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Abstract (Limit 200 words)

The NIOSH Paint Spray Respirator Certification test was evaluated. Included in the evaluation were an assessment of the chamber flow paint spray nozzle, chamber paint concentration, paint aerosol penetration through the respirator cartridge, and paint aerosol particle size study in the chamber. Construction diagrams and specifications were provided, and a new paint and solvent mixture was employed. The paint concentration in the chamber was found to vary significantly, while the flows in the test region of the chamber were low, turbulent, and adequate. The particle size distribution of the paint aerosol was not easily controlled and was probably affected by the nozzle air supply pressure. Project protocol, comparison of various spray chamber dimensions, chamber flow diagrams, evaluation design, results of statistical analysis, construction of sample holder, and study of the NIOSH lacquer test are appended.

a. Descriptors
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b. Identifiers/Non-Indexed Terms

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ABSTRACT

The NIOSH Paint Spray Respirator Certification test was developed about 1962 by the Bureau of Mines and has changed somewhat over the ensuing years. It has been criticized by respirator manufacturers because it specified an outdated alkyd enamel for the test paint.

The test was evaluated by Bendix Launch Support Division under Contract 210-76-0178. The results were questionable since the test chamber did not conform to that currently used by NIOSH, TCB, Morgantown, West Virginia. So, it was decided that an in-house evaluation should be conducted.

This report documents the in-house evaluation of the chamber flow, paint spray nozzle, chamber paint concentration, paint aerosol penetration through the respirator cartridge and paint aerosol particle size study in the chamber. It also includes a set of construction diagrams and specifications. A new paint/solvent mixture was used in the evaluation.

The results of the evaluation indicated that: (1) the paint concentration in the chamber varies significantly according to a statistical test referred to as Duncan's multiple range test; (2) the flows in the test region of the chamber are low, turbulent and adequate; (3) particle size distribution of the paint aerosol is not easily controlled and is probably affected by the nozzle air supply pressure.

Further research is now needed to demonstrate a higher degree of control of the particle size distribution and chamber concentration of the paint spray aerosol. This is essential to the validity of the certification test.

CONTENTS

	<u>Page</u>
I. Introduction	1
II. Construction of the Test Apparatus	4
III. Flow Studies	14
IV. Selection of Paint and Solvent	23
V. Chamber Concentration Study	28
VI. Paint Penetration through Respirator Cartridges	33
VII. Particle Sizing Studies in Chamber	40
VIII. Specifications and Design	68
IX. Summary and Conclusions	95
X. References	98
Appendix A Earliest Sketch of Paint Spray Apparatus (1957)	99
Appendix B Project Protocol	100
Appendix C Comparison of Various Spray Chamber Dimensions	108
Appendix D Chamber Flow Diagrams. Chamber Configuration C	109
Appendix E Experimental Design of Evaluation	112
Appendix F Results of Statistical Analysis	123
Appendix G Detail Construction of Sample Holder	126
Appendix H Study of NIOSH Lacquer Test by Mark Ackley, Scott Aviation	133

LIST OF TABLES

<u>Table</u>		<u>Page</u>
I.	Chamber Flow Calibration 8-11--78	8
II.	Chamber Flow Calibration 8-29-78	9
III.	Analysis of Variance of the Chamber Characterization Data	30
IV.	Duncan's Multiple Range Test Investigating Differences Among the Position Means in the Chamber Characterization Data	30
V.	Results of NIOSH and UBTL Analysis of Paint Penetration and Chamber Concentration	36
VI.	Test Conditions for Spray Pattern Test	41
VII.	Summary of Particle Size Data	51
VIII.	Description of Components of Sample Holders and Cartridge Mounts	82
IX.	Description of Components of Exhaust Filter Box	84

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Paint Spray Test Evaluation Chamber	5
2. Air Flow Calibration Set-up	7
3. Evaluation Test Chamber	10
4. Paint Spray Chamber Flow vs Air Velocity at Index Point	11
5. Chamber Configuration for Flow Studies	16
6. Chamber Configuration for Flow Studies	17
7. Chamber Configuration for Flow Studies	18
8. Velocity Measurement Template	20
9. Method for Flow Direction Indication	21
10. Plot of Equation 1 for Acrylic Enamel and Toluene	25
11. Location of Sampling Points for Chamber Concentration Study	29
12. Effect of Spray Conditions on Paint Deposition	43
13. Details of Spots 20, 21, 23 and 24	44
14. Inlet Adaptor for Andersen Sampler	46
15. Mean Particle Size vs Reciprocal Nozzle Air Pressure	50
16. Particle Size Distribution Run #1 Acrylic Enamel/Toluene	53
17. Particle Size Distribution Run #2 Acrylic Enamel/Toluene	54
18. Particle Size Distribution Run #3 Acrylic Enamel/Toluene	55
19. Particle Size Distribution Run #4 Acrylic Enamel/Toluene	56
20. Particle Size Distribution Run #5 Acrylic Enamel/Toluene	57
21. Particle Size Distribution Run #6 Acrylic Enamel/Toluene	58

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Page</u>
22. Particle Size Distribution Run #7 Acrylic Enamel/Toluene	59
23. Particle Size Distribution Run #8 Acrylic Enamel/Toluene	60
24. Particle Size Distribution Run #9 Acrylic Enamel/Toluene	61
25. Particle Size Distribution Run #12 Acrylic Enamel/Toluene	62
26. Particle Size Distribution Run #13 Acrylic Enamel/Toluene	63
27. Particle Size Distribution Run #14 Alkyd Enamel/Turpentine	64
28. Particle Size Distribution Run #15 Alkyd Enamel/Turpentine	65
29. Particle Size Distribution Run #16 Acrylic Enamel/Toluene	66
30. Particle Size Distribution Run #17 Acrylic Enamel/Toluene	67
31. Composite Drawing of Certification Test Apparatus	71
32. Certification Test Apparatus Without Paint Supply System	72
33. Details of Control Panel - Front	73
34. Detail of Control Panel - Rear	74
35. Blower, Vacuum Pump and Air Pump Mounted Under Working Surface	75
36. Vacuum Regulating System Schematic	76
37. Compressed Air Supply Schematic	77
38. Cut-away View of Chamber	78
39. Respirator Cartridge Sample Location	79
40. Detail Layout of Chamber Components	80
41. Construction Layout of Sample Holders and Cartridge Mounts	81
42. Filter Box Assembly by Major Components	83
43. Filter Box Cover Subassembly	86

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Page</u>
44. Filter Box Cover Detail	87
45. Corrugated Filter Sub-Assembly	88
46. Corrugated Filter Sub-Assembly	89
47. Filter Box Base Sub-Assembly	90
48. Filter Box Base Back Panel Detail	91
49. Filter Box Base Bottom Panel Detail	92
50. Filter Box Base Sub-Assembly Detail	93
51. Filter Box Base Assembly Detail	94

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I. INTRODUCTION

The Paint Spray Respirator Certification Test dates back to at least 1952 as indicated by a memo of B.I. Ferber to S. J. Pearce regarding the particle size analysis of the paint aerosol in the paint spray chamber.¹ The test described is not the same as the test procedure at this time. For example, the ventilation flow rate recommended is 80 CFM compared to 100 CFM now; the spray nozzle used in the test is not stated clearly; and the paint used was a No. 675 white enamel manufactured by W. W. Lawrence and Company of Pittsburgh, Pennsylvania not the alkyd enamel (TT-E-489C) used today.

The first reference to the test as it exists today is in a memo from M. E. Peterson of the Willson Products Company dated 5-10-57 regarding the construction of a paint spray testing apparatus to comply with the Bureau of Mines proposed supplement to Schedule 21A.² The test system referred to is the same used by Willson Products today operated by the same technician who was assigned, over 20 years ago, to the test.

The next reference concerning the early test is a memo by W. J. Wisenesser, BOM to the Director, BOM in 1959.³ Wisenesser comments on the proposed BOM Schedule 23B for Paint Spray Respirators. The comments include recommendations for 20-25 air changes per minute in the spray chamber, a nozzle air supply pressure of 10 psig, a nozzle clean out

needle actuation every 15 seconds; and weighing the enamel paint collection filter directly to eliminate the ashing step. All but the last of these recommendations is included in the present test procedure. The paint used in 1959 was the alkyd enamel TT-E-489C or essentially the same as that used today although the memo in reference 3 did not mention the paint type.

It is apparent that at no time was a documented set of test specifications prepared by the Bureau of Mines. The earliest sketch of the system is by B.I. Ferber, March 8, 1957.⁴ This is shown in Appendix A. The lack of adequate test specifications has resulted in the several test apparatuses in use today being different in details of construction. It is also a fact that the test apparatus at TCB, NIOSH, Morgantown, West Virginia has been altered with no notification to other users of the test of the purpose and effects of the changes. The test is also being criticized because the alkyd enamel paint (TT-E-489C) specified is not commonly used or readily available today.

The test was evaluated by Bendix Launch Support Division, under NIOSH contract 210-76-0178⁵ This evaluation was not adequate because the test specifications supplied to Bendix were not up to date and details of construction were unclear. The resulting test apparatus was not comparable in detail to the NIOSH apparatus being used by TCB in Morgantown.

It was decided to continue the evaluation of the paint spray test apparatus in-house. The purpose of this project was spelled out in a protocol (Appendix B). The protocol described five phases. This report covers Phase 1, 2 and 3 of the protocol which are: 1) construction of the apparatus; 2) evaluation of the apparatus; and 3) determination of the optimum operating conditions for the enamel/solvent system. Phase 4, the evaluation of the lacquer-solvent system, was not performed. This phase was evaluated by Mark Ackley of Scott-Aviation⁶ independently and is judged adequate for the purposes of this report.

II. CONSTRUCTION OF THE APPARATUS

The apparatus was constructed to duplicate the device currently used by NIOSH, TCB with some flexibility in the arrangement of the lower baffle and the size of the air slot in the rear of the chamber.

The chamber was constructed of 1/8" aluminum sheet according to the dimensions in figure 1. The inlet for the paint spray was initially an open area 4" x 3-3/4"; this was later changed to a 15/16" diameter circle when it was learned that the device at the TCB Morgantown had been altered. It should be noted that the apparatus constructed by Scott Aviation to conform to the TCB device had the 4" x 3-3/4" paint spray opening.

The air slot in the rear of the chamber was made 2" high and 18" long with an adjustable height to vary the inlet area. The floor of the chamber was also fitted, for some tests, with two 1-1/2" high x 8" long vanes at 45 angles to the rear wall on opposite sides of the air slot to direct the airflow to the center of the chamber. The purpose of these vanes was to promote mixing of the slot air with the paint spray and to prevent the spray from penetrating the air slot to deposit outside the chamber. The effectiveness of these vanes is discussed under flow studies.

The flow meters used in this apparatus were Dwyer rotometers used by Bendix Launch Support Division in Contract 210-76-0178. TCB uses

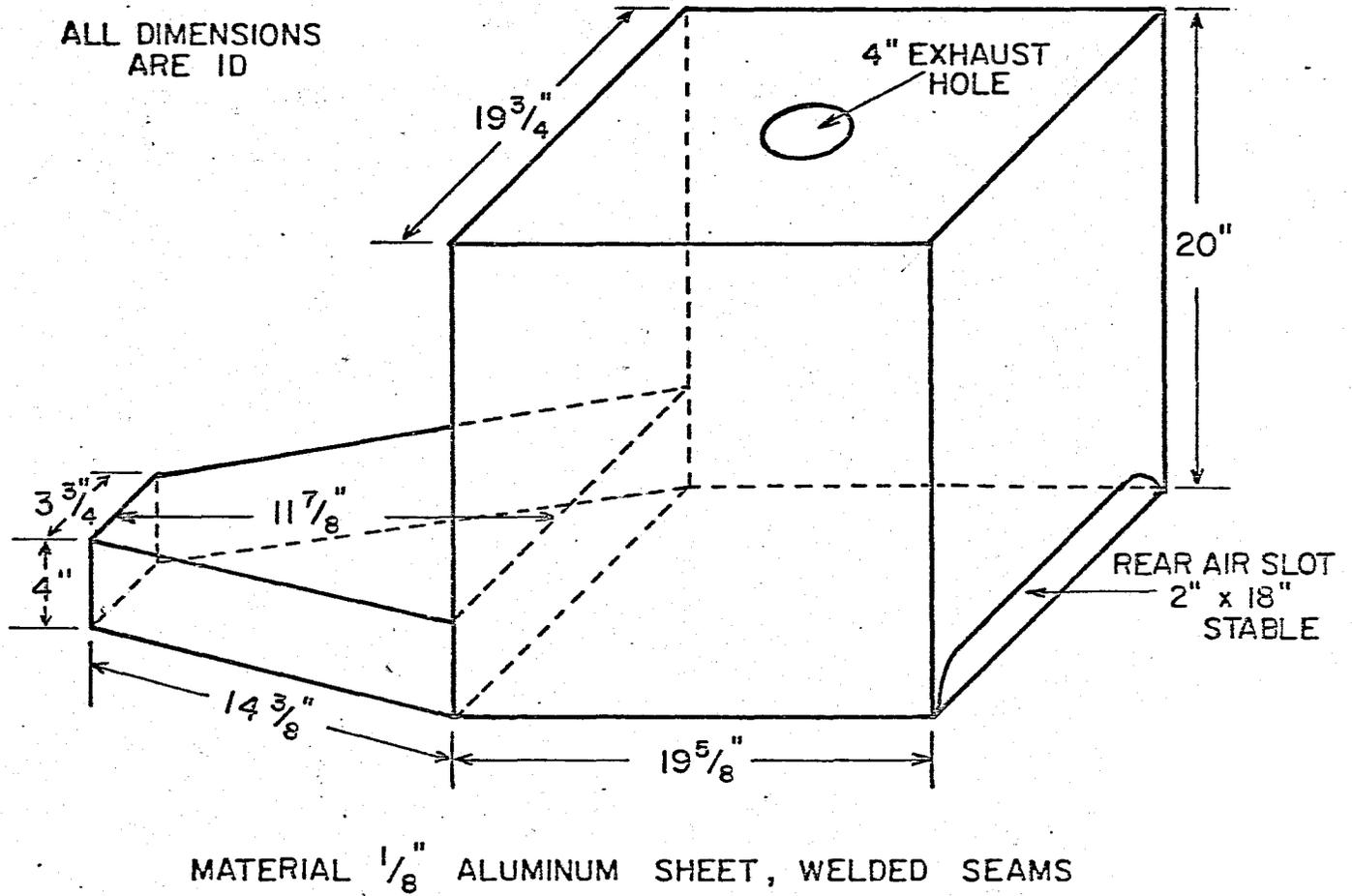


Figure I. Paint spray test evaluation chamber

metering orifices to monitor sample flow. The rotometers were calibrated using a new Matheson precision rotometer with tube No. 603. Large bore sample lines such as used by TCB were not installed in the apparatus to limit line loss. Rubber tubing, 1/4 inch ID, was used instead. The line pressure was monitored and no flow corrections were necessary since the pressure drop across the sample filter did not exceed more than four inches of water. This means that the flow correction was no more than 0.05%.

The air supply system for the nozzle was 80 psig maximum. This was 10 psi less than the air pressure recommended for the pneumatic clean out needle actuator but when the nozzle manufacturers, Spray Systems Inc., were consulted it was declared to be adequate.

The paint filter for the effluent from the spray chamber was designed to hold 2 layers of 1" thick furnace filters. This arrangement didn't have the efficiency of the sinuous filter on the TCB device and required clean filters every sixteen hours of operating time. It was, however, adequate for temporary use and prevented the contamination of objects outside the duct discharge.

The paint spray test chamber required flow calibration to determine the pressure drop in the chamber corresponding to different flow rates. The calibration was performed by rigging a 7.42 ft. straight-run of 4 inch ID PVC pipe (figure 2) connected to the paint spray test chamber. The downstream end of the pipe was connected to a blower, Model PB-9,

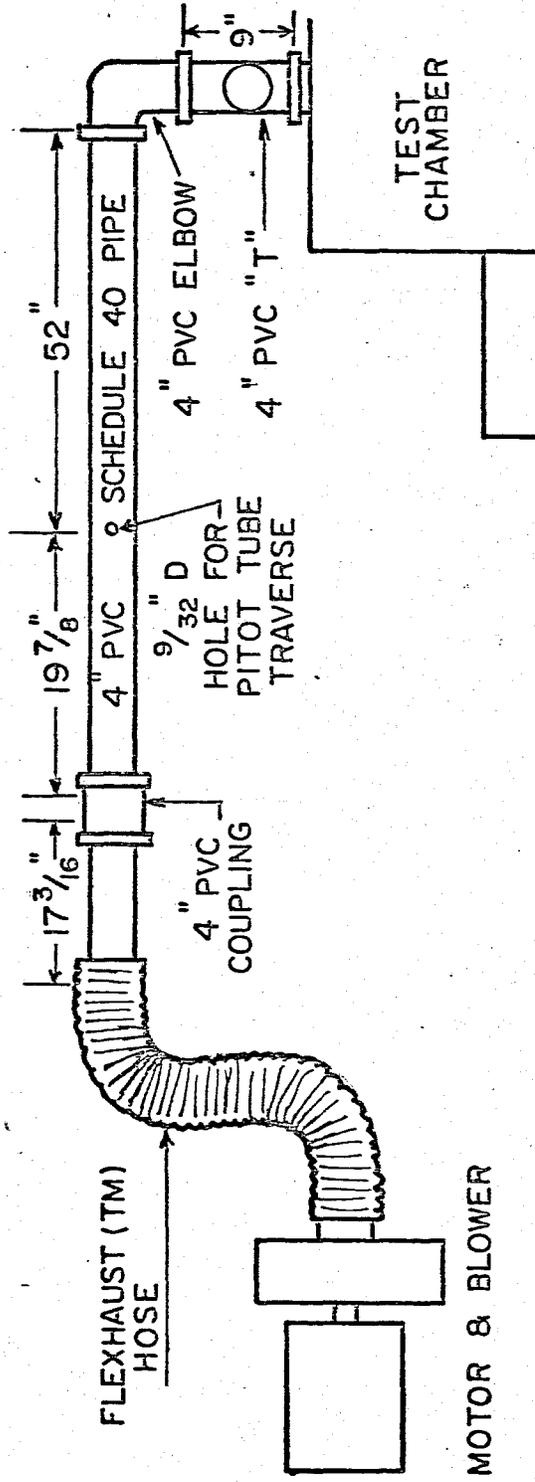


Figure 2. Air flow calibration set-up.

Cincinnati Fan and Ventilation Company, Inc., driven by a Baldar 1 hp, 3450 rpm, 3 phase, 208 volt motor. The air flow was regulated by means of the damper on the blower inlet. The chamber pressure reading was obtained with a Dwyer #452, 0-2" inclined manometer. The flow in the 4" PVC duct was measured at a point 52" downstream from the chamber. The ten point traverse was made with a pitot tube which had been calibrated by Measurements Service Branch, DPSE, NIOSH. The chamber flow was calibrated at chamber pressures of 0.4, 0.5, 0.6, 0.8, 1.0, 1.2, 1.5, 1.6, 1.8 and 2.0 inches of water. In this way chamber flow could set at any predetermined level. The chamber configuration was a 4" x 3-3/4" spray inlet and a 1/2" x 18" air slot at the back of the chamber. The average velocities of the air is shown in Table I.

TABLE I
CHAMBER FLOW CALIBRATION
AUGUST 11, 1978

	Chamber Pressure (in H ₂ O)						
	0.4	0.5	0.6	0.8	1.0	1.2	1.5
Average velocity (ft/min)	1294	1420	1583	1852	2061	2278	2555
Flow rate (ft/min)	113.0	124.0	138.2	161.7	179.9	198.9	223.1

The calibration was repeated on August 19, 1978 to check the results. This data is given in Table II.

TABLE II
CHAMBER FLOW CALIBRATION
AUGUST 29, 1978

	Chamber Pressure (in H ₂ O)							
	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.5
Average velocity (ft/min)	1320	1460	1620	1853	2101	2274	2545	2615
Flow rate (ft/min)	115.2	130.4	141.4	161.8	183.4	198.5	222.2	228.3

This data provided the basic calibration data for the chamber. Flow measurement was also possible by measuring the air velocity in the 4" ID PVC pipe connecting the chamber with the filter. A secondary flow calibration was then performed at various chamber pressures using the paint spray inlet of 4" x 3-3/4" and a rear air slot of 1/2" x 18". The air velocity in the 4" ID duct "T" between the spray chamber and the filter box (see Figure 3) was monitored with an Alnor Velometer 6060 probe. This provided the means to establish desired flow conditions in any chamber configuration.

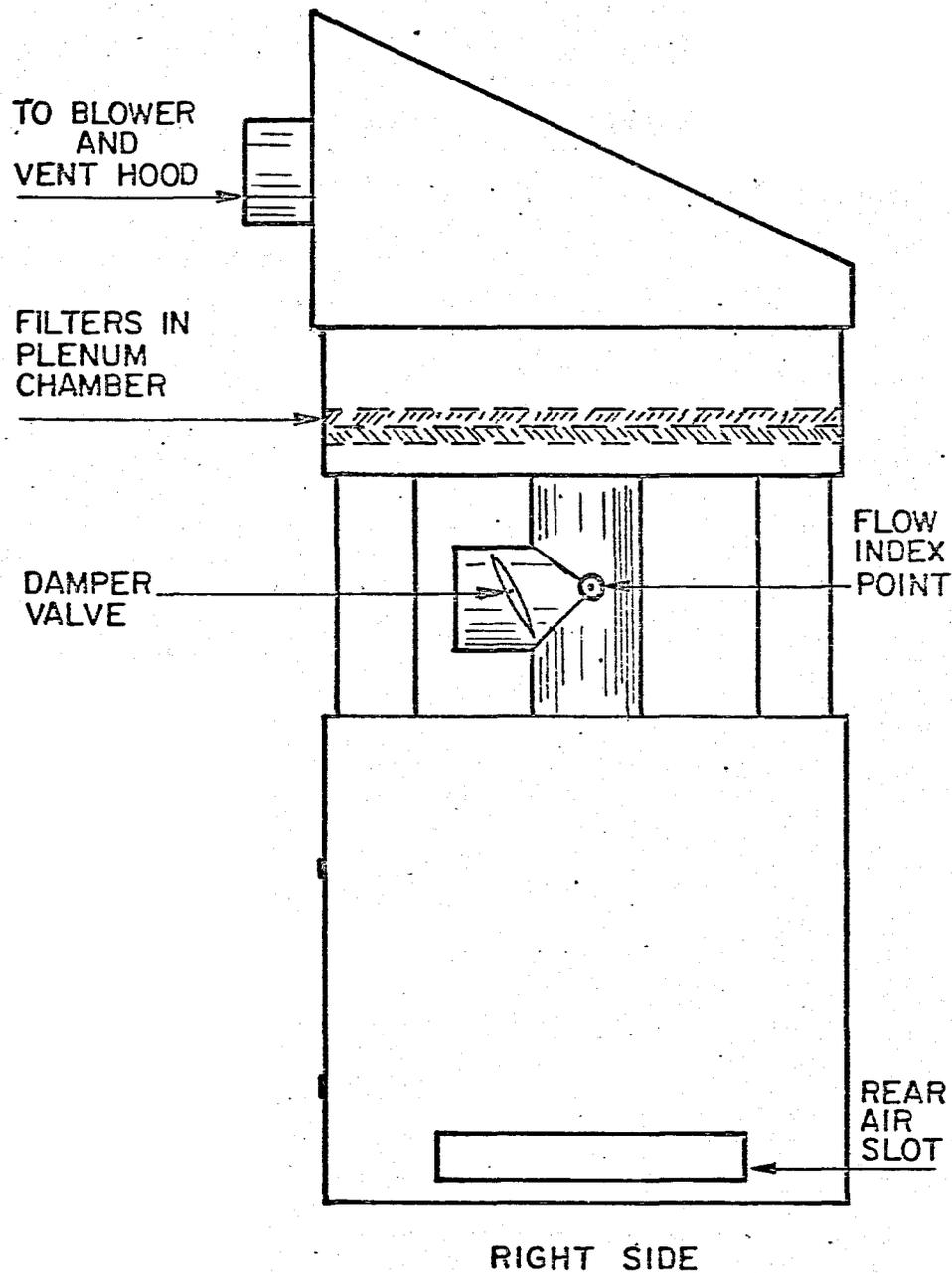


Figure 3. Evaluation test chamber .

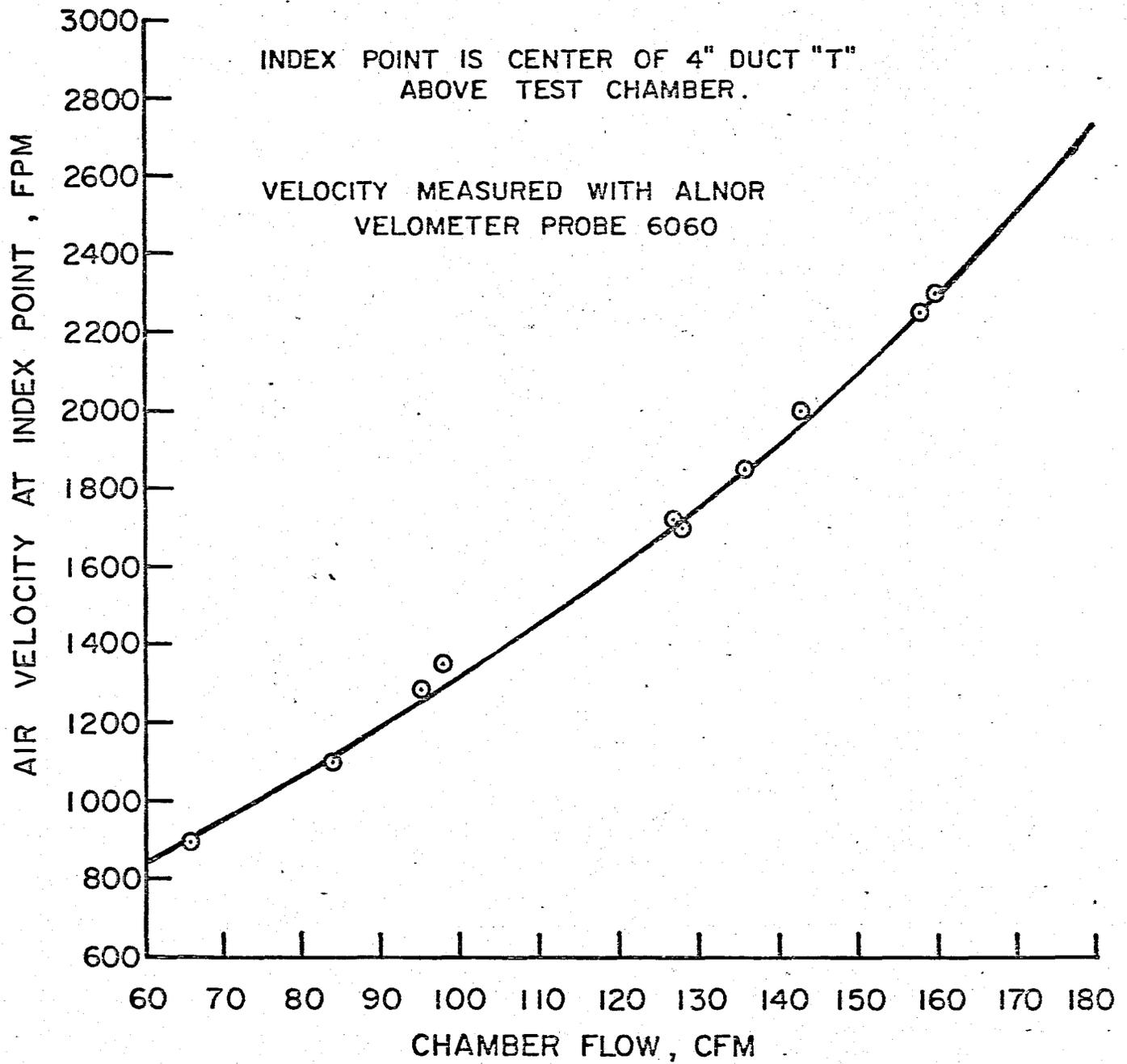


Figure 4. Paint spray chamber flow vs. velocity at index point .

Ideally this line would be linear. It should be noted that the reference point is not far enough downstream from the duct opening or from the "T" in the connecting duct to allow the velocity profile to be uniform for all flow rates. This does not however invalidate the correlation of the two flows.

The paint spray delivery system was assembled initially in the same manner and with the same hardware used by Bendix Launch Support Division in their evaluation. This included: The 1/4 JAU Spray Systems nozzle with the 1650 fluid cap and the 64 air cap; an FMI G20 positive displacement variable stroke length laboratory pump; and a variable interval timer to regulate the pneumatic clean-out needle.

Attempts to calibrate the FMI pump revealed considerable leakage probably due to abrasion by the paint pigment. It was at this point discovered that the TCB paint delivery system used a peristaltic pump to deliver air to a closed paint flask which displaced the paint to the nozzle. It was also discovered at this time that Scott Aviation used a more direct approach by delivering the paint through a capillary tube so that flow rate could be controlled by adjusting the paint height or liquid pressure.⁶ The capillary diameter is not critical but the length and liquid height or pressure must allow adequate flow. In this way the pump is eliminated. The capillary used was about .020" in diameter and 52" long; it was made of Teflon which resisted the paint solvent very well. The paint was delivered from a 500 ml erlenmeyer flask dripping into the spray nozzle liquid inlet.

The chamber sampling system was made up of hardware fabricated in the DPSE machine shop and the Dwyer flow meters and sundry hardware used by Bendix Launch Support Division in contract 210-76-0178. The rotameters were calibrated at the control points (3.0 L/min and 32 L/min) with a Matheson factory calibrated, precision rotameter having a No. 603 tube and stainless steel float. This calibration approach assured precise control of sample flows. Flow control in the sampling system is not a problem in this test.

III. FLOW STUDIES

The present dimensions of the test spray chamber are generally the same as those of the original chamber fashioned in the early fifties. The air slot in the rear of the chamber is now $3/4"$ x $18-1/2"$ instead of $3"$ x $13"$; the spray inlets are flared from a $4"$ x $3-3/4"$ inlet to a $4"$ x $20"$ opening at the chamber wall rather than the $3-3/4"$ diameter PVC pipe; and the bottom baffle is $6"$ from the floor rather than the $7"$ specified in the 1957 drawings. The 1957 drawing shows the samples being taken through electrostatic precipitator tubes. This is not done by any test operator at this time. The high efficiency filter has replaced the electrostatic precipitation.⁴ The upper baffle has not been changed.

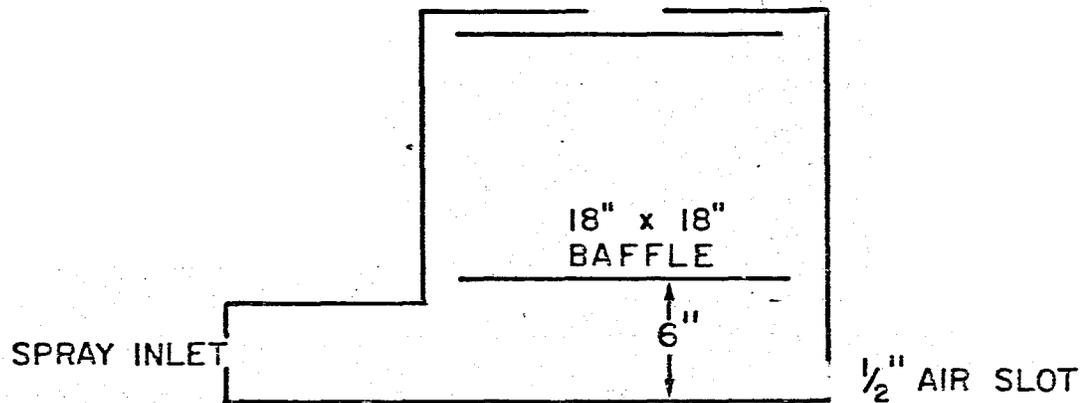
The baffles control the flow and distribution of the paint aerosol through the chamber. The baffles: 1) promote mixing of the paint spray with the inlet air from the opposing $3/4"$ x $18"$ air slot; 2) screen the respirator cartridges and sample filters from direct impingement of the spray. The design of a baffle system will need to focus on the above two objectives.

The mixing of the paint spray with inlet air is promoted by high inlet air velocities but paint aerosol drop out will also be enhanced by the resulting higher inertial forces. The baffles can be enlarged to reduce direct impingement of the paint aerosol on the test cartridges but baffles made too large will screen the respirator cartridge and samplers from the

aerosol and might make it more difficult to achieve the specified chamber concentration.

The flow study was done using five chamber configurations. See figures 5, 6 and 7. The vanes inside the rear air slot were introduced in configurations B, C and D to channel the slot air into the stream of the spray nozzle at a higher velocity and promote mixing of the aerosol. Configuration A was thought to conform to the chamber used at TCB in Morgantown but was found to be in error. Nancy Bollinger, TCB supplied correct information on May 4, 1979. Configuration E is correct. The comparison of the dimensions of other test chambers used by industry is shown in Appendix C. The dimensions of the test chamber should not matter if the specified mean size and concentration of the aerosol can be maintained. However, the mean residence time and flow patterns in the chamber will affect the concentration and mean size of the aerosol since the aerosol changes with time; changes in flow direction preferentially affect the removal of the larger particles. The conclusion is that variations in the volume of the chamber and in the internal flow patterns due to baffles will make it difficult to create comparable aerosol quality in different chambers.

CONFIGURATION A.



CONFIGURATION B.

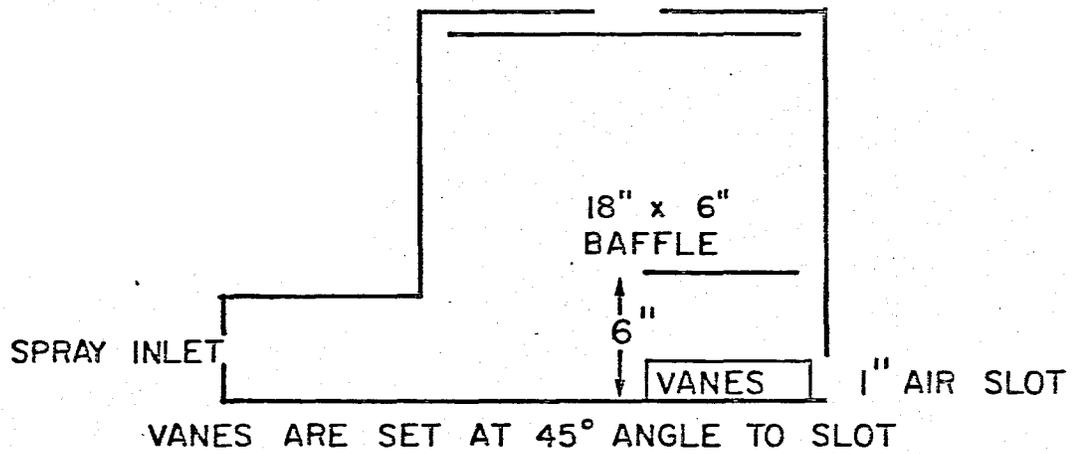
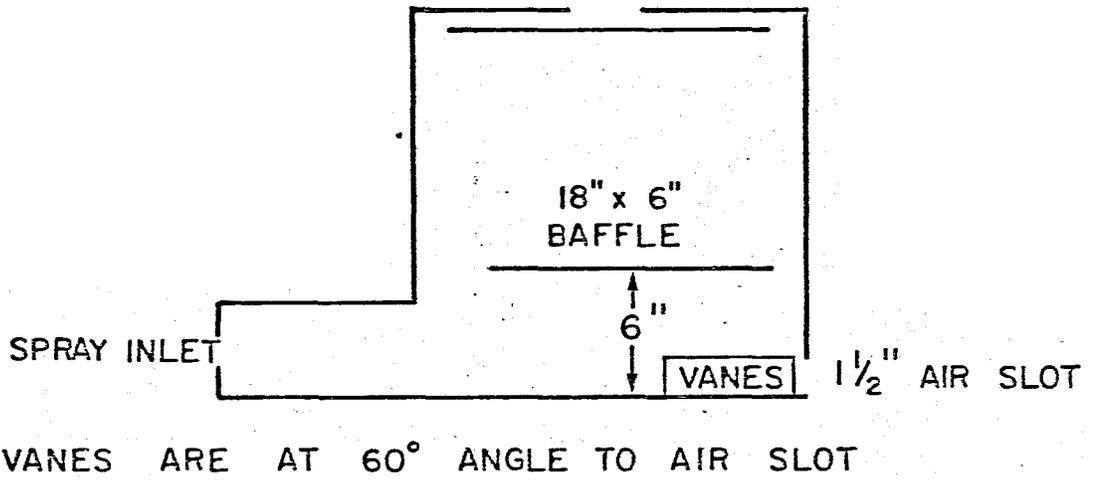


Figure 5. Chamber configuration for flow studies .

CONFIGURATION C.



CONFIGURATION D.

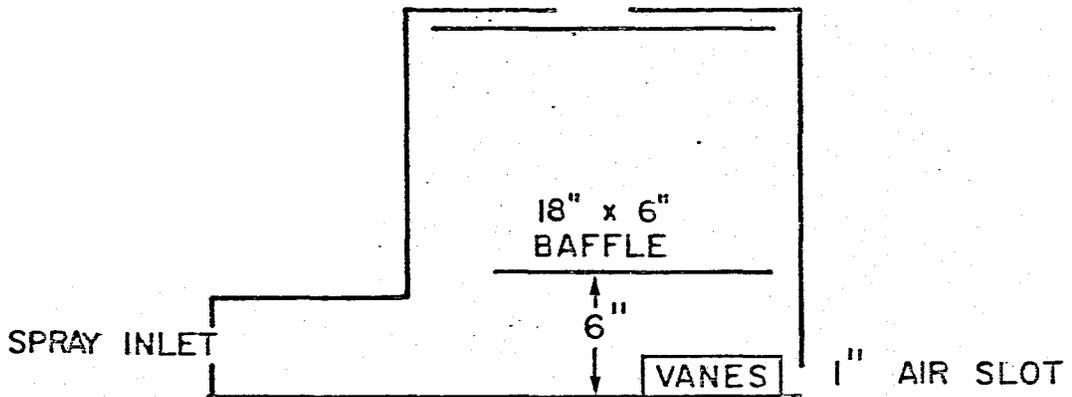


Figure 6. Chamber configuration for flow studies .

CONFIGURATION E.

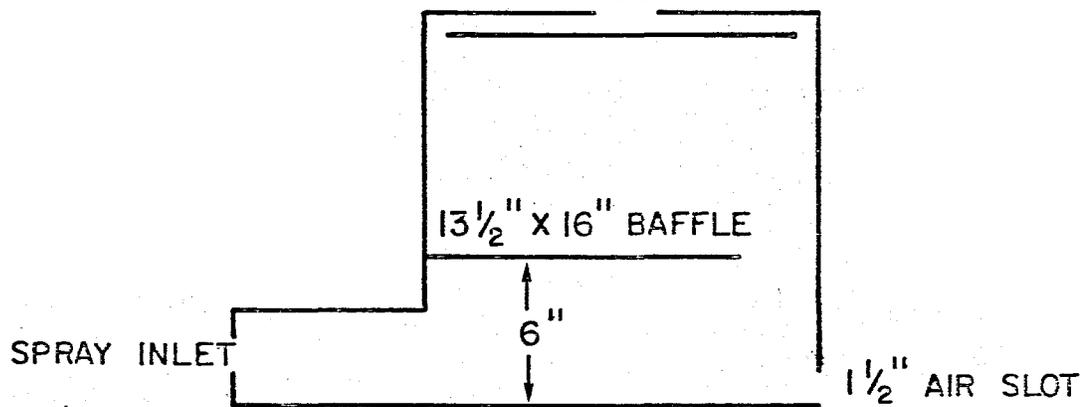


Figure 7. Chamber configuration for flow studies .

The evaluation of the flow characteristics of the spray chamber was done in terms of velocity and direction. The approach was to prepare a sampling grid of 1/8" plastic with 12 sampling positions which was attached to the spray chamber door space. (Figure 8) The velocity of the air was measured using a Sierra Model 440 hot wire anemometer with velocity probe #10762. The direction of the airflow was estimated using a thread glued to a stiff wire and by means of a smoke tube. The thread worked best where velocities were high or where flow was very turbulent. The smoke tube worked best at low velocities. The velocity was measured at 11 depths for each sample position for a total of 132 data points for each configuration. The flow direction was monitored at 7 depths for a total of 84 positions for each configuration so tested.

The estimation of the direction of the air flow at each point was very subjective in nature. Considerable turbulence exists at all points in the chamber which results in erratic flow indications. The judgement was made by observing for up to one minute to decide the predominant direction of flow. The direction is reported as a three dimensional indicator which is not scalar. This is important to note since the indicator varies considerably in actual and apparent length. The directions were recorded as angles, right or left, above a horizontal plane and angles, in or out, from a vertical plane in line with the axis of the paint spray inlet. The method for graphing this is shown in Figure 9.

THIS TEMPLATE WAS TAPED OVER CHAMBER DOOR OPENING

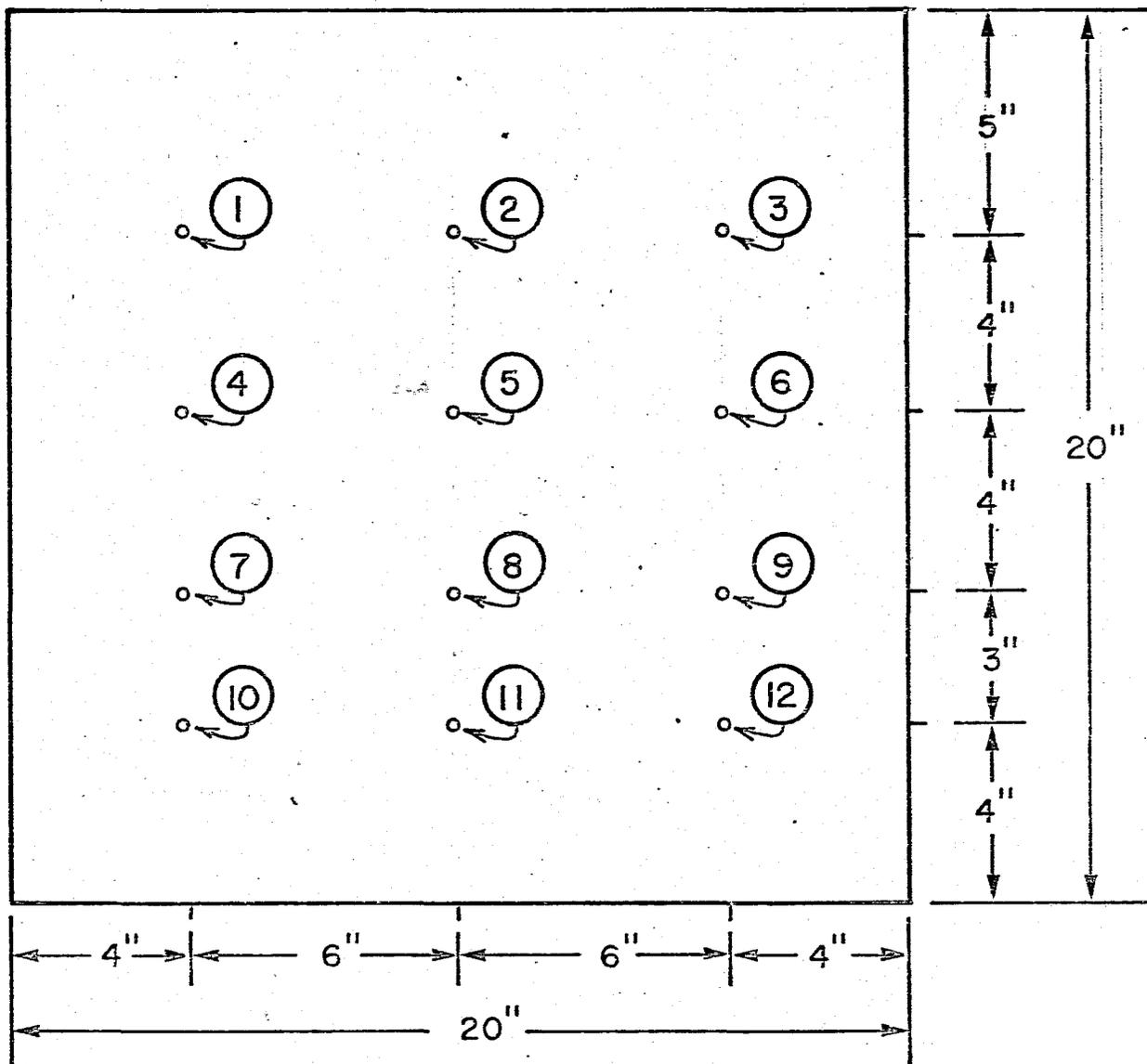


Figure 8. Chamber sampling template .

EXAMPLE OF FLOW DIRECTION INDICATOR

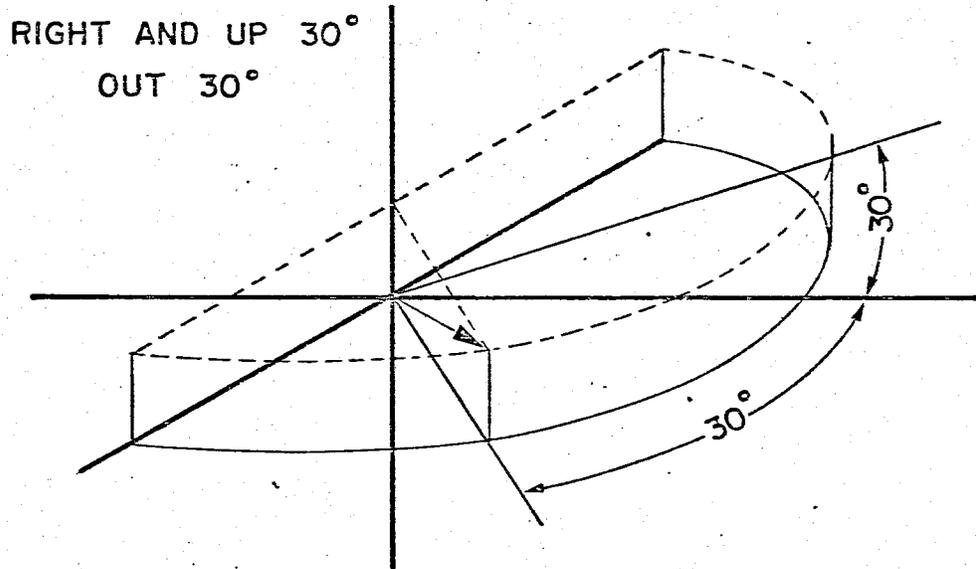


Figure 9. Method of flow direction indication .

It must be noted here that the flow direction tests on configuration A (Figure 5) were made by another method with poor results, this series was not repeated when that chamber configuration was determined to be unsatisfactory because too much paint collected under the bottom baffle. The flow directions for configuration E were not made due to a combination of the lack of time and the feeling that the method was too unsound to provide a precise indication of the flow pattern. The turbulent flow above the lower baffle creates a flow pattern in all chamber configurations difficult to define with the few points sampled. The flow pattern data for Configuration C are shown in Appendix D.

It is this researcher's opinion that it is more important to maintain a low but turbulent air velocity in the test region to keep the paint aerosol in suspension and to minimize the effects of impinging the paint on the respirator cartridges. The latter effect could bias the resistance build-up test. A velocity in the sample space in excess of 20 fpm will assure turbulence. Configuration E, has flow values in the sample space that average 50 fpm for the sample depths 2" through 18" and range from 15 fpm to 150 fpm. This would indicate that the present Configuration E is adequate from the stand point of low turbulent flow in the test zone.

IV. SELECTION OF PAINT/SOLVENT

The criticism of the existing 30 CFR-11 test in terms of the outdated alkyd paint specified is valid if it is important that the test paint be representative of paint currently used in industry. Alkyd paints are not significant in the modern industry. The search for a suitable replacement was carried to the National Paint and Coating Association (NPCA). The suggested replacement was an automotive refinishing acrylic paint which is much used in the auto body repairs shops where the need for respiratory protection is recognized by NPCA.

Messrs. Charles Martens, Charles Berg and David Sarvadi of the Sherwin Williams Company were contacted on June 12, 1978 to discuss the selection of an acrylic enamel for this test. The criteria other than being a much used paint was that it have a finely ground pigment and be capable of generating a fine spray. The paint solvent mixture recommended was Sherwin-Williams F5-Y93 acrylic enamel and their R-7K211 solvent. The F5-Y93 enamel has 10% of iron oxide yellow ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) pigment plus 39.42% resins. The iron oxide pigment has a mean particle size of about $0.2 \mu\text{m}$ which means that it will not be a limiting factor in the aerosol size distribution which is determined by the fluid properties. The RK-7K211 solvent has a boiling range of 133-360 F with an average molecular weight of 101.5 and a flash point of 10 F Tag closed cup and is used in auto refinishing shops to promote drying during cold weather. It was assumed that a light solvent would promote the formation of small

paint droplets but it appears to have little effect. This is made clearer in the following paragraph.

The empirical equation of Nukiyama and Tanasawa as reported by Marshall⁷ for finding the mean drop diameter indicates that control of drop size is not so simple as using a low boiling solvent.

$$D = \frac{585 \sqrt{\gamma}}{V_s \sqrt{\rho_L}} + 597 \left(\frac{\mu}{\sqrt{\gamma} \rho_L} \right)^{0.45} \left(\frac{1000 Q_L}{Q_A} \right)^{1.5} \quad \text{EQ. 1}$$

where: D = mean drop diam, μm

V_s = relative velocity between liquid and ambient air, ft/sec

γ = surface tension of liquid, dynes/cm

ρ = liquid density, lbs/ft^3

μ = liquid viscosity, poise

Q_L = volumetric flowrate of liquid

Q_A = volumetric flowrate of air

The addition of solvent or the use of a lighter solvent affects, ρ , μ and possibly γ . It can be seen in Eq. 1 above that since μ , and ρ will all change in the same direction the effects will be reduced and confounded.

It is also clear that as the volumetric flow rate of the air (Q_A) and relative velocity of the air and liquid (V_s) get larger the diameter

(D) of the drops get smaller. This is explained in Atomization and Spray

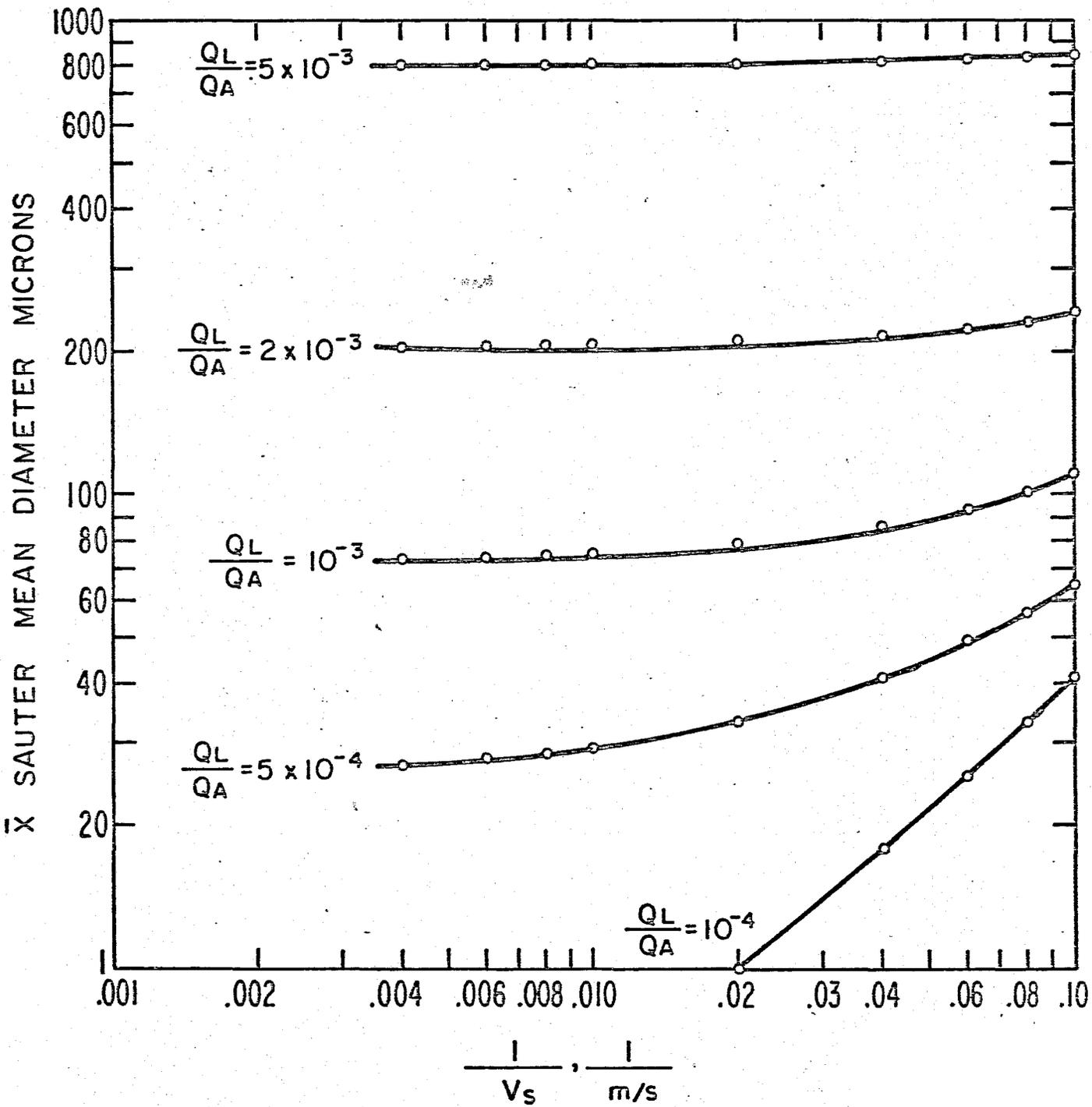


Figure 10. Plot of equation 1.

Drying by W. R. Marshall⁷. Marshall has used equation 1 to develop a plot of the Sauter mean diameter (X_{va}) versus $(1/V_s)$ with parameters of Q_L/Q_A . (See figure 10). This plot is applicable to air-liquid atomization where liquid density ranges from 43.7 to 75 lb/cu ft and viscosities from 0.3 to 50 centipoise. Figure 10 has been calculated from physical properties of paint and solvent used in this test; it is shown to demonstrate the effect of air velocity on the mean aerosol size. Attempts to verify this equation with actual run data have not been successful; the major problem is this equation is the relative velocity term (V_s) which is affected by the volume of paint occupying the nozzle orifice at any instant; it can not be calculated.

While using the R-7K211 solvent, much difficulty was encountered with clogging of the spray orifice. This interfered with the proper paint flow into the chamber. Spray Systems Inc., manufacturer of the nozzle was contacted. Mr. Harush of Spray Systems Inc. said it was very difficult to diagnose the problem without being present to observe the problem. He suggested using more solvent. This was impractical since the experiment called for specific amounts of solvent. Sherwin-Williams was contacted on May 1, 1979; it was suggested that pure toluene be used as the solvent. The toluene would not, in their opinion, interfere with the paint delivery but it would slow down the drying of the paint on the nozzle tip which led to flow problems.

The conclusion is that, to achieve a fine droplet size, it is important to focus on the delivery system rather than on the paint mixture. A high

nozzle air velocity will generate the sheer forces necessary for fine aerosol generation. The use of a light solvent will possibly be beneficial in that it will promote the drying of the paint droplets; it is not known however if this is important in this test.

V. CHAMBER CONCENTRATION

The object of the chamber concentration studies was to determine the variations of paint concentration at specified points in the chamber. The points are located as indicated in Figure 11.

The randomly selected samples were taken at three of the five points during each run. A statistical analysis was performed on the fifteen samples taken in the 5 runs, to determine if a significant difference existed between the concentrations at each of the five points. The Duncan's Multiple Range Test⁸ was performed to test for differences in the paint concentration means at each of the five positions. The results are shown in Tables III and IV and indicate a significant difference between concentrations at the various positions.

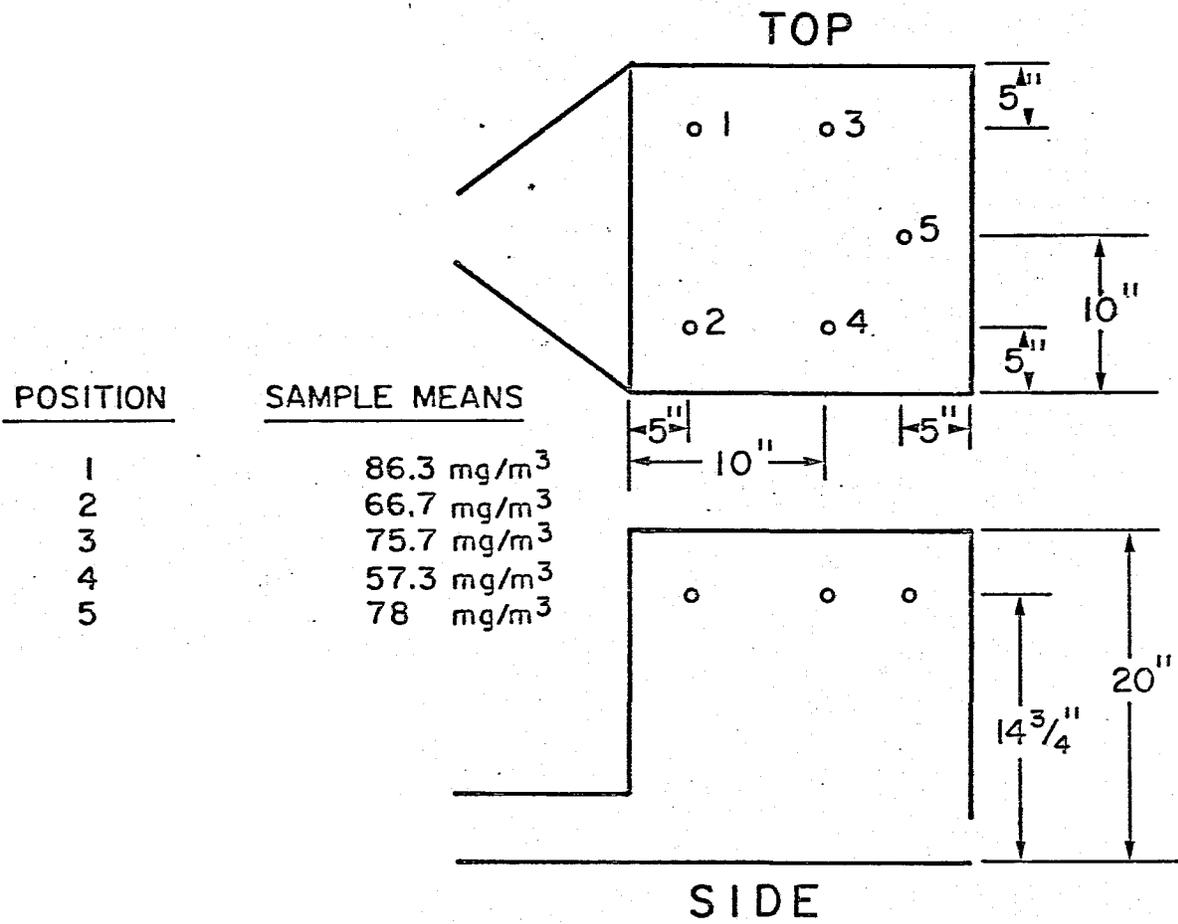


Figure II. Location of sampling points for chamber concentration study.

TABLE III
ANALYSIS OF VARIANCE OF THE CHAMBER CHARACTERIZATION DATA

Source	Degrees of Freedom	Mean Square	F	P
Positions	4	371.43	4.51	.02*
Error	10	82.27	-	-

*Significant at the .05 probability level.

TABLE IV
DUNCAN'S MULTIPLE RANGE TEST INVESTIGATING DIFFERENCES
AMONG THE POSITION MEANS IN THE CHAMBER CHARACTERIZATION DATA

Position ¹	Means (mg/m ³)	Sample Size
4 } 2 } 3 } 5 } 1 }	57.3	3
	66.7	3
	75.7	3
	78	3
	86.3	3

¹Position's included within brackets are not considered significantly different.

The interpretation of Table IV is that the test chamber as set up produced a non uniform distribution of the paint aerosol among the five positions tested. The concentration at point 2 was significantly lower than point 1: the concentration at point 4 was significantly lower than at points 1, 3 and 5. Ackley⁶ determined that the spray nozzle, when carefully aligned along the center axis of the spray inlet, produced a chamber concentration that varied only 2 or 3 percent. When the spray nozzle was misaligned 6.4 mm from the center line and inclined 4 degrees upward the concentration varied as much as 14 percent from one side of the chamber to the other. Paint nozzle alignment is then an important factor in producing a uniform paint aerosol distribution in the chamber.

In the construction of a test chamber, the spray nozzle should be fixed firmly in the same position for each test. The nozzle mounting assembly should also be adjustable laterally and vertically so that the paint spray aerosol concentration can be equalized in the exposure space above the baffle. The paint spray concentration should be tested at specified points in the chamber and nozzle alignment adjustments made until there are no significant differences between concentration means as determined by the Duncan multiple error test.

Ackley's⁶ explanation of the effect of nozzle misalignment was that the paint aerosol was reduced on the side to which the spray was diverted due to paint impingement on the floor and baffle; this would reduce the aerosol on that side. This does not answer the question conclusively

because the side of the chamber receiving the greater amount of paint spray should also receive more fine droplets. The factor not considered by Ackley is the flow characteristics of the chamber. In directing the flow to the side and upward the paint spray should tend to slide over the incoming air from the rear air slot and should tend to curve up and around the center to bring it above the rear of the bottom baffle curling to the opposite side. This is speculative but it provides an explanation based on flow patterns as opposed to one based on selective paint impingement. Chamber flow should be further evaluated to better understand the importance of proper alignment of the paint spray nozzle.

VI. PAINT PENETRATION THROUGH RESPIRATOR CARTRIDGES

The paint penetration studies had the objective to evaluate 4 factors in the paint spray respirator certification test to determine if any correlation exists between the paint aerosol concentration in the chamber and the paint/solvent ratio, nozzle air-supply pressure, paint flow rate and chamber air flow. The paint aerosol concentration was a dependent variable. Two levels of each variable were selected. The experimental design for this test is shown in Appendix E.

The dependent variable for this test was the paint penetration through the respirator filter cartridge. The respirator cartridges were mounted on a Willson 2100 series respirator which were in turn cemented to an epoxy resin face form molded from a mannequin head. This provided a leak-proof seal for the respirator face fit. The use of the entire respirator ensemble should not be necessary for the certification test since only the cartridge penetration is being measured. The penetration was determined by filtering the respirator cleaned air through a Millipore Type SM, 5.0 micron, 47 mm diameter paper. The chamber paint concentration was monitored by sampling at the center port of the chamber near the wall. The sampling procedure used was that specified for paint respirator certification testing by in 30 CFR-11. This procedure calls for a 151 minute penetration test sample at 32 liters per minute through the respirator cartridges and 4 chamber concentration samples during that 151 minute period. With 2 respirators and 4 chamber concentration samples there were 6 samples per run.

The paint used in this test was the Sherwin-Williams Auto refinishing acrylic enamel ACRYLD F5-Y93 cut with toluene. The conditions for the test were as follows:

<u>Test variables</u>	<u>Variable levels</u>
Paint/solvent ratio,	45%, 55% toluene
Paint mixture flow rate,	5.0, 6.0 mL/min
Chamber air flow rate	90, 120 cfm
Nozzle air pressure	20, 30 psig

The conditions of the test will give approximately the same paint concentrations in the chamber as that specified in the NIOSH, TCB test which used the TT-E-489C phthalic alkyd resin paint with 20% titanium dioxide pigment. The lower pigment content, 10% iron oxide yellow, of the paint selected for this test required a more sensitive analytical method than the gravimetric ashing used for the present alkyd enamel. The analytical method selected was atomic absorption and was performed by the Utah Biological Testing Laboratory (UBTL) under contract to NIOSH. The 47 mm filter paper was wet-ashed in nitric and perchloric acids and diluted to 25 ml. The samples were then evaporated to near dryness then diluted to 5 ml. They were then analyzed on an atomic absorption spectrophotometer using the NIOSH method P&CAM 173.¹¹ The sensitivity of this method is 0.4 μg Fe which is equivalent to 0.64 mg of paint. This is far better than the sensitivity of the gravimetric method used at TCB which would involve ashing the sample to Fe_2O_3 and weighing it: it would be sensitive to only 0.1 mg or 1.1 mg paint. The atomic

absorption approach then is about 170 times as sensitive for this paint as the gravimetric method.

The samples were coded then sent to the Utah Biological Testing Laboratory (UBTL). Blank samples were included by sending unexposed Millipore filters. Since penetration of the paint through the cartridges was in most instances not noticeable on the filters, the blanks needed no adulterating to disguise them from the samples. There were two samples in which leakage through the respirator filter pad was obvious. The paint penetrated the pad to leave a stain on the mating surfaces of the filter cartridge. Both of these failures occurred at port #3 which may not be significant. The two runs were #8 and #17 (UBTC sample codes F-38 and F-85 respectively) with penetrations of $0.30 \mu\text{g Fe}_2\text{O}_3$ and $102 \mu\text{g Fe}_2\text{O}_3$. The penetration data for the 2^4 experimental design are listed in Table V.

The data obtained on the paint penetration tests were analyzed by the Statistical Services Branch (analysis performed by William Crouse). The results of this analysis were disappointing. The paint penetration was so low that in some cases the random error calculated from blank samples was greater than sample values. The analysis of variance revealed no significant effects and no correlation between the variables of interest and the concentrations of the paint on the filters. Also there was no evidence of correlation between the paint concentration in the chamber

TABLE V

RESULTS OF NIOSH AND UBTL ANALYSIS OF PAINT
PENETRATION AND CHAMBER CONCENTRATION

SAMPLE NUMBERS			ANALYTICAL RESULTS	
NIOSH		UBTL	PENETRATION	CHAMBER**
RUN NO.	PORT NO.*	LAB NO.	$\mu\text{g Fe}_2\text{O}_3$	$\text{mg Fe}_2\text{O}_3$
1	1	79-08902	3.6	
	3	79-08901	1.7	
	2			47
2	1	79-08617	2.4	
	3	79-08618	2.6	
	2			52
3	1	79-08621	2.3	
	3	79-08622	1.1	
	2			45
4	1	79-08625	3.4	
	3	79-08623	1.6	
	2			41
5	1	79-08626	1.7	
	3	79-08628	7.3	
	2			42
6	1	79-08630	3.3	
	3	79-08629	3.0	
	2			47

* PORTS 1,3 ARE PENETRATION SAMPLES ; PORT 2 IS CHAMBER CONCENTRATION

** CONCENTRATION IS AVERAGE VALUE OF FOUR SAMPLES

TABLE V (continued)

RESULTS OF NIOSH AND UBTL ANALYSIS OF PAINT
PENETRATION AND CHAMBER CONCENTRATION

SAMPLE NUMBERS			ANALYTICAL RESULTS	
NIOSH		UBTL	PENETRATION	CHAMBER**
RUN NO.	PORT NO.*	LAB NO.	$\mu\text{g Fe}_2\text{O}_3$	$\text{mg Fe}_2\text{O}_3$
7	1	79-08633	1.6	
	3	79-08631	2.6	
	2			47
8	1	79-08635	2.1	
	3	79-07769	30.0	
	2			49
9	1	79-08636	4.3	
	3	79-08638	2.4	
	2			50
10	1	79-08639	1.9	
	3	79-08640	2.4	
	2			37
11	1	79-08889	2.0	
	3	79-08888	1.43	
	2			38
12	1	79-08890	1.71	
	3	79-08891	1.14	
	2			36

* PORTS 1,3 ARE PENETRATION SAMPLES ; PORT 2 IS CHAMBER CONCENTRATION
 ** CONCENTRATION IS AVERAGE VALUE OF FOUR SAMPLES

TABLE V (continued)

RESULTS OF NIOSH AND UBTL ANALYSIS OF PAINT
 PENETRATION AND CHAMBER CONCENTRATION

SAMPLE NUMBERS			ANALYTICAL RESULTS	
NIOSH		UBTL	PENETRATION	CHAMBER**
RUN NO.	PORT NO.*	LAB NO.	µg Fe ₂ O ₃	mg Fe ₂ O ₃
13	1	79-08892	2.71	
	3	79-07793	13	
	2			40
14	1	79-08895	1.86	
	3	79-08894	2.0	
	2			37
15	1	79-08896	2.85	
	3	79-08897	<1.0	
	2			47
16	1	79-08899	2.86	
	3	79-08900	2.51	
	2			55

* PORTS 1,3 ARE PENETRATION SAMPLES ; PORT 2 IS CHAMBER CONCENTRATION
 ** CONCENTRATION IS AVERAGE VALUE OF FOUR SAMPLES

and the paint on the filters. The variance may be high enough to mask the effects. The results of the statistical analysis are in Appendix F.

These results were unexpected by the project director. The paint and solvent had been selected to produce a fine aerosol; the light solvent used and the air nozzle pressures above that used in the TCB test should have produced a fine particle size. The paint spray respirator cartridges selected for use in this test are apparently too efficient and prevented sufficient penetration to allow significant differences in test conditions to be detected. A solution to this dilemma could be to use less efficient filters. However, the use of a respirator cartridge so inadequate that a significant penetration of paint occurs could be challenged in that it is not a certified respirator. The evaluation of the test without the use of a respirator penetration test could also be challenged in that it would not evaluate the test.

Since the challenge to the respirator filters in this certification test is the respirable fraction of the aerosol, the control of the test should be based on the quality, concentration and uniformity of distribution of the respirable fraction of the aerosol during the 151 minute test period. The characterization of the paint aerosol is considered in the next section of this report.

VII. PARTICLE SIZING

The evaluation of the particle size of the paint aerosol was approached in two ways. First, a general indication of particle size was made by directing the paint spray for 1 minute at sheets of white paper 18" x 21-1/2" at a distance of 18 inches. The paint flow rate was maintained at 6.0 and 3.0 mL/minute while the nozzle air pressure was varied at 10, 20 and 30 psi; the paint solvent content was varied at 30, 40, 50 and 60%. The paint used was Sherwin-Williams F5-Y93 ACRYLD auto refinishing enamel mixed with the Sherwin-Williams R-7K211 solvent. The paint was delivered to the nozzle using the FMI RP620 positive displacement pump. This pump was later discarded because it performed poorly against pressure. Its performance is not questioned in this test since it did not pump against pressure.

The effect of this test was a paint spot which varied in size and texture with the spray nozzle and paint conditions. The test conditions are listed in Table VI.

TABLE VI
TEST CONDITIONS FOR SPRAY PATTERN TEST

Spot	Test Conditions			Spot	Test Conditions		
	min/ml	psi	Solvent		min/ml	psi	Solvent
1	3.0	10	30%	13	6.0	10	30%
4	"	"	40%	16	"	"	40%
7	"	"	50%	19	"	"	50%
10	"	"	60%	22	"	"	60%
2	"	20	30%	14	"	20	30%
5	"	"	40%	17	"	"	40%
8	"	"	50%	20	"	"	50%
11	"	"	60%	23	"	"	60%
3	"	30	30%	15	"	30	30%
16	"	"	40%	18	"	30	40%
9	"	"	50%	21	"	"	50%
12	"	"	60%	24	"	"	60%

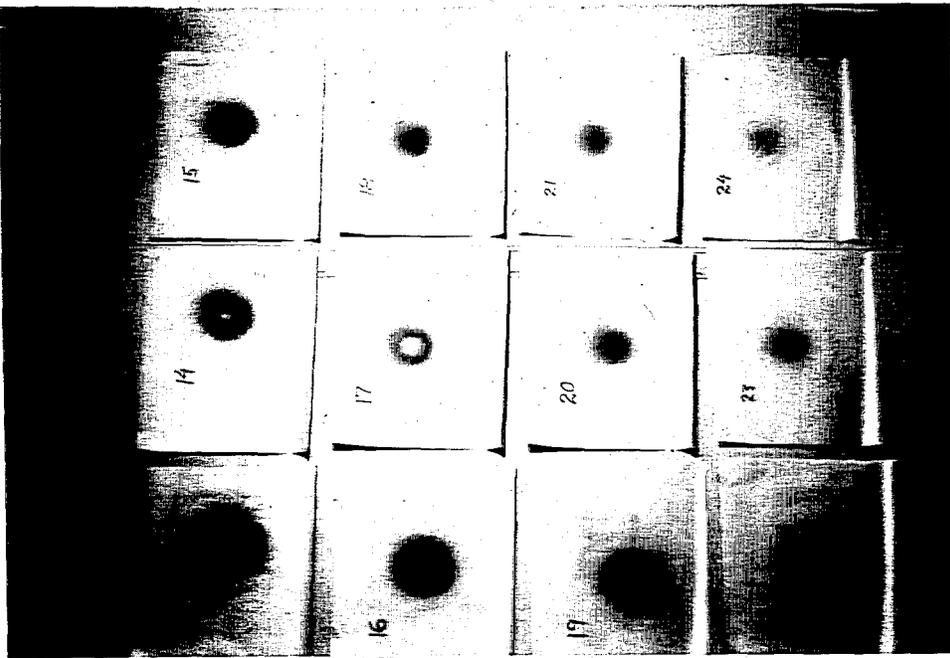
The assumptions in performing this test are:

1. The larger paint drops will impinge on the paper more efficiently than the fine drops; the finer paint drops will divert to generate a back spray.
2. The higher air velocity at higher nozzle air pressure will cause finer paint drops to impinge on the paper.
3. The effect of each variable will be evident in the nature of the paint spot deposited on the paper.

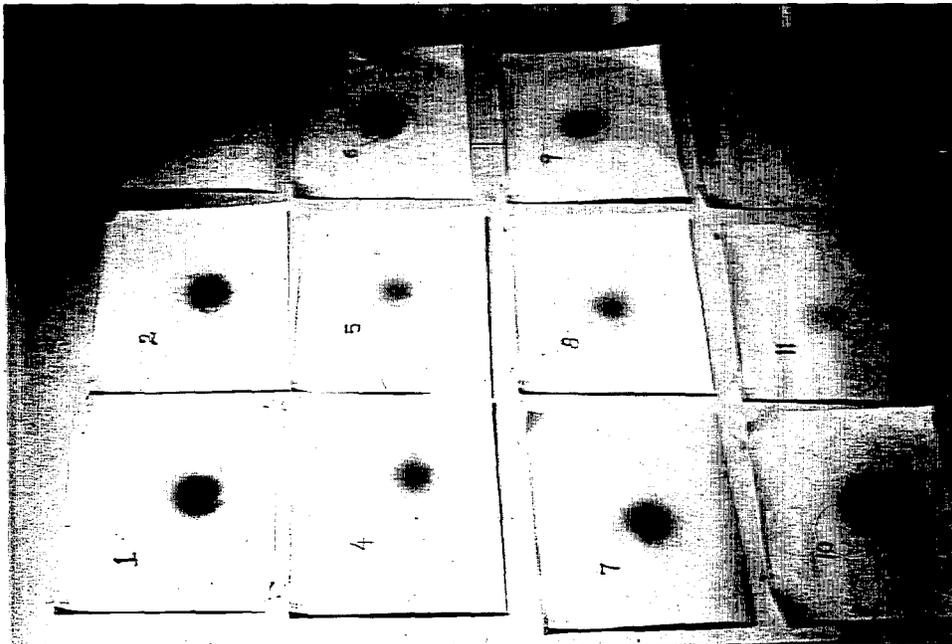
Figure 12 shows the paint spots placed in an array similar to Table III and clearly shows the effects of each variable. The most important effect is the nozzle air pressure. It is apparent in each case that increasing the nozzle air pressure reduces the amount of paint impacted on the paper and supports the interpretation that finer particles generated at higher air velocities impact less. It is also noted that the spots in the upper left side of each array have a glossy appearance, not too evident in the photographs, resulting from being soaked with paint; this is attributed to the impaction of the larger drops of paint in the spray. The effect of doubling the paint flow rate is quite evident by visual inspection of the arrays

This test was the basis for selecting the paint and spray nozzle conditions for the test. The criteria was to select conditions which

FIGURE 12. EFFECT OF SPRAY CONDITIONS ON PAINT DEPOSITION



6.0 mL/Min. PAINT FLOW



3.0 mL/Min. PAINT FLOW

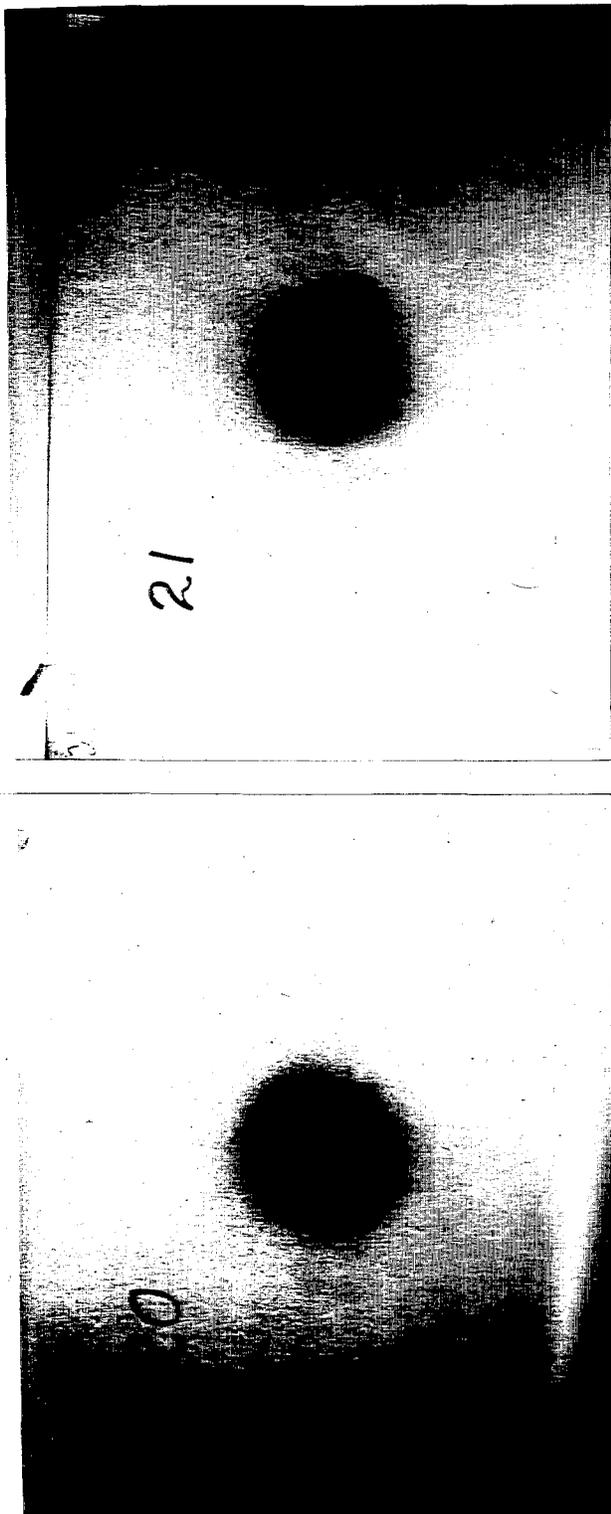
30% SOLVENT

40% SOLVENT

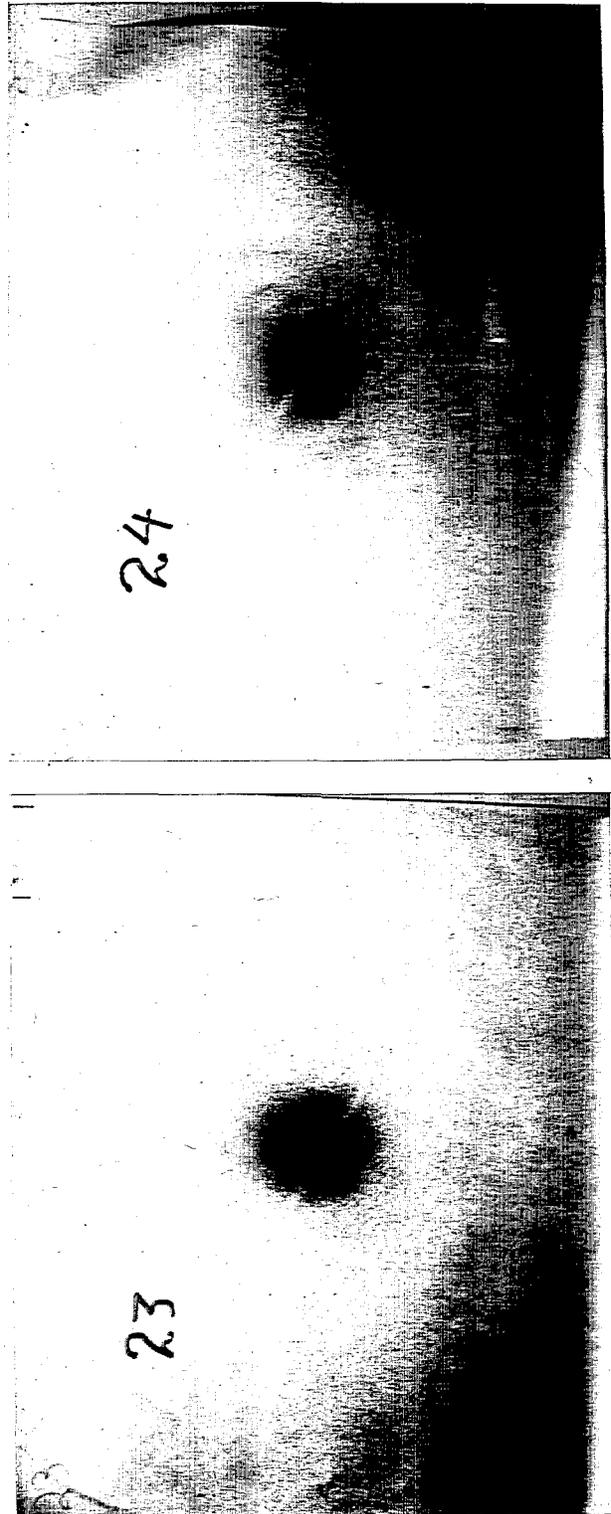
50% SOLVENT

60% SOLVENT

FIGURE 13. DETAIL OF SPOTS 20, 21, 23, AND 24



50%
SOLVENT



60%
SOLVENT

produce a loose texture paint deposit in the 20 to 30 psig nozzle air pressure range and at as high a paint/solvent ratio as possible. The conditions selected were at 6.0 ml/min paint flow and bounded by 20-30 psig nozzle air pressure and 40-60% solvent. The paint spots for blocks 20, 21, 23 and 24 are shown in Figure 13. The paint and spray conditions selected for the test were 40% and 55% solvent, 5.0 ml/min and 6.0 ml/min paint flow, and 20 psig and 30 psig nozzle air pressure.

Particle size distribution analysis was performed on the paint spray within the chamber using an Andersen 2000 Inc. ambient sampler Model #20-800 with a preseparator. The paint delivery system was at this point a capillary tube with gravity feed. This eliminated the pump and the resulting pulsed feed rate. Since the Anderson sampler must sit up-right and would not fit within the sample chamber without disrupting flow it was modified with a 1/2 inch curved stainless steel sample tube having a 3-3/4" radius in an 85 degree arc (see Figure 14).

This sample tube protruded about 1 inch into the chamber at a point in the back wall, 5-1/4" from the top and 6-1/4" from the right corner. This placed the sampler over the edge of the baffle in a position to sample the paint aerosol as it rises and turns in the sample space above the bottom baffle. The total weight of the paint collected was determined in runs 1 through 9 (see Figures 15-23) by washing all paint from the inlet tube and the preseparator with solvent, evaporating it and weighing the nonvolatile residue. In runs 12 through 17 (see Figures 24-29), the chamber concentration was sampled independently at a point

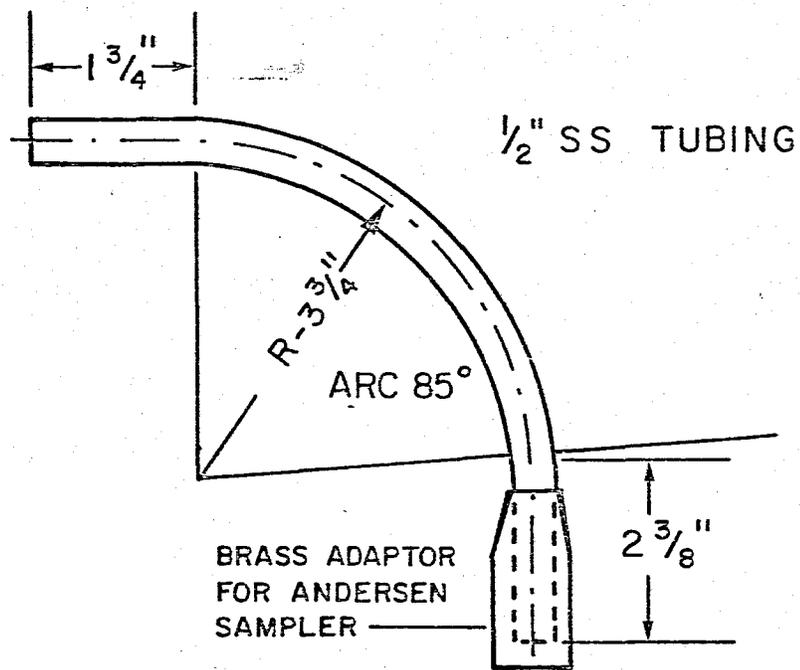


Figure 14. Inlet adaptor for Andersen sampler.

8-1/2" from the right rear corner next to the particle size analyzer while the particle size sample was being drawn. Both approaches are acceptable but the latter approach is simpler.

The results of the particle size tests are shown in Table VII. The data for runs 1 through 9 are from the cartridge penetration tests. Tests 10, 11 and 12 were eliminated due to flow problems in the paint delivery system and/or chamber flow. Attempts to analyze this data have not been too successful. From a theoretical standpoint the mean particle size of a spray aerosol is a complex expression which attempts to relate the phenomena of energy balances of heat and mass transfer, surface effects and physical properties of the fluids to the real variables in the spray system. It is clear however, from the Nukiyama-Tanasawa equation^{8,9,10} that the major factor controlling the particle size with a particular paint mixture is the nozzle air velocity.

The Nukiyama-Tanasawa equation (see equation 1) empirically relates the mean particle size to the physical properties of the fluids and linear dimensions of the spray nozzle. The equation is expressed in references 7 and 8 in three forms, none of which is consistent with the others. The correct expression is not known. The use of this equation to predict the mean size of the paint aerosol was not successful; it does however indicate the effect of important variables in the spray process.

All variables in this equation can be estimated with fair accuracy except the relative velocity v_s of the air and liquid in the nozzle orifice.

Attempts to calculate the paint spray mean size based on estimated relative velocity (V_s) values resulted in mean size diameters too high compared to the analysis by the Andersen impactor. This can be explained in part by the drop out of the large particles in the bottom of the test chamber. Another test made of the equation was the calculation of the relative velocity term, v , using replicate test runs. Since the relative velocity is inversely proportional to the mean particle size; a higher mean particle size should result from a lower relative velocity. Use of this equation to calculate an effective relative velocity resulted in just the opposite effect. The problem exists here again that the size distribution measured by the Andersen impactor is not necessarily the same as the aerosol generated at the tip of the spray nozzle. The complexity of this problem is further described in a paper by Dietrick¹¹ who utilized a sophisticated photo image technique in his size studies. Dietrick noted that the spray cone as generated separates quickly by size due to the greater momentum of the larger particles. This plus the aging of the aerosol makes it very difficult to relate our test results to equation 1.

The Nukiyama-Tanasawa equation also indicates that the mean particle diameter (D) is a linear function of the relative velocity (V_s). This is confirmed by a plot of D vs ($1/V_s$) for all data in Table VII for acrylic enamel/toluene mixtures. It is assumed that the effects of the physical properties of the paint will be minor since they don't change. The plot of these data with the regression line is in Figure 30. The correlation coefficient is 0.566 which is borderline in significance at the 95% confidence level. It is disappointing that the mean size of the paint spray varies so much since this should be an important factor in the performance of the respirator during the certification test. Attempts should be made to improve this or to demonstrate that a particular test apparatus can achieve a satisfactory degree of precision in controlling the aerosol mean size.

Runs 14 through 17 were performed to compare the particle size generated with the acrylic enamel to that of the alkyd enamel. These runs were made in a three day period during which the operating conditions were held, as much as possible, the same. The results, Table II, indicate that the alkyd enamel produces a finer aerodynamic mean size diameter (8.2 μ m) than the acrylic (11.25 μ m). When the correlation coefficient (0.566) of Figure 14 is considered, these four runs may not be adequate to make this comparison. The results do suggest however, that the alkyd enamel will result in a finer mean aerosol size than the acrylic enamel.

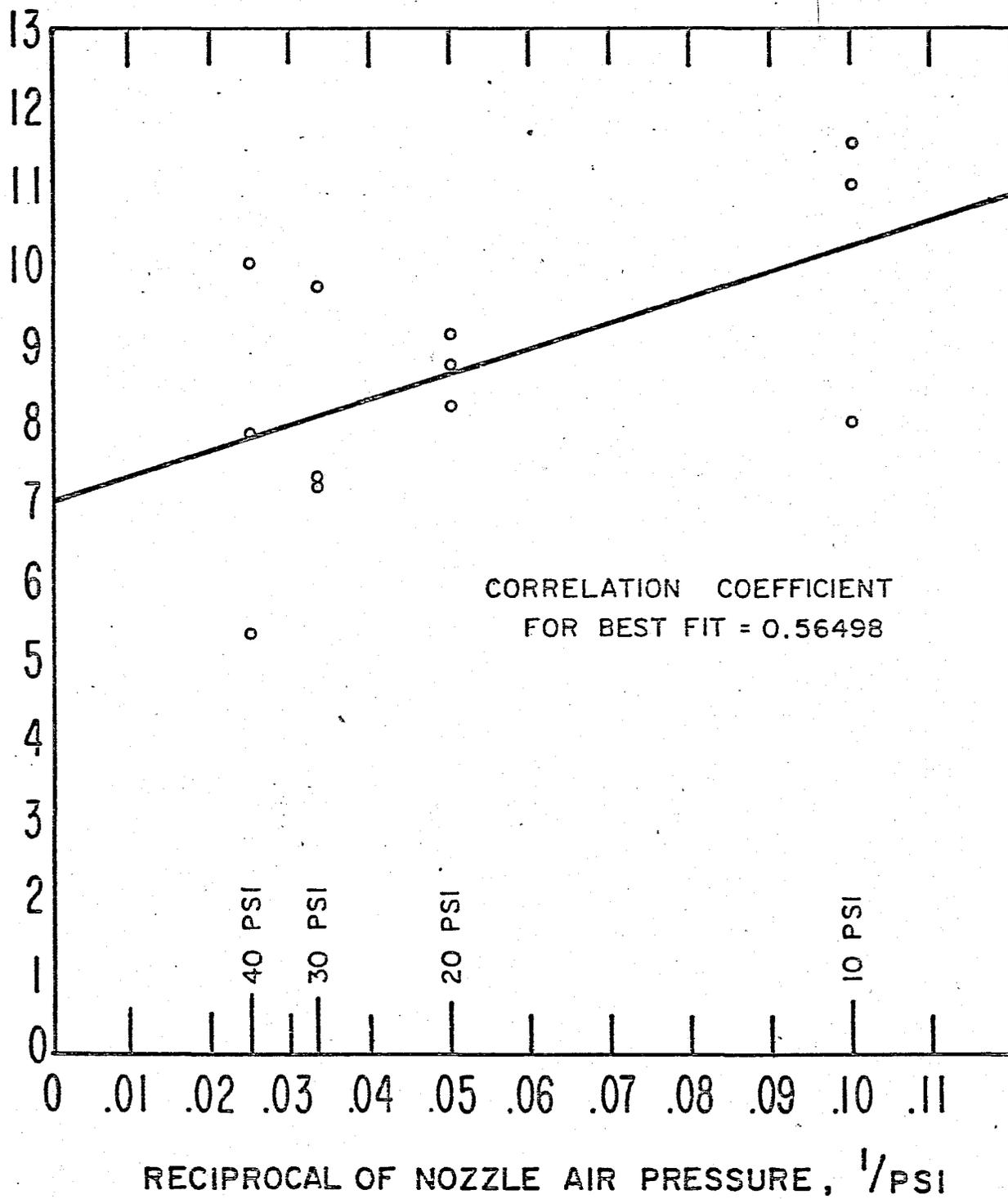


Figure 15. Mean particle size vs. reciprocal of nozzle air pressure .

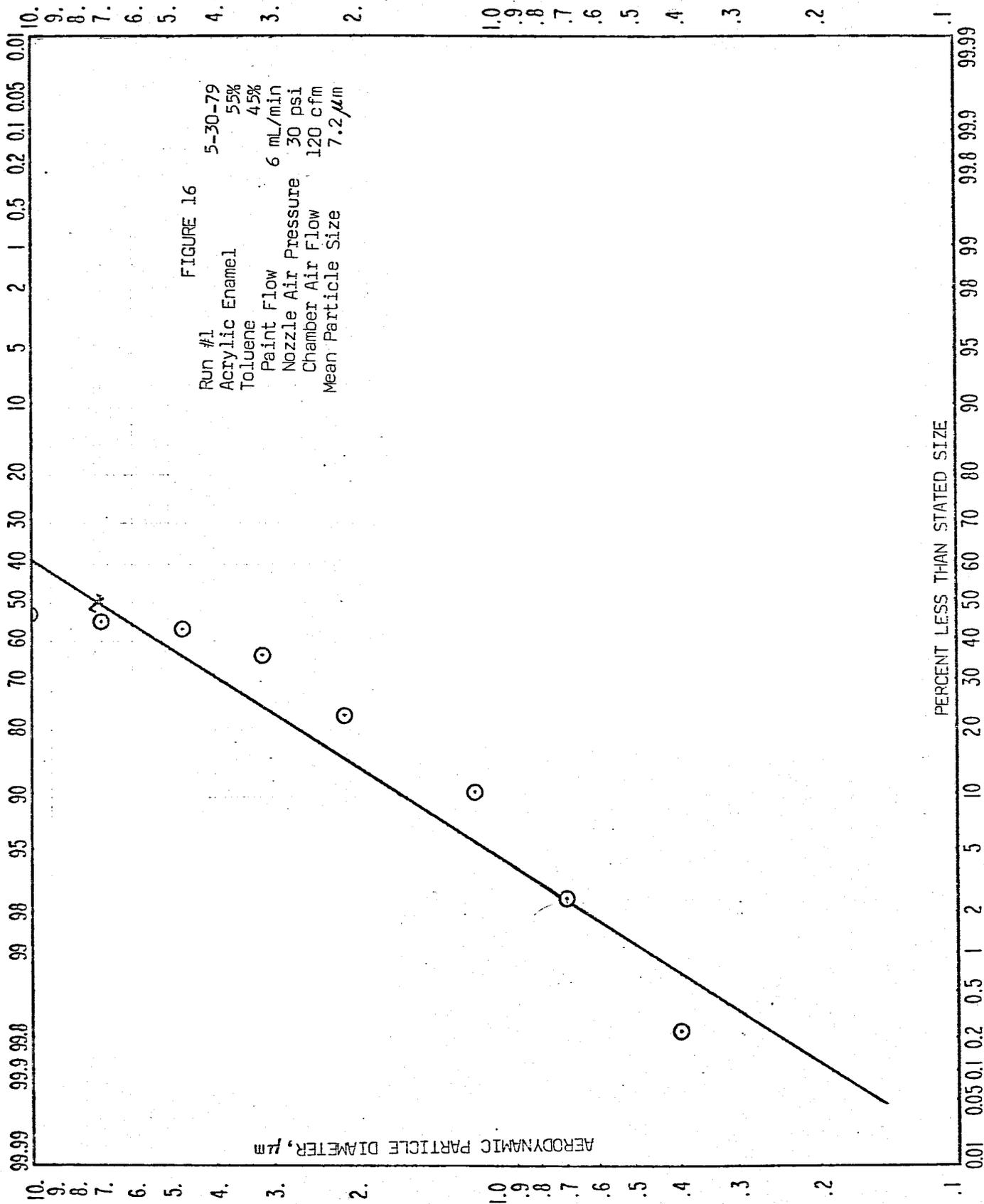
TABLE VII
SUMMARY OF PARTICLE SIZE DATA

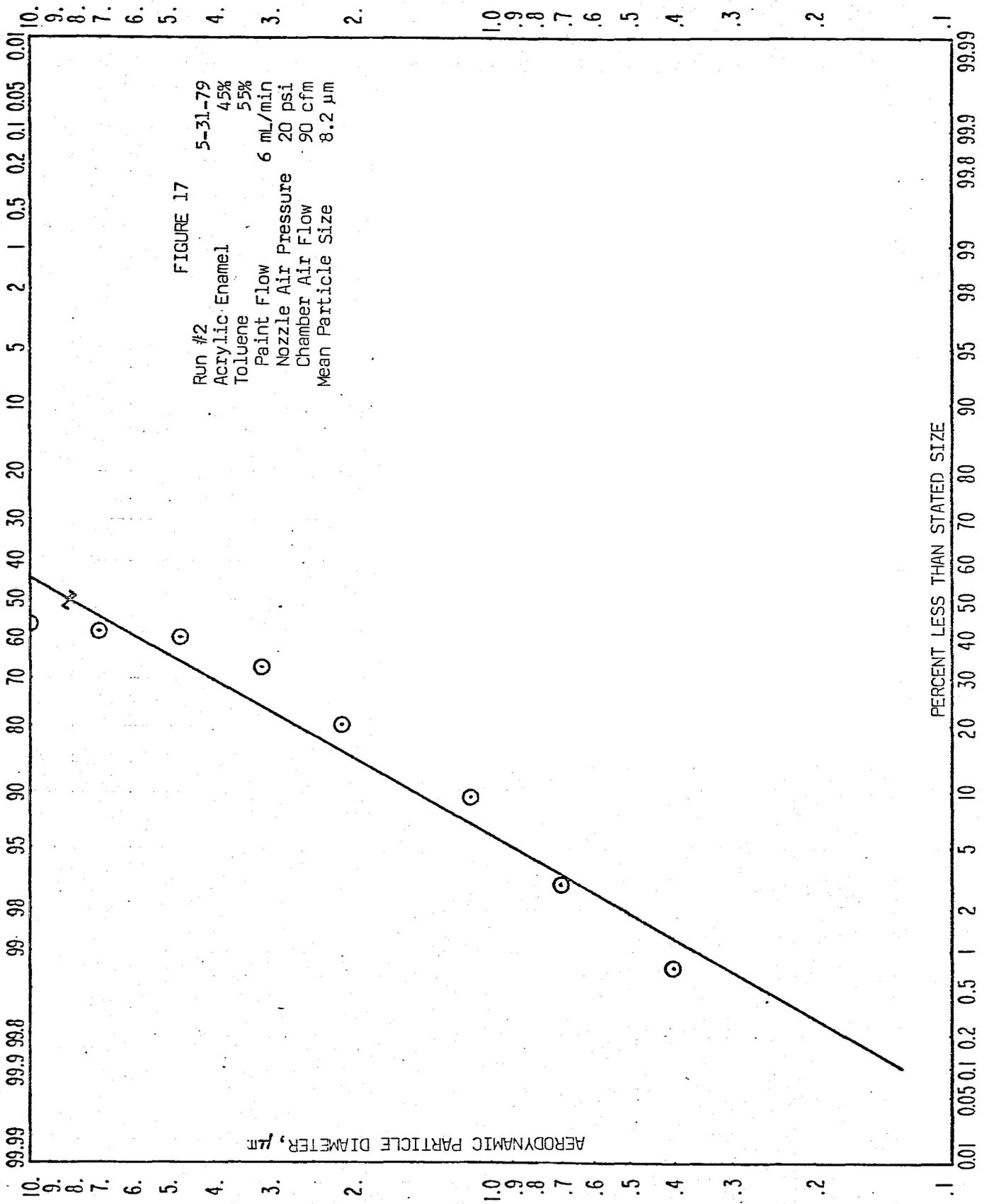
Run #	Date in 1979	Paint Type	Paint Flow (mL/min)	%, Solvent	Nozzle Air Pres. (psig)	Chamber Flow (cfm)	Mean Particle (mm)
1	5/30	Acrylic	6.0	45% toluene	30	120	7.2
2	5/31	"	"	55% "	20	90	8.2
3	6/1	"	5.0	45% "	"	"	8.7
4	6/6	"	6.0	55% "	30	"	9.7
5	6/8	"	"	"	20	120	9.1
6	6/12	"	5.0	"	30	90	7.2
7	"	"	"	"	40	120	7.8
8	6/13	"	"	"	"	"	10
9	6/14	"	"	"	"	"	5.3
13	8/24	"	"	"	10	100	8.0
14	9/25	Alkyd	"	50% turpentine	"	"	8.4
15	"	"	"	"	"	"	8.0
16	9/27	Acrylic	"	55% toluene	"	"	11.5
17	"	"	"	"	"	"	11.0

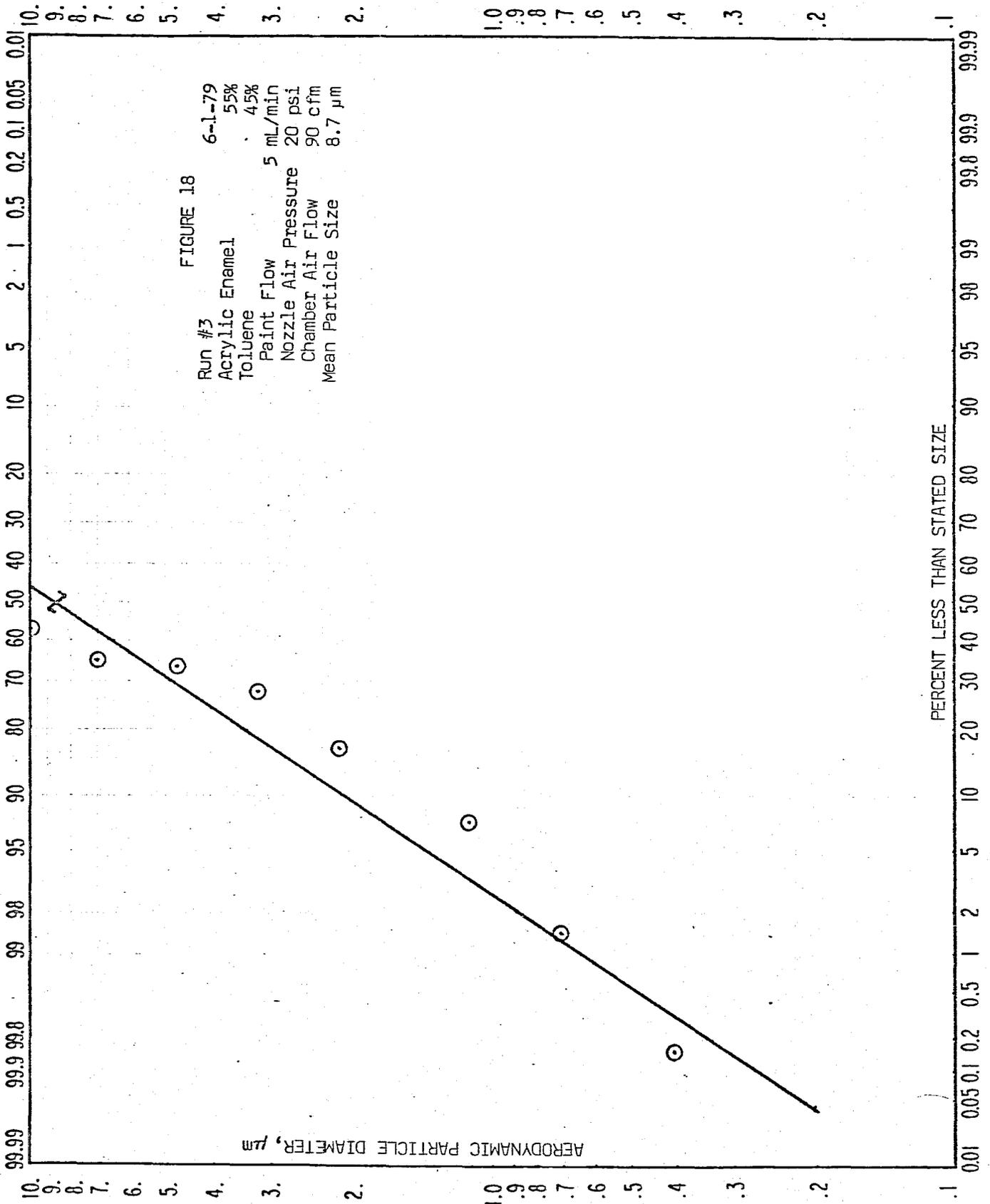
The result of the particle sizing tests is that the paint spray system doesn't generate a consistent quality of paint aerosol.

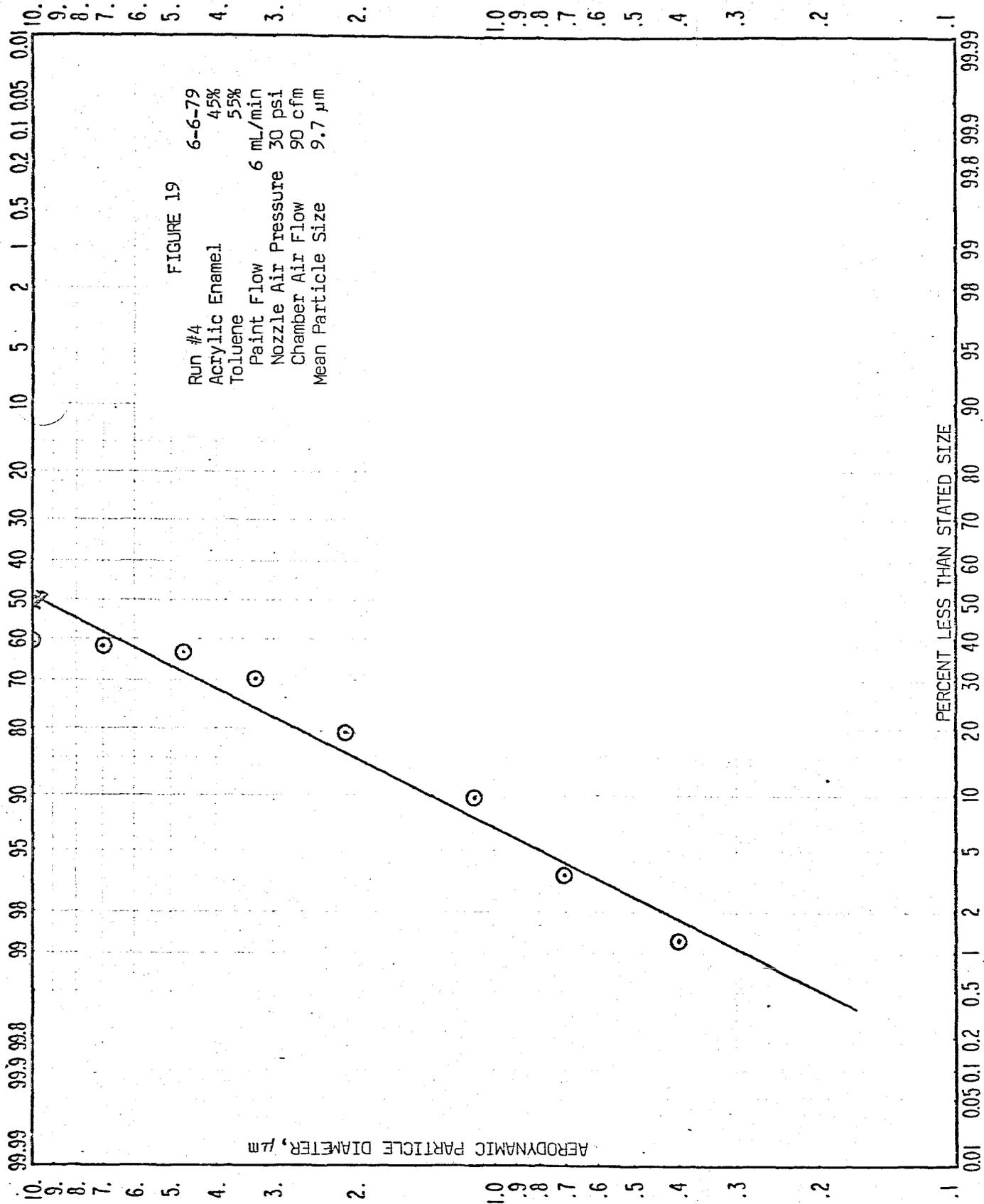
Since the size distribution of the aerosol is the basis for the test, it is essential to demonstrate that it can be controlled. The problem is more difficult if it is important to maintain consistency between other laboratories such as Willson Products, 3-M and Scott Aviation which also have a similar test set-up.

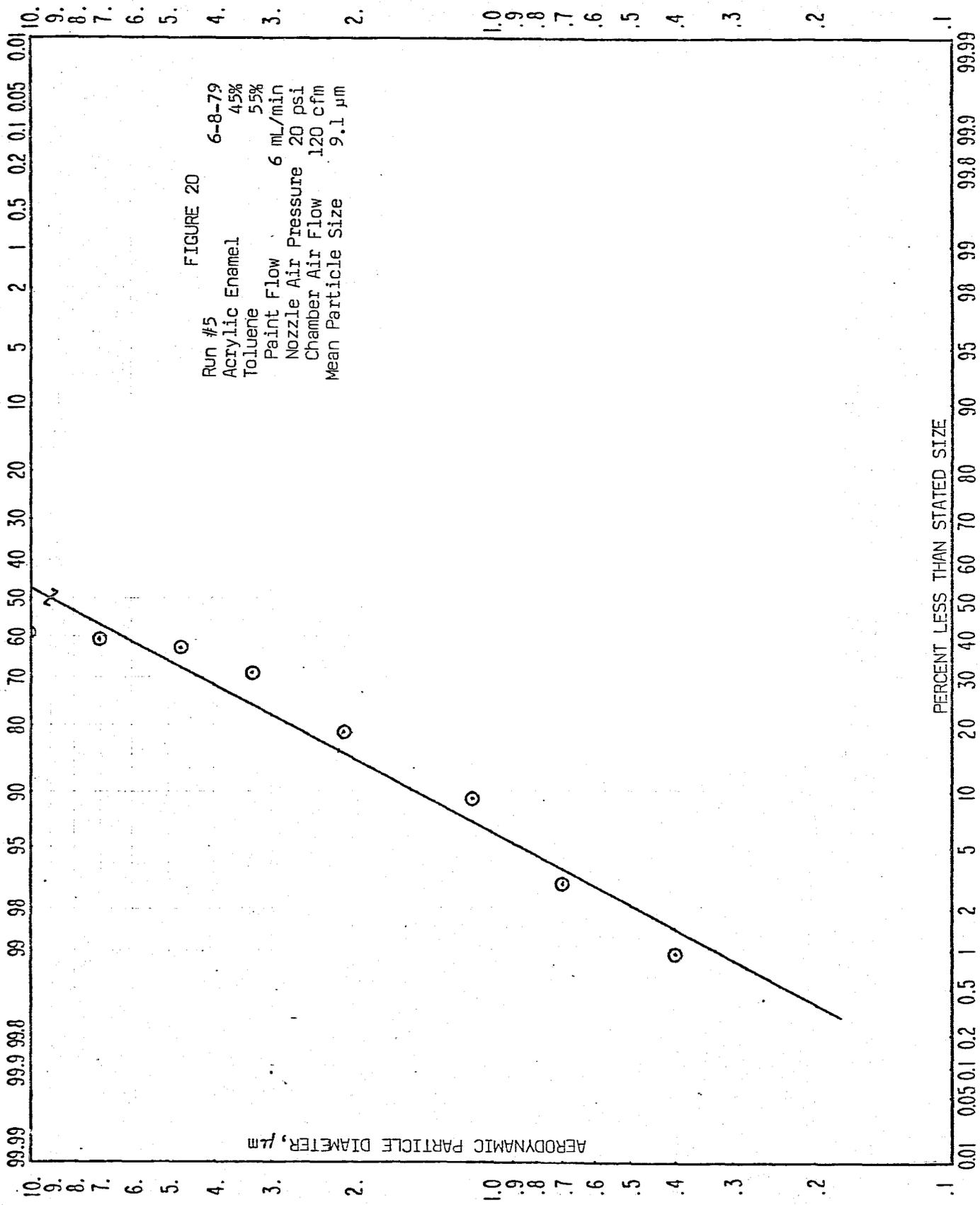
If the respirator certification test is to continue, additional work should be done on controlling the concentration of the finer particles in the aerosol which challenge the penetration efficiency of the respirator cartridge.

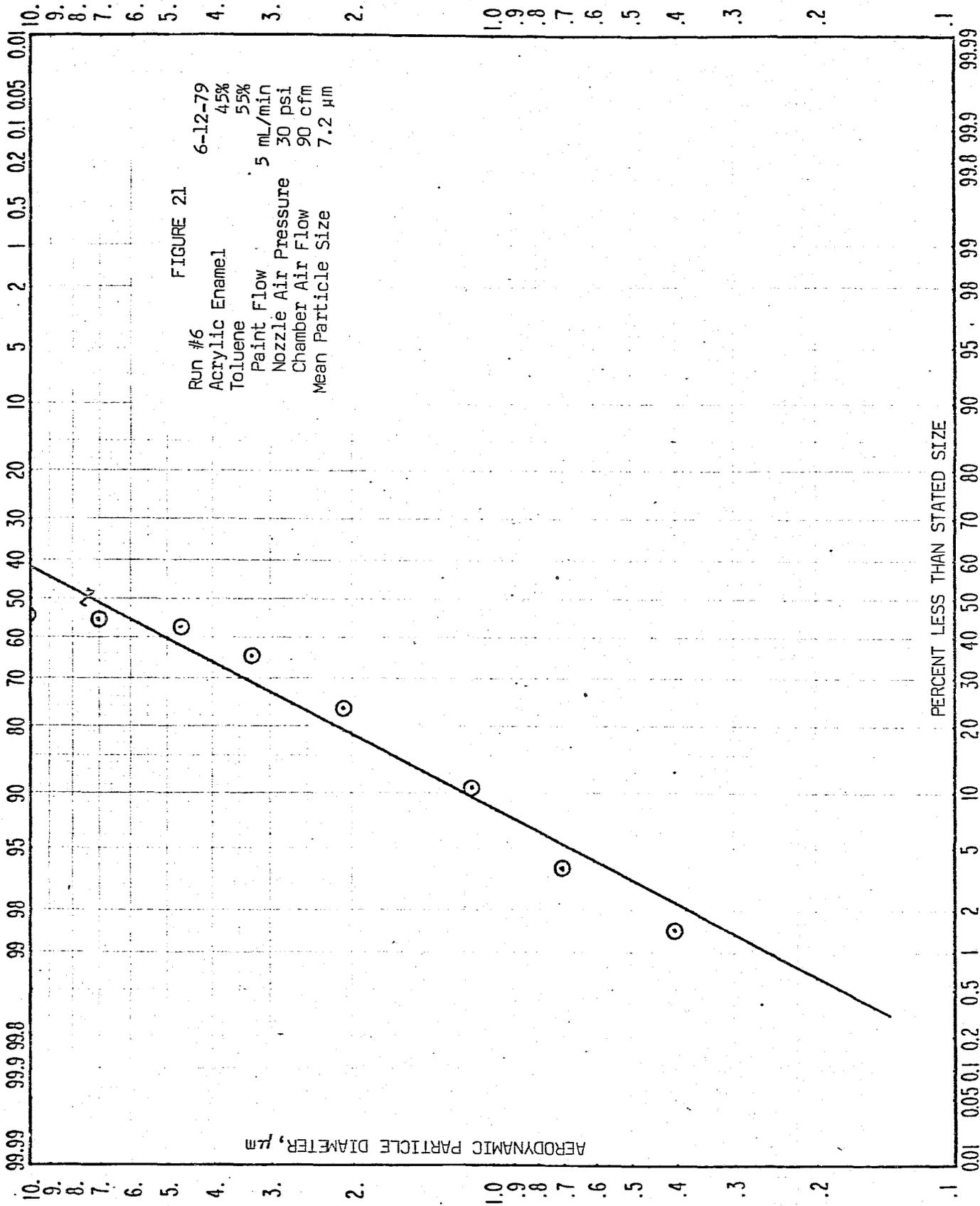


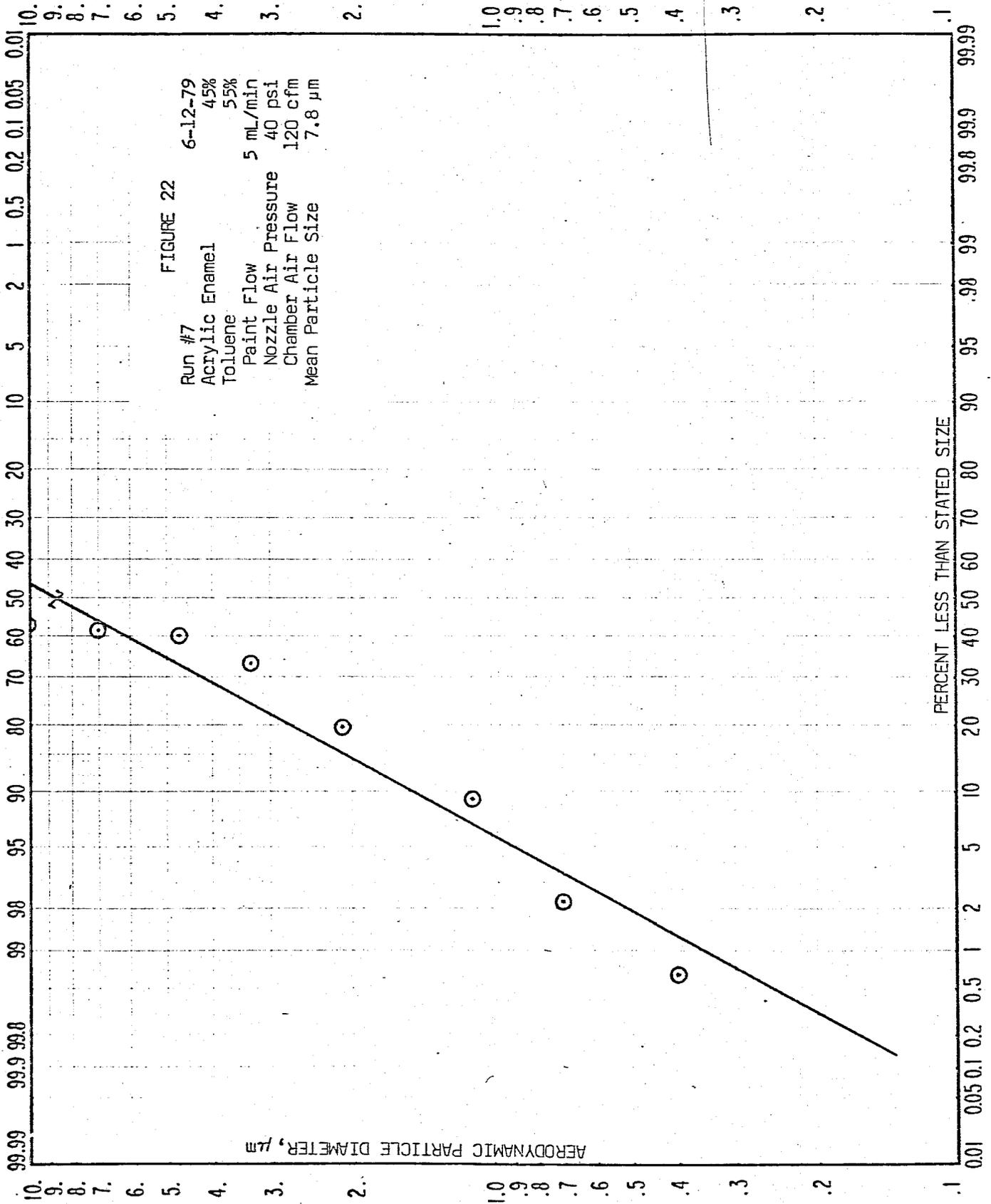


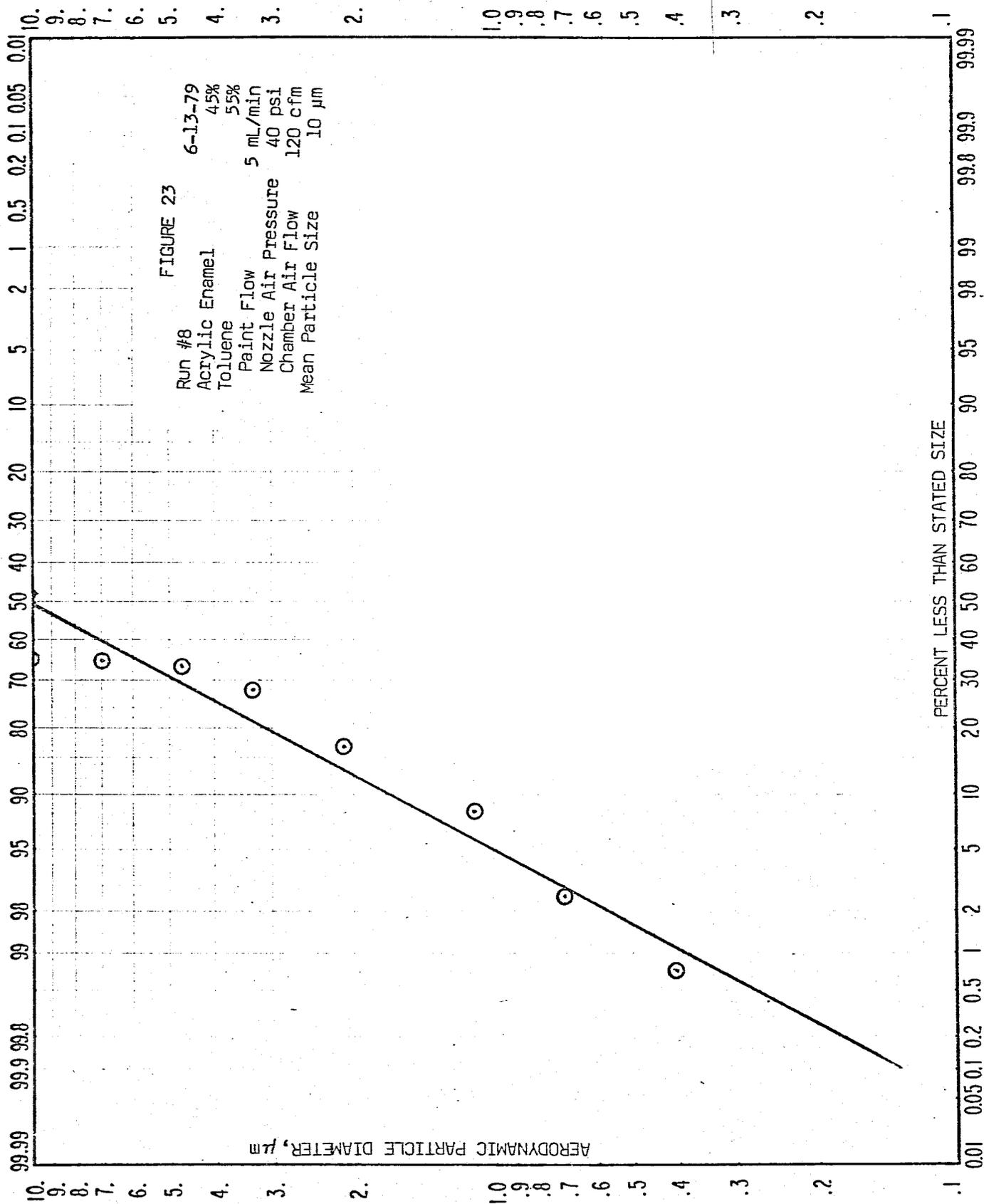


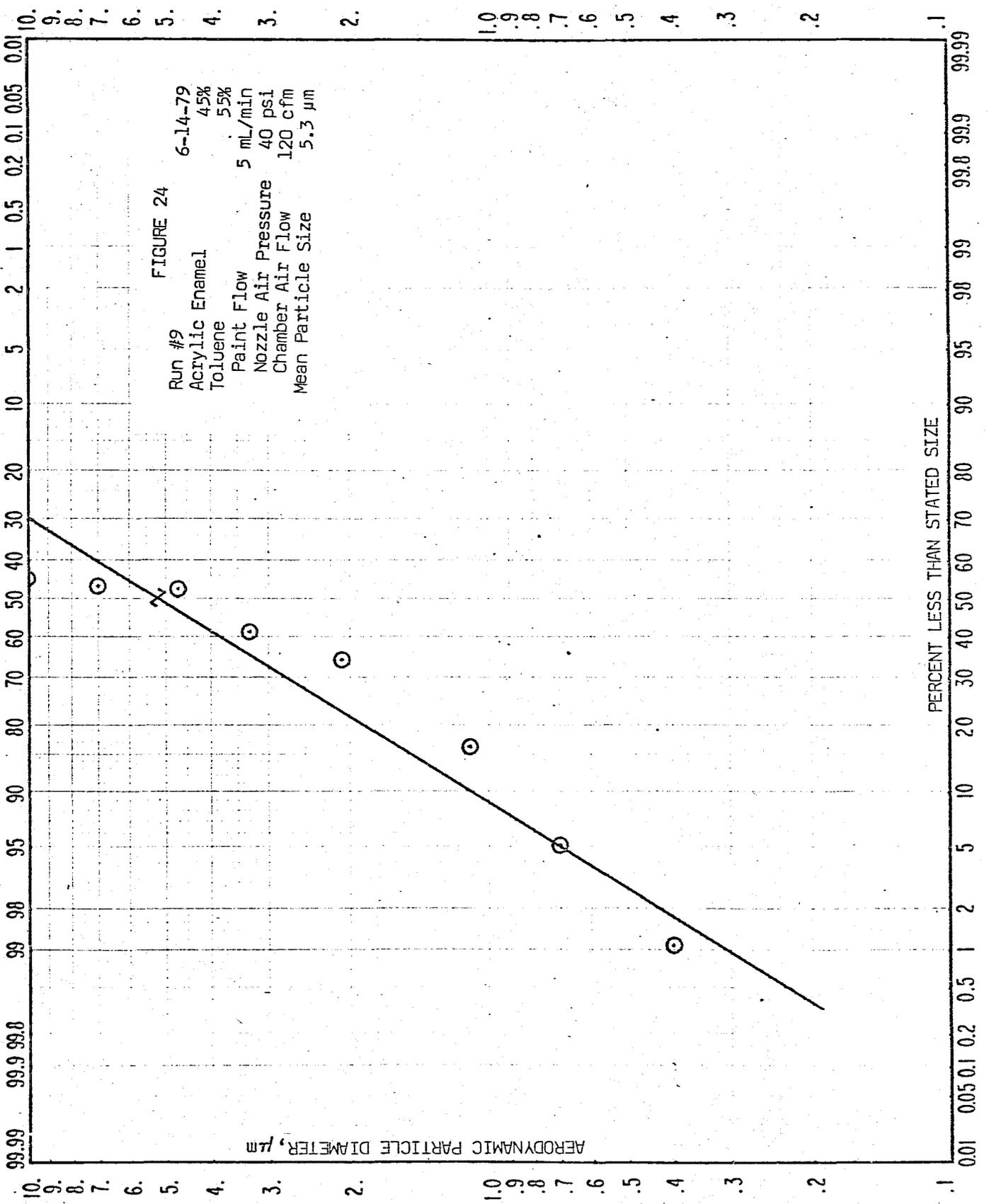


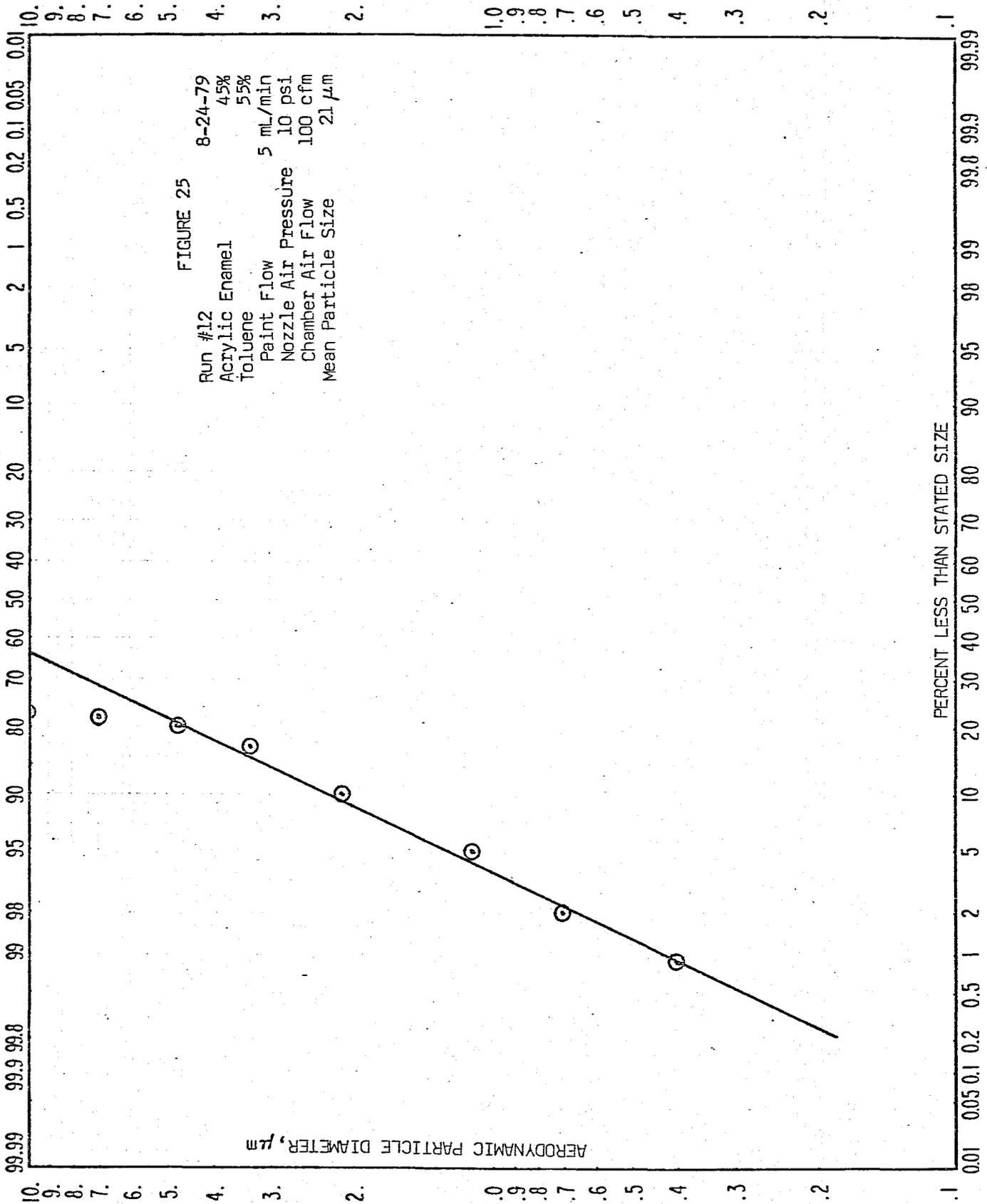


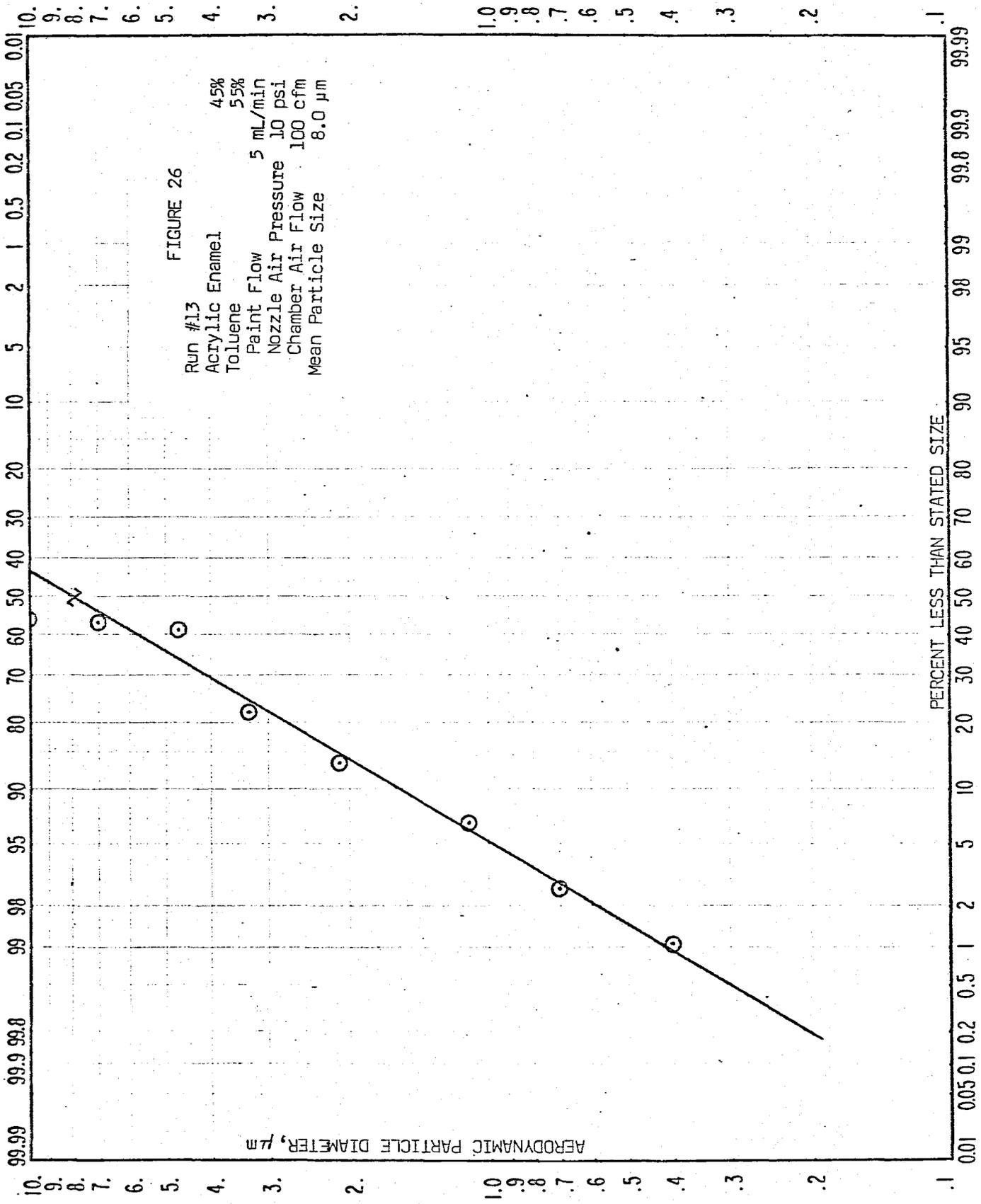


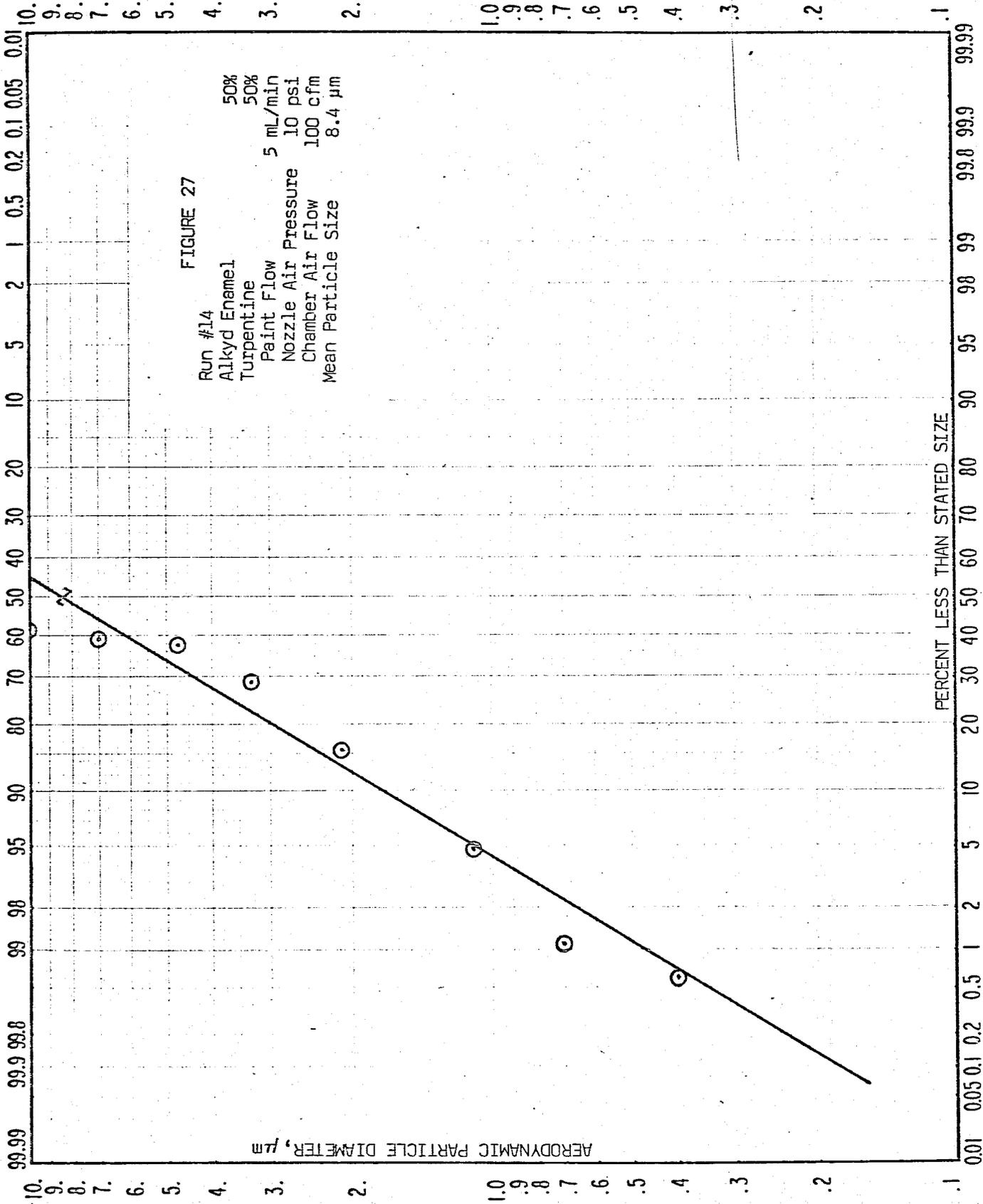


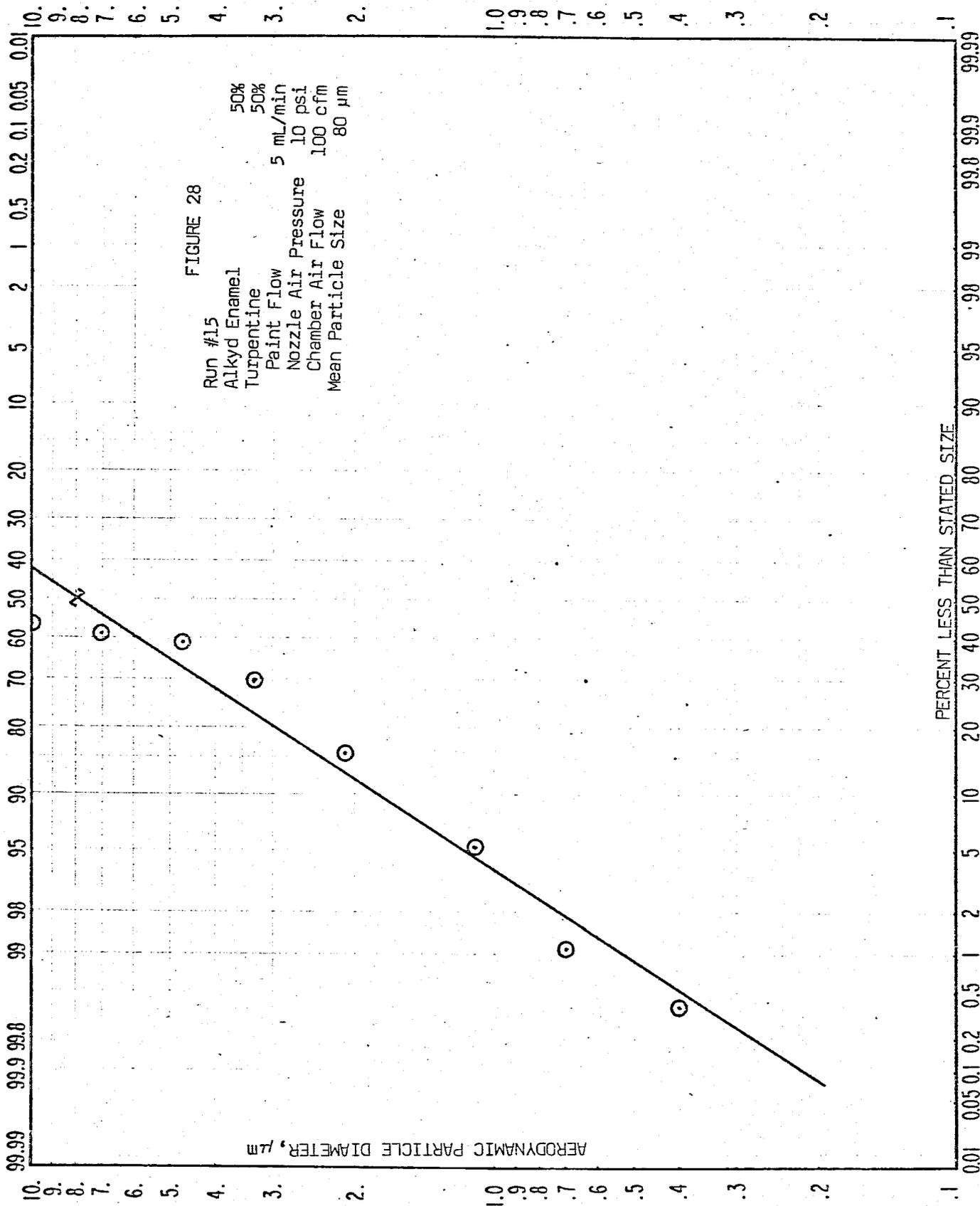


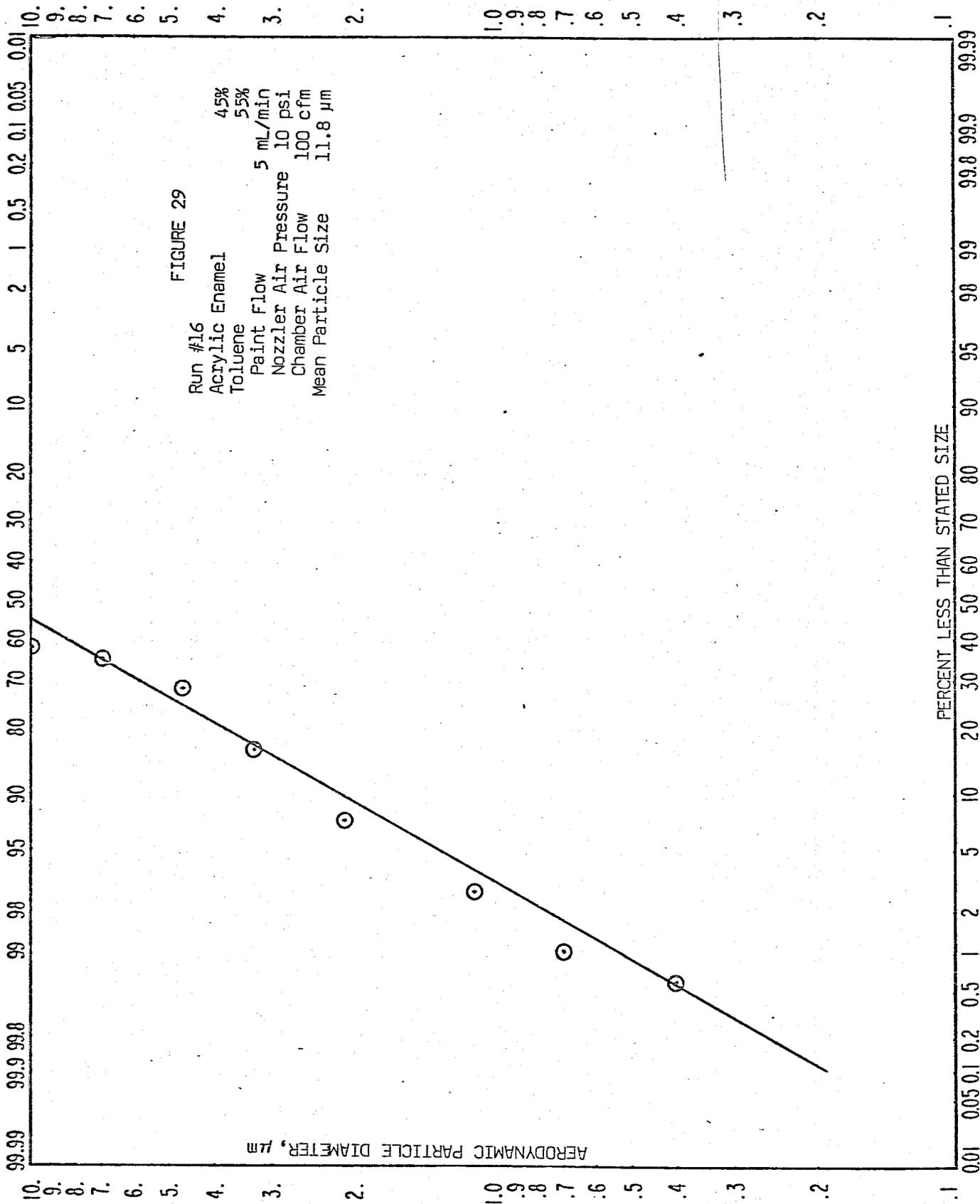


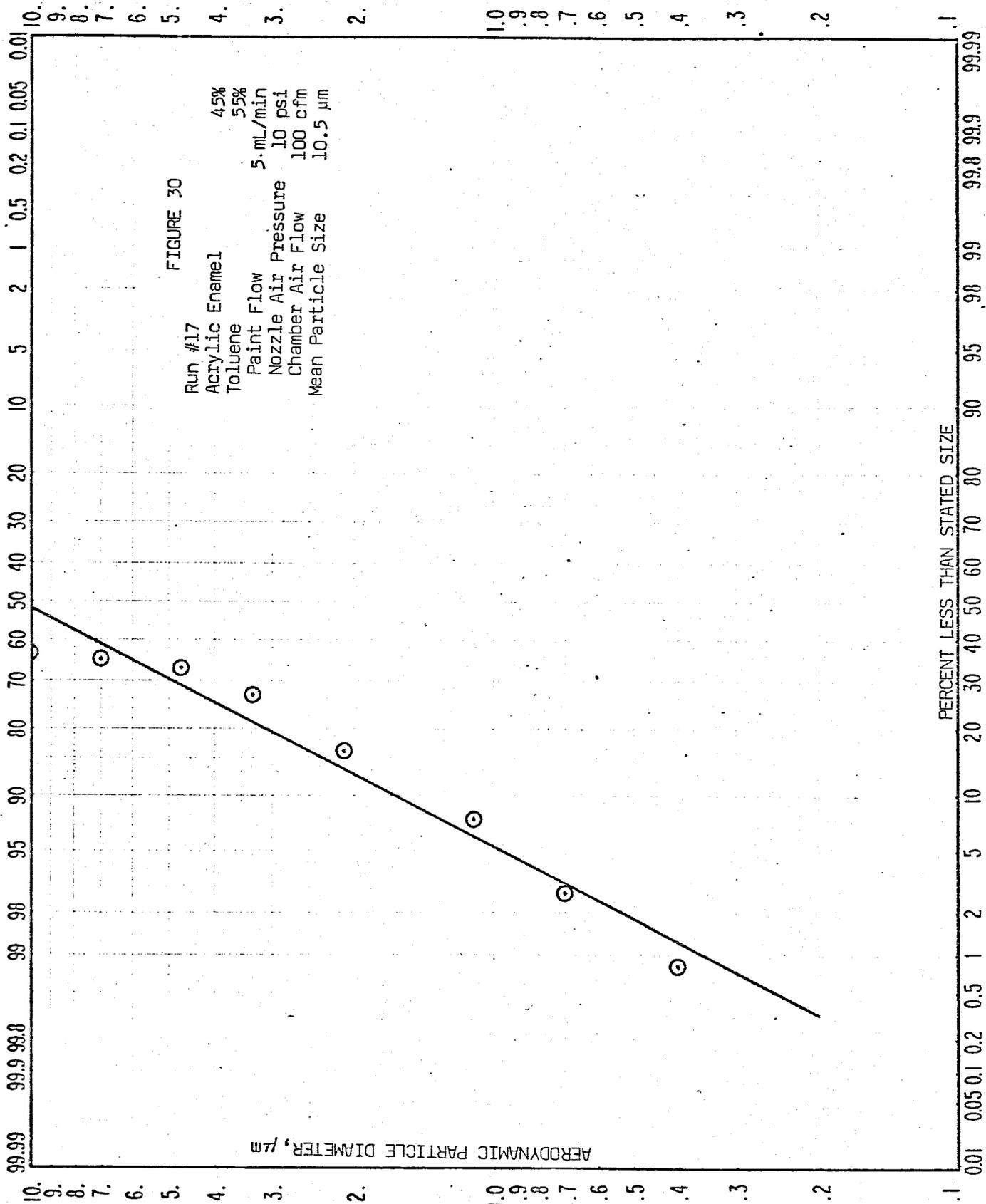












VIII. SPECIFICATIONS AND DESIGN

One of the problems in the use of the paint spray certification test is that the several apparatuses used by the respirator manufacturers are all different. The evaluation of the test has not considered the effect of altering chamber dimensions to the extent that they vary in the apparatuses listed in Appendix A.

It is possible that the chamber dimensions and volume are not critical in the performance of the test; that any test apparatus adequately designed to control direct impingement of the spray onto the test cartridge and able to generate an aerosol with the desired size distribution and concentration will be adequate.

The construction specifications presented in this report are based on the test apparatus as it exists in the NIOSH, TCB laboratory in Morgantown, West Virginia. The purpose is to permit the construction of a test apparatus as nearly as possible like that used by NIOSH.

Certain hardware items such as the blower or the vacuum pump are not critical to the apparatus if laboratory air and vacuum supply are adequate to serve this test. If not, the additional hardware will be necessary to meet the pressure and flow specifications for sampling and/or paint spray generation.

Figure 31 is a composite drawing of the test apparatus which shows the gravity feed capillary paint flow system in place. The paint is kept agitated with a magnetic stirrer. The elevation of the paint above the spray nozzle inlet is maintained with a laboratory scissors jack.

Figure 32 shows the apparatus without the paint supply system to show the detail of the control panel. Figure 33 is a detail of the control panel identifying each component. Further detail is shown in Figure 34 for the back side of the control panel.

The blower, vacuum pump, and air pump are under the work surface as shown in Figure 35. This is a convenient arrangement for a package system; other arrangements are possible if the system is permanently stationed and house compressed air and vacuum are available. The air mover shown is a Buffalo Forge Model 4-1/2E with a 12-1/2 inch wheel driven by a 1/3 HP 1725 rpm electric motor. A blower of less capacity will permit operation for a shorter period of time between exhaust filter changes.

The vacuum pump must be capable of pulling 64 L/min at up to 25 in Hg. Some excess capacity is desirable. The vacuum used in the test apparatus was a Doerr drive (1/2 HP 1725 rpm 115v 9 amp) and a Gast pump Model 0822-V103-G271X. The vacuum tank was 15 gallons capacity.

The air compressor must supply 90 psi and up to 60 scfm. This would be about 5.5 cfm at 150 psi and would require about a 2 hp motor. A rotary compressor is recommended by NIOSH, TCB to reduce the noise level.

The base cabinet ventilation fan is a typical wall mounted kitchen ventilator moving 200-300 cfm. The base cabinet volume is about 40 cu. ft; this will give 5 to 8 changes of air per minute.

Figures 36 and 37 are flow diagrams and wiring diagrams for the paint supply and sampling systems.

Figures 38, 39 and 40 are details showing respectively a cut away of the chamber, the respirator - cartridge sample location and the dimension details for the chamber construction components. Figure 41 is the construction details of the sample holder and cartridge mount apparatus for the enamel and lacquer tests. Table VIII is the description of the individual components.

The paint exhaust filter box is an important part of the apparatus even though it doesn't affect the test factors. The present design used at NIOSH, TCB has proven very effective in removing paint aerosol while keeping the filter resistance build-up at a convenient period of time before filter replacement is necessary. The details of construction are presented in Figures 42 through 52. Table IX is the description of the various components in the drawings included in these figures.

FIGURE 31. COMPOSITE DRAWING OF TEST APPARATUS

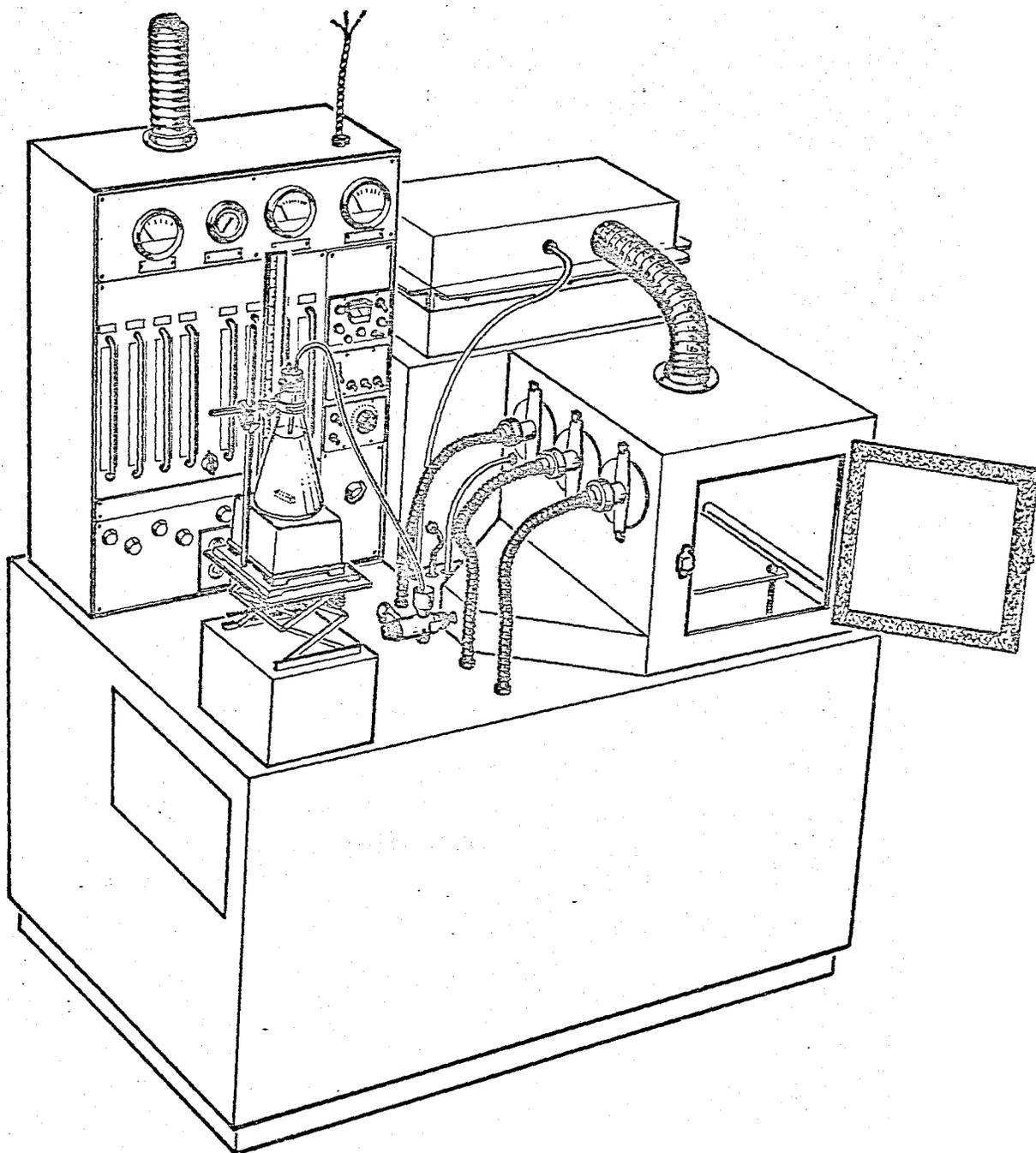
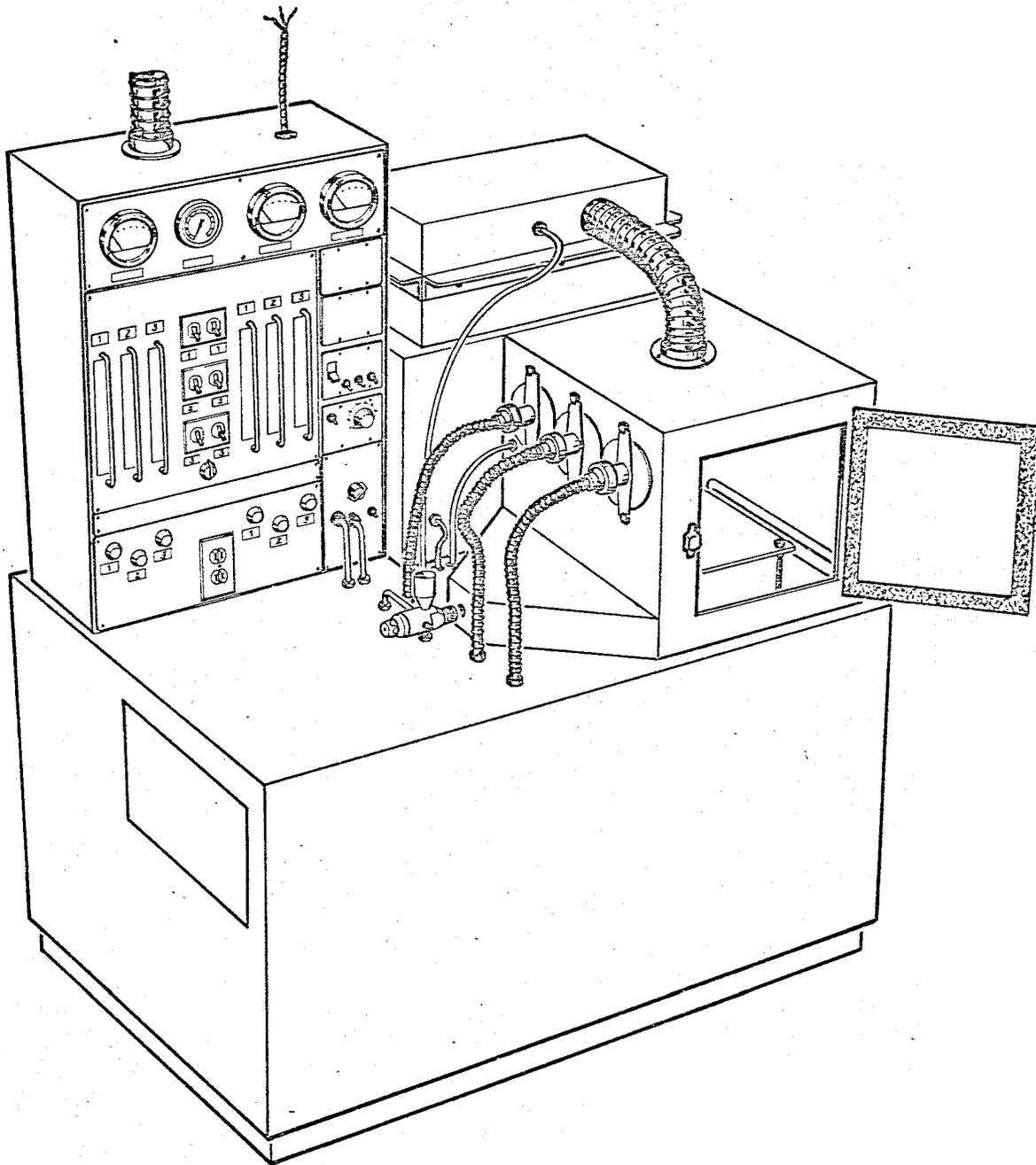


FIGURE 32. CERTIFICATION TEST APPARATUS WITHOUT PAINT

SUPPLY SYSTEM



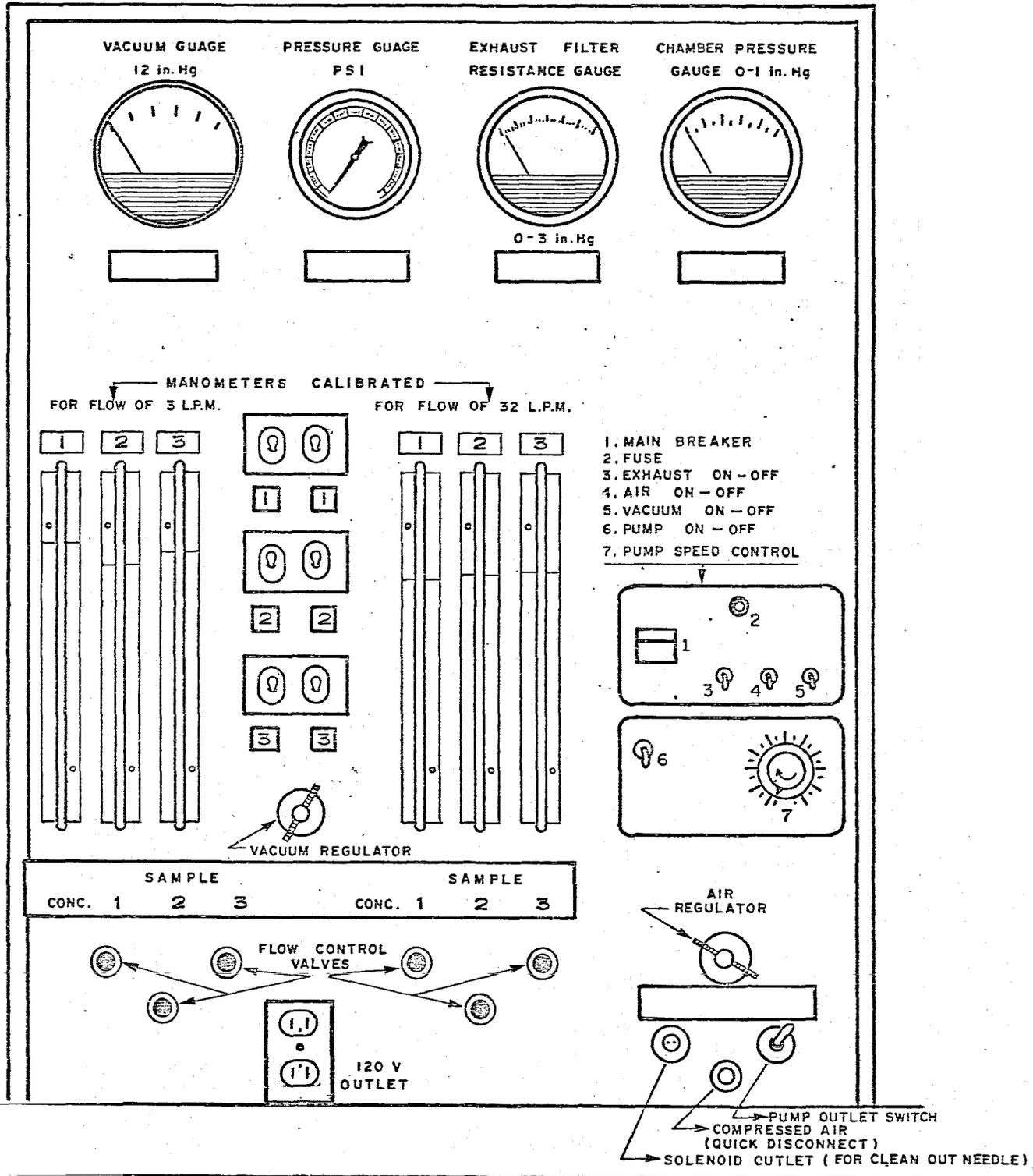
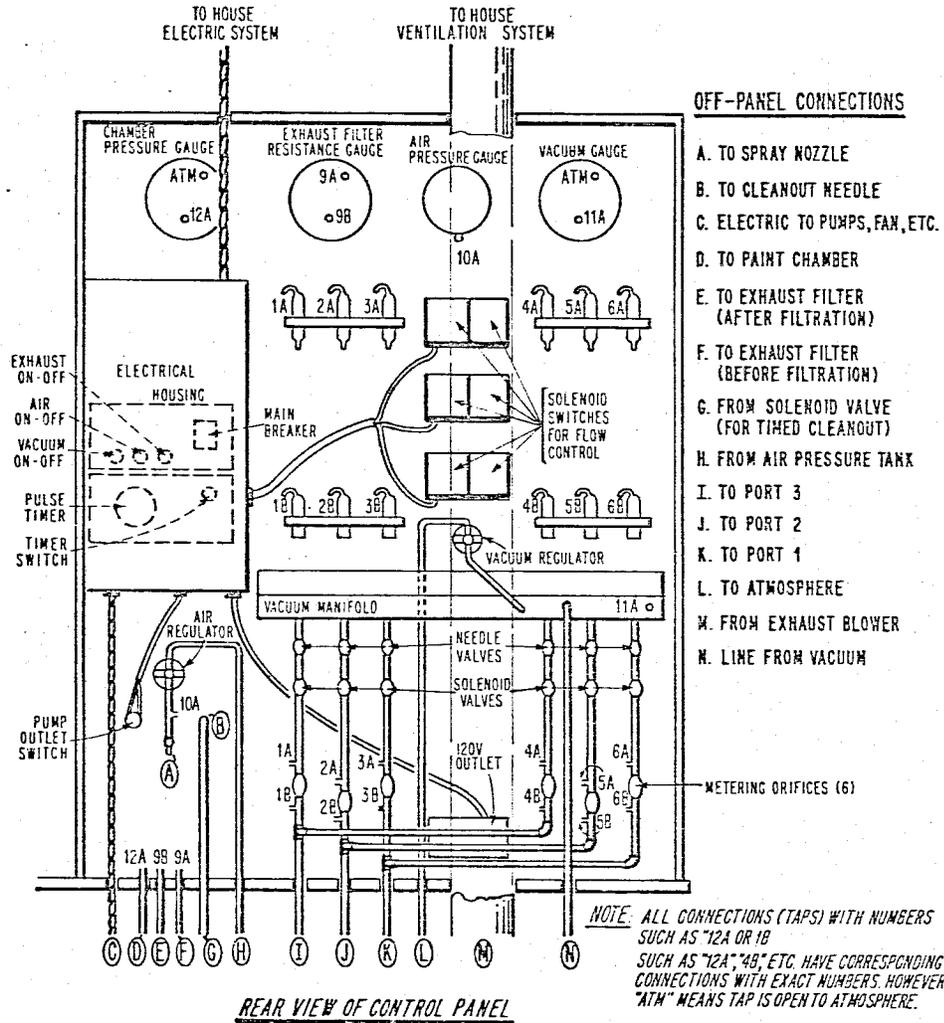


Figure 33. Front view of control panel

FIGURE 34. REAR VIEW OF CONTROL PANEL



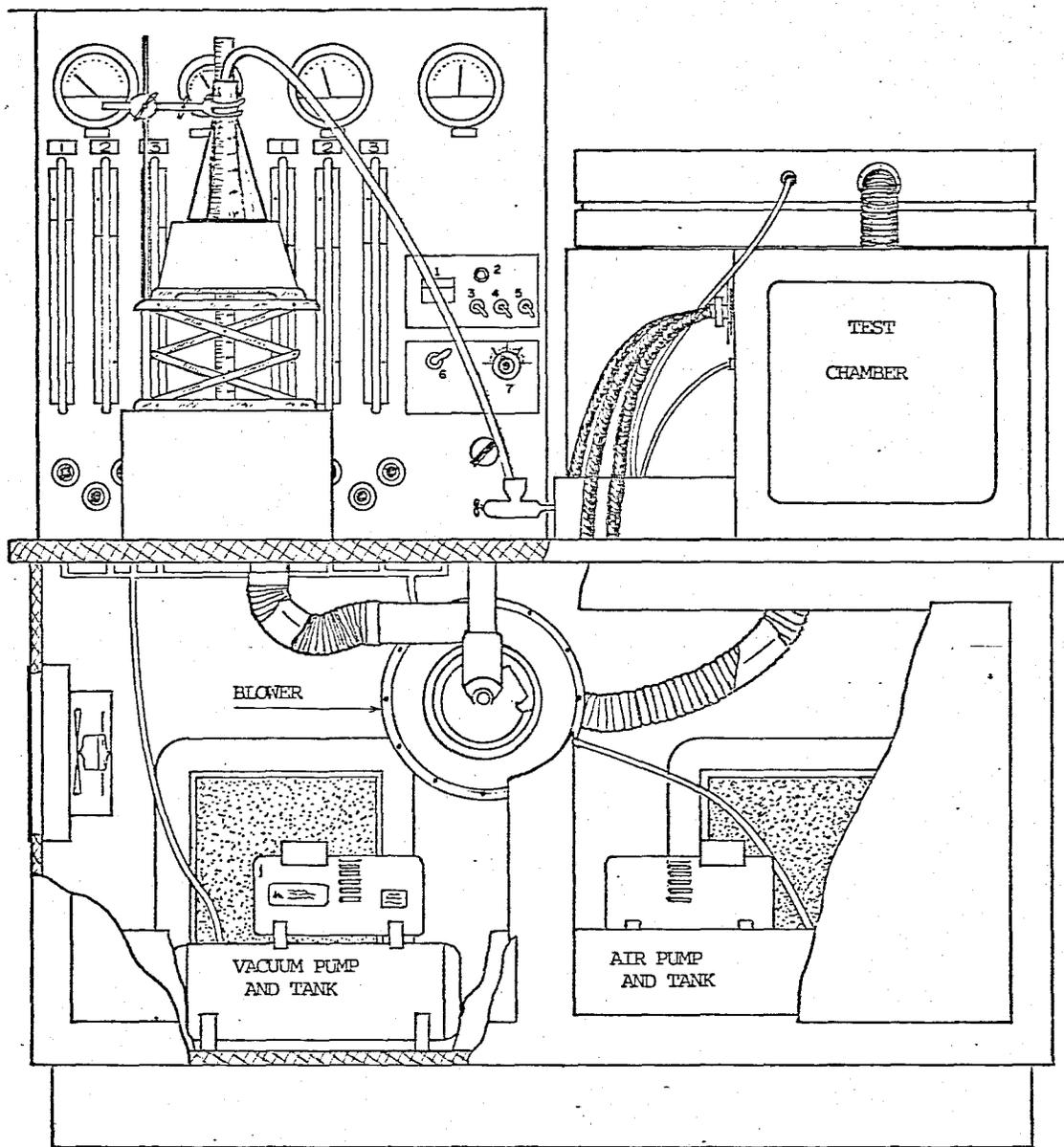


Figure 35. Blower and pumps under working surface .

FIGURE 36. WIRING DIAGRAM FOR CONTROL PANEL AND
 DIAGRAM FOR VACUUM REGULATING SCHEMATIC

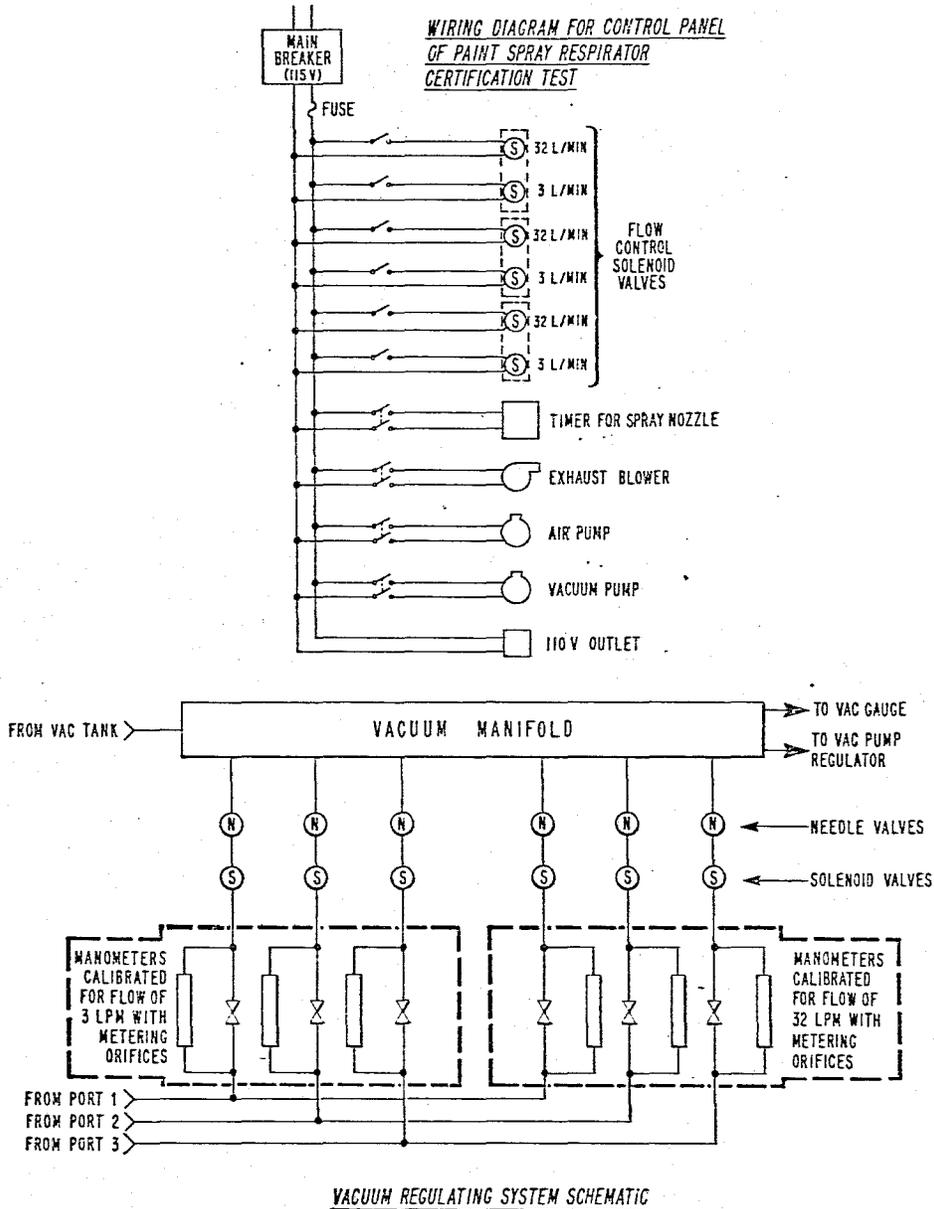
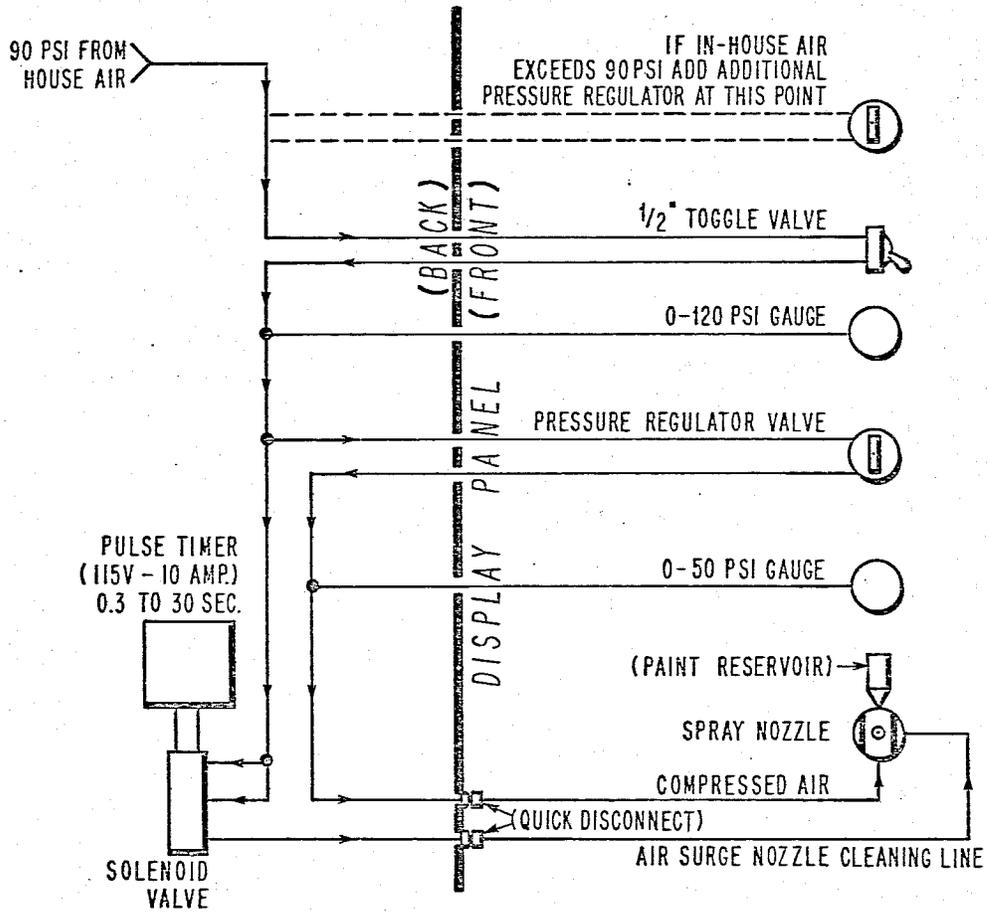


FIGURE 37. FLOW DIAGRAM FOR COMPRESSED AIR SUPPLY SYSTEM



COMPRESSED AIR SUPPLY SCHEMATIC

FIGURE 38. CUT-AWAY VIEW OF CHAMBER

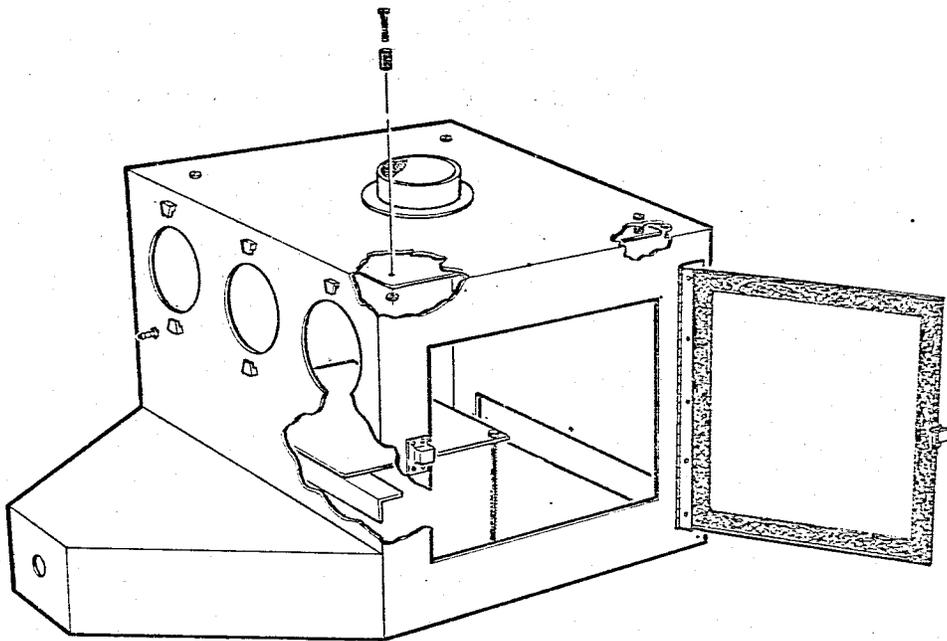


FIGURE 39. RESPIRATOR CARTRIDGE SAMPLE LOCATION

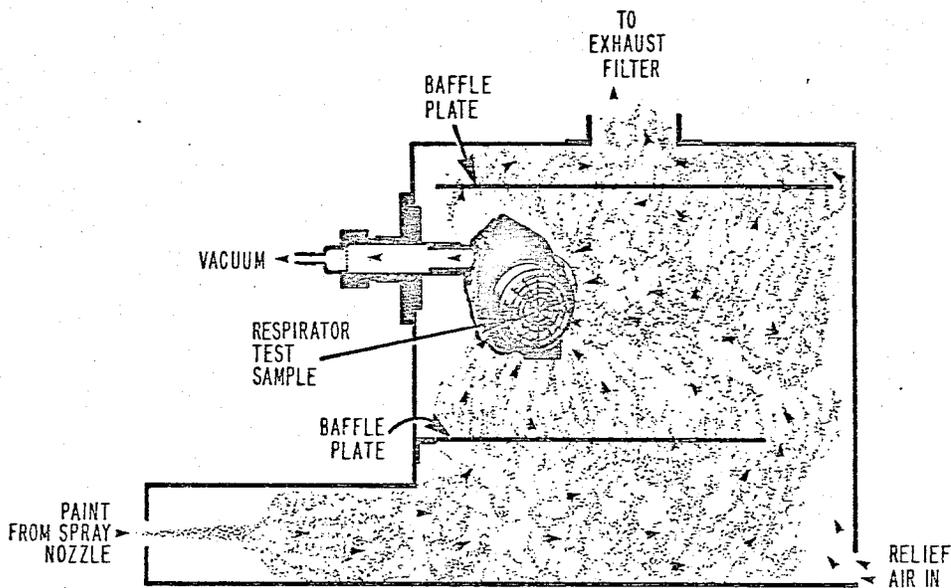


FIGURE 40. DETAIL LAYOUT OF CHAMBER COMPONENTS

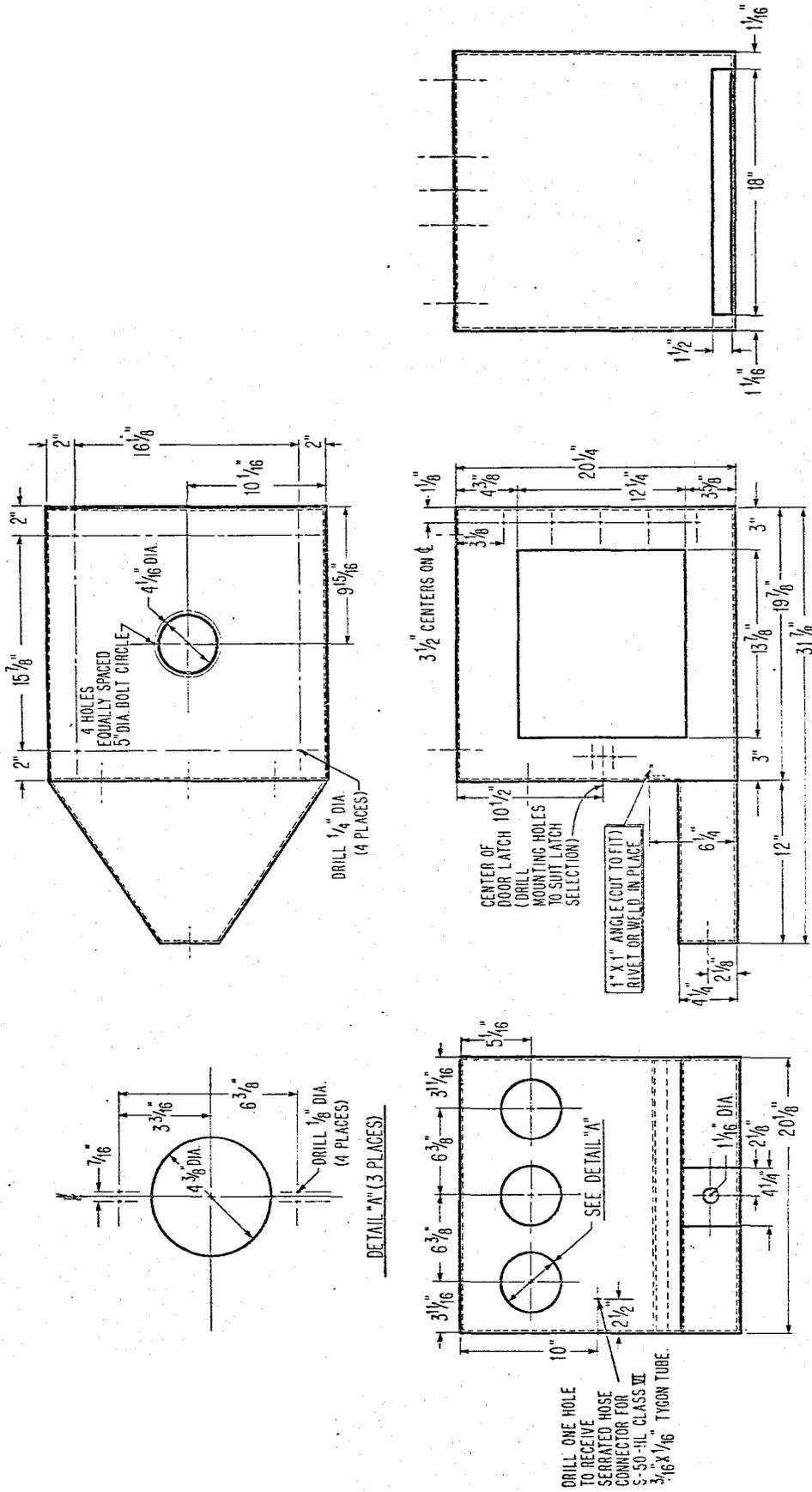
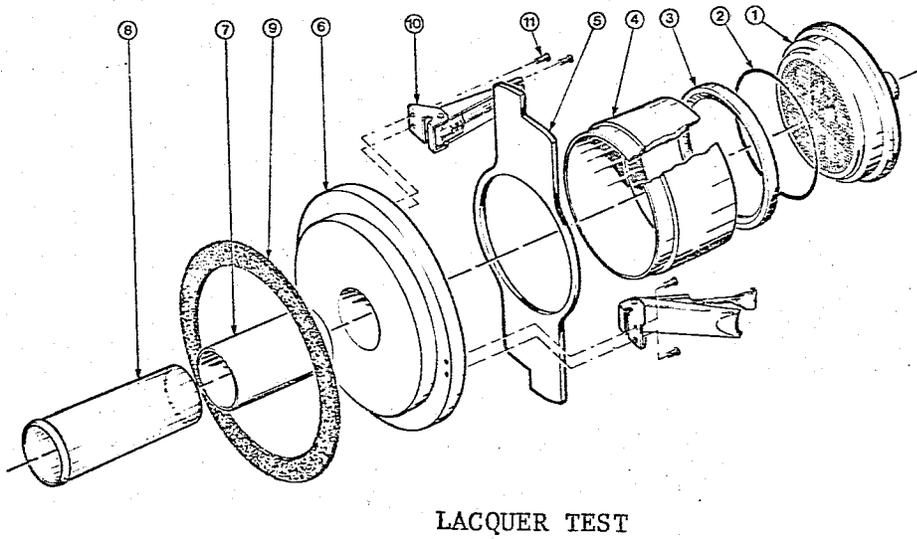
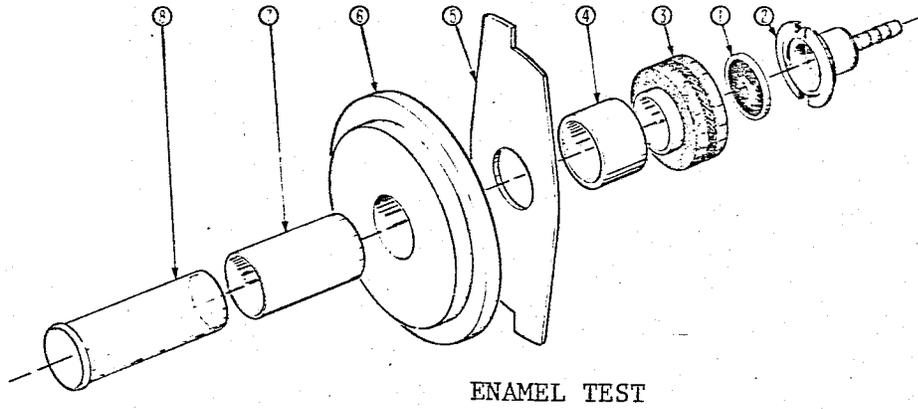


FIGURE 41. CONSTRUCTION LAYOUT OF SAMPLE HOLDERS AND CARTRIDGE
MOUNTS FOR ENAMEL AND LACQUER TESTS

SEE TABLE VI FOR DESCRIPTION OF COMPONENTS



SEE APPENDIX H FOR CONSTRUCTION DETAILS

TABLE VIII

DESCRIPTION OF SAMPLE HOLDERS

Enamel Sampler Part	Quantity	Part No.
SS screen, 47 mm Millipore filter holder	1	1
Outlet plate, 47 mm Millipore filter holder	1	2
Inlet plate, 48 mm Millipore filter holder	1	3
Sleeve, aluminum	1	4
Latch	1	5
Chamber mounting plate	1	6
Sleeve, aluminum	1	7
Glass joint S29/42F	1	8
Lacquer Sampler Part		
Outlet plate with ss. screen. 75 mm	1	1
"O" ring 2 7/8" ID	1	2
Insert for "O" ring seat	1	3
Sleeve, aluminum	1	4
Latch, chamber	1	5
Chamber mounting plate	1	6
Glass insert S29/42F	1	8
Gasket, sponge rubber	1	9
Latch, aircraft hatch	2	10
Machine screws, 8-32	4	11

FIGURE 42. FILTER BOX ASSEMBLY BY MAJOR COMPONENTS

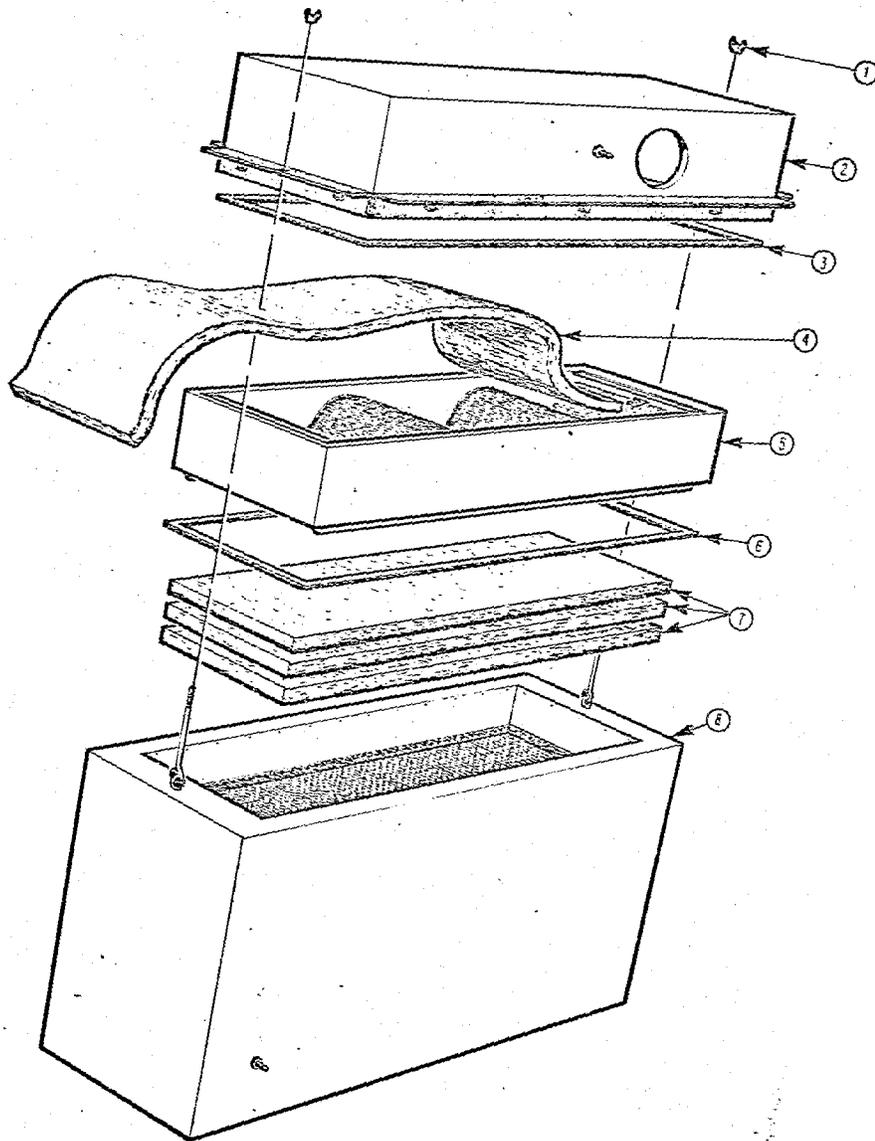


TABLE IX

EXHAUST FILTER ASSEMBLY COMPONENTS

CALL OUT NO.	DESCRIPTION	QTY.	PART
<u>EXHAUST FILTER ASSEMBLY</u>			
2	• <u>Cover Filter, Sub-Assembly</u>		
	Panel, Top - 1/2" plywood x 9-1/2" x 25"	1	K
	Panel, Front - 1/2" plywood x 6" x 25" (with 4" dia. hole)	1	G
	Angle - 1-1/2" x 1-1/2" x 1/8" steel x 25" lg.	1	I
	Screw - 1/4" dia. x 1" R.H. mach.	5	
	Starwasher - 1/4" (I.S.)	5	
	Lockwasher - 1/4" (I.S.)	5	
	Hexnut - 1/4"	5	
	Connector, Serrated Hose (for S-50 NL Class VI 3/16" x 1/16" Tygon tube - length to fit)	1	Y
	Panel, Back - 1/2" plywood x 6" x 25"	1	G
	Angle - 1-1/2" x 1-1/2" x 1/8" steel x 25" lg.	1	I
	Screw - 1/4" dia. x 1" R.H. mach.	5	
	Starwasher - 1/4" (I.S.)	5	
	Lockwasher - 1/4" (I.S.)	5	
	Hexnut - 1/4"	5	
	Panel, End - 1/2" plywood x 6" x 8-1/2"	2	H
	Angle - 1-1/2" x 1-1/2" x 1/8" steel x 9-1/2" lg.	1	J
	Screw - 1/4" dia. x 1" R.H. mach.	2	
	Starwasher - 1/4" (I.S.)	2	
	Lockwasher - 1/4" (I.S.)	2	
	Hexnut - 1/4"	2	
3	Gasket - 1/4" polyurethane foam x 1/2" wide x 25" lg. (glue in place)	2	F
	Gasket - 1/4" polyurethane foam x 1/2" wide x 8-1/2" lg. (glue in place)	2	F
4	• Filter - 3/4" thick x 8-3/4" x 37 lg. Made from English wool (Scott Aviation 716-683-5100x218)	1	
5	• <u>Retainer, Corrugated Filter, Sub-Assembly</u>		
	Panel, Front - 1/2" plywood x 5-3/8" x 25"	1	
	Panel, Back - 1/2" plywood x 5-3/8" x 25" lg.	1	
	Support Form, wiremesh - 1/4" plywood x 4-7/8" x 24"	2	A
	Panel, End - 1/2" plywood x 5-3/8" x 8-1/2"	2	C
	Support wiremesh - 1/4" plywood x 1" x 8-1/2"	2	D
	Clip, End, Filter - 3/4" x 3/4" x 1/16"	2	B
	Woodscrew, No. 8 x 7/16" R.H.	6	
	Wiremesh - 1/8" x 8-1/2" x 37" long (staple in place)	1	E
6	Gasket - 1/4" polyurethane foam x 1/2" wide x 25" lg. (glue in place)	2	F
	Gasket - 1/4" polyurethane foam x 1/2" wide x 8-1/2" lg. (glue in place)	2	F
7	• Filter - 3/4" thick x 8-3/4" x 24-1/2" lg. Made from English wool (Scott Aviation 716-683-5100x218)	3	M

TABLE IX. (Continued)

EXHAUST FILTER ASSEMBLY COMPONENTS

CALL OUT NO.	DESCRIPTION	QTY.	PART
8	• Base Sub-Assembly, Filter Retainer And, Panel, Top - 1/2" plywood x 10-3/4" x 30"	1	R
	Nutsert - 1/4" (to fit threaded end of "P")	2	Q
	Eyebolt - 1/4" dia. (shank) x 1" long (threaded)	2	O
	Lockwasher - 1/4" dia. (I.S.)	2	
	Eyebolt - 1/4" dia. (shank) x 7-1/2" long (threaded)	2	P
	Flatwasher - 1/4" dia. (I.S.)	2	
1	Wingnut - 1/4" (to fit threaded end of "P")	2	
	Retainer, Filter (fabricate from 1/16" aluminum x 14-1/8" x 29-5/8")	1	X
	Nail, Wire - 3/4" flat head	32	
	Wiremesh - 1/8" x 8-1/2" x 24" (rivet in place)	1	L
	Panel, Front - 1/2" plywood x 20" x 30"	1	W
	Connector, Serrated Hose (for S-50 NL Class VI 3/16" x 1/16" Tygon tube - length to fit)	1	Y
	Panel, Back - 1/2" plywood x 20" x 30" (with access hole)	1	U
	Cover Sub-Assembly, Access Hole	1	V
	Plywood - 1/4" x 14" x 14"	1	
	Plywood - 1/2" x 11-7/8" x 11-7/8"	1	
	Gasket - 1/4" polyurethane foam x 1" x 14" lg. (glue in place)	2	F
	Gasket - 1/4" polyurethane foam x 1" x 12" lg. (glue in place)	2	F
	Nutsert - 1/4" dia. (to fit 1/4" dia. bolt)	4	
	Bolt - 1/4" dia. x 1-1/4" lg. R.H. Machine	4	
	Lockwasher - 1/4" dia. (I.S.)	4	
	Flatwasher - 1/4" dia. (I.S.)	4	
	Wingnut - 1/4" (to fit 1/4" dia. bolt; above)	4	
	Panel, End - 1/2" plywood x 9-3/4" x 19"	2	S
	Panel, Bottom - 1/2" plywood x 10-3/4" x 30"	1	T
	Wiremesh - 1/8" x 6" dia. (staple in place)	1	N

FIGURE 43. FILTER BOX COVER SUB-ASSEMBLY

SEE TABLE VIII (CALL OUT NO. 2)

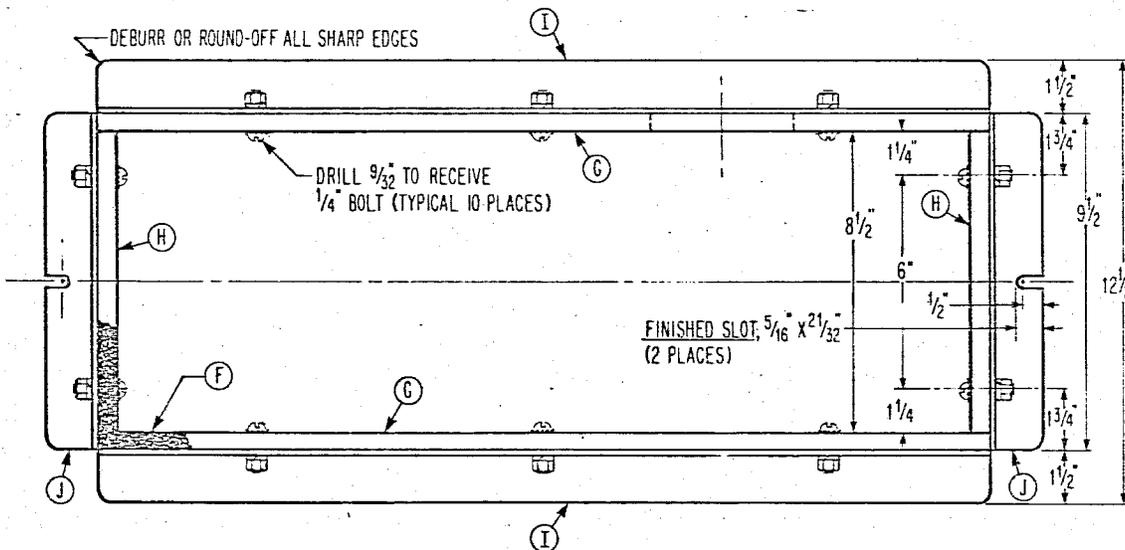
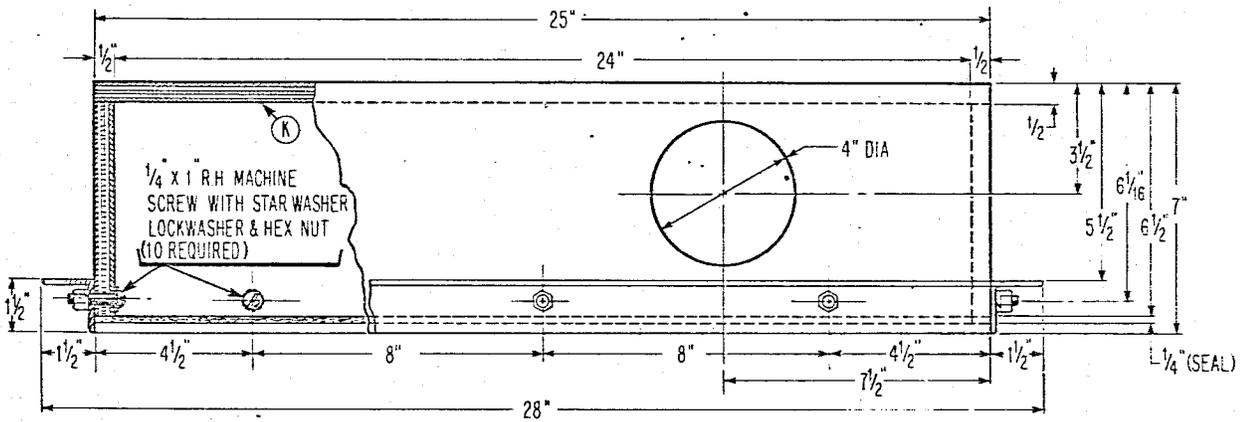
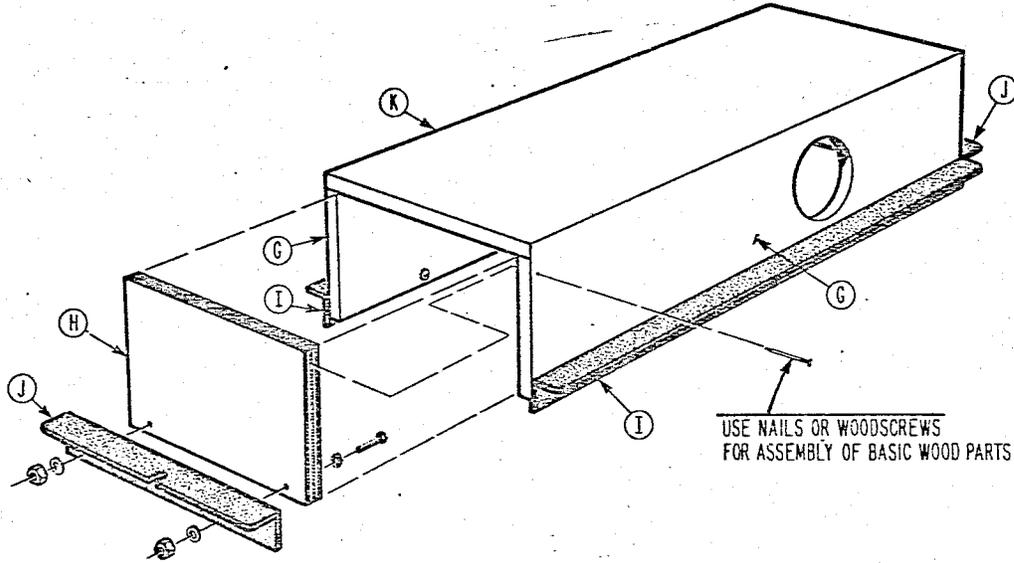


FIGURE 44. FILTER BOX COVER DETAIL

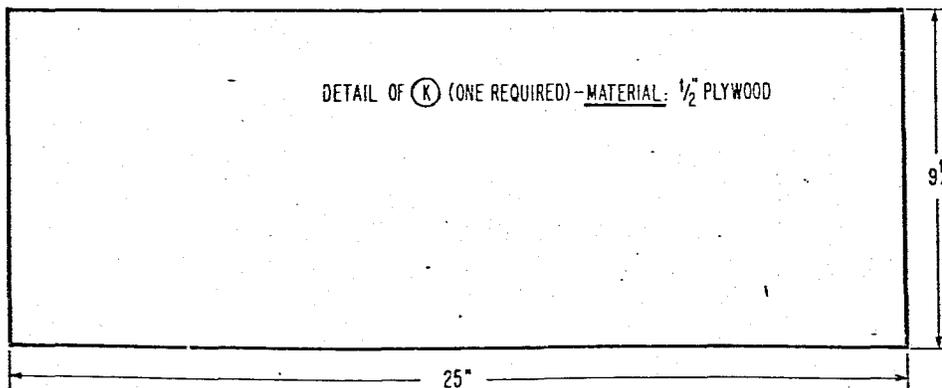
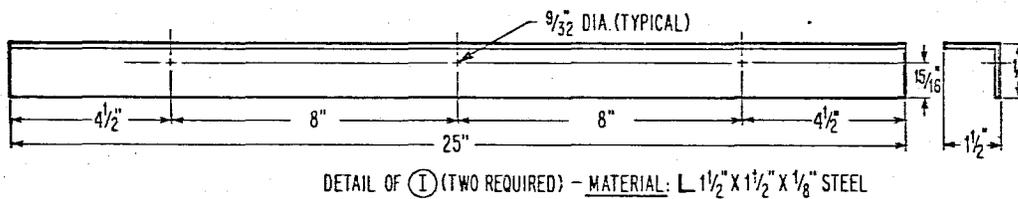
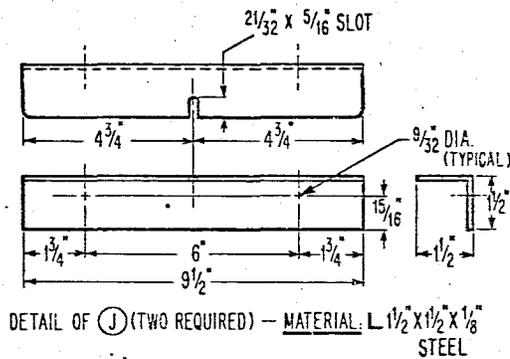
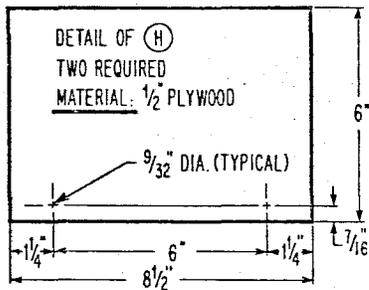
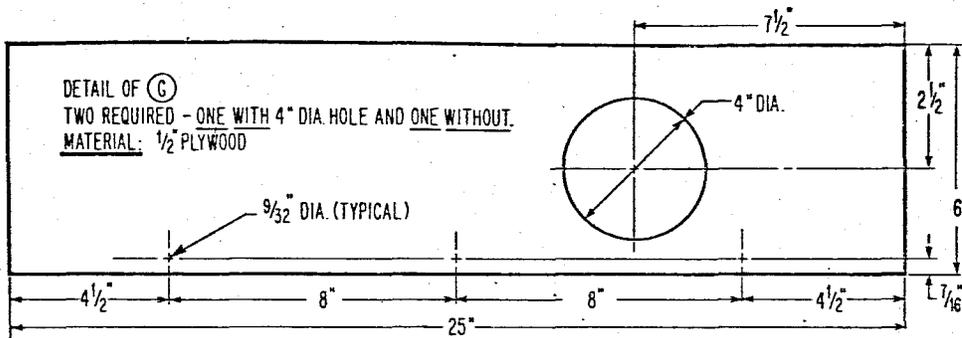
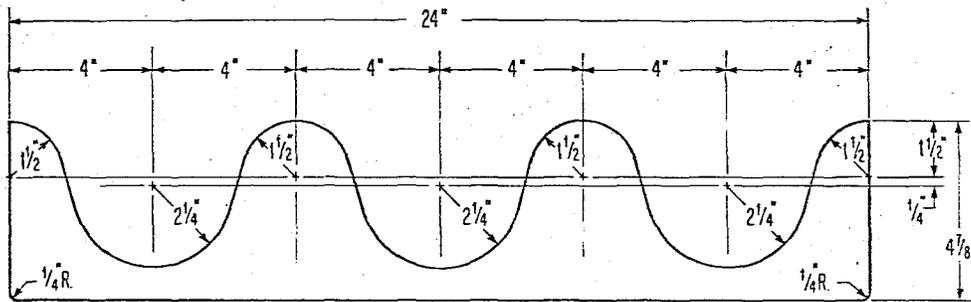
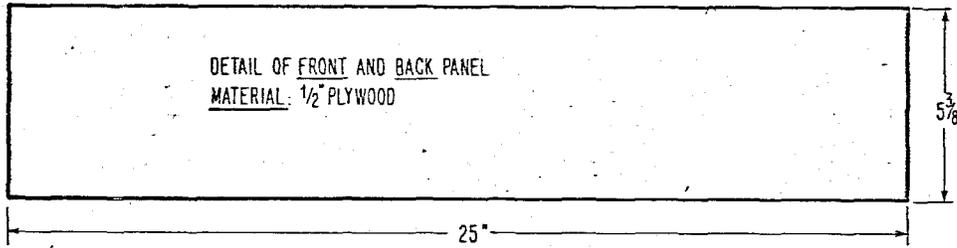
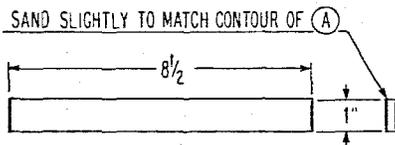


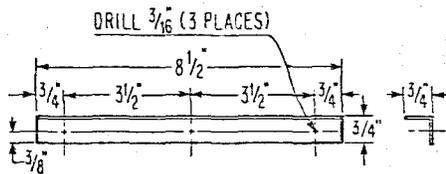
FIGURE 46. CORRUGATED FILTER SUB-ASSEMBLY DETAIL



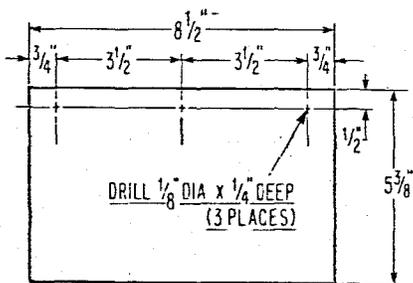
DETAIL OF (A) - (2 REQUIRED)



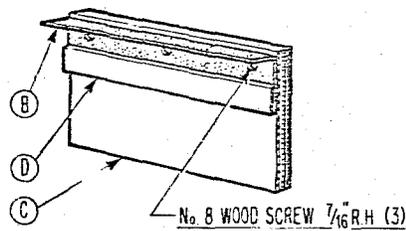
DETAIL OF (D) - (2 REQUIRED)



DETAIL OF (B) - (2 REQUIRED)



DETAIL OF (C) - (2 REQUIRED)



END PIECE ASSEMBLY (2 REQUIRED)

FIGURE 48. FILTER BOX BASE BACK PANEL DETAIL

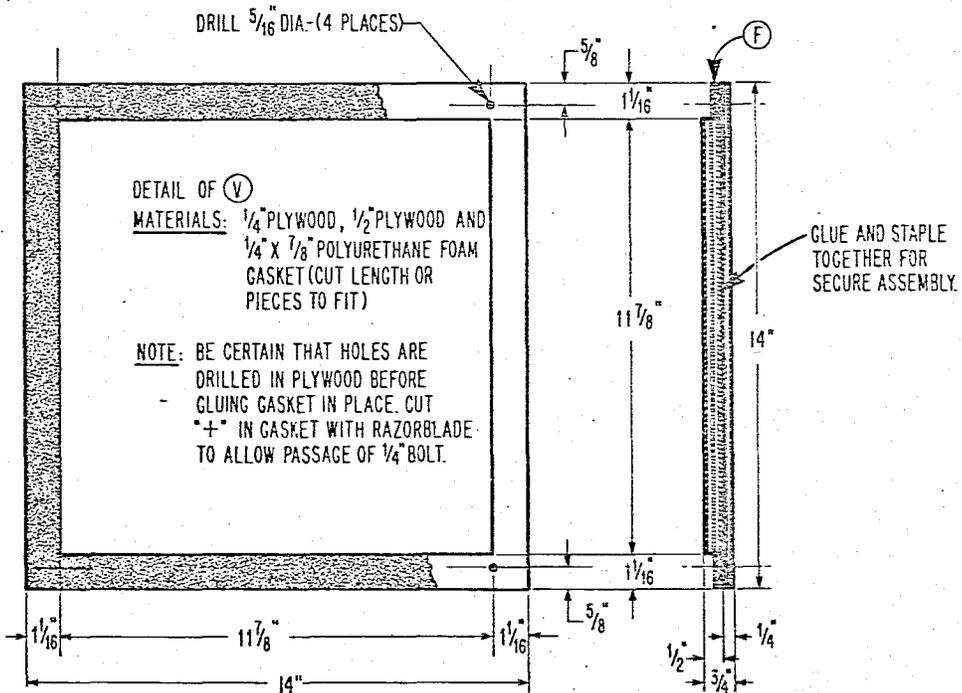
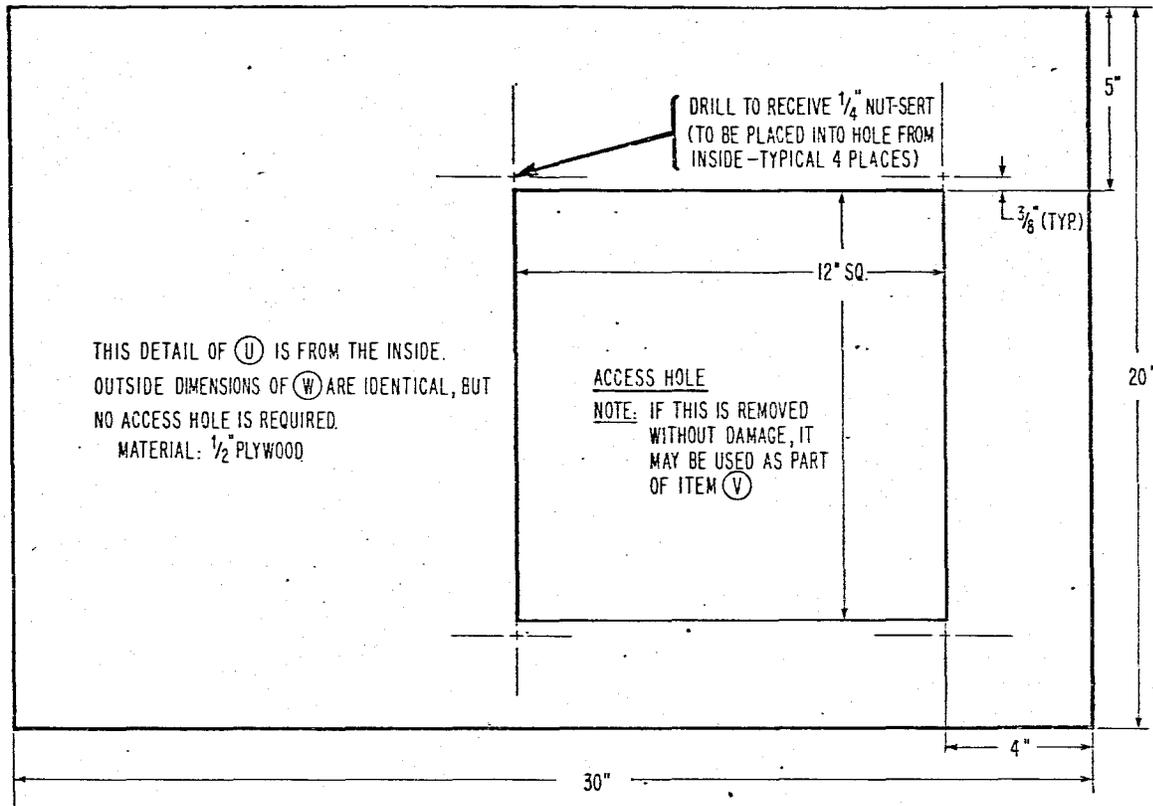


FIGURE 49. FILTER BOX BASE BOTTOM PANEL DETAIL

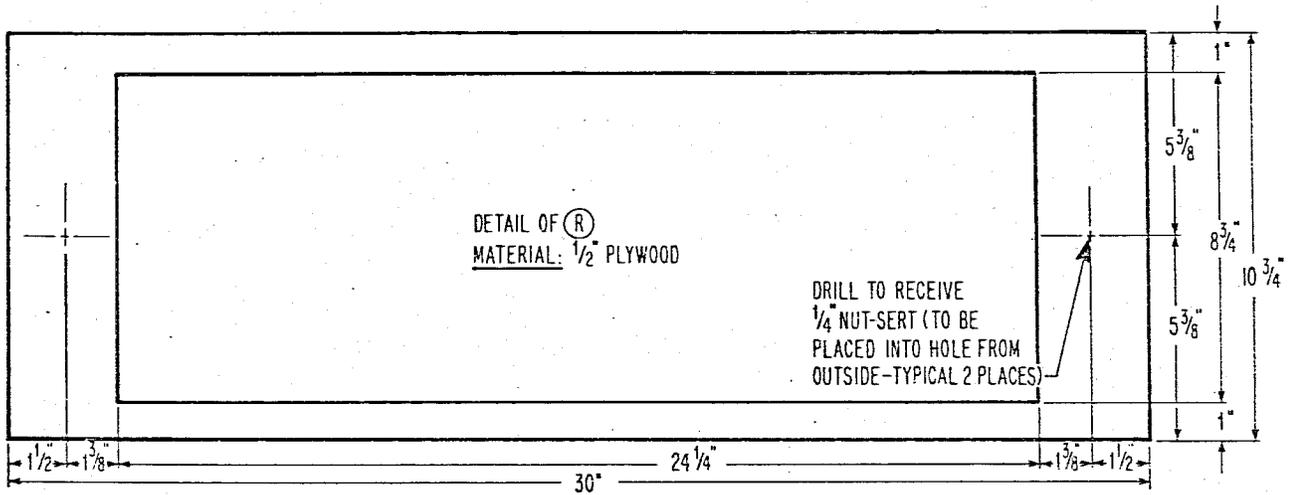
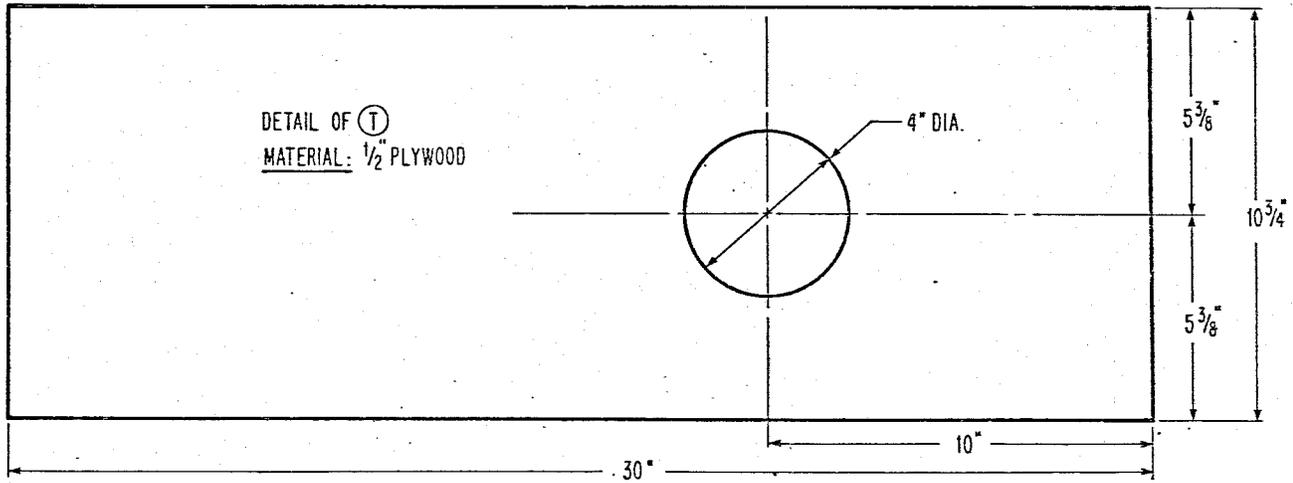
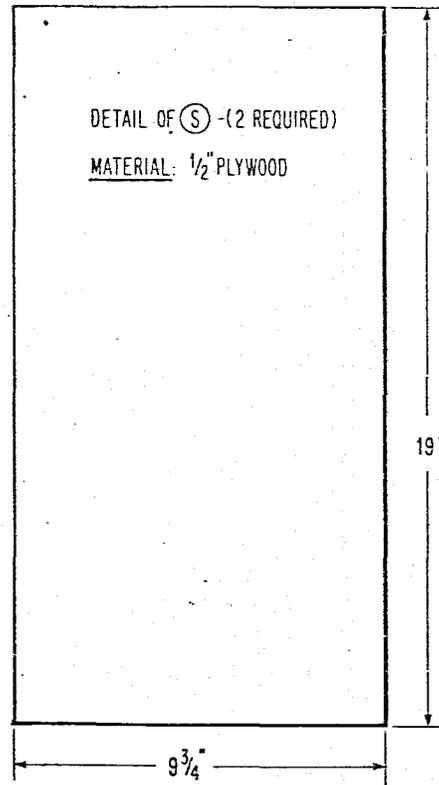
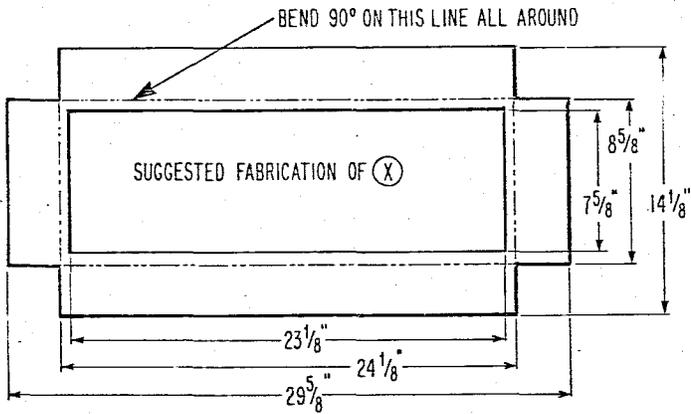
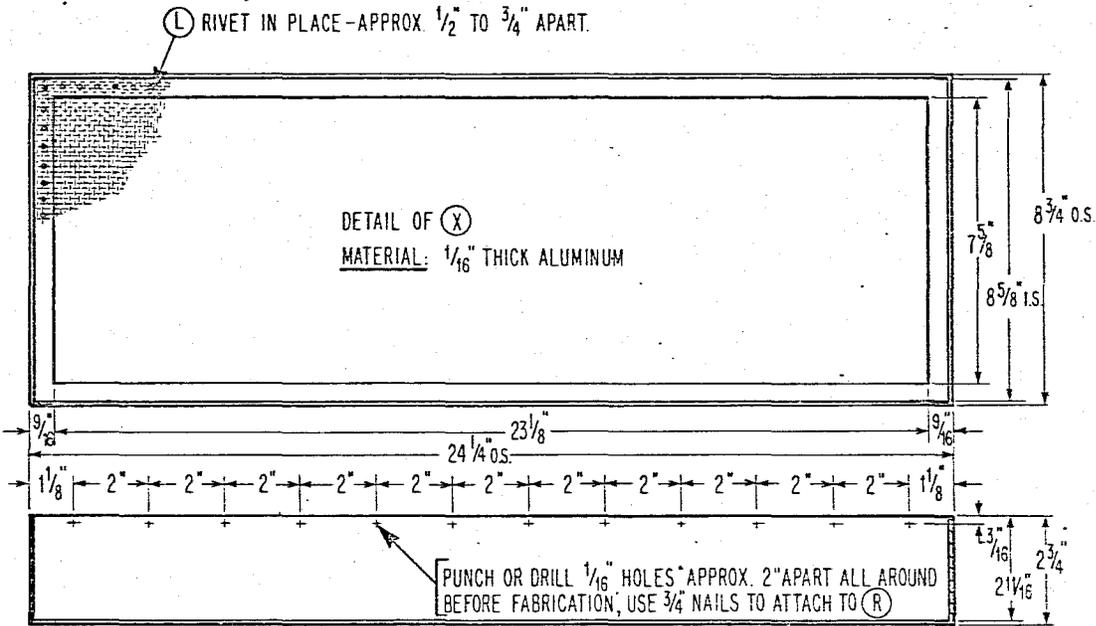


FIGURE 50. FILTER RETAINER AND BASE SUB-ASSEMBLY DETAIL



IX. SUMMARY AND CONCLUSIONS

The objective of this project was to evaluate the Paint Spray Respirator Certification Test as it is constructed in NIOSH, TCB, Morgantown, West Virginia and to make recommendations for improvements in the test. It had been suggested by many critics of the test that the paint currently used is outdated and should be replaced with a paint more commonly used today.

The areas investigated in this project include: flow patterns in the chamber; paint aerosol concentration variations in the chamber; paint penetration through the respirator cartridges and particle size distribution of the paint aerosol.

The study of flow patterns within the chamber was complicated by the turbulent flow in all parts of the chamber. The indications of flow direction were obtained by observing the directions of a smoke tube plume or a fine thread over a period of time, sometimes as long as a minute, to determine the predominant direction. This made the results subjective in nature. The flow velocities at all points in the chamber were turbulent which is desirable.

The variations in the paint concentration at 5 points in the chamber were found to be significantly different according to a statistical test called Duncan's Multiple Range Test. Ackley¹⁰ demonstrated that the nozzle

position about the horizontal and vertical axis affected the paint aerosol distribution in the chamber sample space. It is assumed that the positioning of the spray nozzle can overcome most maldistribution problems of paint aerosol in the chamber. It is recommended that additional work be done on the paint aerosol distribution to demonstrate how uniform the chamber concentration can be made.

The paint penetration tests were disappointing. The low penetration of the aerosol through the respirator cartridges did not permit the experiment to differentiate between positions and paint test conditions of nozzle air pressures, paint/solvent ratio, paint flow rate and chamber air flow. The conclusion from this and the previous attempts of Bendix Launch Support Division NIOSH Contract 210-76-0178 is that the evaluation of the test should be directed to the quality and concentration of the aerosol in the chamber. The effects of test variables will be reflected in the aerosol which can be evaluated independent of aerosol penetrations of the respirator test cartridges.

The particle size distribution analysis of the paint aerosol was performed with an Anderson 2000 Inc respirable aerosol analyzer which was altered to allow sampling from outside the chamber. This alteration certainly affected the performance of the samples but it is assumed that all samples were affected in the same way; the results are comparable if not entirely accurate. The size distribution analysis does indicate some degree of effect on mean size with respect to the nozzle air supply pressure. This is also indicated by the NUKIAMA-TANISAWA empirical

equation relating mean particle size of the aerosol to velocity, paint flow, surface tension, fluid density and viscosity. The low correlation at mean aerosol size with the nozzle air supply pressure obtained in the test is an indication of the difficulty to be encountered in obtaining conclusive results in this test and may be indicative of the poor control possible with the existing test hardware.

Further research on this test must demonstrate a degree of control not accomplished in this evaluation. If the degree of control can only be accomplished by means of a larger number of tests the conclusion must be that the test is not valid when only one certification test is performed. Control of the test must be demonstrated first before certification tests can be assumed to be valid.

The project was terminated with the evaluation of the enamel paint spray certification test due to time limitations plus the knowledge that the lacquer test was evaluated by Mark Ackley of Scott Aviation. The Ackley report is included as Appendix H for the convenience of the reader.

X. REFERENCES

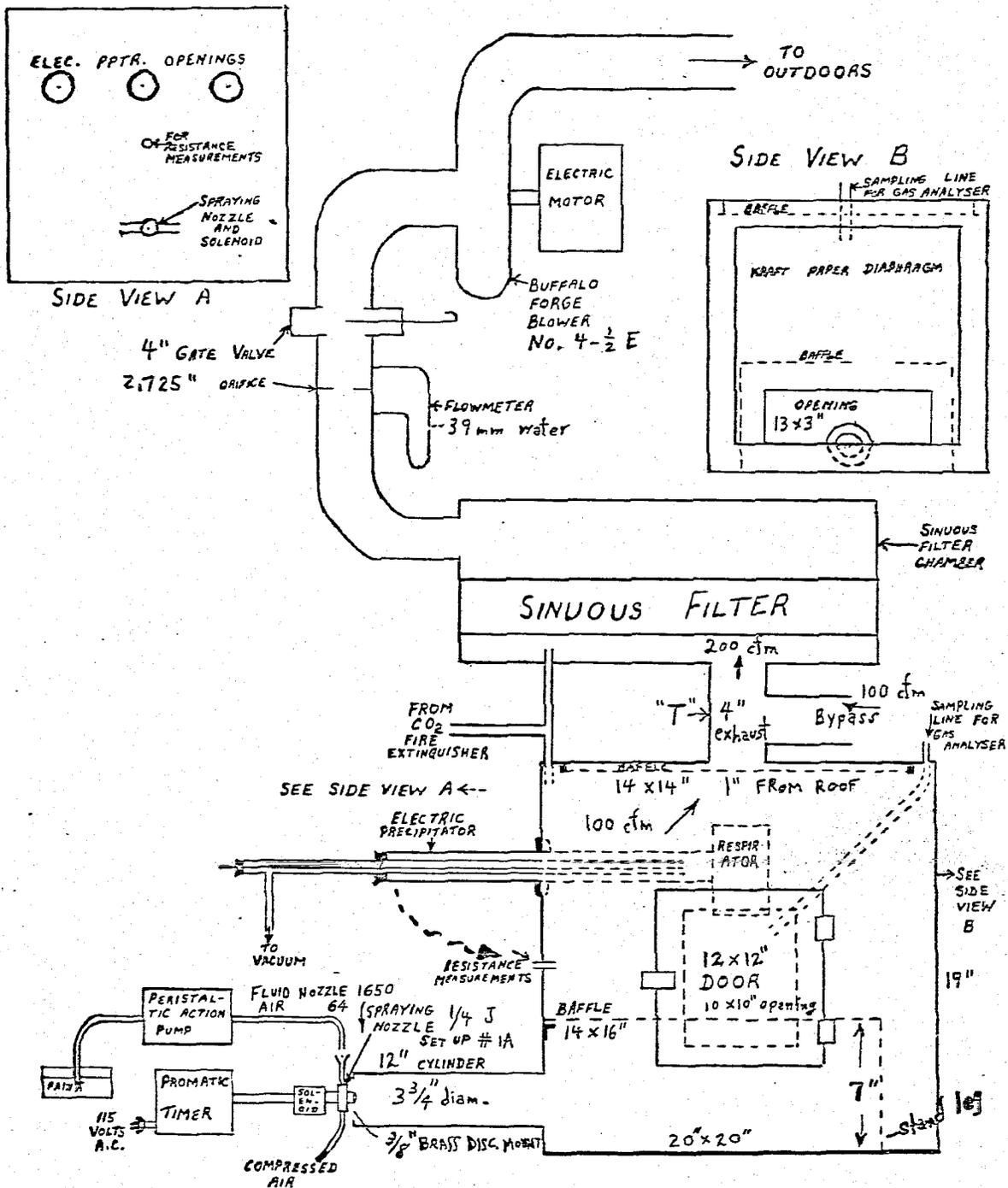
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APPENDIX A

SCHEMATIC DIAGRAM OF EQUIPMENT USED IN THE BUREAU OF MINES APPARATUS FOR THE PROPOSED APPROVAL TESTING OF RESPIRATORS FOR PROTECTION AGAINST PAINT SPRAYS.

MARCH 8, 1957
B. I. FERBER

NOT DRAWN TO SCALE



PAINT SPRAY RESPIRATOR CERTIFICATION TEST PROTOCOL

Objective: To evaluate the newest version of the TCB paint spray respirator certification test (CAN 432).

Outline of the project procedure: The project will be carried out in five (5) phases.

Phase 1. Construction of an apparatus that will duplicate the functions of the existing TCB apparatus and be built to meet the major dimensional specifications of the subject apparatus.

- a. Chamber dimensions must correspond to those of the TCB chamber.
- b. Flow rates of air and paint must be controllable to those recommended by TCB.
- c. The sampling system will equal or surpass that of the existing TCB apparatus.

Phase 2. The apparatus assembled in Phase 1 will be evaluated in three or more steps.

- a. An enamel paint will be selected for the test and a diluting solvent will be chosen that will be compatible with the paint and will help produce the type of paint aerosol desired for this test.
- b. The enamel paint spray aerosol will be optimized by selection of suitable operating conditions. This will result in the best conditions for performing the next phase of the test.
- c. The chamber concentration of paint aerosol will be determined in several different positions.
- d. The respirators will be evaluated in the chamber to determine the performance of the filters in various positions and changes in several process variables.

Phase 3. Determine the optimum operating conditions for the enamel-solvent system being evaluated or determine the shortcomings of the test and propose modifications.

The project will be carried out using experimental designs approved or recommended by the Statistical Services Branch. The project may require more than one experimental design and test series and the project may have a divided path (i.e., the decision may be required to modify the test apparatus before proceeding to the evaluation of respirator cartridges in the chamber).

Phase 4. Determine the optimum operating conditions for the lacquer-solvent system being evaluated or determine the shortcomings of the test and propose modifications.

Phase 5. Prepare a final report which will summarize the findings of the project and present any recommendations or changes proposed for the test procedure and apparatus being evaluated.

CONSTRUCTION OF TEST APPARATUS

A. Construction Specifications

1. The device is being constructed to conform to the TCB test apparatus designed and constructed by Scott Aviation for NIOSH at a cost of \$12,000.
2. The chamber dimensions are the same as the previous TCB device but the entry is flared laterally. Why this was done is not clear but it certainly changes the performance of the chamber airflow pattern and the paint aerosol distribution.
3. The paint pump rates will be different in the new chamber since deposition characteristics of the aerosol will be changed.

B. Construction Materials

1. The chamber will be constructed of the following materials:
 - a. chamber walls of 5052 aluminum 1/8" sheet, cut and welded
 - b. filter holders of aluminum plate 1/2" and 3/4" thick
2. The vacuum sampling system
 - a. vacuum pump, 1/2 HP motor
 - b. surge tank, 15 gallons
 - c. flow control valves
 - d. copper tubing
 - e. aluminum tubing
 - f. tubing fittings
3. Exhaust system
 - a. exhaust blower
 - b. flexihose
 - c. filters (entrainment)
4. The remaining hardware and systems will be obtained from the existing apparatus (Bendix-constructed device)

C. Construction Schedule

The paint spray apparatus will be fabricated in-house. It will be set up in Laboratory 500. Relocation or other changes will delay the completion of the project.

1. Construction of the chamber

The aluminum sheet must be cut to size and welded. All openings must be cut and the door fabricated and attached (24 man-hours).

2. The sample cartridge holders must be machined from the 1/2" and 3/4" aluminum plate. Time estimate: first holder, 3-4 days; second and third holders, 2 days each (64 man-hours).

3. The chamber must be assembled and set in place of the existing chamber (8 man-hours).

4. Construction of the vacuum sampling system

a. mounting pump on tank (4 man-hours)

b. fitting tanks (2 man-hours)

c. making sampling manifold assembly (4 man-hours)

d. assembly of sampling system into existing facility (4 man-hours)

e. miscellaneous fittings, hoses, connectors, pressure relief valve

5. Assembly of the chamber exhaust system

a. mounting of the pump and blower to the floor (4 man-hours)

b. connecting blower to exhaust duct (2 man-hours)

c. connecting blower to chamber (2 hours)

d. wiring blower into system (2 hours)

6. Connecting air line to high pressure air supply (existing air supply) (8 man-hours).

7. The total construction period should cover 4-5 weeks after delivery of the major components. The total labor is estimated to be 152 man-hours.

EXPERIMENTAL DESIGN

- A. Establish the operating conditions for 95-125 mg/m³ paint concentration in the chamber.
1. Select the paint and solvent.

We may want to abandon the existing solvent paint system if a better choice can be made.
 2. Criteria for selecting a paint and solvent
 - a. widely used in spray painting
 - b. enamel and lacquer
 - c. solvent must be lighter than the average solvent (i.e., lower in boiling point)
 - d. paint must be compatible with the spray nozzle we are using
 - e. pigment component which allows quick and accurate analysis
 3. Select a range of spray nozzle variables, air pressure and paint pressure that will be investigated. Chamber airflow will be constant at 20 air changes per minute.
- B. Characterizing the chamber enamel aerosol
1. The chamber concentration will be measured and the particle size range will be determined by the Anderson Impactor while the paint spray nozzle conditions are adjusted to achieve the 95-125 mg/m³. "N" runs will be made to determine the range and average chamber concentration at the wall-center sampling port. A minimum of 25 runs will be made of 1/2 hour each.
 2. The chamber concentration and particle size distribution will be measured at nine (9) different positions in the chamber and at the chamber wall, center port. This will determine the mass distribution of paint aerosol in the chamber and the variation in particle size at the sampling points. The purpose of this step is to establish the "quality" of the challenge conditions in the apparatus. It could be argued that if this step indicates that the challenge conditions are both stable and suitable in terms of concentration and particle size distribution, that the test is adequate. That is, it would not be worth additional testing as long as the values of other test parameters were acceptable. Other test parameters being:

- a. positions of respirator in the chamber
- b. distance of respirator from the sample filter

A minimum of twenty tests will be needed which average about three hours each in time. Two samples will be obtained for each run.

C. Evaluation of respirator cartridge performance

The next phase of the project is to evaluate the respirator cartridge penetration in the chamber while varying non-aerosol test parameters. As mentioned previously in (B), this phase may be unnecessary if the previous phase results indicate that excellent conditions have been achieved. If the multifactored experiment is judged to be unnecessary, there is still some testing that is desirable such as:

1. Actual penetration values obtained in the test chamber to determine the chamber performance compared to the previous test. This may require using the previous paint solvent system (i.e., a 50% mixture of Fed. Spec. TT-E-489B and turpentine). A minimum of 20 runs is necessary.
2. The particle size distribution of the enamel paint aerosol which penetrates the respirator filter cartridge should be determined. The problem here is that a very low value is normal for this test so that the Anderson Impactor will not be suitable to collect an adequate sample during the 15-minute run time. The laser analyzer may be the only device capable of performing this analysis. A minimum of ten runs will be needed which average about 1/2 hour each in length.

D. Evaluation of lacquer spray in chamber

The next phase of this project is to evaluate the performance of a lacquer-solvent system. The approach will be somewhat different with the lacquer than with the enamel because the lacquer spray tends to form filaments of lacquer rather than droplets and the test is to measure airflow resistance buildup rather than aerosol penetration. The particle size distribution is not important here but the mass concentration of the lacquer spray in the chamber is since the different nature of the aerosol may affect the paint distribution in the chamber.

1. A suitable lacquer-solvent system should be selected after consultation with the industry and agents of the industry.

EXPERIMENTAL DESIGN

- A. Establish the operating conditions for 95-125 mg/m³ paint concentration in the chamber.
1. Select the paint and solvent

We may want to abandon the existing solvent paint system if a better choice can be made.
 2. Criteria for selecting a paint and solvent
 - a. widely used in spray painting
 - b. enamel and lacquer
 - c. solvent must be lighter than the average solvent (i.e., lower in boiling point)
 - d. paint must be compatible with the spray nozzle we are using
 - e. pigment component which allows quick and accurate analysis
 3. Select a range of spray nozzle variables, air pressure and paint pressure that will be investigated. Chamber airflow will be constant at 20 air changes per minute.
- B. Characterizing the chamber enamel aerosol
1. The chamber concentration will be measured and the particle size range will be determined by the Anderson Impactor while the paint spray nozzle conditions are adjusted to achieve the 95-125 mg/m³. "N" runs will be made to determine the range and average chamber concentration at the wall-center sampling port. A minimum of 25 runs will be made of 1/2 hour each.
 2. The chamber concentration and particle size distribution will be measured at nine (9) different positions in the chamber and at the chamber wall, center port. This will determine the mass distribution of paint aerosol in the chamber and the variation in particle size at the sampling points. The purpose of this step is to establish the "quality" of the challenge conditions in the apparatus. It could be argued that if this step indicates that the challenge conditions are both stable and suitable in terms of concentration and particle size distribution, that the test is adequate. That is, it would not be worth additional testing as long as the values of other test parameters were acceptable. Other test parameters being:

2. The chamber and paint spray conditions should be adjusted to deliver the lacquer-solvent aerosol in the correct concentration and suitable or preferably the most suitable particle size distribution. This phase of the test should require a minimum of 20 runs. If a suitable particle size method cannot be found for lacquer aerosol, this will be deleted from the procedure.
 3. The lacquer-solvent aerosol chamber concentration will be determined in a manner similar to that used for the enamel test procedure. This will determine the variation of the chamber aerosol concentration in vertical and horizontal planes. Seven sample sites will be used. The lacquer-solvent aerosol particle size distribution will not be measured. The number of runs estimated for this phase is _____ (to be determined by SSB, DTS).
 4. The lacquer-solvent aerosol penetration will be measured at different sampling locations within the test chamber. The particle size distribution of the aerosol passing through the respirator filter will be measured using the laser analyzer. A minimum of ten runs will be necessary.
- E. Qualifications on number and time of sample runs

It should be noted here that the statistical evaluation has not been thoroughly performed at this time and, in some cases, may not be final until previous phases of the project are completed. This may require changes in plans and milestones during the life of the project.

APPENDIX C

COMPARISON OF VARIOUS PAINT SPRAY CHAMBER DIMENSIONS IN USE TODAY

DIMENSION	SCOTT	WILLSON	3M	NIOSH-TCB	NIOSH-CTRB
INTERNAL DIMEN. CHAMBER	L 19-3/4" W 19-5/8" H 20"	L 40" W 30" H 36"	L 20" W 20" H 24"	L 19-3/4" W 19-5/8" H 20"	L 19-5/8" W 19-3/4" H 20"
PAINT SPRAY INLET		4"Diam. Duct	Trapezoid W1 5-1/2" W2 18-1/2" L 13" H 6"	Trapezoid W1 3-3/4" W2 19-3/4" L 12" H 4"	Trapezoid W1 3-3/4" W2 19-3/4" L 11-7/8" H 4"
CHAMBER'S TOP BAFFLE	L 19" W 19"	NONE	L 12" W 12"	L 19" W 19"	L 17-3/16" W 17-3/4"
BOTTOM BAFFLE	L 14" W 16"	L 34" W 19"	L 17" W 14"	L 13-1/2" W 16"	L 13-1/2" W 16"
CHAMBER REAR AIR SLOT	H 11/16" L 11-7/8"	NONE	NONE	H 3/4" L 18-1/2"	H 1-1/2" L 18"
APERTURE FOR SPRAY INLET	H 4" W 3-3/4"	4"Diam.	H 6" W 5-1/2"	7/8"Diam.	7/8"Diam.
CHAMBER VOLUME	4.5 ft. ³	25 ft. ³	6.1 ft. ³ *	4.51 ft. ³ *	4.81 ft. ³ *

*Includes the Inlet Volume

MEMORANDUM

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
CENTER FOR DISEASE CONTROL
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

TO : William F. Todd
Research Chemical Engineer
Protective Equipment Section
Control Technology Research Branch
Division of Physical Sciences and Engineering

DATE: July 26, 1978

FROM : Statistician, Statistical Services Branch,
Division of Technical Services

SUBJECT: Experimental Design for the Development of a Paint Spray Penetration Test
for Certifying Respirators

The experimental design which you requested for the paint spray respirator certification test has been completed and is given below. Its purpose is to enable us to develop a spray mist so fine it can easily penetrate potentially hazardous respirator filters. The following independent variables are to be used to minimize the particle size in the spray mist.

- 1) L = Liquid flowrate through the nozzle (973 mg/min., 1460 mg/min.).
- 2) A = Air flowrate through the spray nozzle (18 psig, 26 psig).
- 3) R = Solvent to paint ratio (37.5% volume, 43% volume).
- 4) C = Air flow through the chamber (100 cfm, 150 cfm).

The dependent variable to be observed in the experiment will be the average size of the paint particles as measured by the Anderson Impactor.

The experimental design is a 2^4 factorial which uses the limits on the range of interest given above as the high and low factor levels. The design is outlined in the attached experimental schedule which gives a random order for performing the 16 tests.

After the experiment is performed, the data will be interpreted and used to plan a series of small supplemental experiments in an effort to "hunt" for the desired spray mist by the techniques used for response surface exploration. Depending on the outcome of this first experiment, the second stage may consist of a similar experiment performed in a more optimal region of the factor space, or more work in the same region according to one of the two following plans:

- 1) replication of the 2^4 design (if greater accuracy is needed).

Page 2

- 2) addition of 9 new tests (to the 16 already performed) to form a 3-level central composite design (if second order effects are too large to make linear extrapolation feasible).

William E. Crouse
William E. Crouse

WECROUSE:pjz, Rm. 230 Taft Lab:7/26/78

cc:

K. Busch

R. Mahon

SSB#277

APPENDIX D CONT.

Experimental Schedule for the Development of a Fine Paint Spray Mist

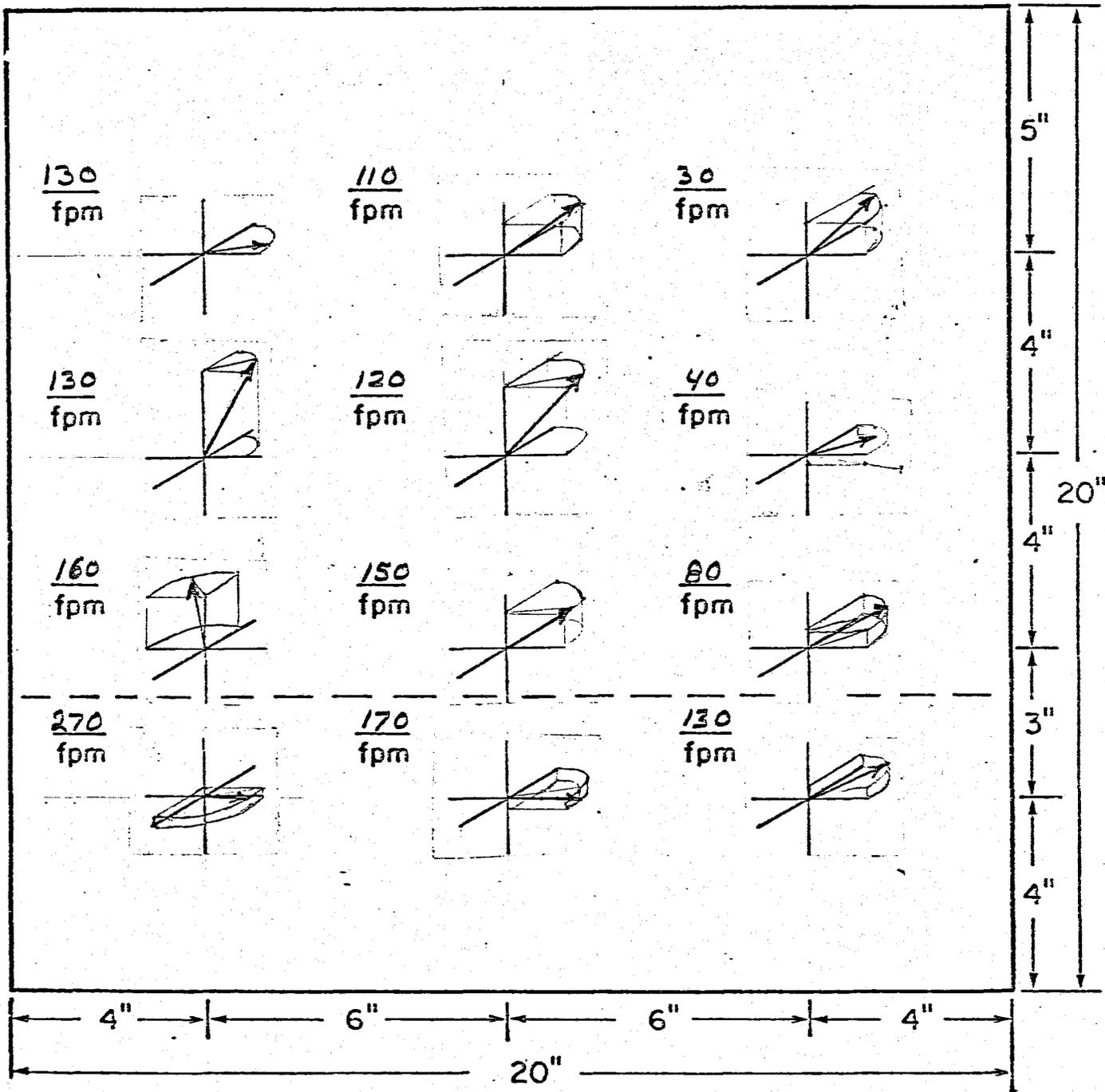
<u>Run #</u>	<u>L(mg/min)</u>	<u>Independent Variables</u>		<u>C(cfm)</u>
		<u>A(psig)</u>	<u>R(% Volume)</u>	
1	973	18	37.5	150
2	1460	26	37.5	150
3	973	26	43	150
4	973	26	37.5	100
5	1460	18	43	100
6	1460	18	37.5	100
7	973	18	37.5	100
8	1460	26	37.5	100
9	1460	26	43	150
10	973	18	43	100
11	1460	26	43	100
12	1460	18	37.5	150
13	973	26	37.5	150
14	973	18	43	150
15	1460	18	43	150
16	973	26	43	100

CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $1\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 1" DEPTH CHAMBER FLOW 75 cfm

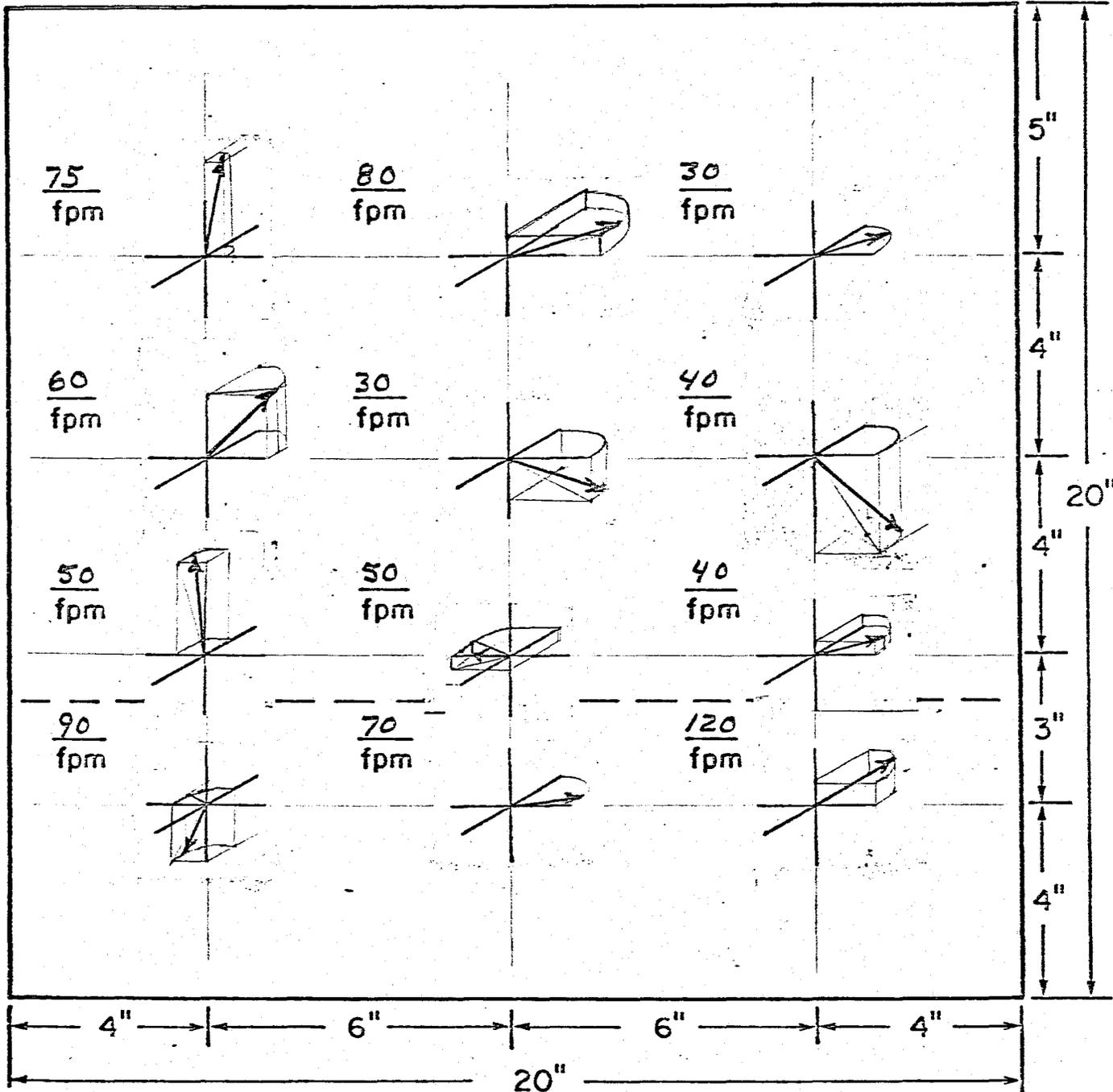


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $1\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 2" DEPTH CHAMBER FLOW 75 cfm

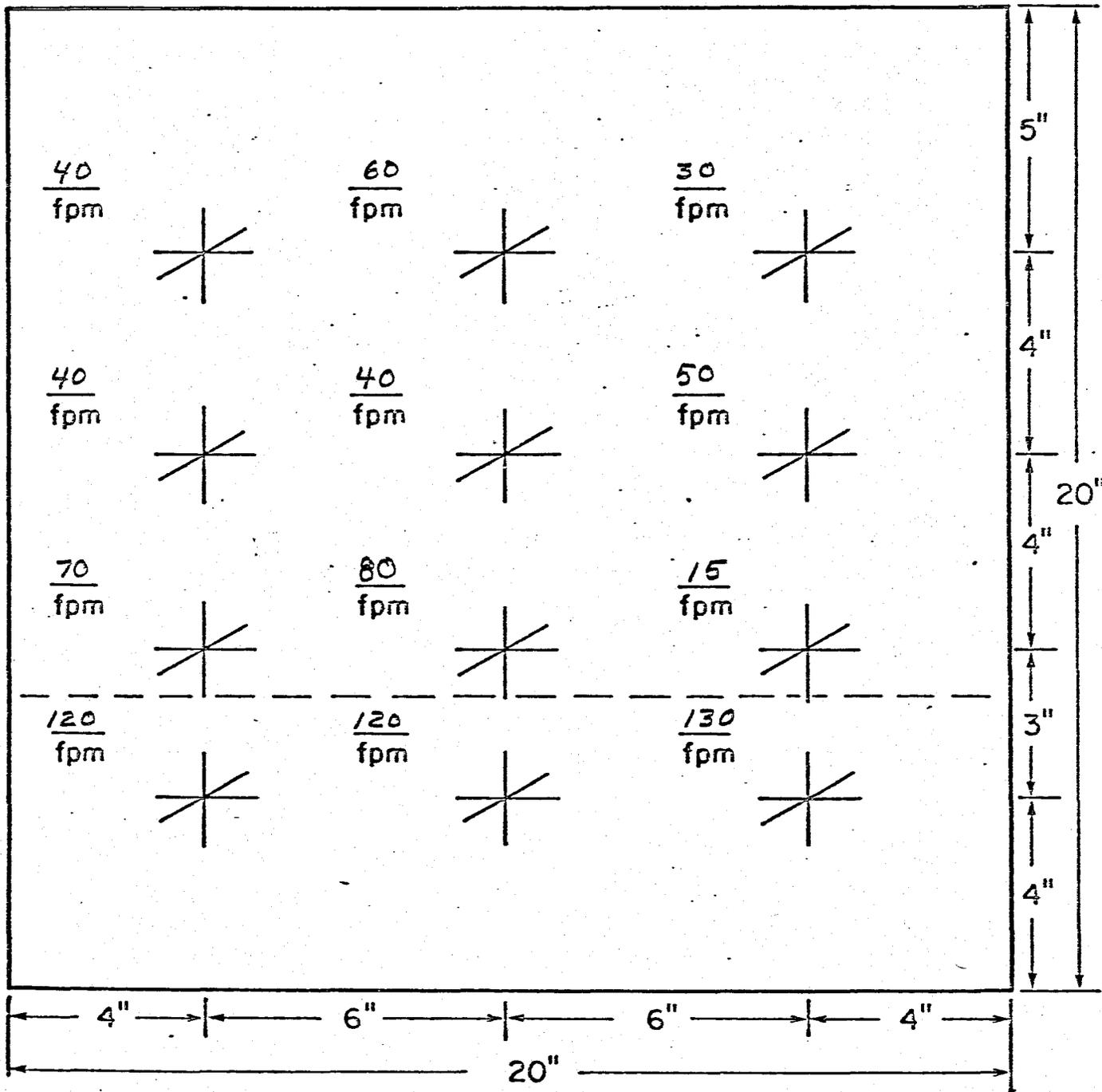


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $1\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 4" DEPTH CHAMBER FLOW 75 cfm

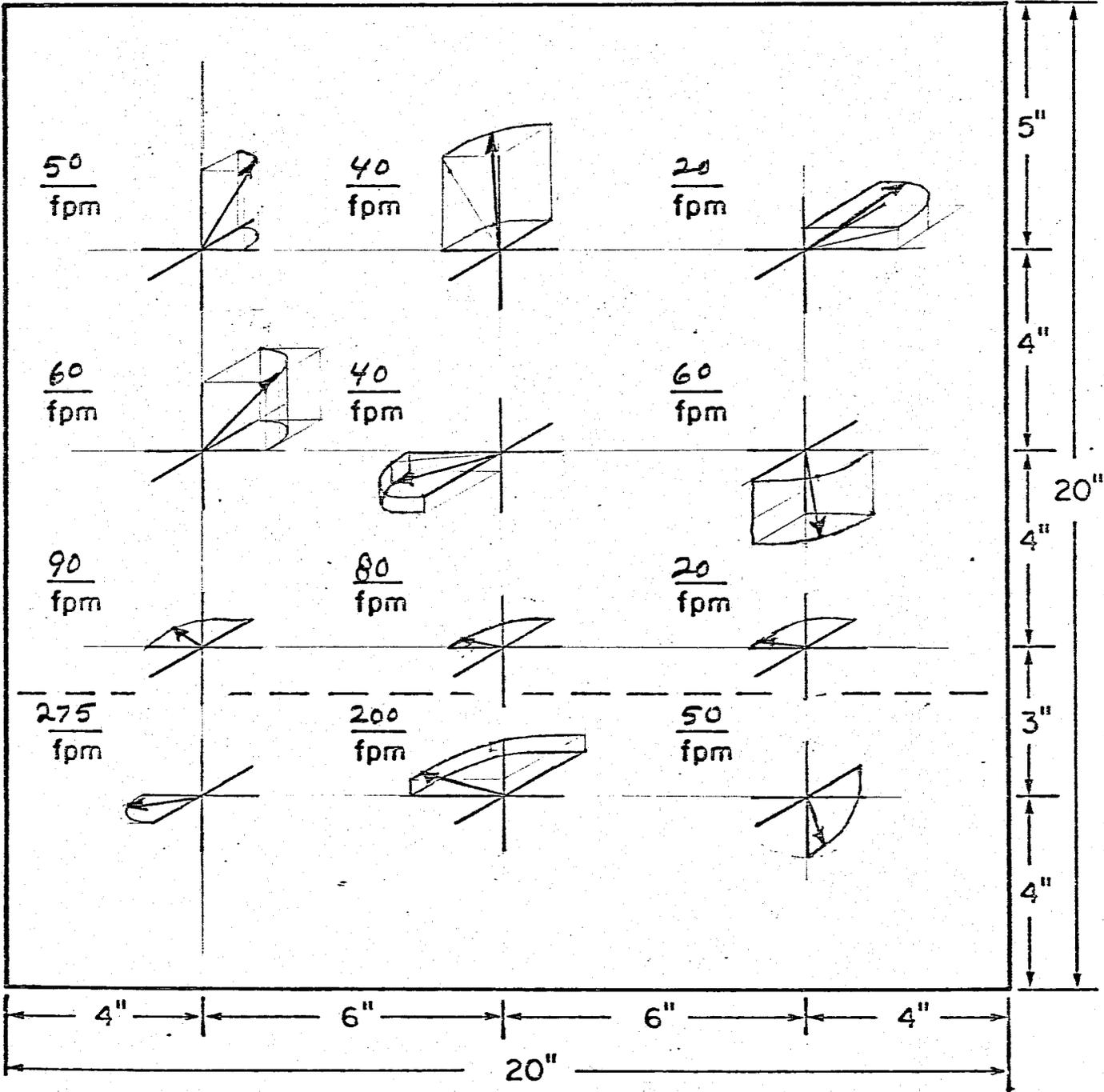


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 6" DEPTH CHAMBER FLOW 75 cfm

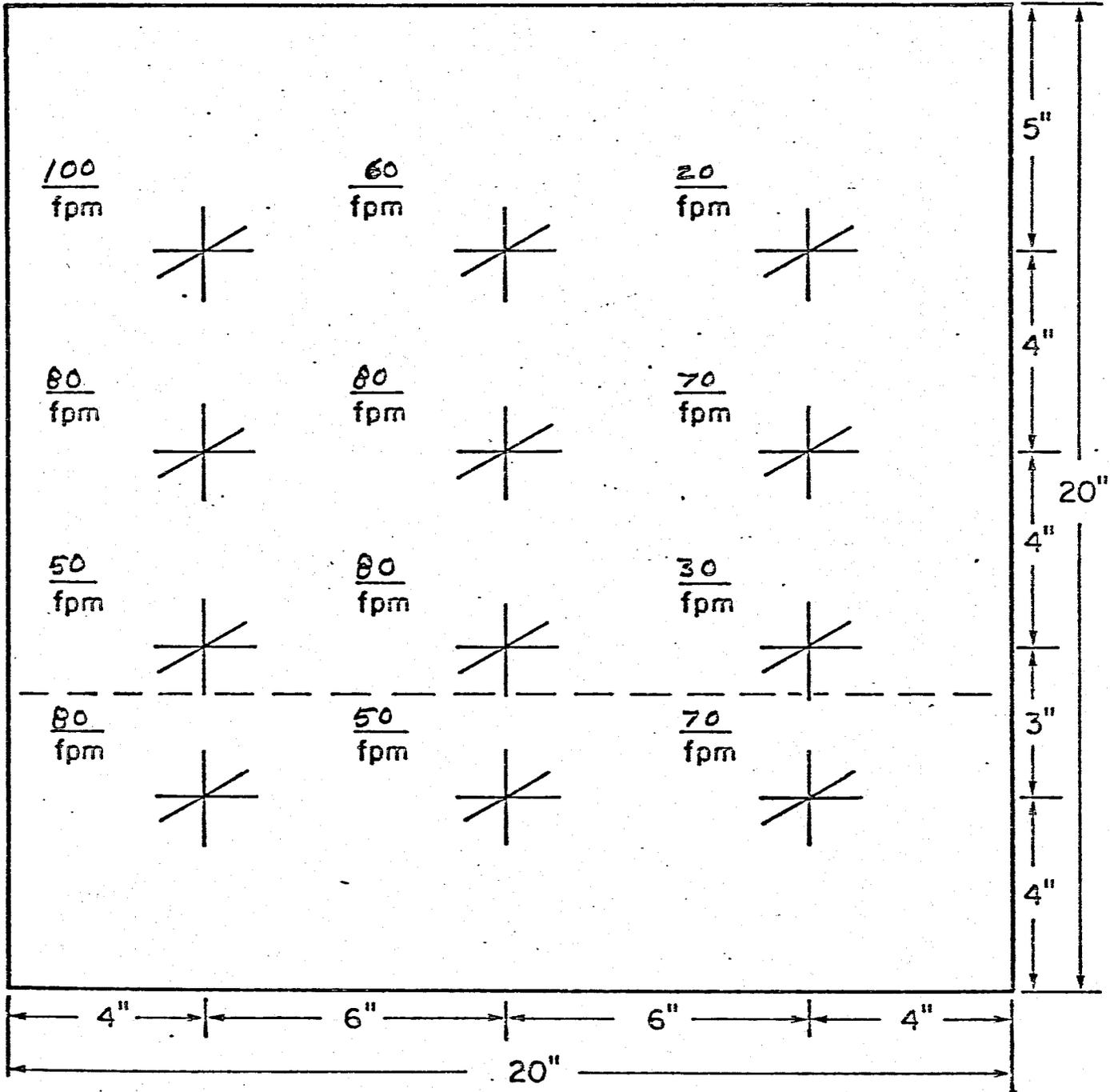


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 8 " DEPTH CHAMBER FLOW 75 cfm

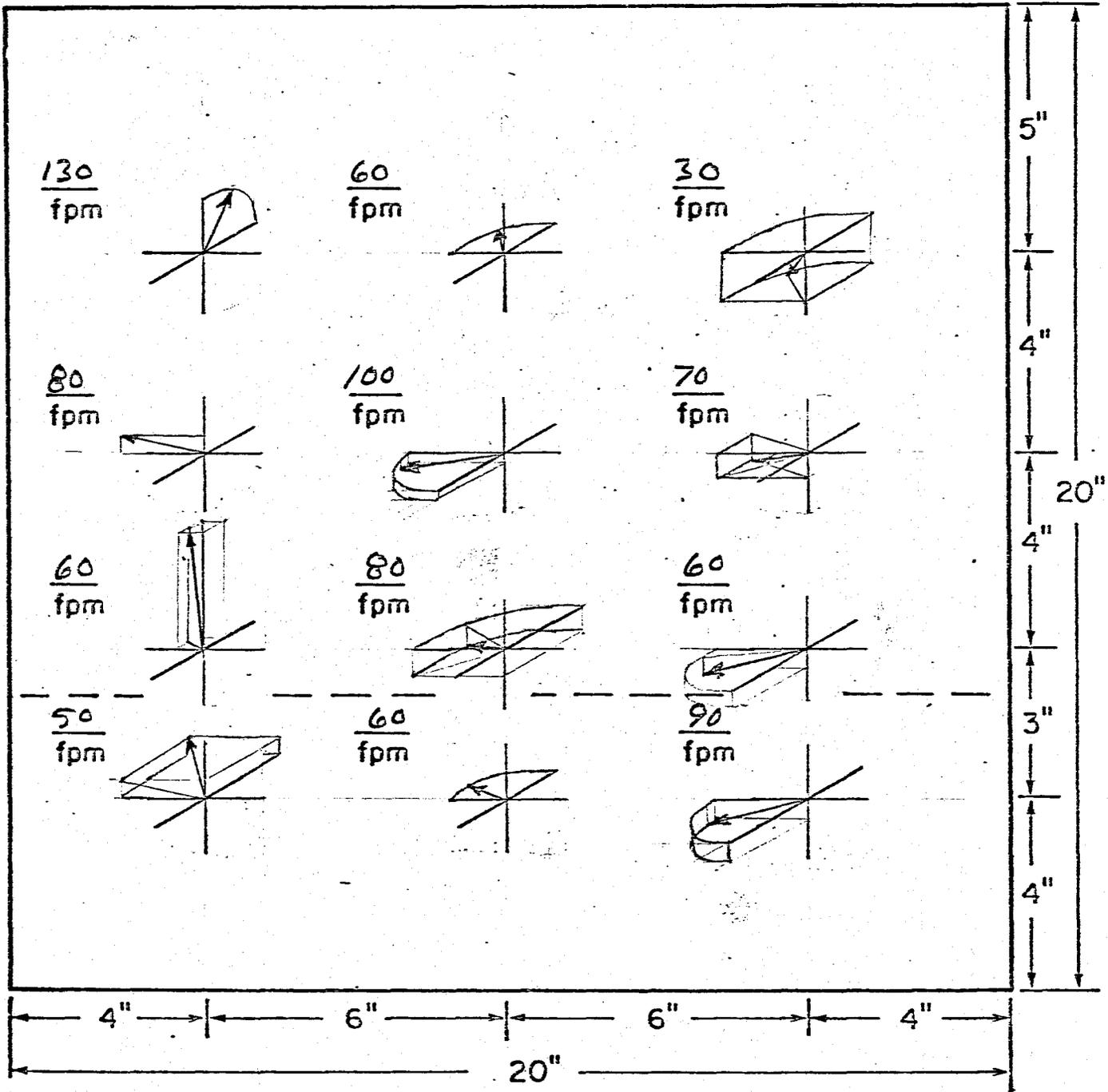


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 10" DEPTH CHAMBER FLOW 75 cfm

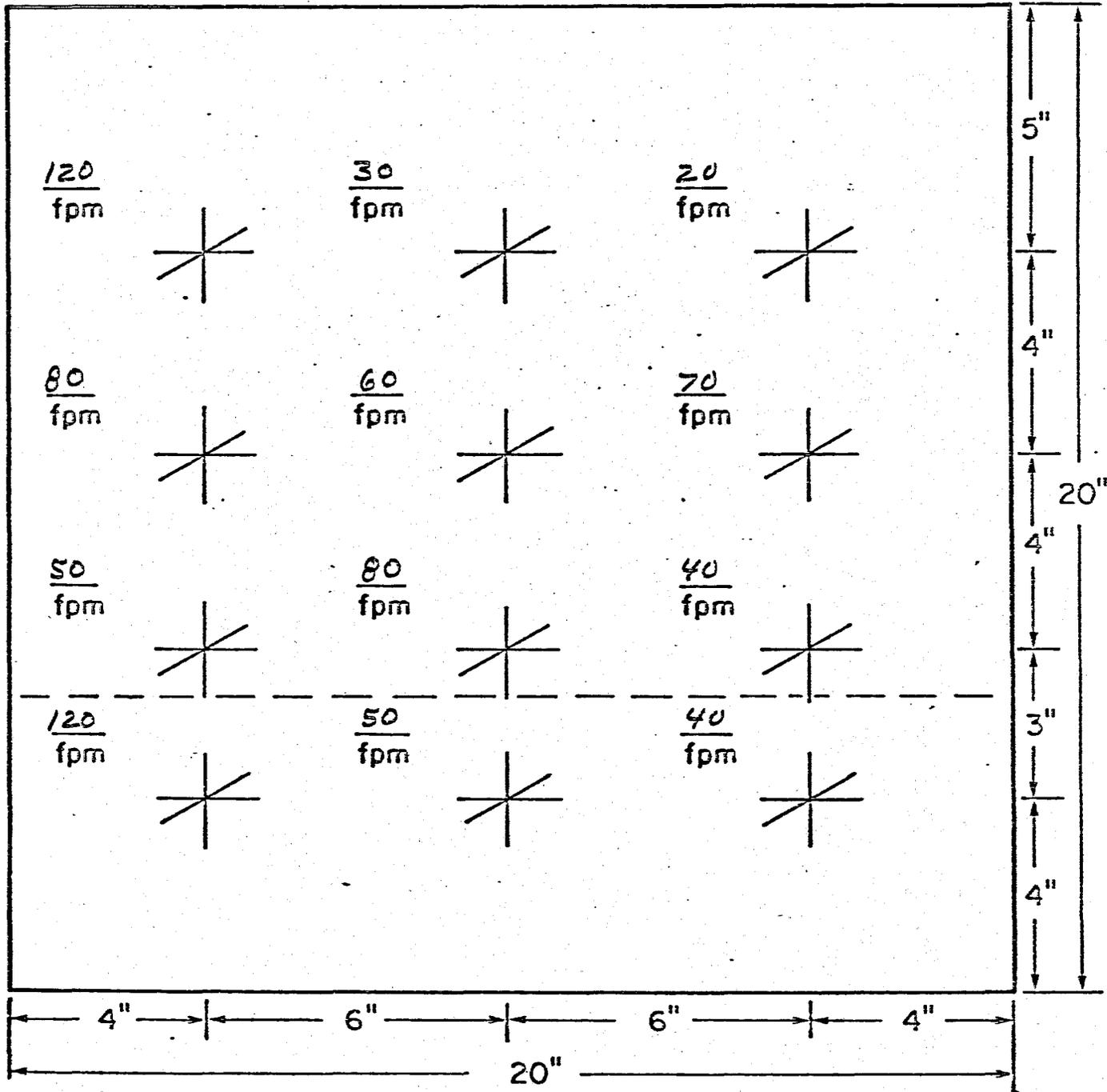


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $1\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 12" DEPTH CHAMBER FLOW 75 cfm

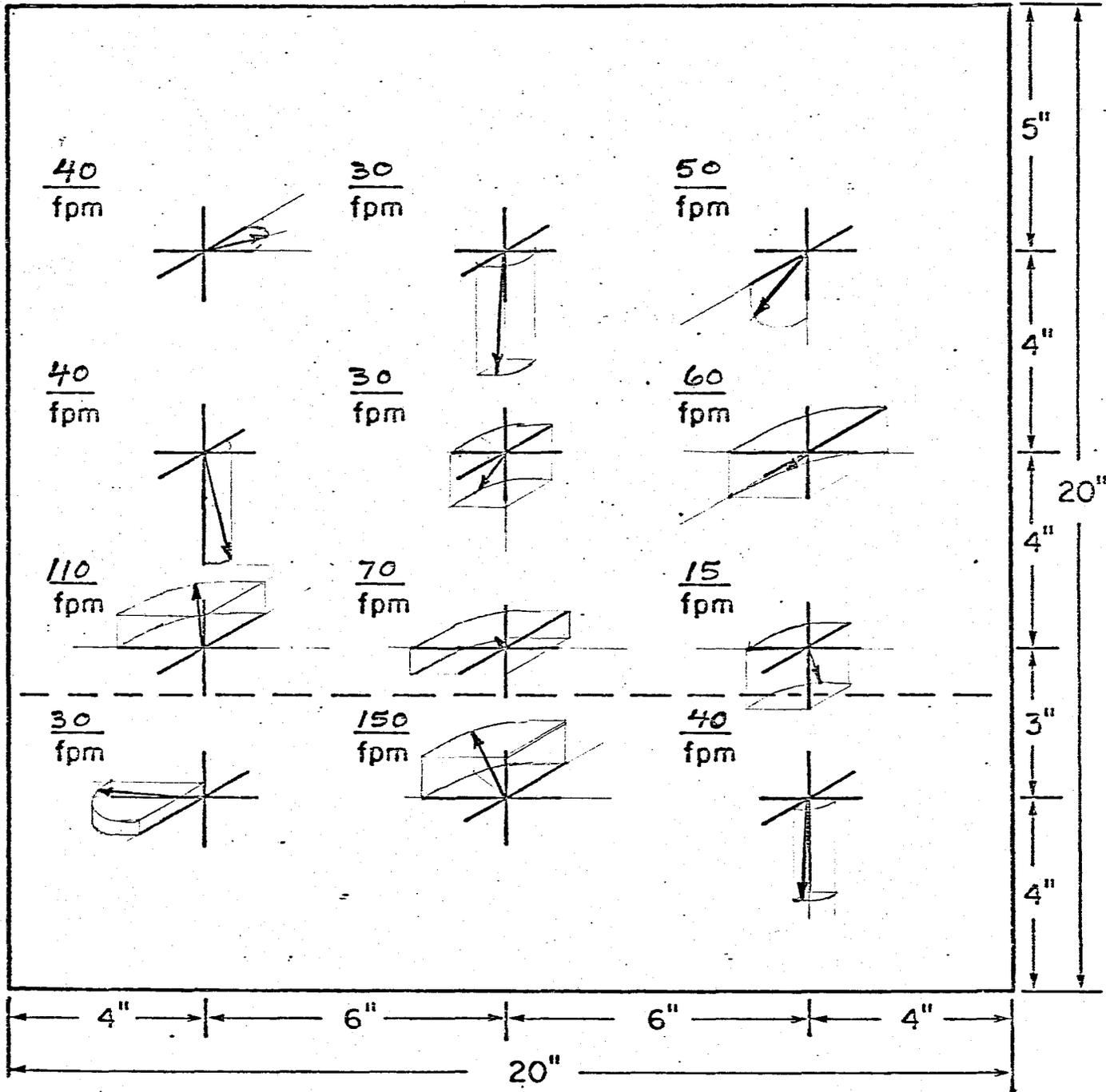


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 14" DEPTH CHAMBER FLOW 75 cfm

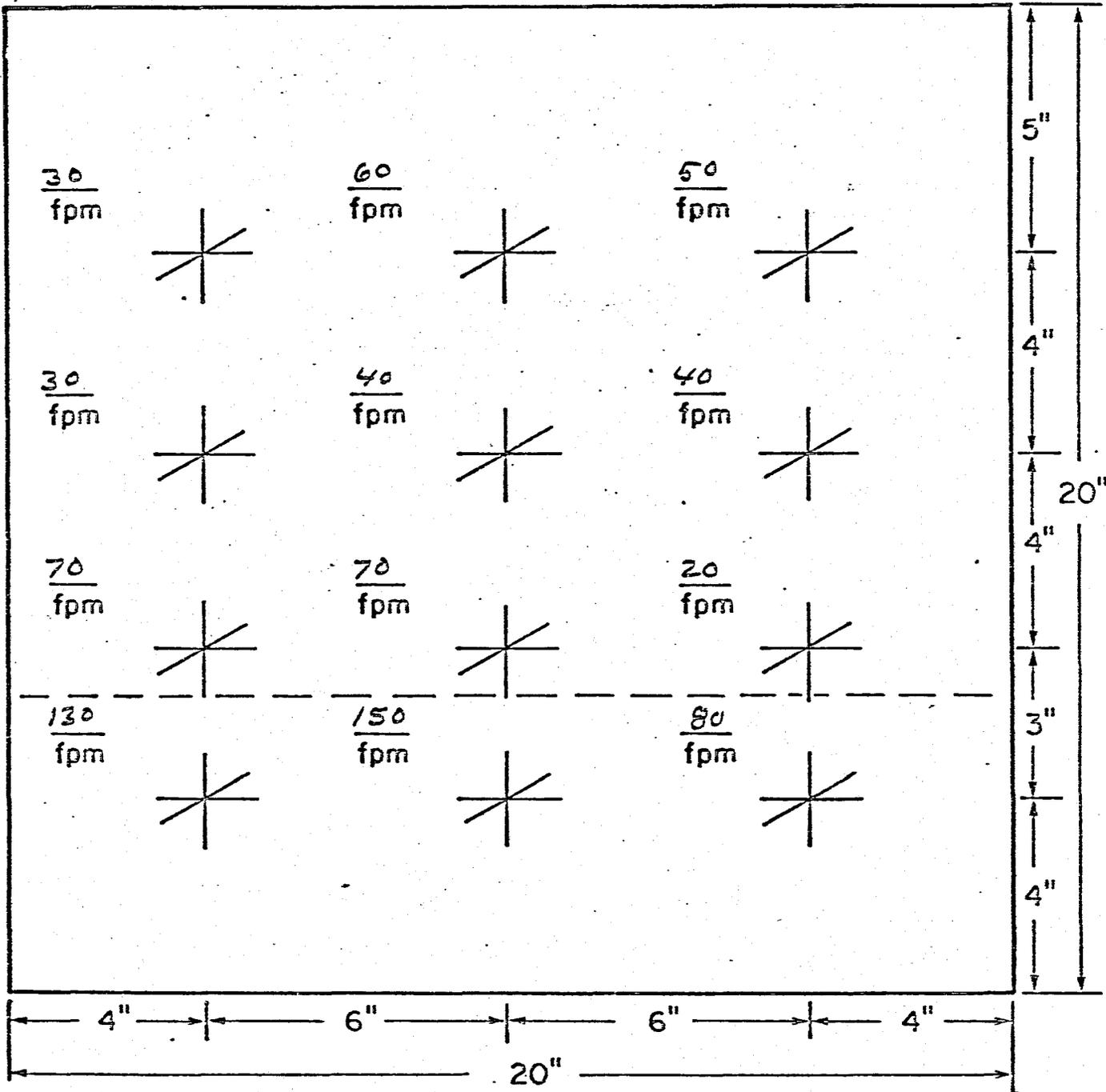


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $1\frac{1}{2}$ " X 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 16 " DEPTH CHAMBER FLOW 75 cfm

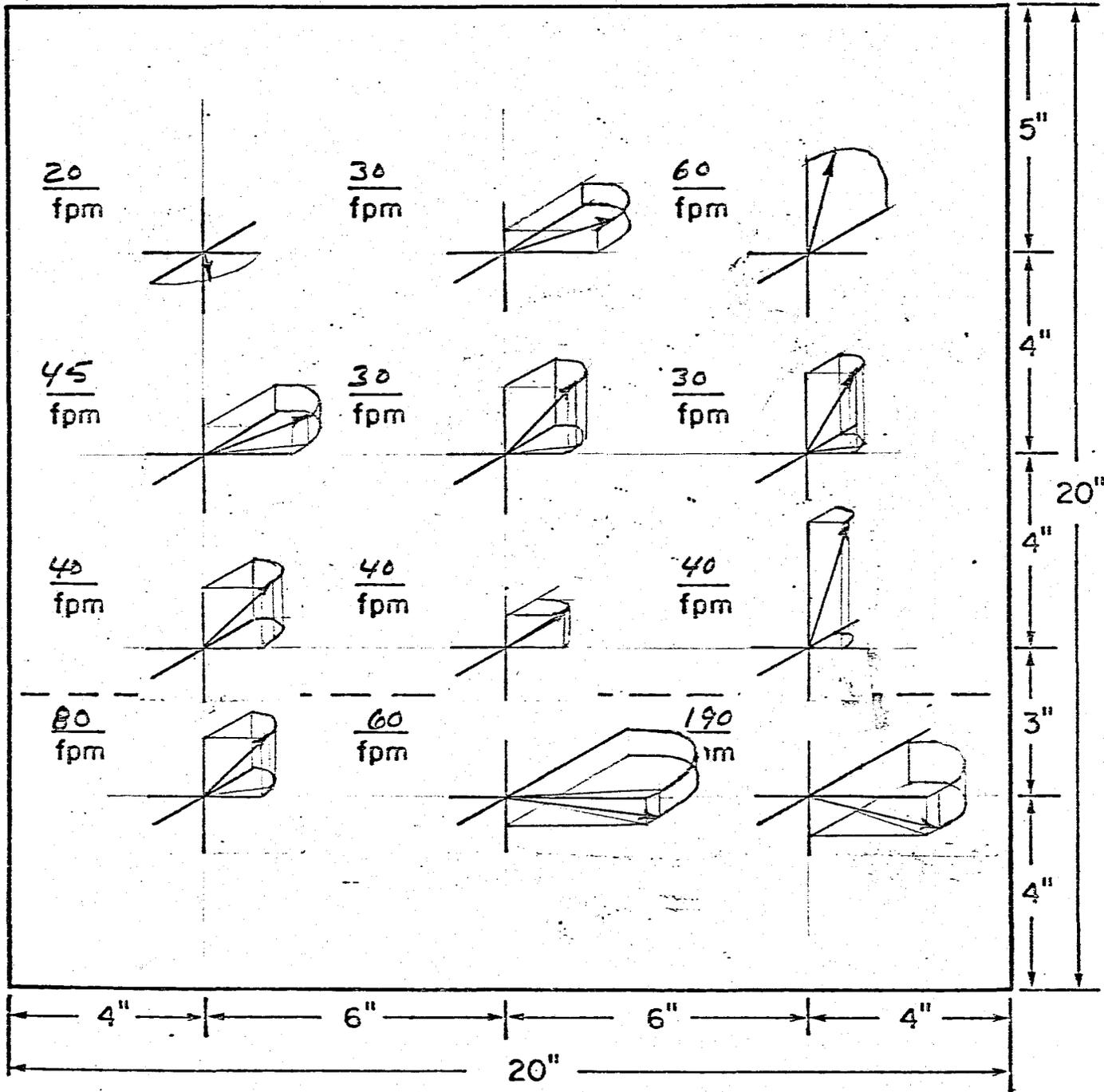


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $1\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 18" DEPTH CHAMBER FLOW 75 cfm

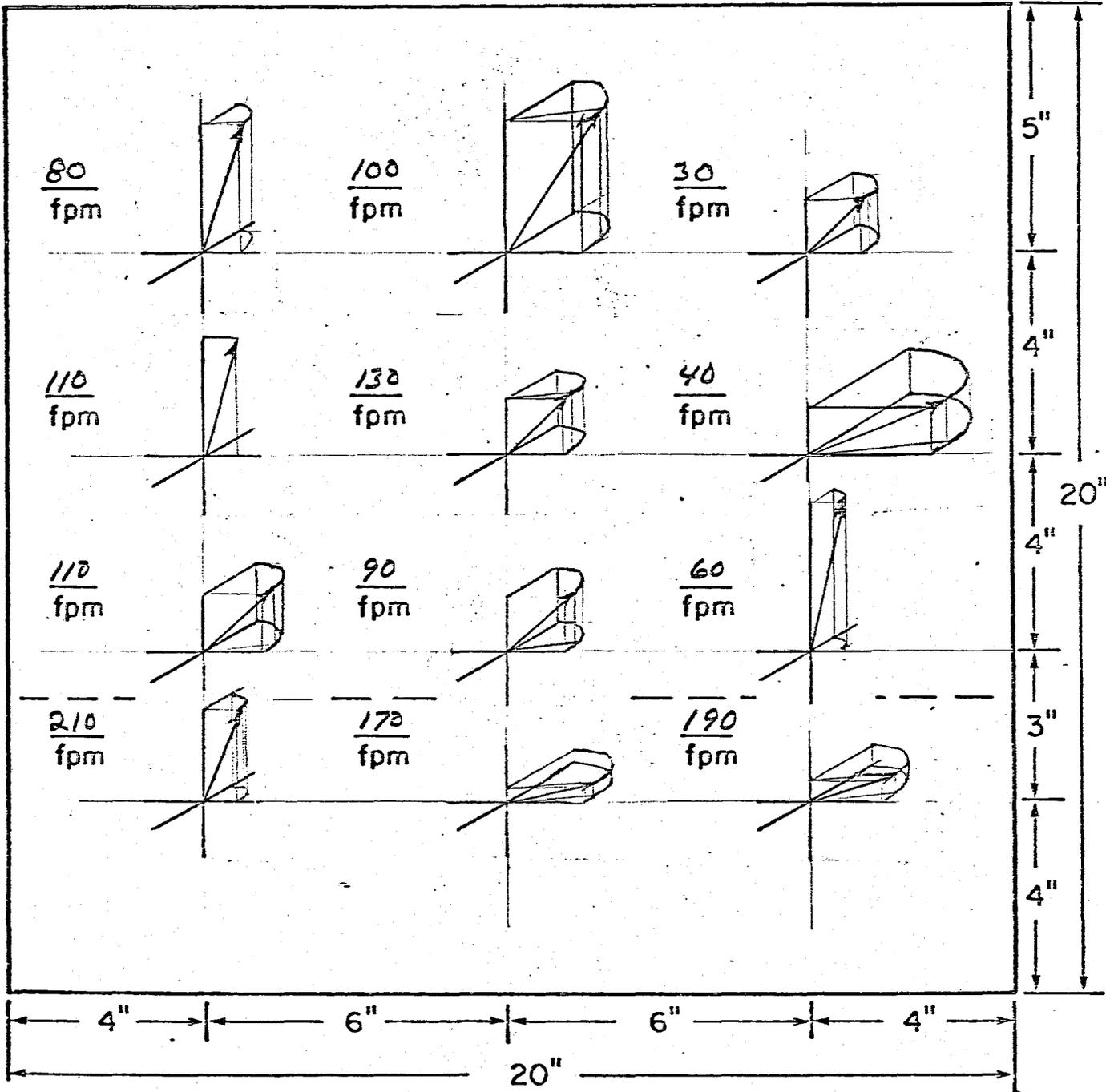


CHAMBER FLOW DIAGRAM

CONFIGURATION SLOT SIZE $1\frac{1}{2}$ " x 18"

ANGLE OF FLOOR VANES TO SLOT 60°

CHAMBER SECTION 12 " DEPTH CHAMBER FLOW 75 cfm



MEMORANDUM

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
 PUBLIC HEALTH SERVICE
 CENTER FOR DISEASE CONTROL
 NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

TO : William Todd
 Protective Equipment Section, CTRB, DPSE

DATE: November 20, 1979

FROM : Statistician, Statistical Services Branch, DTS

SUBJECT: Statistical Analysis of Respirator Paint Spray Penetration Data

The data which you observed using the experimental design I recommended in my memorandum dated July 26, 1978, has been analyzed statistically. Attached is an Analysis of Variance (ANOVA) summarizing the results. The response was the average of the common logs of the observations from the two ports. Note that the three-way interactions were assumed to be error.

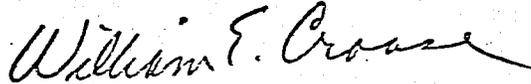
As you can see, there were no significant effects in the ANOVA. This means that the data indicates no correlation between the variables of interest and the concentration of the paint on the filters. Also, there was no evidence of a correlation between the paint concentration in the chamber and the paint on the filters. The CV, estimated from the mean square error, was 97% with a 95% confidence interval of 46% to 608%. This means that the reason there were no significant results may be because the variance was too high. Thus, replicating the experiment would increase the power of the tests and increase the chances of uncovering true effects.

Since the results are contrary to what we expected, I did some exploratory analyses to include:

- 1) An analysis not assuming the three-way interactions were non-existent.
- 2) Two analyses using each of the observations at the ports as a response instead of the average.
- 3) An analysis ignoring the chamber concentration. (This was done in case it was correlated with the levels of the other variables.)
- 4) An analysis with just the chamber concentration considered as an independent variable.
- 5) An analysis assuming all the interactions were non-existent.
- 6) A multivariate analysis of the data using the two ports as the independent variables.

None in these exploratory analyses are presented because nothing was significant and there is no benefit in including it in addition to Table 1.

Please contact me if further experimentation is to be done. Possibly an experiment in another area of the response surface may also be beneficial.



William E. Crouse

WECROUSE/rlc:Room230/Taft:11/20/79

Analysis of Covariance For the Log (Base 10) of Filter Paint Penetration

Concentrations (mgFe₂O₃)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F-VALUE	PH > F
T	1	0.0559	0.0559	0.6500	0.4655
F	1	0.0132	0.0132	0.1500	0.7150
P	1	0.0351	0.0351	0.4100	0.5580
C	1	0.0353	0.0353	0.4100	0.5569
A	1	0.0288	0.0288	0.3300	0.5942
F*P	1	0.0004	0.0004	0.0000	0.9511
F*C	1	0.1704	0.1704	1.9800	0.2322
F*A	1	0.0021	0.0021	0.0200	0.8839
P*C	1	0.0101	0.0101	0.1200	0.7498
P*A	1	0.0260	0.0260	0.3000	0.6122
C*A	1	0.0284	0.0284	0.3300	0.5962
ERROR	4	0.3443	0.0861		

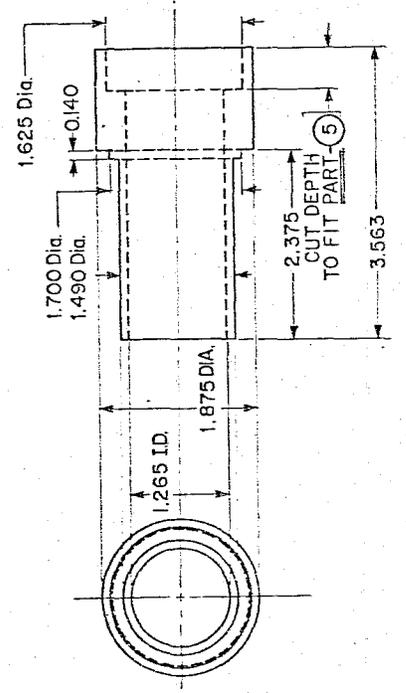
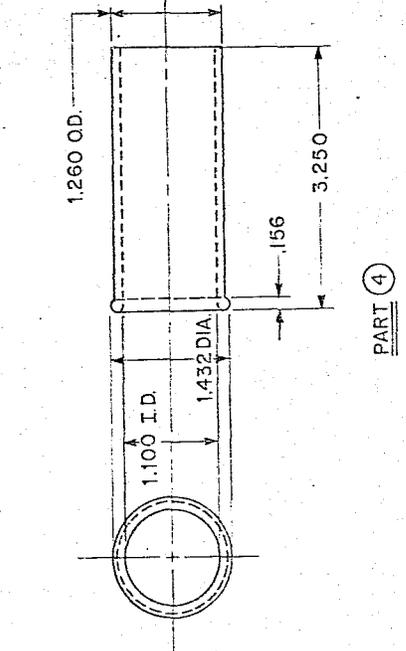
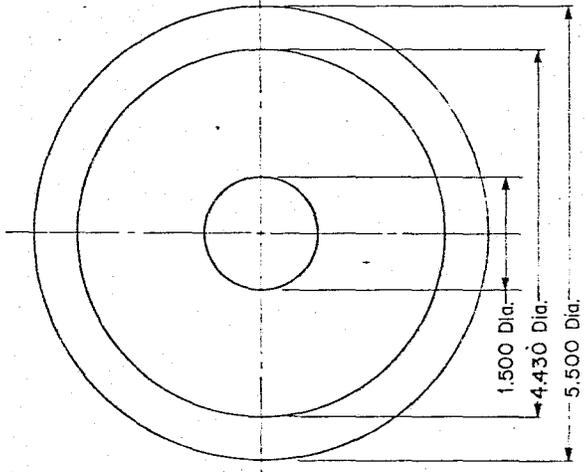
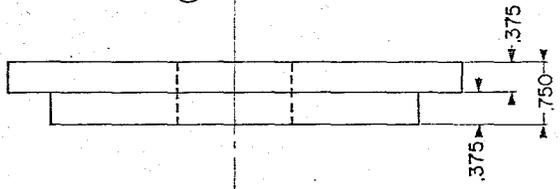
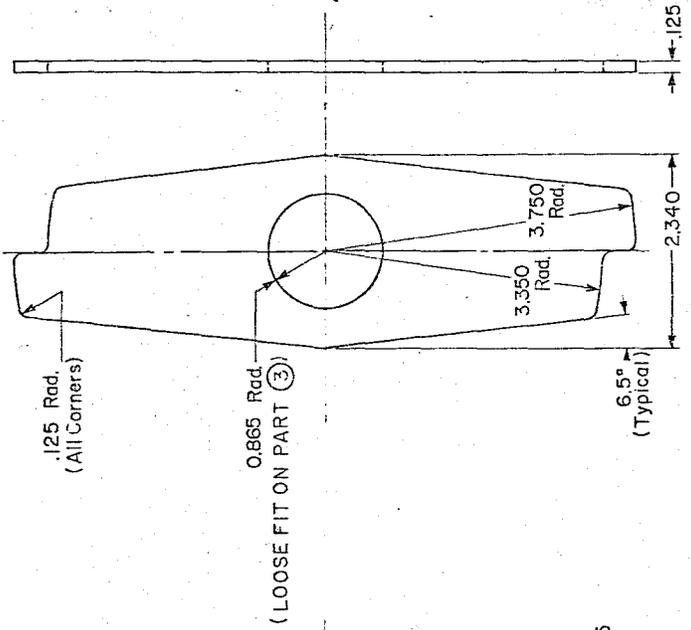
Notation: L - Liquid flowrate through the nozzle

A - Nozzle Air Pressure

R - Solvent to paint ratio

C - Air flow through the chamber

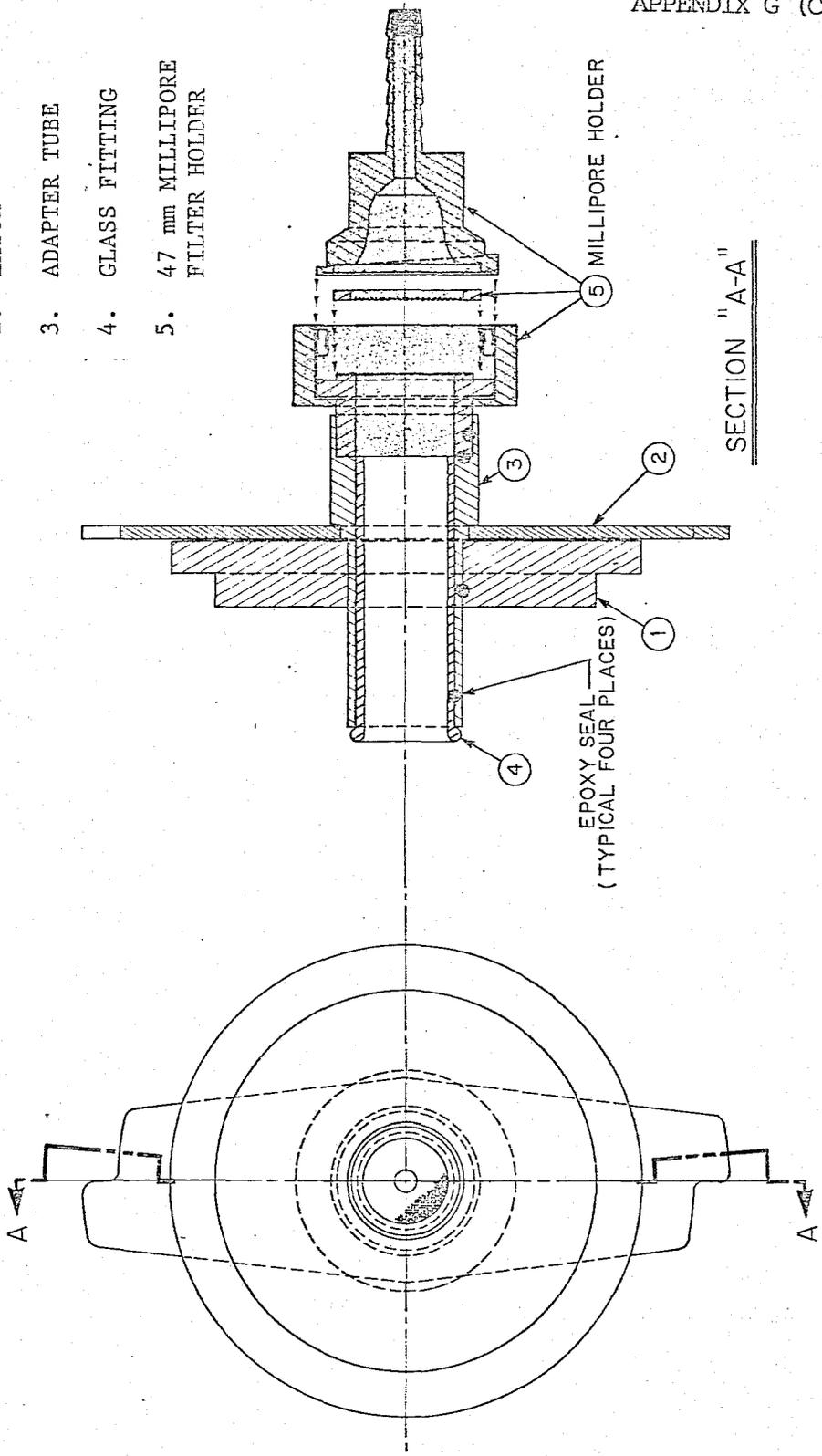
T - log 10 of Chamber Concentration mgFe₂O₃



47 mm FILTER HOLDER (DETAILS OF FABRICATED PARTS)

LEGEND

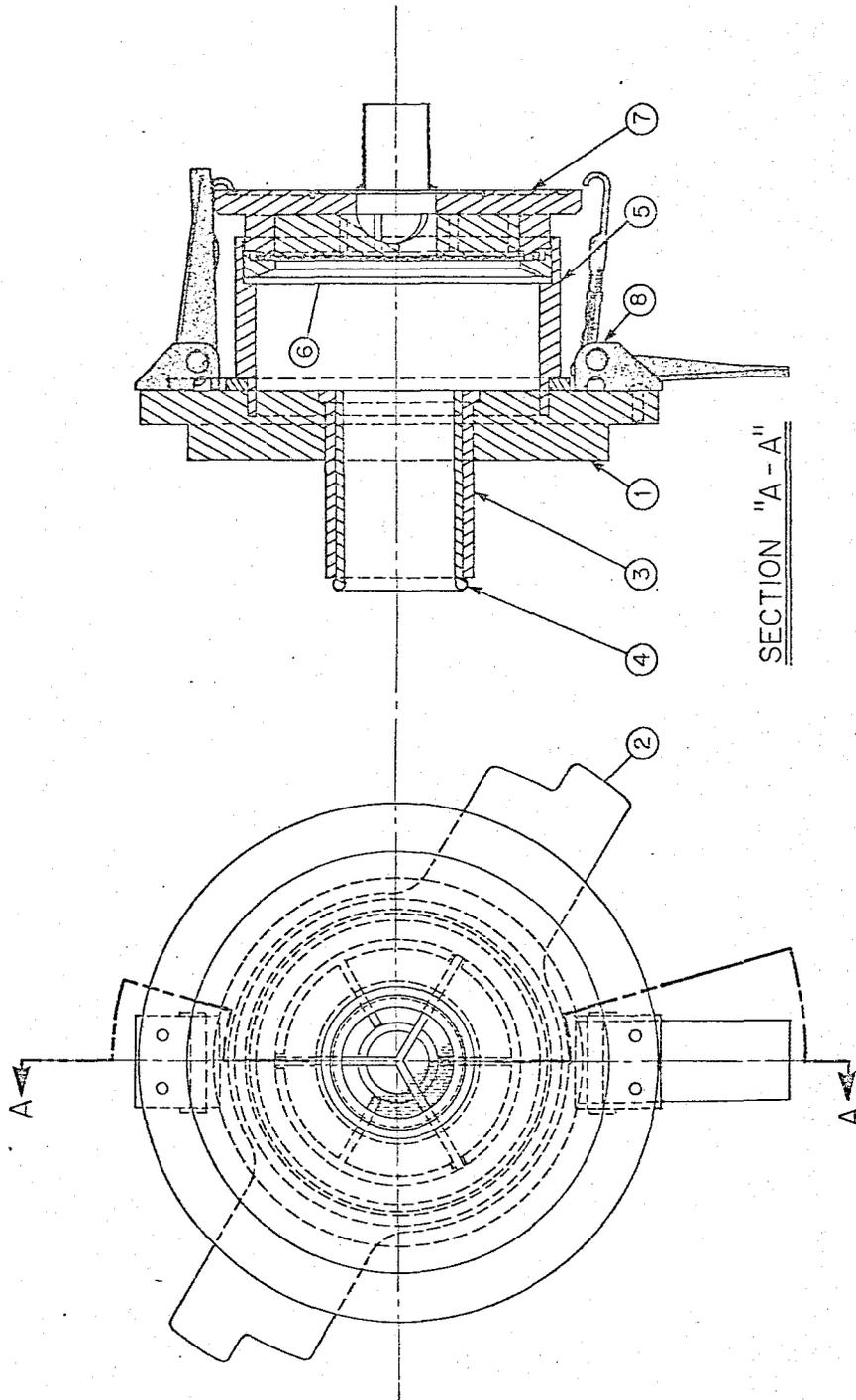
- 1. ALUMINUM PLATE
- 2. LATCH
- 3. ADAPTER TUBE
- 4. GLASS FITTING
- 5. 47 mm MILLIPORE FILTER HOLDER



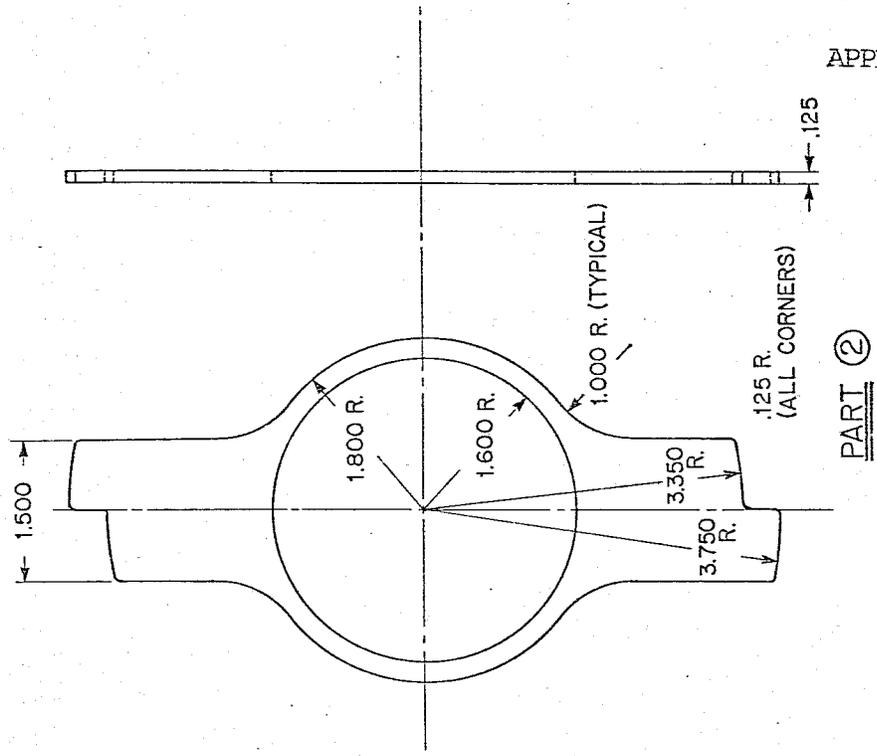
EPOXY SEAL
(TYPICAL FOUR PLACES)

SECTION "A-A"

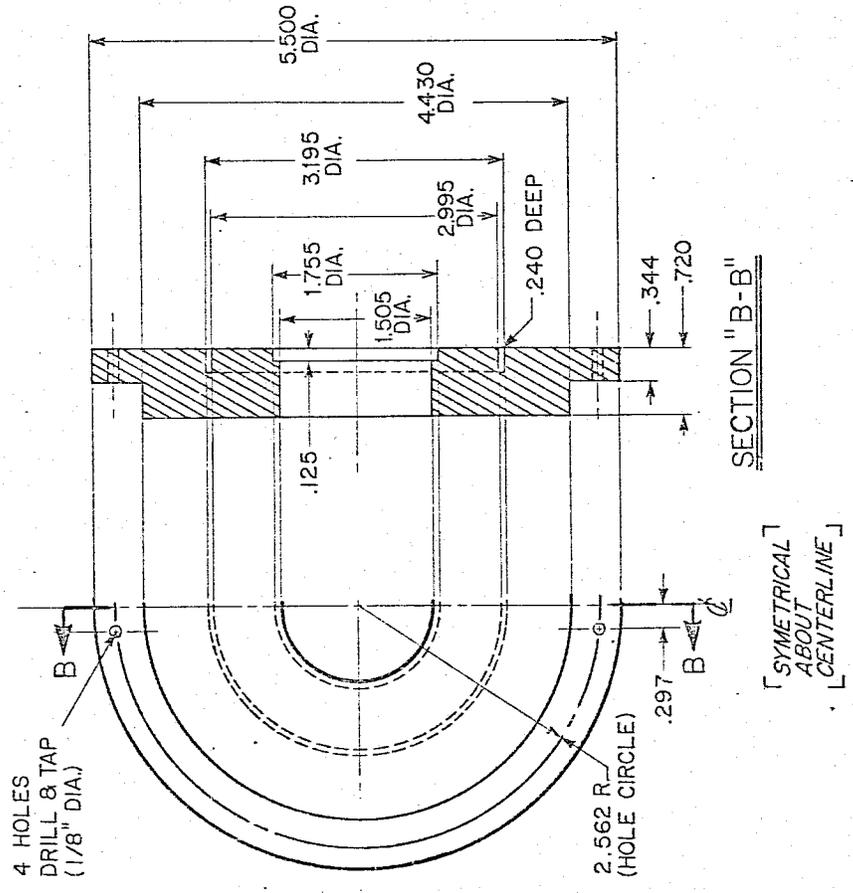
47 mm FILTER HOLDER ASSEMBLY DRAWING



75 mm FILTER HOLDER ASSEMBLY

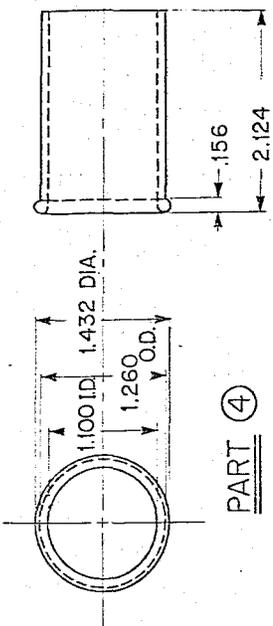


PART ②

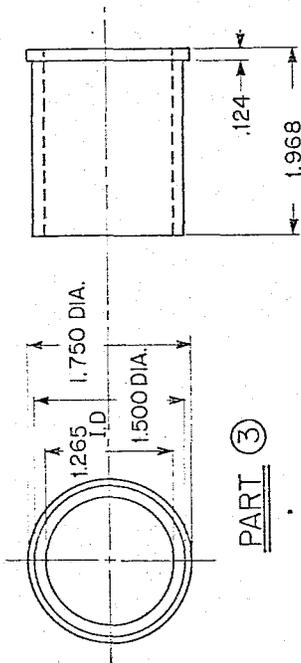


PART ①

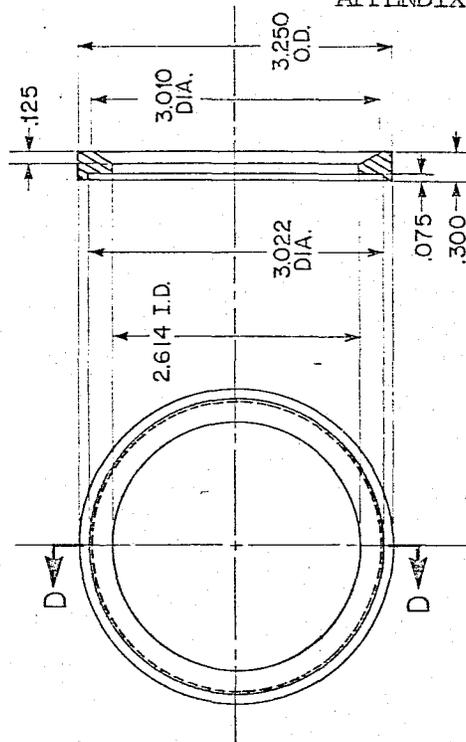
75 mm FILTER HOLDER-DETAIL OF PARTS 1 & 2



PART ④

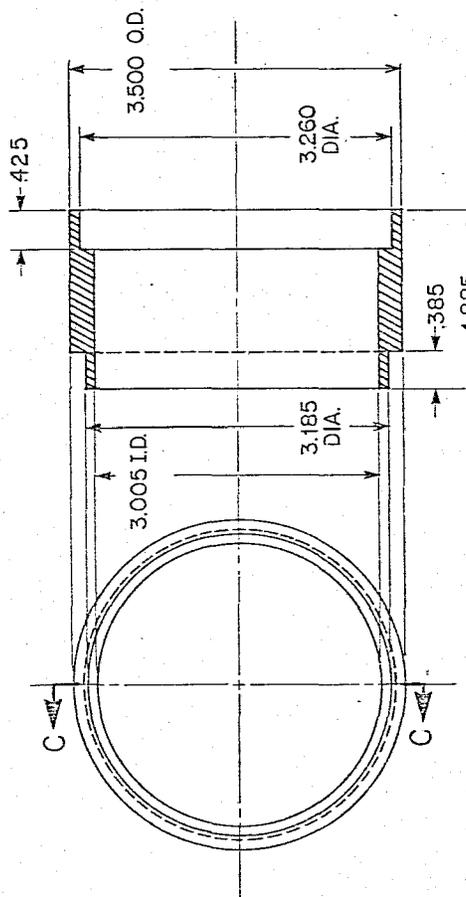


PART ③



SECTION "D-D"

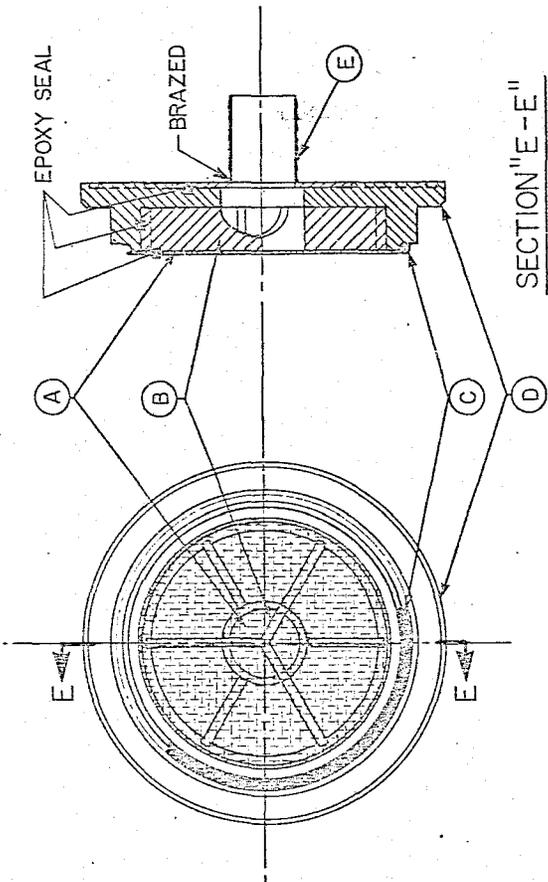
PART ⑥



SECTION "C-C"

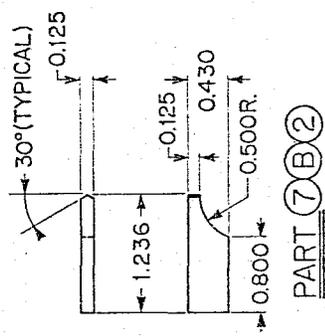
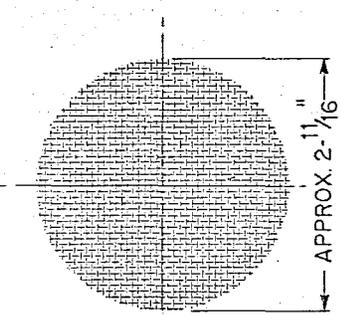
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75 mm FILTER HOLDER-DETAIL OF PARTS 3 THROUGH 6



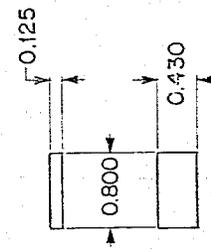
SUB-ASSEMBLY (PART 7)

PART 7 (A)

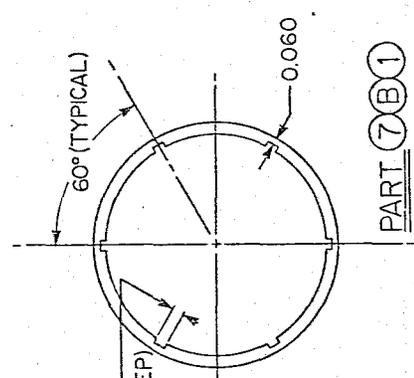


PART 7 (B) 2

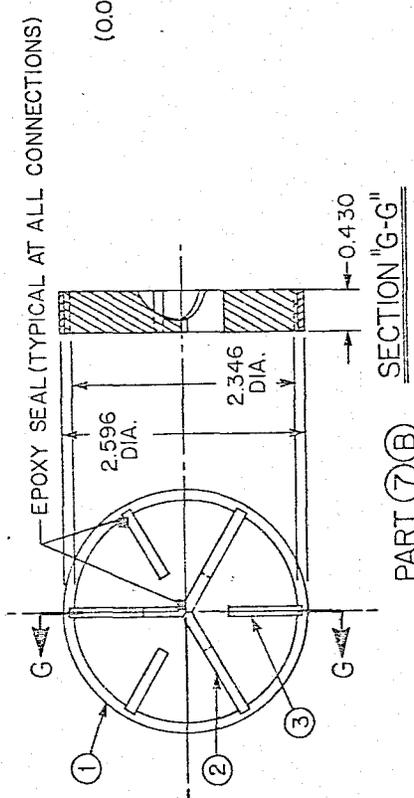
APPENDIX G (CONTINUED)



PART 7 (B) 3



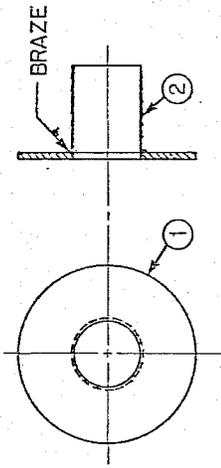
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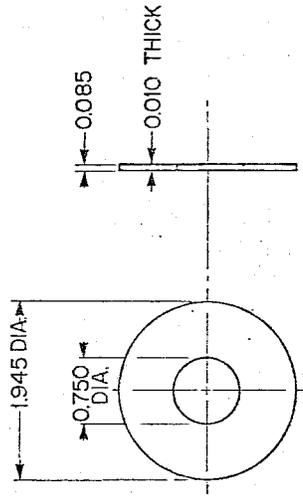
PART 7 (B)

SECTION "G-G"

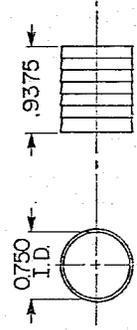
75 mm FILTER HOLDER-SUBASSEMBLY PART 7 AND DETAILS



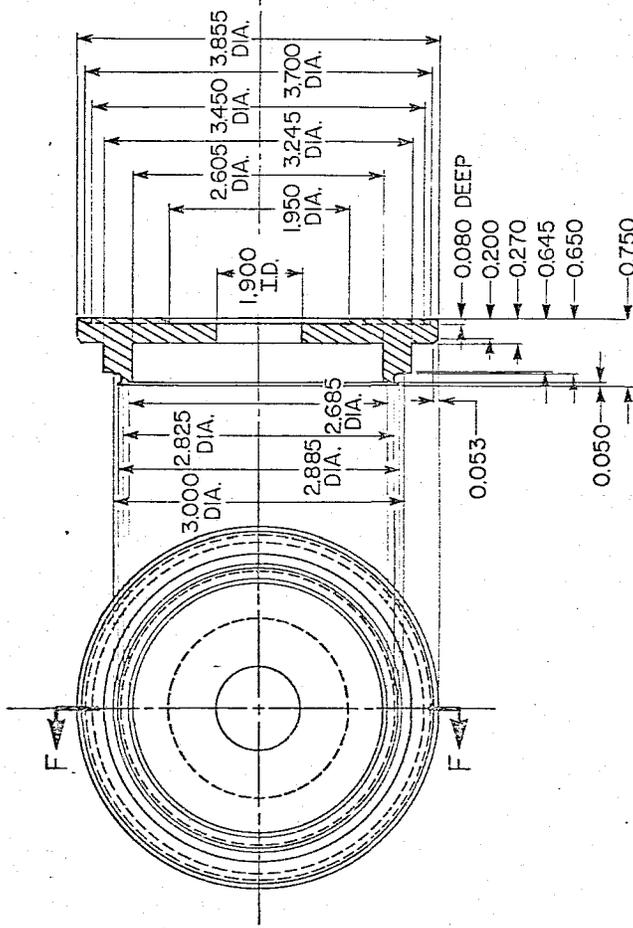
PART 7E



PART 7E1



PART 7E2



SECTION "F-F"

PART 7D

75 mm FILTER HOLDER-SUBASSEMBLY PART 7 AND DETAILS

APPENDIX H

PAINT SPRAY TESTS FOR RESPIRATORS:
AEROSOL CHARACTERISTICS

MARK W. ACKLEY

For Presentation at

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I. INTRODUCTION

Respirators have been utilized in paint spray applications for many years. Tests were designed to measure filter performance in aerosols of paints as early as 1928 (1). NIOSH certification of paint spray respirators is currently governed by Title 30 of the Code of Federal Regulations, Part 11 (2). Tests for Permissibility include a solvent vapor test for chemical cartridges, and lacquer and enamel tests for filters. The criteria for these procedures are outlined in the federal document. The aerosol tests are the topic of this paper.

Repeatability of the test conditions is essential to any standardized test procedure. All major parameters of the test conditions must be clearly defined. Particle-size distribution and concentration are important aerosol properties. Non-uniform test conditions can arise in the present method, causing inconsistent filter performance.

A technique has been developed for controlling concentration reliably. Factors causing concentration gradients in the test environment have been defined, as well as methods for minimizing such gradients. Both lacquer and enamel particle-size distributions have been measured.

II. PAINT SPRAY TESTS - METHOD AND APPARATUS

A schematic of the apparatus used to perform paint spray tests is shown in Figure 1. Liquid paint and compressed

air are introduced into an atomizing nozzle. A spray of droplets is generated by the nozzle and is diluted by incoming ambient air. The aerosol mixture is drawn through the test chamber by a centrifugal blower.

Respirator test units are mounted inside the chamber. The test procedure requires an airflow of 32 lpm through each respirator for a duration of 156 minutes. Any particulate penetrating the respirator is collected on an absolute filter. Respirator penetration is then determined gravimetrically. Measurements of the filter pressure drop at the beginning and at the end of the test characterize the aerosol loading resistance of the filter.

The key component in the system is the atomizing nozzle. The nozzle and spray cone are illustrated in Figure 2. Liquid issues from the circular orifice along the nozzle center line where expanding air immediately impinges upon the liquid stream. Droplets form as a result of the shearing action of the air-jet upon the liquid film. The specific surface area of the liquid increases by as much as one thousand times in the liquid break-up process (3). The droplets begin to evaporate as soon as they are formed. The diameter of the droplets decreases during evaporation--causing a time-variant, or unstable particle-size distribution. A solid aerosol, composed of particles of the dissolved solid fraction of the paint, remains at the end of droplet evaporation.

Spray nozzles of this type generate droplets typically in the range of 20 μm to 100 μm in diameter (4). The mean droplet size (d_m) can be functionally described by the relation of Nukiyama and Tanasawa (4) given in Equation 1.

$$d_m = f [U, \sigma, \rho_L, \mu, Q_R] \quad (1)$$

where d_m = surface-volume mean diameter
 U = liquid velocity relative to air velocity
 σ = surface tension of liquid
 ρ_L = density of liquid
 μ = viscosity of liquid
 Q_R = $\frac{\text{Vol. airflow}}{\text{Vol. liquid flow}}$

The droplet size is dependent upon the surface tension, density and viscosity of the liquid, as well as the nozzle flow conditions.

Initial droplet size directly affects droplet evaporation rate. The life-time of a droplet is a complex function of several parameters as illustrated in Equation 2 (4):

$$t = f [D_p, P_1, P, M, T, D_1, \delta, \alpha, \Delta] \quad (2)$$

where t = droplet lifetime
 M_1 = mol. wt. of liquid vapor
 D_1 = diffusivity of the liquid vapor through the gas
 T = temperature
 δ = degree of saturation
 P_1 = liquid vapor pressure
 P = droplet vapor pressure
 α = evaporation coefficient
 Δ = mean free path of the molecules
 D_p = droplet diameter

Equations 1 and 2 are useful in developing a physical concept of the atomization process. When evaporation is completed, the aerosol is composed entirely of solid particles, and the particle-size distribution is steady. Coagulation, neglected in this study, can contribute additionally to unsteady aerosol behaviour.

Steady or quasi-steady particle-size distributions are the most desirable aerosol conditions for reliable filter testing. Steady aerosol conditions exist after droplet evaporation, as described above. Quasi-steady conditions could be achieved with an aerosol of liquid droplets if the solvent in the paint has a very low vapor pressure, i.e. such that the time-rate-of-change of droplet size due to solvent evaporation is very small. In either case, it is necessary to maintain constant spray-nozzle conditions.

III. CONTROL OF LIQUID FLOW AND DILUENT AIRFLOW

It has been shown that the aerosol properties are determined by the atomization process. Atomization is a function of the liquid properties and nozzle flow conditions. Once the nozzle hardware and paint have been chosen, the aerosol concentration and particle-size distribution are primarily dependent upon the flow rates of the liquid paint, nozzle

air, and diluent air. Control of the nozzle-air rate of flow can be easily accomplished by the proper choice of regulator and pressure gauge.

III. a. Liquid flow

A schematic of the liquid feed system designed for paint spray tests is illustrated in Figure 3. The primary advantage of this method is that the liquid supply has been de-coupled from the nozzle. The liquid drips freely into the nozzle inlet, independent of the nozzle conditions. As a result, the liquid flow rate can be calibrated and easily controlled at a constant rate. The liquid flow in this system follows the Hagen-Poiseuille principle-commonly known as laminar or capillary flow (5). The Hagen-Poiseuille relation is given by Equation 3:

$$Q = \frac{\pi(P-P_0)R^4}{8\mu L} \quad (3)$$

$P-P_0$ is the pressure drop across the tube, and can be described by the hydrostatic law given in Equation 4:

$$P-P_0 = \rho_L g(z-z_0) \quad (4)$$

where

- R = internal radius of feed tube
- μ = liquid viscosity
- ρ_L = liquid density
- L = tube length
- g = gravitational constant
- $z-z_0$ = liquid head (inches of liquid)

Separate tubes of prescribed internal diameter and length were chosen for lacquer and enamel. Measurement of $(z-z_0)$ is illustrated in Figure 3. Liquid flow rate is linearly proportional to $(z-z_0)$. The flow characteristics are shown in Figure 4. Constant liquid flow is achieved in a test by maintaining $(z-z_0)$ constant. The lab-jack, on which the liquid reservoir is placed, is utilized for this purpose.

III. b. Diluent airflow

The rates of diluent airflow and liquid flow determine the aerosol concentration. NIOSH test criteria establishes the dilution airflow between twenty and twenty-five "air changes" per minute. However, the actual airflow rate is determined by the internal volume of the chamber. The internal volume of the chamber used in this study is approximately 4.5 ft.³.

The diluent airflow rate was calibrated by measuring the velocity profile in the four-inch circular exhaust duct using a standard pitot-probe. The desired airflow was set at 112 cfm, and was found to correspond to a chamber static pressure of -0.05 in. w.c. The diluent airflow can be changed by adjusting a damper in the exhaust duct. The reliability of the combined liquid flow/diluent airflow control technique is demonstrated in the concentration history shown in Figure 5. Each data point in this figure represents the concentration measured at the beginning of a test. The same control settings of $z - z_0$, nozzle air pressure and chamber pressure were used for each test.

IV. CONCENTRATION MEASUREMENTS

Lacquer has been used to study concentration gradients in the test region. The aerosol concentration in the test region is composed primarily of the solid fraction of the lacquer mixture. Although 30 CFR, Part 11 specifies lacquer concentration in terms of cellulose nitrate, NIOSH tests are actually based upon the total solids concentration. Approximately one-third of the solid fraction of the lacquer is cellulose nitrate. The liquid used in this study was #9335 Clear Lacquer manufactured by Pruett-Schaffer Chemical Co. Concentrations have been measured along two normal axes in the test plane, as illustrated in Figure 6. The

horizontal direction (x) has been defined along the three respirator test points. The vertical axes (y) extends above and below the no. 2 probe. All measurement sites are located in the same test plane. When the spray nozzle is aligned, the nozzle center line is normal to the test plane.

Horizontal profiles were measured using the C,1,2, and 3 probes, while the C, IV, 2, and 3V probes were used to determine vertical profiles. The measurement obtained from location C is a reference concentration. The concentrations measured in each test have been normalized to the corresponding reference concentration. The results of all tests can then be compared directly.

When the spray nozzle was carefully positioned at the center of the chamber inlet, concentrations measured along the x and y axes varied a maximum of two to three percent. However, concentrations along the respirator test points (x) were found to vary as much as fourteen percent when the nozzle was slightly misaligned. Horizontal profiles for both nozzle configurations are shown in Figure 7. The misaligned nozzle was positioned one-quarter of an inch from the center of the chamber inlet toward probe 3, and rotated approximately 4° upward from the horizontal.

The concentration gradient arises due to the imbalance in the deposition of the aerosol on the internal surfaces of the chamber. When the nozzle is properly aligned at the chamber inlet, particulate at the periphery of the spray cone impinges

on the chamber side walls and floor, and on the underside of the tray in such a manner that a nearly uniform aerosol concentration is created across the horizontal test points. In the misaligned nozzle configuration, higher aerosol wall deposition occurs in the side of the chamber where probe no.3 is located-causing a lower concentration at position 3. Conversely, less wall deposition occurs on the opposite side of the chamber, resulting in a high concentration at position 1. The same phenomena is expected to occur with enamel.

V. FILTER PERFORMANCE

A typical arrangement for testing twin cartridge filters is shown in Figure 8. Filter pairs are mounted on dummy (empty) cartridges attached to a "y" fitting at each of positions 1, 2, and 3 in the chamber. Facepieces have not been used in the tests in order to isolate filter performance from total respirator performance. All filters were selected such that their initial resistance to airflow fell within a narrow band of resistance measurements. The filter, designated "Filter A," is NIOSH-approved for use in paint spray environments.

Standard filter tests were conducted under uniform and non-uniform lacquer concentration conditions. These conditions were achieved exactly as described in the preceding section of this paper. Filter loading resistance ($\delta\Delta P$) is shown as a function of chamber position for "uniform" concentration conditions in Figure 9. The loading resistance is the difference between the final and initial filter-pair pressure

drops measured at an airflow rate of 85 lpm. Uniformity in $\delta\Delta P$ is illustrated by the results in Figure 9. The small differences in loading resistance between filter pairs can possibly be attributed to slight differences in aerosol concentration and small differences in the filters.

A concentration gradient was induced by misaligning the spray nozzle, and a second test of A Filters was conducted. These results are given in Figure 10. The loading resistance for the filter pair located at position 1 is significantly higher than those at the other positions. This corresponds to the higher lacquer concentration in this region.

Filter A has a very favorable loading characteristic, i.e., the rate of resistance increase with particulate loading is slow. Filters which load more rapidly respond to nonuniform aerosol concentrations more severely than Filter A. This is illustrated in Figure 11, in which the loading resistances of A Filters are compared to those of B Filters under non-uniform aerosol concentration conditions. Filter B is also NIOSH-approved for paint spray applications.

Variations in the penetrations of A and B Filters under non-uniform aerosol conditions were not detected. This is primarily due to the fact that the efficiency of these filters is very high, e.g. $\eta_{\text{lacquer}} \geq 99.95\%$. Lower-efficiency filters would probably be more sensitive to differences in concentration. However, the minimum filter efficiency required for lacquer is 99.2% (2). Thus, chamber concentration

gradients are believed to have a more serious effect upon filter loading resistance than on filter penetration.

Variation in filter performance has been shown to occur where the aerosol concentration is not uniform in the test chamber. Significant differences in filter loading resistances were measured in lacquer environments containing a fourteen percent concentration gradient. Another potential "gradient" exists, i.e. the difference in concentration from test to test as is allowable by current NIOSH criteria ($95 \text{ mg/m}^3 \leq \bar{w} \leq 125 \text{ mg/m}^3$). Tests conducted at the two extremes of the allowable concentration range represent a concentration difference of approximately thirty percent. Under such variable test conditions, consistent filter performance evaluation becomes exceedingly difficult.

VI. PARTICLE SIZE MEASUREMENT

Particle-size measurements have been made using a cascade inertial impactor. The device is an eight-stage, Mark III, Particle-Sizing Stack Sampler manufactured by Andersen Samplers, Inc. The particle-size distribution was determined near position 2 in the chamber. Average cumulative distributions for both lacquer and enamel have been given in Figure 12. The mass-mean aerodynamic diameter (MMAD) and geometric standard deviation (σ_g) for lacquer are $6.4 \text{ } \mu\text{m}$ and 3.4, respectively. The enamel distribution can be characterized by $\text{MMAD} = 5.7 \text{ } \mu\text{m}$ and $\sigma_g \approx 2.0$.

The aerodynamic size of the enamel particles is slightly smaller than that of the lacquer particulate.

More significant, however, is the fact that the lacquer particle-size distribution is much broader than the enamel particle size distribution. Approximately thirty-five percent of the lacquer particulate is composed of particles of diameter greater than 10 μm . The cascade impactor has an upper separation limit in the neighborhood of 10 μm . A second instrument (possibly an optical particle counter) would be required to measure the complete lacquer size distribution. The enamel distribution can be adequately measured with the impactor alone. These measured distributions, of course, characterize the aerosol size at only one point in the test chamber.

The cumulative size distributions given in Figure 12 are useful in computing overall geometric characteristics of the aerosol. A more informative method, however, is one that has been successfully employed for several years in the characterization and interpretation of atmospheric aerosols (6,7). In this technique, the mass, surface-area, or volume distribution is plotted against the particle diameter on a linear-log scale, e.g. $\Delta M/\Delta \log d_p$ vs. $\log d_p$. The advantage of this method is in the clear definition of the modal characteristics of the distribution that are not evident in cumulative plots.

The lacquer data in Figure 12 is shown in the form of $\Delta M/\Delta \log d_p$ vs. $\log d_p$ in Figure 13 (circle data points). The apparent area under the distribution curve (cross-hatched area) is proportional to the integral mass

concentration in the size range. The distribution is bimodal and possibly trimodal. The shape of the coarse mode distribution (indicated by the dashed line) is not well defined because of the upper cut-off diameter limitation of the sampling device. The total mass of aerosol comprising this mode is known from the measurement, but cannot be size-fractionated by the impactor. As a result, an upper size limit of 100 μm has been chosen for the purposes of the computation.

Lacquer particle-size distribution was also measured downstream of the nozzle on the nozzle center line. The impactor was positioned under the tray, facing the spray nozzle, and located approximately half way between the front and back chamber walls (see Figure 6). The resulting mass distribution is shown in Figure 13. The total aerosol mass concentration at this chamber position is 2 1/2 - 3 times that at position no. 2. This is a clear indication of the unsteady nature of the aerosol at this upstream position, i.e. droplet evaporation is still in process. If distributions were measured at progressively greater downstream positions, a complete family of curves could be plotted between the two distributions in Figure 13. This evolution process of the distribution is quite complex. In addition to evaporation (in which particles are transferred from the coarse mode into the fine mode), mechanisms of settling and coagulation must be accounted for. The mass concentration in the coarse mode of the test plane distribution is either an indication of incomplete evaporation of droplets, or of coagulation of solid particles.

VII. CONCLUSIONS

Liquid paint is sprayed from an atomizing nozzle to form an aerosol for testing paint spray respirators. The generated aerosol conditions are dependent upon liquid properties, spray-nozzle flow conditions and droplet evaporation. A technique was developed for controlling the aerosol conditions reliably. The particle-size distributions of lacquer and enamel were measured. The mean aerodynamic diameter was found to be approximately 6.0 μm for both aerosols.

It was shown that aerosol concentration gradients arise when the nozzle is not properly positioned. Furthermore, there is an inherent "gradient" in concentration between tests due to the large concentration range allowable by NIOSH criteria. Such gradients significantly affect particulate loading of filters.

The reliability of the lacquer and enamel test methods could be improved by modifying the current NIOSH criteria to include the following:

- 1) The mass mean aerodynamic diameter and geometric standard deviation of the aerosol modal distributions.
- 2) A more precise definition of the paint and paint thinner chemical compositions to insure constant liquid properties.
- 3) Reduce the allowable concentration range from 30 mg/m^3 (125 mg/m^3 - 95 mg/m^3 = 30 mg/m^3) to 10 mg/m^3 .

Although internal chamber design will directly affect the ability to obtain specified conditions, such criteria is generally outside the scope of the NIOSH specification. A clear definition of the aerosol conditions should be sufficient.

VIII. REFERENCES

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- 2) U.S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, "Part 11 - Respiratory Protective Devices; Tests for Permissibility; Fees," Code of Federal Regulations, Title 30, Subchapter B of Chapter I, HEW Publication No. (NIOSH) 76-145, December 15, 1975.
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- 4) Handbook on Aerosols, R. Dennis, Editor, Energy Research and Development Administration, Technical Information Center, TID-26608, January 1976.
- 5) Bird, R.B., Stewart, W.E., Lightfoot, E.N., Transport Phenomena, John Wiley and Sons, Inc., New York, 1960.
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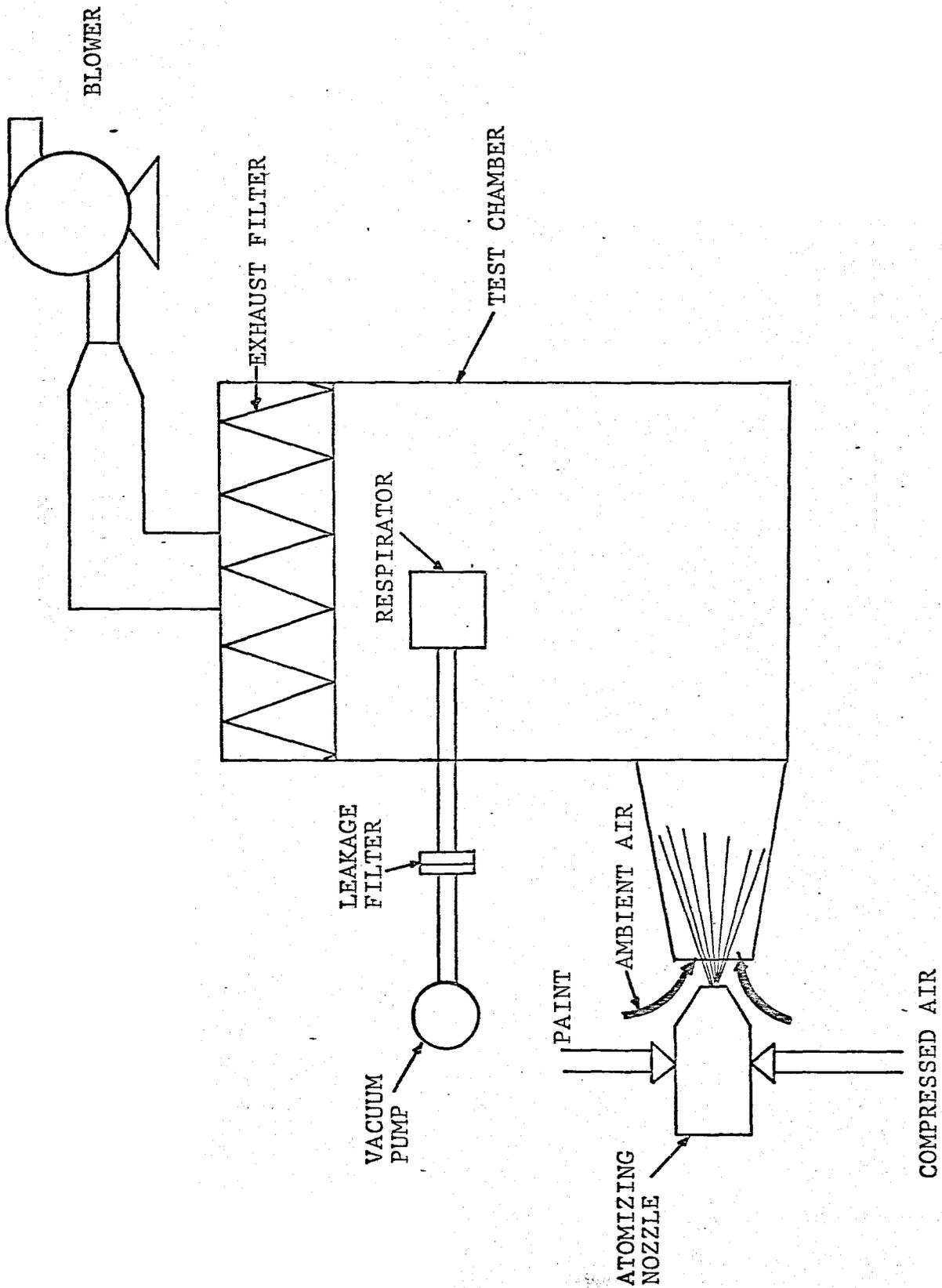


FIGURE 1 PAINT SPRAY TEST SYSTEM

ATOMIZING NOZZLE

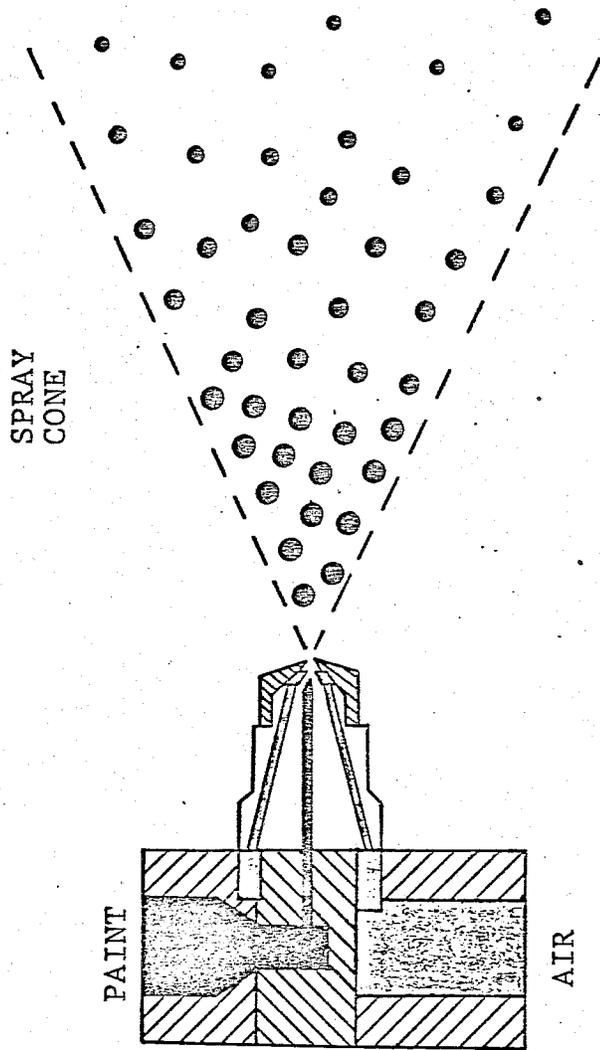


FIGURE 2: ATOMIZATION

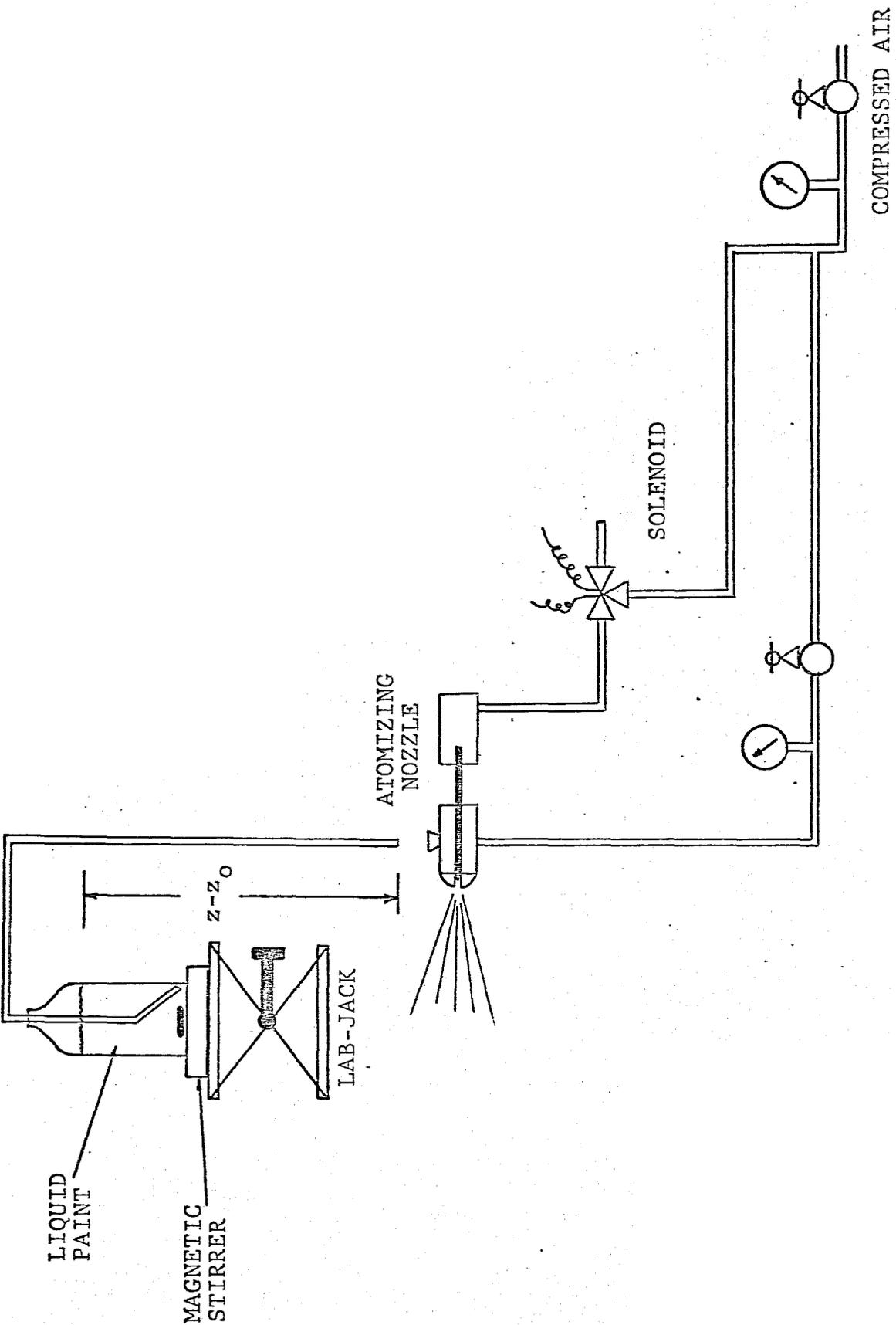


FIGURE 3: MIST GENERATION SYSTEM

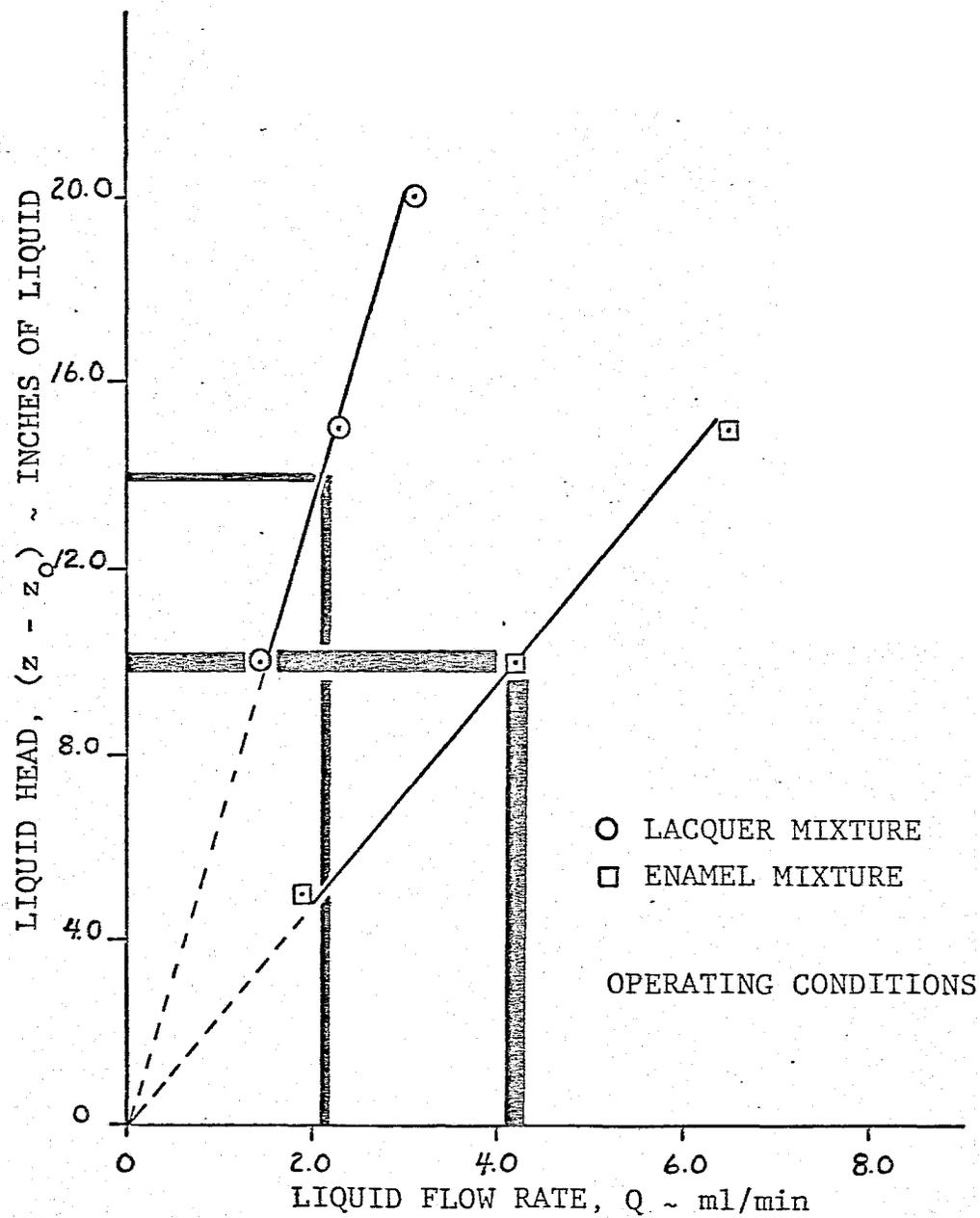


FIGURE 4: LIQUID FLOW RATE CALIBRATION

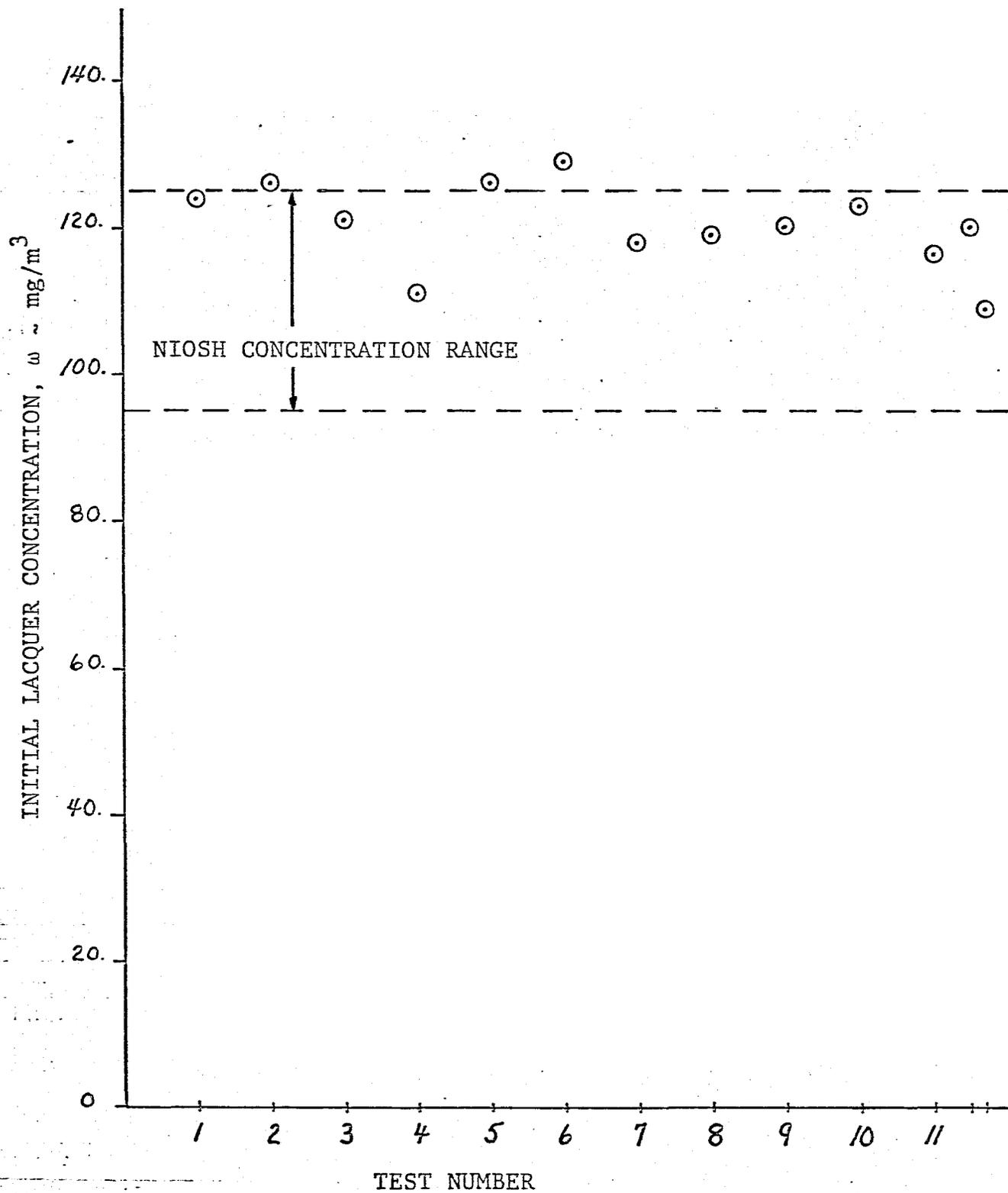


FIGURE 5: CHAMBER CONCENTRATION

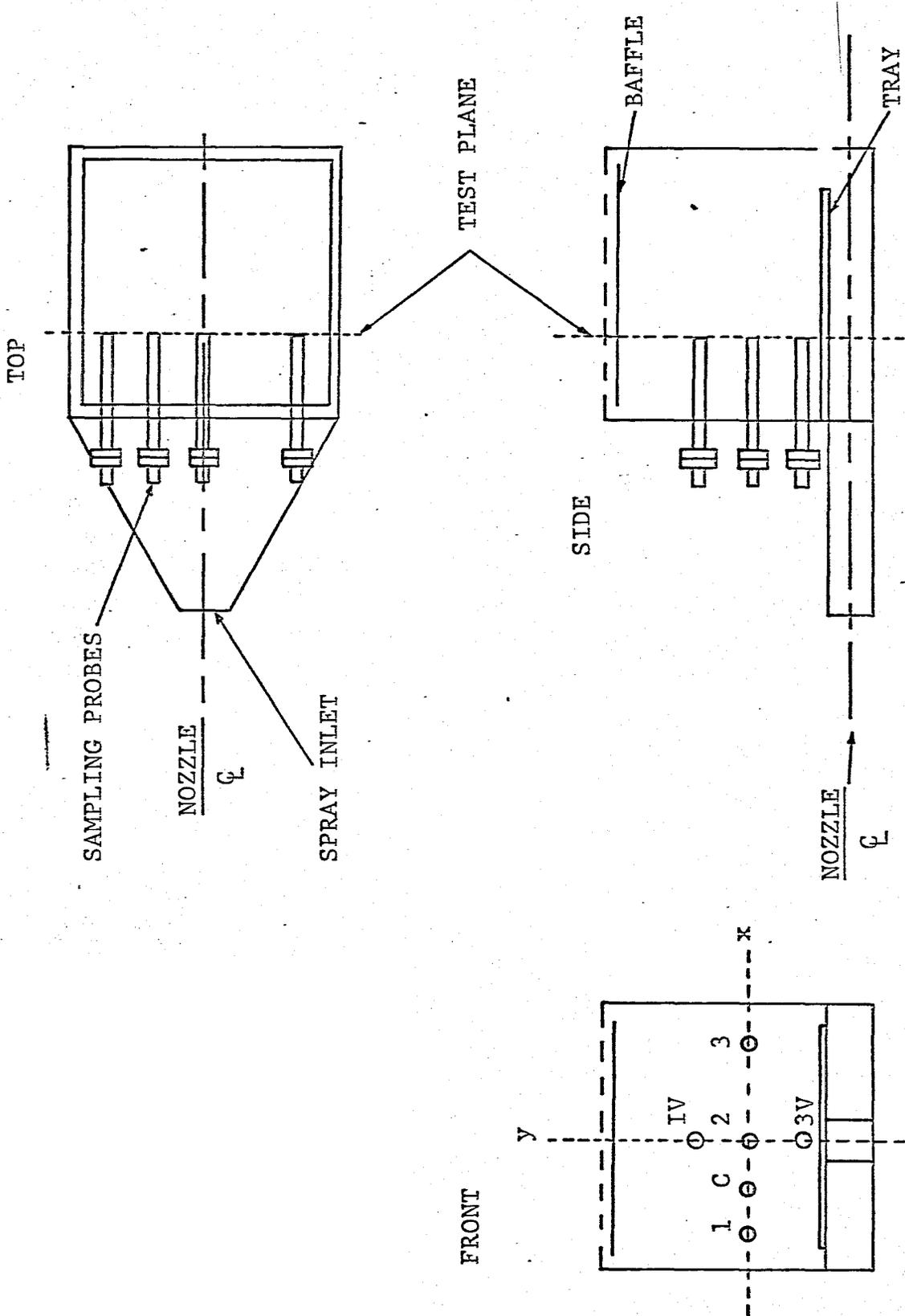


FIGURE 6: TEST CHAMBER

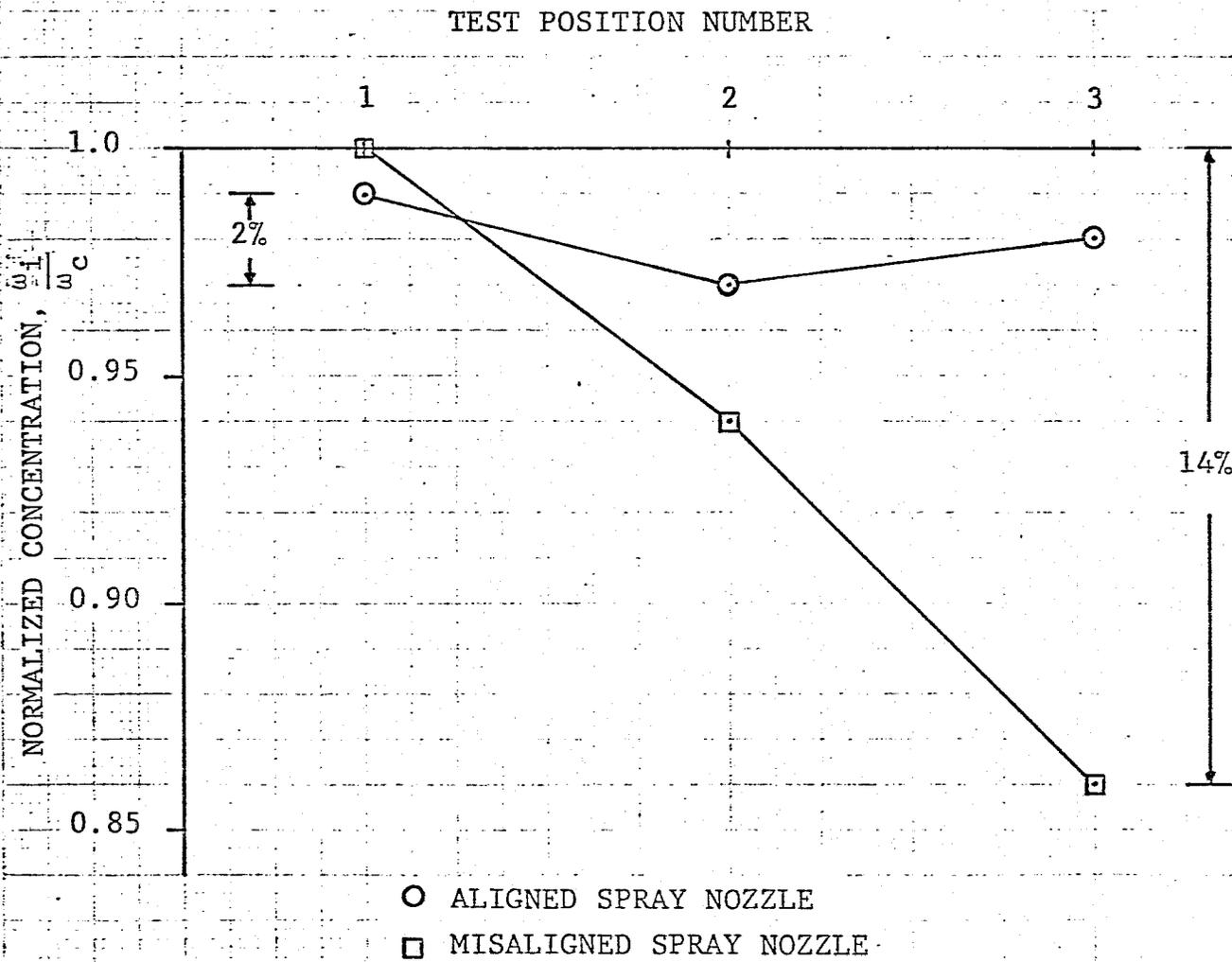


FIGURE 7: CONCENTRATION PROFILES

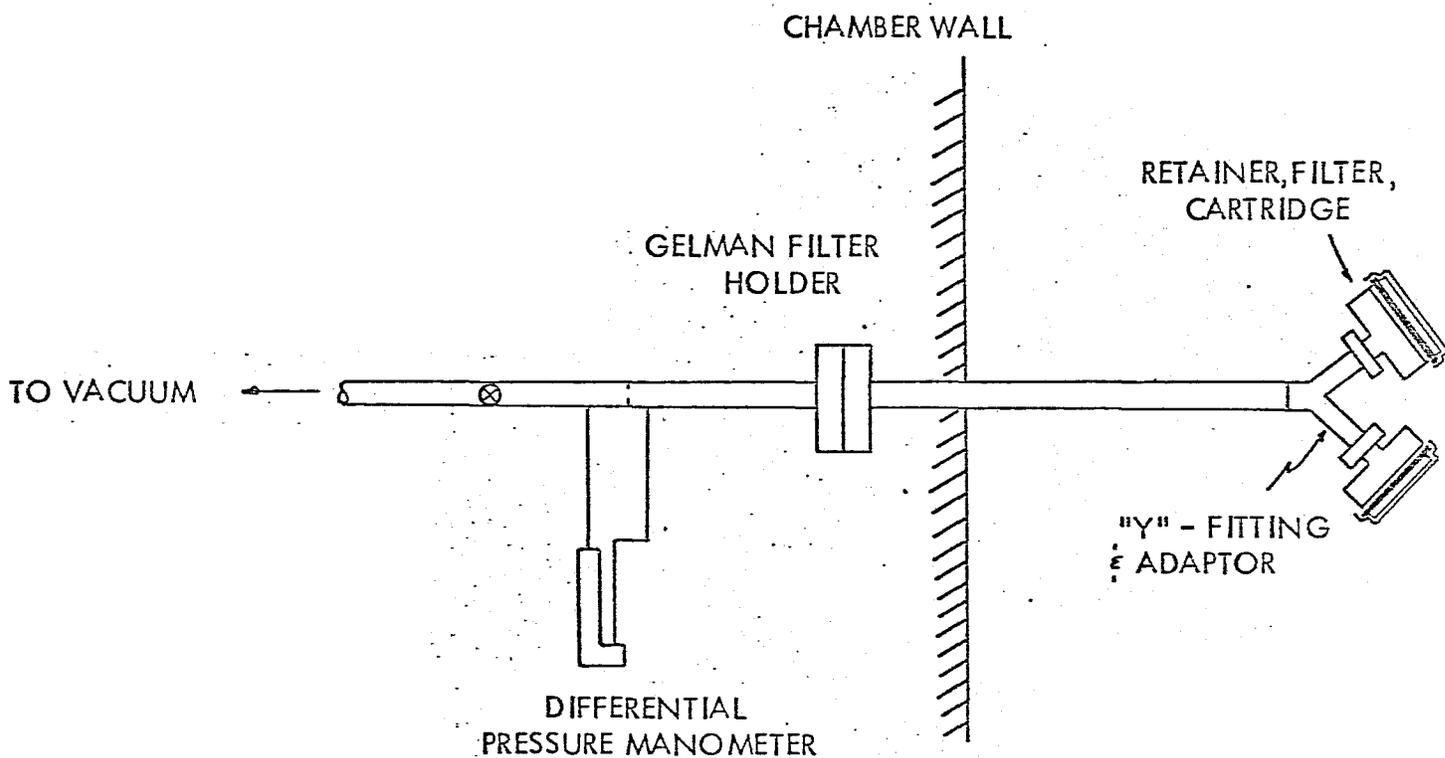
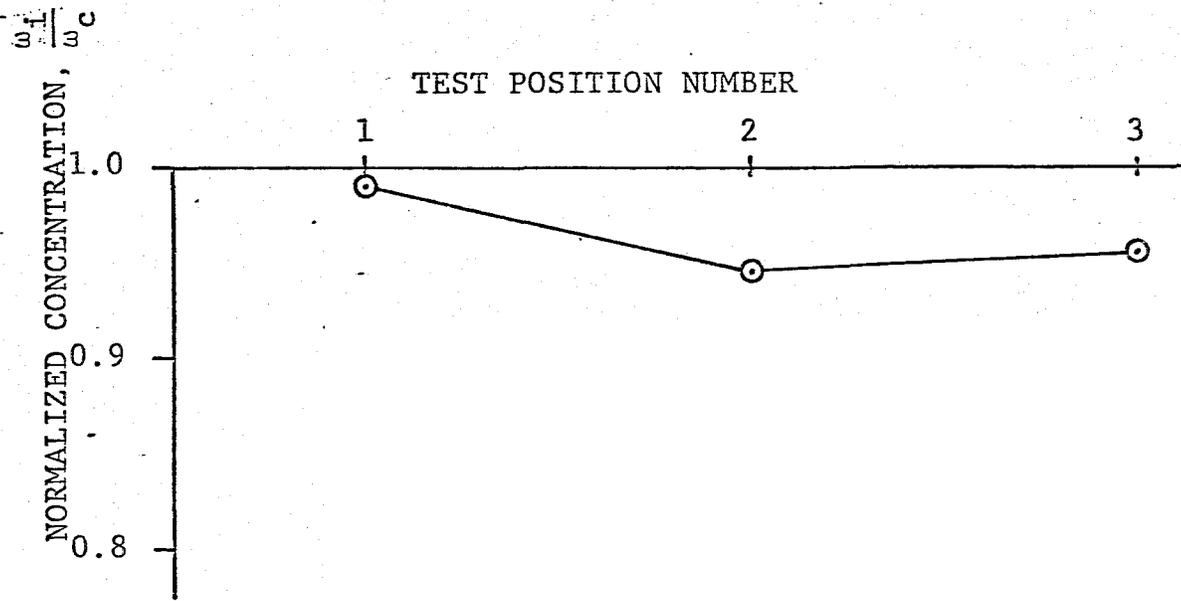


FIGURE 8: SAMPLING PROBE



SPRAY NOZZLE CONFIGURATION: ALIGNED

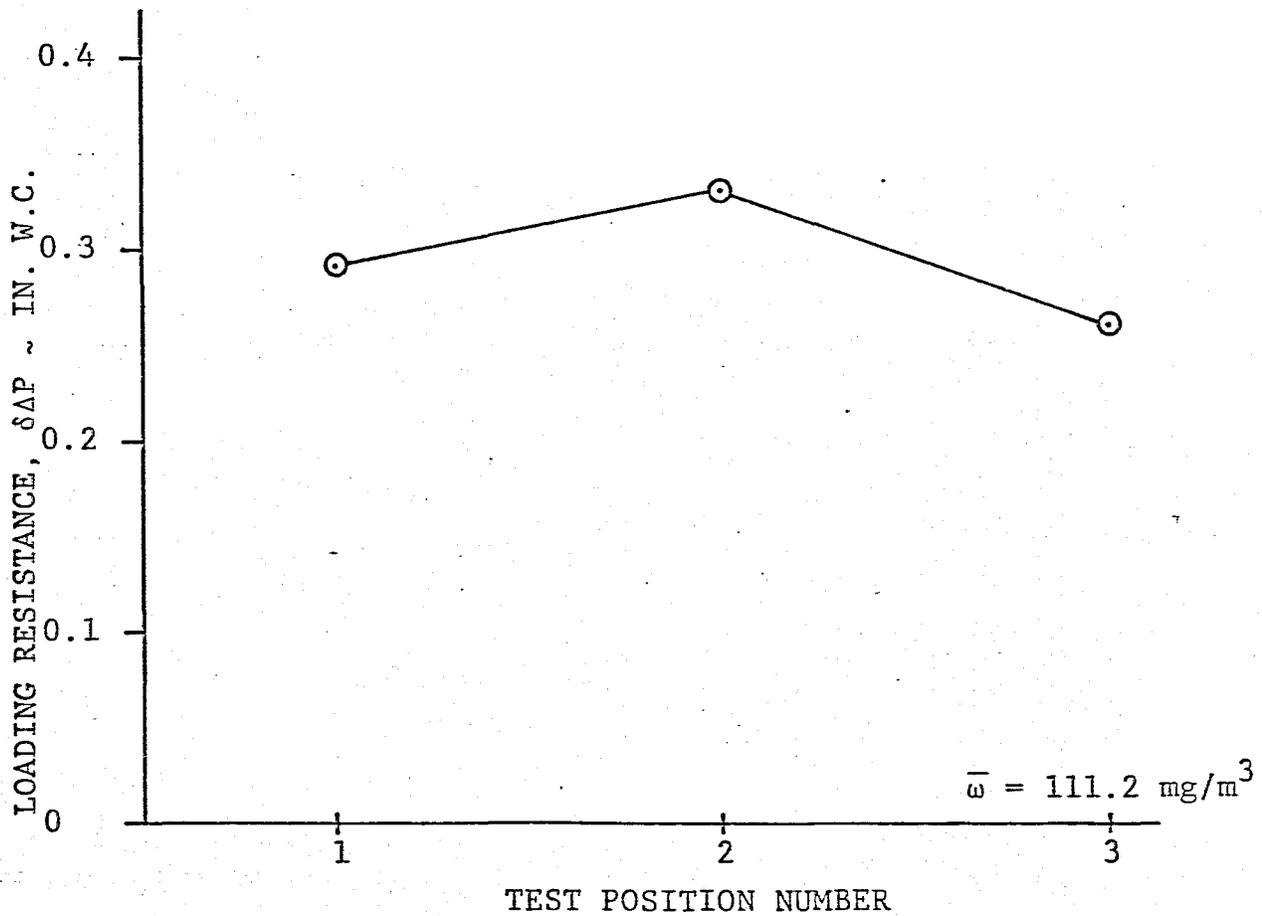


FIGURE 9: LOADING RESISTANCE OF "A" FILTERS IN A UNIFORM CONCENTRATION ENVIRONMENT

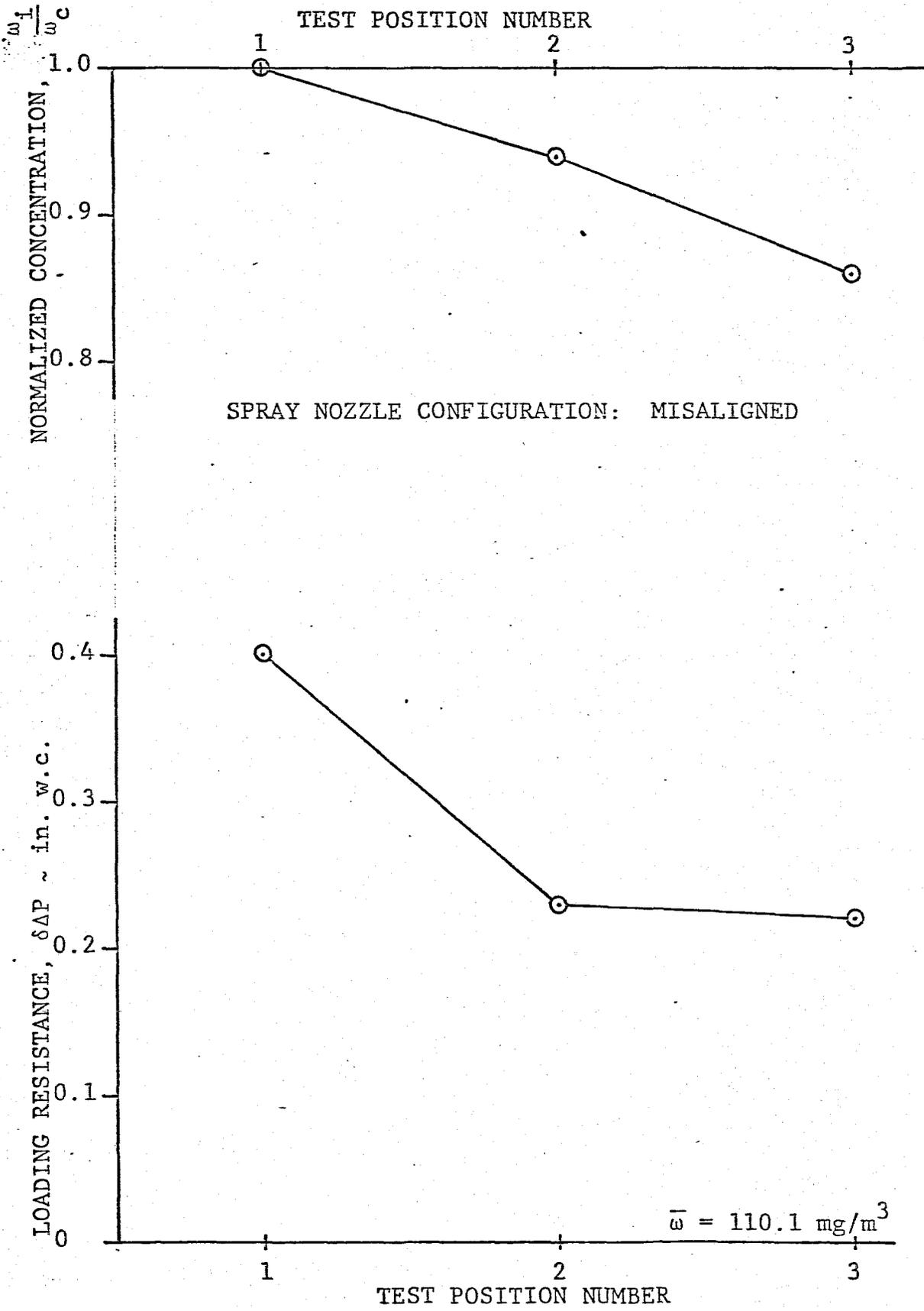


FIGURE 10: LOADING RESISTANCE OF "A" FILTERS IN A NON-UNIFORM CONCENTRATION ENVIRONMENT

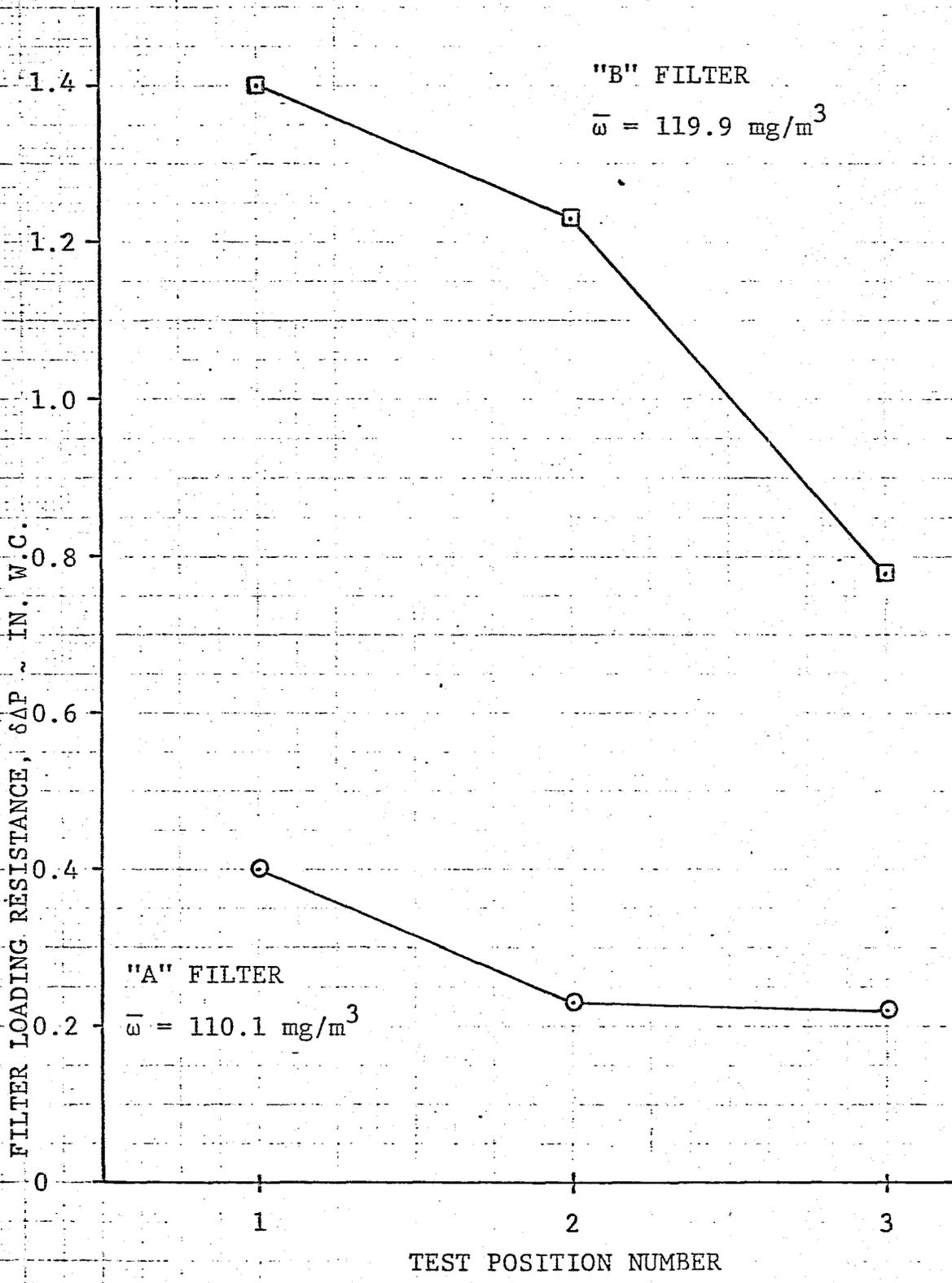


FIGURE 11: FILTER LOADING RESISTANCES IN NON-UNIFORM CONCENTRATION ENVIRONMENT

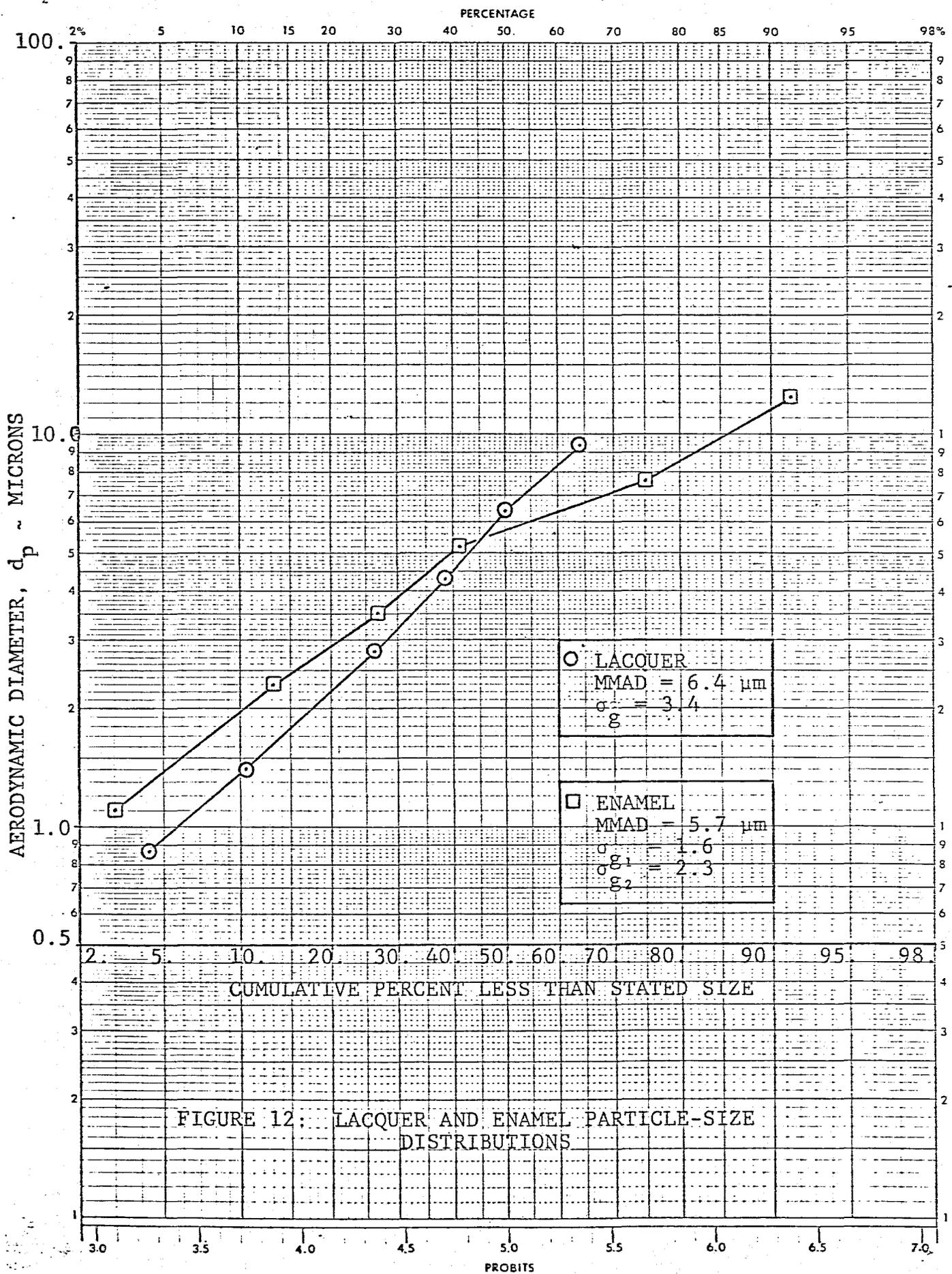


FIGURE 12: LACQUER AND ENAMEL PARTICLE-SIZE DISTRIBUTIONS

