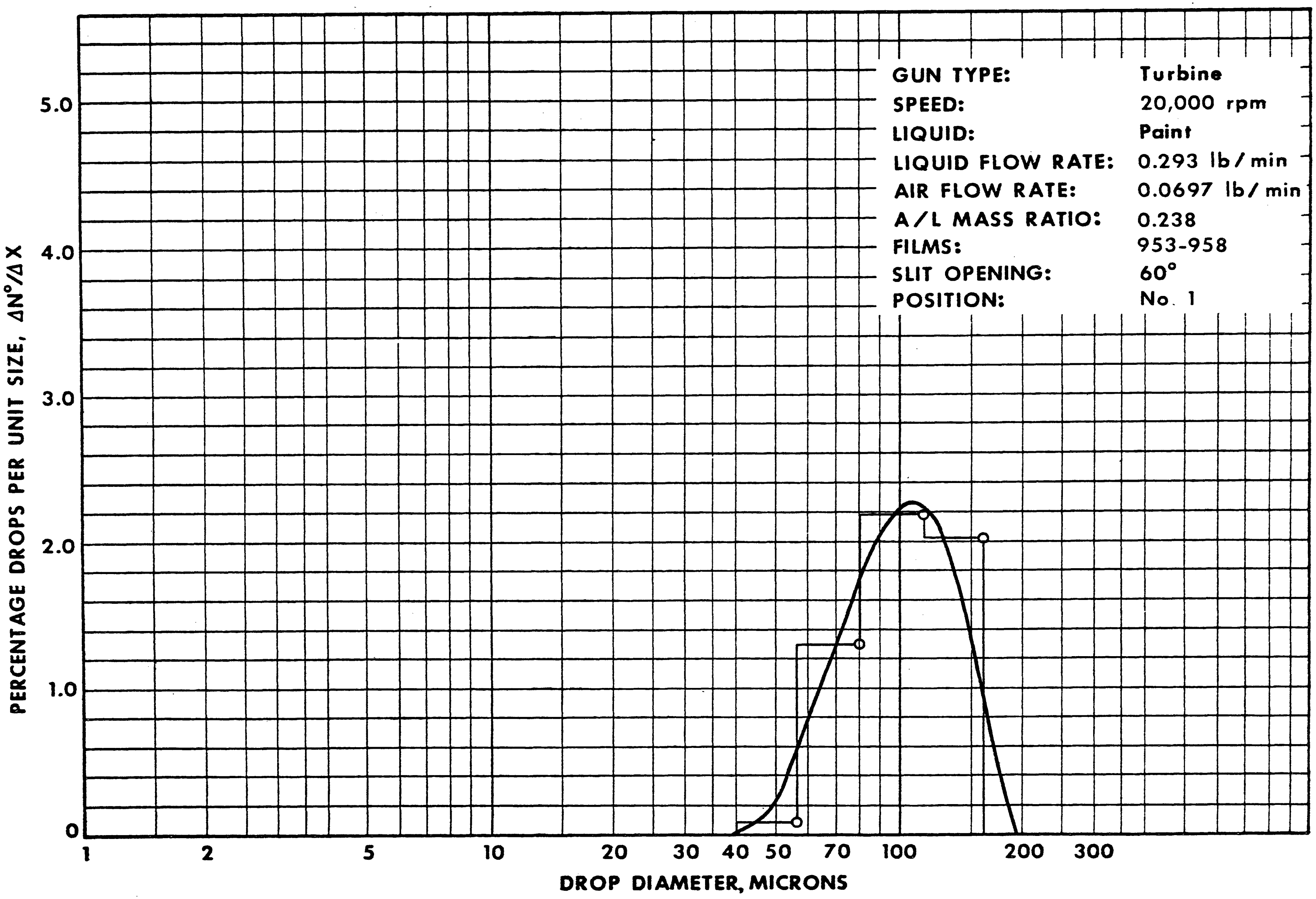

Fig. 43. Mass distribution.

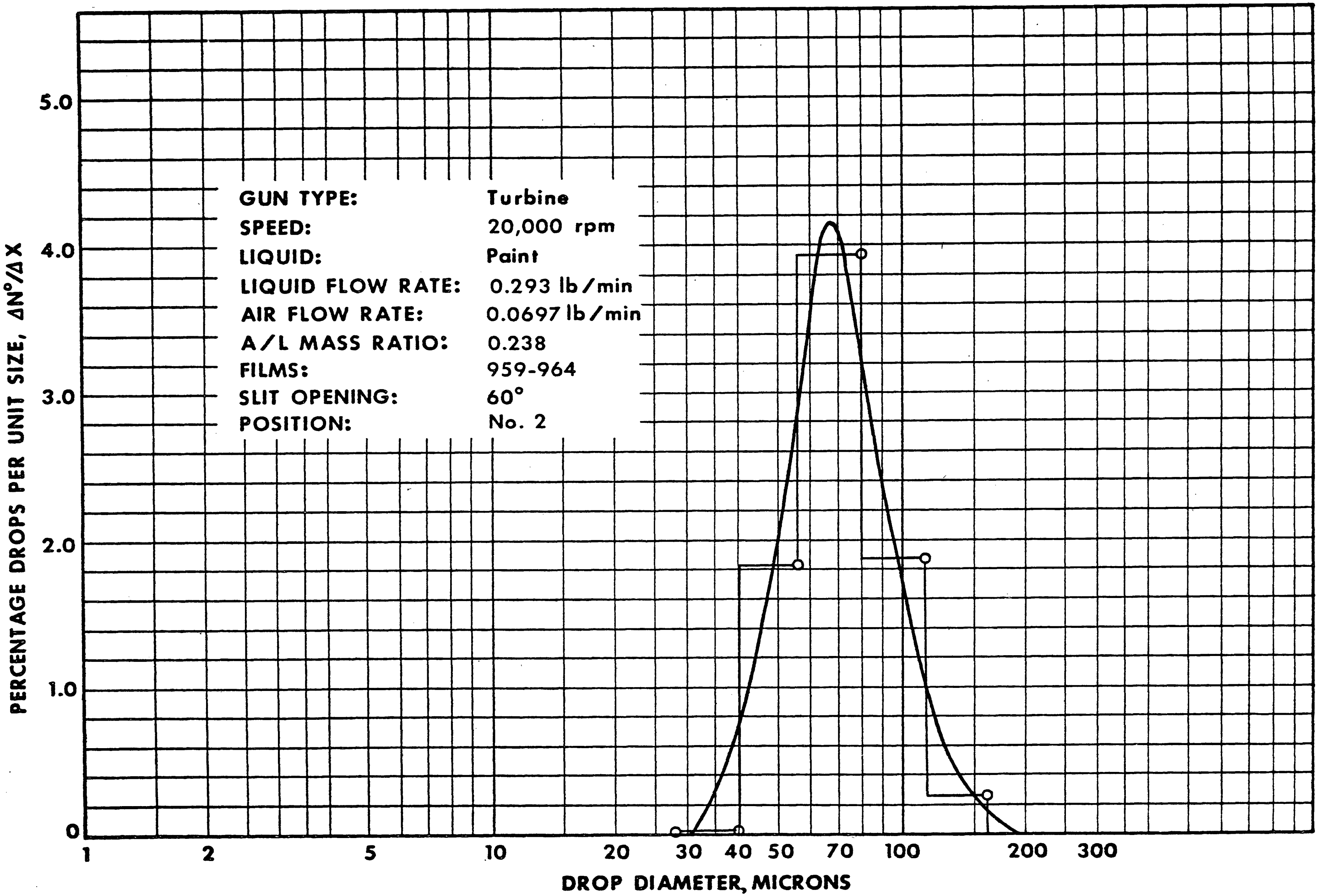

Fig. 44. Mass distribution.

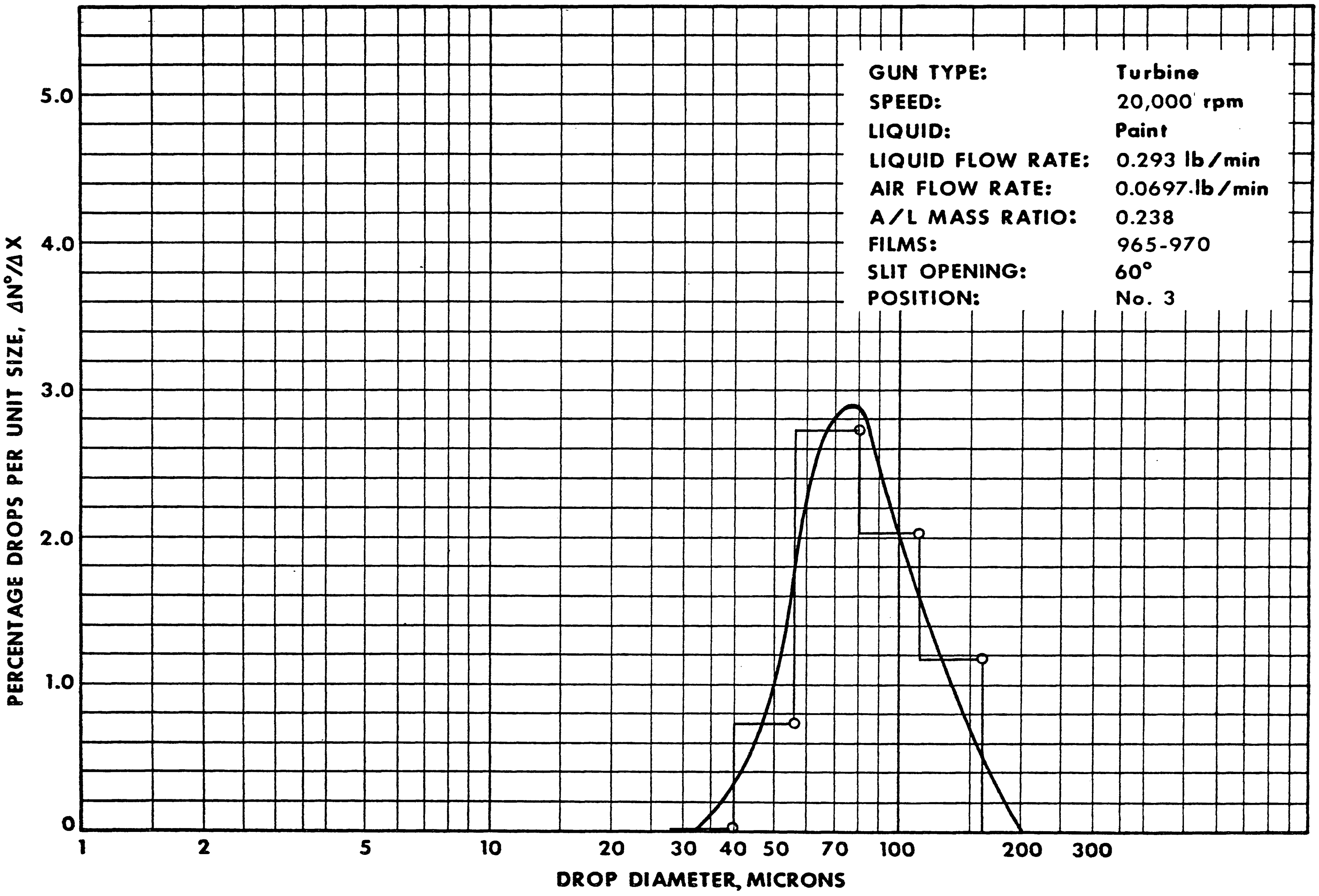

Fig. 45. Mass distribution.

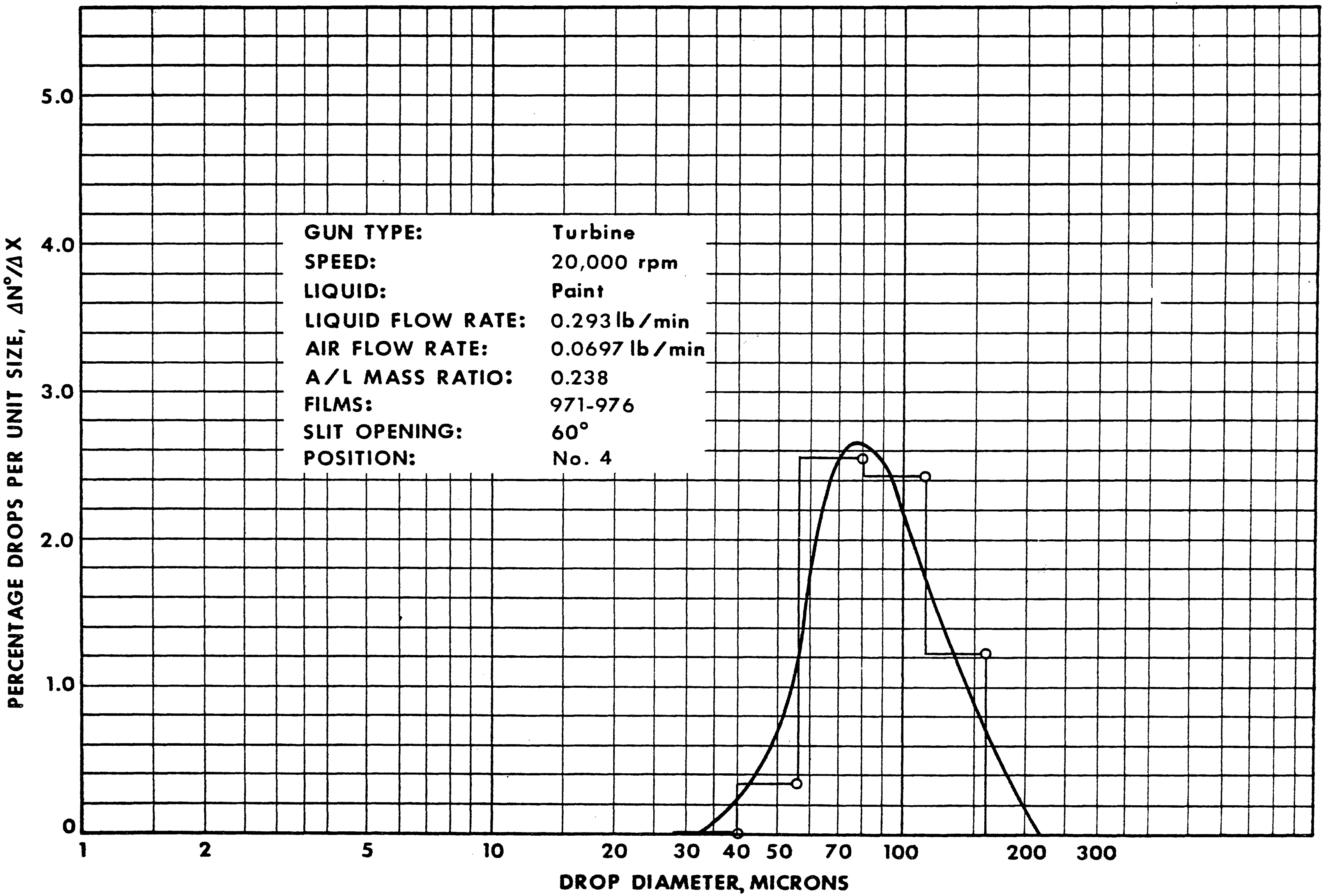

Fig. 46. Mass distribution.

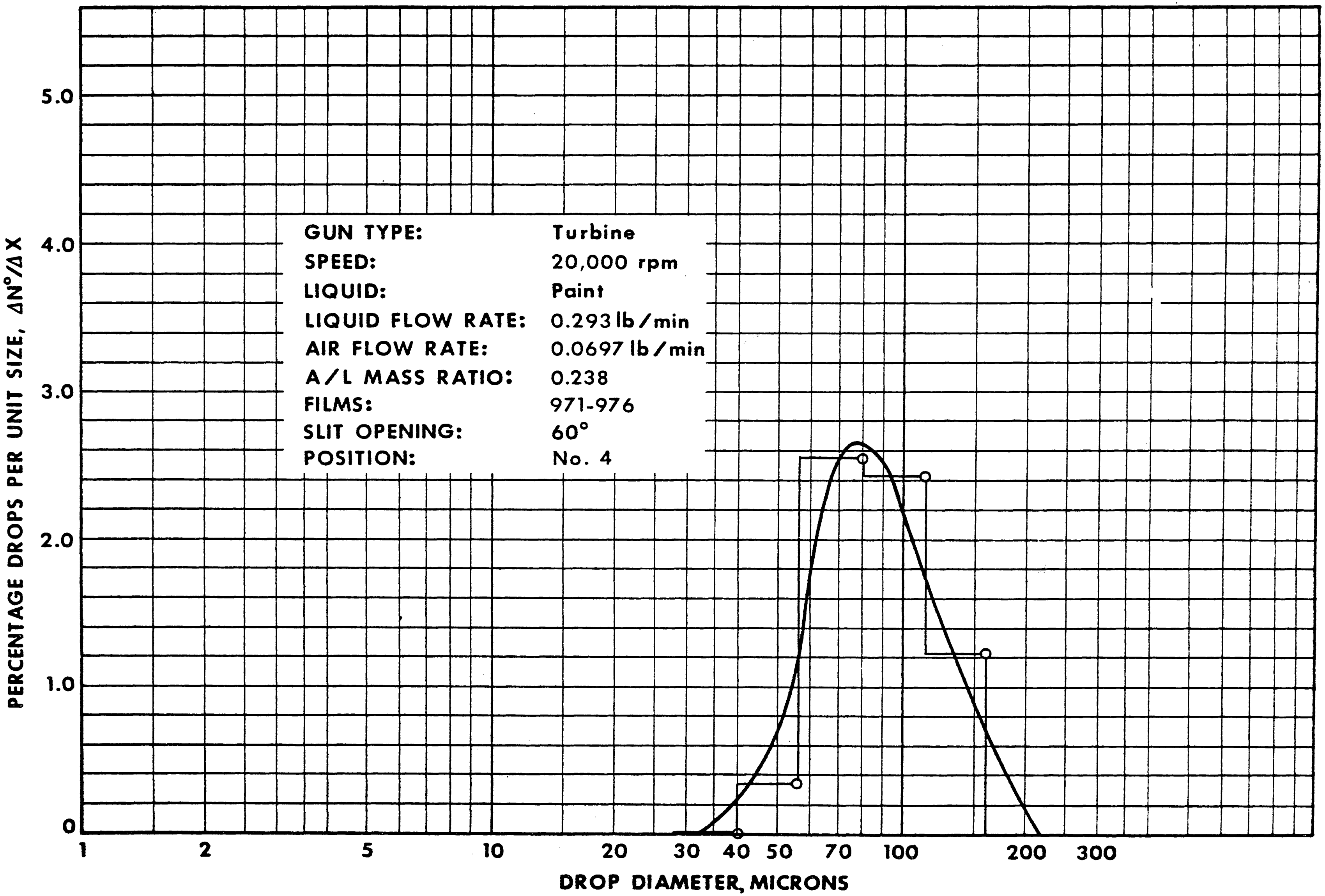

Fig. 46. Mass distribution.

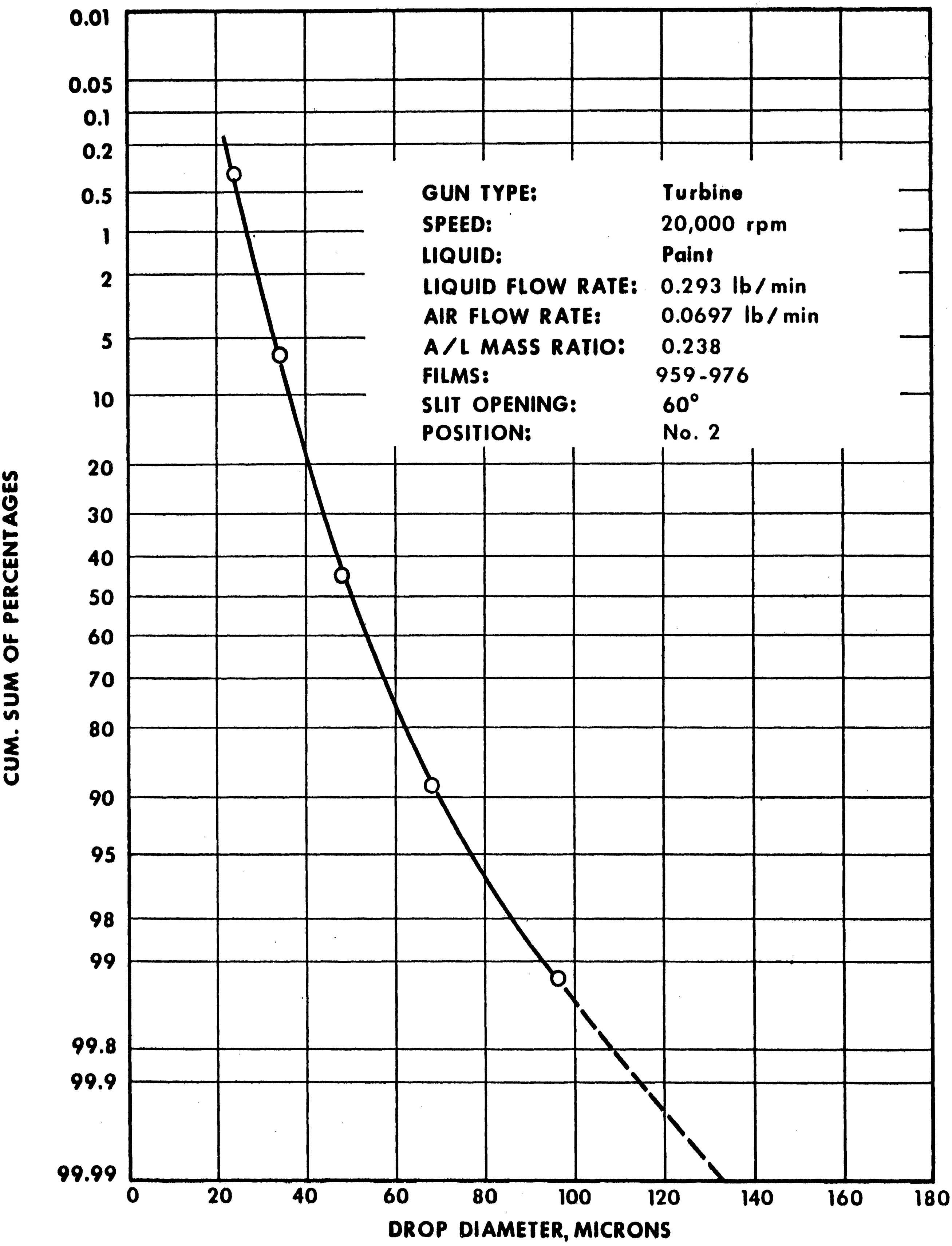

Fig. 47. Cumulative drop-size distribution.

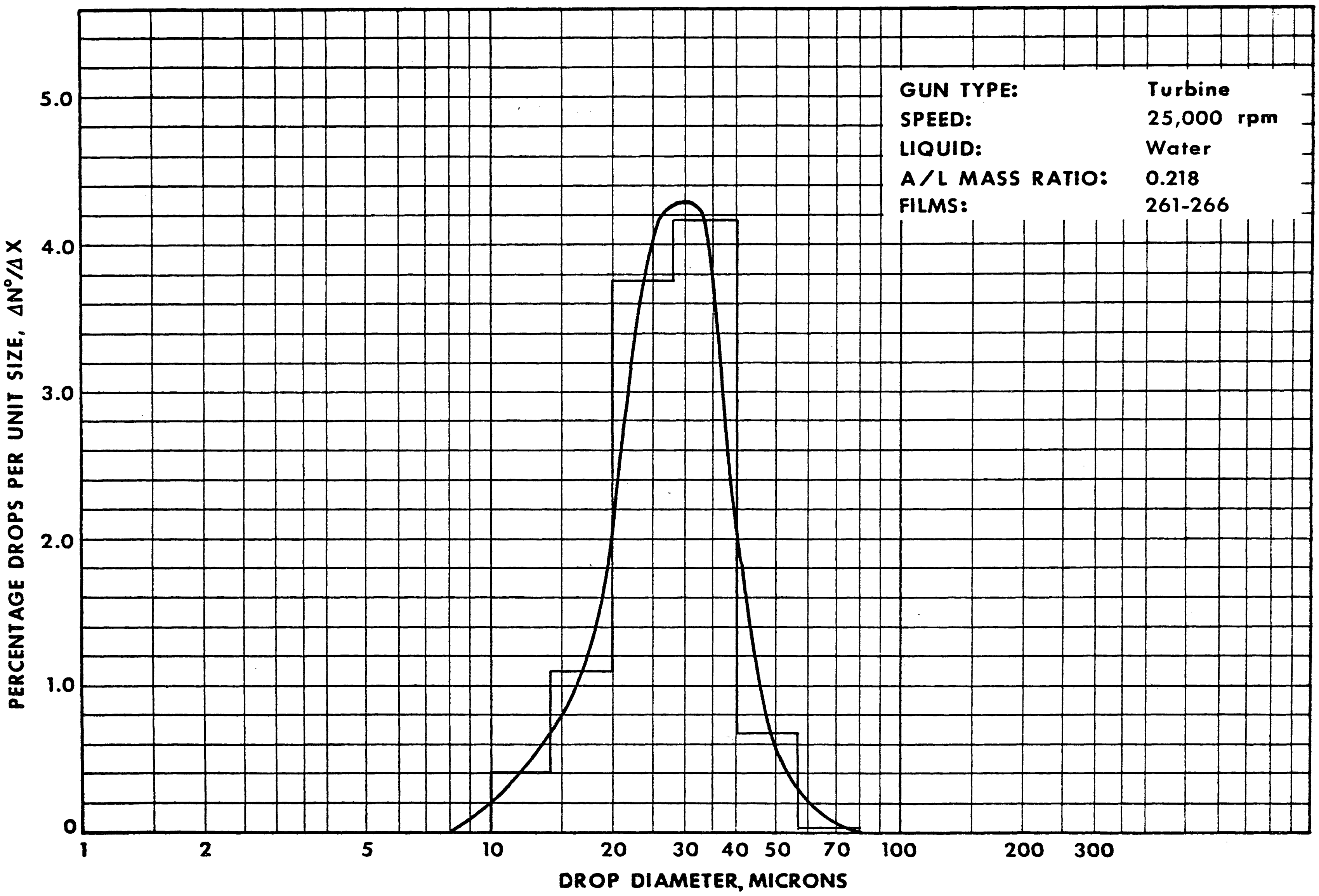

Fig. 48. Direct size distribution.

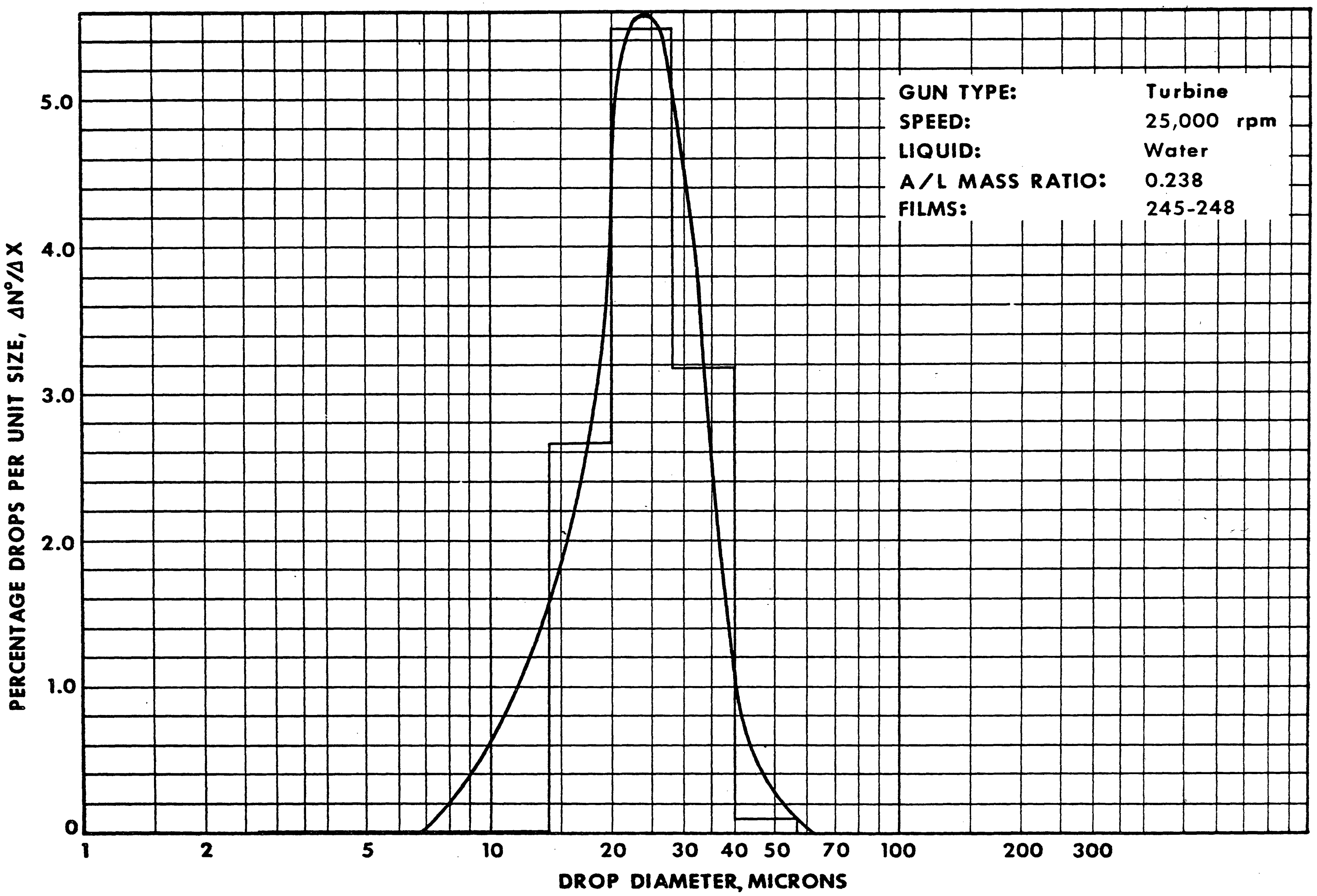

Fig. 49. Direct size distribution.

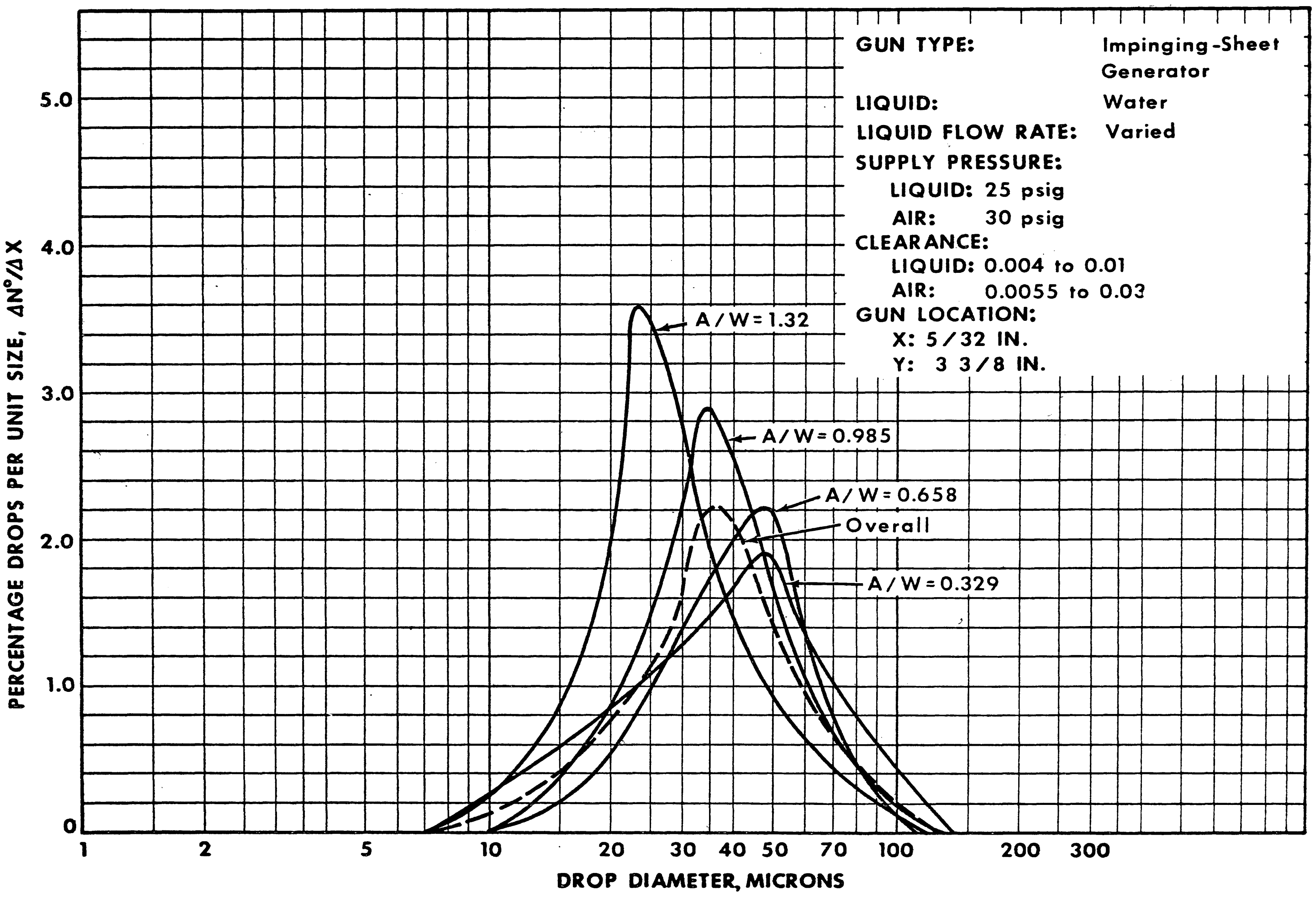

Fig. 50. Direct size distribution.

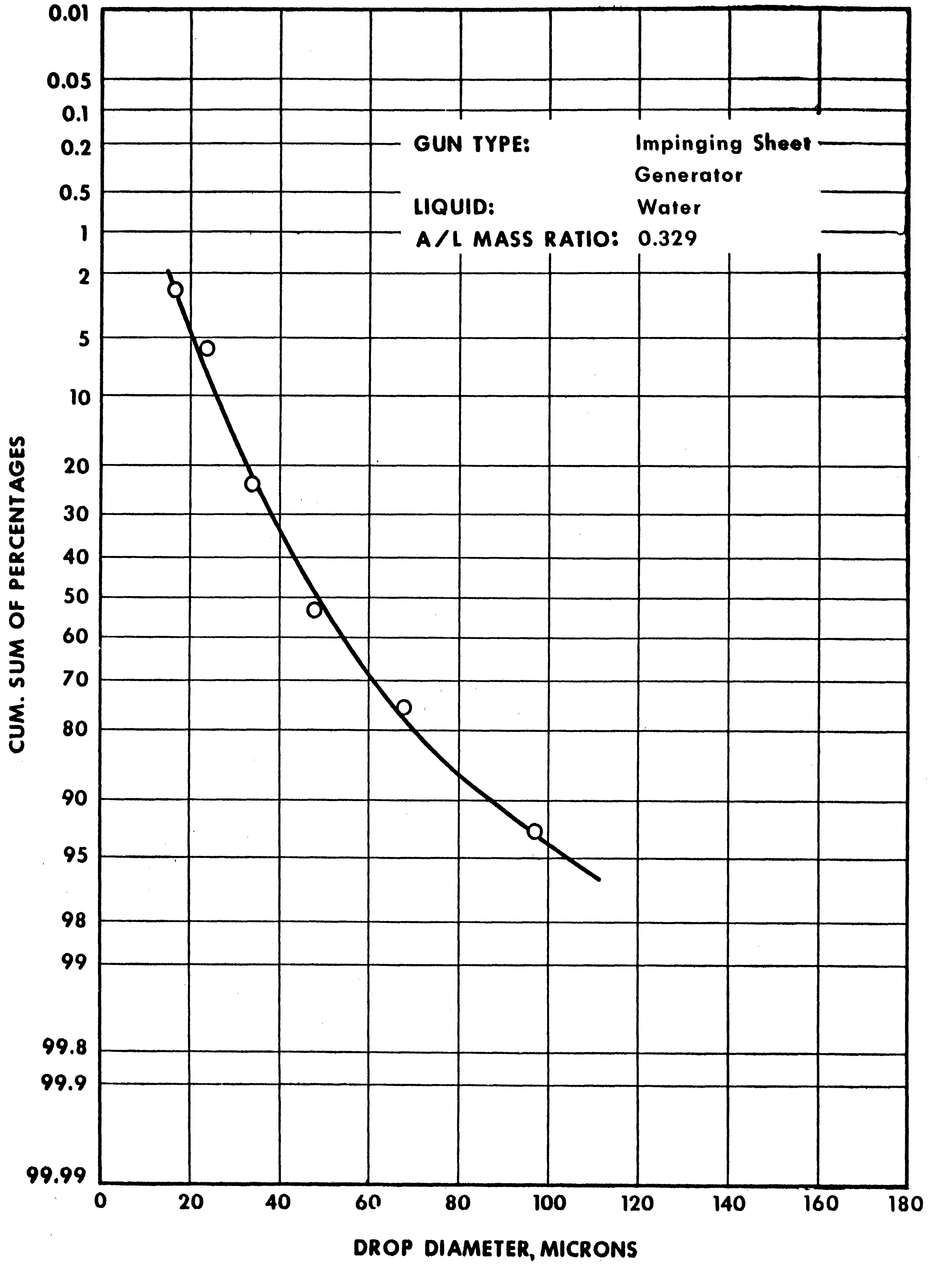

Fig. 51. Cumulative drop-size distribution.

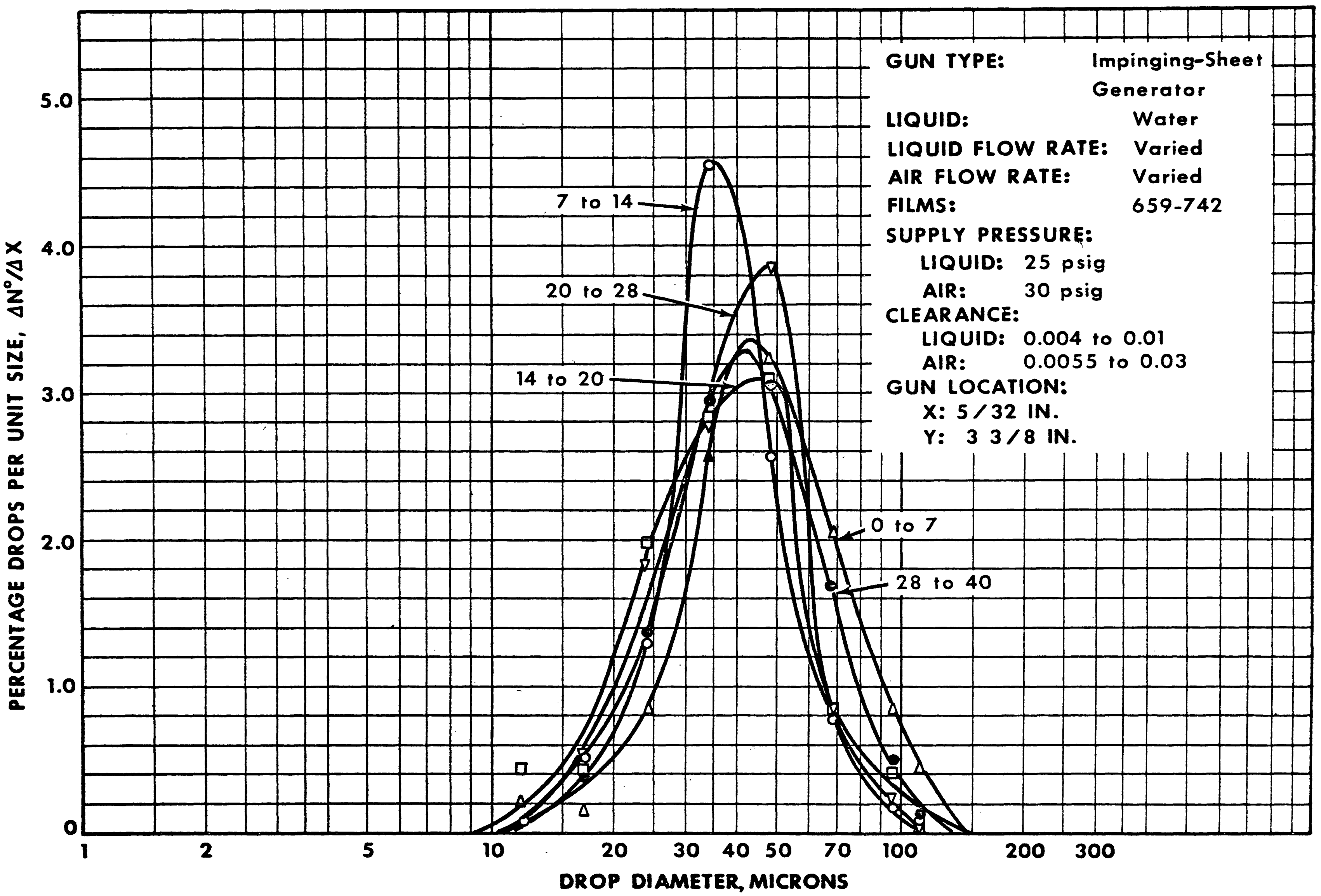

Fig. 52. Diameter-velocity relationship (velocity in ft/sec as parameter).

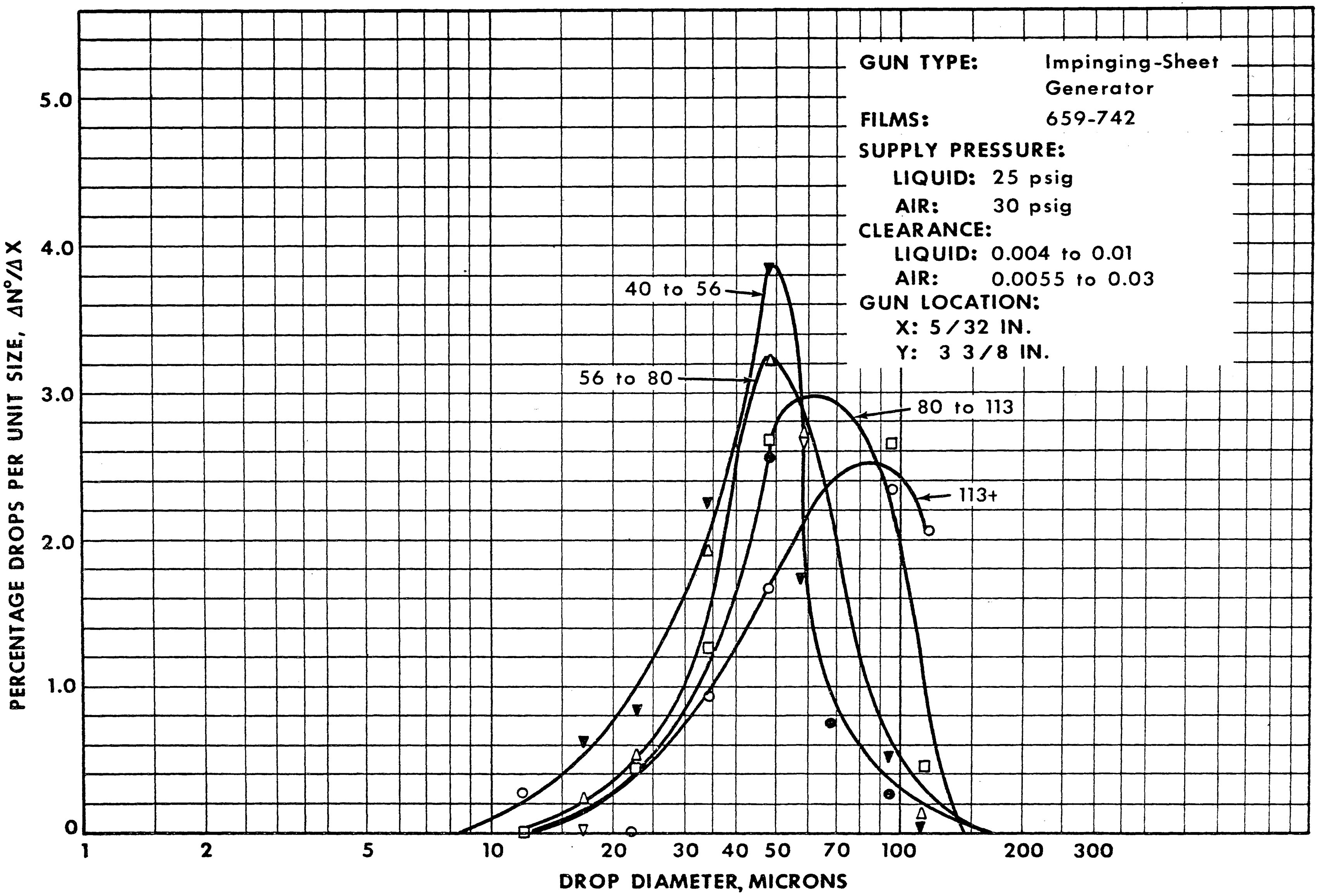

Fig. 53. Diameter-velocity relationship (velocity in ft/sec as parameter).