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EXPERIMENTAL EVALUATION OF THE SKYLAB ORBITAL WORKSHOP VENTILATION SYSTEM CONCEPT

By Steve L. Allums, Leon J. Hastings,
and James T. Ralston
Astronautics Laboratory
Science and Engineering

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George C. Marshall Space Flight Center
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16. ABSTRACT

Extensive testing was conducted to evaluate the Orbital Workshop ventilation concept. Component tests were utilized to determine the relationship between operating characteristics at 1 and 0.34 atm. System tests were conducted at 1 atm within the Orbital Workshop full-scale mockup to assess delivered volumetric flow rate and compartment air velocities.

Component tests with the Anemostat circular diffusers (plenum- and duct-mounted) demonstrated that the diffuser produced essentially equivalent airflow patterns and velocities in 1- and 0.34-atm environments. The tests also showed that the pressure drop across the diffuser could be scaled from 1 to 0.34 atm using the atmosphere pressure ratio.

Fan tests indicated that the performance of a multiple, parallel-mounted fan cluster could be predicted by summing the single-fan flow rates at a given ΔP. The fan volumetric flow rate and the Orbital Workshop system flow rate at 28 V, 1 atm are equivalent to the flow rates at 26 V, 0.34 atm. The shutdown of one fan in a four-fan cluster resulted in a flow decrease of approximately 40 percent because of the backflow through the inoperative fan.

For normal operation at 28 V, the average air velocity in the crew quarters was 6.1 to 15.2 m/min (20 to 50 ft/min) depending upon diffuser flow-pattern. The average air velocity in the forward plenum could be varied from 4.6 to 9.1 m/min (15 to 30 ft/min) with the crew quarters diffusers or from 9.1 to 12.2 m/min (30 to 40 ft/min) with the use of three portable fans. The portable fans could supply $\geq$30.5 m/min (100 ft/min) to localized areas.

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ABSTRACT (Concluded)

Compartment flowrate and velocity distributions measured can be directly applied to the flight Orbital Workshop if floor ΔP is simulated. The data presented herein should not be applied to the Orbital Workshop without first satisfying this criteria.

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DEFINITION OF SYMBOLS

Symbol	Definition
ΔP	Pressure drop (N/m^2)
ΔP_1	Pressure rise across fan cluster 1 (N/m^2)
ΔP_2	Pressure rise across fan cluster 2 (N/m^2)
ΔP_3	Pressure rise across fan cluster 3 (N/m^2)
ΔP_4	Pressure drop across floor (N/m^2)
m	Meters
N	Newtons
Q_T	Flow rate across floor based on measured duct flow (m^3/min)
Q_1	Flow rate through duct 1 (m^3/min)
Q_2	Flow rate through duct 2 (m^3/min)
Q_3	Flow rate through duct 3 (m^3/min)
Q_4	Flow rate across floor based on measured floor ΔP (m^3/min)
V	Volts (dc)
$V_1, V_2, \ldots, V_{24}$	Velocities at measurement stations 1 through 24 (m/min)

Abbreviations

LOX	Liquid oxygen
MDA	Multiple Docking Adapter
NMT	No measurement taken

DEFINITION OF SYMBOLS (Concluded)

Abbreviations (Concluded)

OWS	Orbital Workshop
STS	Structural Transition Section
WMA	Waste Management Area
4TW	Circular diffuser flow pattern setting at four turns from wide open
5TN	Circular diffuser flow pattern setting at five turns from full narrow
6TW	Circular diffuser flow pattern setting at six turns from wide open

TECHNICAL MEMORANDUM

EXPERIMENTAL EVALUATION OF THE SKYLAB ORBITAL WORKSHOP VENTILATION SYSTEM CONCEPT

INTRODUCTION

Component and system tests conducted at Marshall Space Flight Center (MSFC), Alabama, between February 1969 and December 1970 defined the Skylab Workshop ventilation system capabilities. Component tests were performed with the duct fans, both individually and in clusters, and with circular and rectangular diffusers. System testing was conducted in a full-scale engineering mockup (Fig. 1) with atmospheric conditions; i.e., 1 atm with no outside air conditioning equipment.

The objectives of the component and system testing were as follows:

1. To establish the relationship between component performance at 1 and 0.34 atm.

2. To determine the delivered Orbital Workshop (OWS) flow rates and system flow resistance (ΔP) for various combinations of component adjustments.

3. To define the air-velocity distribution in the OWS compartments for various operating conditions.

4. To compare the measured system capabilities with performance design goals.

The resulting data have been informally documented in MSFC internal memorandums referenced throughout this report and are compiled in Appendices A through D. This report supersedes the material presented in these appendices.

The ventilation system mockup was tested against certain design criteria. Most of these criteria have not been formally established and, therefore, must be considered more as design guides rather than rigid design requirements. The criteria utilized are listed in the following section.

Mockup Design Criteria

Comfort. The average velocity for the crew area, without portable fans, must be adjustable from 4.6 to 12.2 m/min (15 to 40 ft/min) on demand. Velocities in excess of 12.2 m/min (40 ft/min) are to be provided in localized areas by portable fans and/or diffuser adjustment to the narrow (projection) pattern.

The average velocity range of 4.6 to 12.2 m/min (15 to 40 ft/min) is to be provided with three ducts operating at fan voltage settings of 28 ± 2 Vdc. One duct may be shut down, if necessary, to obtain the 4.6 m/min (15 ft/min) velocity. However, during uncomfortably cold conditions, the simultaneous operation of all heaters (one in each duct) is desirable.

Before the ventilation tests, no guarantee was made concerning forward plenum ventilation except that air velocities above the bulk air velocity would be provided by portable fans only.

The design flow rate through the waste management area (WMA) fan/filter/odor-removal unit is 3.4 m^3/min (120 ft^3/min) at 28 Vdc.

Safety. Crew-quarters air velocities less than 0.6 m/min (2 ft/min) are considered unsafe relative to CO_2 accumulation. Lower velocities in small, localized areas, however, are not to be of concern, i.e., corners and other isolated areas that the crew members would be unlikely to occupy.

In order to assure adequate CO_2 control for crew safety, the minimum target bulk flow rate is 17 m^3/min (600 ft^3/min). Such a minimal flow condition is not expected since unlikely conditions such as less than six duct fans operating are required for the unsafe conditions to occur.

Component Requirements. The minimum allowable flow through each operating fan to prevent fan overheating problems is 1.4 m^3/min (50 ft^3/min).

The minimum acceptable flow over each duct heater is 2.8 m^3/min (100 ft^3/min). This criterion, verbally received from McDonnell Douglas, Western Division (MDAC-WD), is based on tests conducted at MDAC-WD. Flow rates $\geq$2.3 m^3/min (100 ft^3/min) prevent heater overheating.

The aft plenum is sealed except for the duct inlets and diffuser outlets.

Fan Voltage. Voltage to the fans, in orbit, is to be 28 ± 2 Vdc.

OWS VENTILATION SYSTEM DESCRIPTION

Background

The Skylab is to be a manned, earth-orbiting laboratory consisting of an Orbital Workshop (modified Saturn V/S-IVB Stage), an airlock/structural transition section (STS) and a multiple docking adapter (MDA) (Fig. 2). The airlock/STS contains the equipment for conditioning air in the OWS and, with the MDA, provides a means of ingress and egress for the crew. The entire assembly will provide a zero-gravity laboratory in which and from which a variety of scientific experiments are to be conducted.

Modification of the S-IVB stage (Fig. 1) includes installation of two floors, perpendicular to the stage longitudinal axis, in the liquid hydrogen tank. One aft floor is a triangular grid-work located approximately 0.30 m (1.0 ft) above the apex of the LOX dome and sealed on the LOX dome side to provide an aft plenum. (Note: The terms aft and forward noted herein apply to the S-IVB stage in the launch attitude.) The forward floor (more appropriately, the floor-ceiling) is located 1.98 m (78 in.) above the grid-work and consists of two parallel grids, 0.15 m (6 in.) apart. The volume between the floors contains the ward room, work area, sleep area, and WMA. The volume forward of the floor/ceiling is designated the forward plenum and contains various scientific experiment packages and life-support equipment. A hatch in the forward plenum dome provides access to the airlock and MDA.

Ventilation System

The OWS ventilation flow system consists of three 0.30-m (12-in.)-diameter ducts, each with a four-fan cluster, that transports air from a mixing chamber on the forward plenum dome (Fig. 3) to the aft plenum. Each of the three-fan clusters (Figs. 4 and 5) contains brushless dc-motor-driven vaneaxial fans (Fig. 6). These fans are manufactured by the AiResearch Corporation (Part No. 826070-4) and are termed post-landing ventilation (PLV) fans.

Conditioned air from the airlock module is mixed with recirculated air in the mixing chamber. This air mixture is circulated continuously through the aft plenum and exits the aft plenum into the crew quarters through nine, 0.15-m (6-in.) Anemostat, type C-2, circular diffusers (Fig. 7) and three, 0.089 × 14-m (3.5- × 5.5-in.) Air Devices, Inc., rectangular diffusers (Fig. 8).

The diffuser layout is shown in Figure 9. Three circular diffusers are located in the ward room floor, five in the work area floor, and one in the WMA floor. Each diffuser contains a manually-adjustable damper to allow control of the airflow into the crew quarters. The diffusers can also be adjusted to provide air-distribution patterns from a wide distribution, parallel to the floor, to a higher velocity narrow (projection) distribution perpendicular to the floor.

The WMA door is to be normally closed so that air exiting the compartment will pass through an odor removal/filter unit. Air circulation is provided by the floor diffuser in conjunction with a PLV fan attached to the odor/filter unit above the compartment ceiling.

Rectangular diffusers, located in the floor in each of the three sleep compartments, are adjustable from the standpoint of volumetric flow (three adjustable levers) and jet-stream direction.

EXPERIMENTAL APPROACH

Figure 10 illustrates the overall program approach. The tests consisted of two major categories: the component/subsystem tests and the OWS mockup system tests. Component/subsystem experimentation was used to assess the detailed performance of individual system elements and to provide a means for scaling performance from 1 to 0.34 atm. The latter was a significant concern since the OWS mockup tests could be conducted only in a 1-atm environment. Scaling of performance between 1 and 0.34-atm environments at the component/subsystem level had to be accomplished before the mockup data could be applied to flight conditions (0.34 atm).

Component/subsystem testing was performed at 1 and 0.34 atm with fans and diffusers. The fans were examined at various flow resistances and voltages, both individually and in the cluster configuration. Velocity profiles, flow patterns, and flow resistances of the circular and rectangular diffusers were investigated in detail.

The total OWS system air delivery and flow/velocity distribution capabilities were determined using the full-scale mockup. Air-delivery parameters of interest included total flow resistance, system volumetric flow, and backflow through nonoperating ducts. Alternate approaches for measuring these characteristics were utilized, when possible, to maintain a check on the validity of the data.

The two major concerns in the system flow/velocity tests were the volume flow apportionment among the crew area compartments of the total flow delivered to the aft plenum and the suitability of the velocity ranges and distributions within the compartments and forward plenum.

Instrumentation utilized in this program consisted of standard equipment for measuring ventilation parameters. Static pressure taps were used to measure fan headrise (or system flow resistance), flow meters for volumetric flow (excepting mockup tests), a manometer for mockup floor ΔP, and hot-wire anemometers for air velocity. Specific descriptions of the instruments utilized in each test series are contained in Appendices A through D.

COMPONENT PERFORMANCE TESTING

Fan Performance

The fan test objectives were to verify the manufacturer's specification; to measure performance as a function of voltage, flow resistance, and atmospheric pressure; and to examine the fan application (single- and cluster-mounted). Detailed test procedures and results are presented in Reference 1. Generally, the fans performed satisfactorily, i.e., at or above the required nominal level. Significant results and experimental approaches are summarized in subsequent paragraphs.

Single Fans. Figure 11 represents the test setup for the individual fan tests. It should be noted that the static pressure ports downstream of the fan outlet are beyond the region of fan-induced flow swirl [approximately 1.2 m (4 ft) from the fan]. Typical data produced by the four test fans at 1 and 0.34 atm are illustrated in Figure 12. The nominal and minimum required PLV fan performance at 0.34 atm [2] is also presented. The fan performances were slightly above the nominal values.

Contrary to an assumption often used by designers, the fan performance at 0.34 atm could not be multiplied by the density ratio to produce the 1-atm performance at the same voltage. However, the performance at 1 atm, 28 V did correspond approximately to the 0.34 atm, 26-V performance corrected to 1 atm (Fig. 13).

Multiple Fans. The setup for testing fans in parallel is presented in Figure 14. The fans were installed in an OWS four-fan cluster housing. Performance of a representative four-fan cluster is presented in Figures 15 and 16 for 0.34 and 1 atm, respectively. Figures 15 and 16 illustrate that the flow rate of four fans in parallel is essentially equal to the sum of the four individual fan flow rates at the same pressure rise for either 0.34 or 1 atm.

The effects of one nonoperating fan in a cluster was also evaluated. Two nonoperating fan conditions were examined, one in which the "dead" fan was allowed to "freewheel" and another in which the dead fan ports were sealed; i.e., no backflow could occur. Results for 1 and 0.34 atm are presented in Figures 17 and 18, respectively. The cluster flow rate degradation caused by a freewheeling fan increases with increasing system resistance (ΔP). Using the 0.34-atm case as an example, the flow rate decrease ranges from 24 to 80 percent for a corresponding resistance range of 2.5 to 62.3 N/m^2 (0.01 to 0.25 in. of water). The degradation anticipated in the OWS application is 30 to 40 percent.

The magnitude of backflow can be estimated by comparing the freewheeling fan and sealed dead fan port data. Again using the 0.34-atm condition as an example, the backflow magnitude varies from 60 to 0 percent of the total flow. The backflow ceases at resistances below 9.5 N/m^2 (0.038 in. of water) because the upstream dynamic pressure equals or exceeds cluster pressure rise.

The backflow rate versus pressure drop through a nonoperating fan was measured using an individual fan within a single 0.13-m (5-in.)-diameter duct at 0.34 atm. These data are compared with those measured in 0.34-atm cluster tests in Figure 19. For a given ΔP across the dead fans, the single nonoperating fan test indicates more backflow than would exist in a cluster-mounted fan. The influence of the flow velocity head on the nonoperating fan in the cluster accounts for the 10 to 15 percent less flow (0.34 atm) at pressure rise values above 25 N/m^2 (0.10 in. of water). The flow rate difference increases sharply for cluster pressure rise values below 25 N/m^2 (0.10 in. of water) until at 9.5 N/m^2 (0.038 in. of water), the cluster nonoperating fan ceases to backflow and allows forward flow.

Circular Diffuser Performance

An intensive examination of the circular diffuser flow patterns, velocities, and resistance at 0.34 and 1 atm was conducted using duct-mounted diffusers and simulated OWS plenum-mounted diffusers. The flow pattern visualization was enabled using colored smoke as a tracer and 16-mm photography. Velocity magnitudes were measured using hot-wire anemometers. Specific information concerning the duct- and plenum-mounted diffuser testing is contained in References 3 and 4, respectively. Major results from the testing are outlined in the subsequent sections.

Duct Mounted. The duct-mounted diffuser test setup is shown in Figures 20, 21, and 22. A pair of diffusers was mounted flush with a flat, vertical plexiglass surface and was spaced 1.2 m (4 ft) between center lines.

The most significant result from the testing was that the flow patterns and velocities that were produced were essentially the same in 1- and 0.34-atm environments. Example velocity data for a narrow flow-pattern setting are shown in Figure 23. Also, it was determined that the change in slope of the pressure drop across the diffuser from 1 to 0.34 atm is equal to the density ratio.

The tests also indicated that the narrow diffuser pattern was not stable; i.e., little or no disturbance was required to cause the narrow pattern to suddenly change to a wide pattern. Flow pattern stability was achieved by adding a 1/16-inch spacer between the diffuser and the smooth mounting surface [3]. Another problem was associated with a diffuser without flow straighteners being supplied by an inlet duct. The flow swirl produced by the supply fan could pass on through the diffuser, thereby disrupting the diffuser produced flow pattern. Also, the flow out of the diffuser was often "one sided" due to a nonuniform velocity profile at the diffuser inlet [4].

Flow-pattern testing with smoke was conducted with the two diffusers operating simultaneously. Example results are presented in Figures 24, 25, and 26 for various combinations of wide and narrow patterns. The narrow flow patterns had little or no interaction with each other. When the wide patterns collided, a vertical wall of air (relative to the diffuser mounting surface) was formed and, at a distance of 0.9 to 1.2 m (3 to 4 ft) from the mounting surface, started to diffuse. These flow patterns are not a problem but simply illustrate that the total flow pattern of a multiple diffuser system cannot always be predicted based upon single diffuser test results.

Plenum-Mounted. Two test series were conducted with the plenum-mounted arrangement (Fig. 27), the first with development-type hardware and the second with OWS mockup hardware (flight-type hardware).[1] The first series examined flow profiles and the influence of bellmouth inlets on diffuser ΔP. Only flow resistance was measured in the second series with the mockup hardware. Although not a significant problem, the diffuser ΔP was noticeably higher with the mockup hardware than with the development hardware. This difference is not completely understood, but it is presently attributed to differences in the shape of the bellmouths. The observed data and other conclusions are summarized in the succeeding paragraphs.

1. The diffuser was flight-type from a flow performance standpoint; however, the number of turns required to convert from the wide to narrow pattern was fifteen, whereas the flight diffusers will require nine turns.

In the first series, tests were performed with and without a 0.038-m (1.5-in.) radius (180-deg) bellmouth on a 0.6-m (2 ft)-long, straight pipe inlet. The bellmouth inlet decreased the flow resistance about 23 percent (Figs. 28 and 29) and enabled close correlation with the manufacturer's specifications. The flow resistance of the duct-mounted diffuser was significantly lower (factor of two to three) than the plenum arrangement with the horizontal pattern. However, in the projection (narrow) pattern the resistance of the ducted diffuser was slightly higher but comparable to the plenum diffuser.

The diffuser flow patterns were stable and symmetrical provided that the straight pipe inlet was utilized. Flow patterns with dual diffusers were comparable with those presented in Figures 24, 25, and 26.

The second test series was a detailed study of flow resistance for various flow-pattern settings with OWS mockup hardware. Circular diffusers used in the work area/ward room and in the WMA were evaluated. The data were generated primarily to enable an estimate of the ΔP across the OWS mockup floor versus flow rate. The WMA diffuser had a 0.098-m (3.875-in.) orifice installed and therefore had a higher flow resistance (Fig. 30) than the fully open work area/ward room diffuser (Fig. 31). With the damper closed the work area/ward room diffuser flow resistance, of course, increased significantly (Fig. 32).

When the data in Figure 31 are compared with those of the first series (Figs. 28 and 29), the mockup diffuser exhibited a 50 percent higher ΔP. The mockup configuration differed from that tested in the first series in the following respects:

	Development Hardware	Mockup Hardware
1.	No damper	Damper installed
2.	Inlet pipe: 0.6 m (2 ft) long	Inlet pipe: 0.30 m (1 ft) long
3.	Bellmouth: 0.038-m (1.5-in.) radius, 180-deg turn	Bellmouth: 0.03-m (1-in.) radius, 90-deg turn

Based on test experience, items (1) and (2) should not have significantly affected the ΔP. Theoretically the smaller bellmouth should not have had a significant effect, but it is believed to have been the primary factor. It is speculated that the curved lip should have continued through 180 deg.

Although the diffuser ΔP was higher than expected, it does not significantly affect the total system performance (3 percent reduction in delivered flow).

Rectangular Diffuser Performance

The rectangular diffusers 0.089 × 14 m (3.5 × 5.5 in.) were not subjected to the intensive testing conducted with the circular diffuser. It was reasoned that the scaling criteria (between 1 and 0.34 atm) developed for the circular diffusers could be extrapolated to the rectangular diffusers. Also the rectangular diffusers affect a more limited region in the OWS and, therefore, were emphasized less than the circular outlets. The diffuser pressure drop was examined at 1 atm with the flow louvers open and closed. The diffuser tested was used in the OWS mockup and, therefore, was representative of flight hardware. The resulting data are presented in Figure 33 [5]. The diffuser is expected to nominally flow about 4.5 m^3/min (160 ft^3/min).

SYSTEM TESTS

Air Delivery

As mentioned previously, the objective of this portion of the test program was to establish the overall OWS airflow delivery system capabilities. The system was tested with: fan voltages ranging from 24 to 32; various diffuser settings with fully open/closed dampers; two- and three-fan clusters operating and one or two nonoperating fans in a particular cluster. The OWS system proved capable of delivering adequate flow from a safety (CO_2) standpoint under severe conditions. All measured system pressure drop and airflow data are tabulated in Tables 1 and 2. Detailed test information is presented in Reference 5. Significant results and conclusions are presented in the following subsections.

<u>Measurements Methods</u>. This subsection describes the various approaches investigated for measuring the overall system performance parameters of delivered flow rate and system flow resistance. Three methods for measuring flow rates produced by the three-duct fan clusters were attempted:

1. Subsystem testing was used to calibrate three anemometers for flow versus velocity in a 0.30-m (12-in.) duct. One of these anemometers was then installed in each of the three mockup ducts and used to measure the velocities and corresponding system flow rates.

2. The pressure rise across each fan cluster, which is equal to the total resistance encountered by each cluster, was measured. By determining each cluster performance curve in component tests, a flow rate corresponding to the measured cluster pressure rise could be determined.

TABLE 1. PERFORMANCE DATA WITHOUT DAMPERS

Test C-091	Ducts	Fans Per Duct	Vdc	Circular Diffuser Pattern	Rectangular Diffuser Pattern	WMA Fan	ΔP_1 (N/m²)	Q_1 (m³/min)	ΔP_2 (N/m²)	Q_2 (m³/min)	ΔP_3 (N/m²)	Q_3 (m³/min)	ΔP_4 (N/m²)	Q_4 (m³/min)	Q_T (m³/min)
- 55	3	4	24	Wide	Open	Off	79.6	15.3	72.2	15.4	65.9	16.1	26.1	44.6	46.8
- 56	3	4	24	Wide	Closed	Off	88.3	14.6	82.1	14.6	75.9	15.3	39.8	42.8	44.5
- 85	3	4	24	Wide	Open	Off	80.9	15.3	72.2	15.4	64.7	16.1	27.4	45.5	46.9
86	3	4	24	Wide	Open	On	80.9	15.3	70.9	15.5	63.5	16.3	24.9	43.4	47.1
- 51	3	4	24	8TW	Open	Off	78.4	15.4	72.2	15.4	67.2	16.0	28.6	45.3	46.9
- 52	3	4	24	8TW	Closed	Off	89.6	14.5	82.1	14.6	77.1	15.2	43.6	43.6	44.2
- 64	3	4	24	Narrow	Open	Off	90.8	14.4	82.1	14.6	77.1	15.2	42.3	45.6	44.2
- 80	3	4/4/3	24	Wide	Open	Off	73.4	15.8	63.5	16.1	39.8	11.6	19.9	38.7	43.5
- 57	2	4/0/4	24	Wide	Open	Off	61.0	16.7	11.2	-7.4	48.5	17.4	10.0	26.5	26.7
67	2	4/0/4	24	4TW	Open	Off	62.2	16.6	13.7	-8.5	49.8	17.3	10.0	25.2	25.5
- 69	2	4/0/4	24	Narrow	Open	Off	64.7	16.4	13.7	-8.5	53.5	17.0	14.9	26.1	24.1
-101	2	4/0/4	24	5TN	Open	Off	62.2	16.6	13.7	-8.5	51.0	17.2	12.4	27.2	25.3
- 72	2	3/0/3	24	Wide	Open	Off	33.6	12.4	7.5	-4.8	24.9	13.6	6.2	20.5	21.2
- 75	2	3/0/3	24	Narrow	Open	Off	34.8	12.2	11.2	-7.1	28.6	13.0	10.0	21.6	18.1
- 58	3	4	28	Wide	Open	Off	102.0	18.1	92.1	17.9	84.6	18.9	33.6	50.5	54.9
- 62	3	4	28	4TW	Open	Off	105.8	17.8	92.1	18.0	85.9	18.8	36.1	52.0	54.7
- 84	3	4	28	Wide	Open	Off	105.8	17.8	93.3	17.8	84.6	18.9	34.8	51.8	54.6
- 87	3	4	28	Wide	Open	On	104.5	17.9	92.1	18.0	84.6	18.9	34.8	51.8	54.8
- 97	3	4	28	6TW	Open	Off	105.8	17.8	93.3	17.8	87.1	18.7	37.3	52.1	54.4
- 98	3	4	28	6TW	Closed	Off	121.9	16.7	112.0	16.6	104.5	17.4	59.7	51.9	50.7
- 65	3	4	28	Narrow	Open	Off	118.2	17.0	108.2	16.8	100.8	17.7	54.7	53.1	51.5
- 81	3	4/4/3	28	Wide	Open	Off	97.1	18.3	84.6	18.5	53.5	13.0	27.4	45.3	49.8
- 59	2	4/0/4	28	Wide	Open	Off	80.9	19.5	14.9	-9.2	61.7	20.4	12.4	29.9	30.0
- 60	2	4/0/4	28	4TW	Open	Off	80.9	19.5	14.9	-9.2	64.7	20.4	12.4	28.7	30.6
- 70	2	4/0/4	28	Narrow	Open	Off	84.6	19.2	17.4	-11.0	69.7	20.1	19.9	30.8	28.3
- 78	2	4/0/2	28	Wide	Open	Off	74.7	19.8	11.2	-7.4	23.6	9.3	7.5	22.2	21.8
- 79	2	4/0/2	28	4TW	Open	Off	74.7	19.8	11.2	-7.4	23.6	9.3	8.7	23.7	21.8
- 73	2	3/0/3	28	Wide	Open	Off	42.3	14.2	10.0	-6.5	33.6	15.3	7.5	22.2	22.9
- 76	2	3/0/3	28	Narrow	Closed	Off	49.8	13.5	17.4	-10.6	42.3	14.2	18.7	20.7	17.0
- 61	3	4	32	Wide	Closed	Off	146.8	19.2	133.1	19.5	124.4	20.0	64.7	56.6	58.4
- 83	3	4	32	Wide	Open	Off	133.1	20.0	117.0	20.3	107.0	21.1	43.6	58.3	61.5
- 88	3	4	32	Wide	Open	On	134.4	20.0	118.2	20.2	108.2	21.0	44.8	59.4	61.2
- 63	3	4	32	4TW	Closed	Off	153.0	18.7	136.9	19.3	129.4	19.7	69.7	57.9	57.7
- 66	3	4	32	Narrow	Open	Off	149.3	19.0	136.9	19.3	128.2	19.7	70.9	61.3	58.0
- 82	3	4/4/3	32	Wide	Open	Off	123.2	20.7	107.0	20.9	68.4	14.6	36.1	52.[illegible]	56.2
- 99	3	4	32	6TW	Closed	Off	151.8	18.8	136.9	19.3	129.4	19.7	70.9	57.6	57.8
-100	3	4	32	5TN	Closed	Off	155.5	18.5	141.9	19.0	134.4	19.3	79.6	57.3	56.9
-102	3	4/2/4	32	5TN	Open	Off	124.4	20.5	72.2	11.6	100.8	21.6	37.3	49.7	53.7
- 53	2	4/0/4	32	Wide	Open	Off	99.5	22.2	16.2	-10.2	79.6	23.1	16.2	34.[illegible]	35.1
- 54	2	4/0/4	32	Wide	Closed	Off	104.5	21.9	19.9	-11.8	87.1	22.2	23.6	32.3	32.6
- 68	2	4/0/4	32	4TW	Closed	Off	108.2	21.7	19.9	-11.8	88.3	22.4	24.9	32.6	32.3
- 71	2	4/0/4	32	Narrow	Open	Off	107.0	21.7	19.9	-11.8	88.3	22.4	24.9	34.6	32.3
- 74	2	3/0/3	32	Wide	Closed	Off	107.0	15.7	14.9	-9.2	46.0	16.9	14.9	25.2	23.4
- 77	2	3/0/3	32	Narrow	Open	Off	57.2	15.7	14.9	-9.2	44.8	17.0	14.9	26.3	23.5

NOTES:

1. No flow through WMA fan when not operating, but leakage out of WMA compartment exists.
2. Q_4 does not include WMA fan flow rate when fan is operating.
3. In Test 102, cluster 2 has only two fans installed (no backflow).

TABLE 2. PERFORMANCE DATA WITH DAMPERS INSTALLED

Test C-091	Ducts	Fans per Duct	Vdc	Circular Diffuser Pattern	Rectangular Diffuser Pattern	Damper Setting	WMA Fan	ΔP_1 (N/m^2)	Q_1 (m^3/min)	ΔP_2 (N/m^2)	Q_2 (m^3/min)	ΔP_3 (N/m^2)	Q_3 (m^3/min)	ΔP_4 (N/m^2)	Q_4 (m^3/min)	Q_T (m^3/min)
-111	3	4	24	Wide	Open	Open	Off	82.1	15.2	73.4	15.4	65.9	16.1	28.6	46.7	46.6
-116	3	4	24	Wide	Closed	Open	Off	92.1	14.3	84.6	14.4	78.4	15.1	44.8	45.4	43.8
-117	3	4	24	Wide	Open	Open	On	82.1	15.2	74.7	15.2	67.2	16.0	29.9	47.6	46.4
-105	3	4	24	6TW	Closed	Closed	Off	128.2	10.8	124.4	9.9	119.4	11.5	100.8	39.3	32.1
-115	3	4	24	Narrow	Open	Open	Off	89.6	14.5	82.1	14.7	74.7	15.4	42.3	46.1	44.6
-108	2	4/0/4	24	6TW	Closed	Closed	Off	82.1	15.2	29.9	-16.2	72.2	15.6	41.1	22.8	14.3
-110	3	4	28	Wide	Open	Open	Off	107.0	17.7	94.6	17.8	85.9	18.8	38.6	54.5	54.3
-118	3	4	28	Wide	Open	Open	On	107.0	17.7	97.1	17.6	87.1	18.7	38.6	54.5	54.0
-120	3	4	28	Wide	Open	Open	Off	109.5	17.6	98.3	17.6	87.1	18.7	37.3	53.6	53.8
-121	3	4	28	Wide	Open	Closed	Off	135.6	15.7	129.4	15.1	119.4	16.3	79.6	51.5	47.1
-104	3	4	28	6TW	Closed	Closed	Off	171.7	12.4	164.2	11.7	159.3	12.7	134.4	44.3	36.8
-114	3	4	28	Narrow	Open	Open	Off	118.2	17.0	108.3	16.8	99.5	17.8	54.8	53.0	51.5
-107	2	4/0/4	28	6TW	Closed	Closed	Off	107.0	17.7	32.4	-17.6	93.3	18.3	51.0	25.8	18.4
-128	3	4	28	6TW	Open	Open	Off	110.7	17.5	102.0	17.3	92.1	18.4	44.8	57.6	53.1
-109	3	4	32	Wide	Open	Open	Off	134.4	20.0	120.7	20.1	109.5	21.0	48.5	61.6	61.0
-112	3	4	32	Wide	Closed	Open	Off	153.0	18.8	140.6	19.0	129.4	19.7	75.9	61.5	57.5
-119	3	4	32	Wide	Open	Open	On	134.4	20.0	121.9	20.0	109.5	21.0	48.5	61.6	60.9
-103	3	4	32	6TW	Closed	Closed	Off	215.3	13.7	205.3	13.9	199.1	14.1	168.0	51.0	41.8
-113	3	4	32	Narrow	Open	Open	Off	148.1	19.1	134.4	19.4	134.4	20.0	68.4	59.8	58.5
-106	2	4/0/4	32	6TW	Closed	Closed	Off	134.4	20.0	38.6	-18.2	117.0	20.5	64.7	29.8	22.3

NOTES:

1. No flow through WMA fan when not operating, but leakage out of WMA compartment exits.
2. Q_4 does not include WMA fan flow rate when fan is operating

3. The pressure drop across the floor was measured and was used in conjunction with the diffuser flow resistance curves to calculate a flow rate across the floor (no leakage). The floor resistance and a calculated duct resistance were summed to obtain a total system pressure drop.

Method 1 proved unreliable. Previous experience with a component test indicated that an anemometer in a 0.30-m (12-in.) duct was difficult to operate but was accurate. In the mockup, however, the velocity profile across the ducts was very erratic and unrepeatable from test to test because of the elbows and short, straight duct sections in the region of the measurement location.

Method 2 proved to be a reliable approach. Each fan in the three clusters was tested for performance, and the performance curve for each cluster was calculated by adding the four individual fan curves. The derived performance data are presented in Figures 34, 35, and 36 for ducts 1, 2, and 3 (Fig. 4), respectively. The maximum performance variation from cluster to cluster was only 5 percent for normal operating conditions. At off-nominal conditions near the stall region [$\approx 11.3\ m^3/min$ ($400\ ft^3/min$)/cluster], the variation increased to 10 percent.

The cluster pressure rise was measured in the mockup by static pressure taps in the straight sections of each duct near the floor/ceiling and at the water tank level, thereby circumventing the influence of backflow through nonoperating fans.

In Method 3, the resistance data for single diffusers (Figs. 31 through 33) were utilized to calculate the combined diffuser resistance curves presented in Figures 37 through 39. The floor ΔP was easily measured in the mockup; and by using the aforementioned diffuser resistance curves, reasonably accurate flow rates were obtained except in off-nominal conditions with high flow resistances (no floor leakage).

In view of the above, Method 2 was selected as the primary method for determining flow into the aft plenum and total system resistance. Method 3 was used both as a check on the Method 2 data and on analytical approaches.

In the case of a nonoperating fan cluster, duct backflow had to be measured. Calibration of a nonoperating cluster was accomplished by:

1. Sealing all diffuser outlets in the floor and all nonoperating fans except in the test cluster

2. Operating one, two, or three fans, other than in the test cluster, at varying voltages

3. Measuring flow rate through operating fans (from fan performance curves) and the pressure drop across the test cluster.

Figure 40 presents the measured nonoperating cluster system curve under OWS mockup test conditions.

System Resistance. The mockup system flow resistance, or fan cluster pressure rise, was measured for each flow duct (Method 2) with several voltages and floor diffuser settings. The tabulated data in Tables 1 and 2 were obtained without and with circular diffuser dampers, respectively. However, fully open dampers had negligible effects on system pressure drop.

The measured system flow resistance curves with the highest and lowest resistance ducts, ducts 1 and 2, respectively, are presented in Figure 41 for two diffuser flow-pattern settings. The variation from duct to duct in system flow resistances is a maximum of about 35 percent and can be attributed to duct geometry differences. Also presented in Figure 41 is a predicted system resistance curve generated by using measured diffuser flow data and a calculated flow resistance for duct 1, the maximum resistance duct. The predicted 1 atm duct resistance curve was based on the calculated ΔP components given in Table 3 and correlated reasonably well with that measured.

The 1 atm measured floor resistance and extrapolations of the data to 0.34 atm conditions are presented in Figure 42 for several diffuser settings. The system flow resistance minus the floor resistance is approximately equal to the duct pressure drop. On this premise, indirectly measured duct resistance curves were generated and are presented in Figure 43.

The preceding data illustrate the type of variations in flow resistance that will be encountered in the OWS system. Total system resistance is, of course, important, but it should be recognized that the system flow rate does not change in direct proportion to a pressure drop shift. For example, a 20 percent increase in system resistance decreases the system flow only about 6 percent at 28 V. The effects of system resistance and other parameters on system flow are discussed in the following subsections.

TABLE 3. CALCULATED ΔP COMPONENTS

Component	ΔP at 14.1 m^3/min (500 ft^3/min)	Assumptions for Duct Geometry
Mixing chamber screen	0.747 N/m^2 (0.003 in. of water)	Duct length: 12.7 m (500 in.)
Duct inlet	0.747 N/m^2 (0.003 in. of water)	Duct diameter: 0.305 m (12 in.)
Fan cluster	8.70 N/m^2 (0.035 in. of water)	Surface roughness ϵ/D: 0.001
Duct heater	3.74 N/m^2 (0.015 in. of water)	Number of bends: 1
Duct	2.74 N/m^2 (0.011 in. of water)	
Duct bend	1.24 N/m^2 (0.005 in. of water)	
Duct outlet	2.49 N/m^2 (0.010 in. of water)	

System Flow/Nominal Conditions. It is anticipated that generally only the diffuser flow-pattern settings and fan voltage will be adjusted or vary during orbital operations; i.e., all fans will be operating and diffuser dampers are fully open, except perhaps for one or two dampers. This subsection discusses system flow capabilities assuming that these nominal conditions exist.

The flow performance of the OWS ventilation system was evaluated for various voltages and diffuser settings. The net flow rate into the aft plenum Q_T was calculated by summing the flow rates (Q1, Q2, Q3) that correspond to the measured pressure rise across each of the three clusters (Method 2). Flow rate across the floor (Q4) was based on the measured pressure drop across the floor, ΔP_4 (Method 3). The flow rates Q_T and Q_4 agreed within 9 percent although Q_T is considered more accurate.

The effect of voltage changes and diffuser settings on the delivered flow rate Q_T can be examined in Tables 1 and 2. An approximate gain of 7.1 m^3/min (250 ft^3/min) resulted from a 2-V increase in voltage. Maximum flow rate (minimum flow resistance) occurred with dampers open, sleep area diffusers open, and the circular diffusers set on a wide pattern. The measured maximum flow rates were 46.6, 54.3, and 61.0 m^3/min (1646, 1917, and 2155 ft^3/min) at 24, 28, and 32 V, respectively. A minimum flow condition of all circular diffusers set on the narrow pattern and the sleep area outlet louvers closed resulted in about a 13 percent flow decrease.

Therefore, the flow delivery capabilities of the OWS ventilation system were proven to be satisfactory and generally within anticipated limits for nominal system settings. The effects of off-nominal settings and fan backflow are discussed in the next subsection.

System Flow/Off-Nominal Conditions. Off-nominal conditions that were examined include various combinations of nonoperating fans/ducts and open/closed diffuser dampers. The system net flow rates were measured with two methods. In the case of a nonoperating duct, the backflow, (indicated as a negative flow rate in Tables 1 and 2) has been subtracted from the flow delivered to the plenum to obtain the flow across the floor, i.e., the net delivered flow Q_T. The two methods provided comparable results except when all dampers were closed. Detailed results are discussed below.

The effects of nonoperating fans within a cluster were essentially as observed in the cluster subsystem tests. The loss of one fan out of twelve resulted in an 8 percent net flow reduction. The loss of one of the three fan clusters caused a 43 to 47 percent reduction in net delivered flow. The effect of one nonoperating cluster and three fans operating in each of two clusters was a 55 to 60 percent flow rate reduction.

With all dampers/rectangular diffusers closed and 28 V to the 12 fans, a flow rate range of 36.8 to 45.3 m^3/min (1300 to 1600 ft^3/min) (depending on the diffuser pattern setting) to the crew quarters was measured. A 2-V increase will cause a flow rate increase of 4.8 m^3/min (170 ft^3/min). The worst-case flow rate at 28 V was 18.4 m^3/min (650 ft^3/min) with one nonoperating duct and all dampers/rectangular diffusers closed.

It was observed that the net flow rates Q_T and Q_4 differed by up to 29 percent in cases where all dampers/rectangular diffusers were shut. As outlined previously, the flow resistance for the eight circular diffusers was based upon the performance of a single diffuser. Apparently, the single diffuser tested had a lower resistance than the other diffusers when the damper was closed. Therefore, the ceiling flow data Q_4 in tests 103 through 108 are questionable.

In view of the preceding results, it can be concluded that the OWS system will deliver a crew area flow rate above the minimum acceptable level of 17.0 m^3/min (600 ft^3/min) even with very adverse conditions.

If desired, the system can operate with one duct shut down, and adequate backflow will be provided to maintain acceptable duct heater temperatures [flow of at least 2.8 m^3/min (100 ft^3/min) required].

The apportionment among the crew compartments of the flow across the floor and resulting crew area air velocities are discussed in the following sections.

Flow/Velocity Distribution

The flow rates and velocity distributions were observed throughout the habitable volume of the OWS for about the same range of conditions discussed in the previous section (Air Delivery). Generally, the data proved that the OWS ventilation system has sufficient flexibility to meet the range of flow and velocity conditions required for crew comfort and safety. The tests conducted on specific items and the investigations in the various crew areas are described in the following subsections.

Preliminary Tests. In order to provide baseline data, two subjects were investigated: natural convection effects and single diffuser flow profiles. Details on these investigations are outlined below.

Initial tests in the OWS mockup determined an air-velocity baseline to assure that natural convection effects on the air velocity were negligible. The OWS was left undisturbed overnight with the fans and lights deactivated. At the end of this period, the temperature was measured at seven internal locations and one external location. The maximum temperature differential was 2°C (3.6°F) from the LOX-dome apex to the mixing chamber. The measured air velocity, with no ventilation equipment operating, was below the readability of the anemometer, i.e., less than 0.3 to 0.6 m/min (1 to 2 ft/min). After 3 hr of system operation, the maximum temperature differential inside the OWS was 0.5°C (0.9°F). Convection effects on air velocity were therefore considered negligible.

A number of tests concerning flow profiles provided by the circular diffusers were conducted on an example diffuser. Figure 44 presents the range of measured velocities corresponding to a narrow pattern with 24, 28, and 32 V to the 12 fans. Only slight velocity changes occurred although a 0.56-m^3/min (20-ft^3/min) increase was produced for each 2-V increase. The average velocity ranged from 21 to 11 m/min (70 to 37 ft/min) between the floor and ceiling at 28 V. The pattern diameter was about 0.61 m (2 ft). Tests with and without the dampers installed demonstrated negligible differences in produced flow patterns. Additional data on the single diffuser narrow pattern profile are reported in Reference 1.

Two other flow patterns were visually observed, the full-wide pattern and an intermediate pattern termed the 6TW (six turns from the full-wide pattern or about halfway between the full-wide and narrow patterns). The wide pattern exited the diffuser parallel to the floor and produced a reasonably uniform low-average velocity of 4.6 to 9.1 m/min (15 to 30 ft/min) over a wide area. The effectiveness of the wide pattern was diminished somewhat because some of the flow turned through the grid into the volume beneath the floor. For maximum average velocities, the 6TW pattern appeared best. The 6TW pattern exited the diffuser at an angle of about 45 deg.

Overall flow/velocity distributions that were measured using these preliminary tests as a starting point are delineated in the subsequent subsections. However, it should be noted that the velocity profile of a diffuser can be significantly altered by the influence of obstacles. Flat surfaces (control panels and walls) near the flow stream can cause the flow to shift to a direction parallel to the flat surface and adhere to the surface for long distances, e.g., up the crew area walls to the forward plenum.

Velocity Measurements. The air velocities for each test condition were measured at 18 to 26 positions throughout the crew area (Fig. 9). At each position, measurements were made at three levels, 0.15, 0.99, and 1.83 m (6, 39, and 72 in.) above the floor. In tests 51 through 76, the velocity measurements were biased toward the low-velocity side for diffuser patterns other than the wide pattern. Therefore, velocity measurement positions above each diffuser were added in tests 97 through 121 to provide a more representative average velocity.

Work Area and Ward Room. All velocities measured in the work area and ward room are tabulated in Table 4. Figures 45 and 46 present the range of velocities available with the three ducts operating at 28 V (corresponds to 26 V in orbit) and with the sleep area diffusers fully open. The minimum velocity wide pattern (Fig. 45) provided average velocities of 7.9 and 7.0 m/min (26 and 23 ft/min) in the work area and ward room, respectively, with a flow of about 4.8 m^3/min (170 ft^3/min) per diffuser. Figure 46 presents the maximum average velocity pattern (6TW pattern) data with a flow of about 4.0 m^3/min (140 ft^3/min) per outlet. Average velocities of 16.2 and 13.1 m^3/min (53 and 43 ft/min) occurred in the ward room and work area, respectively.

The preceding velocities can be influenced by further adjustments; e.g., the wide-pattern velocities can be lowered to an average between 4.6 to 6.1 m/min (15 to 20 ft/min) by shutting off one duct (test 59, Table 4). The maximum velocities can be increased about 14 percent, and the diffuser flow increased 25 to 30 percent by closing the sleep area outlets.

Tests were conducted at the maximum operating voltage of 32 V (30 V in orbit), and the results of the wide- and intermediate- (6TW) pattern tests are presented in Figures 47 and 48, respectively. The intermediate- and wide-pattern average velocities for the work/ward areas increased about 21 and 7 percent, respectively, when compared with the same conditions at 28 V. The delivered flow rate increased 10 and 20 percent for the intermediate and wide patterns, respectively.

Air velocities corresponding to the unlikely low flow rate condition of one nonoperating duct, sleep area diffusers closed and circular diffuser dampers closed, were also measured. An average crew area air velocity of 9.1 m/min (30 ft/min) occurred for both 24 and 32 V with the circular diffusers set at a 6TW pattern. Velocities away from the diffuser jet streams[2] ranged from 4.6 to 6.1 m/min (15 to 20 ft/min). The corresponding flows through each diffuser were about

2. The diffuser dampers do not completely shut off the flow. Therefore, with all outlets closed, a high-plenum pressure results and forces a high-velocity flow past the dampers.

TABLE 4. AIR VELOCITY DATA

Test C-091	Air Velocity (m/min)																								
	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}	V_{17}	V_{18}	V_{19}	V_{20}	V_{21}	V_{22}	V_{23}	V_{24}	V_{avg}
- 51	10.7 3.1 9.1	6.1 12.2 9.1	6.1 6.1 6.1	45.7 15.2 1.5	0 0 10.7	12.2 9.1 6.1	12.2 6.1 4.6	12.2 6.1 6.1	6.1 3.1 6.1	9.1 6.1 6.1	15.2 12.2 6.1	13.7 6.1 4.6	6.1 3.1 9.1	6.1 12.2 10.7	3.1 9.1 4.6	12.2 1.5 1.5	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	11.0 7.4 6.1
- 52	13.7 13.7 10.7	1.5 0 7.6	4.6 0 3.1	6.1 1.5 1.5	10.7 1.5 4.6	16.8 12.2 6.1	12.2 15.2 3.1	30.5 12.2 12.2	6.1 6.1 15.2	6.1 3.1 3.1	12.2 6.1 3.1	12.2 10.7 1.5	6.1 9.1 3.1	9.1 6.1 6.1	3.1 3.1 9.1	12.2 6.1 3.1									10.1 7.0 5.9
- 53	4.6 6.1 12.2	12.2 9.1 4.6	3.1 4.6 7.6	15.2 6.1 6.1	NMT	6.1 6.1 3.1	6.1 3.1 4.6	13.7 15.2 7.6	4.6 6.1 3.1	4.6 6.1 6.1	3.1 3.1 22.9	3.1 4.6 10.7	7.6 12.2 6.1	4.6 3.1 9.1	7.6 6.1 15.2	6.1 9.1 6.1									6.8 6.7 8.3
- 54	3.1 3.1 6.1	6.1 4.6 1.5	6.1 4.6 4.6	6.1 3.1 3.1		3.1 4.6 4.6	6.1 3.1 3.1	15.2 9.1 6.1	6.1 10.7 9.1	6.1 6.1 6.1	6.1 15.2 27.4	4.6 4.6 12.2	4.6 3.1 4.6	9.1 4.6 7.6	10.7 6.1 9.1	1.5 1.5 15.2									6.3 5.6 8.0
- 55	9.1 9.1 3.1	12.2 6.1 12.2	24.4 6.1 6.1	30.5 3.1 9.1		9.1 10.7 3.1	3.1 9.1 6.1	6.1 3.1 15.2	6.1 12.2 9.1	6.1 3.1 12.2	6.1 12.2 13.7	3.1 6.1 9.1	9.1 12.2 6.1	6.1 4.6 9.1	12.2 12.2 4.6	3.1 6.1 9.1									9.8 7.7 8.5
- 56	3.1 6.1 9.1	3.1 6.1 3.1	6.1 3.1 1.5	3.1 3.1 3.1		3.1 3.1 9.1	4.6 6.1 6.1	6.1 9.1 15.2	13.7 12.2 10.7	3.1 3.1 12.2	4.6 10.7 32.0	4.6 4.6 18.3	7.6 6.1 9.1	3.1 3.1 6.1	12.2 12.2 12.2	1.5 1.5 24.4									5.3 7.0 10.7
- 57	4.6 6.1 4.6	12.2 3.1 1.5	6.1 3.1 4.6	12.2 3.1 3.1		4.6 7.6 3.1	6.1 4.6 3.1	7.6 7.6 15.2	3.1 7.6 9.1	3.1 3.1 15.2	3.1 3.1 9.1	6.1 3.1 7.6	6.1 3.1 3.1	4.6 6.1 6.1	9.1 6.1 6.1	4.6 6.1 6.1									6.4 4.9 6.6
- 58	4.6 9.1 3.1	9.1 6.1 3.1	18.3 3.1 1.5	15.2 6.1 6.1		6.1 7.6 3.1	4.6 7.6 7.6	6.1 6.1 15.2	6.1 12.2 10.7	3.1 3.1 6.1	6.1 9.1 24.4	3.1 12.2 3.1	4.6 3.1 6.1	3.1 6.1 4.6	12.2 15.2 12.2	7.6 3.1 16.8									7.3 7.3 8.2
- 59	4.6 6.1 6.1	6.1 6.1 4.6	15.2 6.1 4.6	24.4 4.6 4.6		3.1 3.1 4.6	4.6 4.6 4.6	15.2 18.3 12.2	4.6 6.1 3.1	4.6 6.1 4.6	4.6 3.1 19.8	3.1 3.1 6.1	4.6 9.1 6.1	3.1 3.1 6.1	4.6 6.1 4.6	3.1 3.1 6.1									7.0 5.9 6.5
- 60	3.1 4.6 4.6	12.2 3.1 3.1	18.3 4.6 4.6	18.3 6.1 6.1		1.5 3.1 3.1	3.1 3.1 4.6	6.1 6.1 6.1	9.1 4.6 6.1	4.6 1.5 4.6	7.6 6.1 24.4	3.1 12.2 1.5	3.1 4.6 12.2	3.1 3.1 12.2	3.1 3.1 3.1	6.1 4.6 9.1									6.8 4.6 7.0
- 61	3.1 4.6 9.1	3.1 3.1 1.5	6.1 3.1 3.1	0 12.2 3.1		3.1 6.1 12.2	12.2 6.1 9.1	3.1 9.1 27.4	7.6 9.1 6.1	3.1 9.1 7.6	12.2 15.2 27.4	3.1 3.1 15.2	3.1 9.1 6.1	3.1 9.1 24.4	12.2 12.2 15.2	6.1 4.6 15.2									6.2 7.7 12.2
- 62	9.1 6.1 6.1	3.1 18.3 12.2	12.2 9.1 3.1	30.5 6.1 1.5	NMT	3.1 3.1 12.2	1.5 3.1 3.1	21.3 9.1 9.1	12.2 3.1 1.5	4.6 9.1 15.2	6.1 6.1 24.4	6.1 6.1 9.1	6.1 3.1 9.1	6.1 3.1 18.3	6.1 3.1 6.1	3.1 9.1 9.1	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	8.7 6.5 9.3

TABLE 4. AIR VELOCITY DATA (Continued)

Test C-091	Air Velocity (m/min)																							
	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}	V_{17}	V_{18}	V_{19}	V_{20}	V_{21}	V_{22}	V_{23}	V_{24}	V_{avg}
63	3.1 9.1 6.1	6.1 3.1 3.1	6.1 1.5 6.1	3.1 6.1 3.1	NMT	3.1 4.6 6.1	6.1 6.1 3.1	21.3 7.6 15.2	4.6 4.6 1.5	6.1 6.1 4.6	15.2 4.6 18.3	6.1 18.3 9.1	3.1 6.1 3.1	1.5 12.2 24.4	1.5 3.1 12.2	6.1 6.1 18.3	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	6.2 6.2 9.1
-67	3.1 3.1 3.1	18.3 6.1 6.1	18.3 6.1 6.1	6.1 3.1 6.1		4.6 3.1 3.1	3.1 3.1 3.1	9.1 6.1 6.1	7.6 3.1 1.5	4.6 3.1 9.1	3.1 3.1 19.8	4.6 4.6 3.1	4.6 6.1 10.7	4.6 4.6 9.1	6.1 4.6 9.1	9.1 6.1 9.1									7.1 4.4 7.0
-68	4.6 9.1 9.1	6.1 4.6 3.1	6.1 7.6 4.6	6.1 6.1 6.1		3.1 6.1 6.1	6.1 6.1 6.1	24.4 15.2 12.2	6.1 9.1 6.1	3.1 3.1 6.1	7.6 4.6 3.1	4.6 6.1 6.1	6.1 3.1 10.7	6.1 6.1 15.2	4.6 3.1 10.7	9.1 7.6 9.1									6.9 6.5 7.6
-72	6.1 4.6 4.6	10.7 4.6 3.1	3.1 6.1 7.6	10.7 6.1 6.1		6.1 6.1 6.1	9.1 4.6 3.1	12.2 13.7 15.2	6.1 6.1 1.5	6.1 6.1 4.6	6.1 6.1 12.2	6.1 6.1 4.6	6.1 7.6 6.1	6.1 6.1 4.6	6.1 7.6 6.1	6.1 6.1 12.2									7.1 6.5 6.5
-73	6.1 6.1 6.1	6.1 6.1 4.6	6.1 4.6 6.1	12.2 4.6 3.1		6.1 6.1 7.6	7.6 6.1 1.5	15.2 13.7 15.2	6.1 9.1 1.5	6.1 6.1 6.1	6.1 6.1 18.3	6.1 6.1 6.1	6.1 6.1 7.6	6.1 6.1 4.6	6.1 9.1 3.1	6.1 4.6 12.2									7.2 6.7 6.9
-74	7.6 3.1 12.2	6.1 6.1 4.6	6.1 6.1 4.6	6.1 9.1 3.1		6.1 9.1 12.2	6.1 6.1 6.1	12.2 6.1 12.2	6.1 9.1 7.6	6.1 9.1 6.1	9.1 15.2 27.4	6.1 6.1 10.7	6.1 6.1 6.1	6.1 6.1 9.1	9.1 9.1 9.1	4.6 6.1 9.1									6.9 7.5 9.3
-76	4.6 4.6 13.7	6.1 6.1 4.6	4.6 4.6 3.1	6.1 4.6 3.1		6.1 3.1 3.1	6.1 6.1 4.6	15.2 15.2 15.2	4.6 6.1 6.1	12.2 9.1 7.6	21.3 12.2 6.1	7.6 4.6 3.1	6.1 6.1 6.1	6.1 6.1 4.6	9.1 6.1 6.1	6.1 3.1 3.1									8.1 6.5 6.0
-83	NMT	91.4^+ 91.4^+ NMT	91.4^+ 91.4^+ NMT	91.4^+ 76.2^+ NMT		NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT									NMT
-85		91.4 91.4 NMT	91.4^+ 91.4^+ NMT	91.4^+ 91.4^+ NMT																					
-86		137.2 137.2 NMT	137.2 137.2 NMT	137.2 152.0 NMT																					
-87		152.0 213.4 NMT	159.6 137.2 NMT	137.2 152.0 NMT																					
-88	NMT	167.6 185.8 NMT	137.2 259.0 NMT	152.0 198.1 NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT	NMT

TABLE 4. AIR VELOCITY DATA (Concluded)

Test C-091	Air Velocity (m/min)																								
	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}	V_{17}	V_{18}	V_{19}	V_{20}	V_{21}	V_{22}	V_{23}	V_{24}	V_{avg}
- 97	12.2 3.1 3.1	NMT	NMT	NMT	NMT	3.1 6.1 9.1	6.1 6.1 4.6	19.8 15.2 9.1	12.2 10.7 4.6	4.6 6.1 3.1	13.7 6.1 3.1	12.2 6.1 6.1	12.2 6.1 18.3	3.1 9.1 9.1	4.6 6.1 15.2	6.1 6.1 6.1	4.6 12.2 18.3	6.1 6.1 21.3	27.4 54.9 61.0	30.5 45.7 61.0	4.6 12.2 15.2	3.1 9.1 18.3	6.1 27.4 57.9	6.1 12.2 30.5	9.9 14.8 18.7
- 98	4.6 9.1 12.2					9.1 10.7 7.6	6.1 16.8 9.1	39.6 27.4 9.1	6.1 6.1 6.1	6.1 6.1 12.2	6.1 12.2 18.3	9.1 4.6 12.2	6.1 12.2 18.3	12.2 15.2 9.1	3.1 6.1 15.2	9.1 9.1 9.1	6.1 18.3 24.4	7.6 9.1 30.5	27.4 61.0 45.7	33.5 45.7 61.0	6.1 12.2 24.4	4.6 12.2 18.3	15.2 33.5 76.2	12.2 18.3 32.0	11.5 17.3 22.6
- 99	6.1 12.2 12.2					4.6 12.2 10.7	6.1 21.3 13.7	39.6 30.5 12.2	9.1 4.6 9.1	6.1 9.1 12.2	6.1 12.2 30.5	13.7 12.2 12.2	6.1 12.2 6.1	6.1 6.1 13.7	4.6 21.3 12.2	13.7 12.2 9.1	9.1 18.3 29.0	12.2 12.2 24.4	33.5 61.0 51.8	48.8 67.1 76.2	12.2 15.2 45.7	9.1 12.2 15.2	18.3 39.6 91.4	12.2 24.4 30.5	13.9 20.8 25.9
*-103	12.2					4.6	12.2	6.1	12.2	4.6	21.3	6.1	6.1	12.2	6.1	6.1	4.6	4.6	24.4	15.2	27.4	30.5	33.5	30.5	14.0
*-105	3.1					4.6	12.2	4.6	3.1	3.1	7.6	6.1	6.1	6.1	4.6	3.1	9.1	4.6	18.3	9.1	19.8	33.5	24.4	27.4	10.5
*-106	1.5					4.6	4.6	3.1	6.1	3.1	3.1	4.6	6.1	3.1	9.1	6.1	6.1	24.4	21.3	18.3	12.2	18.3	6.1	21.3	9.1
*-108	3.1					3.1	3.1	3.1	6.1	3.1	9.1	4.6	12.2	3.1	12.2	4.6	10.7	16.8	18.3	13.7	18.3	15.2	12.2	21.3	9.3
-120	3.1 10.7 1.5					7.6 4.6 12.2	4.6 4.6 3.1	18.3 12.2 13.7	7.6 1.5 6.1	4.6 6.1 15.2	6.1 6.1 12.2	6.1 3.1 16.1	3.1 1.5 27.4	6.1 4.6 6.1	6.1 6.1 12.2	4.6 6.1 9.1	4.6 4.6 13.7	18.3 7.6 21.3	16.8 25.9 24.4	6.1 4.6 15.2	6.1 4.6 18.3	6.1 4.6 13.7	4.6 3.1 15.2	3.1 3.1 12.2	7.2 6.2 13.0
-121	6.1 12.2 13.7					6.1 4.6 6.1	4.6 6.1 9.1	6.1 3.1 9.1	6.1 9.1 4.6	6.1 4.6 4.6	6.1 6.1 6.1	4.6 3.1 6.1	6.1 3.1 6.1	6.1 4.6 6.1	7.6 4.6 12.2	6.1 4.6 4.6	6.1 6.1 12.2	4.6 3.1 12.2	12.2 24.4 21.3	3.1 6.1 13.7	6.1 4.6 15.2	4.6 4.6 13.7	4.6 3.1 24.4	6.1 4.6 13.7	5.9 6.1 10.7
-128	NMT ↕ NMT	NMT	NMT	NMT	NMT	6.1 3.1 6.1	3.1 6.1 6.1	13.7 4.6 7.6	NMT ↕ NMT	NMT ↕ NMT	NMT ↕ NMT	NMT ↕ NMT	NMT ↕ NMT	NMT ↕ NMT	NMT ↕ NMT	NMT ↕ NMT	6.1 12.2 24.4	29.0 19.8 21.3	3.1 12.2 30.5	NMT ↕ NMT	NMT ↕ NMT	NMT ↕ NMT	NMT ↕ NMT	NMT ↕ NMT	

NOTES:
1. NMT denotes no measurement taken.
2. * indicates measurements at 0.99 m (39 in.) level only.
3. Top-line measurements in each test made 0.15 m (6 in.) below floor/ceiling.
4. Middle-line measurements in each test made 0.99 m (39 in.) level.
5. Bottom-line measurements in each test made 0.15 m (6 in.) above floor.
6. Dampers installed in tests -103 and on.

2.3 m^3/min (80 ft^3/min) and 3.0 m^3/min (105 ft^3/min) at 24 and 32 V, respectively.

The preceding data indicate that an average velocity range from about 4.6 to 14 m/min (15 to 45 ft/min) could be obtained with the minimum OWS operating voltage. Velocities in excess of 14 m/min (45 ft/min) can be provided in localized areas near diffusers and/or by using portable fans.

Sleep Area. Each sleep area diffuser contains three independent adjustable louvers that can limit flow rate and direct the jet stream.

The velocities measured at the three positions in the sleep area are given in Table 4. Using 28 V with three ducts operating as an example condition, the following observations can be made. With the louvers open, the flow rate per diffuser was about 4.2 to 6.8 m^3/min (150 to 240 ft^3/min) depending upon the circular diffuser settings. The range of velocities within and outside the jet stream were 137 to 247 m/min (450 to 810 ft/min) and 6 to 9 m/min (20 to 30 ft/min), respectively. With the louvers closed, a flow range of 0.56 to 2.0 m^3/min (20 to 70 ft^3/min) occurs with compartment velocities of 3.0 to 4.6 m/min (10 to 15 ft/min).

Since the diffuser can provide such a wide range of flow rates and velocities and the flow can be directed toward or away from the sleeping bag, suitable velocities for crew comfort should be present.

Waste Management Area. The waste management area (WMA) has a single diffuser and independent operating exhaust fan to provide ventilation. In the early portion of the test program, the WMA diffuser contained a 0.098-m (3.875-in.) orifice. Velocity tests in the WMA indicated that inadequate velocities existed in the WMA because of the low flow rate through the high-resistance orifice; therefore, the orifice was replaced with a damper, and the WMA ventilation system was retested. Throughout the WMA tests it was noted that leakage into and out of the WMA affected the relative flows through the diffuser and exhaust fan; i.e., flow through the diffuser varied while fan flow remained essentially constant.

The flow rates through the diffuser and exhaust fan were about 3.1 m^3/min (110 ft^3/min) and 3.7 m^3/min (132 ft^3/min), respectively, at 28 V with the orifice in the diffuser. With diffuser patterns of wide to narrow, the resulting average velocities ranged from 4 to 7.3 m/min (13 to 24 ft/min)[3] (Fig. 49).

3. These average velocities do not include the localized high velocities near the exhaust fan.

Replacement of the orifice with an open circular diffuser damper increased the diffuser flow rate range to 4.2 to 4.7 m^3/min (150 to 165 ft^3/min) at 28 V while the fan flow was 3.9 m^3/min (138 ft^3/min). The corresponding average velocity was about 9.1 m/min (30 ft/min)[4] with a 6TW diffuser setting (Fig. 50). With the damper closed an average velocity of 7.0 m^3/min (23 ft/min)[4] and a diffuser flow of 2.6 m^3/min (90 ft^3/min) occurred.

The flow rate through the WMA when the exhaust fan is not operating is presented in Figure 51 for 1 and 0.34 atm with the WMA door closed. Under nominal conditions at 28 V, 1 atm, there will be approximately 0.85 m^3/min (30 ft^3/min) through the diffuser. Less than 0.85 m^3/min (30 ft^3/min) will pass through the filter because of leakage. When the WMA door is open, the diffuser will flow at a rate corresponding to the single diffuser performance curve (Fig. 30) and the floor pressure drop.

In summary, adequate velocity and flow ranges were achieved with the damper installed in the diffuser. However, it should be noted that the open diffuser allowed slight compartment pressurization and forced leakage out of the compartment. With an orifice in the diffuser, the leakage was into the compartment. If necessary, the damper can be partially closed so that the fan and diffuser flow are more equally balanced. It should also be noted that the flight unit WMA may be better sealed than the mockup unit tested.

Forward Plenum. Ventilation of the forward plenum area was of special concern since the effectiveness of the crew area diffusers above the floor/ceiling was questionable and the forward plenum area is a relatively large volume [184 m^3 (6500 ft^3)]. It was anticipated that velocities adequate for crew comfort would have to be provided by the portable fans. Hence, the general objective of the forward plenum test was to evaluate air-velocity distribution produced with and without the portable fans. The velocity survey was not as detailed as in the crew area since a relatively small portion of the crew work load was expected for the forward plenum.

Tests were conducted first without the portable fans. The velocities measured with the crew area diffusers set on the wide and narrow patterns are presented in Figures 52 and 53, respectively. Average velocities ranged from 7.9 to 16.5 m/min (26 to 54 ft/min) with the wide and narrow (5TN) settings, respectively, at the positions measured. Since positions above the diffusers were emphasized, the narrow-pattern average velocities must be considered on the "high side." The velocity in the region above the sleep area was

4. These average velocities do not include the localized high velocities near the exhaust fan.

approximately 30.5 m/min (100 ft/min) when the sleep area diffusers were wide open. It was noted during the testing that in the region above the water tank level (about 3.05 m) the average velocity rapidly decreased to bulk velocity [about 0.9 to 1.5 m/min (3 to 5 ft/min)].

The air velocities measured with only the three portable fans operating are presented in Figure 54. As illustrated in Figure 54, the fans were installed on the floor of the forward plenum and directed across the OWS at the water tanks. An average velocity of 9.8 to 11.9 m/min (32 to 39 ft/min) was measured outside the fan jet stream. The portable fans had no attachments to diffuse the flow; therefore, a narrow, high-velocity jet stream was produced and is depicted in Figure 55.

Testing with three portable fans and three fan clusters operating was restricted since only thirteen fans were available. Therefore, a test was conducted with four fans in two clusters and two fans in the third cluster with the vacant fan holes sealed. The cluster fans were operated at 32 V to simulate the flow rate produced by twelve fans operating at 28 V. Figure 56 presents the measured velocities. An average velocity of 13.7 to 16.8 m/min (45 to 55 ft/min) was measured outside the portable fan jet stream. The installation of diffusers on the flight portable fans should significantly increase their effectiveness and utilization.

Several experiments in the forward plenum area require a low, uniform ventilation velocity for correct experiment operation. To obtain a low, uniform stable velocity requires that the sleep area diffusers be closed and the the work area and ward room diffusers be set for a full-wide pattern. The average measured velocity at 28 V, wide pattern, was 7.9 m/min (26 ft/min) with three fan clusters operating. By shutting down one fan cluster, an average velocity of about 4.6 m/min (15 ft/min) can be produced.

In summary, at a level up to 3.05 m (10 ft) above the floor/ceiling, the crew area diffusers provide generally acceptable ventilation. However, above the 3.05-m (10-ft) level the velocities rapidly decrease to the average bulk velocity of 0.9 to 1.5 m/min (3 to 5 ft/min). If higher velocities are required above the 3.05-m (10-ft) level, the portable fans must be utilized. Also, the portable fans can be used effectively to supplement the ventilation provided by the crew area diffusers.

CONCLUSIONS

The workshop Anemostat diffuser flow patterns and velocities are essentially the same in 1 and 0.34 atms. Pressure drop across the diffuser can be scaled from 1 to 0.34 atms using the atmospheric density ratio. If the diffuser is to be mounted on a smooth surface then at least a 0.0016-m (1/16-in.) spacer (between diffuser and surface) is required for stable narrow-pattern flow. The addition of a properly designed bellmouth inlet to a plenum-mounted diffuser/inlet duct system can result in a 23 percent reduction in the diffuser resistance. Diffusers connected to a supply duct require flow straighteners to produce symmetrical stable flow patterns.

The operating voltage for the Skylab is 28 ±2 V. Individual fan tests demonstrated that the performance at 28 V, 1 atm corresponds approximately to the 0.34-atm fan performance at 26 V corrected to 1 atm. Thus, OWS tests at 28 V, 1 atm simulate volumetric flow and velocities at 26 V, 0.34 atm.

Single- and multiple-fan tests demonstrated that the performance of four fans in parallel is essentially equal to the sum of the four individual fan performance curves for either 0.34 or 1 atm. In a four-fan cluster, backflow through nonoperating fans sharply decreases cluster performance. The loss of one fan results in a 30 to 40 percent decrease in cluster flow rate from that of four fans operating either at 1 or 0.34 atm or a 8 percent reduction in total delivered flow from that of twelve fans operating. Two fans backflowing result in a 50 to 75 percent reduction in the cluster flow rate. The loss of one fan cluster out of three results in a 43 to 47 percent reduction in net delivered flow.

Attempts to use an anenometer to measure the velocity inside the 0.30-m (12-in.) supply ducts proved unsuccessful. This was caused by the unstable, turbulent flow patterns within the ducting. It is anticipated that similar problems may be encountered with the turbine flowmeter being utilized in the OWS flight system. Therefore, caution must be used in flight system calibration and data interpretation.

Work Area and Ward Room

The grid floor interfered with the wide-flow pattern distribution and, thereby, degraded the system performance relative to the performance that would have existed with a smooth floor. For normal operating conditions (28 V, 12 fans operating, and all diffusers and dampers open) the wide-pattern setting produced an average velocity of 7.0 to 7.9 m/min (23 to 26 ft/min) at a total flow rate of 54.9 m^3/min (1940 ft^3/min).

The highest average velocity was produced by an intermediate diffuser pattern of six turns from the wide pattern. For normal operating conditions, an average velocity of 13.1 and 16.2 m/min (43 and 53 ft/min) occurred in the work area and ward room, respectively, at a total flow rate of 54.4 m^3/min (1920 ft^3/min). By shutting off the sleep area diffusers, the average velocity increased by about 14 percent at flow rate of 50.7 m^3/min (1790 ft^3/min).

The shutdown of one four-fan cluster indicated no flow rate or ventilation problem from a safety standpoint. The loss of one fan cluster reduced the average velocity 10 to 30 percent. The closing of one or all the circular diffuser dampers does not decrease the flow or velocity sufficiently to be a problem. The lowest average velocity can be produced by one four-fan cluster off, dampers closed, sleep area diffusers open, and circular diffusers on wide pattern. With such conditions average velocity at 28 V is estimated to be 4.6 to 6.1 m/min (15 to 20 ft/min) at a flow rate of 19.8 m^3/min (700 ft^3/min) across the floor.

Forward Plenum

With the crew quarter diffusers set on a wide pattern, the average velocity was 7.9 to 9.1 m/min (26 to 30 ft/min) (for 28 to 32 V) about 1.5 m above the floor. The average velocity rapidly decreased to the bulk velocity [0.9 to 1.5 m/min (3 to 5 ft/min)] above the water tanks (about 3.05 m above the floor).

The five turns from the narrow diffuser pattern produced the highest forward plenum velocity without portable fans. Measured velocities ranged from 9.1 to 16.5 m/min (30 to 54 ft/min). Velocity measurements with three portable fans only were 9.8 to 11.9 m/min (32 to 39 ft/min) outside the fan jet stream. With circular diffusers and portable fans operating simultaneously, an average velocity of 13.7 to 16.8 m/min (45 to 55 ft/min) was produced. Portable fans can supply above 30.5 m/min (100 ft/min) at any localized area.

WMA

The average velocity in the WMA with an orificed diffuser was 6.1 m/min (20 ft/min) with a flow rate of 2.9 to 3.1 m^3/min (104 to 110 ft^3/min.

The replacement of the orifice with a damper resulted in an average velocity of 9.0 m/min (30 ft/min) with a flow rate of 4.2 to 4.7 m^3/min (150 to 165 ft^3/min). It was noted that the flow through the WMA exhaust fan was essentially constant [3.7 to 3.9 m^3/min (132 to 138 ft^3/min)] for both diffuser configurations.

Sleep Area

With the sleep area diffuser open, the average velocities outside and within the diffuser jet stream were 7.6 m/min (25 ft/min) and 159 m/min (520 ft/min), respectively. The corresponding volume flow rate ranged from 4.2 to 6.8 m^3/min (150 to 240 ft^3/min). With the diffuser louvers shut, the flow rate and average velocity was about 0.56 m^3/min (20 ft^3/min) and 3.7 m/min (12 ft/min), respectively.

Data Application

Duplication in the actual OWS of the compartment flow and velocity distributions presented herein is dependent on maintaining similarity of aft plenum pressure or floor ΔP. The mockup data should not be directly applied to the OWS without first satisfying this criteria.

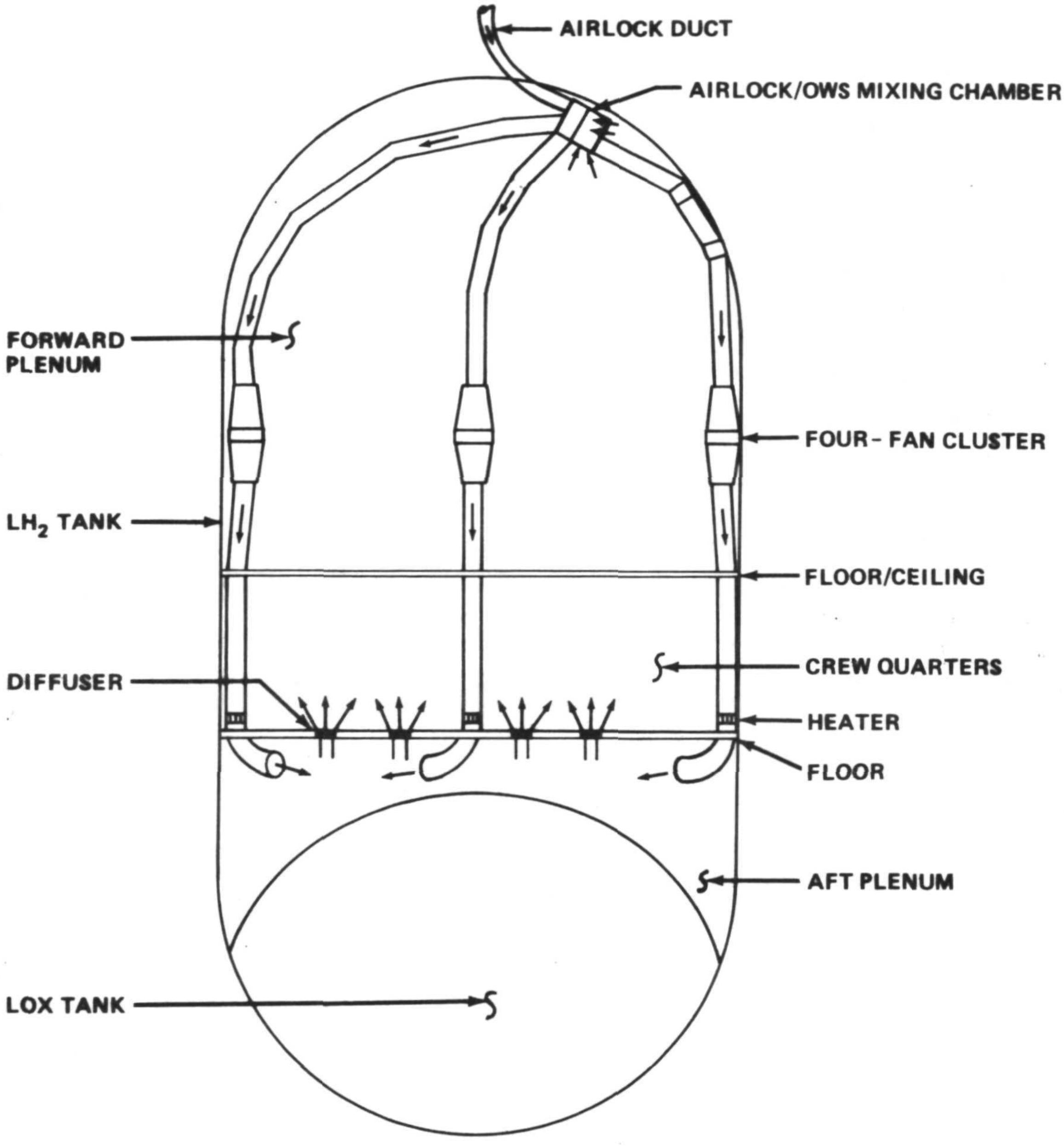


Figure 1. Orbital Workshop ventilation system.

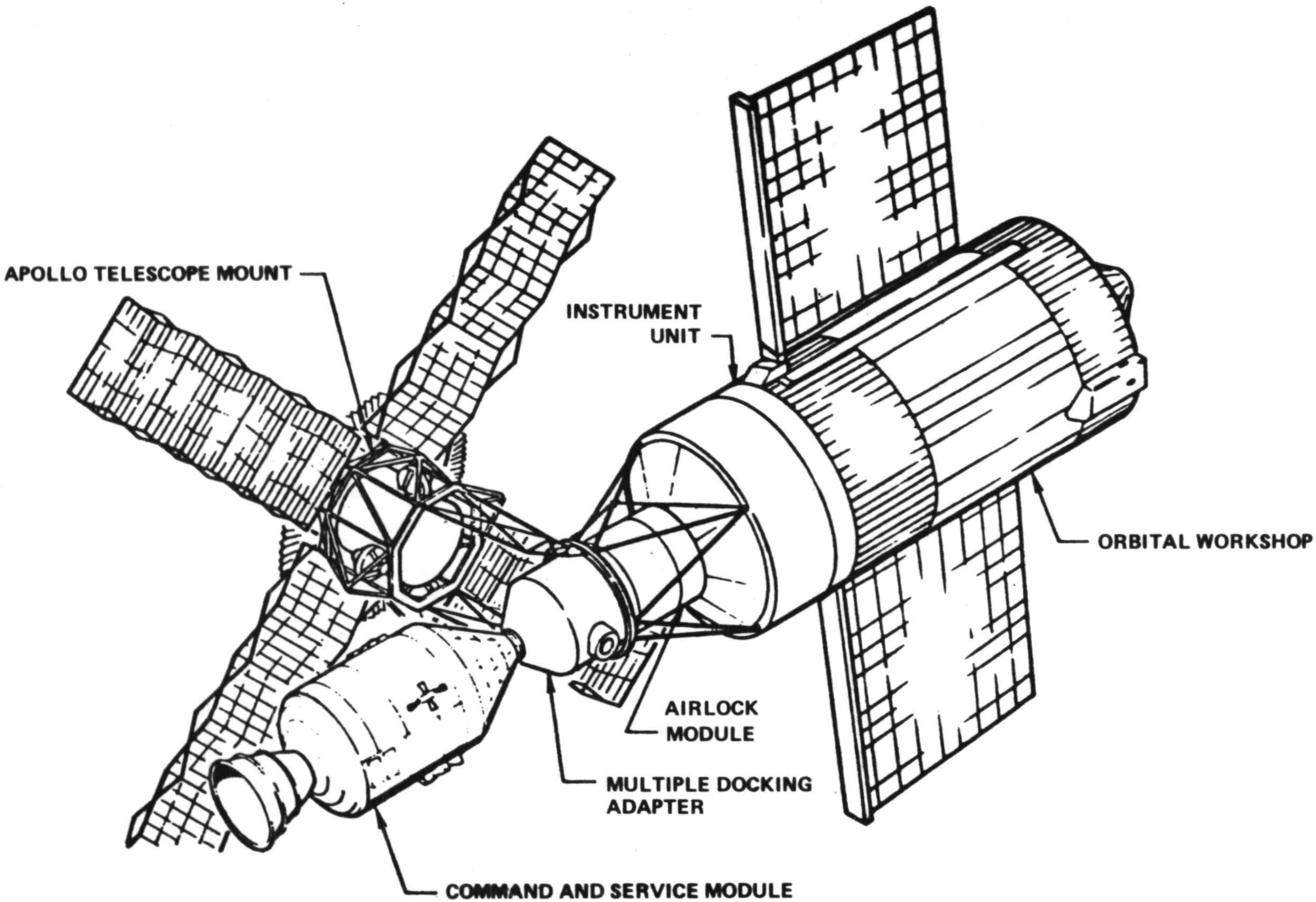


Figure 2. Skylab orbital assembly.

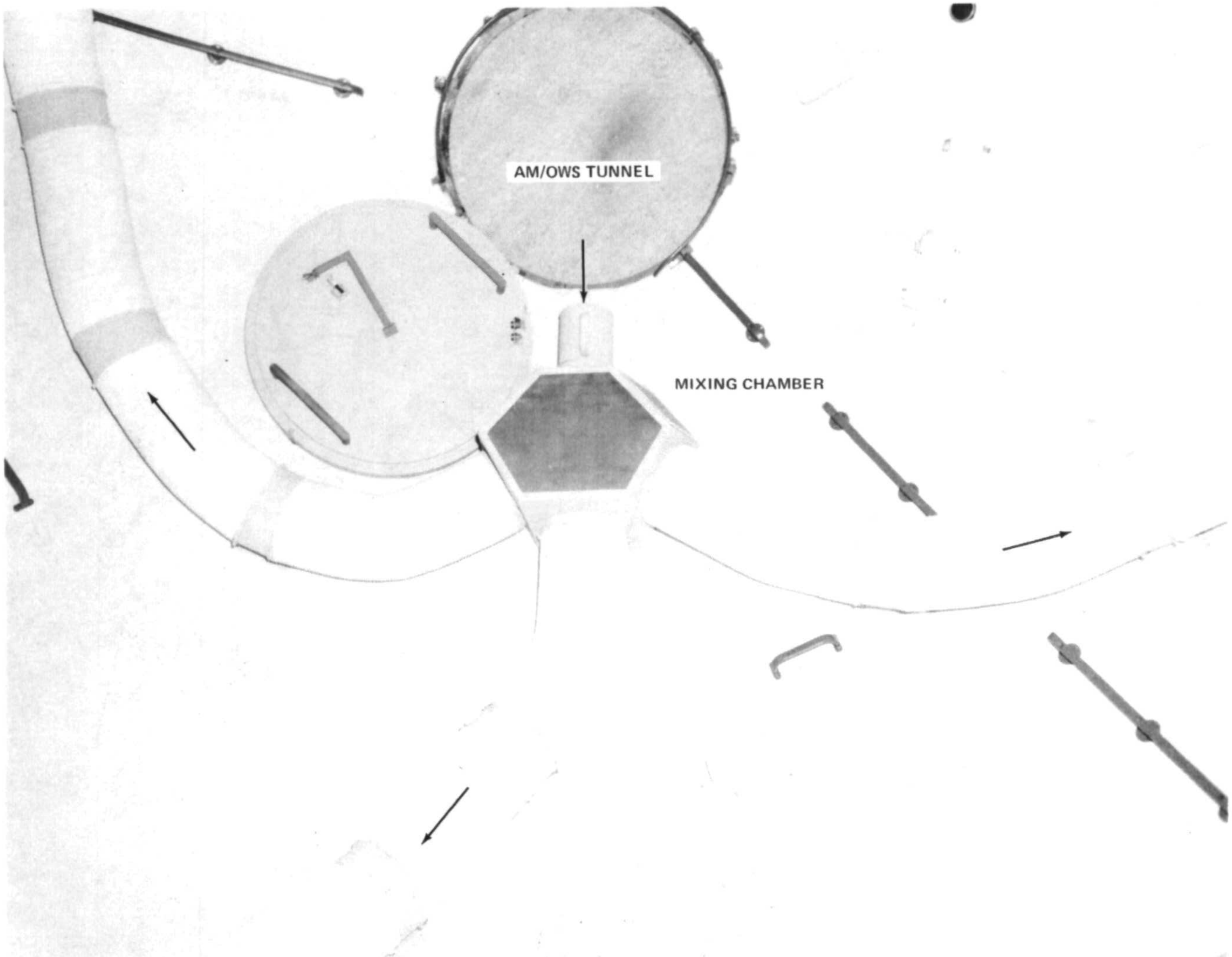
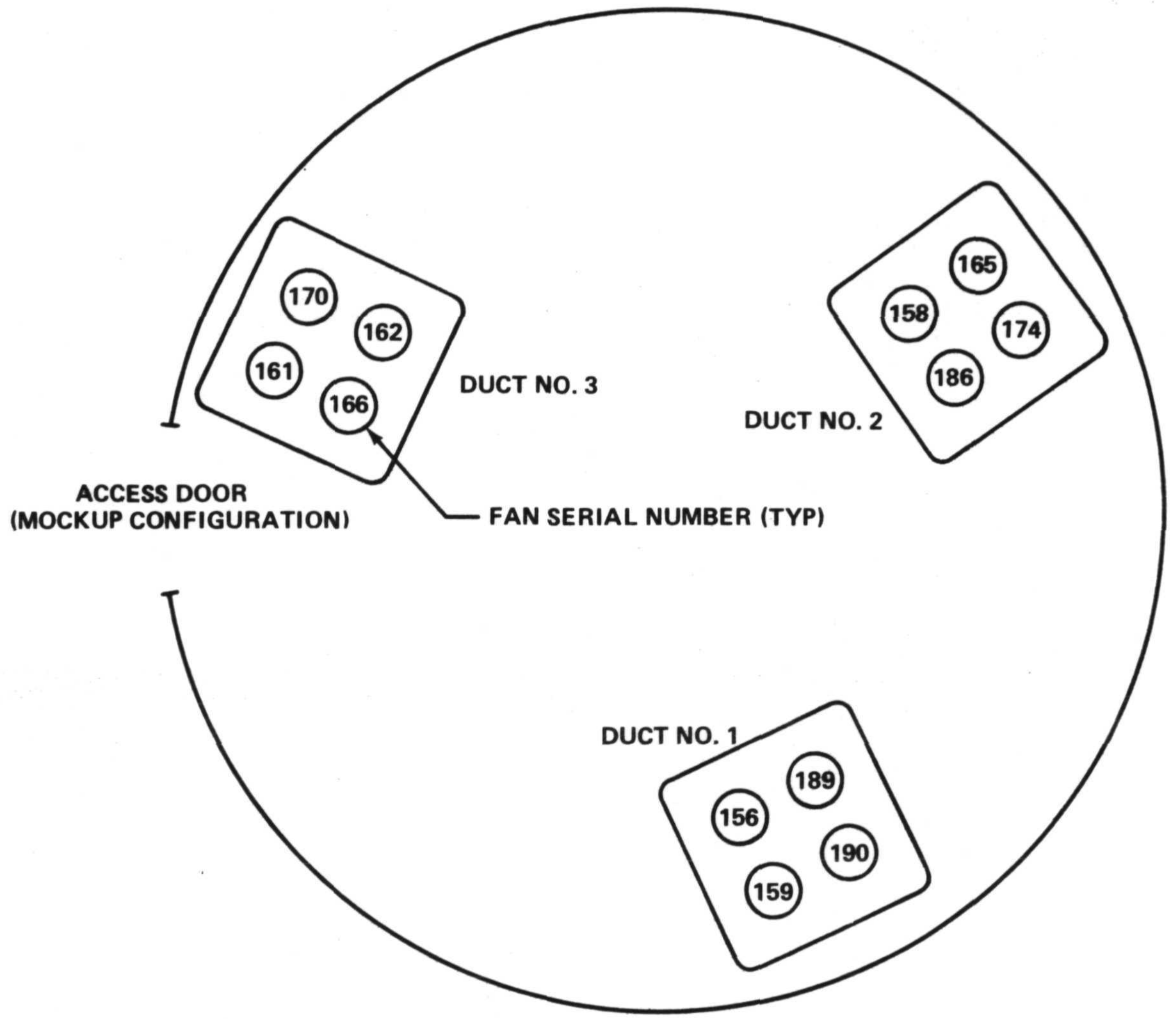


Figure 3. Mixing chamber and forward plenum ducting.



NOTE: FANS S/N 97-154 & 97-164
USED AS PORTABLE FANS

Figure 4. Fan/cluster location and designation.

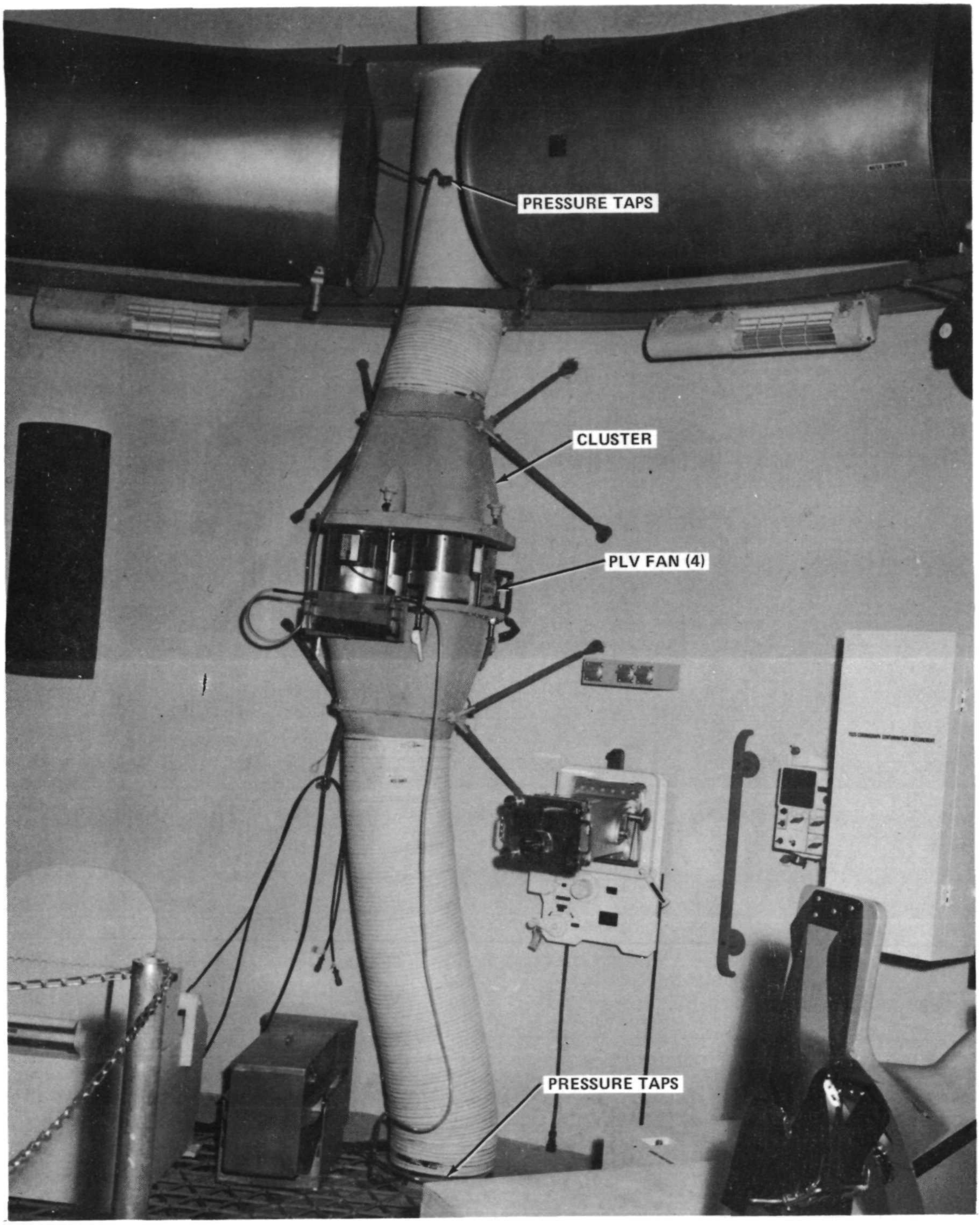


Figure 5. Typical four-fan cluster.

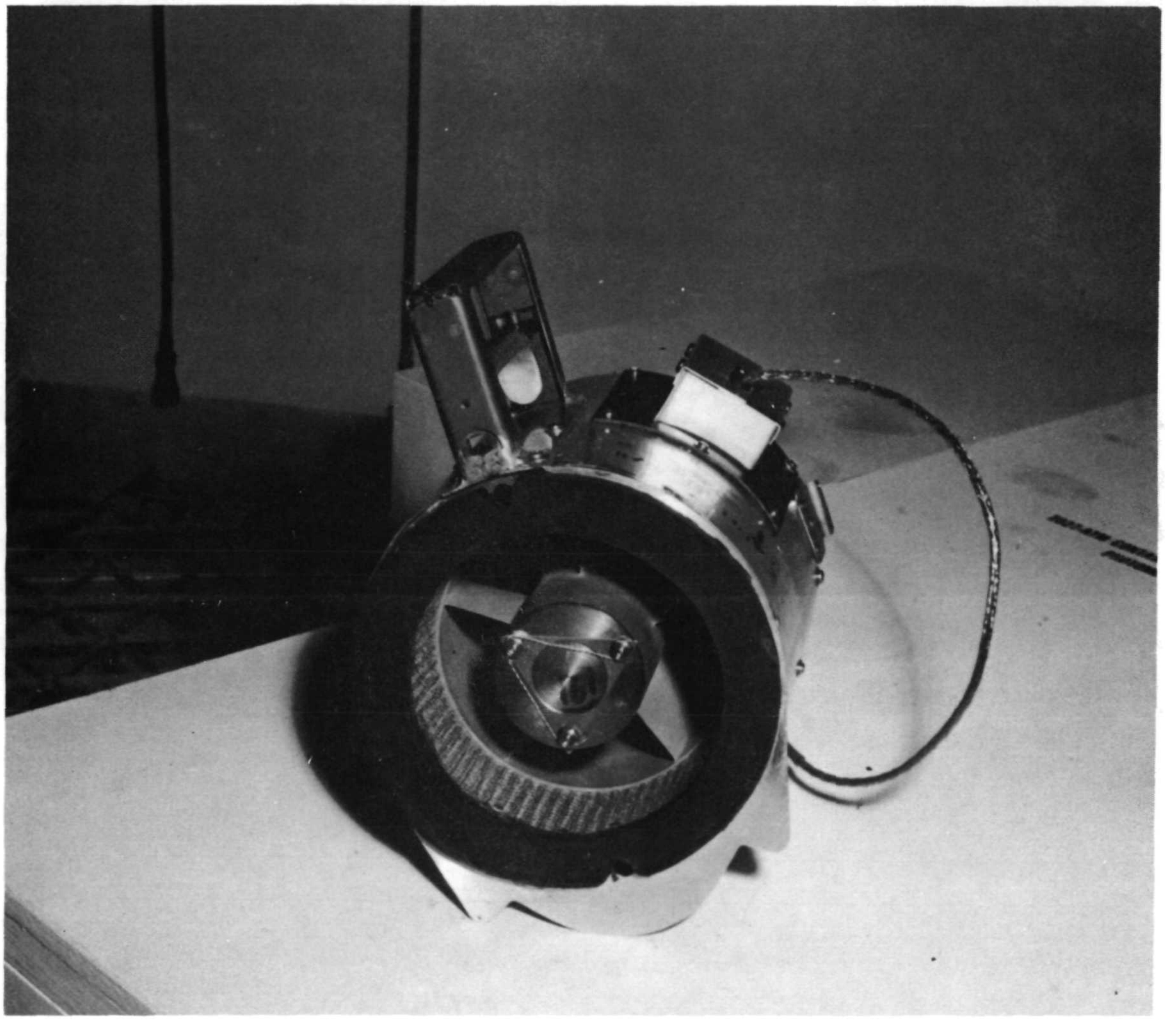


Figure 6. Shrouded PLV fan.

Figure 7. Six-inch Anemostat circular diffusers.

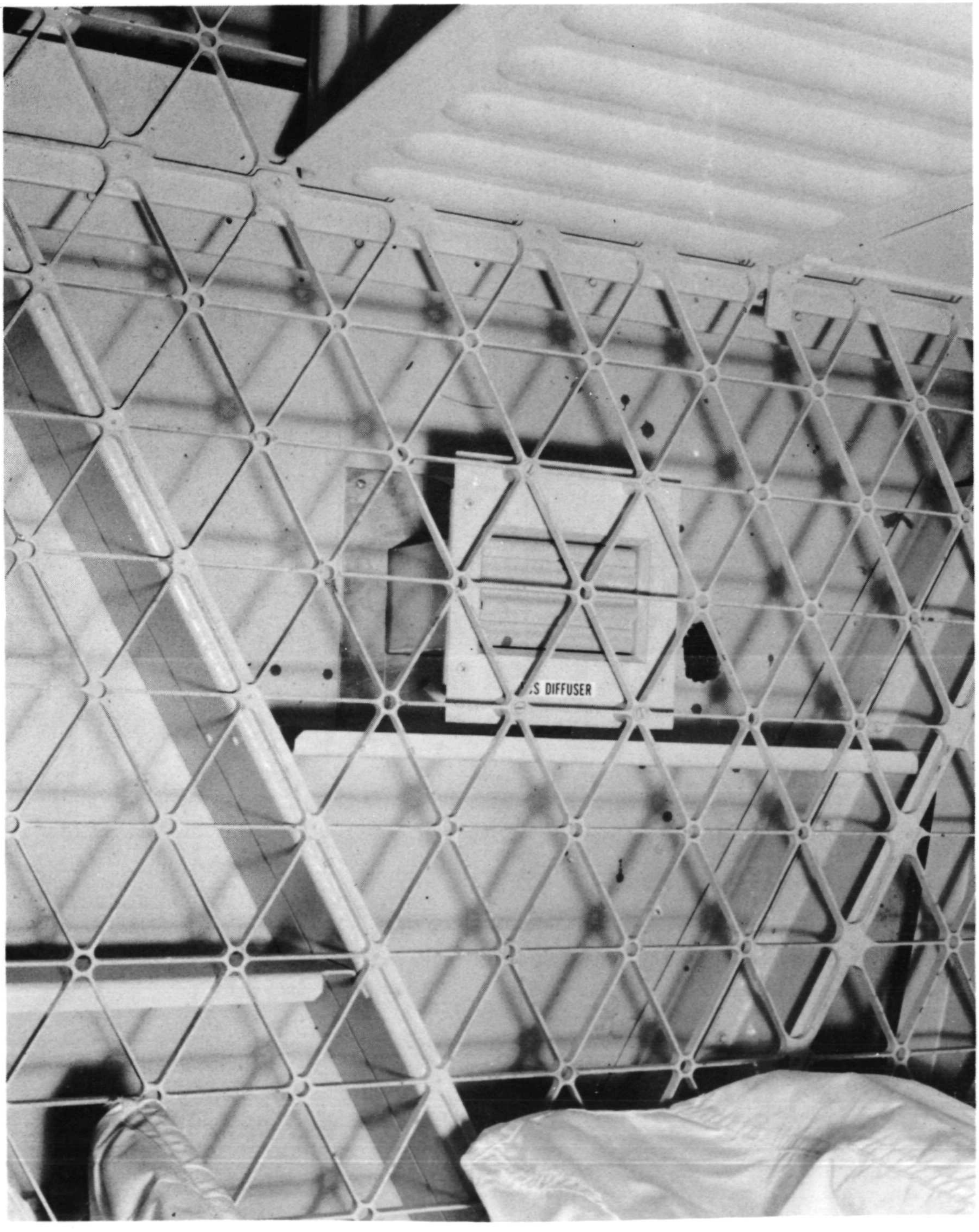


Figure 8. Sleep area rectangular diffuser.

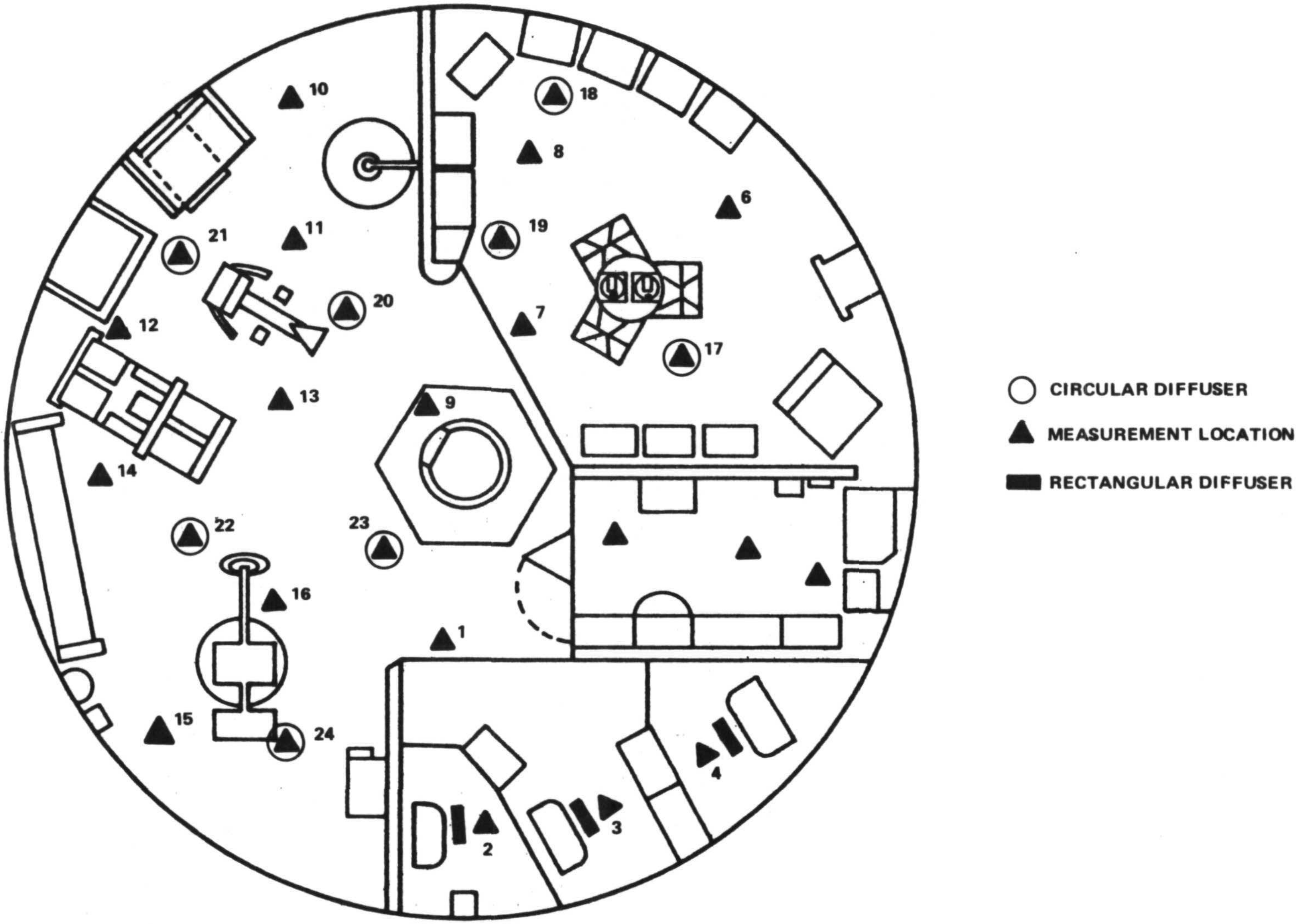


Figure 9. Velocity survey measurement location — crew quarters.

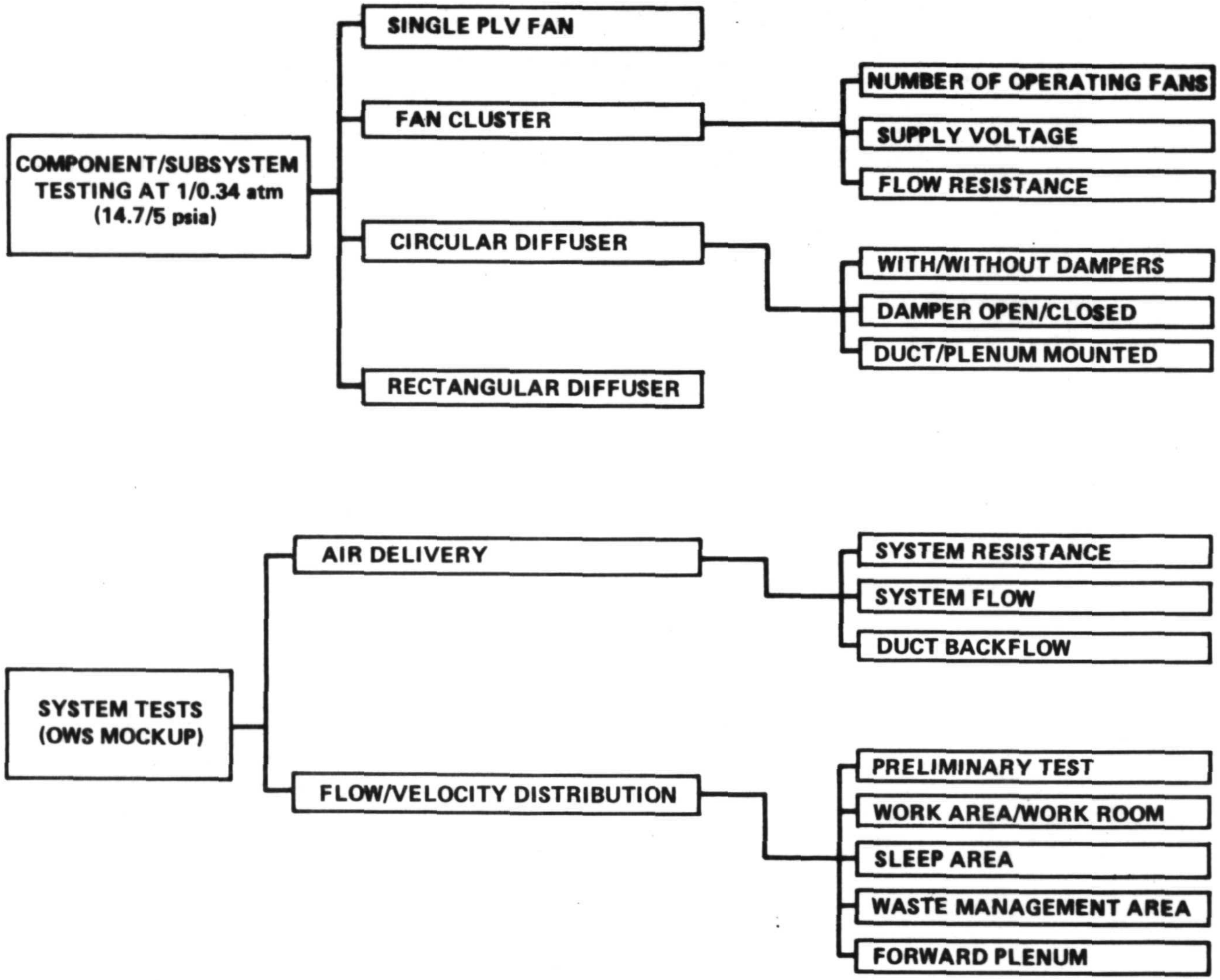


Figure 10. Orbital Workshop ventilation test program.

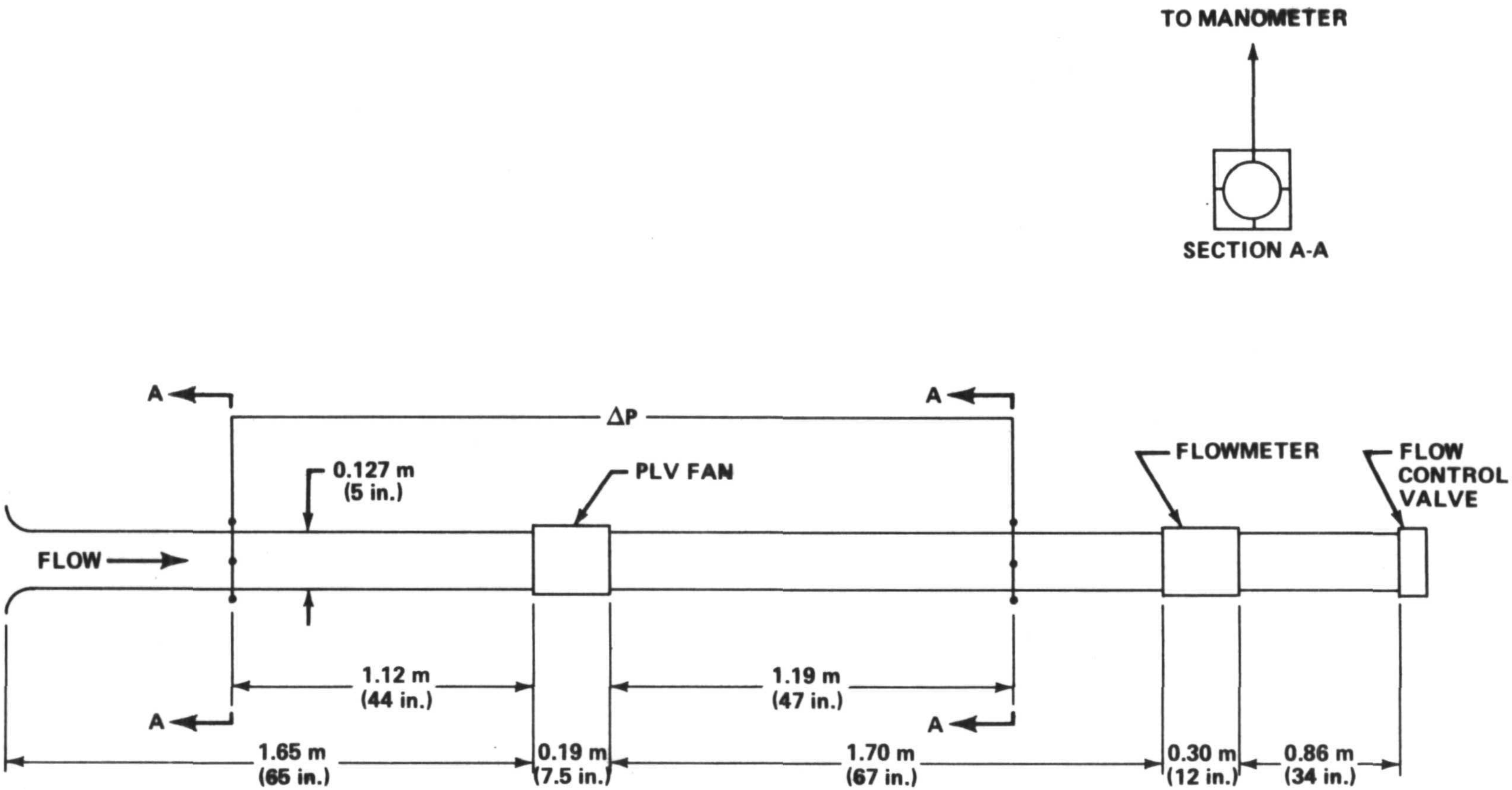


Figure 11. Single-fan performance test setup.

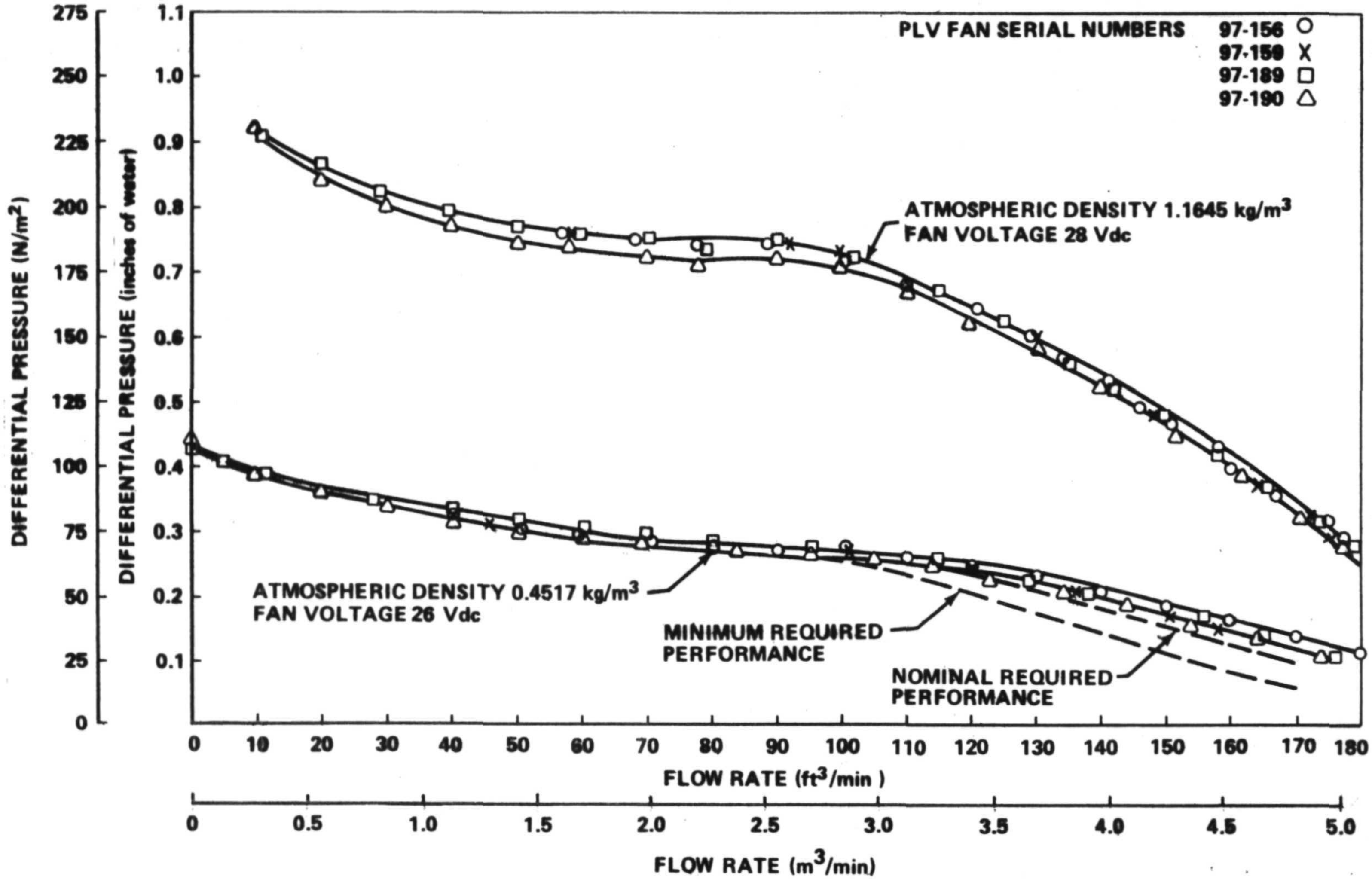


Figure 12. Single-fan performance at 0.34 and 1 atm.

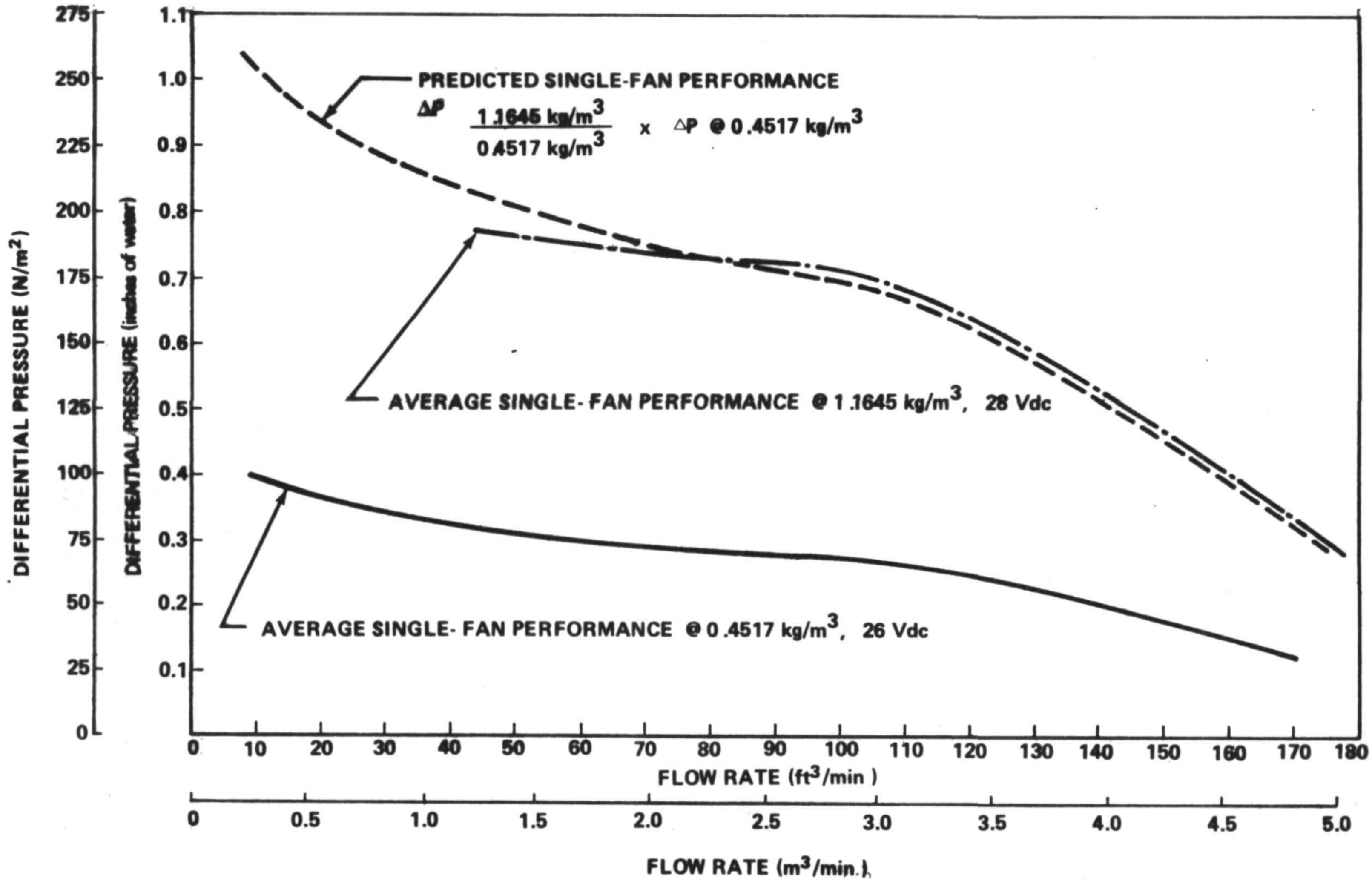


Figure 13. Prediction of 1-atm fan performance from 0.34-atm performance.

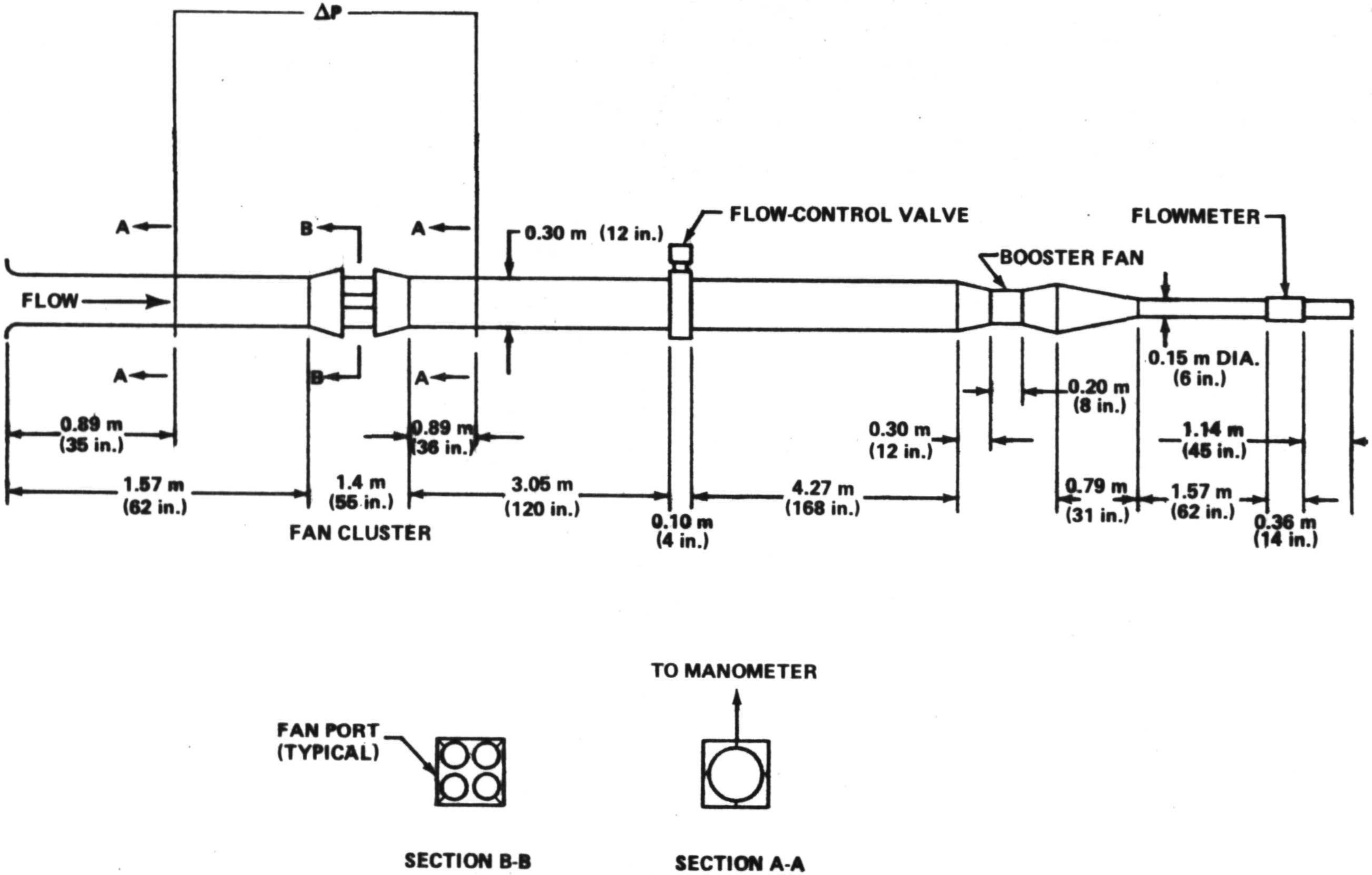


Figure 14. Four-fan cluster performance test setup.

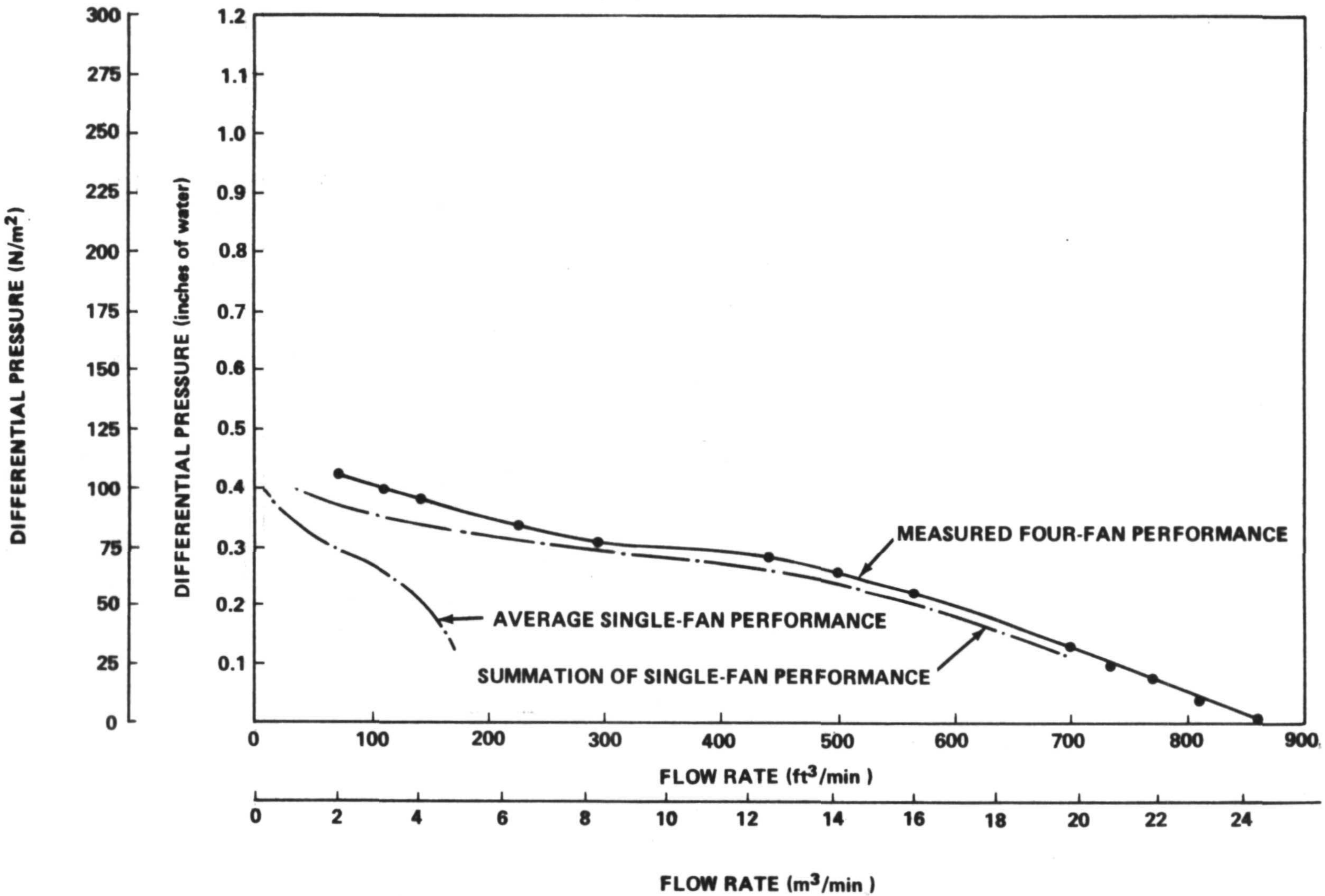


Figure 15. Comparison of measured and predicted cluster performance at 0.4517 kg/m^3, 26 Vdc.

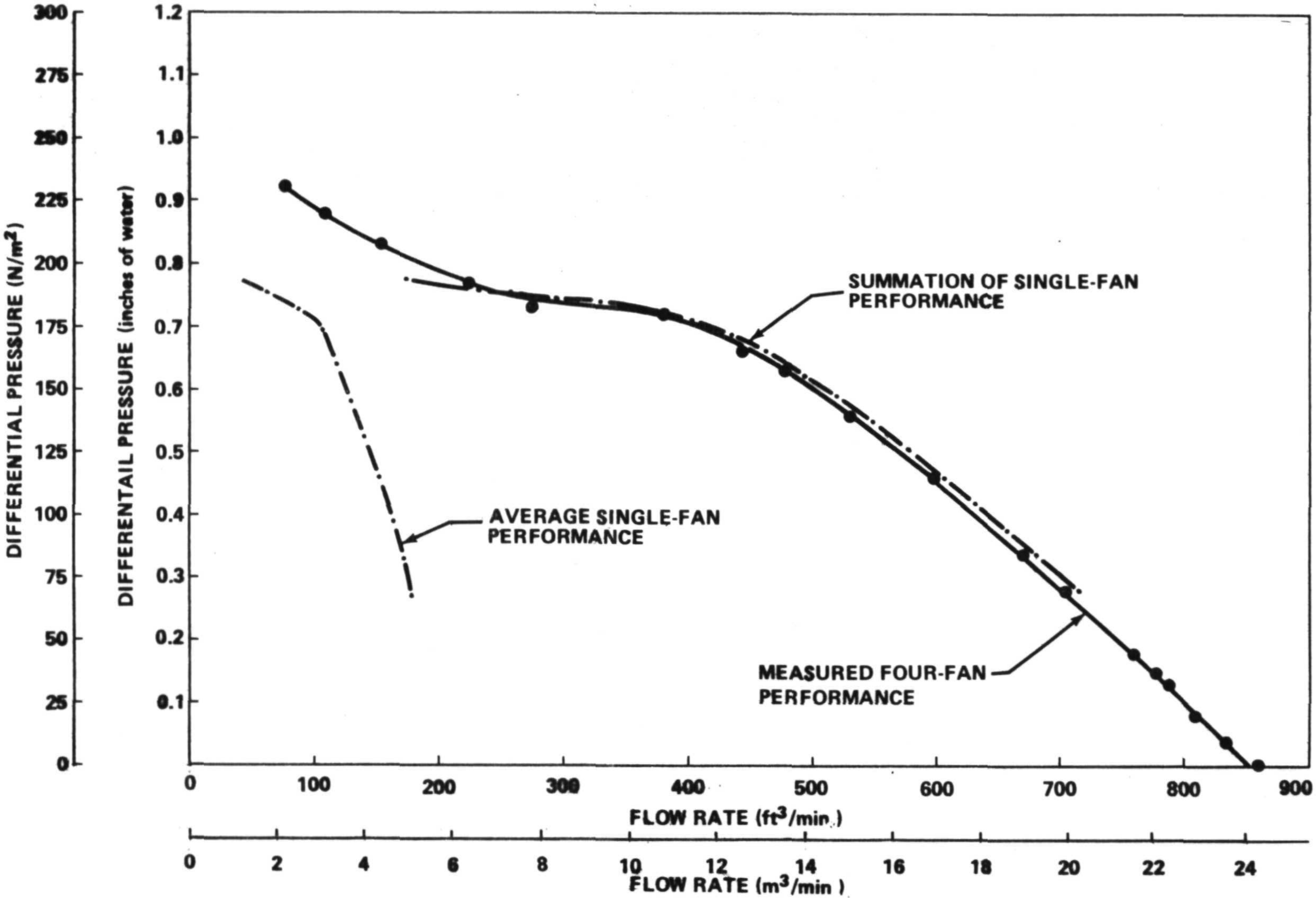


Figure 16. Comparison of measured and predicted cluster performance at 1.1645 kg/m^3, 28 Vdc.

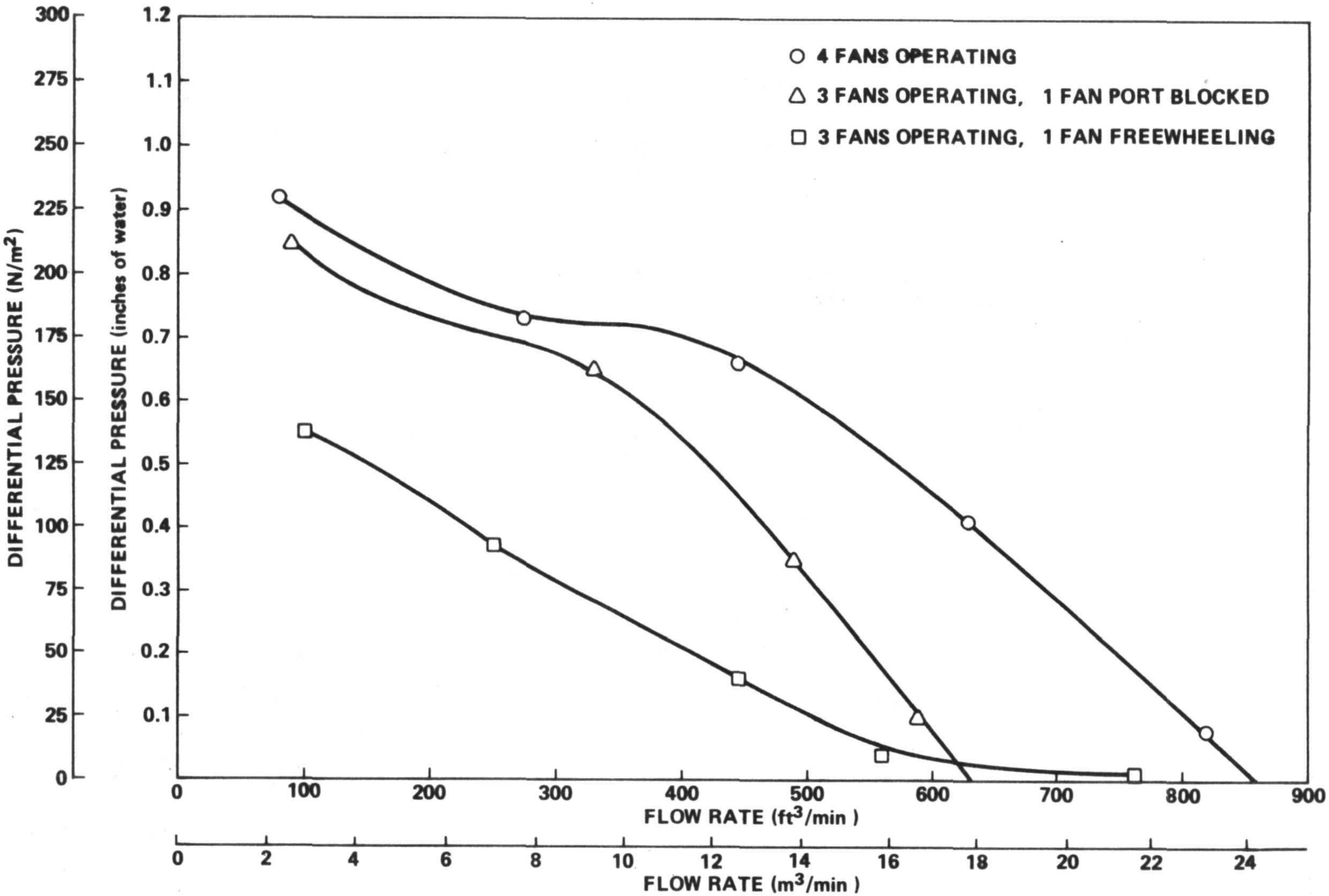


Figure 17. Effect of nonoperating fan on cluster performance at 1.1645 kg/m^3, 28 Vdc.

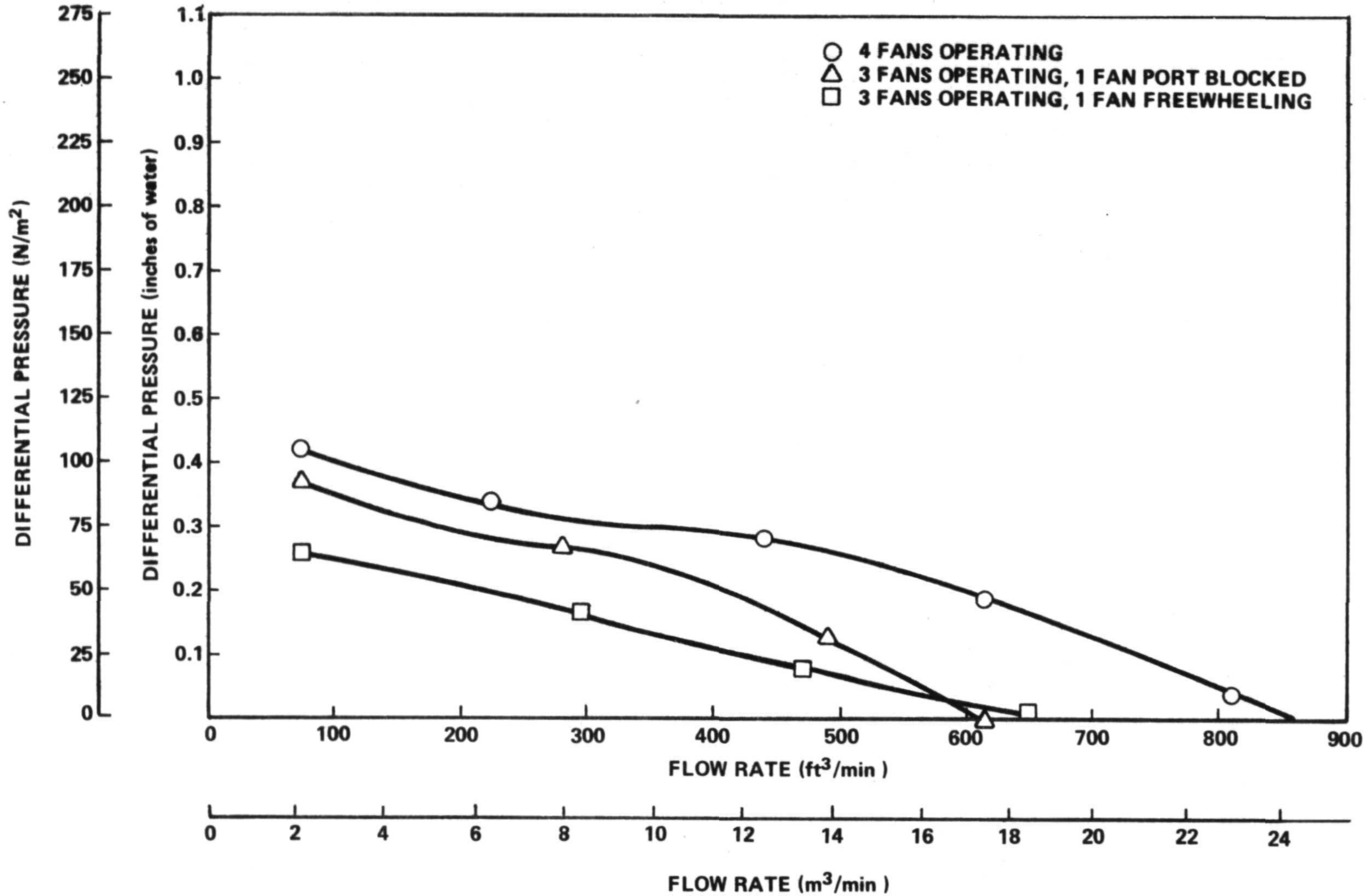


Figure 18. Effect of nonoperating fan on cluster performance at 0.4517 kg/m^3, 26 Vdc.

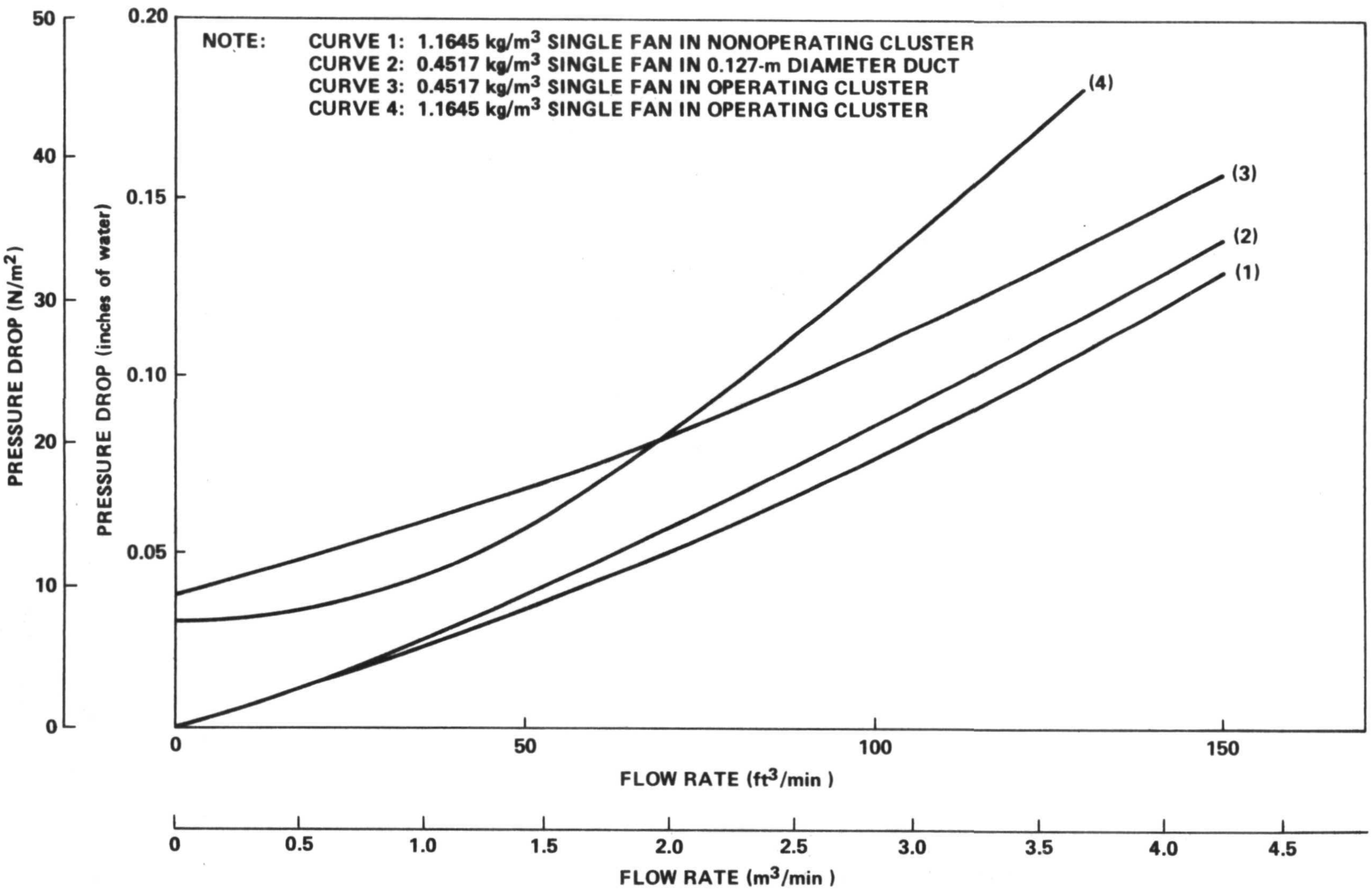


Figure 19. Backflow through a nonoperating PLV fan.

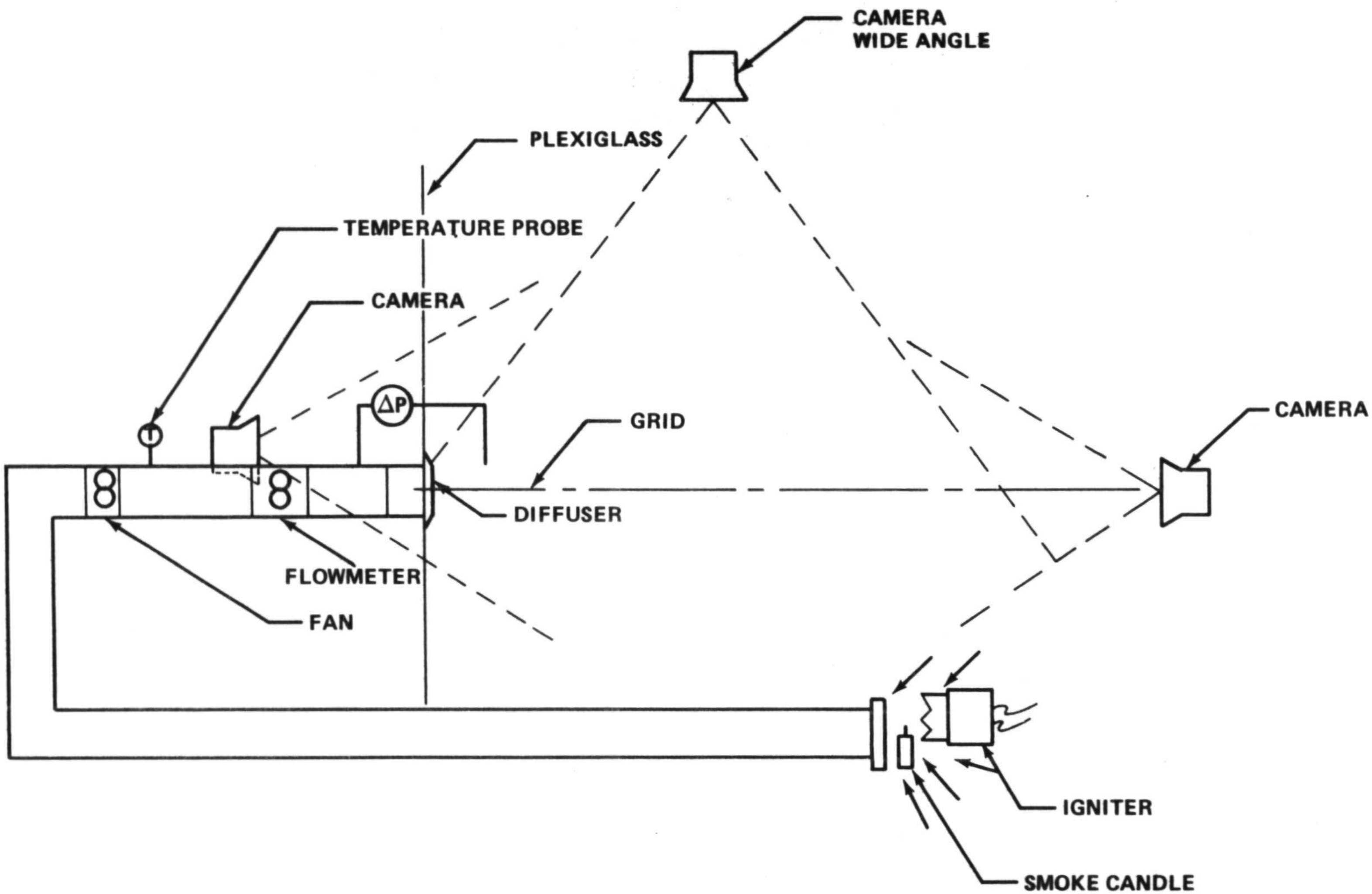


Figure 20. Duct-mounted circular diffuser performance test setup.

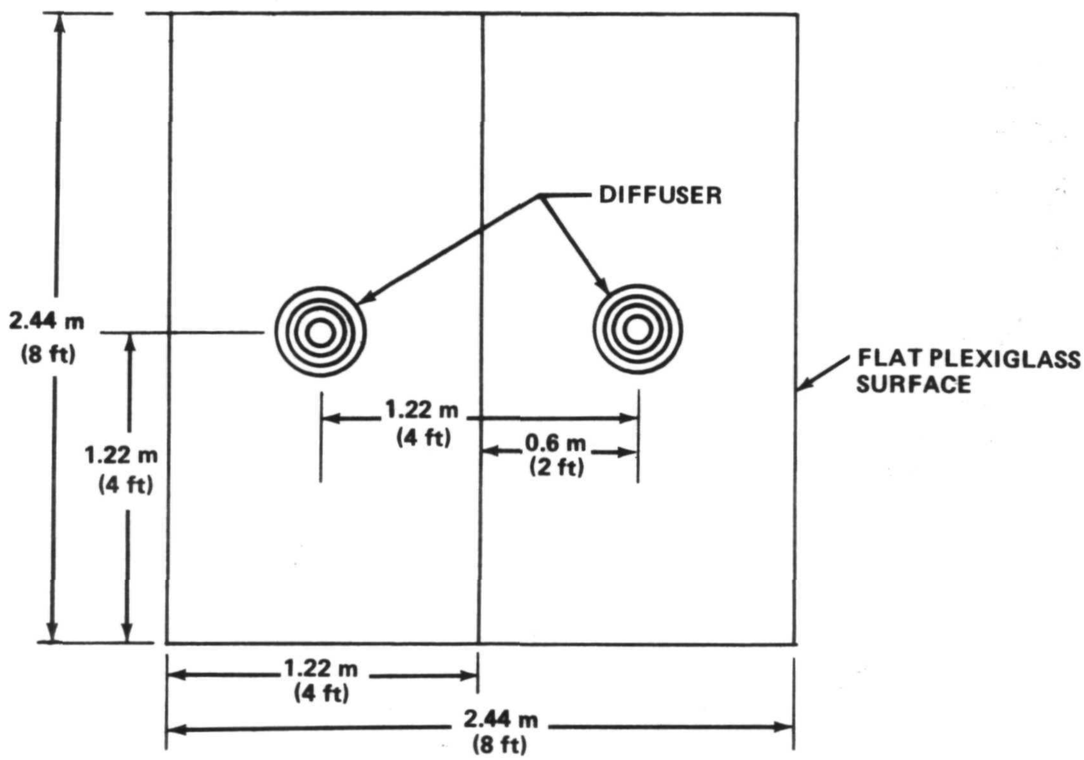


Figure 21. Circular diffuser spacing in performance tests.

Figure 22. Diffuser test setup in vacuum chamber.

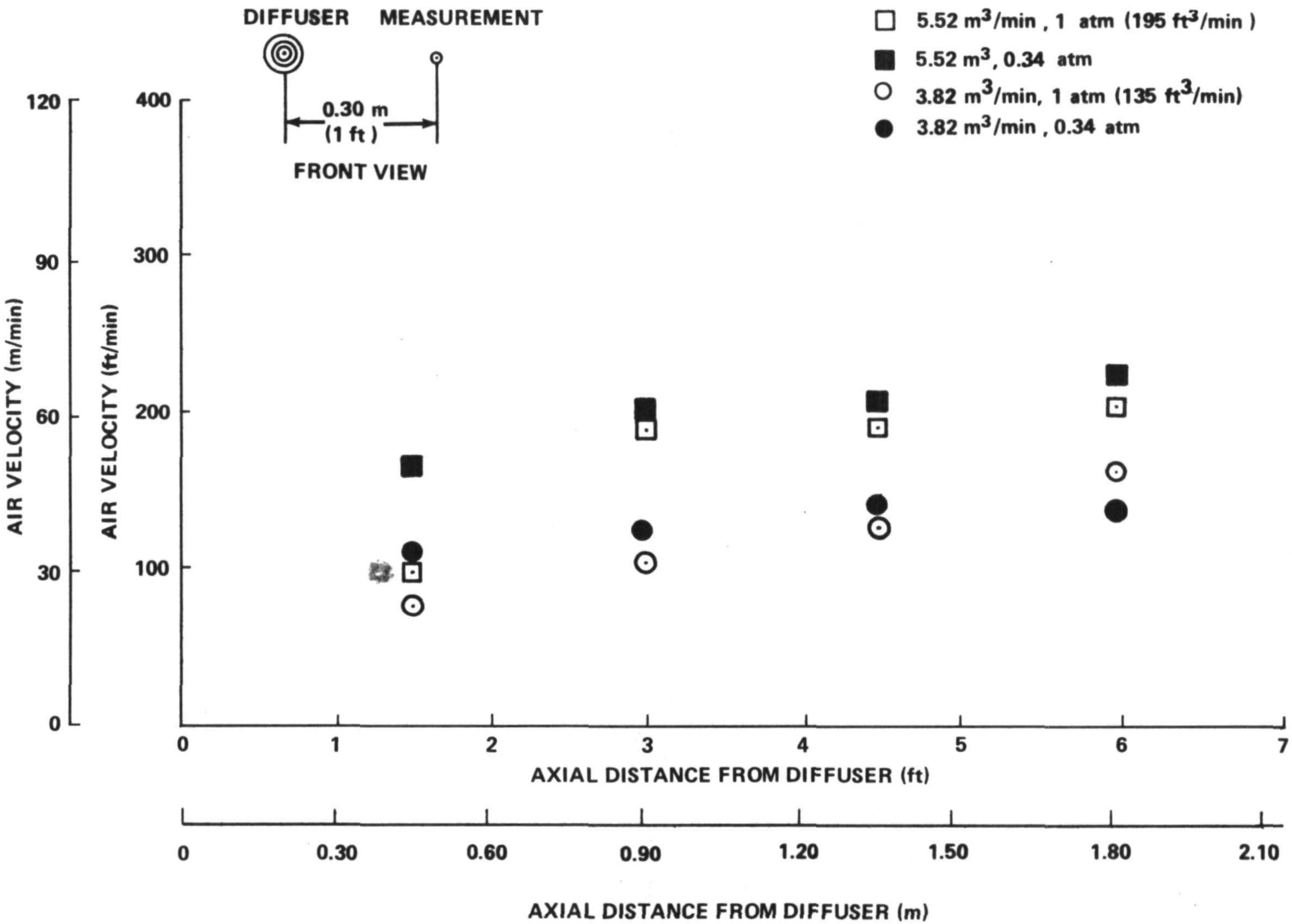


Figure 23. Circular diffuser narrow-pattern velocities, 1 and 0.34 atm.

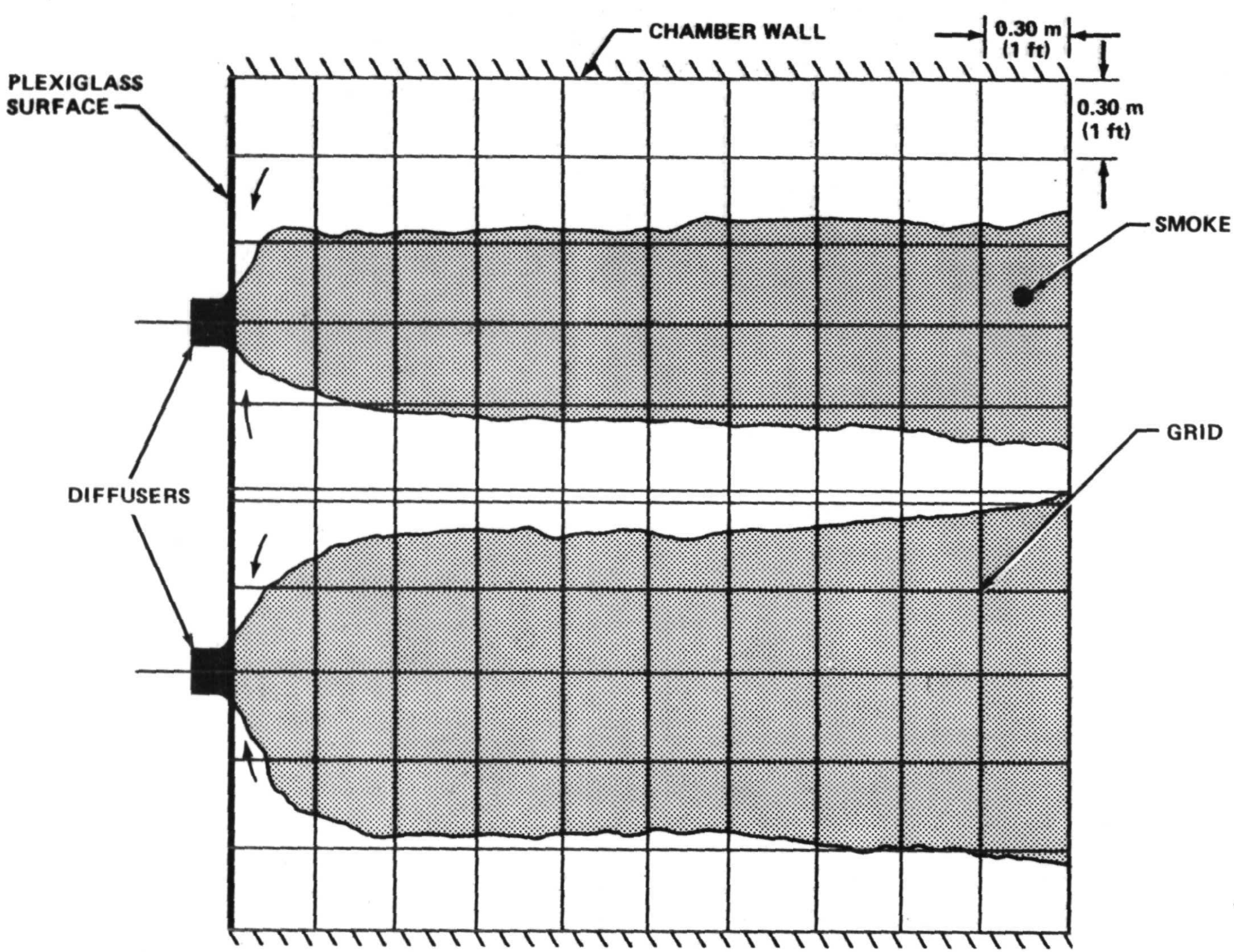


Figure 24. Dual diffusers set in narrow-pattern smoke test.

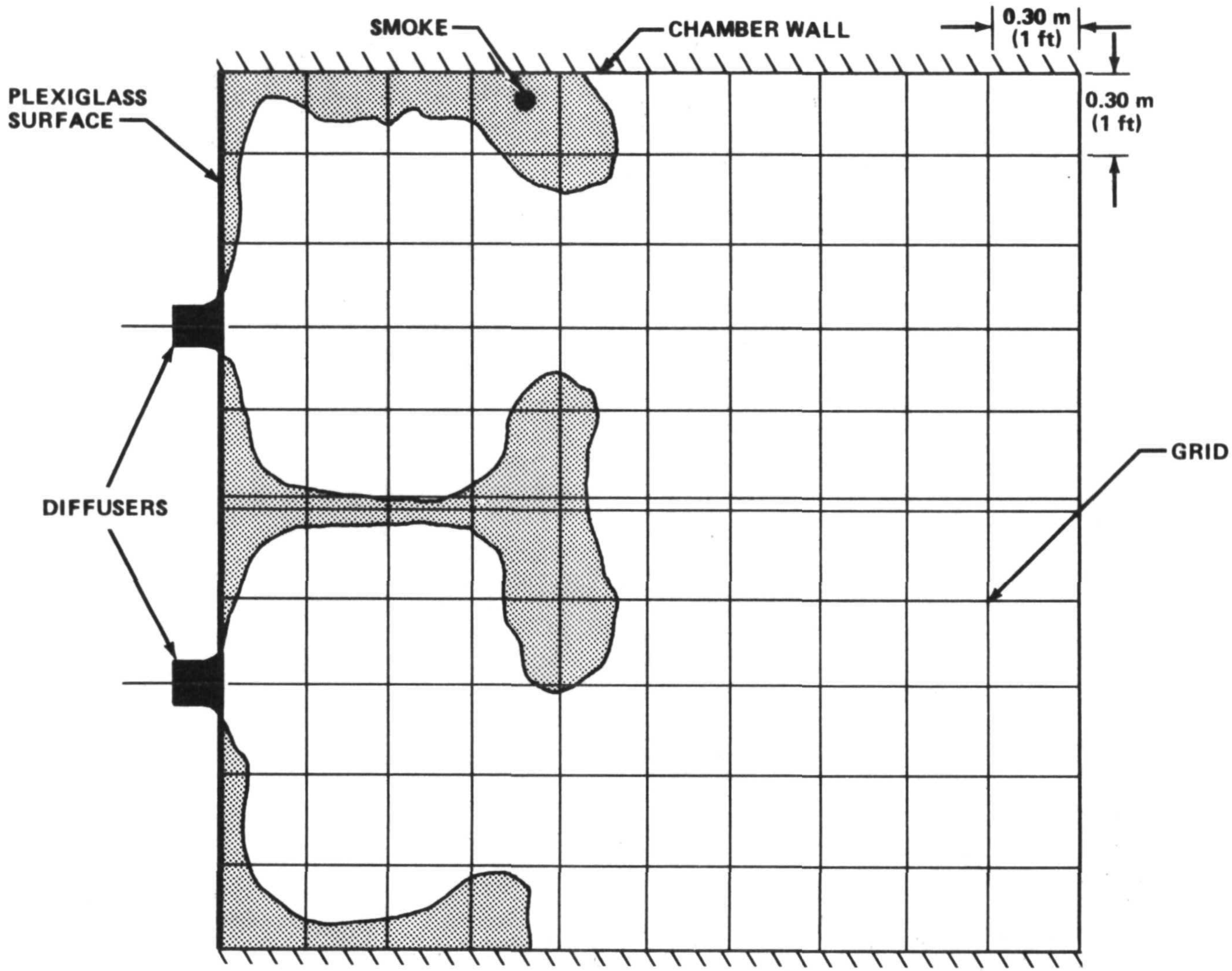


Figure 25. Dual diffusers set in wide-pattern smoke test.

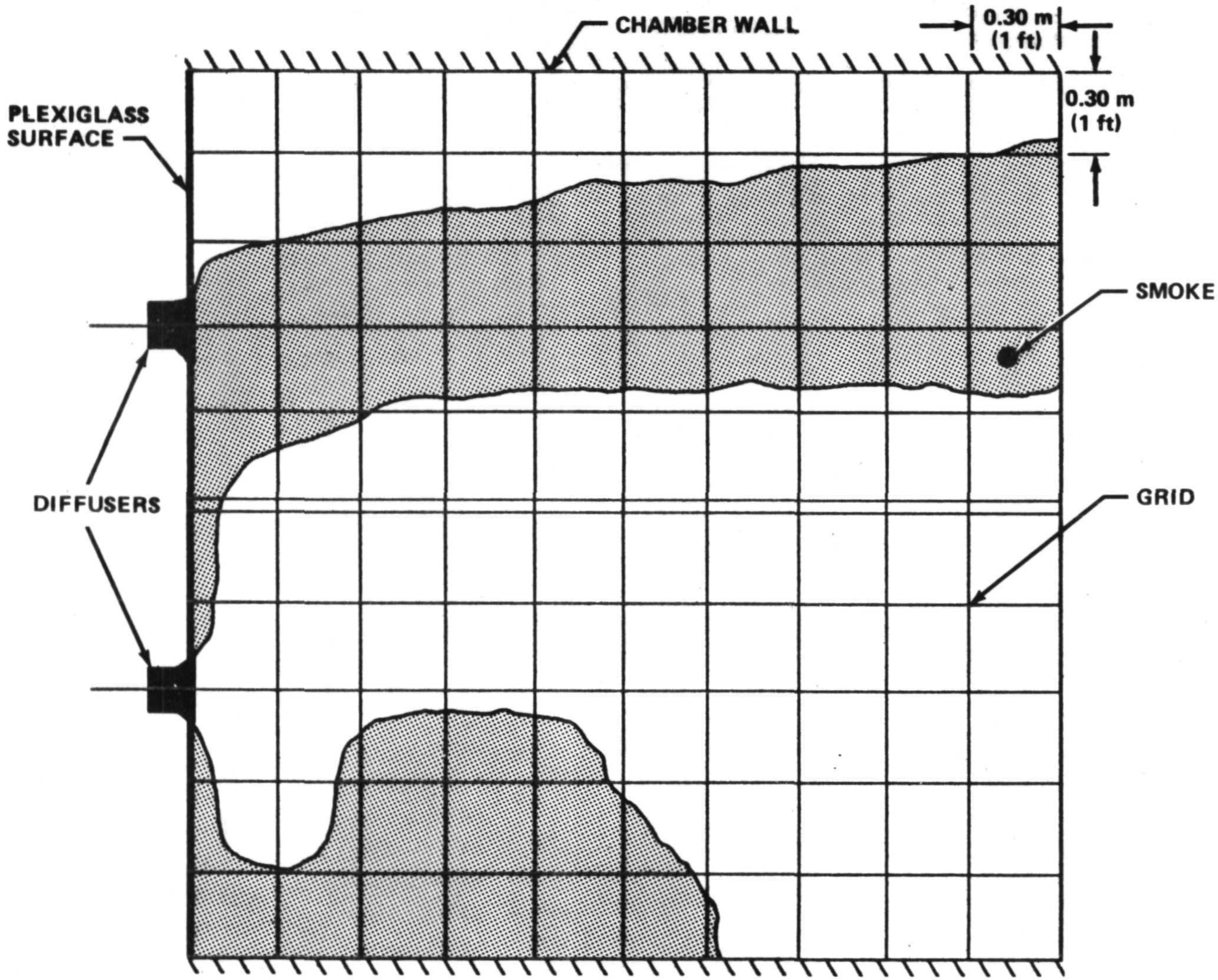


Figure 26. Dual diffusers set in wide- and projection-pattern smoke tests.

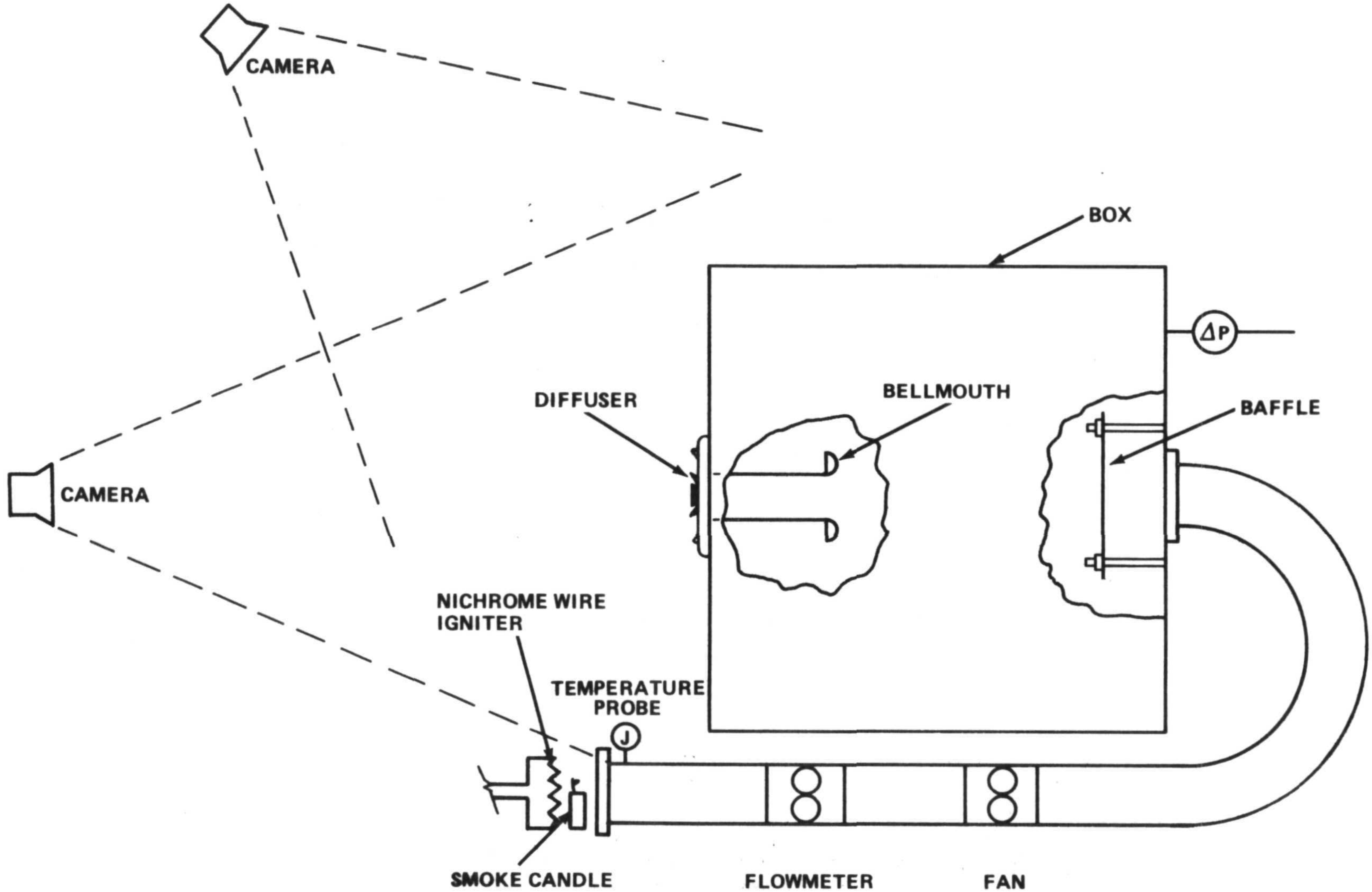


Figure 27. Plenum-mounted circular diffuser performance test setup.

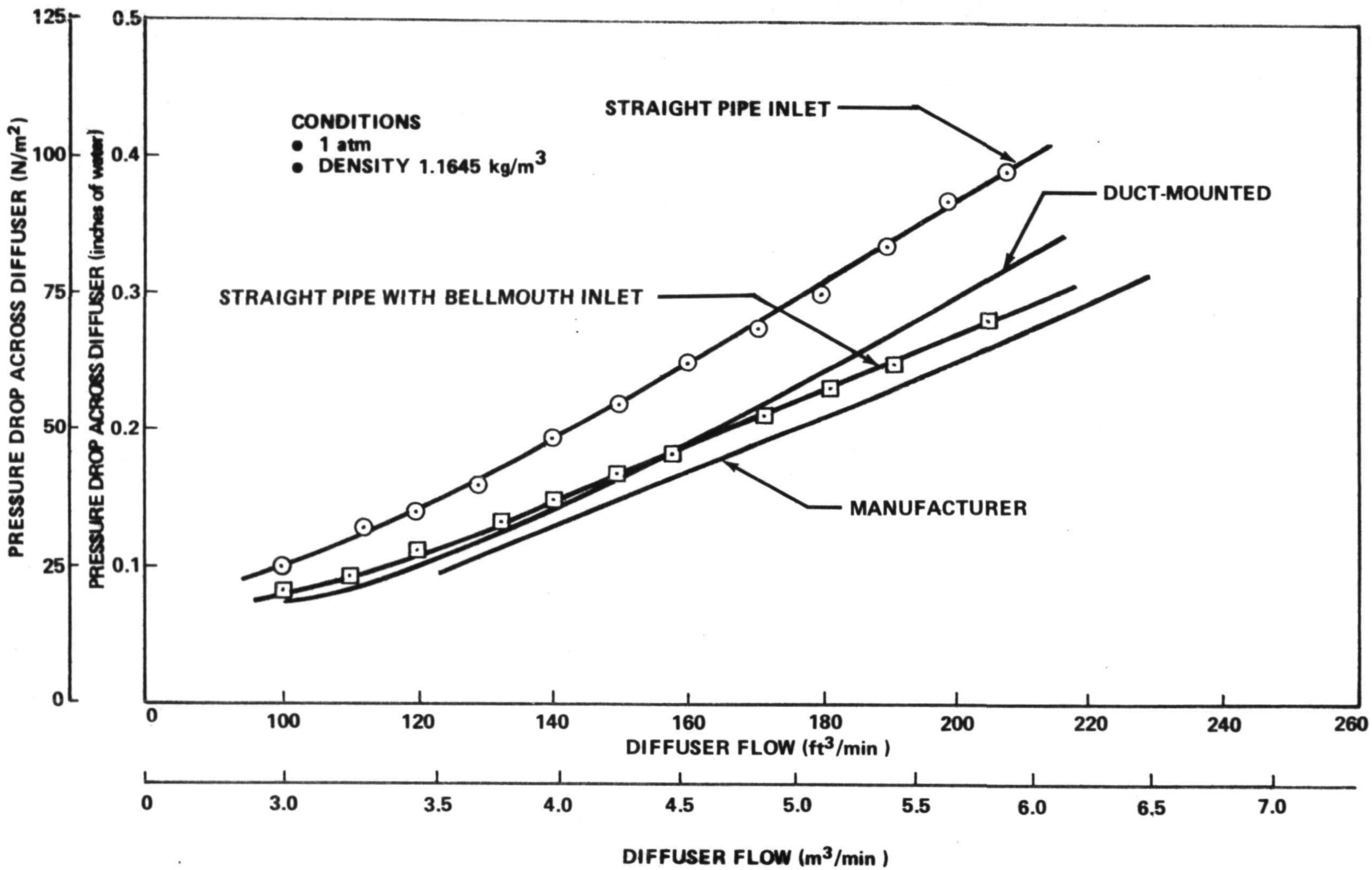


Figure 28. Circular diffuser pressure loss data — narrow pattern.

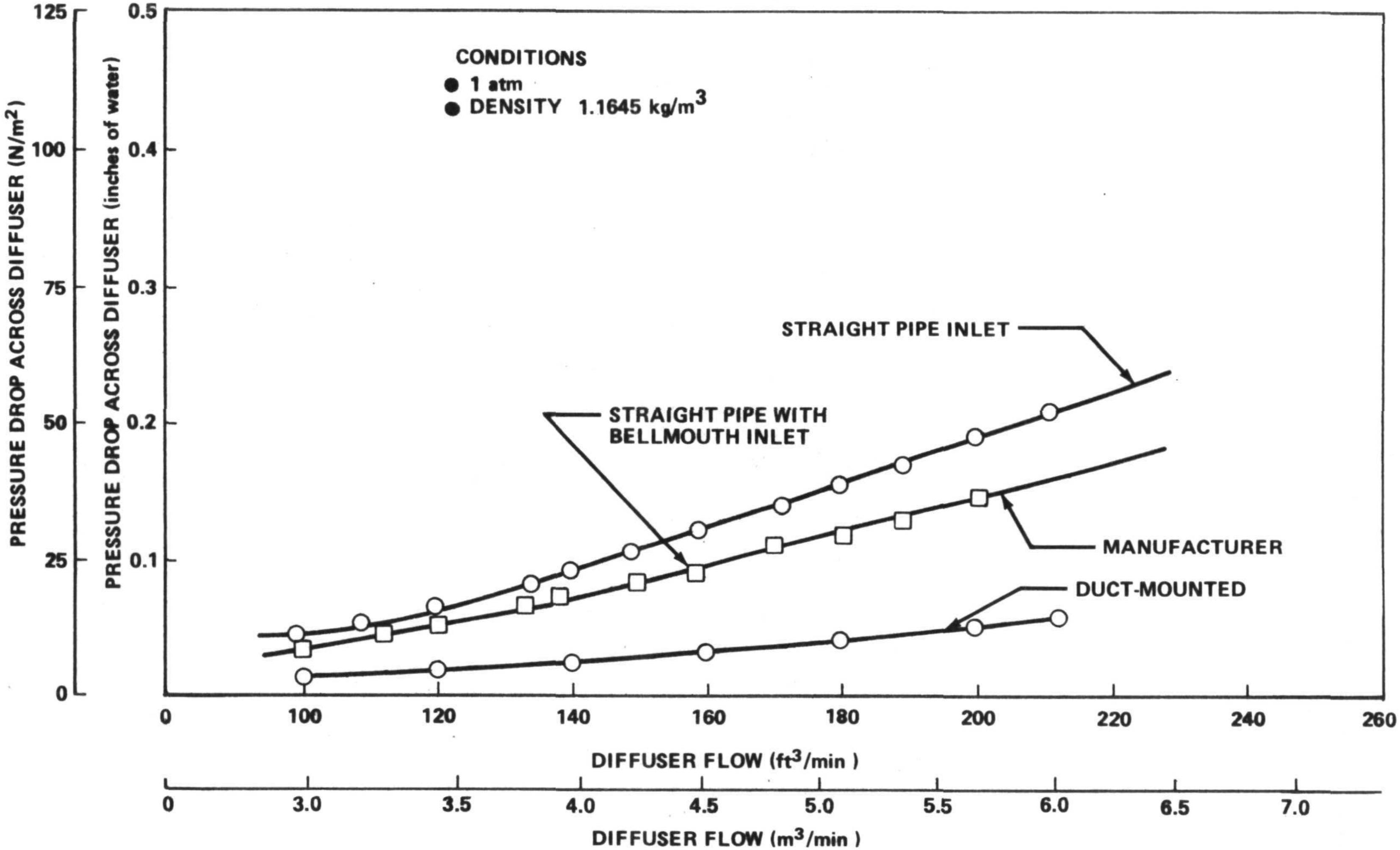


Figure 29. Circular diffuser pressure drop data — wide pattern.

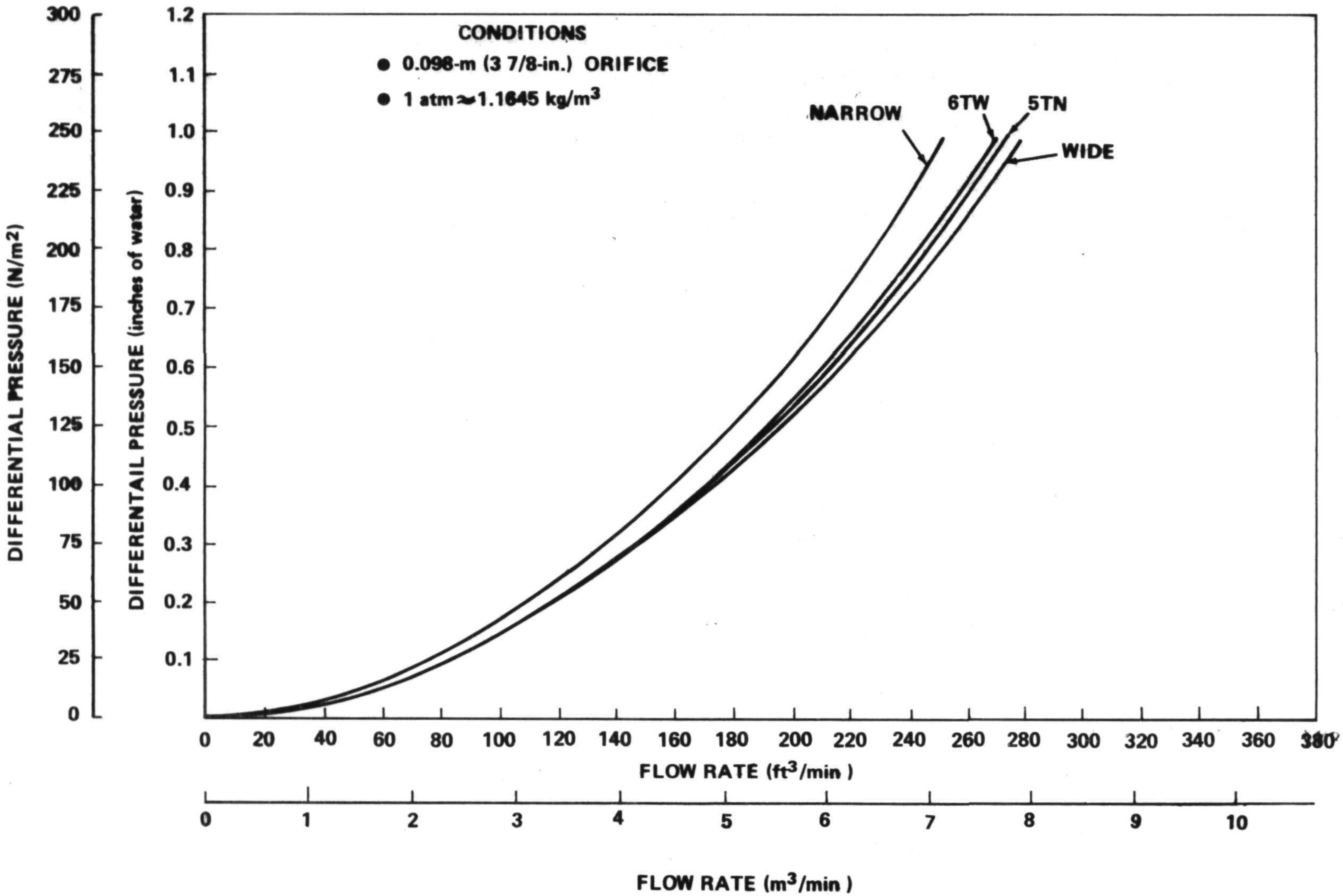


Figure 30. Single-circular diffuser pressure loss data — with orifice.

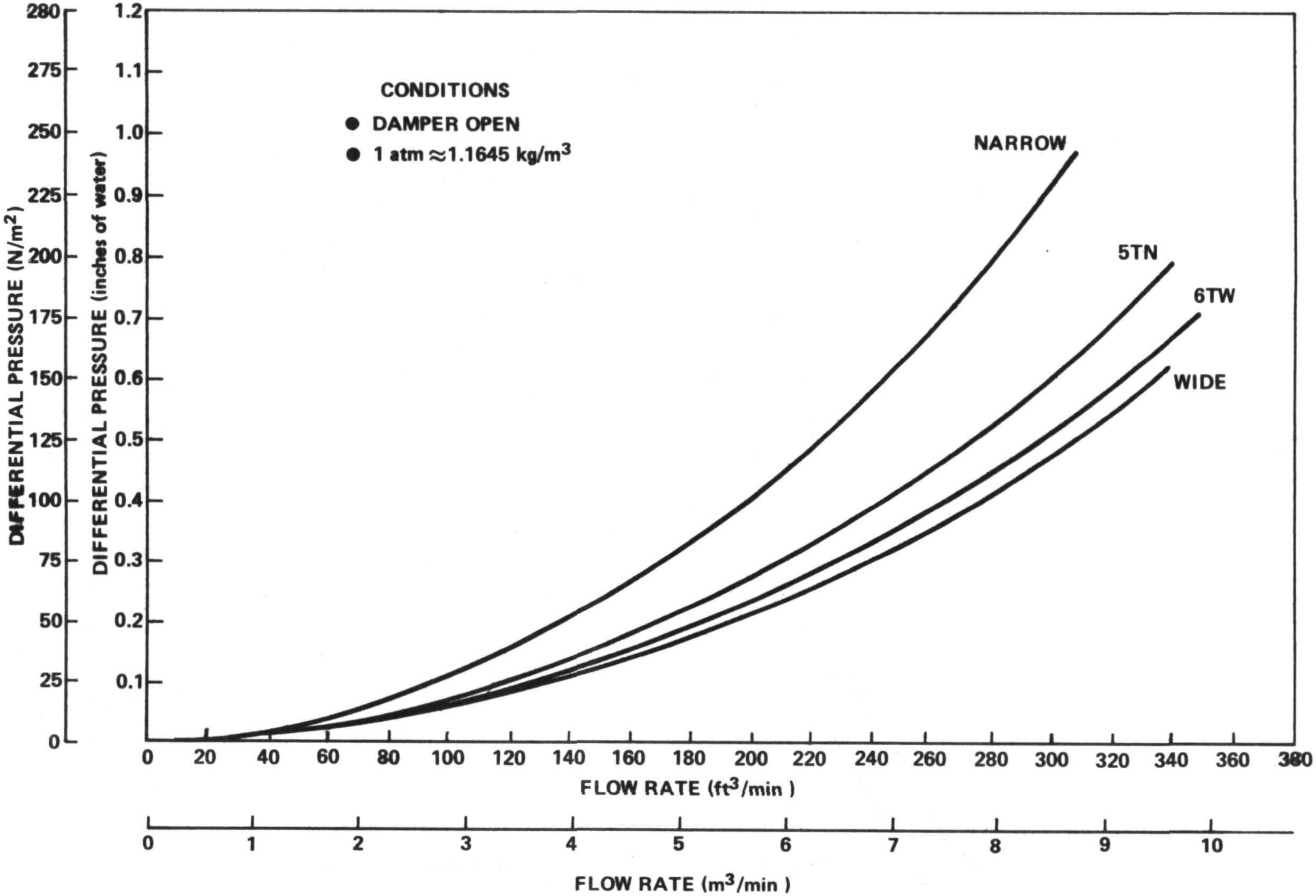


Figure 31. Single-circular diffuser pressure loss data — OWS mockup configuration.

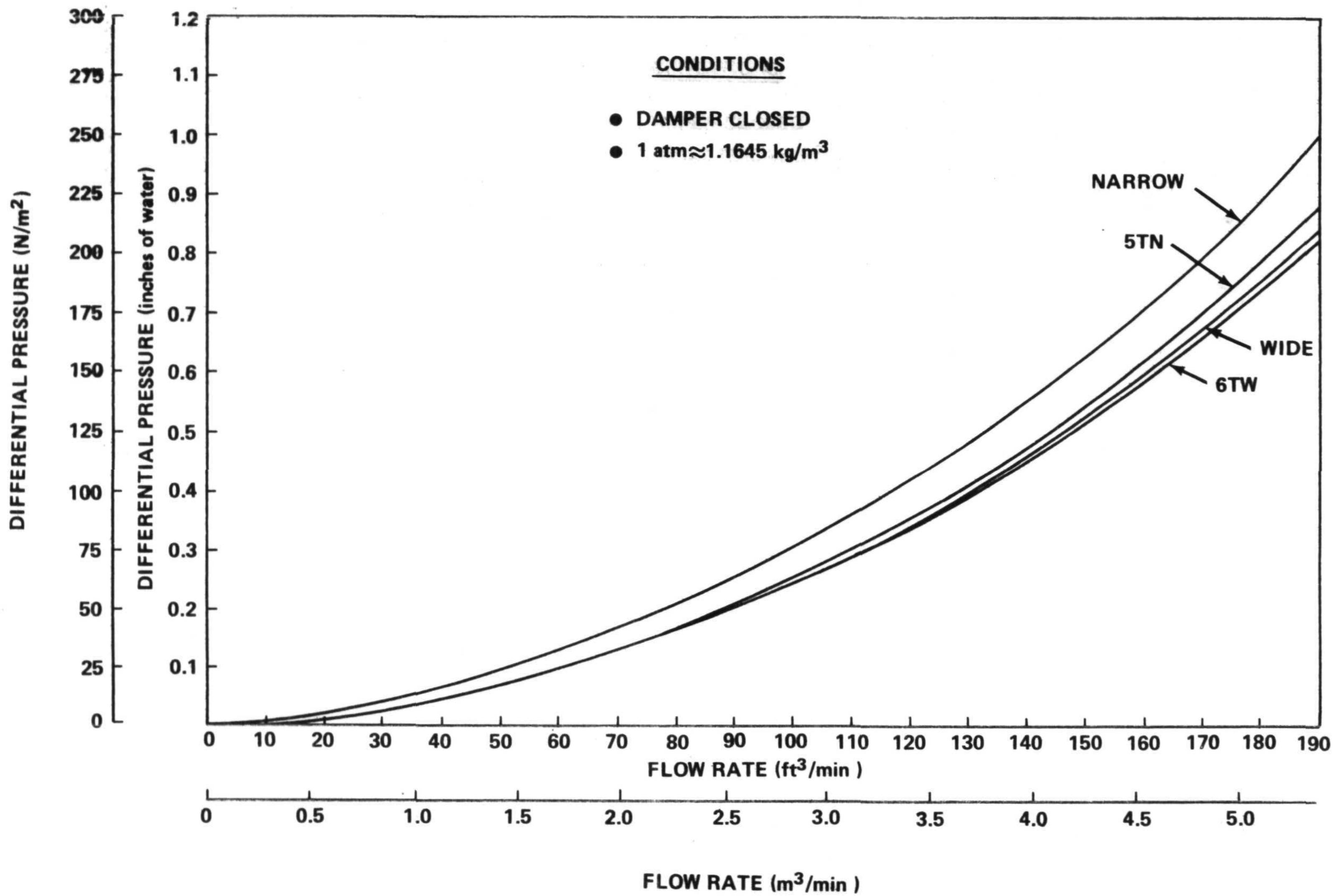


Figure 32. Single-circular diffuser pressure loss data — OWS mockup configuration.

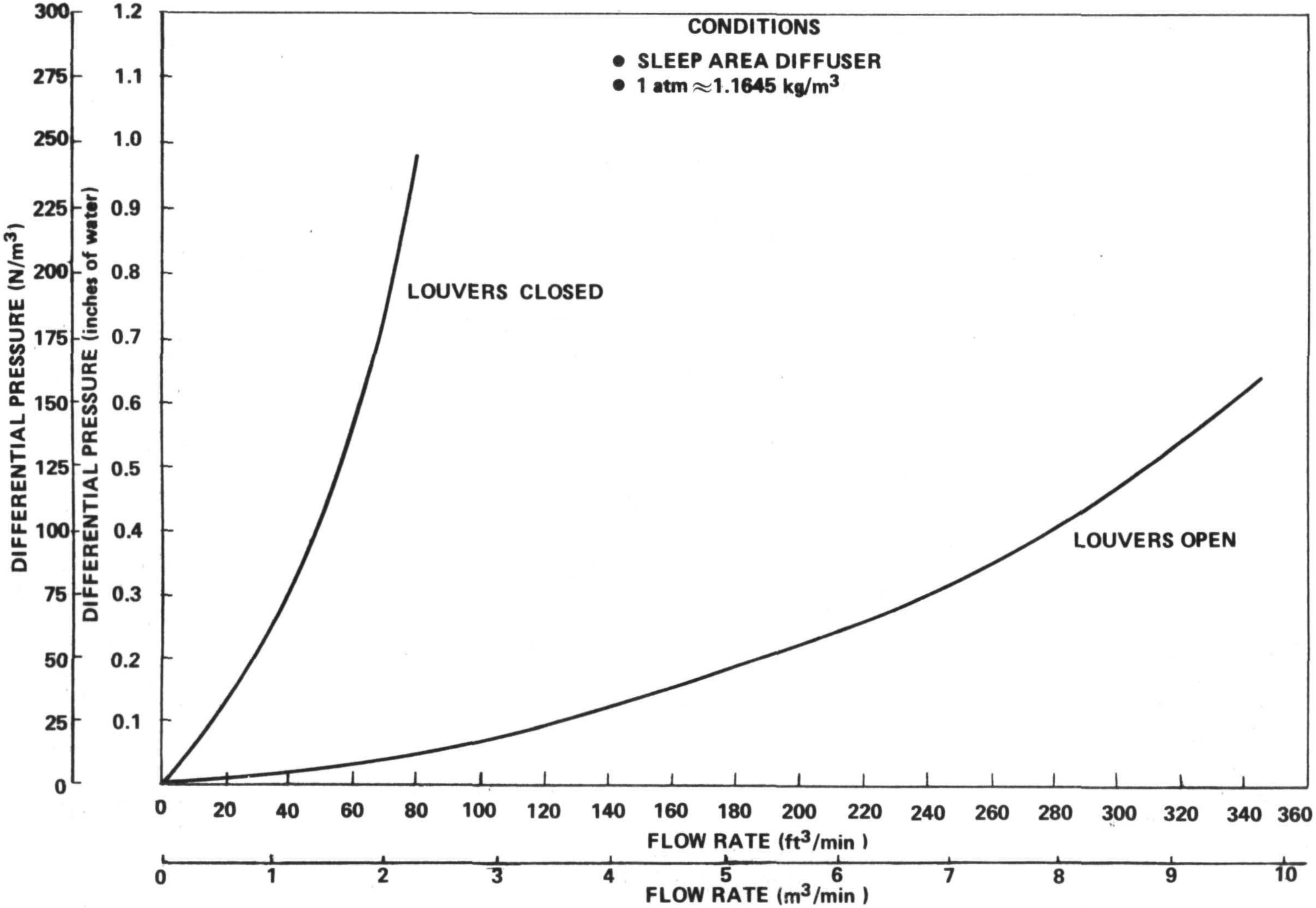


Figure 33. Single-rectangular diffuser pressure loss data — OWS mockup configuration.

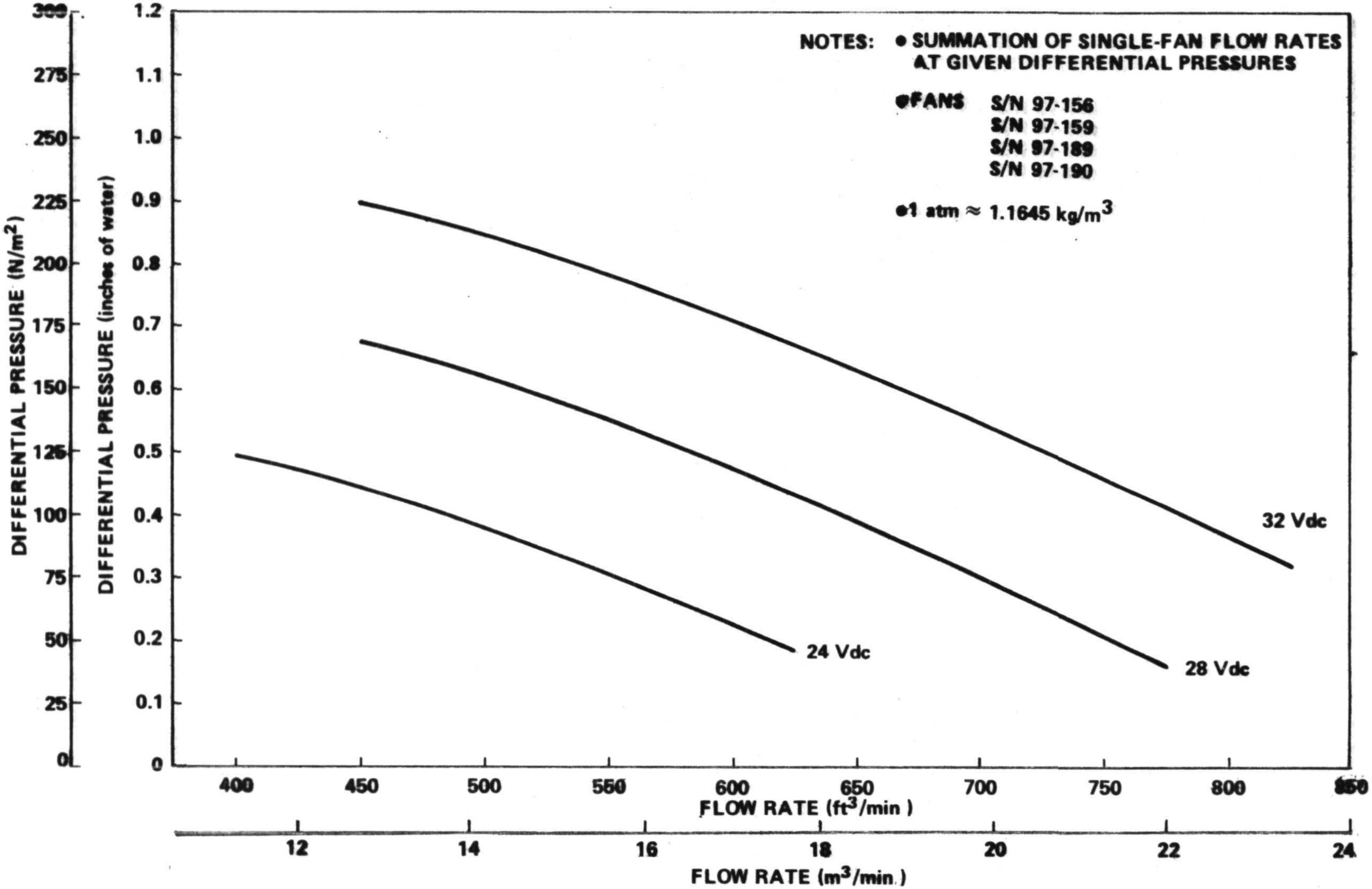


Figure 34. Mockup fan cluster No. 1 performance.

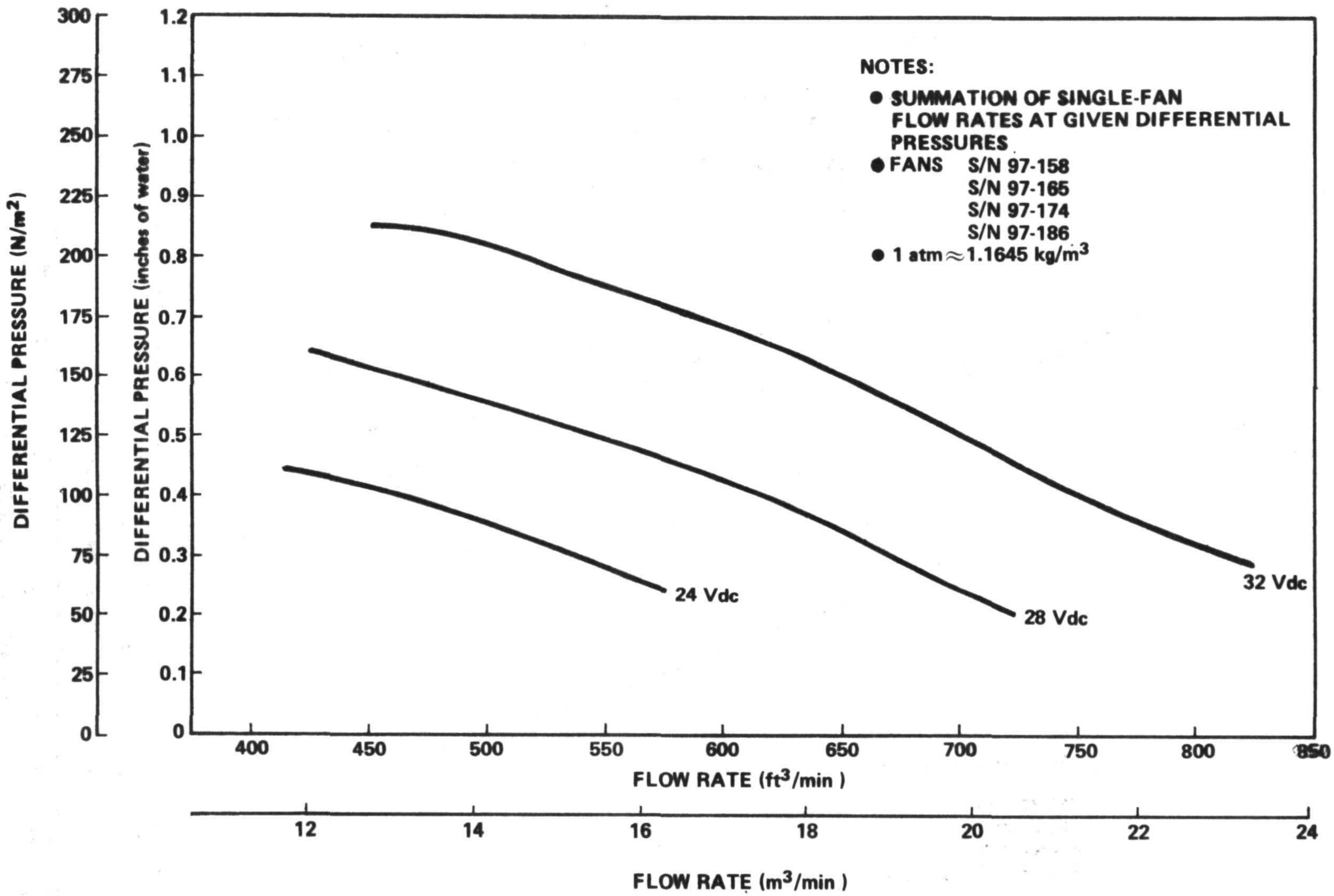


Figure 35. Mockup fan cluster No. 2 performance.

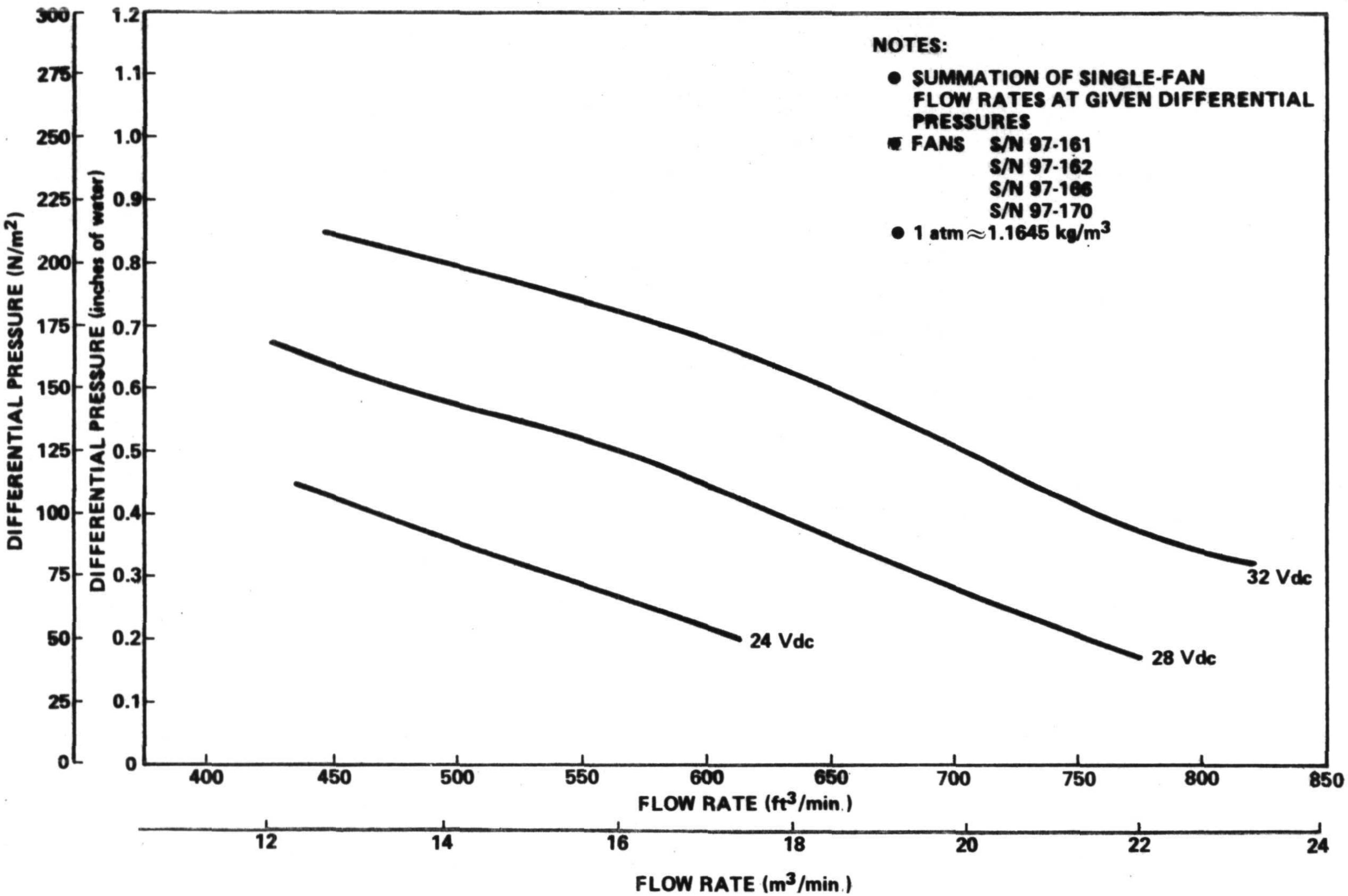


Figure 36. Mockup fan cluster No. 3 performance.

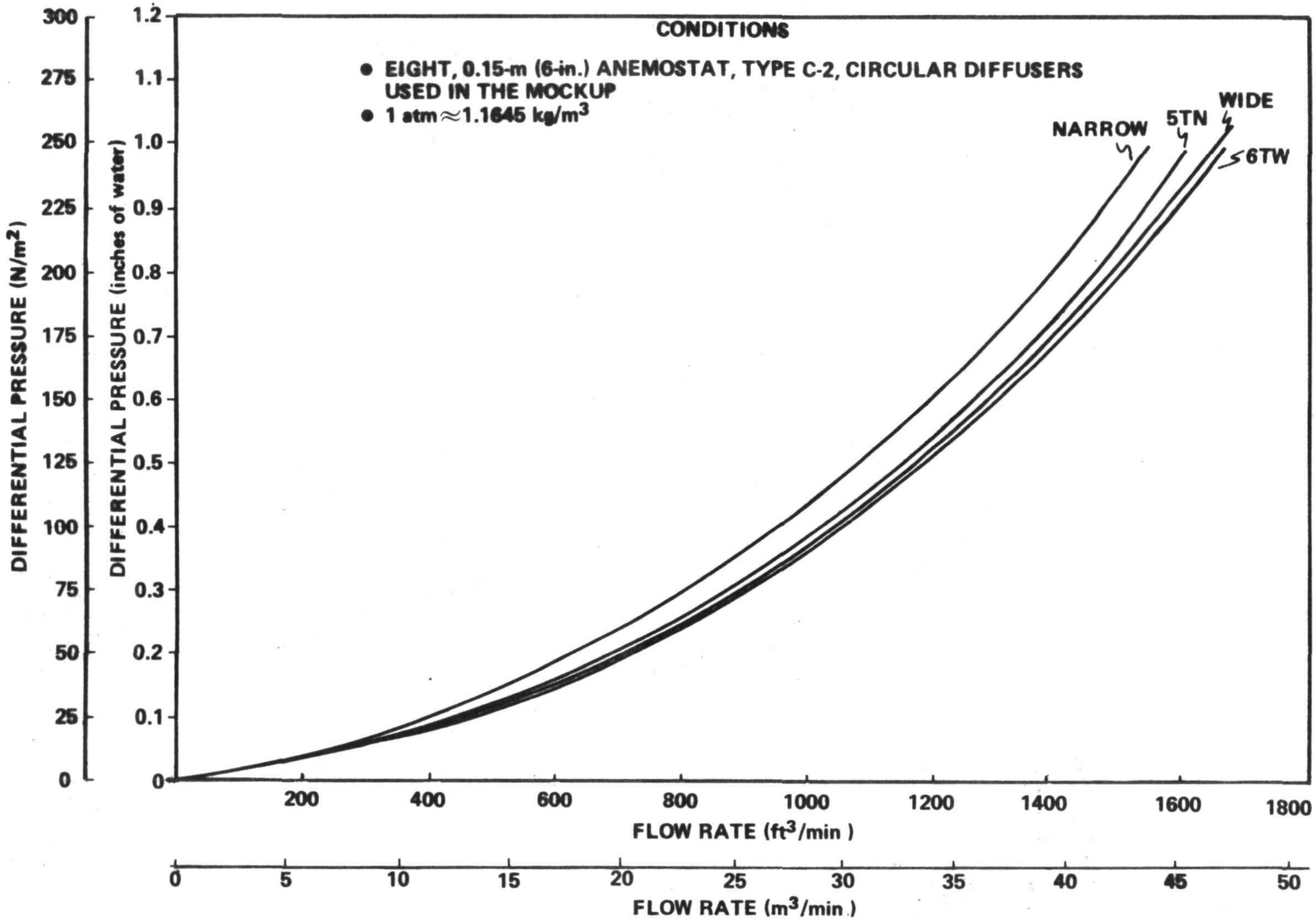


Figure 37. Work area and ward room diffuser performance — dampers closed.

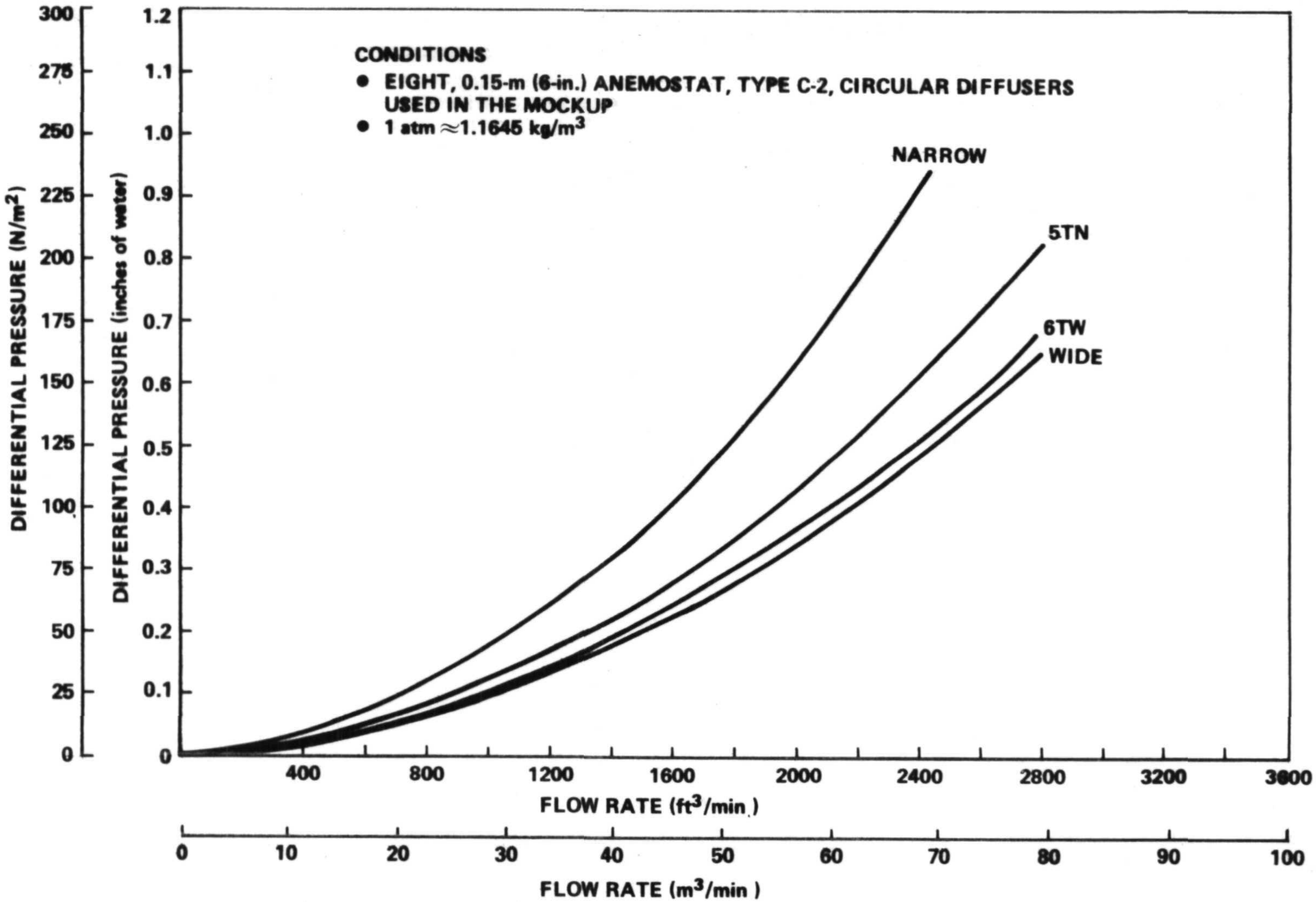


Figure 38. Work area and ward room diffuser performance — dampers open.

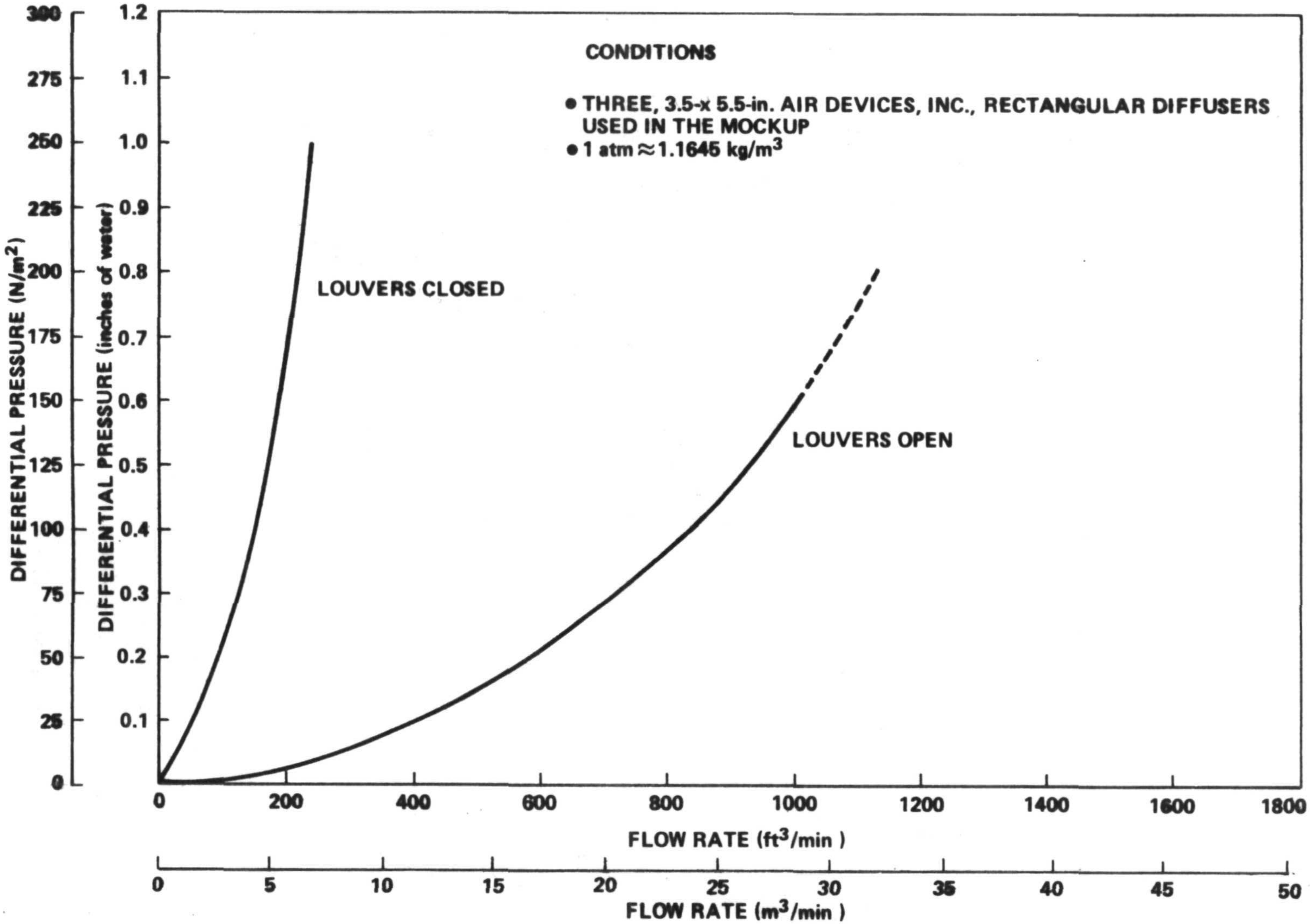


Figure 39. Sleep area diffuser performance.

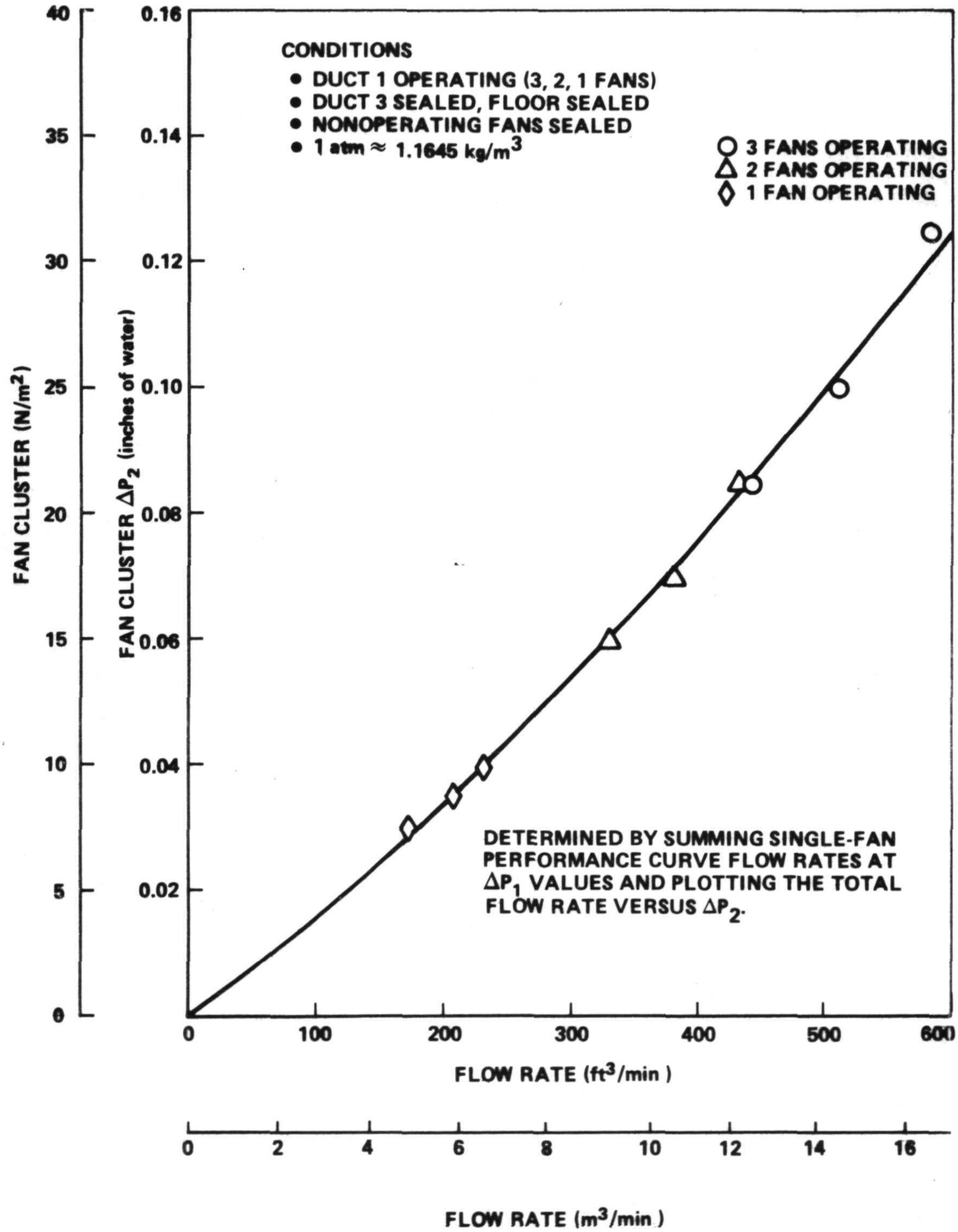


Figure 40. Backflow calibration curve for duct 2.

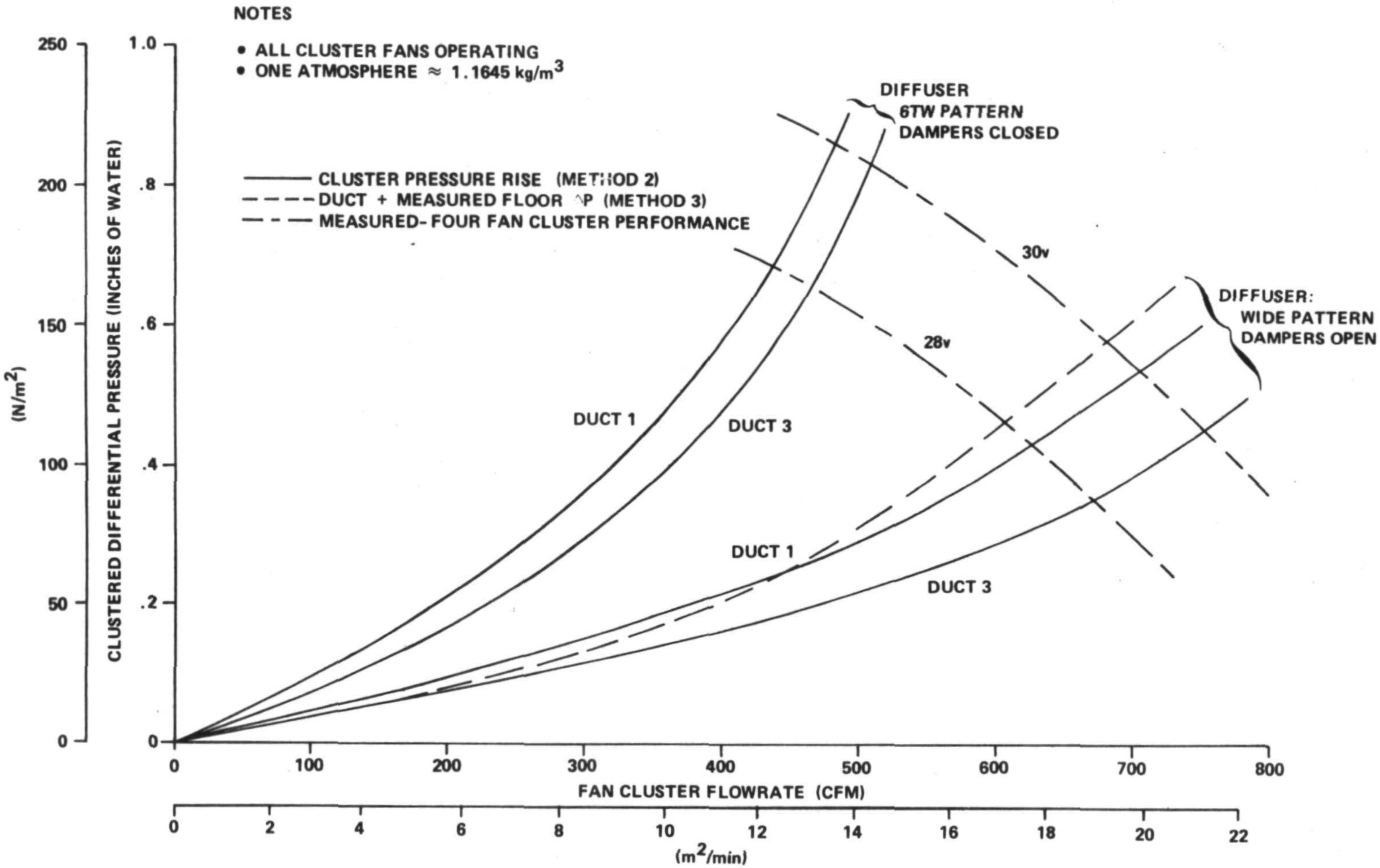


Figure 41. Measured total system resistance with maximum and minimum resistance ducts.

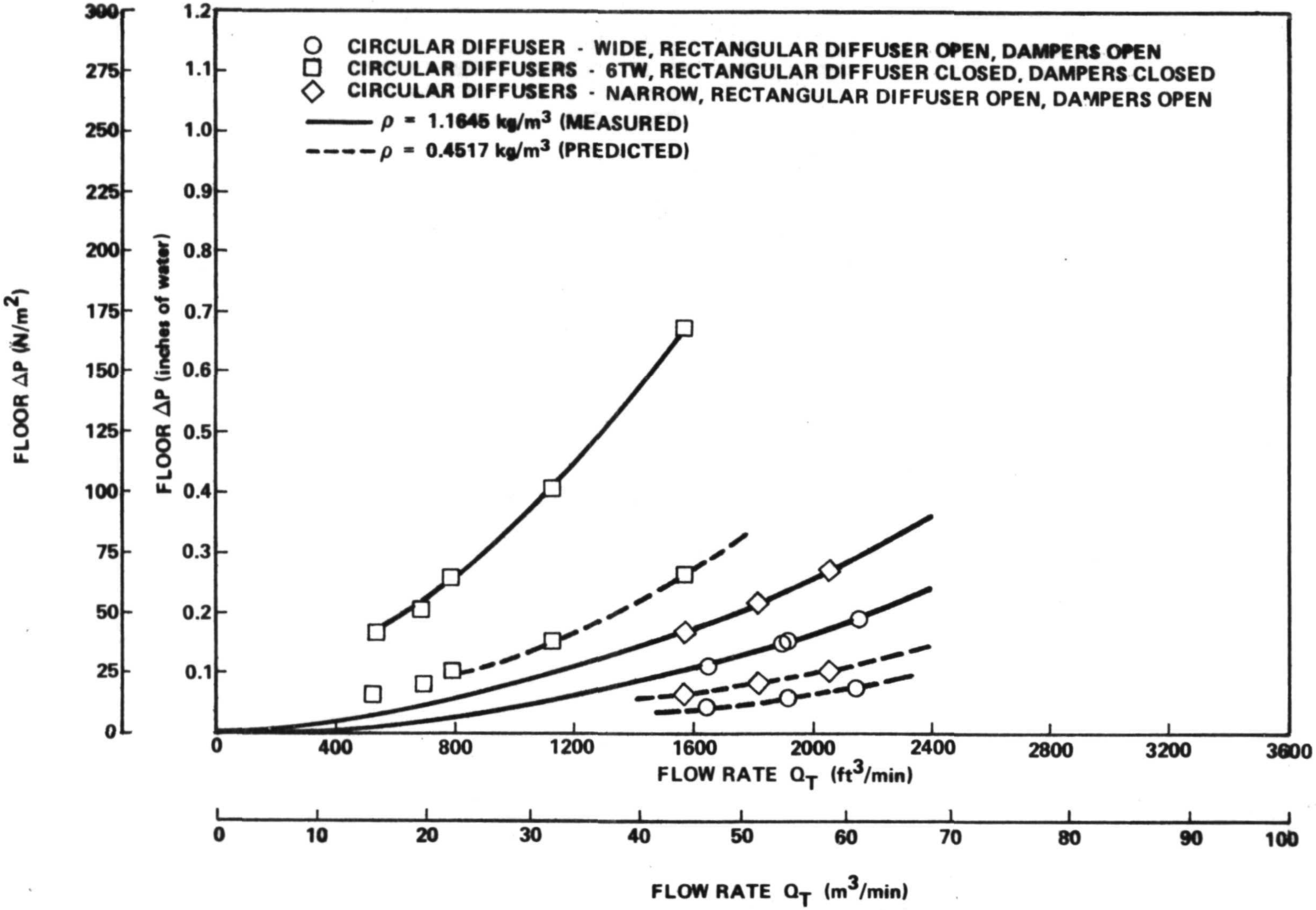


Figure 42. OWS mockup floor resistance.

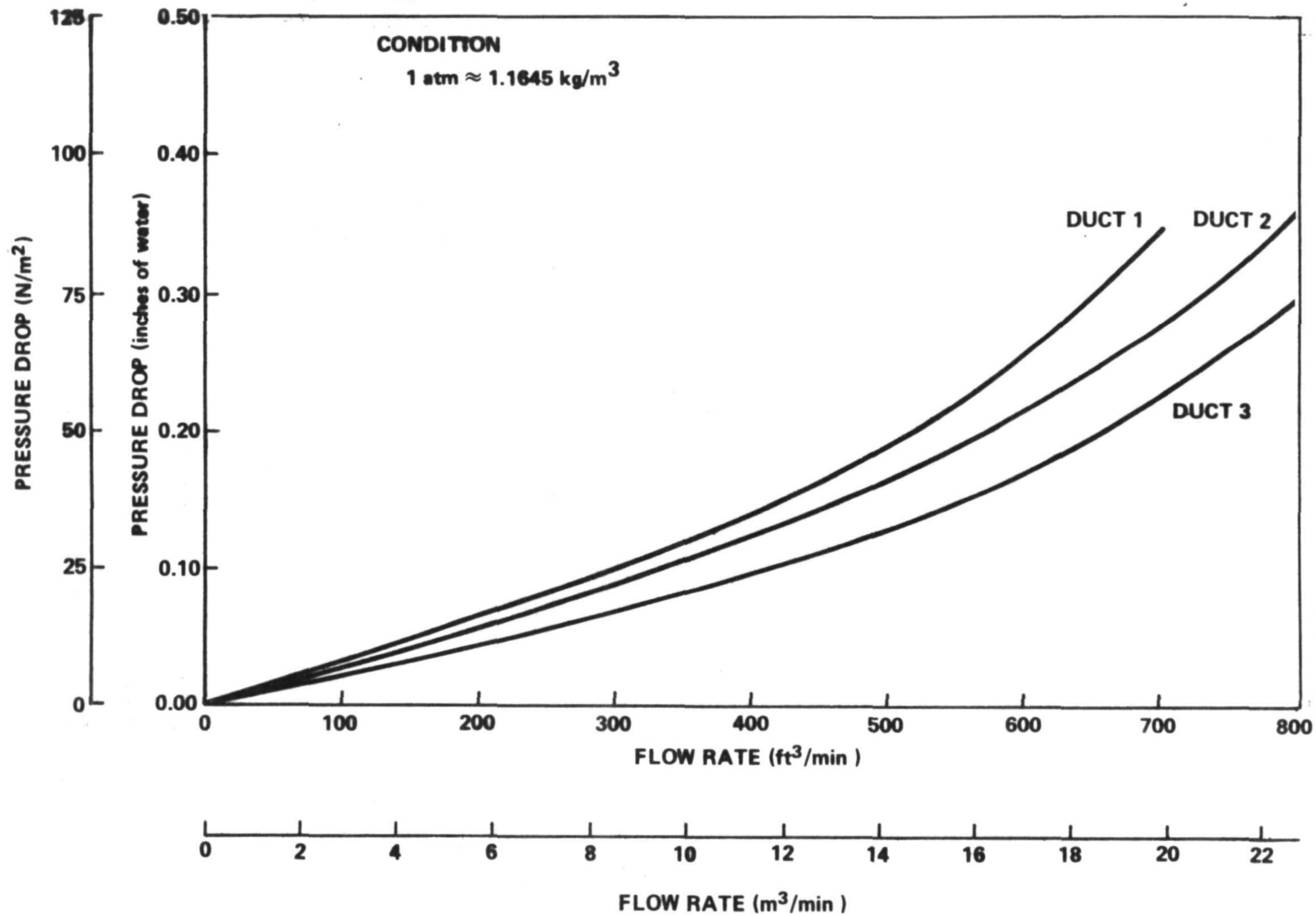


Figure 43. OWS ventilation duct measured resistance.

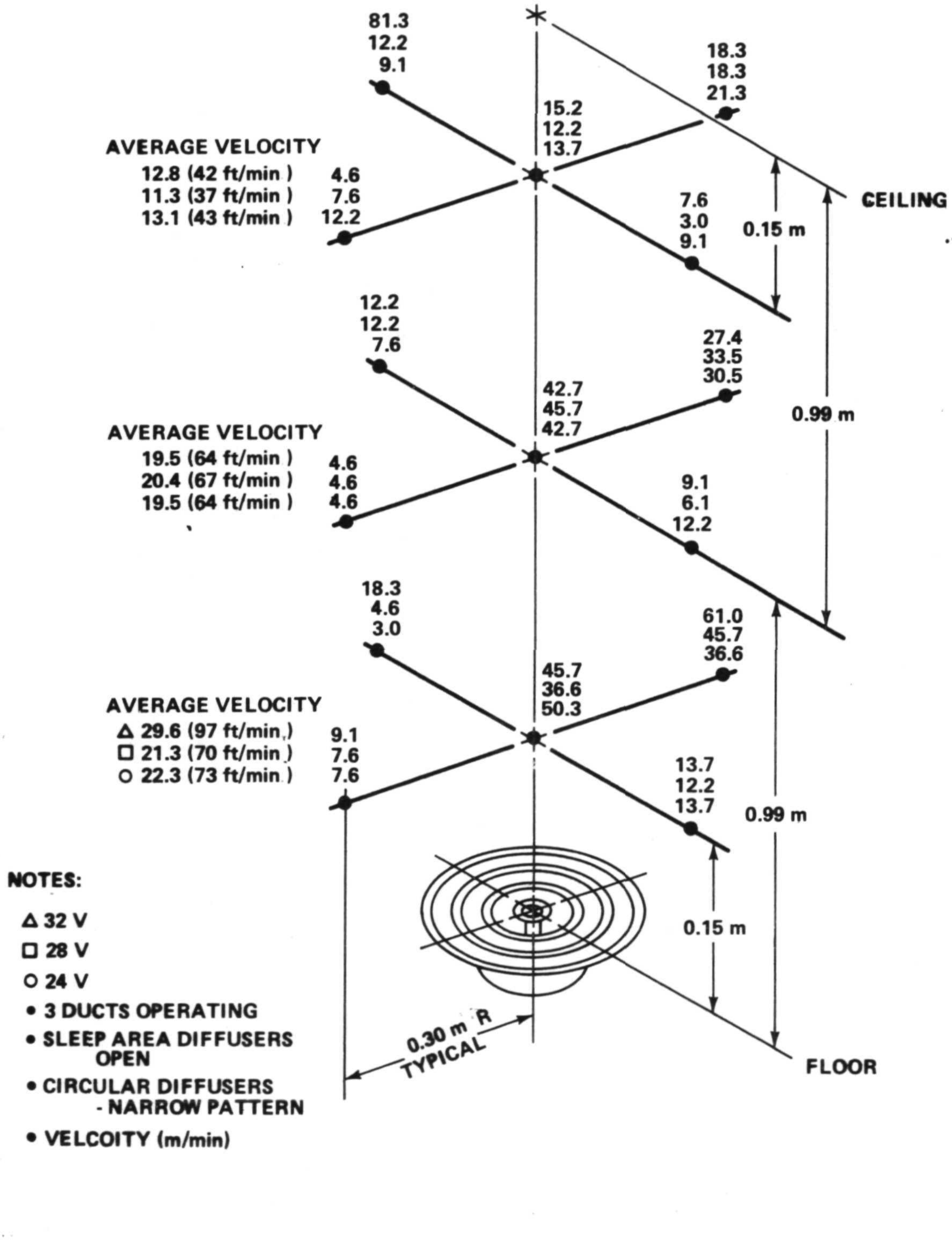


Figure 44. Circular diffuser air-velocity profile — comparison of velocities as affected by fan voltage.

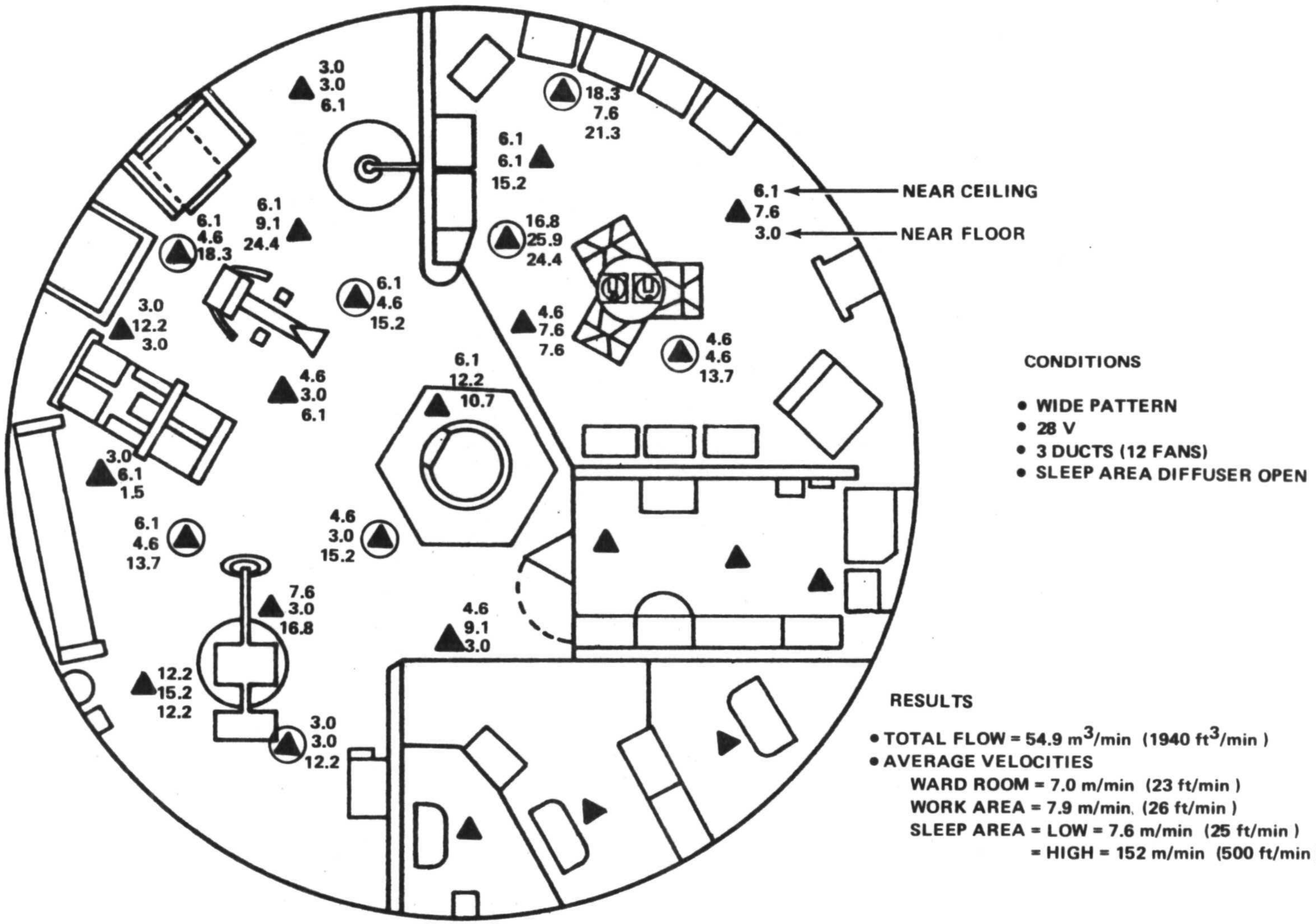


Figure 45. Crew area air velocities.

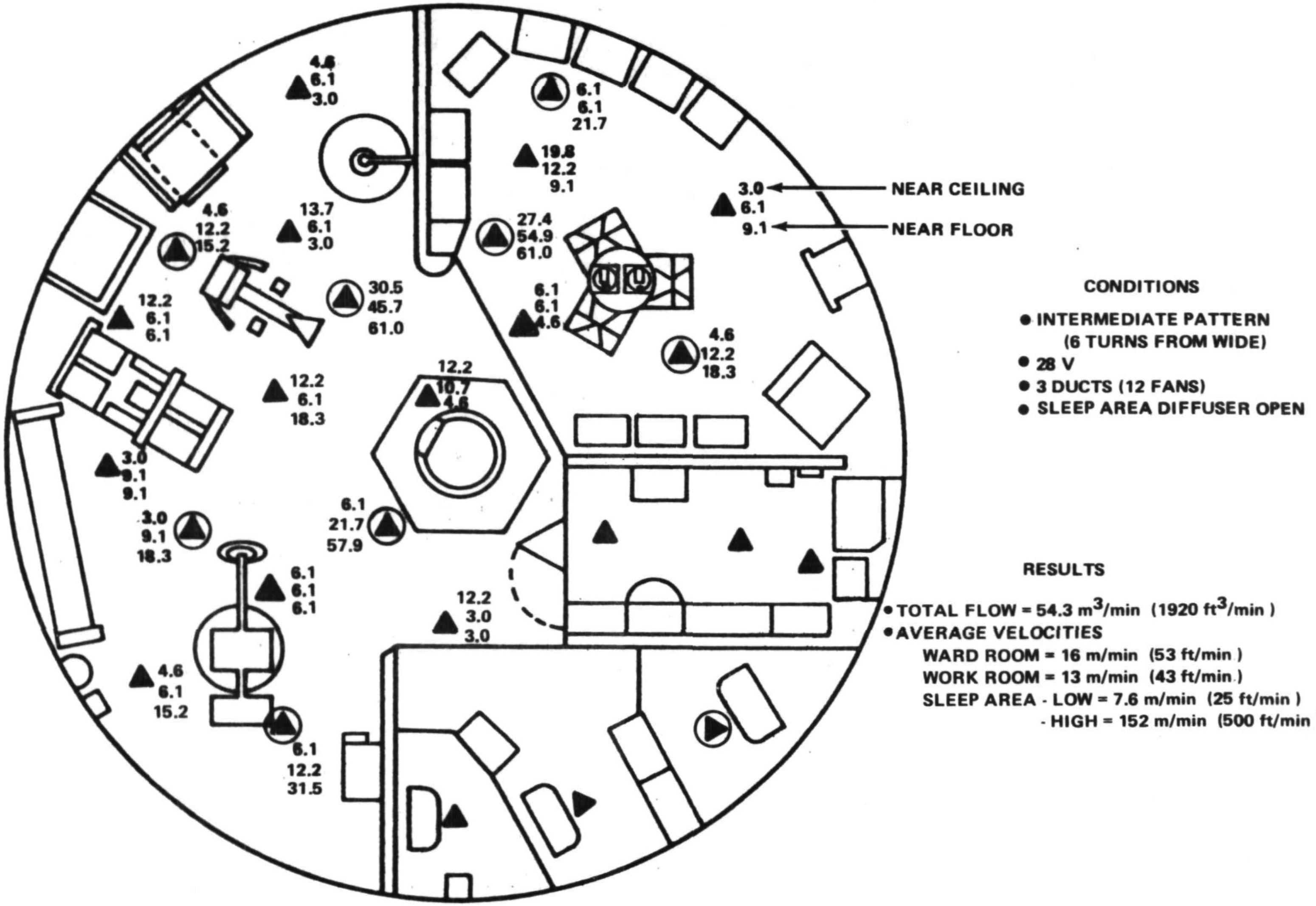
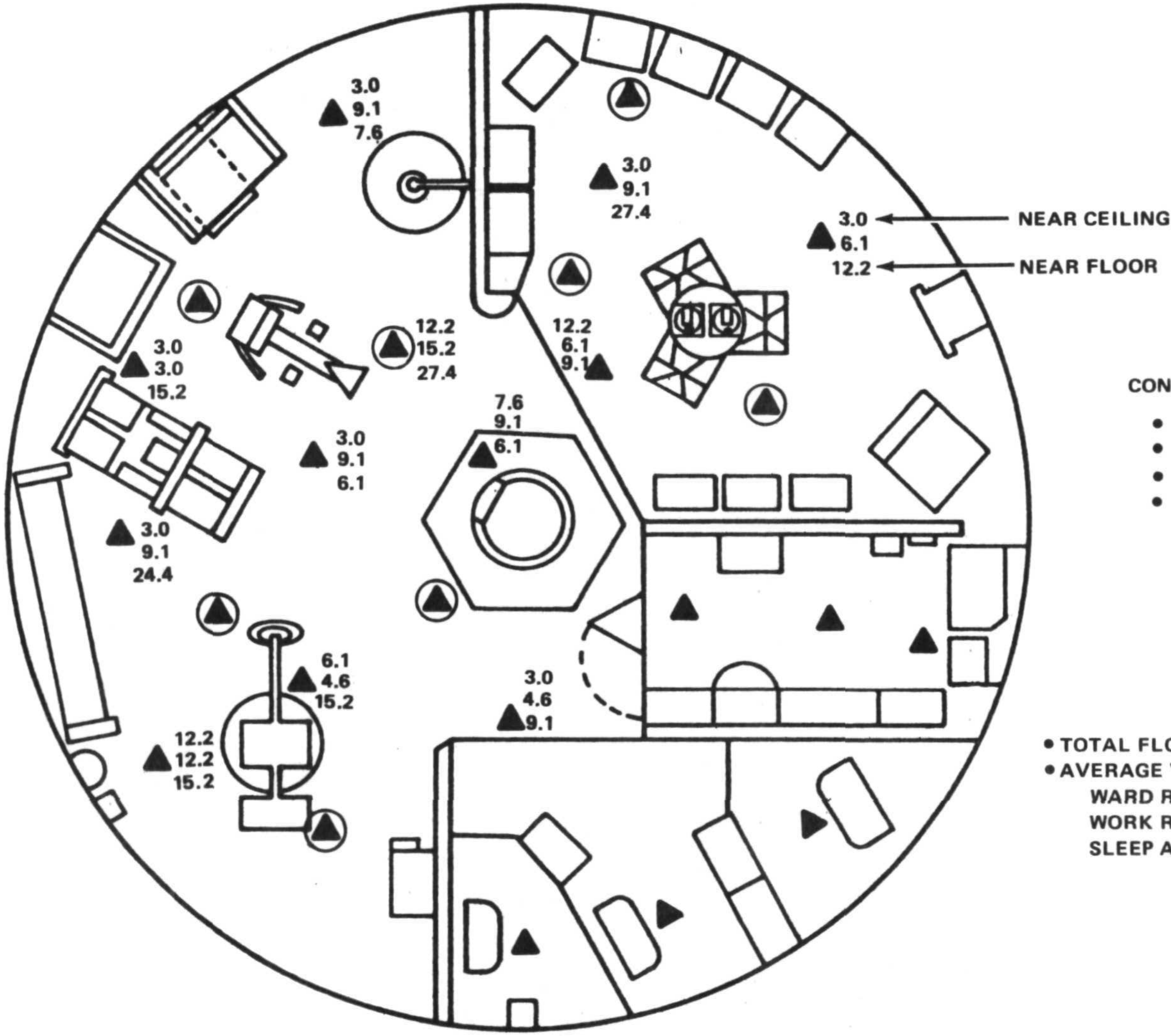


Figure 46. Crew area air velocities.



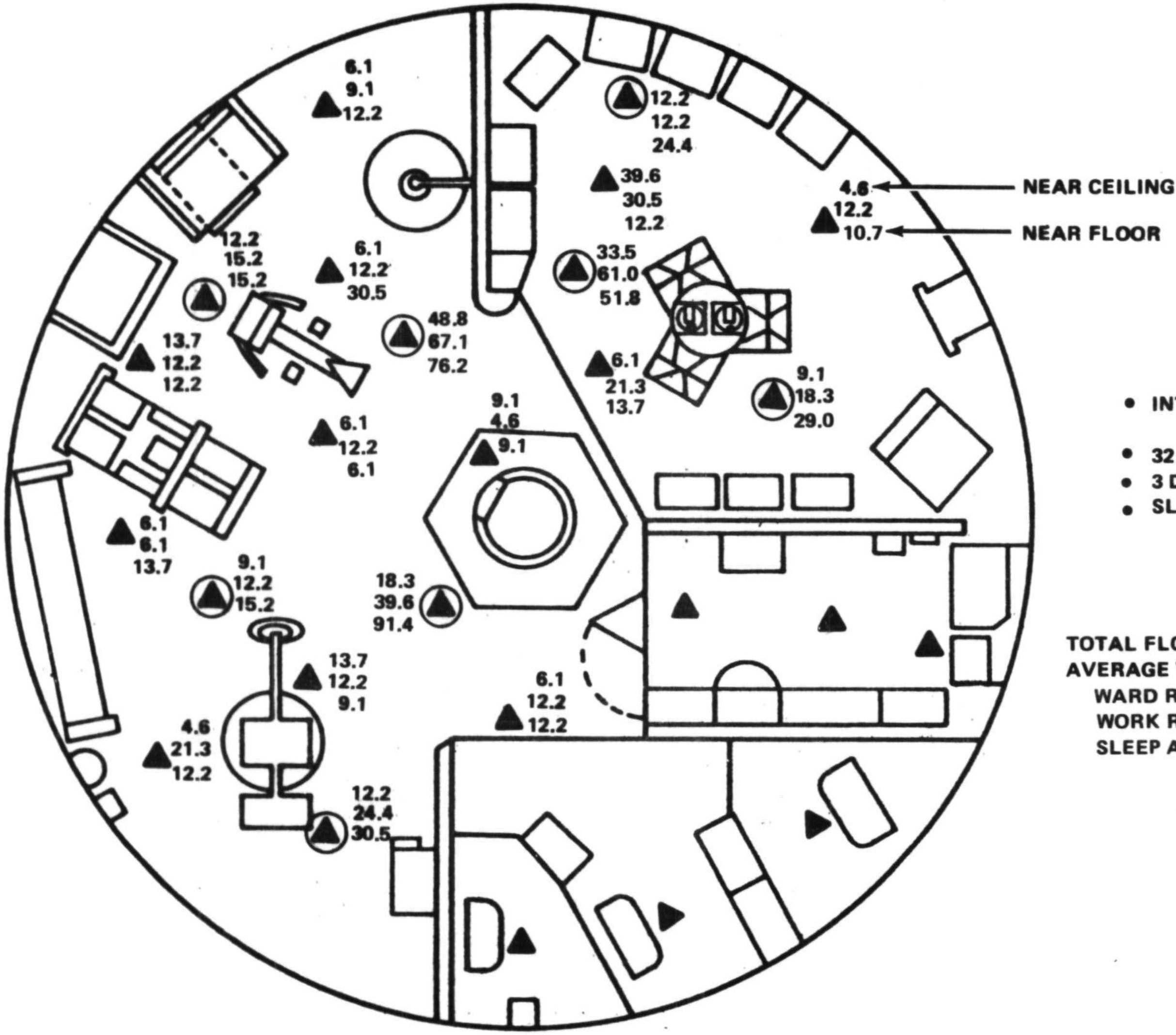
CONDITIONS

- WIDE PATTERN
- 32 V
- 3 DUCTS (12 FANS)
- SLEEP AREA DIFFUSER OPEN

RESULTS

- TOTAL FLOW = 58.3 m^3/min (2060 ft^3/min)
- AVERAGE VELOCITIES
  - WARD ROOM = 9.4 m/min (31 ft/min)
  - WORK ROOM = 9.8 m/min (32 ft/min)
  - SLEEP AREA = 4 m/min (13 ft/min)

Figure 47. Crew area air velocities.



CONDITIONS

- INTERMEDIATE PATTERN (6 TURNS FROM WIDE)
- 32 V
- 3 DUCTS (12 FANS)
- SLEEP AREA DIFFUSER OPEN

RESULTS

TOTAL FLOW = 57.7 m^3/min (2040 ft^3/min)
AVERAGE VELOCITIES
WARD ROOM = 22 m/min (73 ft/min)
WORK ROOM = 19 m/min (63 ft/min)
SLEEP AREA = 4.6 m/min (15 ft/min)

Figure 48. Crew area air velocities.

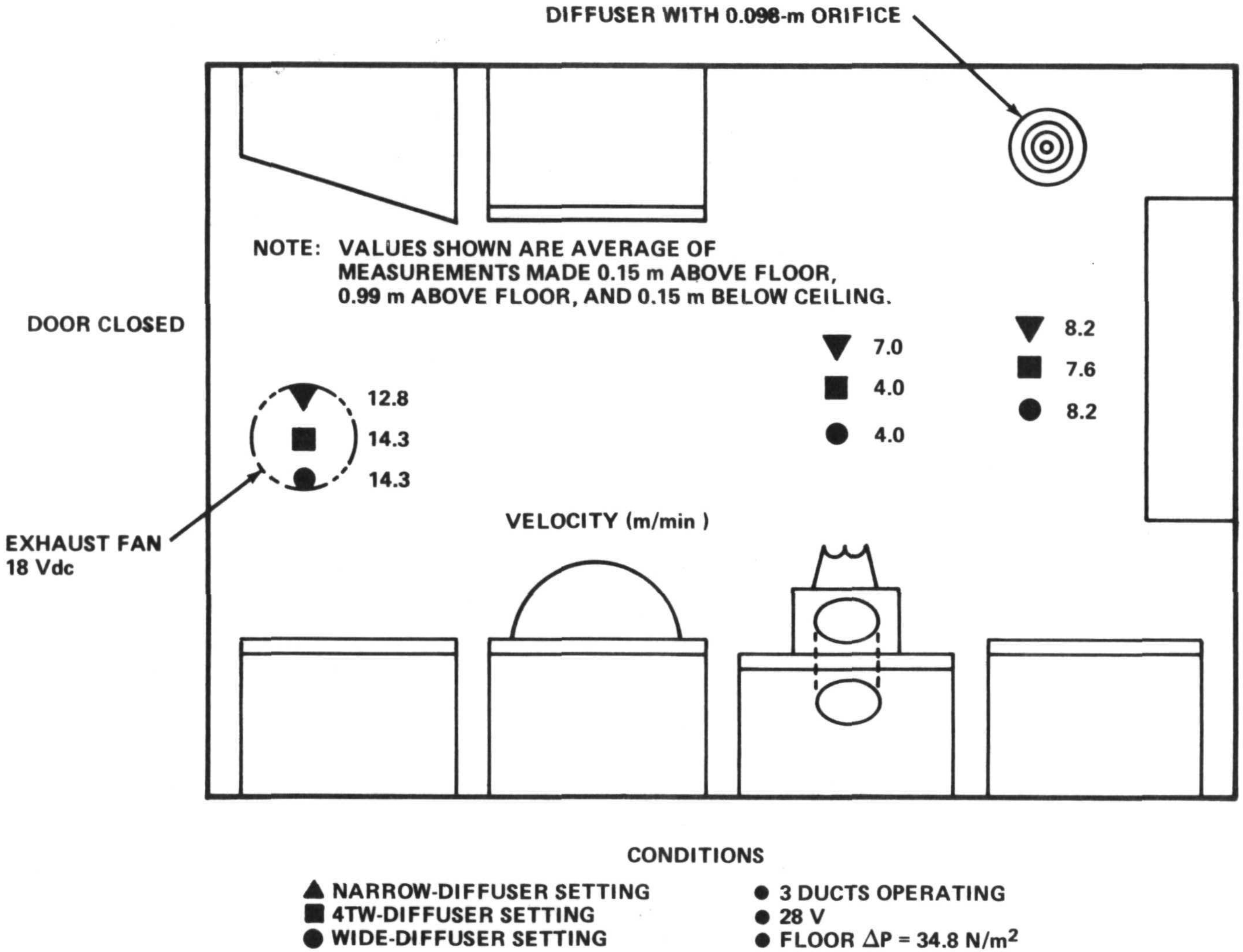


Figure 49. WMA average velocities with orificed diffuser.

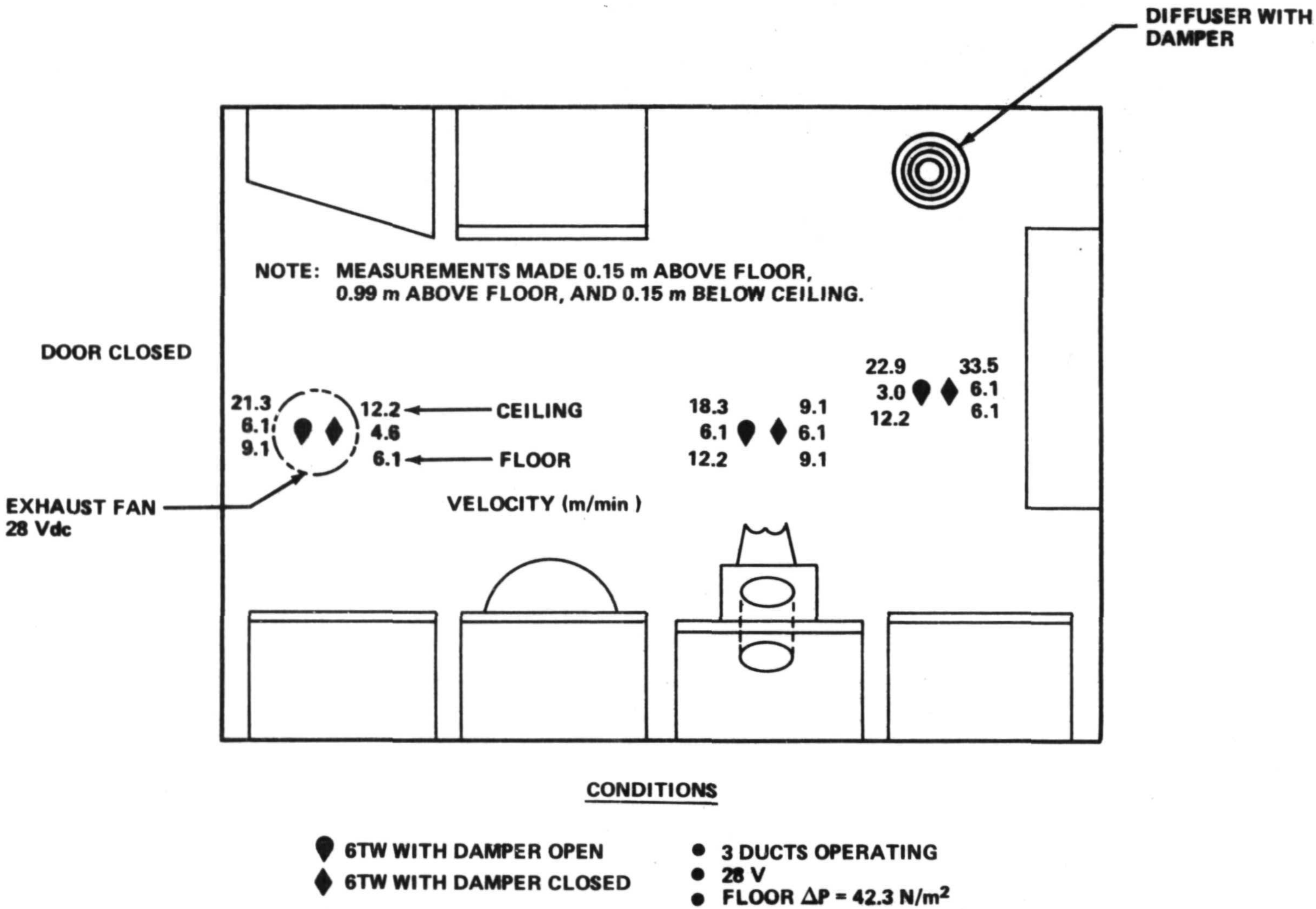


Figure 50. WMA average velocity with dampered diffuser.

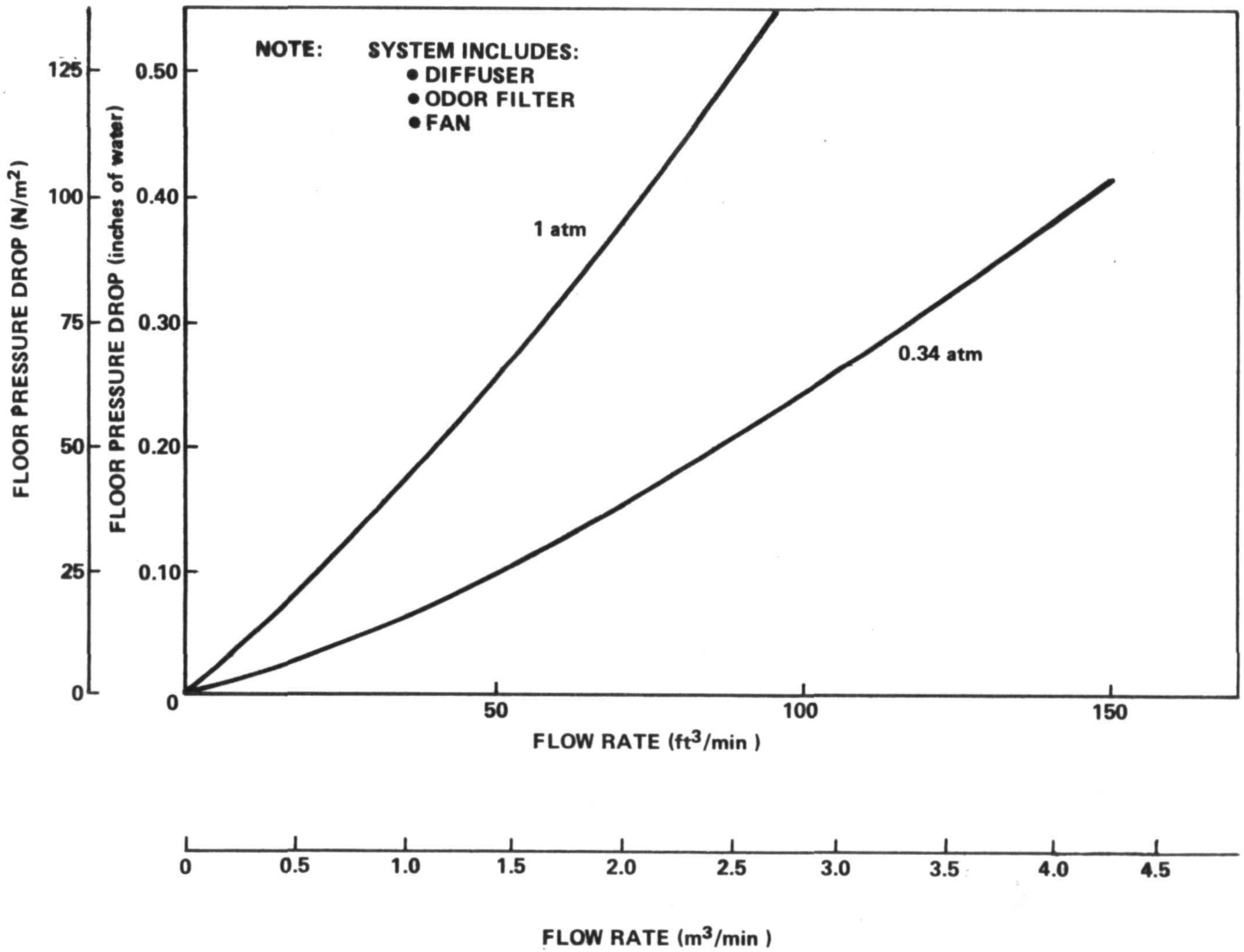


Figure 51. Flow through nonoperating WMA system.

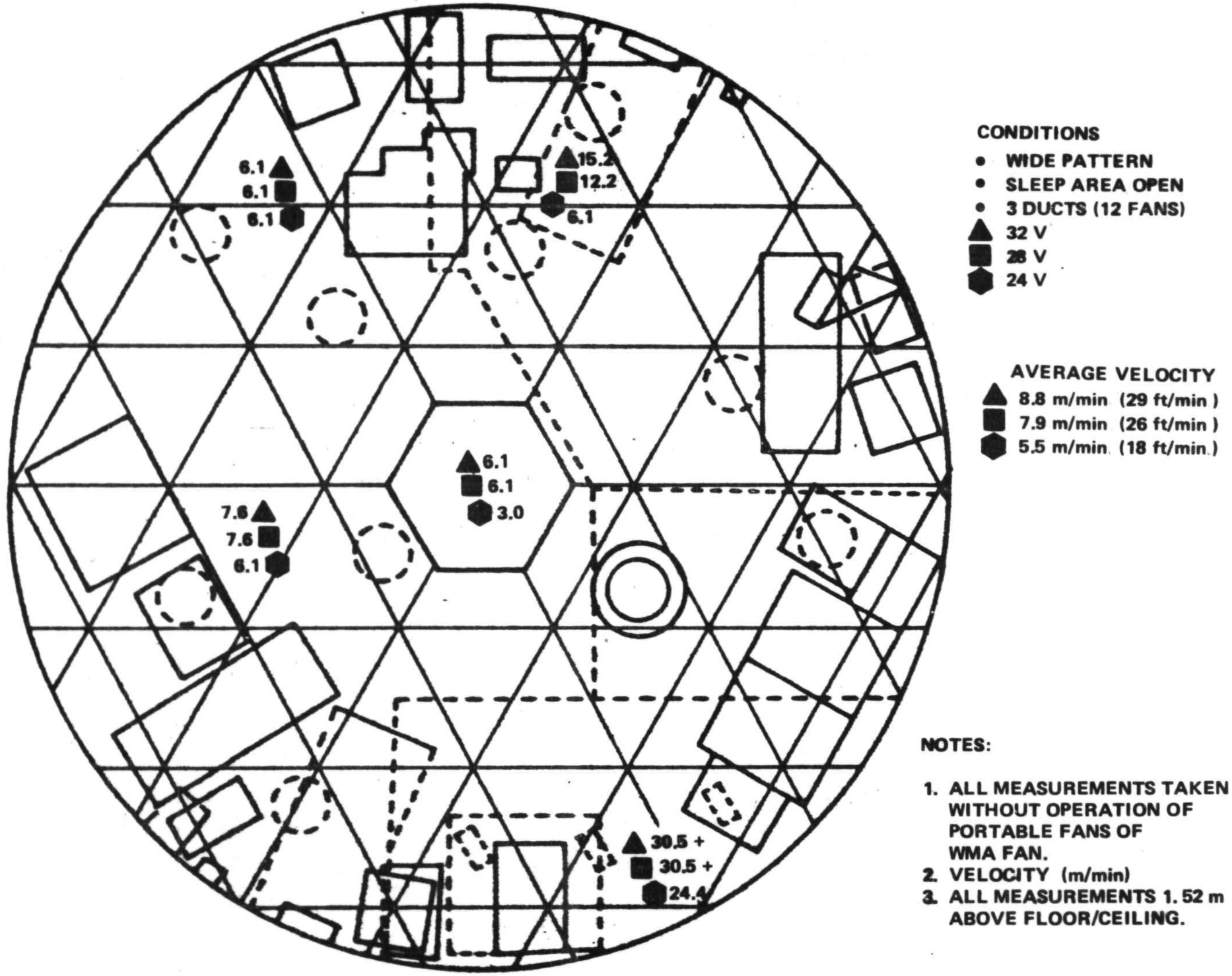


Figure 52. Forward plenum velocity measurements.

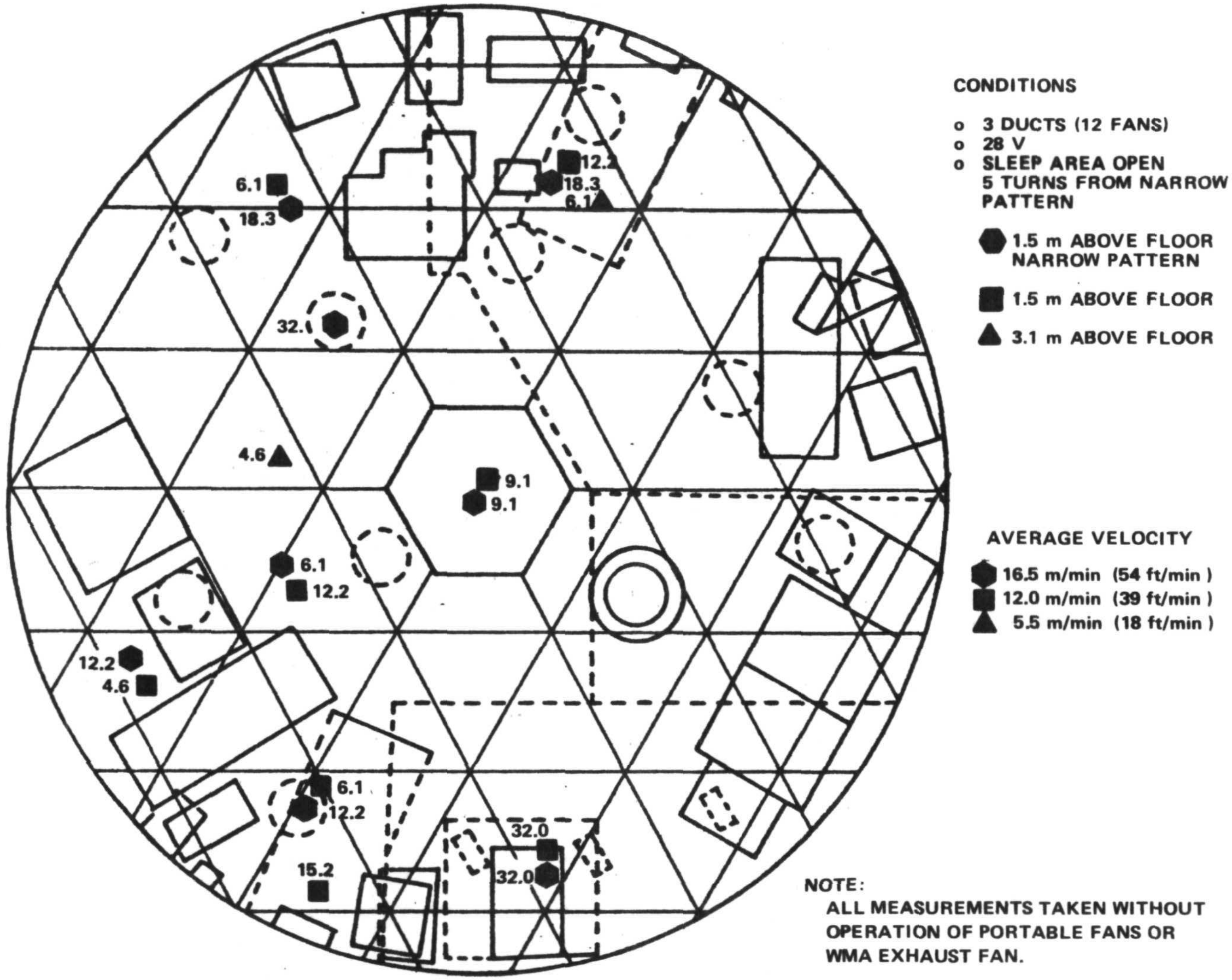


Figure 53. Forward plenum velocity measurements.

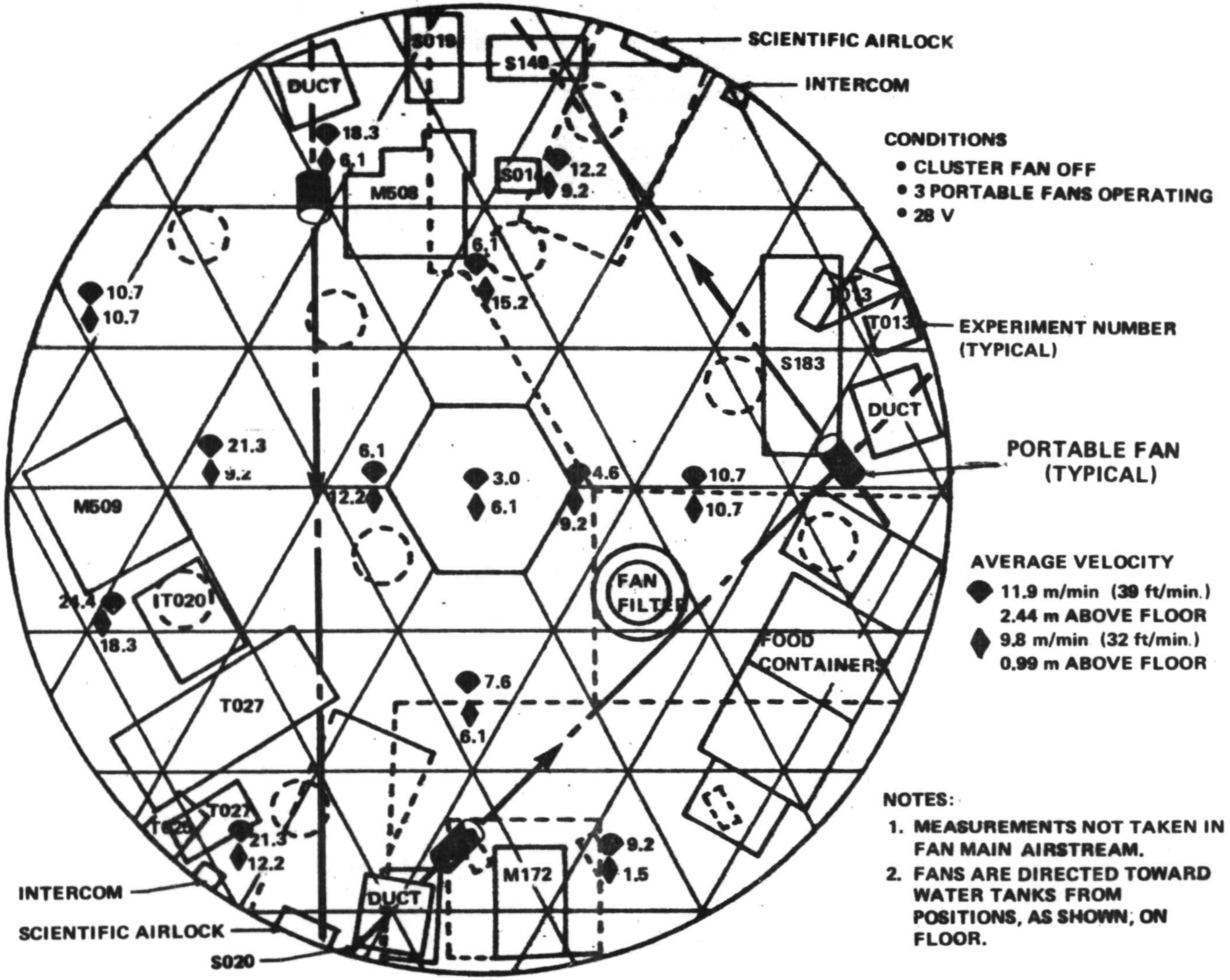


Figure 54. Forward plenum velocity measurements.

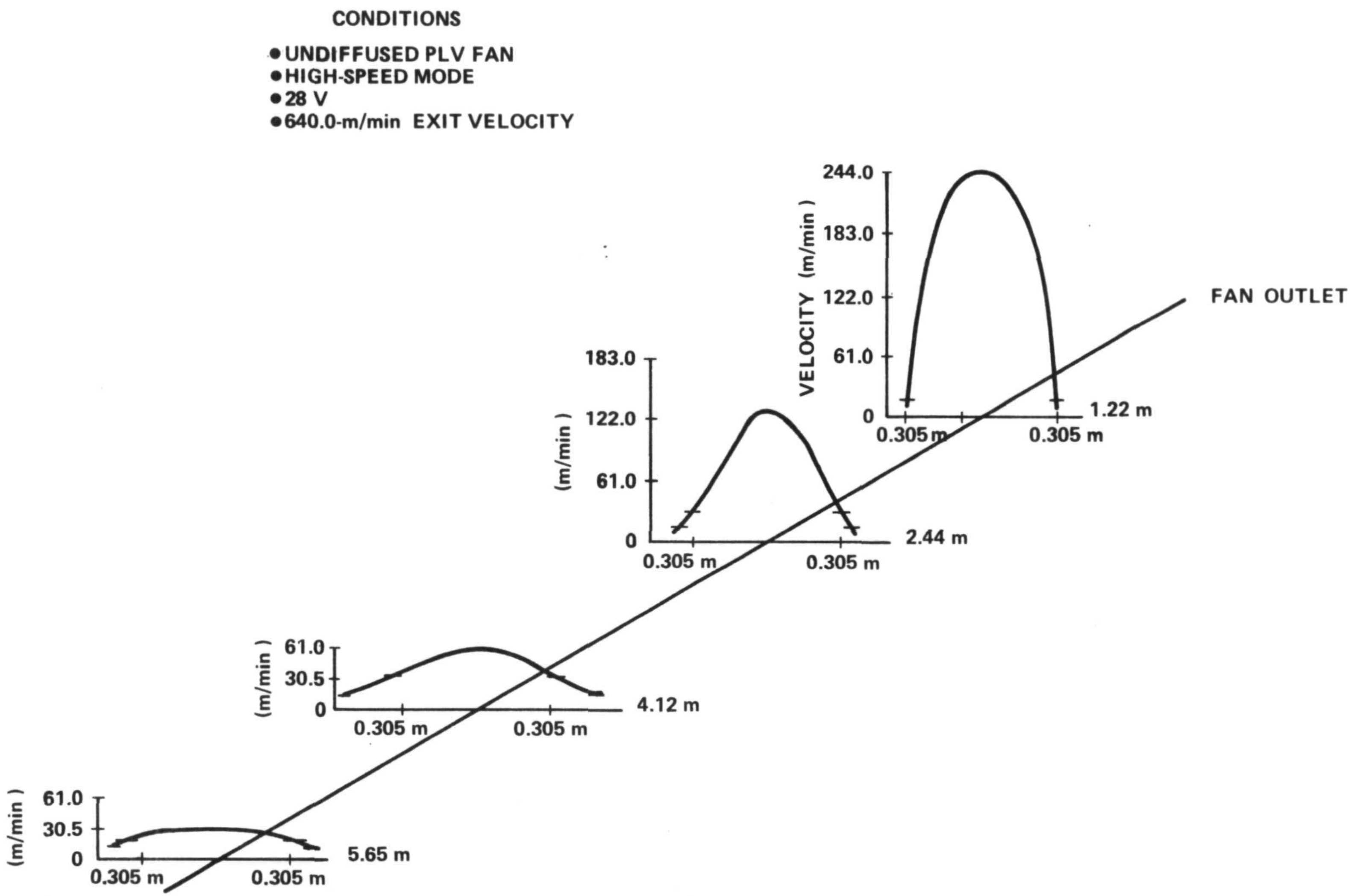


Figure 55. Portable fan velocity profile.

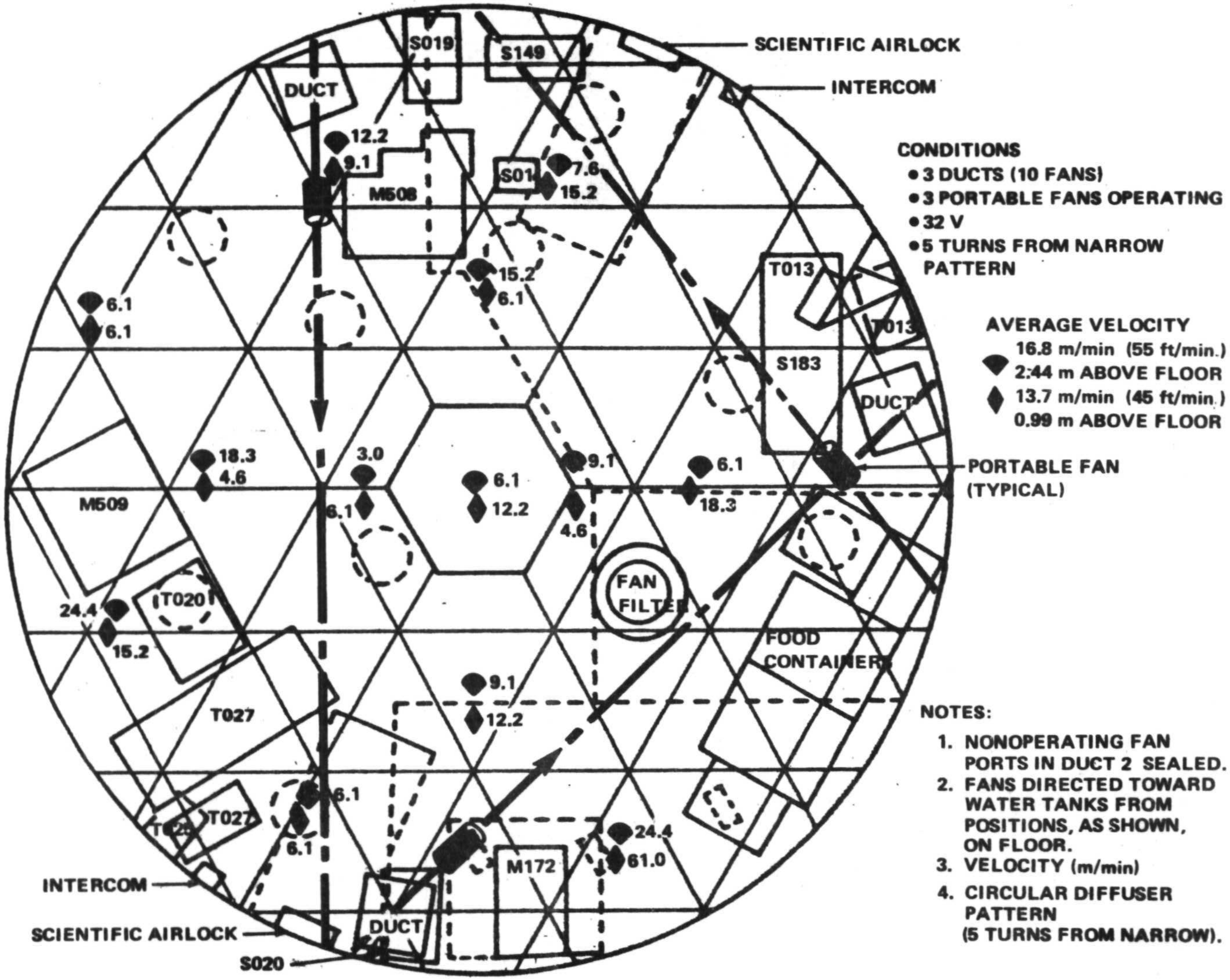


Figure 56. Forward plenum velocity measurements.

REFERENCES

1. Ralston, J. T.: Test Results of the Skylab Workshop Ventilation System Four-Fan Cluster Test. MSFC Memorandum S&E-ASTN-TF-68-70, December 3, 1969.

2. NASA/MSFC Drawing No. 20M42273, Motor Driven Vaneaxial Fan, Specification For, Revision C, March 19, 1969.

3. Ralston, J. T.: Results of the Orbital Workshop "6" Anemostat Diffuser Tests. MSFC Memorandum S&E-ASTN-TF-29-69, June 12, 1969.

4. Ralston, J. T.: Results of the Orbital Workshop "6" Modified Diffuser Tests. MSFC Memorandum S&E-ASTN-TF-45-69, October 6, 1969.

5. Ralston, J. T.: Results of Ventilation Tests Conducted on the Skylab I Orbital Workshop Full-Scale Mockup. MSFC Memorandum S&E-ASTN-TF-09-71, February 22, 1971.

APPENDIX A

TEST RESULTS OF THE SKYLAB WORKSHOP VENTILATION SYSTEM FOUR-FAN CLUSTER TEST

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

REPLY TO ATTN OF: S&E-ASTN-TF-68-70

December 3, 1970

CPV
EJC
GDP

TO See List Attached

FROM Chief, Environmental Test Section
S&E-ASTN-TFE

SUBJECT Test Results of the Skylab Workshop Ventilation System Four-Fan Cluster Test

Reference: Memorandum S&E-ASTN-PF-69-M-125; "Minutes of Meeting to Evaluate Testing Required to Evaluate the Flow Performance of the Workshop Fan Cluster at Five p.s.i.a."

1. The Skylab Workshop ventilation system contains three clusters of four, parallel-mounted fans. The fans are brushless, DC - motor - driven vanexial, PLV (post-landing ventilation) fans, P/N 826070-4, manufactured by the Airesearch Corporation. Figures 1 and 2 show a typical workshop fan cluster and a typical PLV fan, respectively.

Tests were conducted by S&E-ASTN-TFE for the Propulsion and Thermodynamics Division (S&E-ASTN-P) to obtain data for cluster performance evaluation. The Redstone Vacuum Drying Chamber at Building 4750 was utilized for these tests conducted during the period October 26, 1970 through October 30, 1970. The purpose of this memorandum is to document the methods and results of testing.

2. <u>Test Objectives</u>

Performance evaluation of the workshop cluster required testing to meet four objectives:

a. Determination of the performance of each PLV fan used in the cluster.

b. Determination of cluster performance with four fans operating.

c. Determination of cluster performance with three fans operating, one fan freewheeling.

d. Determination of cluster performance with three fans operating, one fan port blocked.

3. Test Method

a. Single-Fan Performance Tests:

Tests were conducted on each fan used in the cluster test to determine performance characteristics at atmospheric densities of 0.0282 lb/ft^3 and 0.0727 lb/ft^3, and fan voltage settings of 26 VDC and 28 VDC, respectively, at those densities. The test setup was as depicted in Figure 3.

The vacuum chamber atmospheric density and fan voltage were set as required and the flow-control valve setting was varied, incrementally, from the open to the closed position. The head rise and flowrate produced by the fan were recorded for each valve setting.

b. Cluster Performance - Four Fans Operating:

With the test setup depicted in Figure 4, atmospheric density and fan voltage were set as required (0.0282 lb/ft^3, 26 VDC; 0.0727 lb/ft^3, 28 VDC). The flow-control valve setting was varied, incrementally, from the open to the closed position. The head rise and flowrate produced by the cluster were recorded for each valve setting.

c. Cluster Performance - Three Fans Operating, One Fan Freewheeling

The test setup and procedure were the same as the above cluster test, except power was not applied to fan serial number 97-159.

d. Cluster Performance - Three Fans Operating, One Fan Port Blocked:

The test setup and procedure were the same as the above cluster test, except fan serial number 97-159 was removed from the cluster and it's port blocked to prevent backflow.

4. Test Results and Discussion:

Single fan performance data are graphically presented in Figure 5. The curves are self-explanatory.

Figure 6 shows a comparison of measured cluster performance and predicted cluster performance. The "predicted" curve was obtained from single fan performance data by adding the flowrate produced by each fan at given differential pressures. Also shown in Figure 6 is a curve constructed by averaging the flowrates of the single fans at given differential pressures. All data for Figure 6 were obtained at 0.0727 lb/ft^3 chamber air density and 28 VDC fan voltage.

Figure 7 shows the same comparison as Figure 6 except at a chamber air density of 0.0282 lb/ft^3 and 26 VDC fan voltage.

Figure 8 corroborates the reason for conducting tests at 28 VDC in a 0.0727 lb/ft^3 environment and 26 VDC in a 0.0282 lb/ft^3 environment. The lower curve of Figure 8 was determined by averaging the flowrate, at given differential pressures, of the four single-fan tests conducted at 0.0282 lb/ft^3 density and 26 VDC fan voltage. The "predicted" ΔP (ΔP_p) was then determined by multiplying the average curve ΔP (ΔP_a), at given flowrates, by the ratio of the test densities; that is, $\Delta P_p = \Delta P_a \times \frac{0.0727}{0.0282}$. The predicted performance agrees very well with the average of single-fan tests conducted at 0.0727 lb/ft^3 density and 28 VDC fan voltage.

To allow comparison of cluster performance with four fans operating; three fans operating, one fan freewheeling; and three fans operating, one fan port plugged, data are graphically presented in Figure 9. These curves represent tests conducted at 0.0727 lb/ft^3 air density and 28 VDC fan voltage. Figure 10 graphically depicts the same type tests as those shown in Figure 9, except the tests were conducted at 0.0282 lb/ft^3 air density and 26 VDC fan voltage.

Figures 11 and 12 show measured cluster performance with three fans operating/one fan port blocked, and a summation of single-fan flowrate data at given ΔP's for the same three fans operating individually. These curves show further the predictability of performance.

5. Conclusions

a. Performance of multiple, parallel - mounted PLV fans is predictable, i.e., if the performance of each fan is known, the summation of single-fan flowrates at a given ΔP determines the combined performance.

b. In the event of power failure to one or more fans in a cluster, performance of the remaining operating fans, or clusters, may be increased by sealing the port(s) of the inoperative fan(s) to prevent backflow.

J.T. Ralston

J. T. Ralston

Enc:
a/s

Addressees:
S&E-ASTN-P, Messrs. Paul/Wood
S&E-ASTN-T, Messrs. Connor/Verschoore
S&E-ASTN-TF, Mr. Perry
S&E-ASTN-PF, Mr. Worlund
S&E-ASTN-PJ, Mr. Miller
S&E-ASTN-PL, Messrs. Hopson/Littles/Patterson
S&E-ASTN-EM, Mr. Burns
S&E-ASTN-PFA, Messrs. Hastings/Allums
S&E-ASTN-TF, File 3.12.81

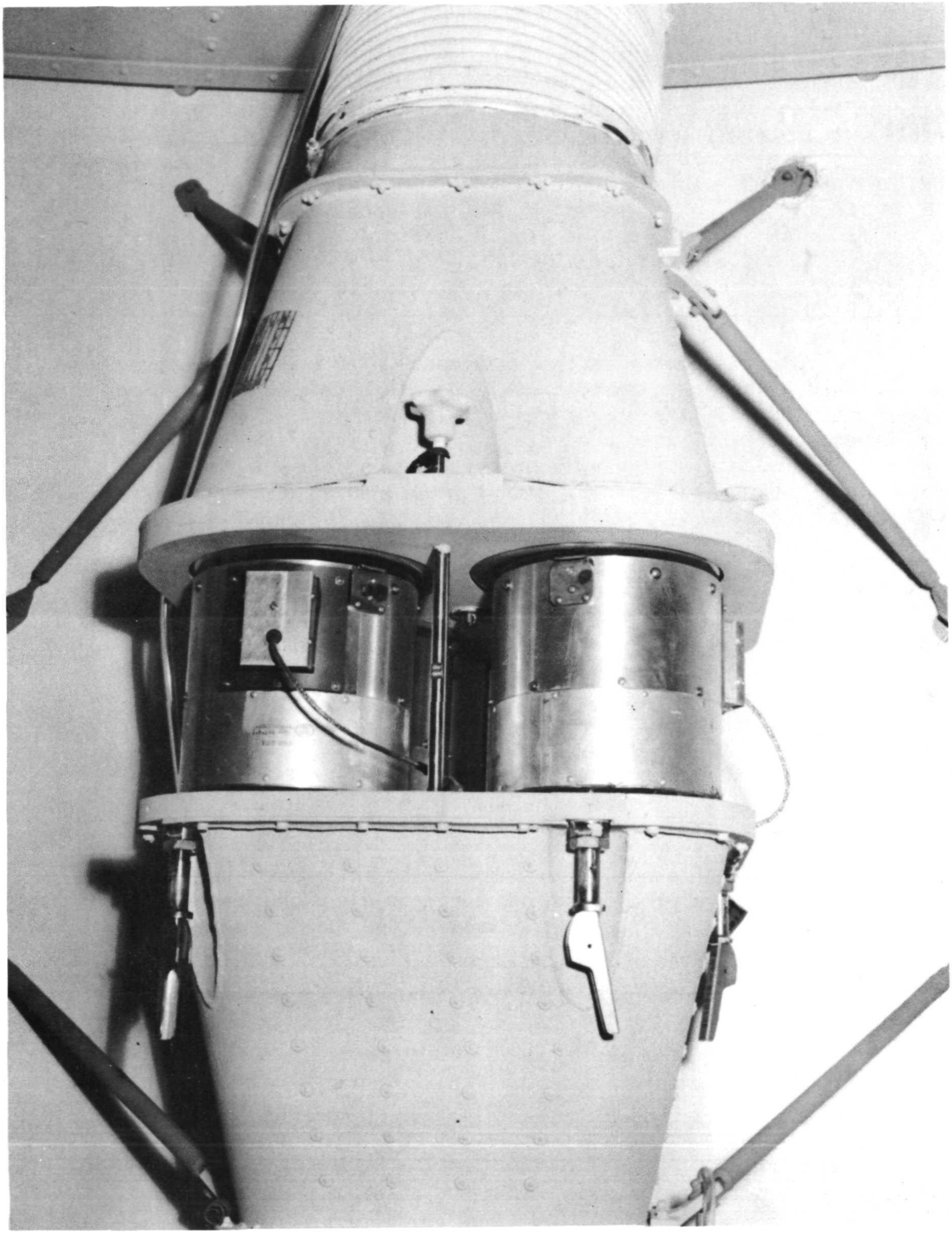

FIGURE 1. TYPICAL FAN CLUSTER

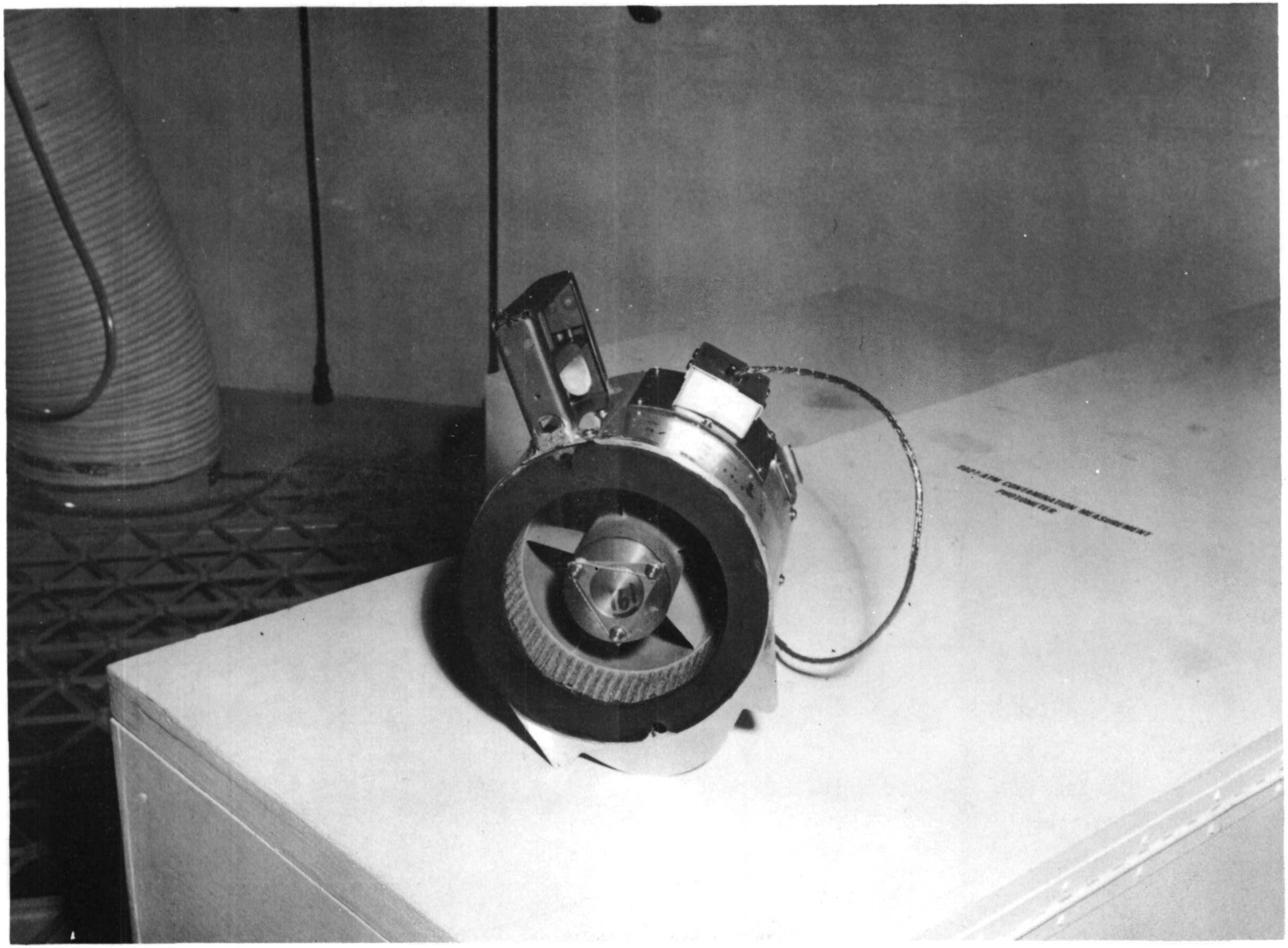

FIGURE 2. PLV (POST LANDING VENTILATION) FAN

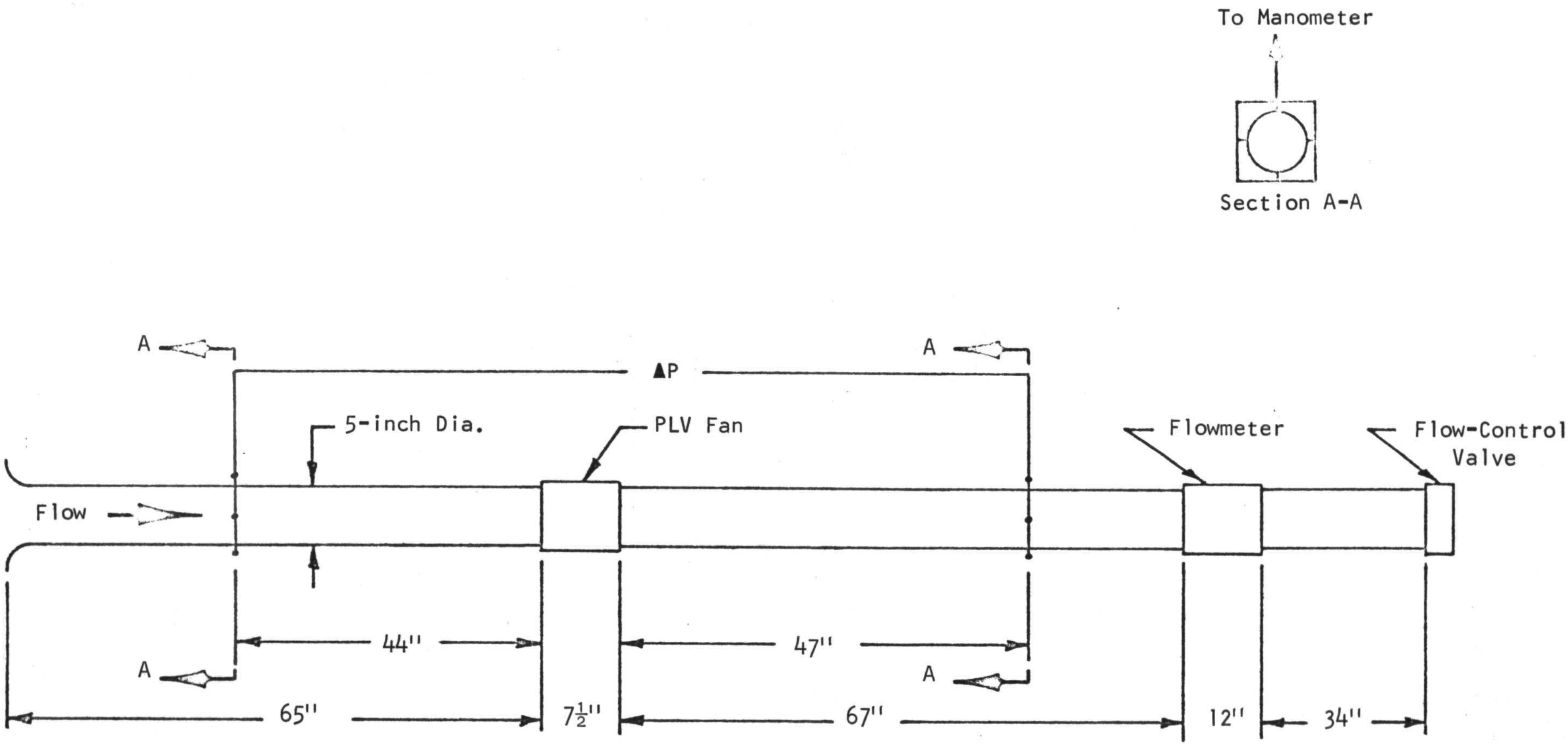

FIGURE 3. SINGLE FAN TEST SETUP

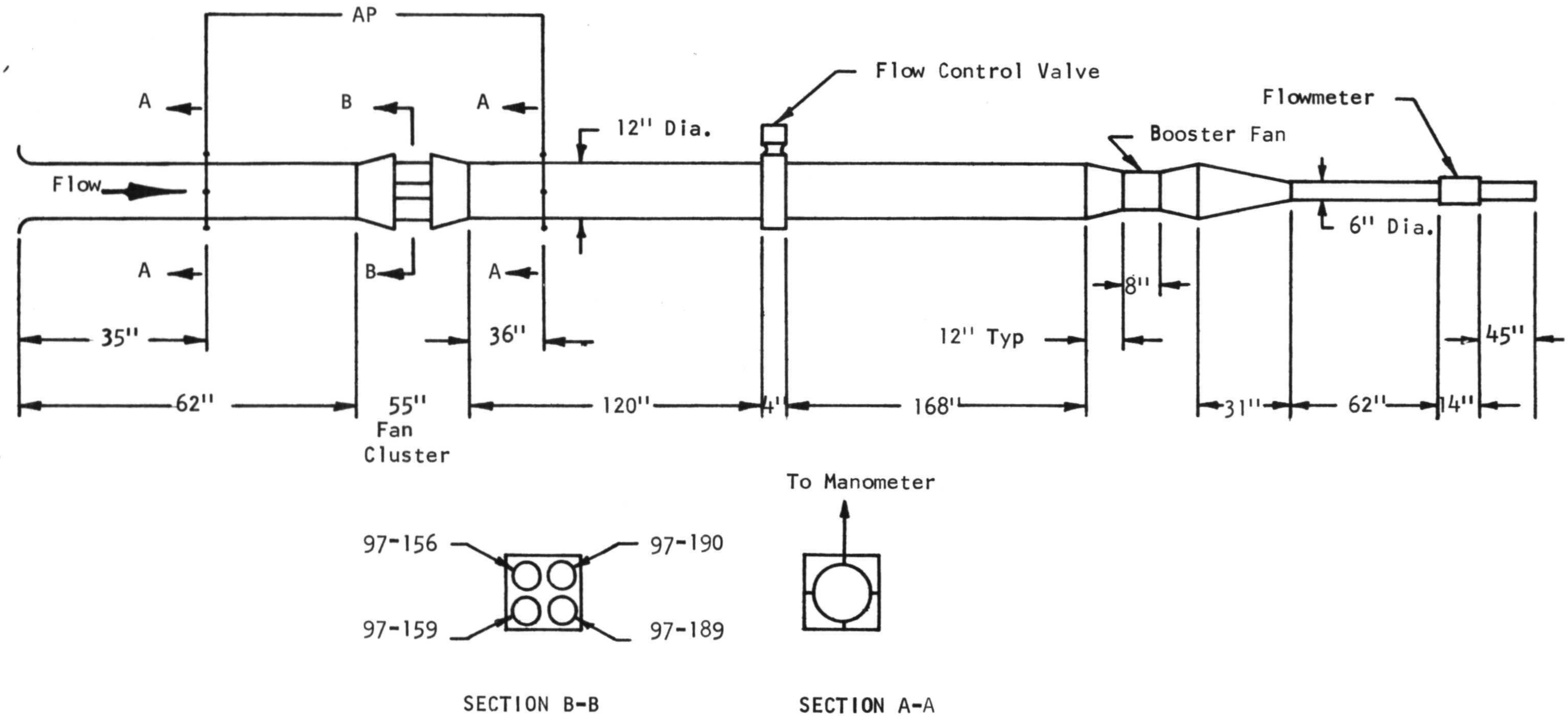

FIGURE 4. CLUSTER TEST SETUP

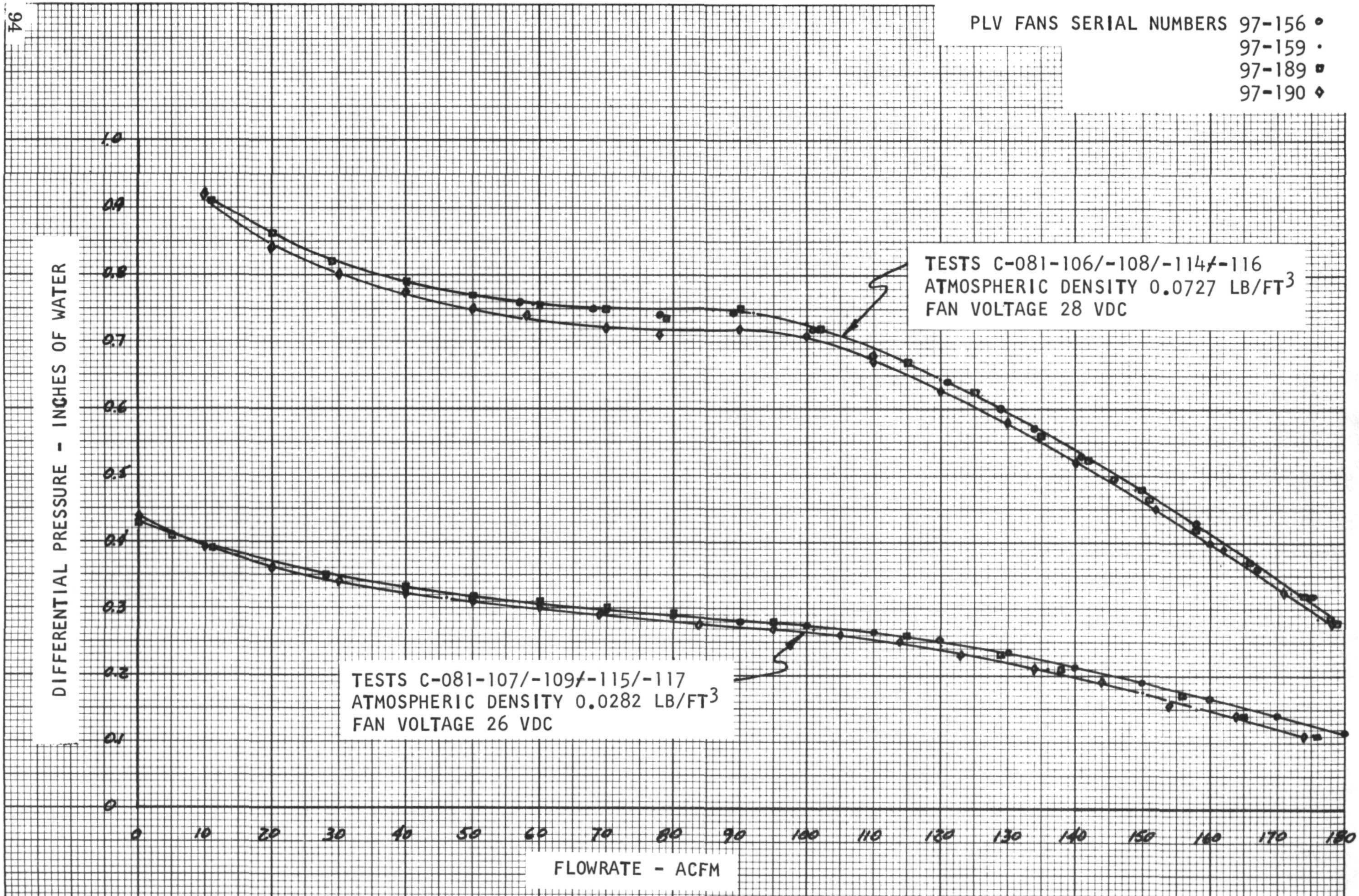

FIGURE 5. SINGLE FAN PERFORMANCE TESTS

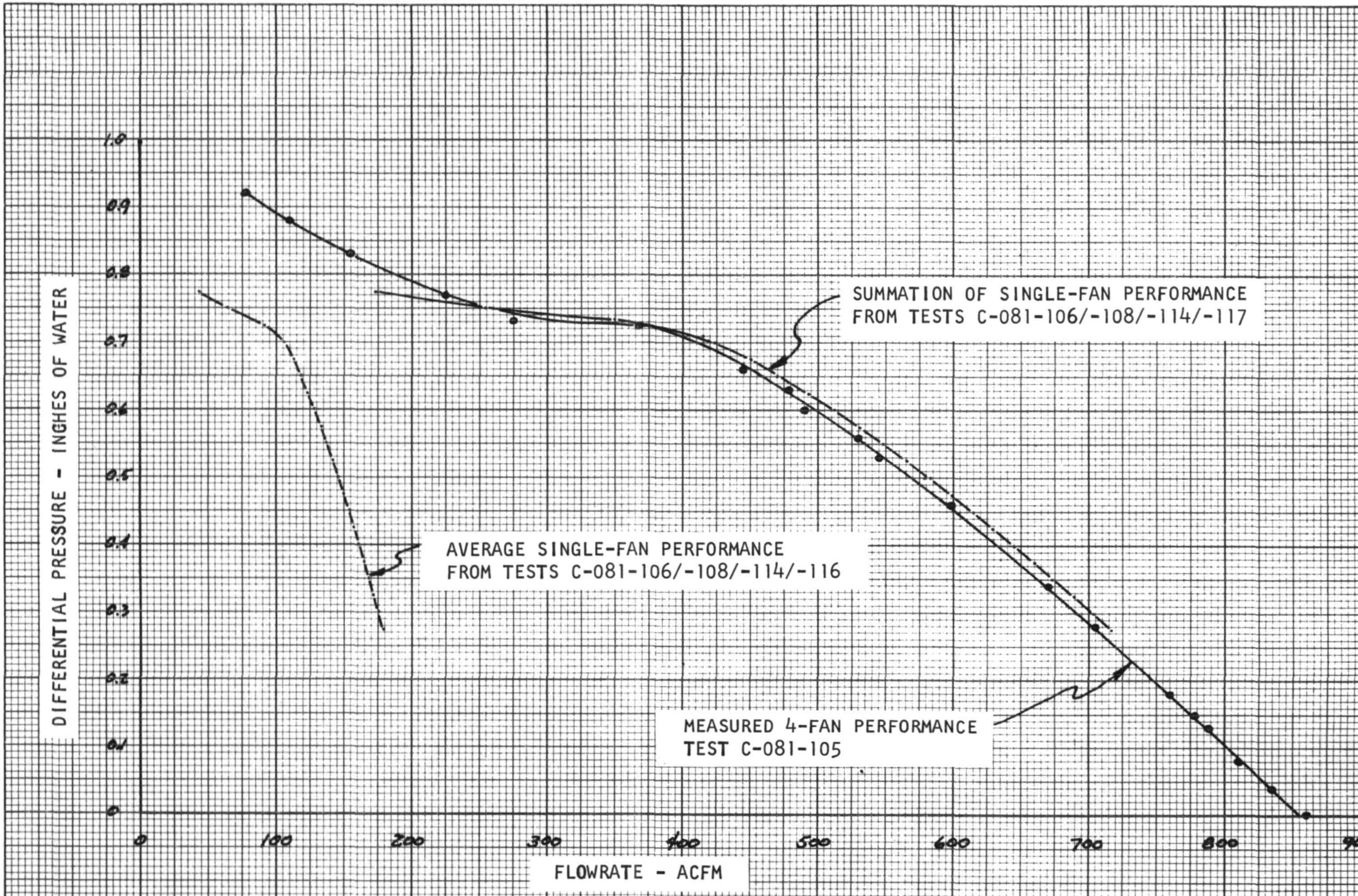

FIGURE 6. COMPARISON OF MEASURED AND PREDICTED CLUSTER PERFORMANCE
$0.0727\ LB/FT^3$, 28 VDC

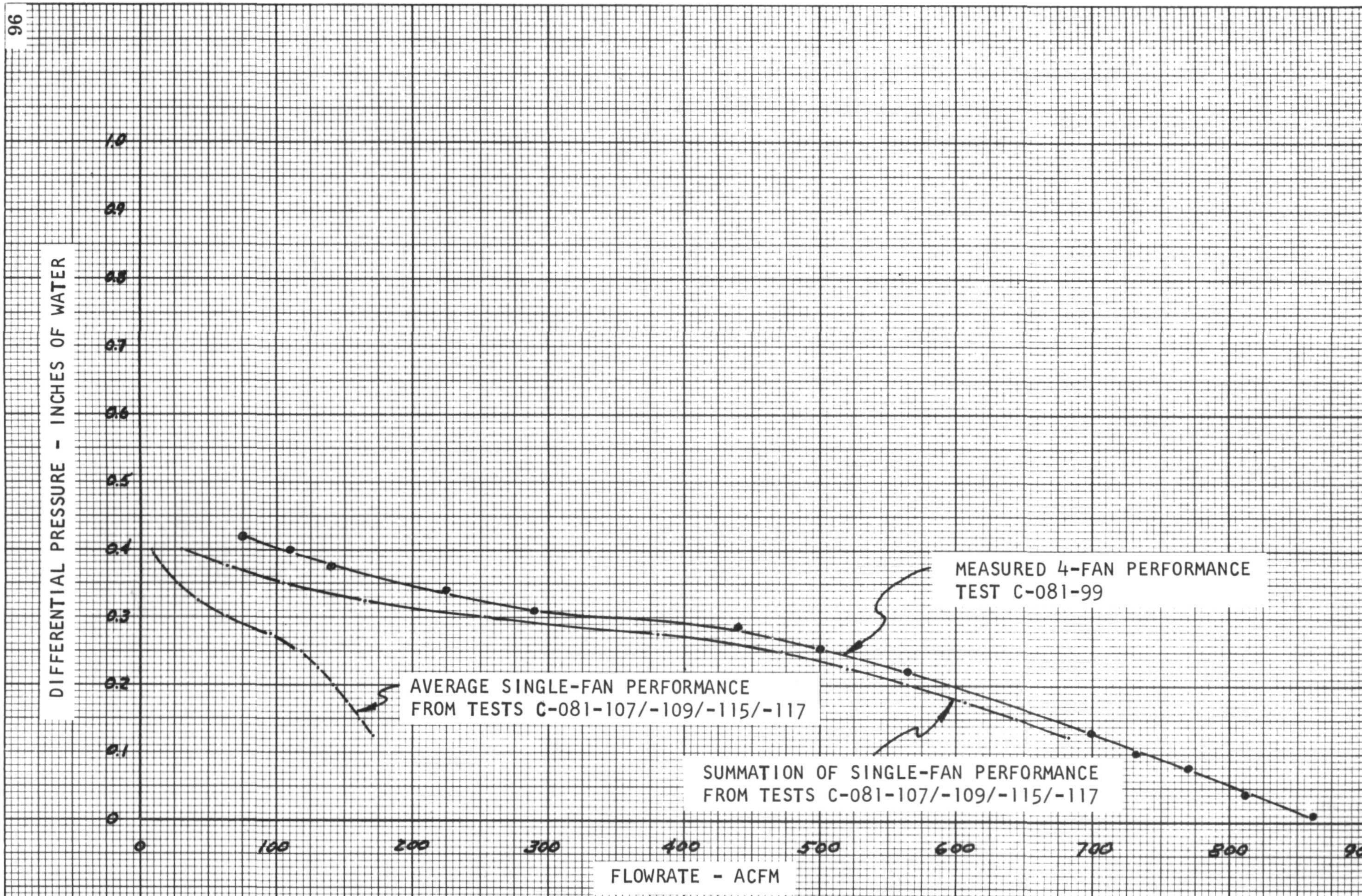

FIGURE 7. COMPARISON OF MEASURED AND PREDICTED CLUSTER PERFORMANCE
0.0282 LB/FT^3, 26 VDC

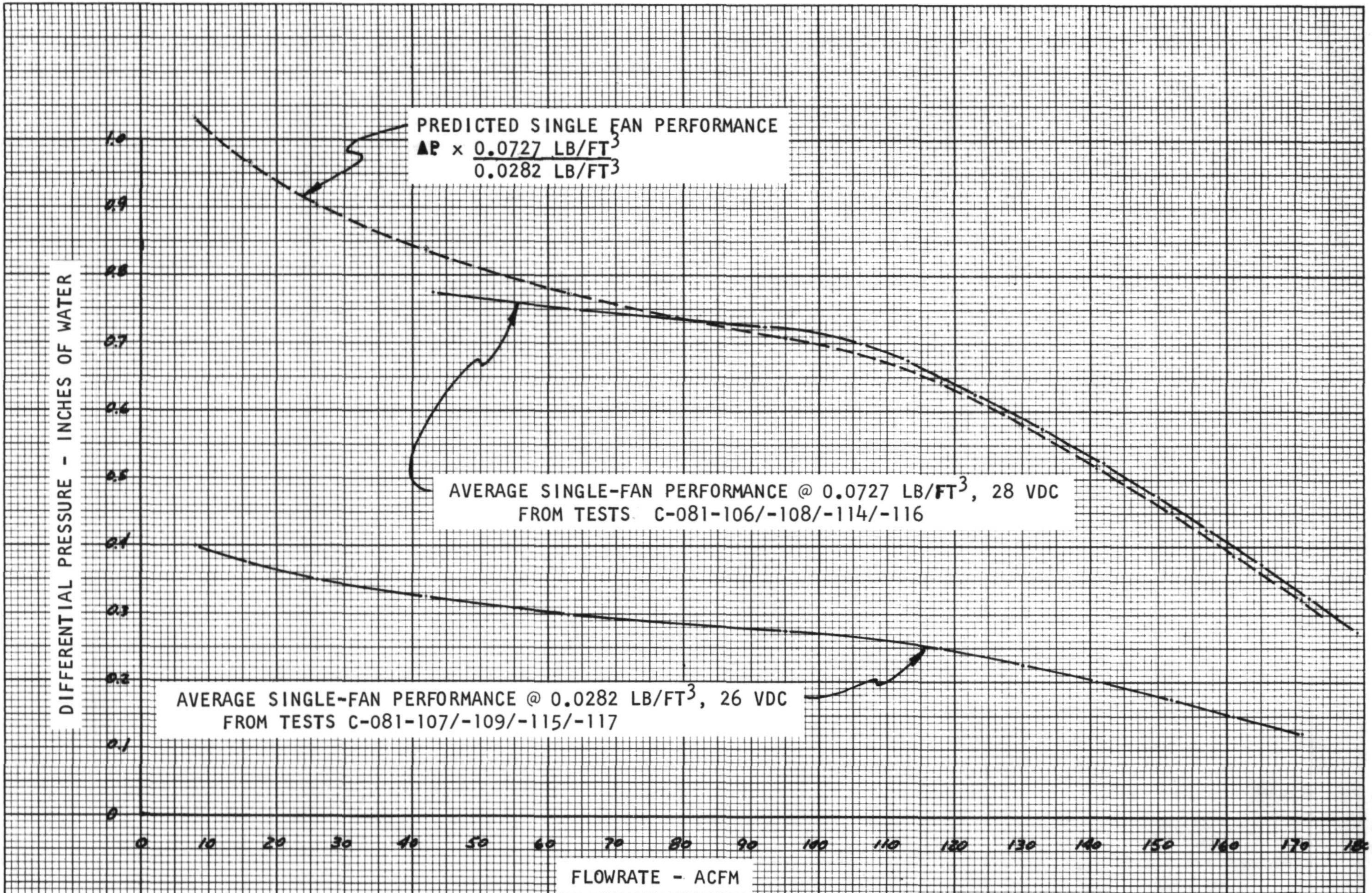

FIGURE 8. PREDICTED CLUSTER PERFORMANCE AT 0.0727 LB/FT^3, 28 VDC FROM SINGLE-FAN PERFORMANCE DATA MEASURED AT 0.0282 LB/FT^3, 26 VDC

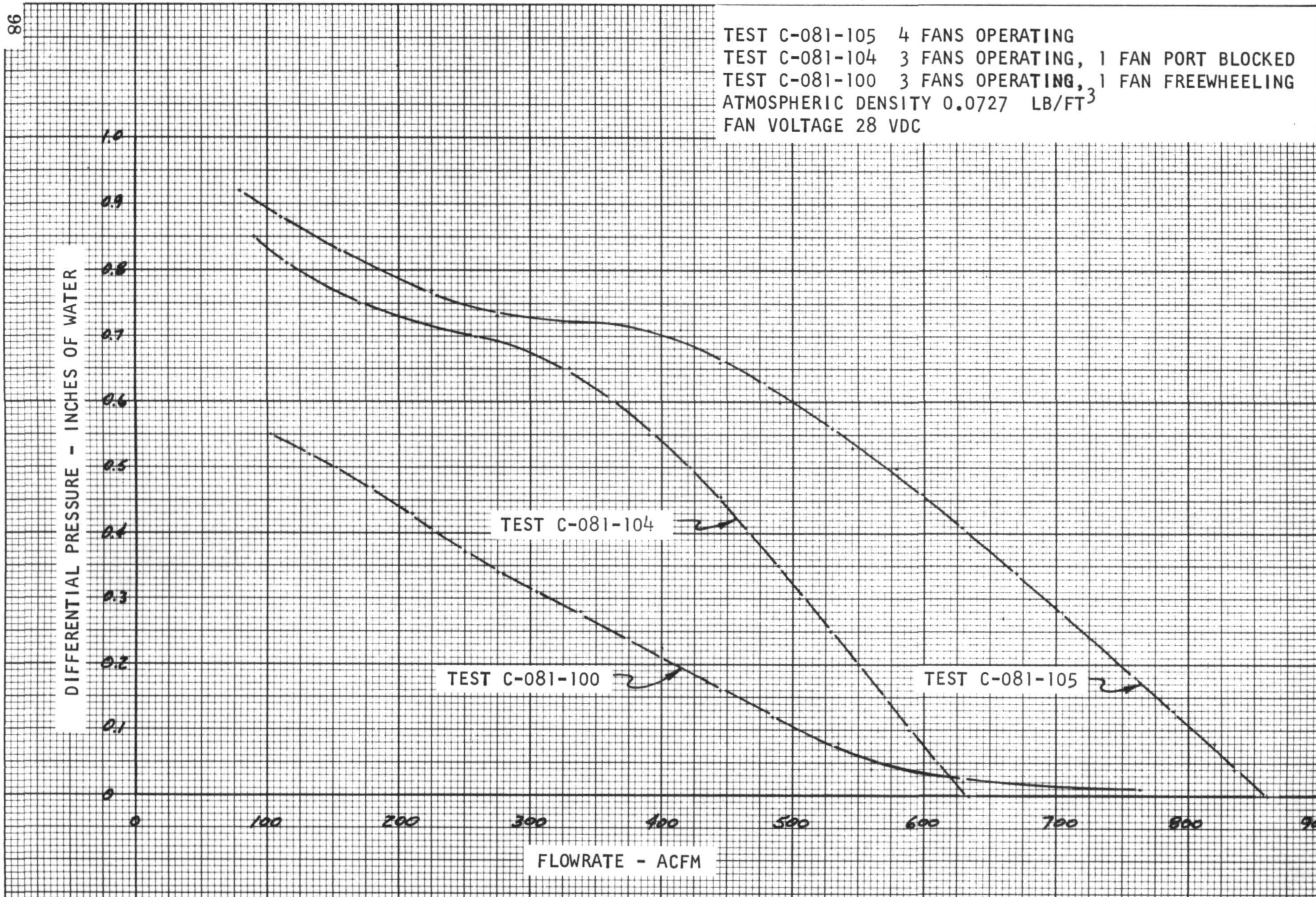

FIGURE 9. CLUSTER PERFORMANCE COMPARISON AT 0.0727 LB/FT^3, 28 VDC

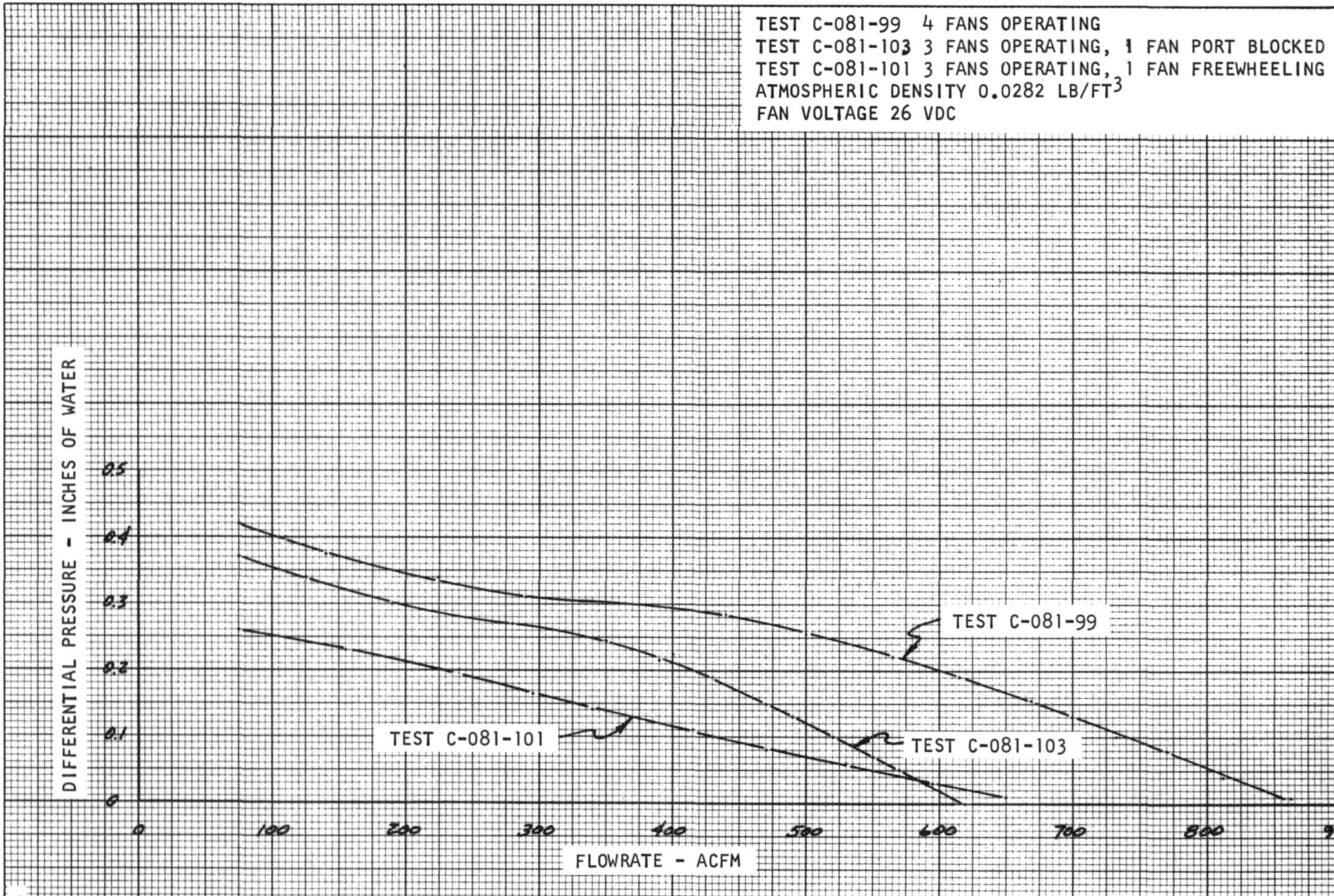

FIGURE 10. CLUSTER PERFORMANCE COMPARISON AT 0.0282 LB/FT^3, 28 VDC

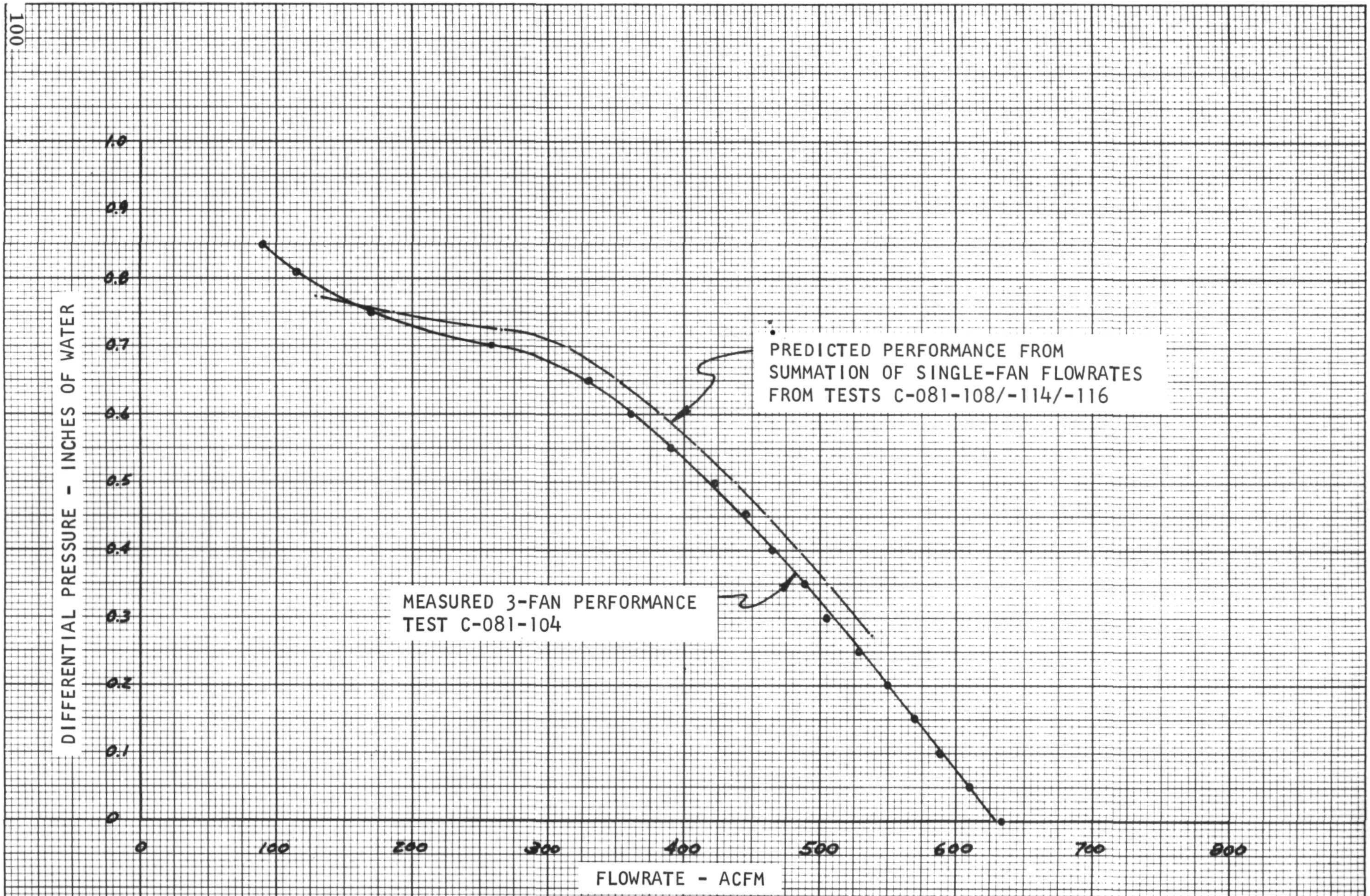

FIGURE 11. MEASURED AND PREDICTED PERFORMANCE - 3 FANS OPERATING IN PARALLEL
0.0727 LB/FT^3, 28 VDC

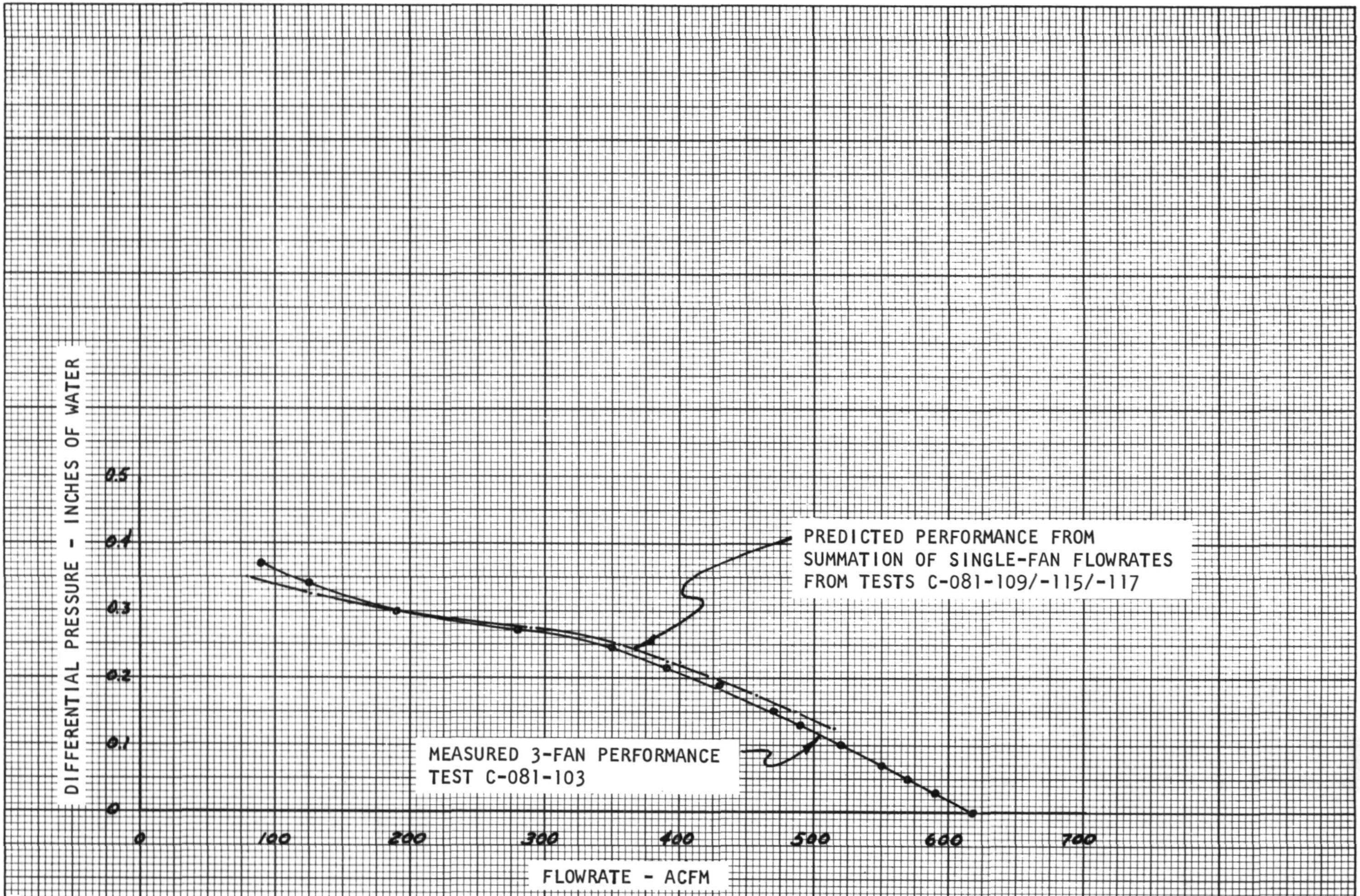

FIGURE 12. MEASURED AND PREDICTED PERFORMANCE - 3 FANS OPERATING IN PARALLEL
0.0282 LB/FT^3, 26 VDC

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APPENDIX B

RESULTS OF THE ORBITAL WORKSHOP 6-INCH ANEMOSTAT DIFFUSER TEST

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FILE 3.12.60

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

Memorandum

TO : Chief, Fluid Mechanics Section
S&E-ASTN-PFE

DATE: June 12, 1969
In reply refer to:
S&E-ASTN-TF-29-69

FROM : Chief, Environmental Test Section
S&E-ASTN-TFE

GDP
WLG

SUBJECT : Results of the Orbital Workshop 6" Anemostat Diffuser Test

Reference: Test Request Memorandum R-P&VE-PT-69-M-42-F

1. Introduction

In order to establish confidence in the Saturn I Workshop Ventilation System's capability to provide comfortable living conditions for its occupants, full-scale vent tests were performed at 14.7 p.s.i.a. in the workshop mock-up. The objective of the full-scale vent tests was to demonstrate the ability of the diffusers to provide satisfactory air distribution in the crew quarters area.

Since the orbital workshop interior operational pressure is 5 p.s.i.a., and the mock-up configuration was conducive only to the conduct of tests at 14.7 p.s.i.a. (local ambient pressure), it became necessary to determine a relationship of diffuser performance in a 5-p.s.i.a. environment to that in a-14.7 p.s.i.a. (local ambient pressure) environment. Establishment of a correlation of performance in the two pressure environments was required to verify the applicability of the mock-up full-scale vent test results (at 14.7 p.s.i.a.) to a 5-p.s.i.a. environment. S&E-ASTN-TFE was therefore requested by S&E-ASTN-PT, to determine this correlation. Seventy-five tests were conducted in the Redstone Vacuum Drying Chamber on the 6" Anemostat C-2 diffusers during the period of April 1, 1969 through May 23, 1969.

2. Test Hardware and Setup

For these tests S&E-ASTN-P furnished two 6" Anemostat C-2 circular diffusers (see Figure 1). The diffusers were mounted in a vertical plexiglass wall (Figures 2 and 3) in the west-end of the Redstone Vacuum Drying Chamber (Figure 4).

A duct and fan system was connected to each diffuser so that a flow path would be established which would not disturb the diffuser outlet pattern (Figure 2). A Joy Manufacturing Company fan in each duct provided flow up to 200 a.c.f.m. through each diffuser. Each diffuser was connected to its duct differently to allow identification of effects due to duct or diffuser mounting geometry (Figures 5 and 6). The diffuser flow patterns were recorded by motion picture cameras with yellow smoke as a tracer gas and a grid network for dimensional reference. The smoke was generated by a smoke candle (Figure 7) ignited remotely by a NICHROME wire coil

MSFC - Form 488 (August 1960)

(Figures 8 and 9). The candle generated yellow smoke for a minimum of 30 seconds, and the smoke was pulled directly into the suction-end of the duct by the fan. The grid network was constructed of white electrical wire which was held rigid by the tension of rubber bands on each end of each wire (Figure 10). The grid was installed on a horizontal plane coinciding with the longitudinal centerline of the diffusers. Therefore, even with the distortion of the fisheye camera, accurate measurements could be taken from the film. The test procedure was as listed in the attached Appendix.

3. Instrumentation

Instrumentation for the test program consisted of two Dwyer inclined manometers, two Cox gas flowmeters, three copper-constantan thermocouples, one C.E.C. pressure transducer, eight Thermo-Systems hot film anemometers, one T.T. smoke gun, one Thermo-Systems hot film anemometer calibrator, and one Anemotherm air meter, as shown in Figures 11, 12, 13, 14, and 15. Three movie cameras were used to record the smoke patterns. Two 140° lens cameras and one semi-fisheye 160° lens camera, with a frame speed of 64 frames-per-second, were used at locations shown in Figure 5. Timing blips of 60 cycles-per-second were incorporated on all film. Mounting method and location of the Thermo-System anemometers may be seen in Figures 16, 17, and 18.

4. Test Discussion and Results

A checkout was conducted to verify the function of the Thermo-Systems hot film anemometer at 5 p.s.i.a. This was accomplished by utilizing the anemometers to measure the air velocity in a 5" duct at a given volumetric flow at 14.7 and 5 p.s.i.a. The velocity reading at 5 p.s.i.a. was multiplied by the pressure ratio (as per manufacturer's specification) to determine an actual velocity reading. The difference in measured velocity at 14.7 and 5 p.s.i.a. was 5% or less (see Table I).

A test was conducted to determine the differential pressure profile across diffusers 1 and 2 in a 14.7-p.s.i.a. atmosphere. This profile is shown in Figure 19 for the projection pattern and Figure 20 for the wide pattern. The pressure differentials of diffusers 1 and 2 determined from this test varied significantly from each other. The pressure differential across diffusers 1 and 3 was also plotted for 5 p.s.i.a. and is shown along with the 14.7-p.s.i.a. profile in Figures 21 and 22. The pressure differential was found to be directly proportional to the environmental pressure ratio for diffusers 1 and 2. Upon conclusion of the test series on the 6" diffusers, three diffusers (3, 4, and 5) were removed from the full scale mock-up and pressure profiles were plotted for each. These pressure profiles are shown in Figures 23 and 24 for the projection and wide patterns, respectively. From these data it was obvious that diffuser No. 2 had an abnormally high pressure drop. The diffuser was dismantled and the center cone was found to be damaged (Figure 25). The difference in pressure profile was attributed to this damage.

Velocity profiles were plotted for flows of 100, 135, and 195 a.c.f.m. in the wide and projection patterns and are shown in Figures 26, 27, 28, 29, 30, 31, 32, 33, 34, and 35. The location of the velocity probes is shown in Figures 16, 17, and 18 and all velocity data are shown in Table II.

When in the projection pattern, the velocities in the first 1 to $1\frac{1}{2}$ feet along the centerline from the diffusers was lower than that 2 or 3 feet away from the diffuser. This can be explained by Figure 36 which shows that there is an area of almost no flow for the first 1 to 2 feet along the centerline. For comparison, Figure 37 shows the flow in a wide pattern.

The velocity measured along the centerline of the diffuser in the projection pattern was always slightly higher at 14.7 p.s.i.a. than at 5 p.s.i.a., whereas the velocity along the ceiling with the diffuser in the wide pattern was always slightly higher at 5 p.s.i.a. than at 14.7 p.s.i.a.

The diffuser cone velocity (between cones 3 and 4) was measured two ways, both being shown in Figure 38. First the cone velocity was measured with the hand held anemometer perpendicular to the cone, as it was held when the cone velocities were measured in the full-scale vent tests. Next, the velocities were measured with the anemometer held horizontal to the cone - a method considered to yield more reliable data (shown as "true velocity" on Figure 38).

During the conduct of velocity tests, a phenomenon called "flip-flop" flow was encountered. With an established projection pattern flow through the diffuser, a narrow flow was observed until the flow was disturbed by either removing the center body and reinstalling it or by passing one's hand in close proximity to the diffuser exit. Once the flow was disturbed it flipped into a wide pattern and would not return to a projection pattern. Upon a more detailed study it was also seen that the flow would flip for no apparent reason, especially at 5 p.s.i.a. The manufacturer has stated that the "flip-flop" can be corrected by a slight diffuser modification. Modified diffusers are presently on order for future tests. A stable projection pattern can be re-established and maintained by removing the center body of the diffuser (see Figure 39).

Tests C-060-89 through C-060-97 were conducted with two diffusers flowing simultaneously. When both diffusers were set for a projection pattern there was little apparent interaction between the pattern (Figure 40). But, when the diffusers were set for a wide pattern, a wall of smoke formed between them (Figure 41) with the smoke otherwise staying against the ceiling until the sides of the vacuum chamber were reached.

Figure 42 shows the smoke pattern when one diffuser is flowing wide and the other diffuser is flowing in a projection pattern. The narrow pattern is not affected by the wide pattern, and the wide pattern is affected by the narrow pattern only where they intersect.

According to the diffuser manufacturer, the flip-flop problem can be eliminated by modifying the diffuser so that the outer cone surface is 1/8-inch higher than the outer cone surface of the diffusers used in this test. In anticipation of receipt and subsequent tests of the modified diffusers, S&E-ASTN-TFE simulated the modification by building up the outer cone 1/8-inch with putty (Figure 42). A smooth transition of surfaces and maintenance of close tolerances obviously could not be accomplished utilizing the putty, but, it was considered that some knowledge might be gained by conducting several tests with this "in-house" modified unit. The last series of tests (C-060-112 through C-060-115), therefore, were conducted with an "in-house" modified diffuser. Plots of pressure drop across the diffuser are shown in Figures 44 and 45. Smoke tests demonstrated that the projection pattern was more defined (as compared to projection patterns of the as-received diffusers). Tests also showed that the projection pattern continued when the diffuser was set for a wide pattern. Considering that the modification (with putty) was, at best, a crude simulation, and that the pattern results were unpredictable, it was apparent that further testing of the "in-house" modified diffuser would not yield reliable data. As a result, tests were terminated on this unit.

The seventy-five tests were conducted for a duration of about 3 minutes each. Data from each test were transmitted to S&E-ASTN-PT with copies of all film data. The test data are enclosed in Table III. The seventy-five tests completed the evaluation of the standard 6" diffuser. Another series of tests is planned to evaluate 6" modified diffusers.

5. <u>Summary</u>

When operated in a 5-p.s.i.a. environment, the diffuser produced a flow pattern essentially the same as that produced in a 14.7-p.s.i.a. environment.

The significant difference in the measured pressure differential between diffuser No. 2 and the other four can be attributed to the damage to the center cone of No. 2.

It can be seen from Figures 21 and 22 that the change in slope of the pressure drop across the diffuser from 14.7 to 5 p.s.i.a. is equal to the pressure ratio $\left(\frac{14.7}{5} = 2.94\right)$.

It is anticipated that future tests on the 6" modified diffusers will show that the modification will correct the flip-flop problem.

6. Any questions or comments concerning this series of tests or the enclosed data should be addressed to Mr. Robinson, S&E-ASTN-TFE, Phone 453-1709.

J. T. Ralston

J. T. Ralston

48 Enc:
as stated

cc: See page 5

APPENDIX

The subject test procedure consisted of:

1. Adjust to diffuser pattern desired.
2. Pump the chamber down to 5 p.s.i.a.
3. Set up diffuser flow desired.
4. Turn recorder ON.
5. Ignite smoke candle.
6. Turn movie cameras and lights ON.
7. Upon depletion of smoke:
    a. Turn movie cameras and lights OFF.
    b. Turn recorders OFF.
8. Pump chamber down to 50 torr to remove smoke.
9. Repressurize chamber with air.

cc:
S&E-ASTN-PL, Mr. Hopson
S&E-ASTN-PF, Mr. Worlund
S&E-ASTN-T, Messrs. Grafton/Verschoore CMV
S&E-ASTN-TF, Messrs. Perry/Harsh
S&E-ASTN-TF, File 3.12.60.4

S&E-ASTN-TFE:GARobinson:lb 6-12-69 GAR

TABLE I

VERIFICATION OF ANEMOMETER FUNCTION AT 5 P.S.I.A.

Thermosystems (FPM)	Flow (ACFM)	Pressure (PSIA)	Press. Ratio (P_A/P_C)	True Velocity (FPM)	Percent Difference
79	56	14.36	1	79	5:0
31	56	5.36	2.68	83	
775	99.8	14.36	1	775	4.8
290	99.8	5.12	2.80	812	

$$\text{True Velocity (FPM)} = \frac{\text{Thermosystems (FPM)} \times P_A}{P_C}$$

$$\text{Percent Difference} = \frac{(\text{True Velocity @ } P_A - \text{True Velocity @ } P_C)\ 100}{\text{True Velocity @ } P_C}$$

TABLE II. 6" DIFFUSER VELOCITY DATA

Test C-060-	Flow (ACFM)	Chamber Pressure (PSIA)	Velocity - Ft/Min (See Figure 18) V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	Comments
49	134.4	14.68	130	-	55	-	-	-	-	-	-	-	-	-	-	-	-	Pattern probably flipped.
50	194	14.68	200	200	95	-	-	-	-	-	-	-	-	-	-	-	-	Same as above.
51	135	14.68	135	120	50	-	-	-	-	-	-	-	-	-	-	-	-	Same as above.
52	125.4	5.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Same as above.
53	183	5.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Same as above.
54	130.7	14.62	190	265	210	190	-	-	-	-	-	-	-	-	-	-	-	
55	192.7	14.62	290	360	315	200+	-	-	-	-	-	-	-	-	-	-	-	
56	191.9	14.62	-	-	-	-	250	265	280	200+	-	-	-	-	-	-	-	
57	133.8	14.62	-	-	-	-	170	215	200	200+	-	-	-	-	-	-	-	
58	133.8	14.60	200	200+	190	190	-	-	-	-	-	-	-	-	-	-	-	
59	134.9	14.60	-	-	-	-	200+	195	152	195	-	-	-	-	-	-	-	
60	195.9	14.60	-	-	-	-	200+	200+	200+	200+	-	-	-	-	-	-	-	
61	194.3	14.60	200+	200+	200+	200+	-	-	-	-	-	-	-	-	-	-	-	
62	132	4.90	134.1	202.6	306.9	163.9	-	-	-	-	-	-	-	-	-	-	-	
63	194.8	4.92	146.1	326.7	302.9	267.3	-	-	-	-	-	-	-	-	-	-	-	
64	133.3	5.30	-	-	-	-	-	-	-	-	107.6	104.8	121.4	126.9	-	-	-	
65	194.6	5.36	-	-	-	-	-	-	-	-	169.3	196.6	207.5	221.2				
66	132.3	14.68	-	-	-	-	-	-	-	-	71	125	144	160	-	-	-	
67	192.7	14.68	-	-	-	-	-	-	-	-	100	180	190	200+				
68	193.8	14.68	-	-	-	-	-	-	-	-	42	29	30	30	-	-	-	
69	134.4	14.58	-	-	-	-	-	-	-	-	30	31	35	35	-	-	-	
70	132	14.58	28	34	31	30	-	-	-	-	-	-	-	-	-	-	-	
71	193	14.58	48	42	25	25	-	-	-	-	-	-	-	-	-	-	-	
72	134	14.68	-	-	-	-	-	-	-	-	-	-	-	-	124	156	-	
73	193	14.62	-	-	-	-	-	-	-	-	-	-	-	-	150	210	-	
74	138	5.22	-	-	-	-	-	-	-	-	-	-	-	-	184.8	168.0	-	
75	192.7	5.30	-	-	-	-	-	-	-	-	-	-	-	-	226.1	231.67	-	
76	136	14.62	-	-	-	-	-	-	-	-	-	-	-	-	110	200	-	
77	192.7	14.62	-	-	-	-	-	-	-	-	-	-	-	-	150	295	-	
78	130.9	5.40	-	-	-	-	-	-	-	-	-	-	-	-	189.7	162.6	-	
79	194	5.44	-	-	-	-	-	-	-	-	-	-	-	-	228.5	268.7	-	
108	104.5	5.38	-	-	-	-	-	-	-	-	-	-	-	-	94.8	113.8	81.3	
109	191.7	5.34	-	-	-	-	-	-	-	-	-	-	-	-	240.2	114.7	139.2	
110	134.4	5.24	-	-	-	-	-	-	-	-	-	-	-	-	189.1	111.2	86.2	
111	99	4.92	-	-	-	-	-	-	-	-	-	-	-	-	154.5	90.01	-	

TABLE III. 6" DIFFUSER TEST DATA

Test C-060	Position No.	Diffuser No.	Pattern	Flow (ACFM)	Chamber Pressure (psia)	Duct Temperature (°F)	Chamber Temperature	Comments
41	2	2	Narrow	196.25	14.72	65.9	69.5	Flip-Flop Demonstration
42	2	2	Narrow	138.5	14.70	67.6	72.7	Pattern pulled to right - not a definite narrow pattern.
43	2	2	Narrow	133.75	5.12	64.0	64.6	Pattern pulled to right - almost no pattern.
44	2	2	Narrow	195.75	14.68	80.6	83.4	Pattern pulled to right - not a definite narrow pattern.
45	2	2	Narrow	192.0	5.12	76.6	76.4	
46	2	2	Narrow	193.0	14.70	78.0	88.0	
47	2	2	Wide	190.	5.24	78.2	76.1	
48	2	2	Narrow	195.	14.70	--	--	Flip-Flop Demonstration
49	1	1	Narrow	134.4	14.68	--	83.2	
50	1	1	Narrow	194.0	14.68	--	83.6	
51	1	1	Narrow	135.0	14.68	--	83.6	
52	1	1	Narrow	125.4	5.28	73.0	75.2	
53	1	1	Narrow	183.0	5.32	72.6	78.5	
54	1	1	Narrow	130.7	14.62	73.5	70.4	
55	1	1	Narrow	192.7	14.62	73.5	71.1	
56	1	1	Narrow	191.9	14.62	73.6	71.4	
57	1	1	Narrow	133.8	14.62	73.6	71.4	
58	1	1	Narrow	133.8	14.60	77.4	80.7	
59	1	1	Narrow	134.9	14.60	78.1	81.2	
60	1	1	Narrow	145.9	14.60	78.8	81.6	
61	1	1	Narrow	194.3	13.60	79.1	81.8	
62	1	1	Narrow	132.	4.90	76.4	75.8	
63	1	1	Narrow	194.8	4.92	77.4	78.2	
64	1	1	Narrow	133.3	5.30	78.9	73.4	
65	1	1	Narrow	194.6	5.36	79.2	77.5	
66	1	1	Narrow	132.3	14.68	83.2	87.9	
67	1	1	Narrow	192.7	14.68	83.2	86.5	
68	1	1	Wide	193.8	14.68	83.2	84.9	
69	1	1	Wide	134.4	14.58	83.0	84.0	
70	1	1	Wide	132.	14.58	82.6	83.3	

Test C-060	Position No.	Diffuser No.	Pattern	Flow (ACFM)	Chamber Pressure (psia)	Duct Temperature (^oF)	Chamber Temperature	Comments
71	1	1	Wide	193	14.58	82.5	83.1	
72	1	1	Wide	134	14.62	73.8	76.6	
73	1	1	Wide	193	14.62	73.3	76.6	
74	1	1	Wide	138	5.22	69.0	60.8	
75	1	1	Wide	192.7	5.30	69.0	66.8	
76	1	1	Wide	136.0	14.62	73.6	73.9	
77	1	1	Wide	192.7	14.62	72.7	73.7	
78	1	1	Wide	130.9	5.40	63.6	60.0	
79	1	1	Wide	194	5.44	62.5	64.5	
80	1	1	Wide	150.2	14.62	57.7	59.0	No Grid
81	1	1	Narrow	149.9	14.56	60.4	61.4	No Grid - Flip-Flop Demonstration
82	1	1	Narrow	193.2	14.56	62.9	62.9	
83	1	1	Narrow	134.1	14.56	63.9	73.0	
84	1	1	Narrow	196.2	5.10	59.7	55.6	
85	1	1	Narrow	135.7	5.32	63.1	65.1	
86	1	1	Wide	193.8	14.60	70.8	75.4	
87	1	1	Wide	188.5	5.14	66.3	61.4	
88	1	1	Wide	133.3	14.60	75.6	77.0	
89	1 & 2	1 & 2	Wide/Wide	130.7/128.5	5.42	74.3/72.0	76.0	
90	1 & 2	1 & 2	Wide/Wide	133.3/131.5	14.60	82.5/79.7	84.4	
91	1 & 2	1 & 2	Wide/Wide	201.7/201.0	4.80	80.0/73.3	85.1	
92	1 & 2	1 & 2	Wide/Wide	192.7/187.5	14.60	90.0/86.3	89.5	
93	1 & 2	1 & 2	Narrow/Narrow	190.1/186.5	14.60	90.7/85.9	89.2	
94	1 & 2	1 & 2	Narrow/Narrow	133.6/131.25	14.58	89.9/85.6	89.5	
95	1 & 2	1 & 2	Narrow/Wide	186.9/184.8	14.55	66.4/65.9	71.2	
96	1 & 2	1 & 2	Narrow/Wide	137.0/131.2	14.50	71.7/71.3	78.4	
97	1 & 2	1 & 2	No-Center/ Wide	191.7/183.8	14.50	76/73.7	81.4	
98	2		---	99.8	14.36	--	--	Data for verification of anemometer function (tests 98–101)
99	2		---	99.8	5.12	--	--	
100	2		---	151	5.18	--	--	
101	2		---	199	5.22	--	--	
102	1	1	Narrow	188.0	14.60	66.9	70.8	

Test C-060	Position No.	Diffuser No.	Pattern	Flow (ACFM)	Chamber Pressure (psia)	Duct Temperature (°F)	Chamber Temperature	Comments
103	1	1	Narrow	195.4	5.06	66.7	71.8	This pattern flipped to wide.
104	1	1	Wide	191	14.58	73.9	74.4	
105	1	1	Wide	193.5	4.58	73.8	74.1	
106	1	1	Narrow	100	--	--	--	
107	1	1	Narrow	100	--	--	--	
108	1	1	Narrow	104.5	5.38	75.3	80.0	
109	1	1	Wide	191.7	5.34	75.1	64.1	
110	1	1	Wide	134.4	5.24	74.3	74.1	
111	1	1	Wide	99.0	4.92	74.0	77.0	
112	1	4	Wide	128.0	14.58	64.2	69.9	In-house modified 6" diffuser; No wide pattern.
113	1	4	Wide	133.3	5.0	63.7	67.0	In-house mouified 6" diffuser; no wide pattern.
114	1	4	Narrow	128.0	14.58	70.3	77.4	Modified 6" diffuser
115	1	4	Narrow	141.6	5.28	66.0	60.6	Modified 6" diffuser

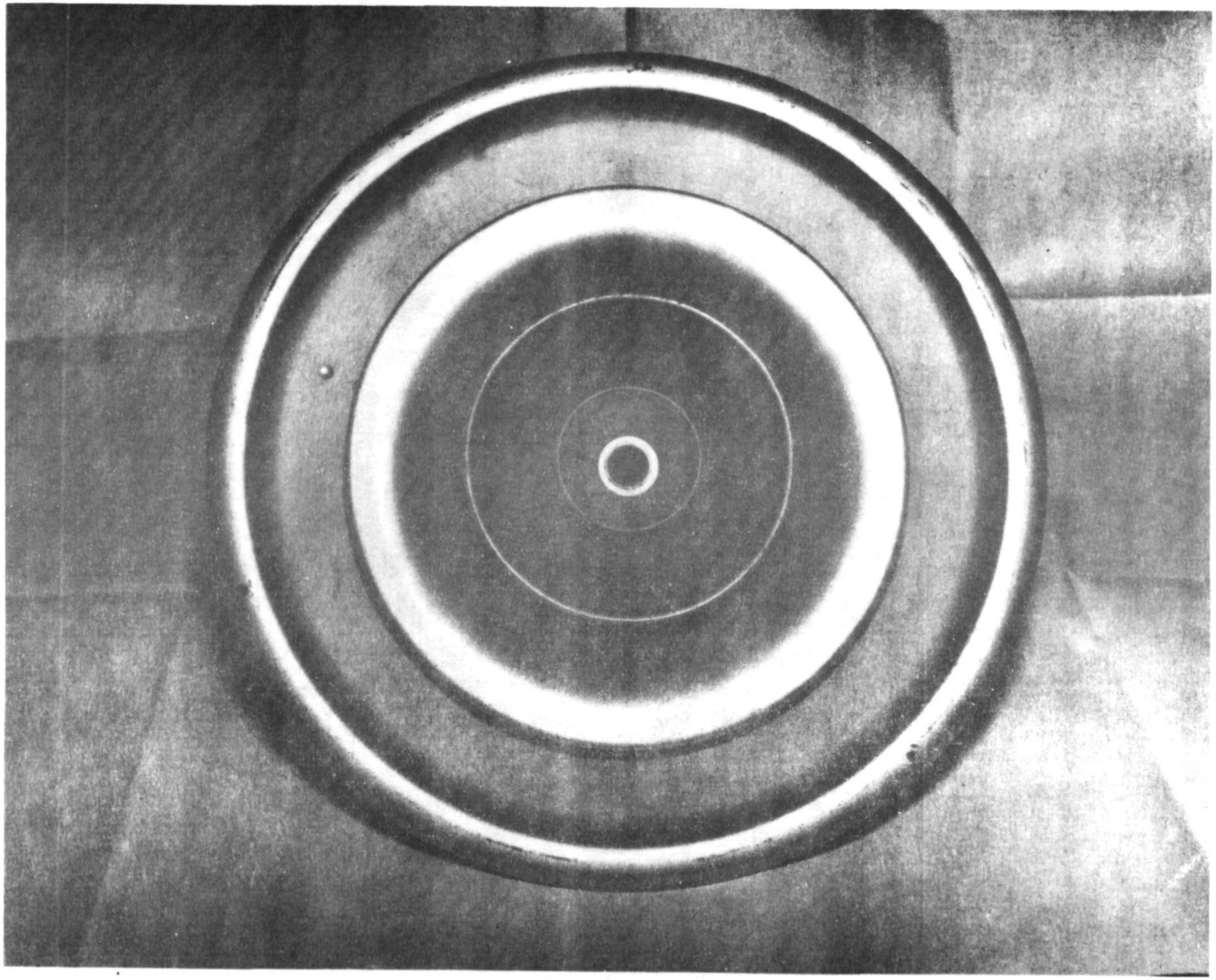

FIGURE 1. ANEMOSTAT 6" C-2 DIFFUSER

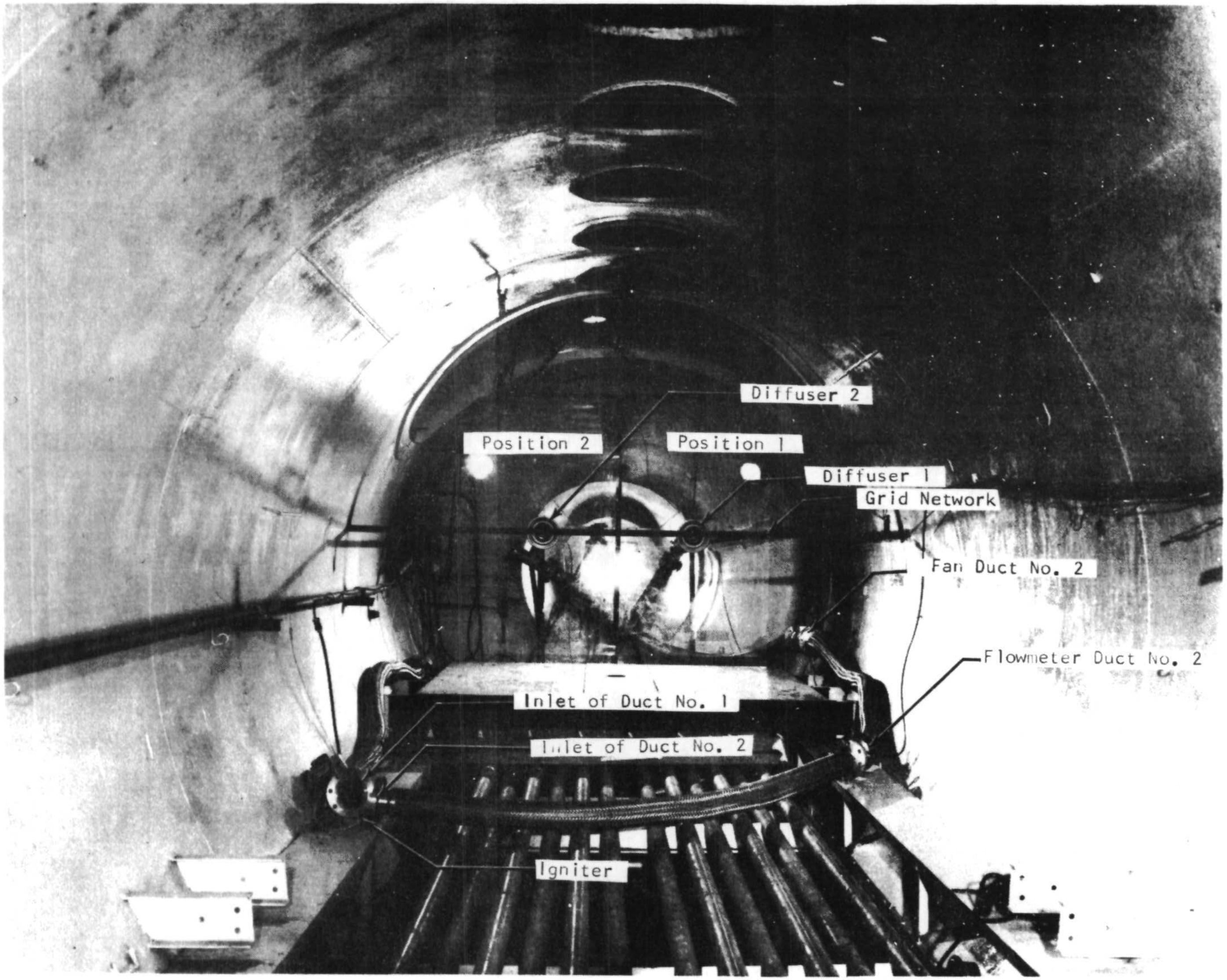

FIGURE 2. 6" DIFFUSER TEST SETUP

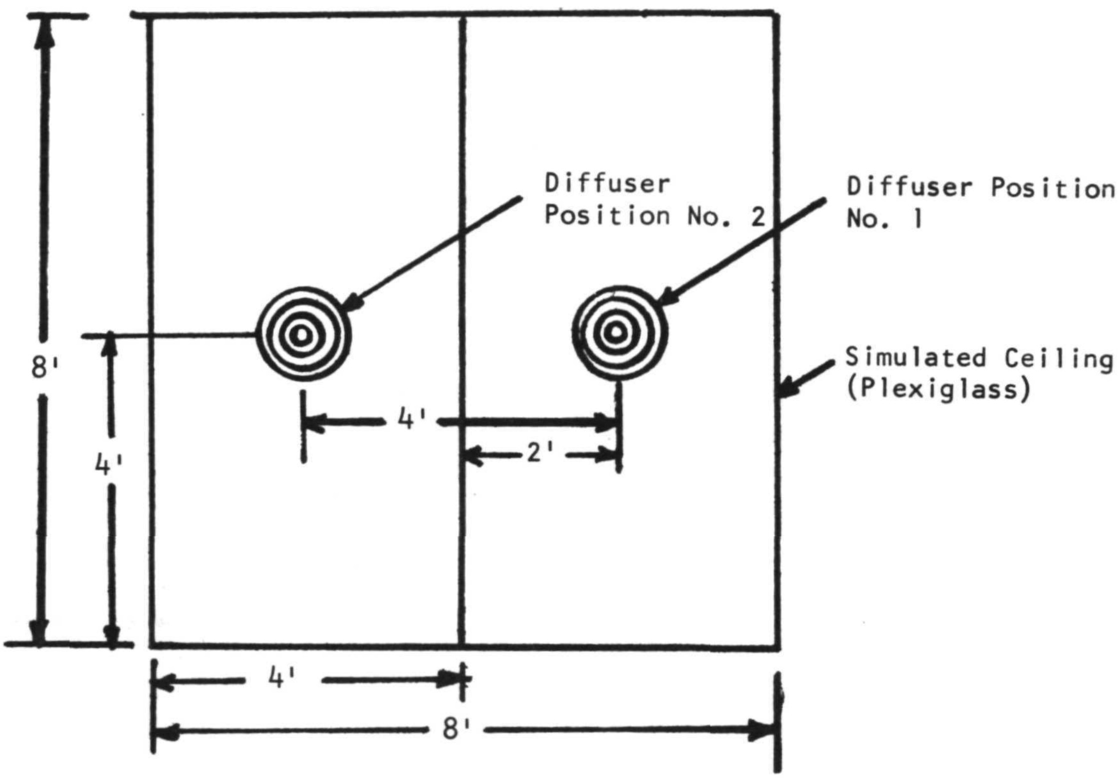

FIGURE 3. DIFFUSER CEILING CONFIGURATION

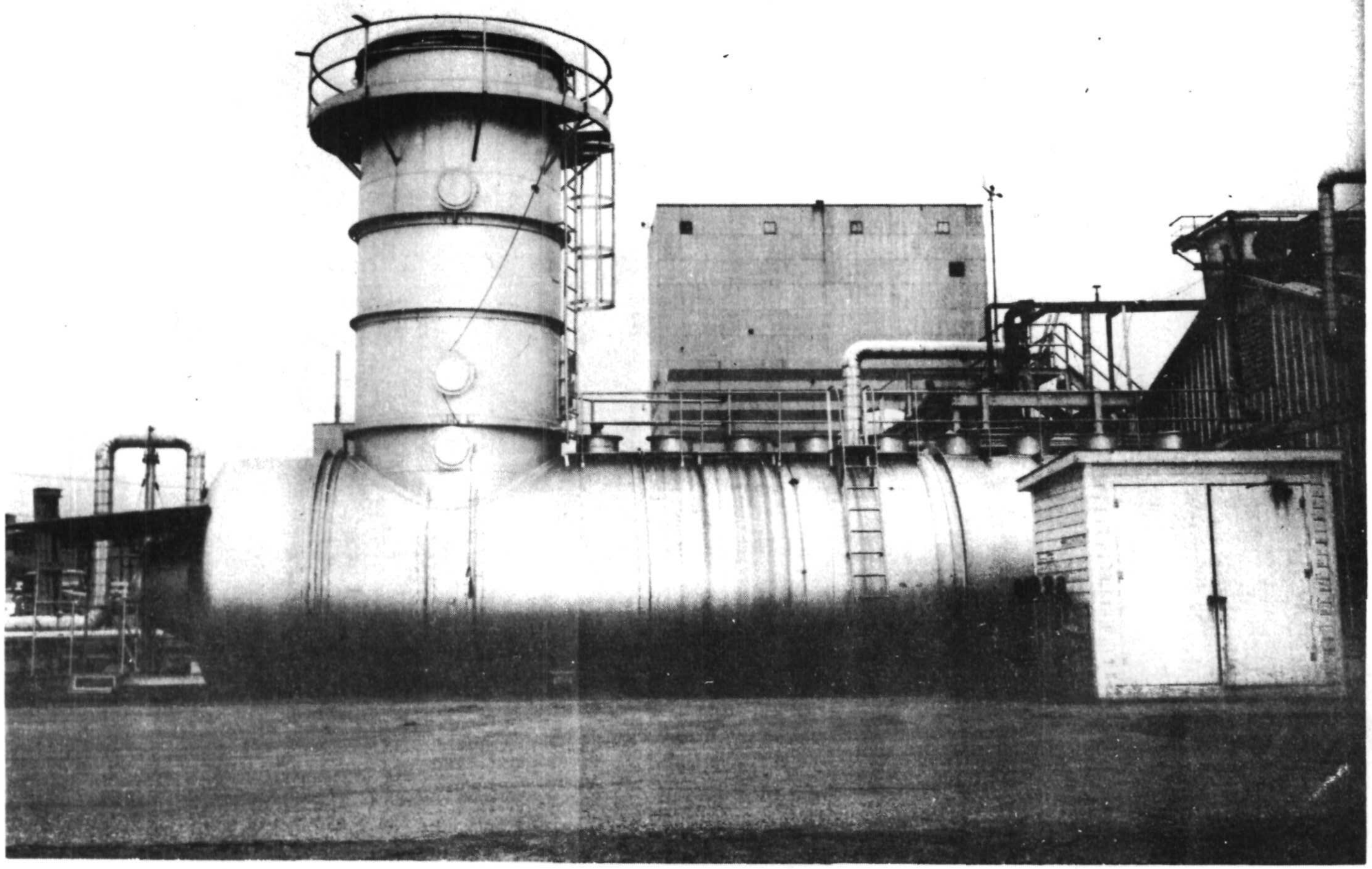

FIGURE 4. REDSTONE VACUUM CHAMBER

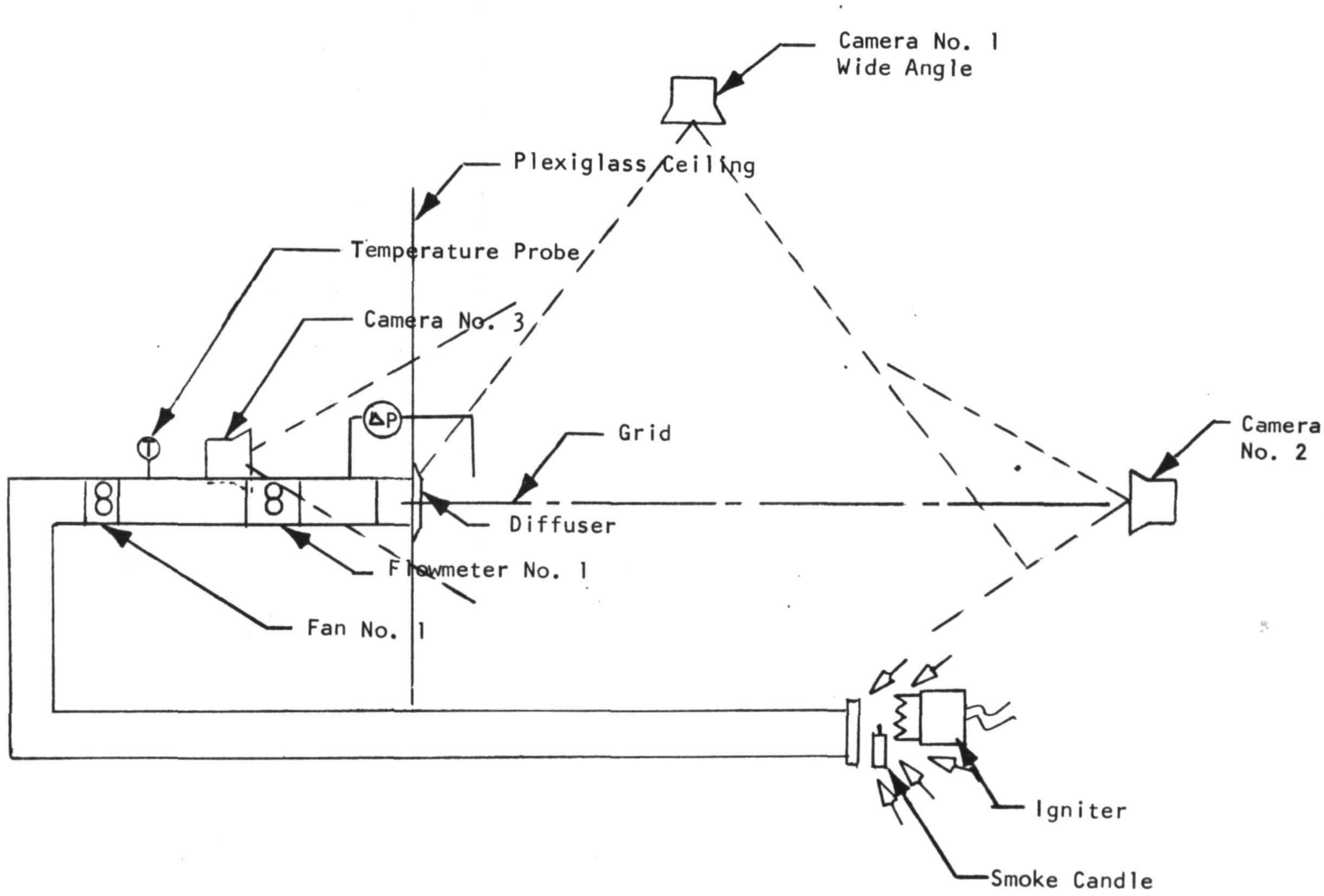

FIGURE 5 . TEST SETUP DIFFUSER 1

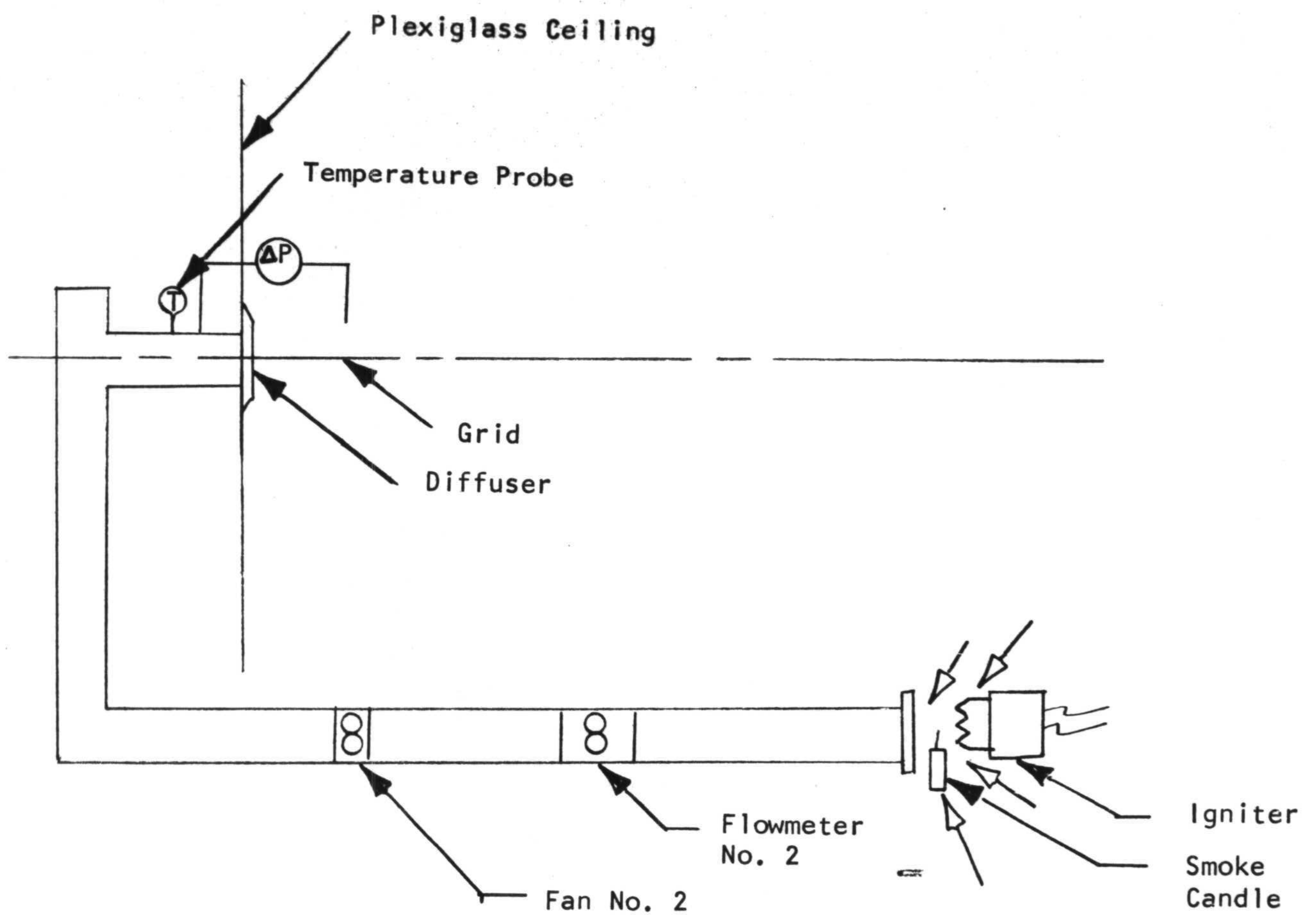

FIGURE 6. TEST SETUP DIFFUSER NO. 2

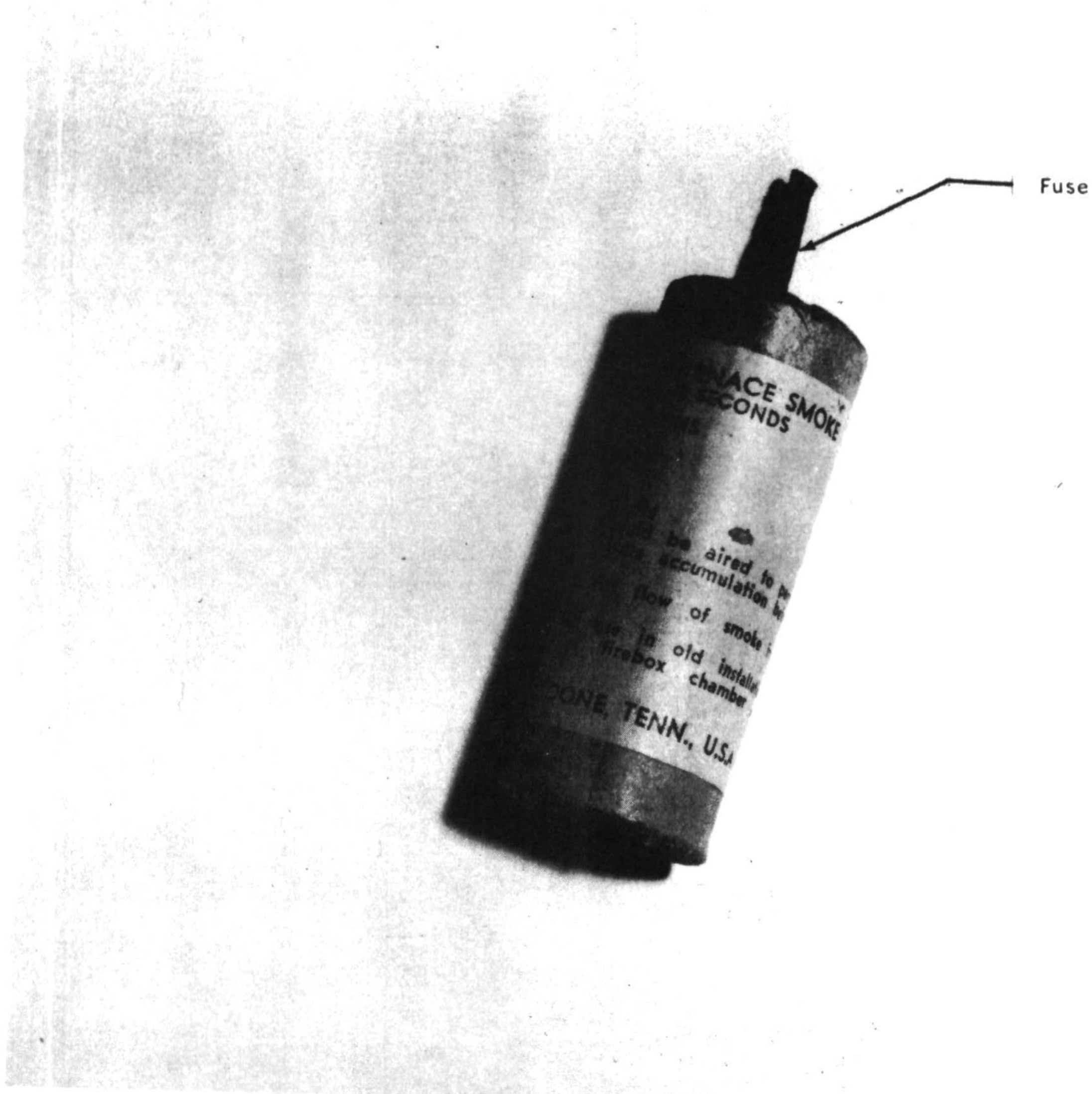

FIGURE 7. SMOKE CANDLE

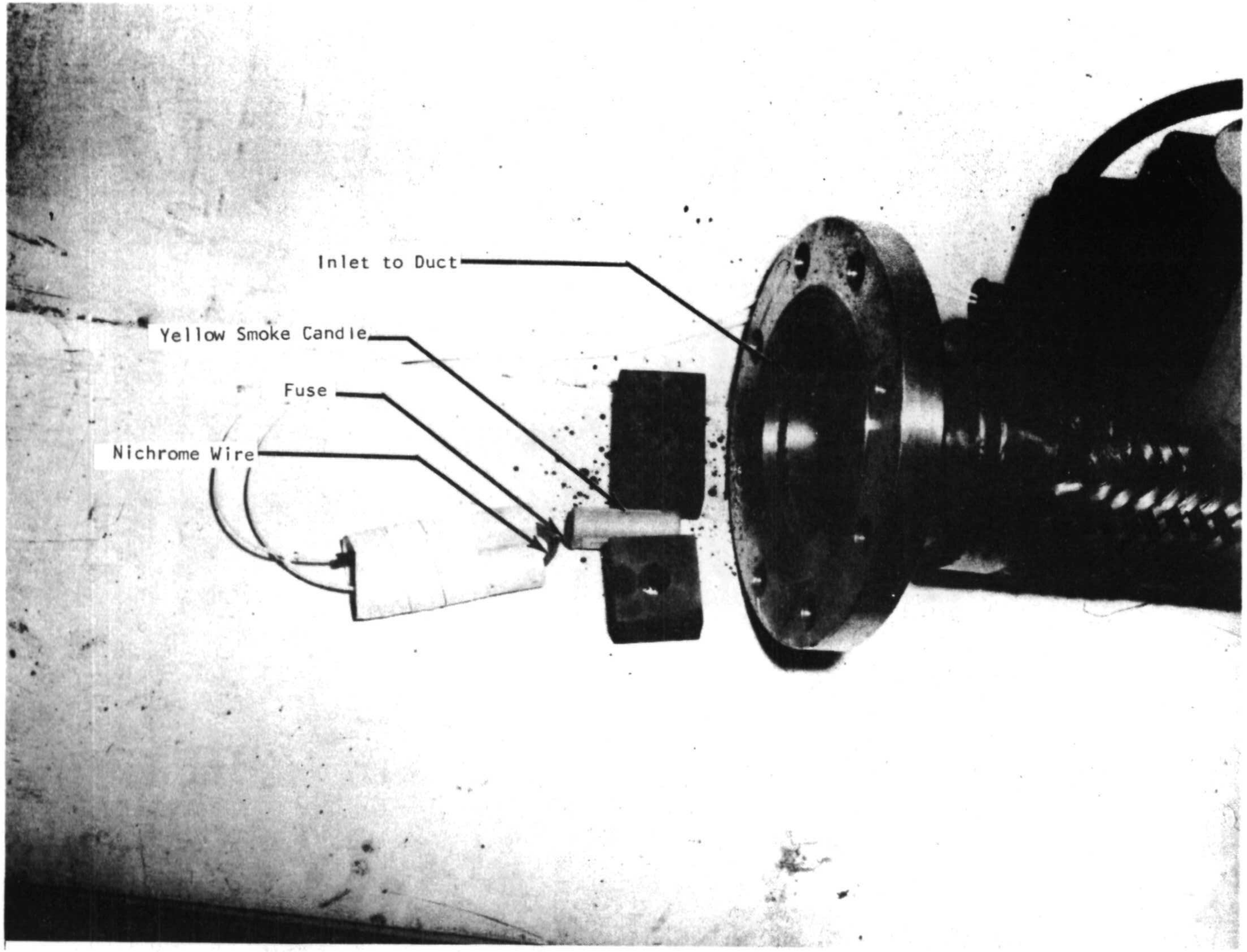

FIGURE 8. SMOKE CANDLE IGNITER

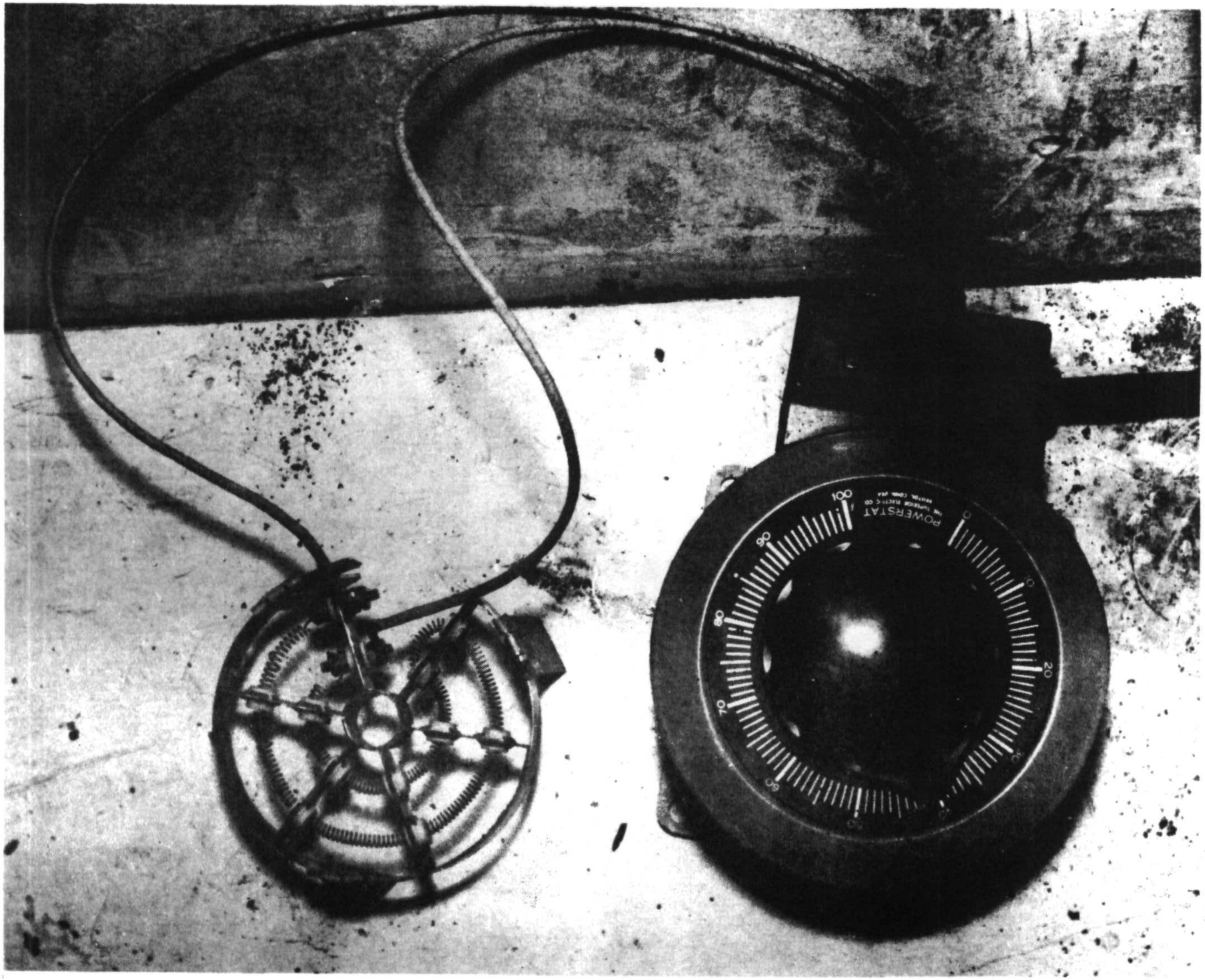

FIGURE 9. SMOKE CANDLE IGNITER

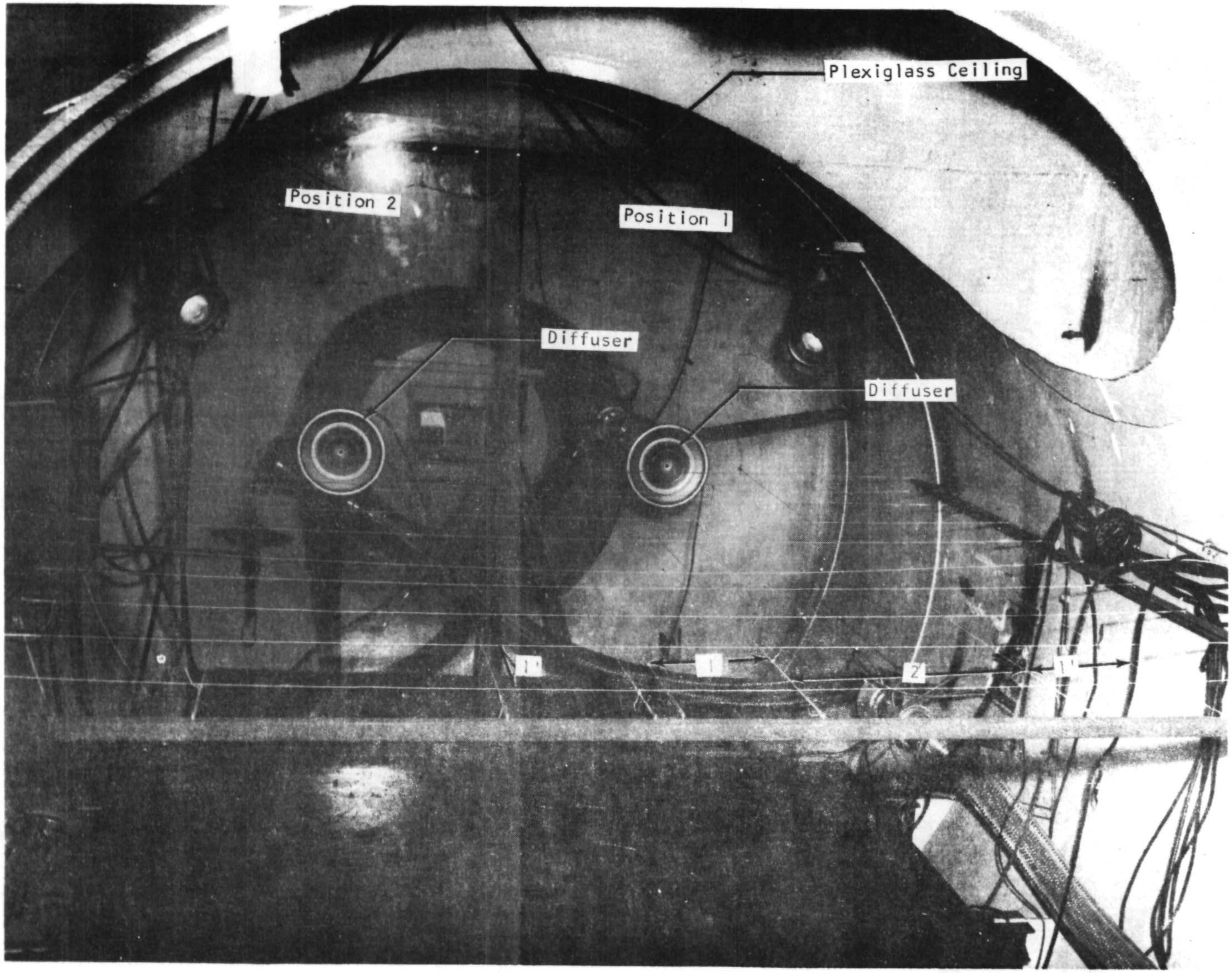

FIGURE 10. DIFFUSER SETUP WITH GRID

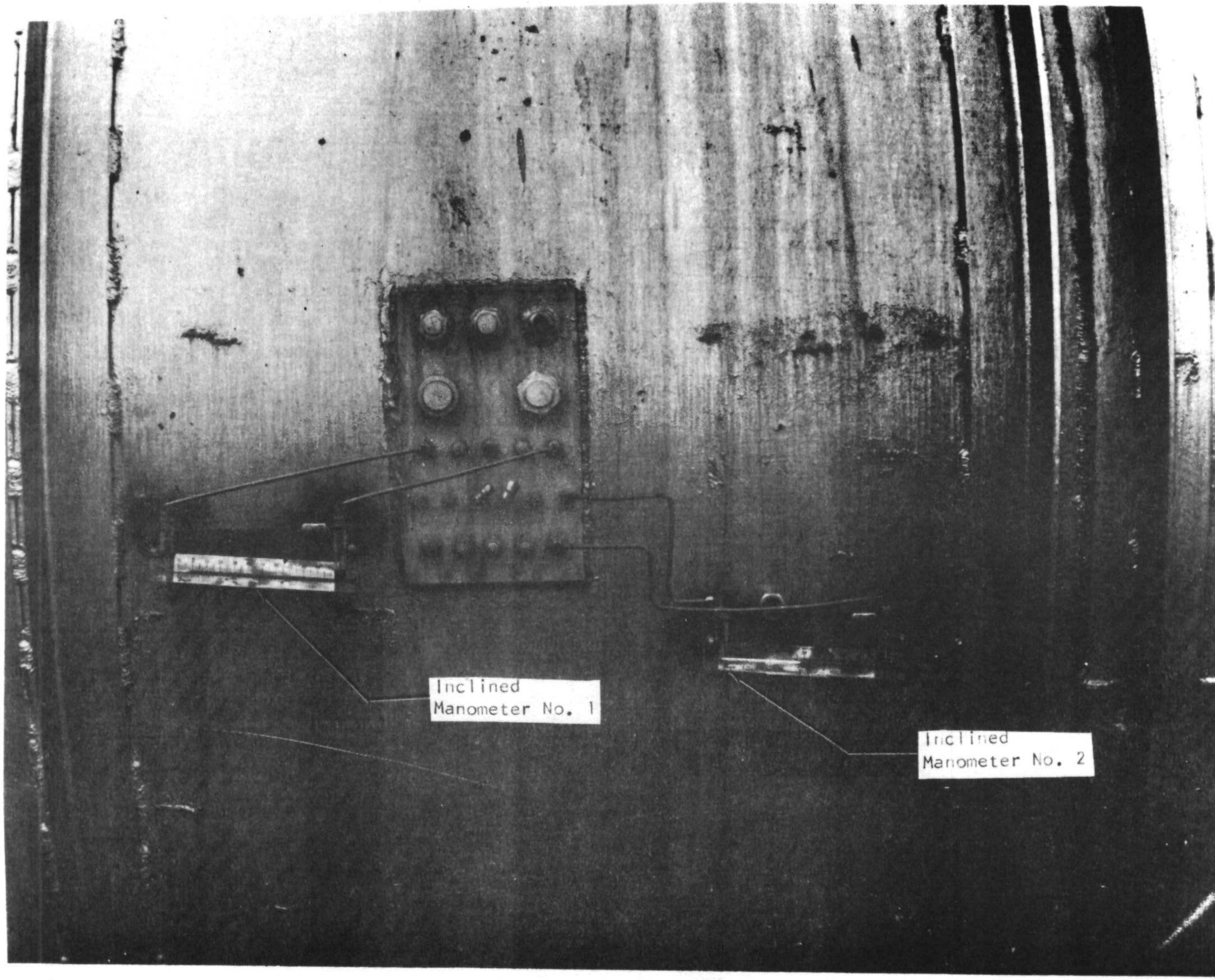

FIGURE 11. INCLINED MANOMETERS

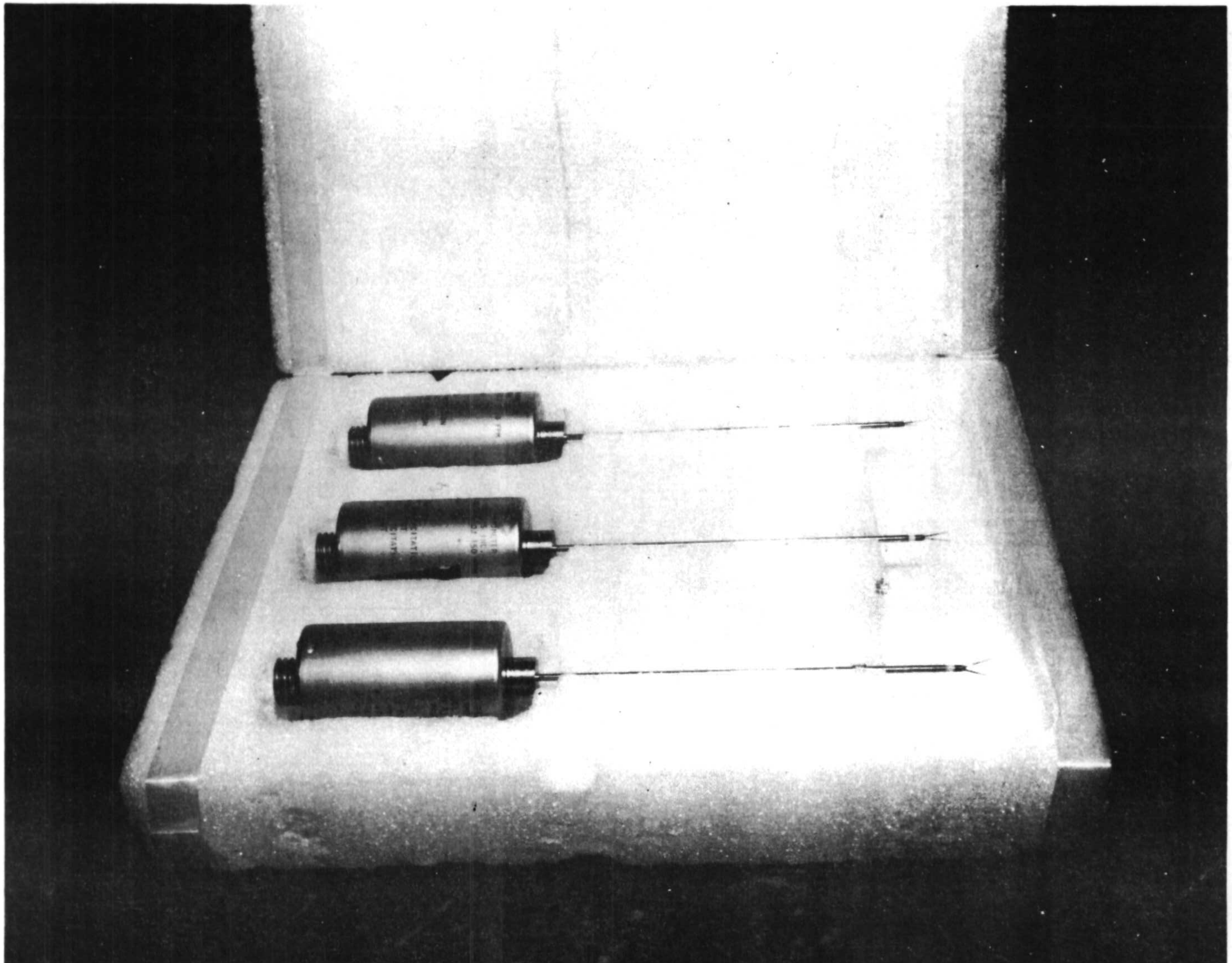

FIGURE 12. THERMO SYSTEMS HOT FILM ANEMOMETER

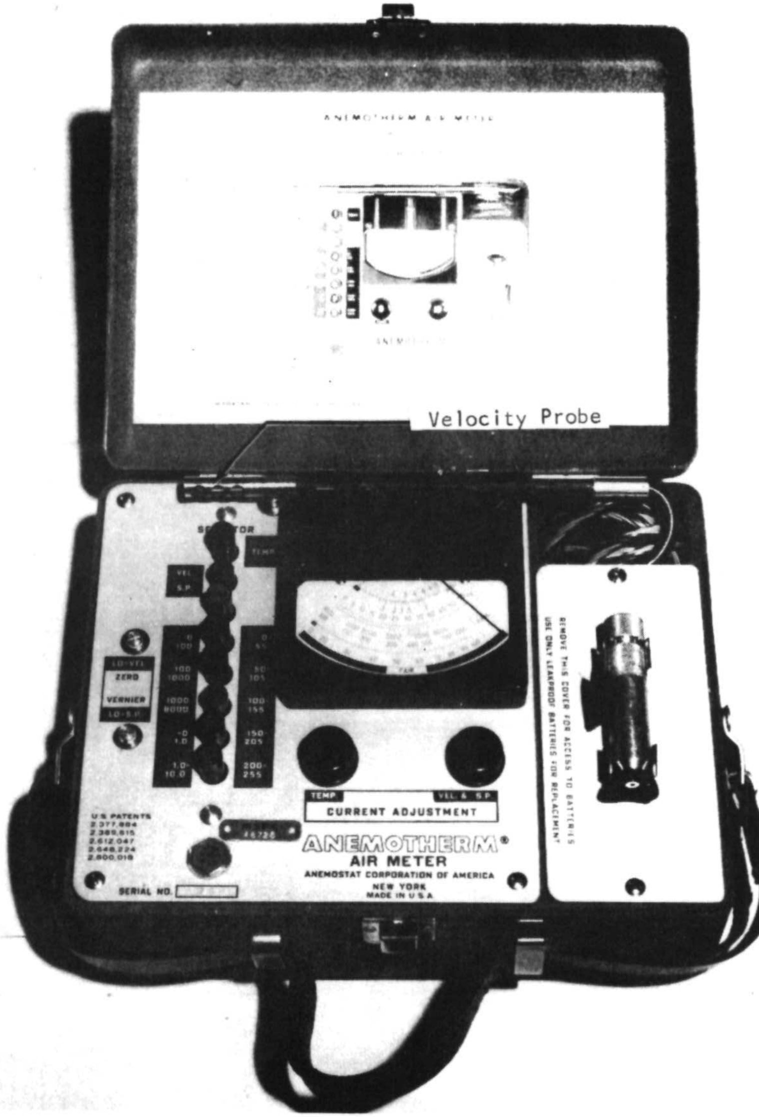

FIGURE 13. ANEMOTHERM AIR METER

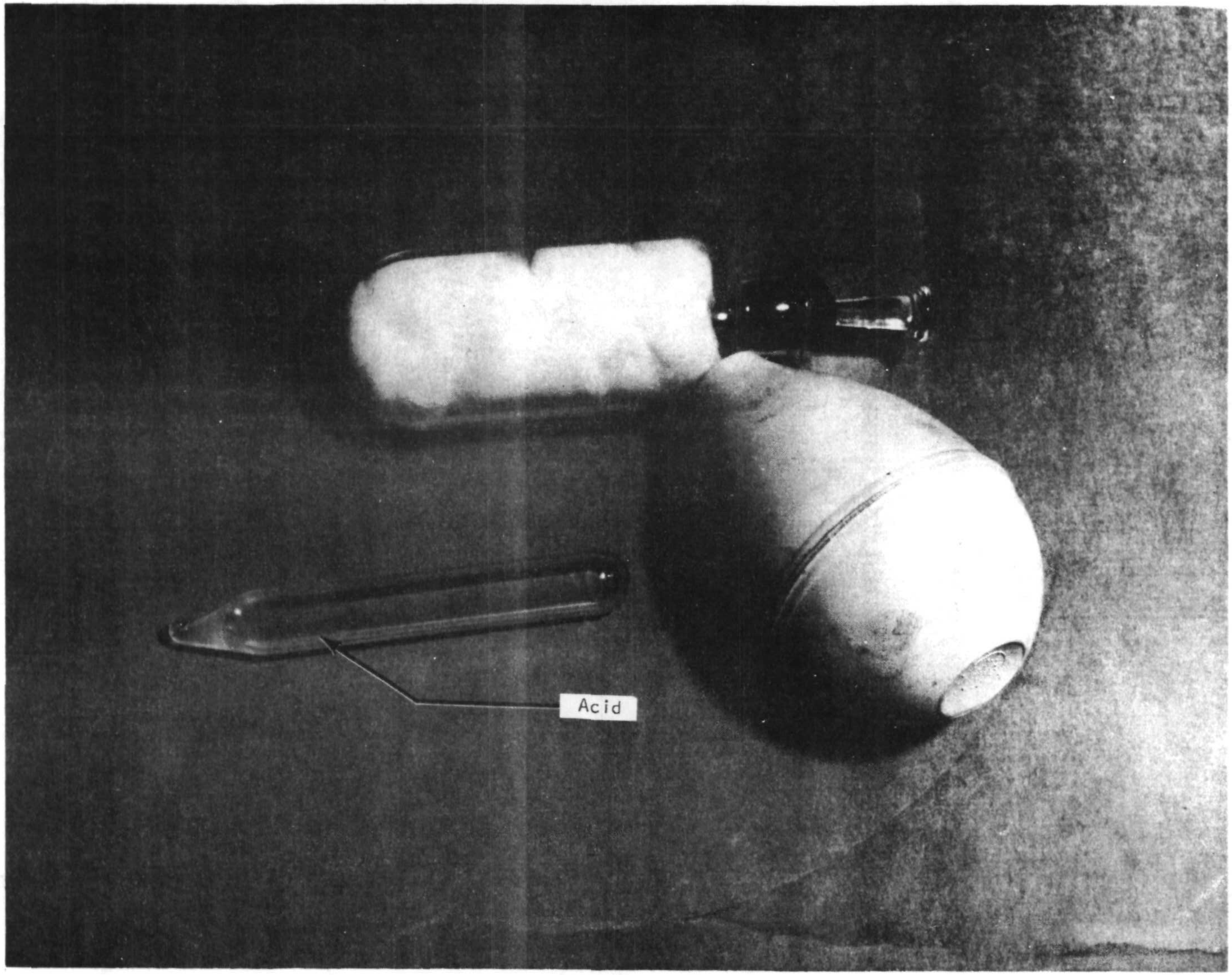

FIGURE 14. T.T. SMOKE GUN

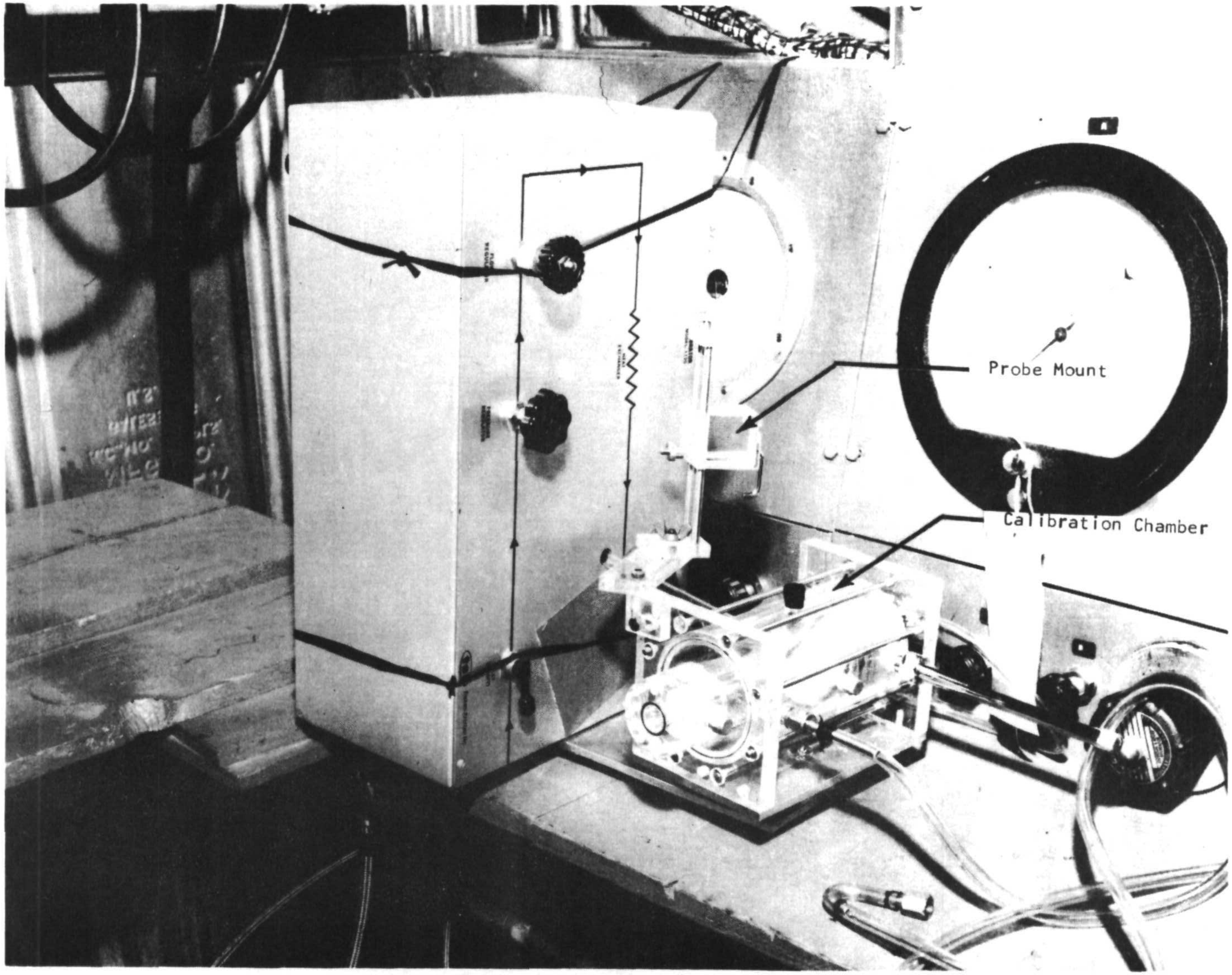

FIGURE 15. THERMO SYSTEMS HOT FILM ANEMOMETER CALIBRATOR

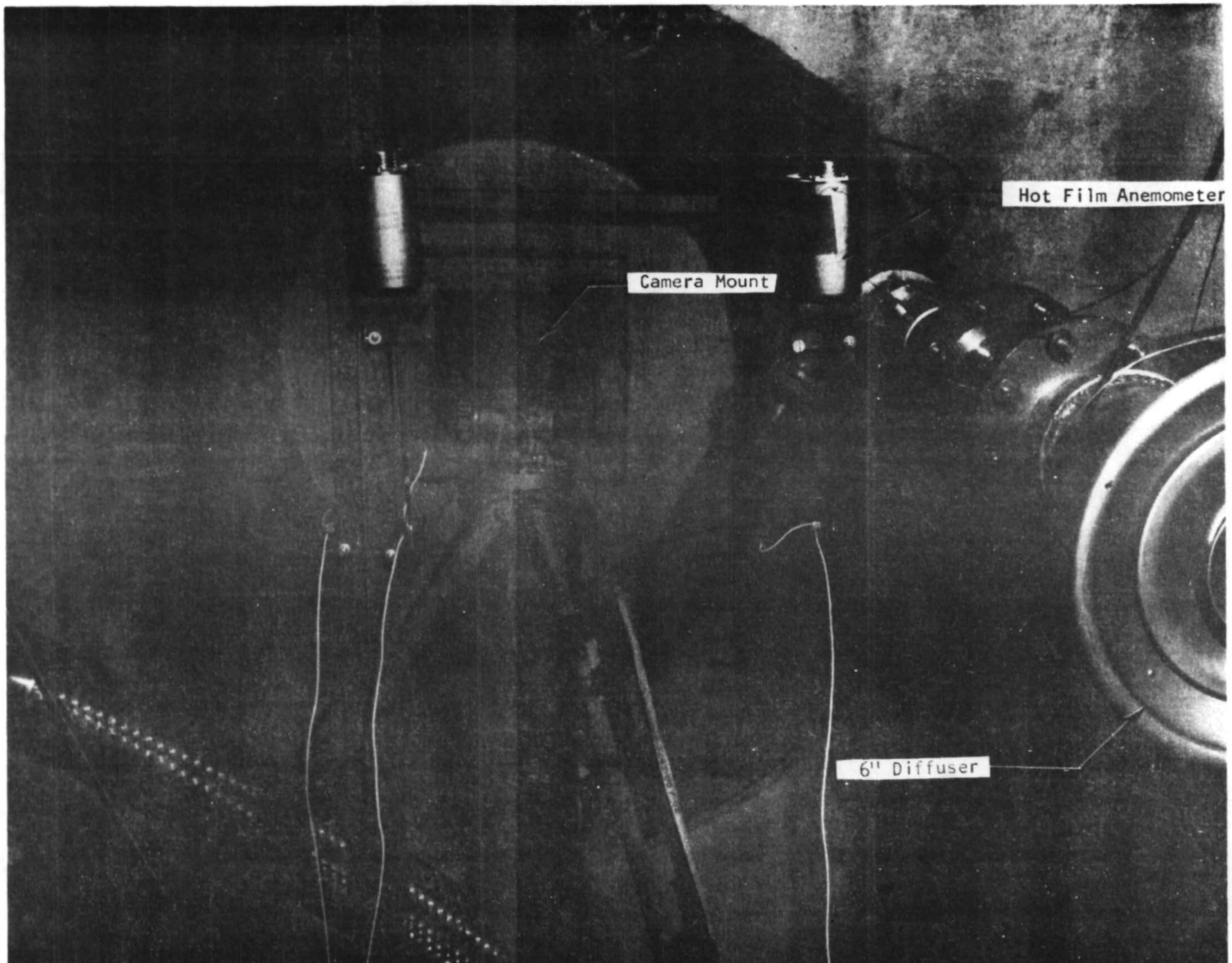

FIGURE 16. THERMO SYSTEMS CEILING ANEMOMETER MOUNTS

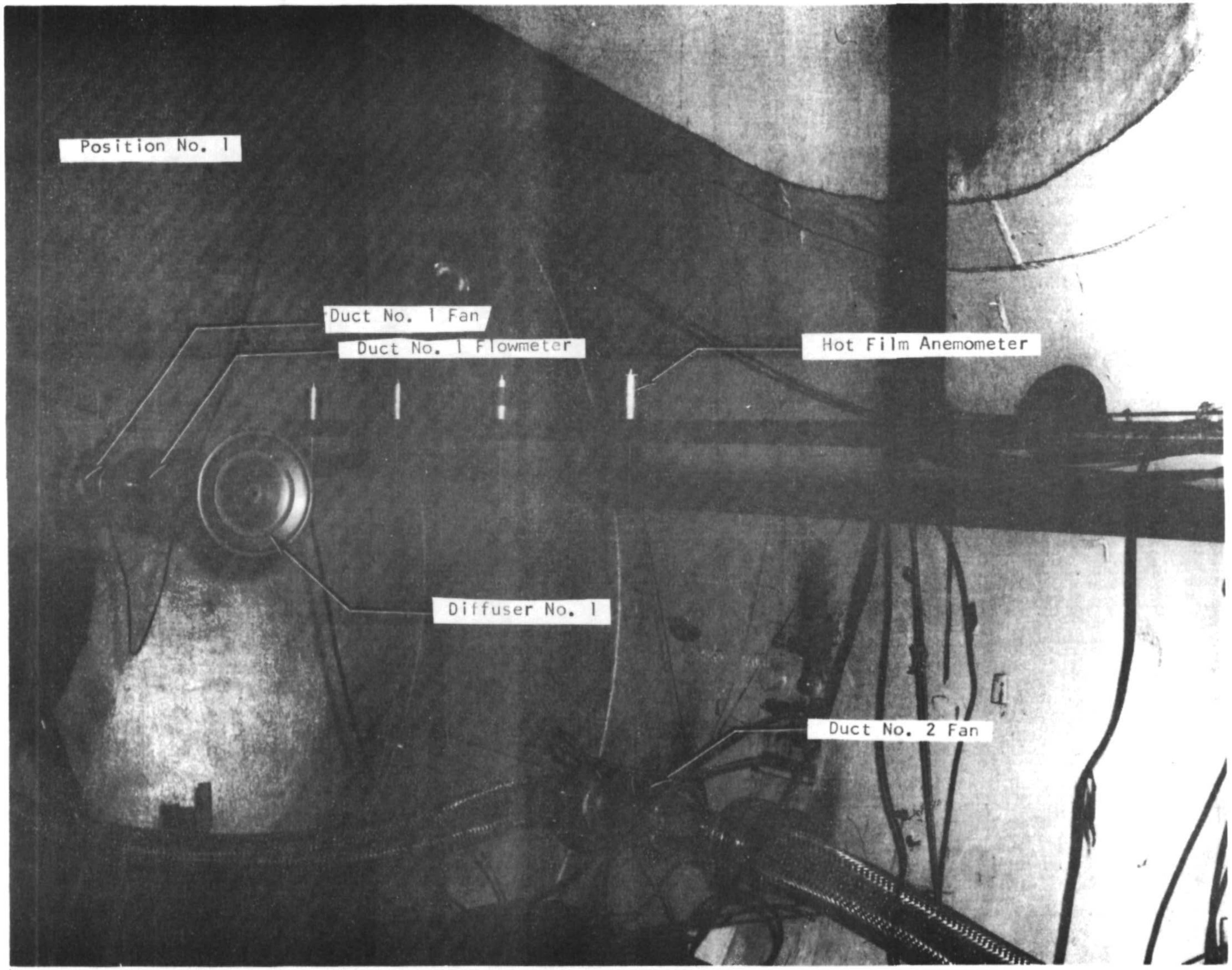

FIGURE 17. THERMO-SYSTEM ANEMOMETER MOUNT

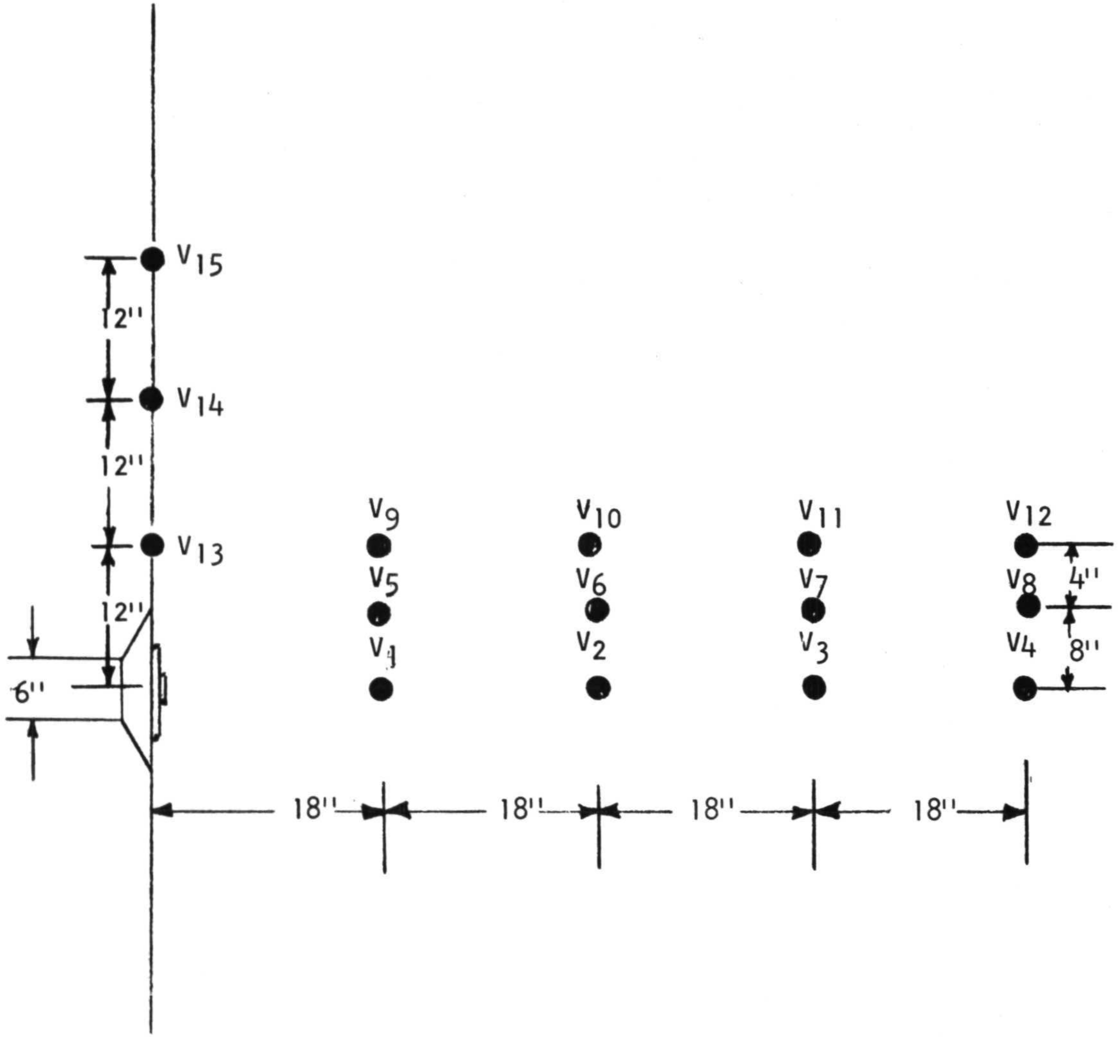

FIGURE 18. THERMO SYSTEMS VELOCITY DATA POINTS

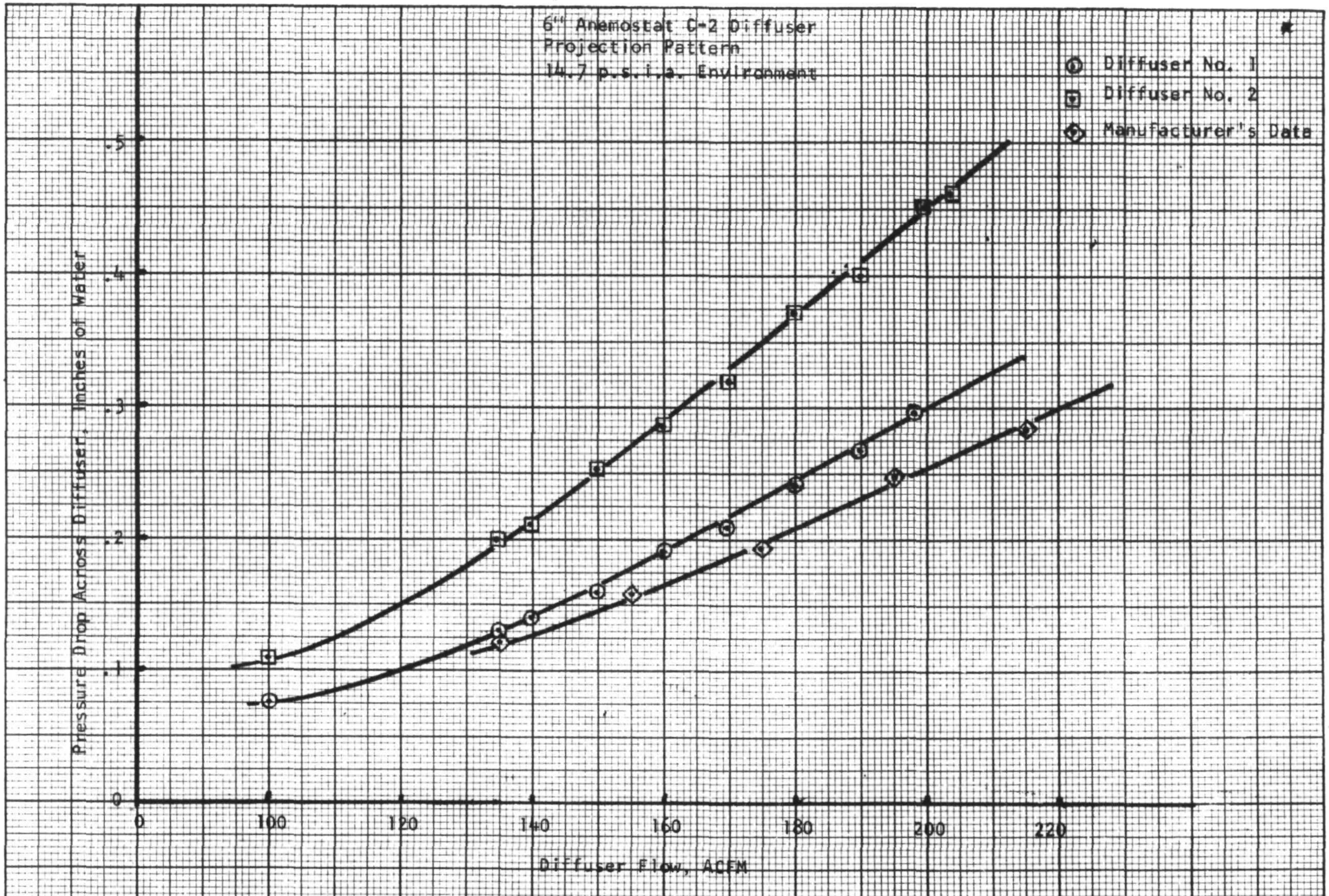

FIGURE 19. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

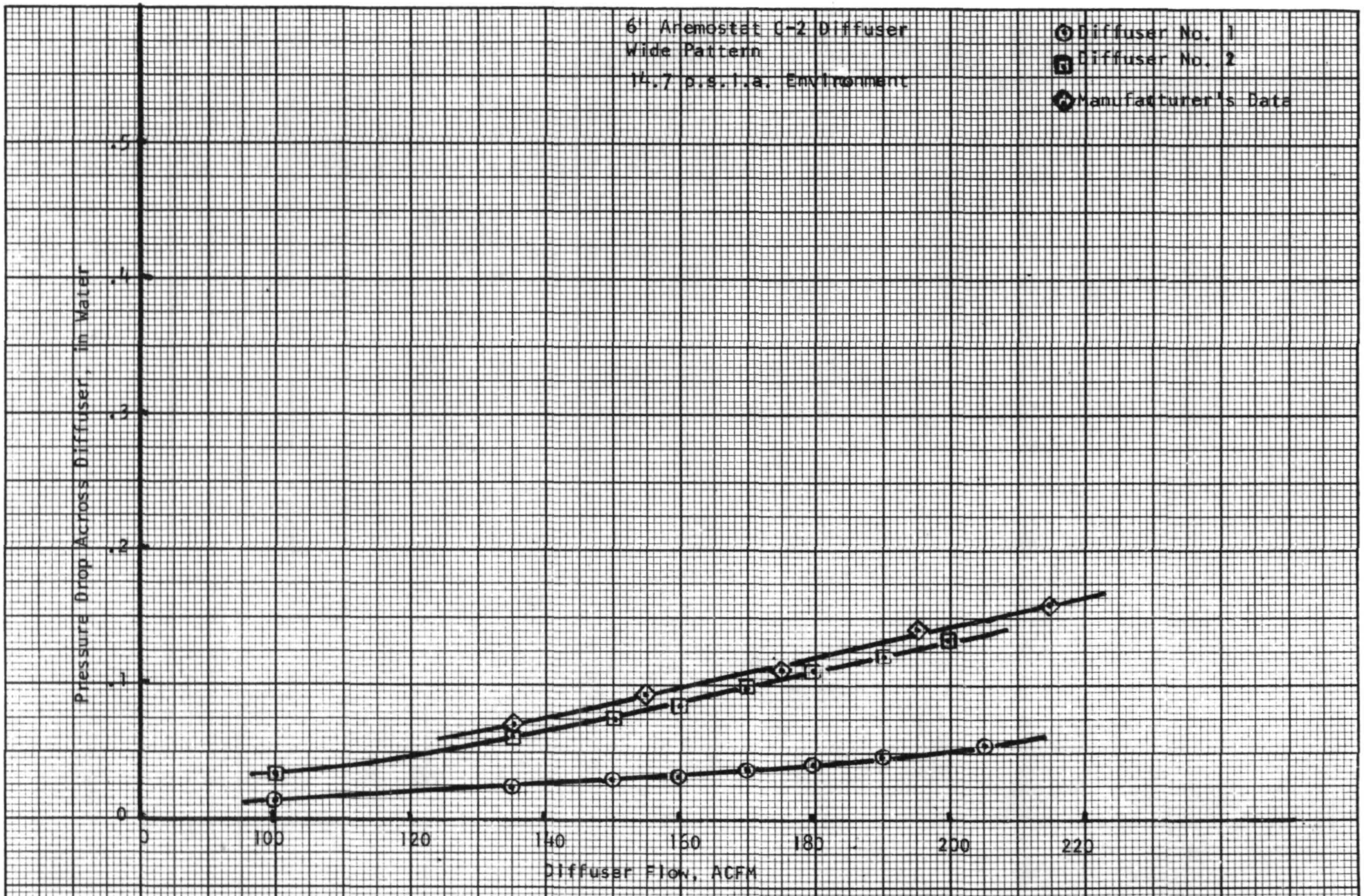

FIGURE 20. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

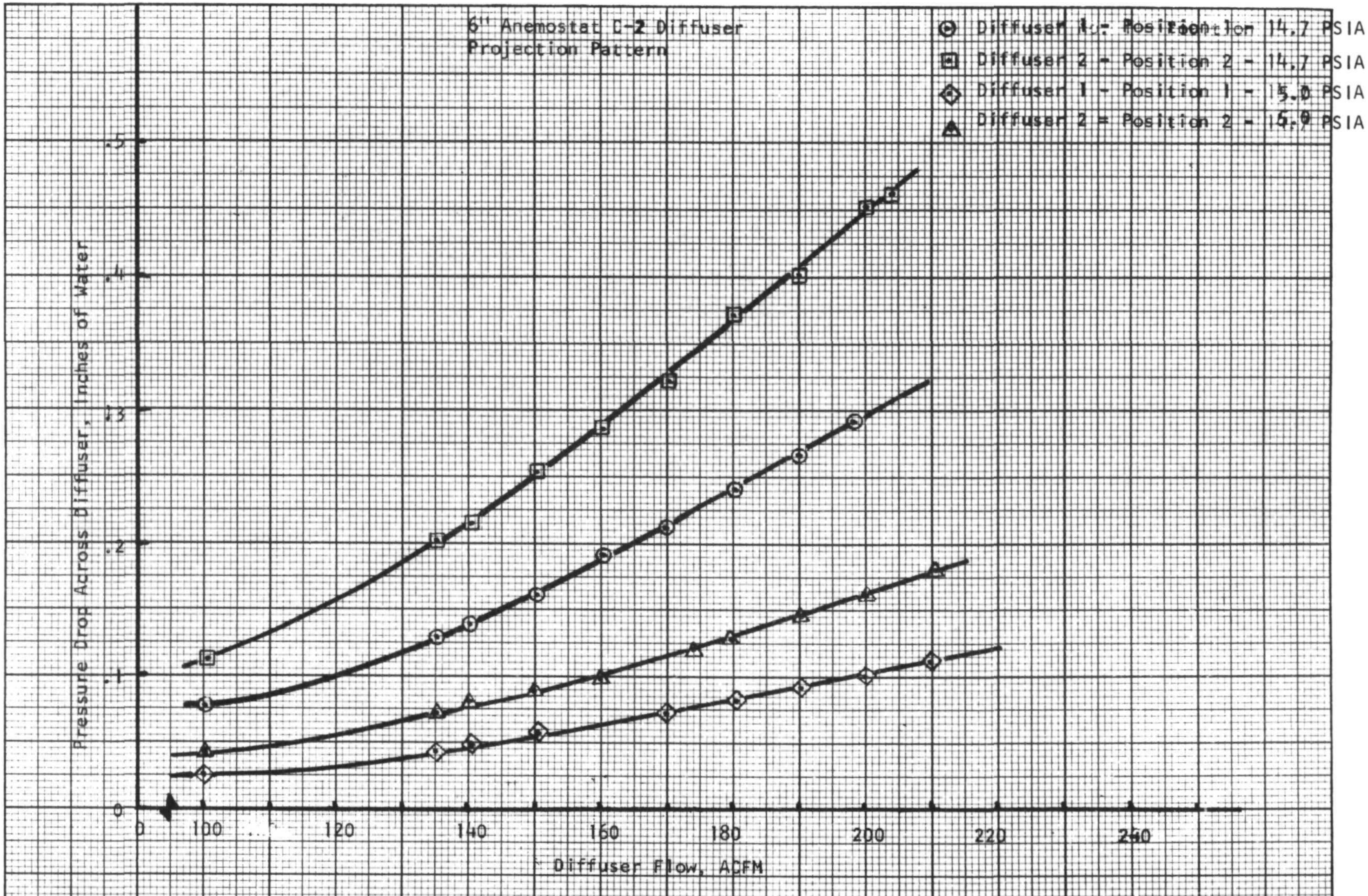

FIGURE 21. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

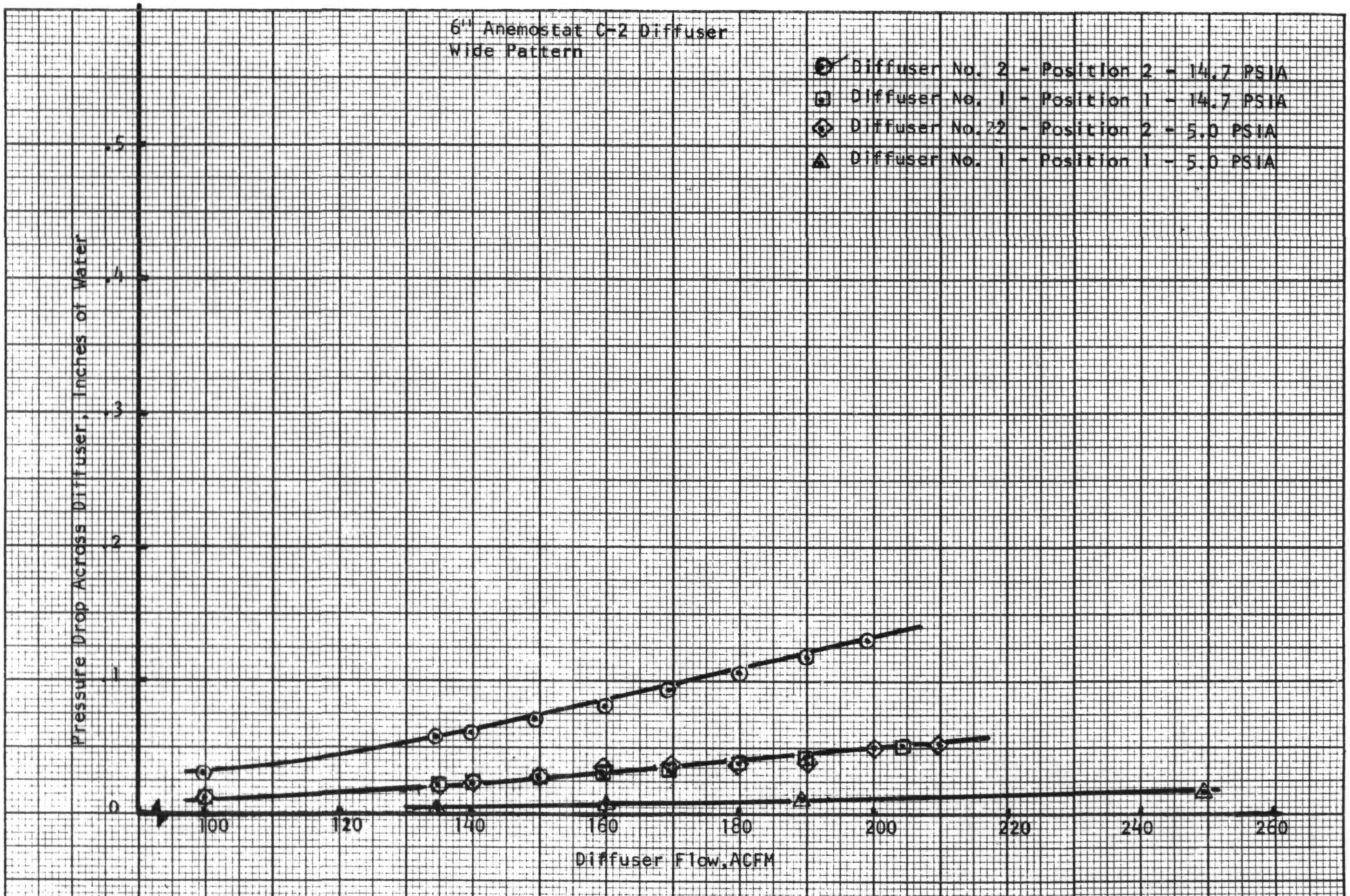

FIGURE 22. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

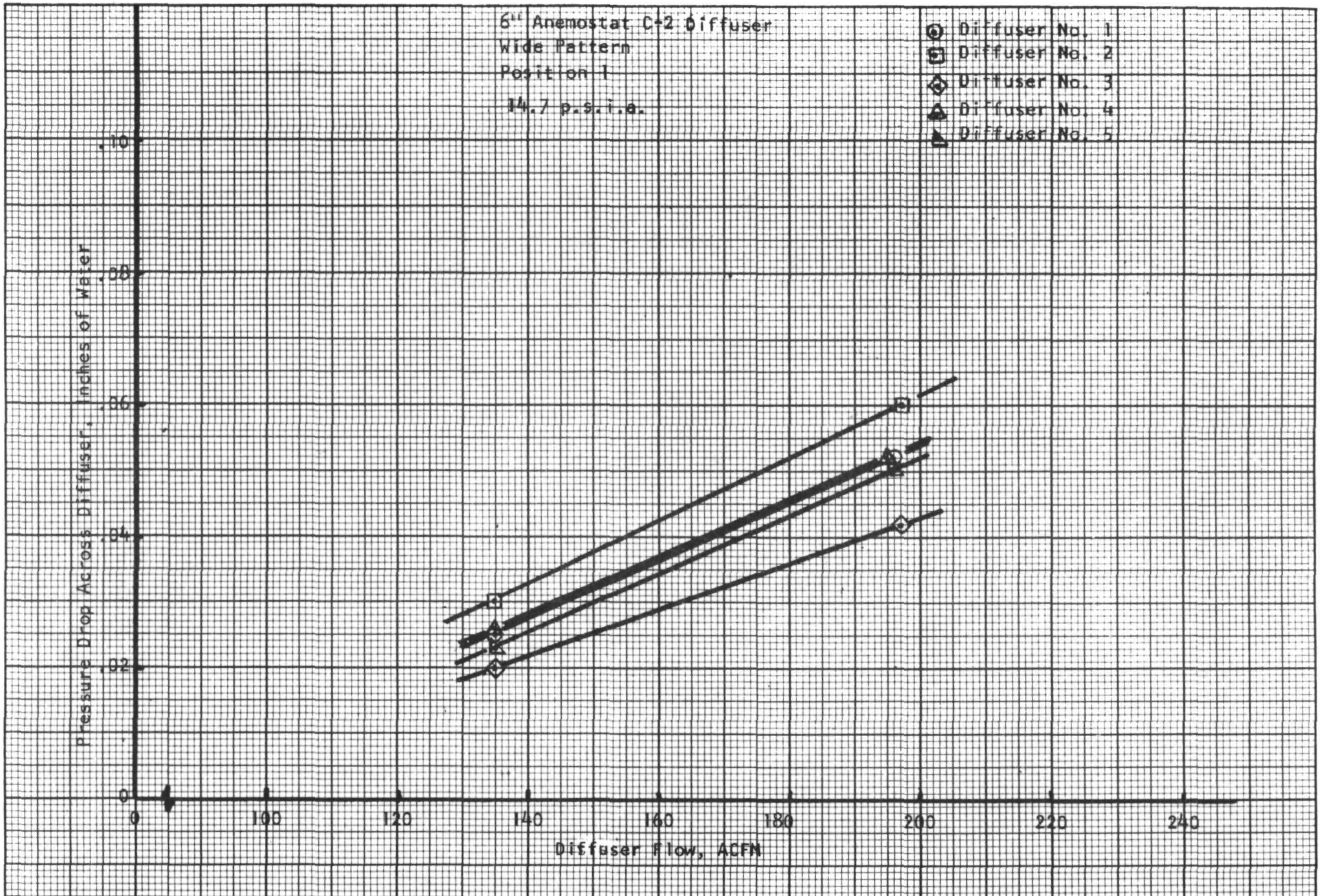

FIGURE 23. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

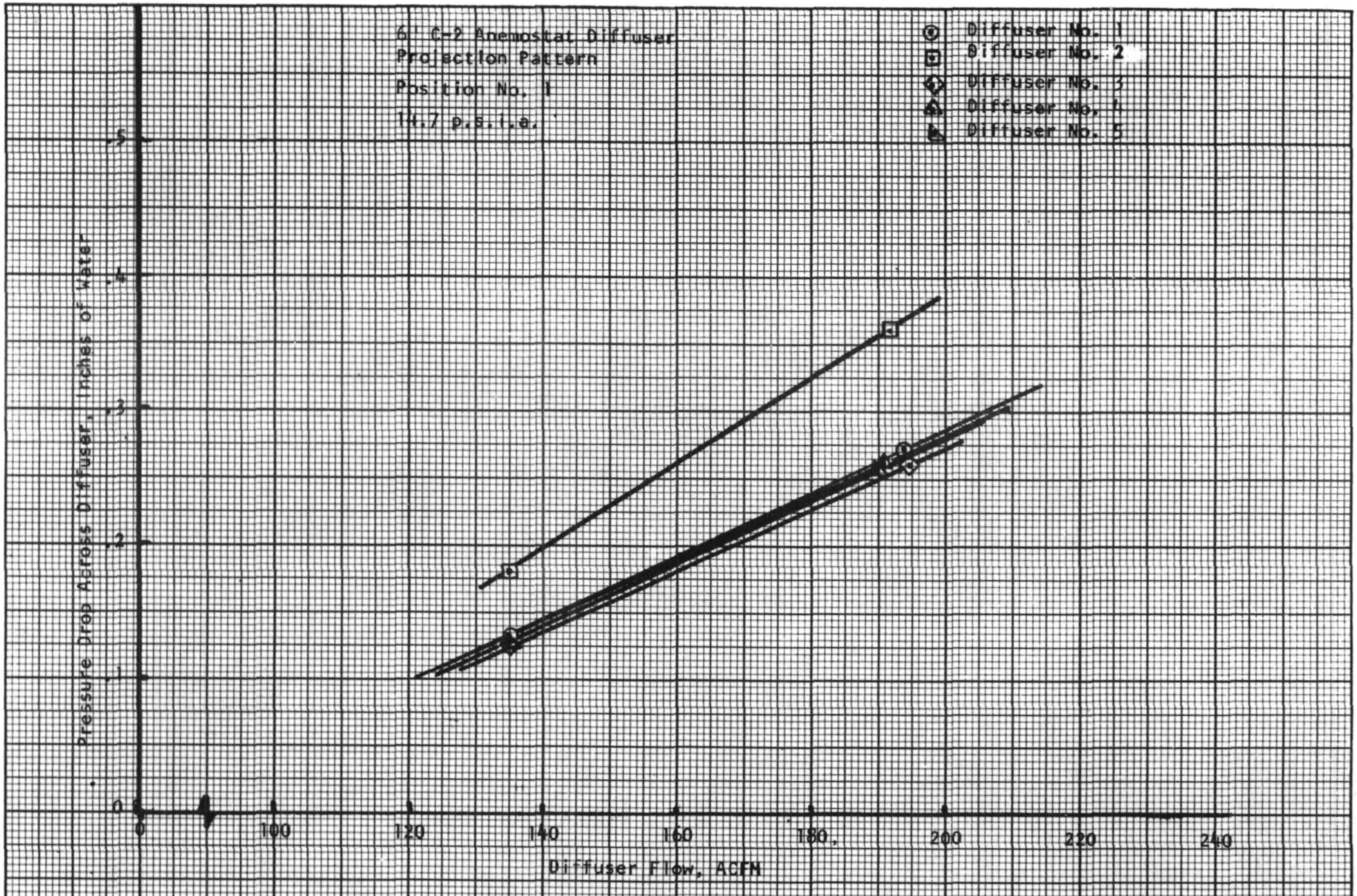

FIGURE 24. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

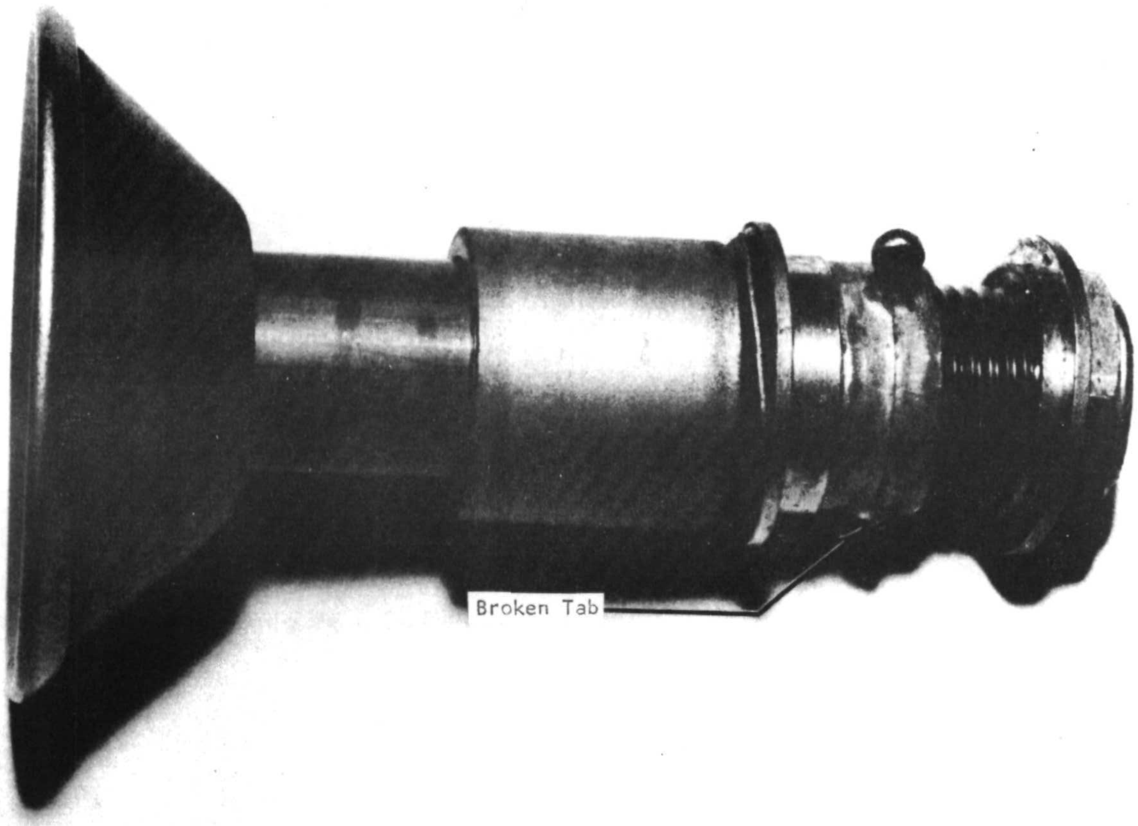

FIGURE 25. CENTER CONE OF NO. 2 DIFFUSER

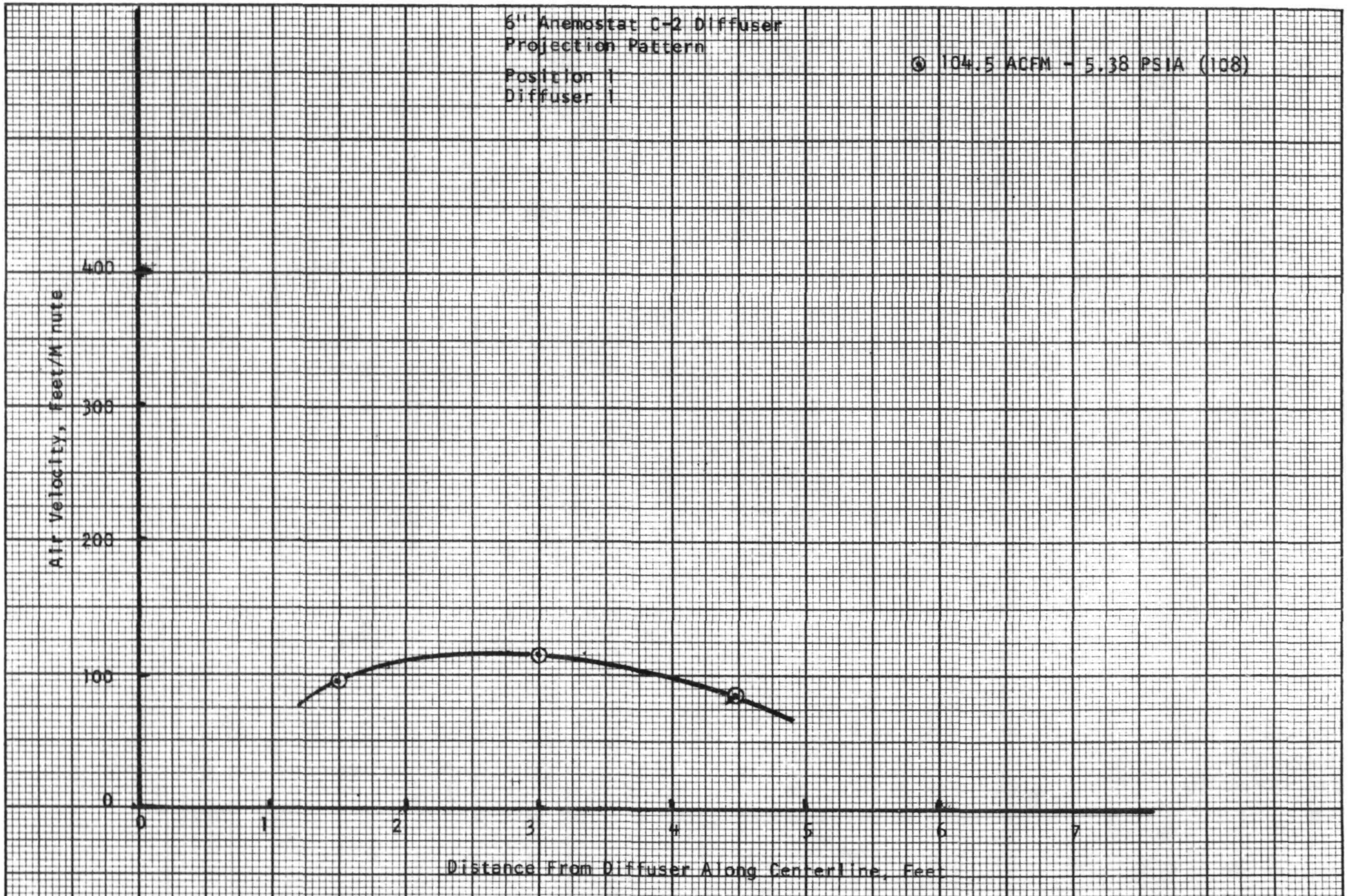

FIGURE 26. DISTANCE FROM DIFFUSER VS AIR VELOCITY

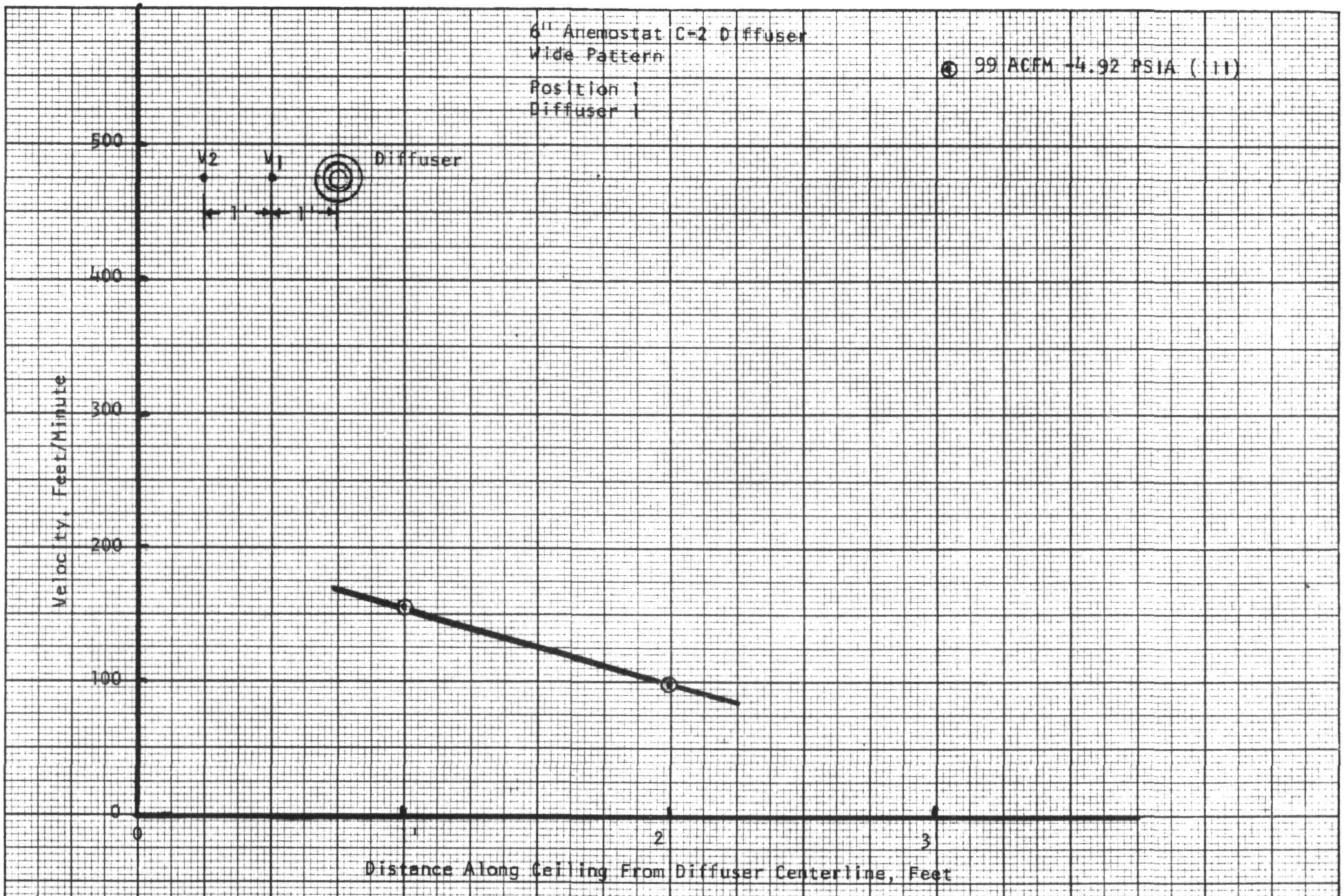

FIGURE 27. DISTANCE ALONG CEILING VS AIR VELOCITY

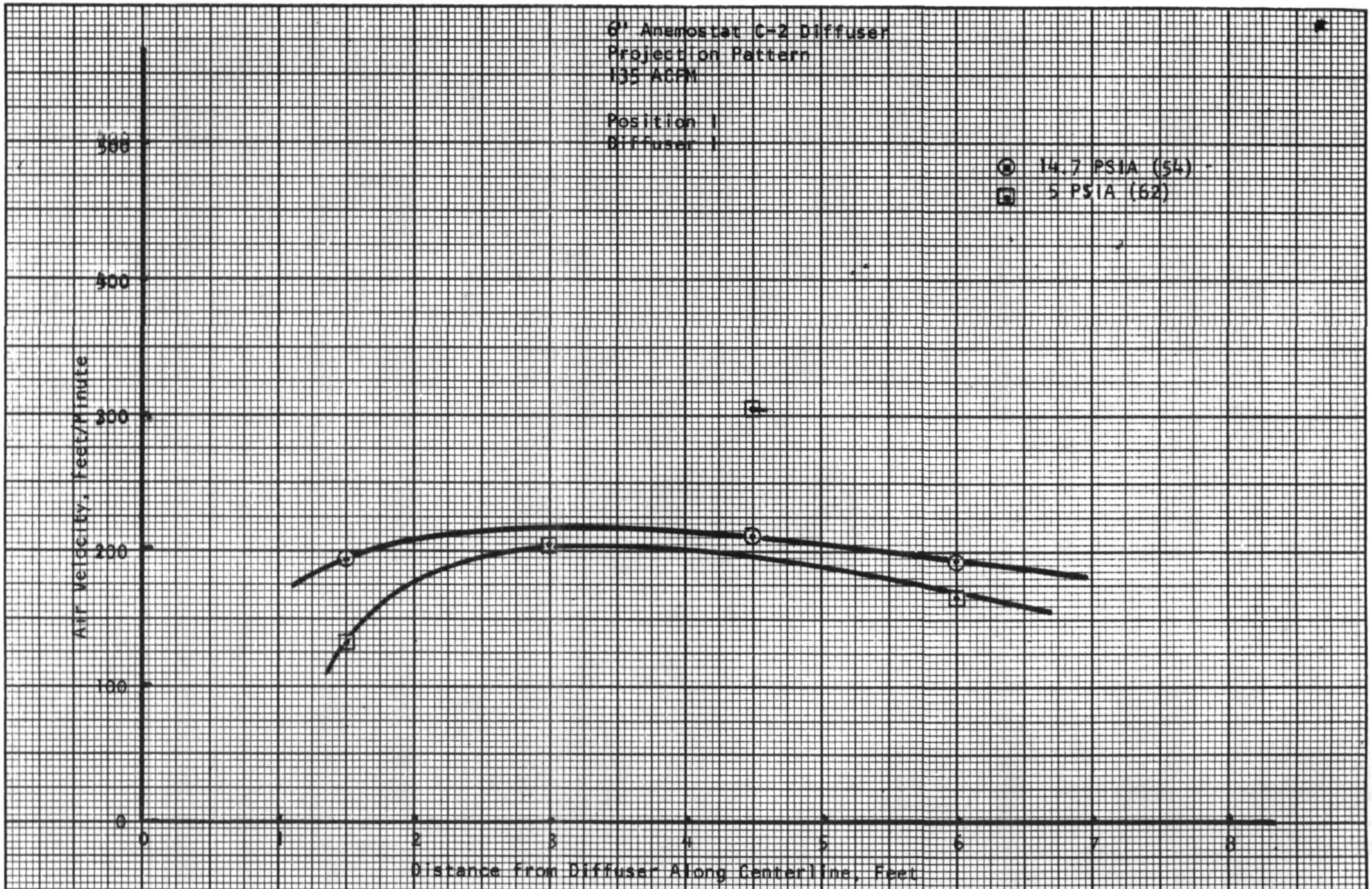

FIGURE 28. DISTANCE FROM DIFFUSER VS AIR VELOCITY

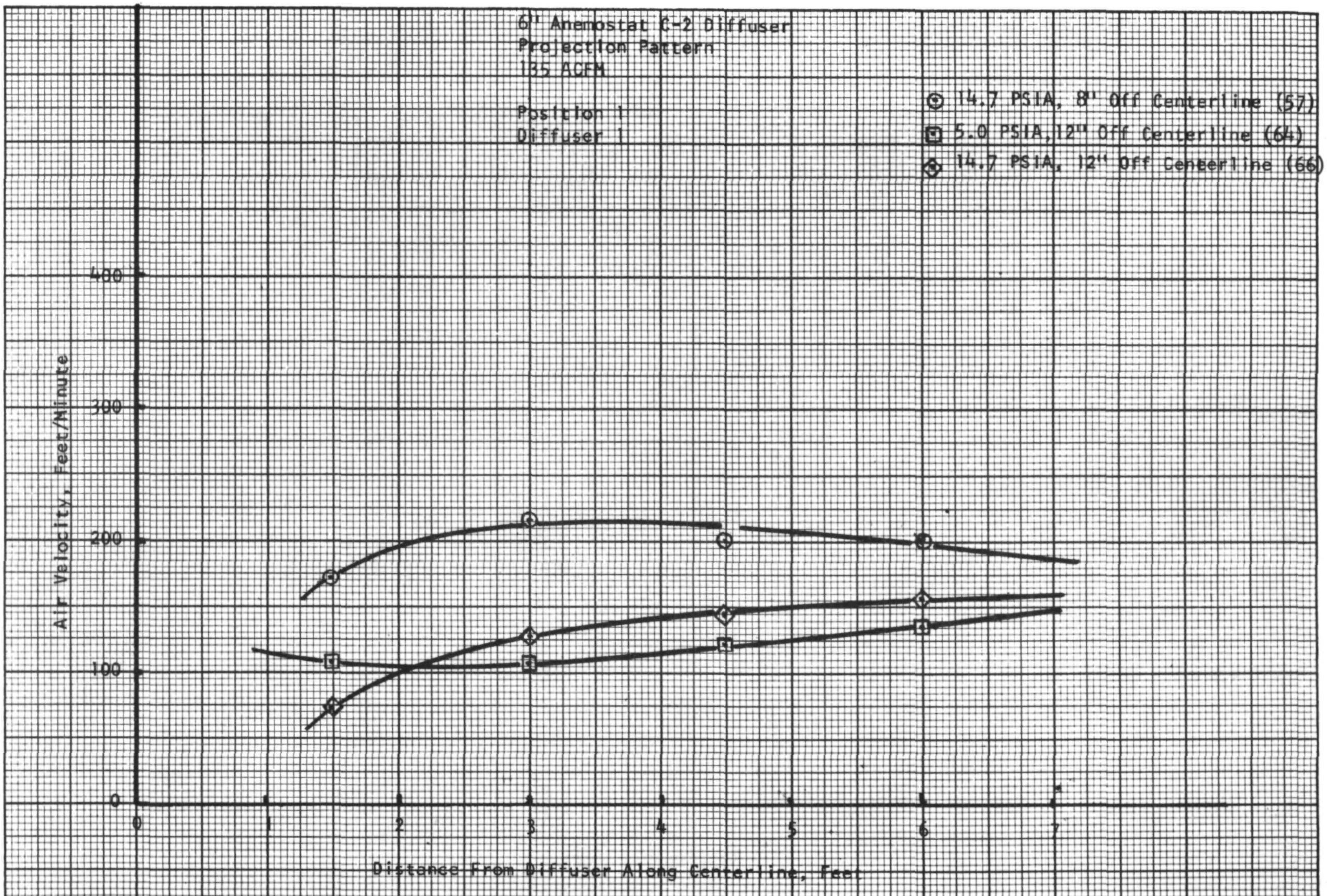

FIGURE 29. DISTANCE FROM DIFFUSER VS AIR VELOCITY

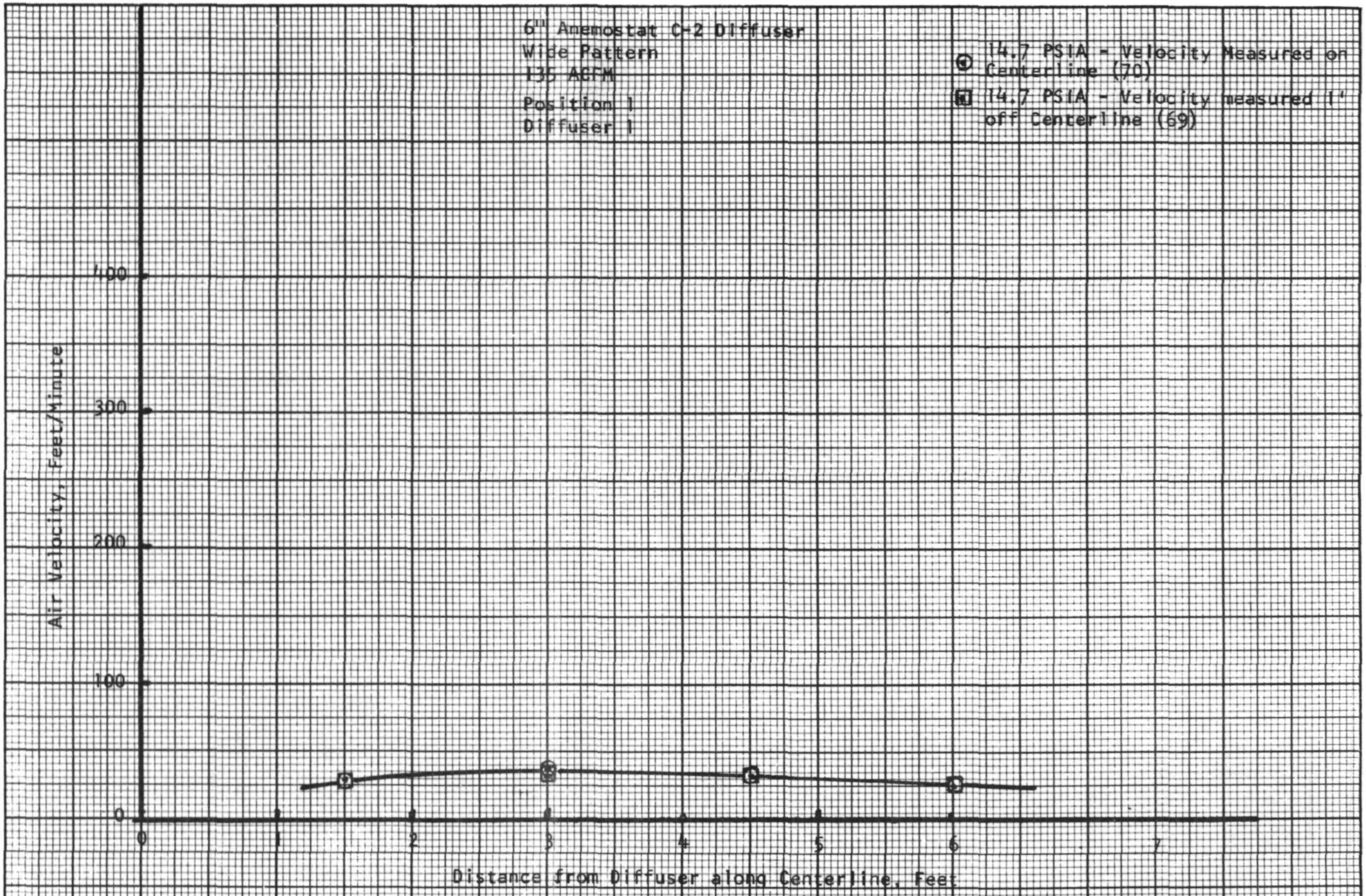

FIGURE 30. DISTANCE FROM DIFFUSER VS AIR VELOCITY

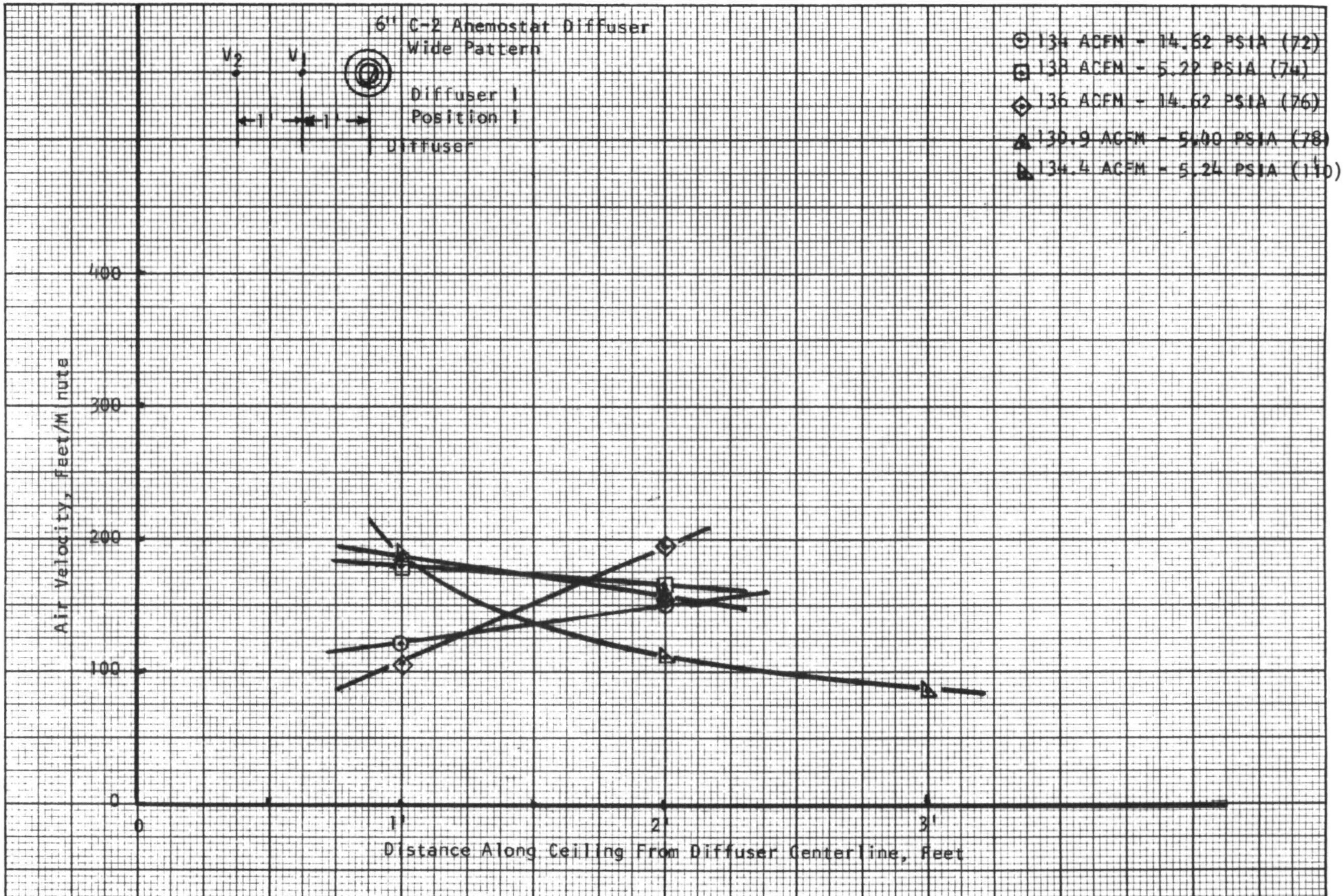

FIGURE 31. DISTANCE ALONG CEILING VS AIR VELOCITY

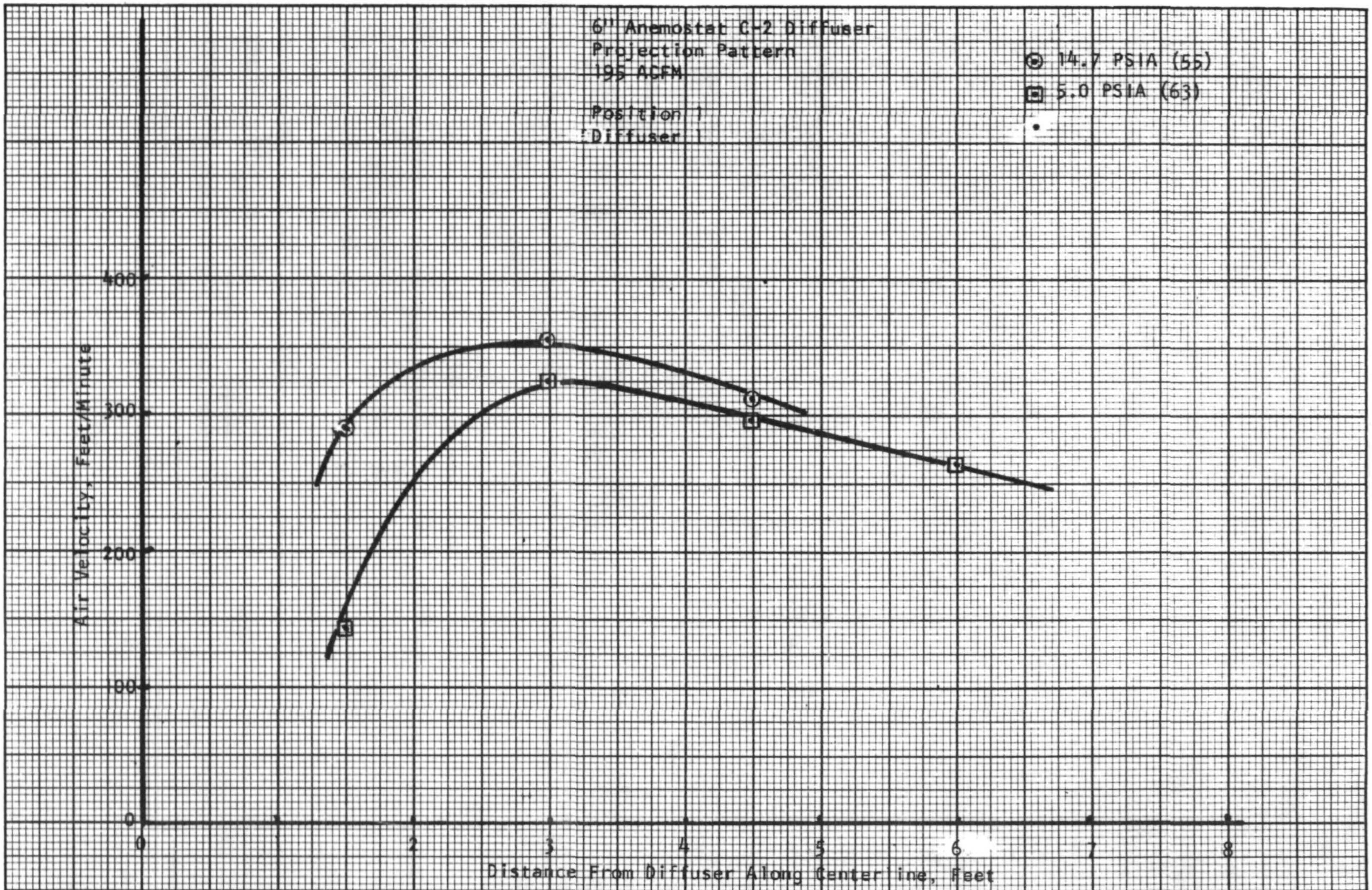

FIGURE 32. DISTANCE FROM DIFFUSER VS AIR VELOCITY

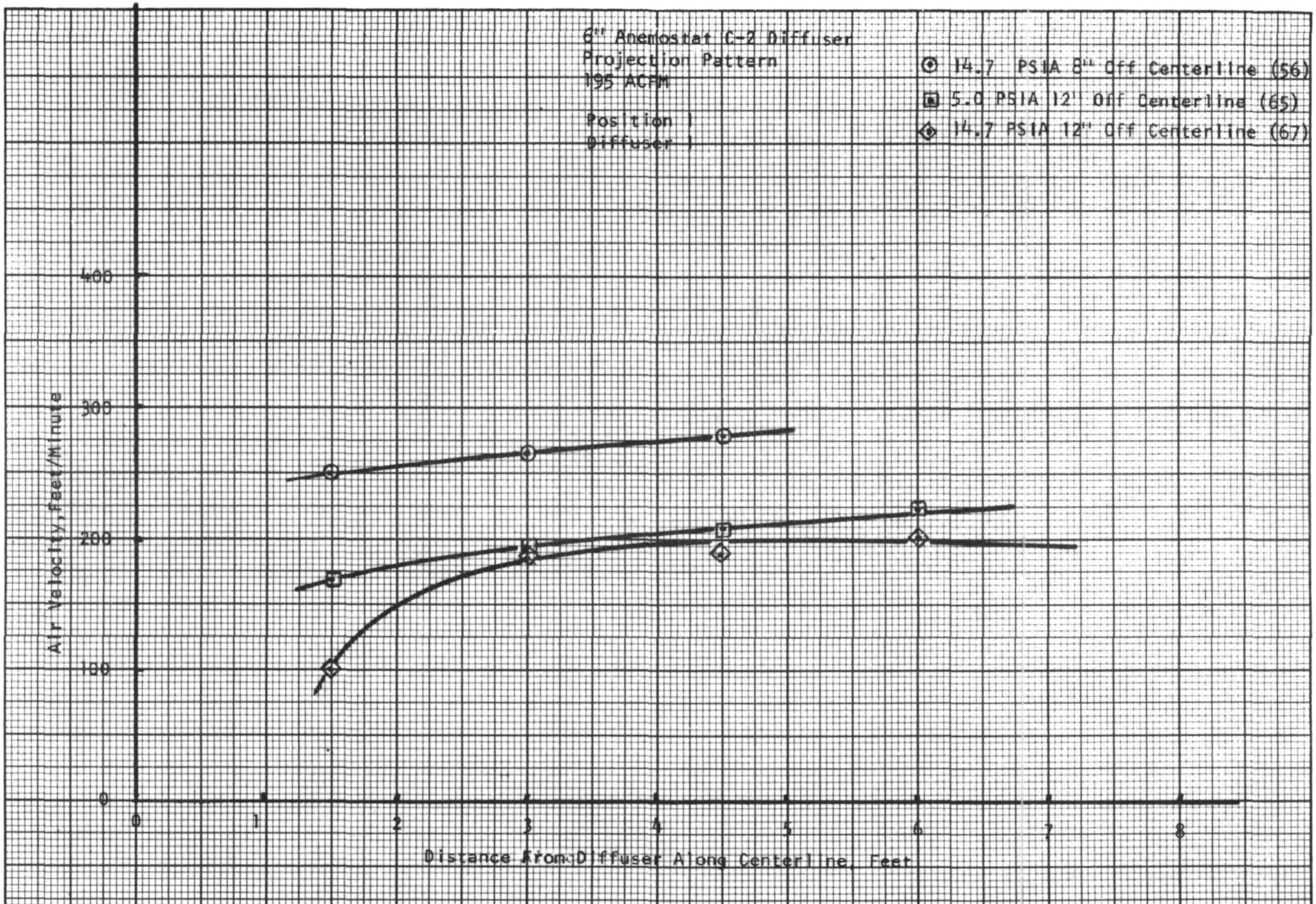

FIGURE 33. DISTANCE FROM DIFFUSER VS AIR VELOCITY

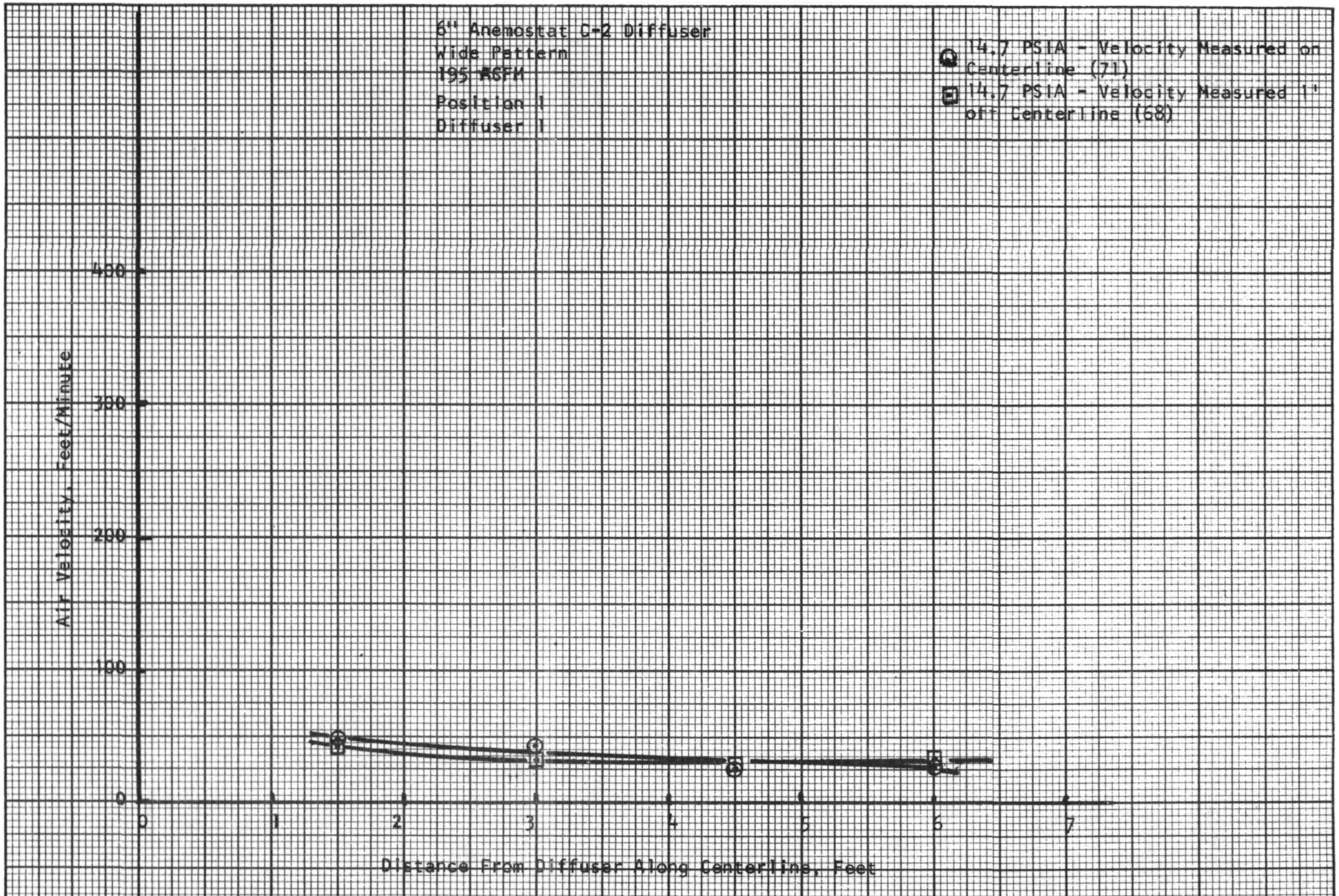

FIGURE 34. DISTANCE FROM DIFFUSER VS AIR VELOCITY

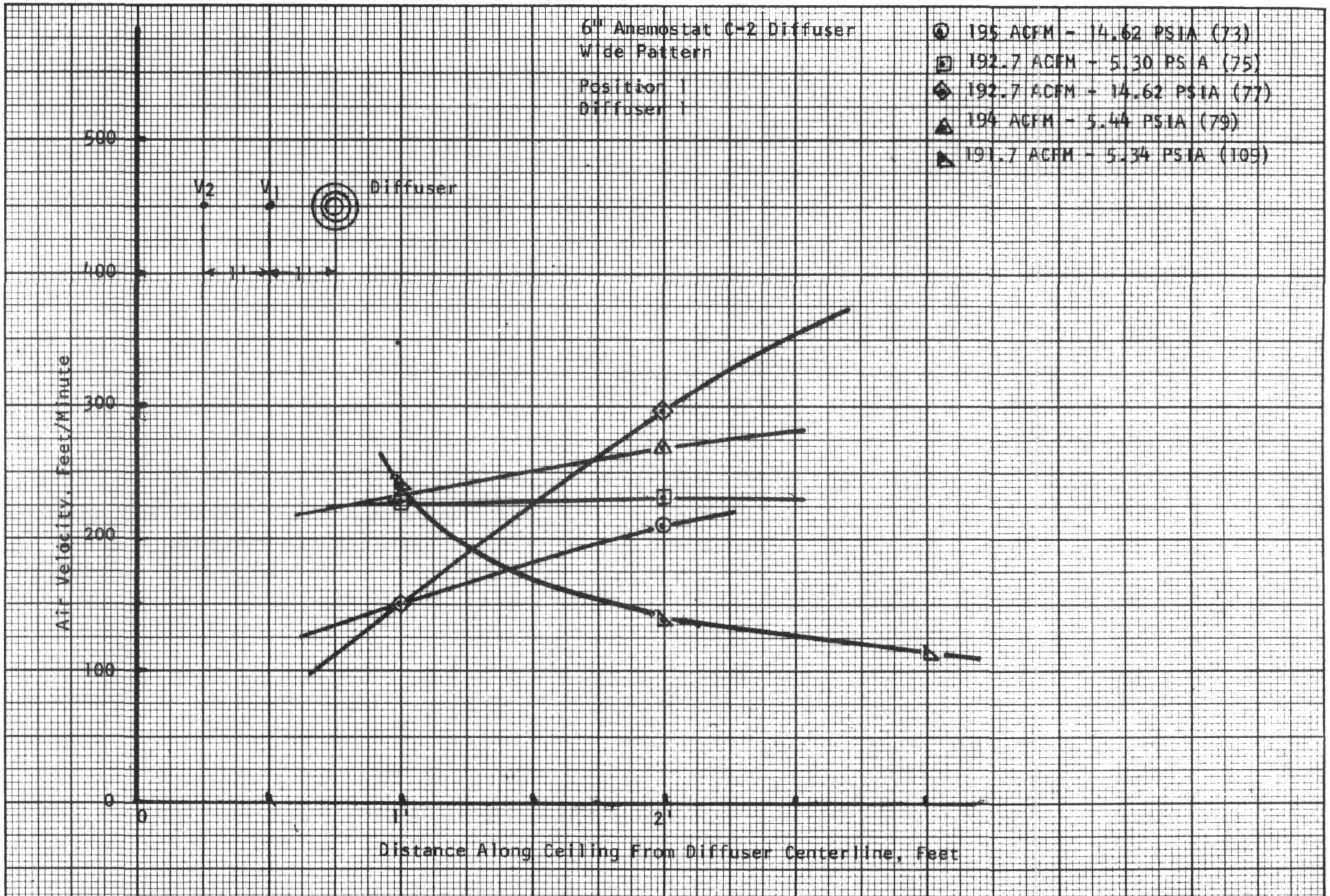

FIGURE 35. DISTANCE ALONG CEILING VS AIR VELOCITY

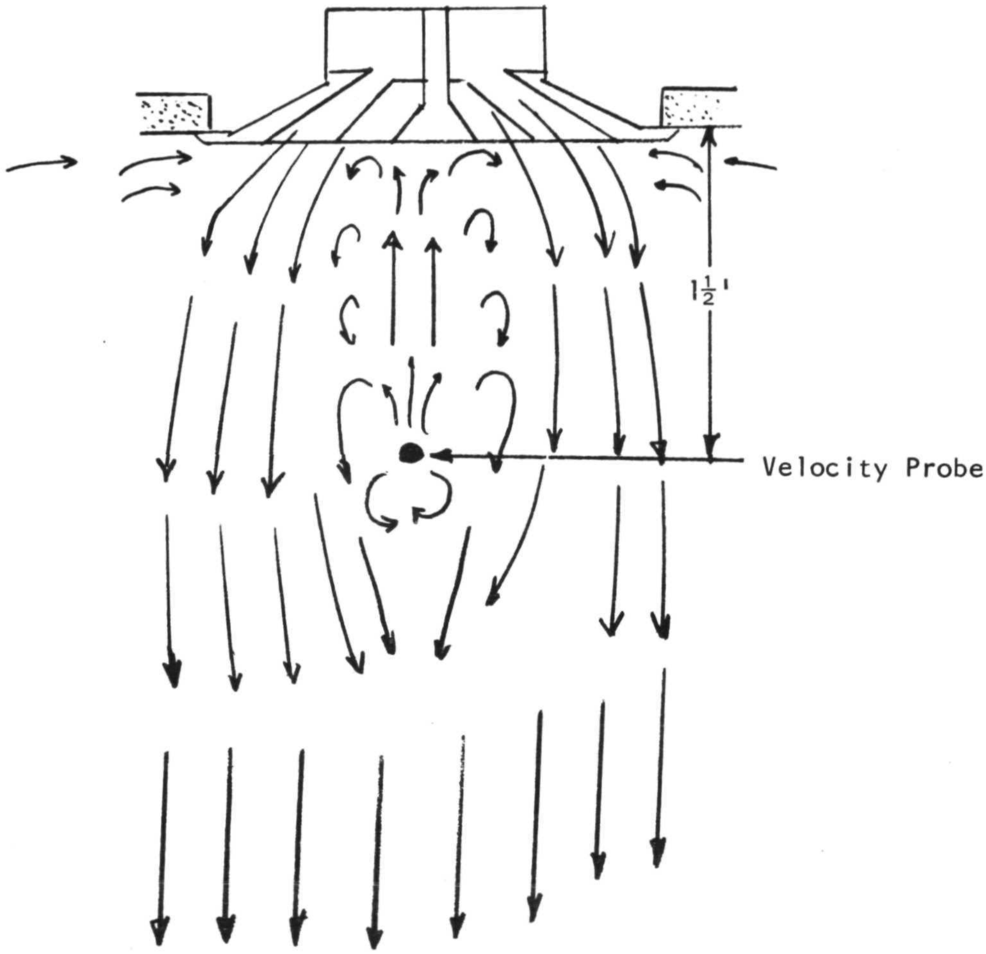

FIGURE 36. DIFFUSER FLOW IN PROJECTION PATTERN

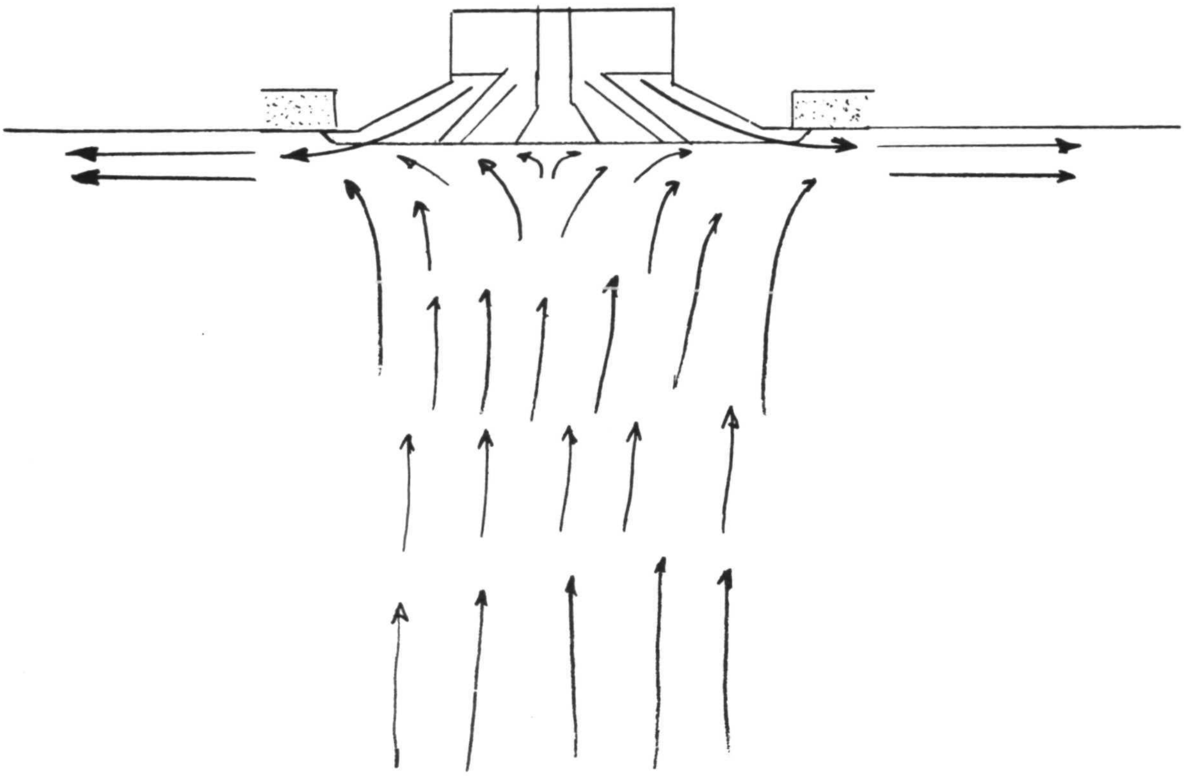

FIGURE 37. DIFFUSER FLOW IN WIDE PATTERN

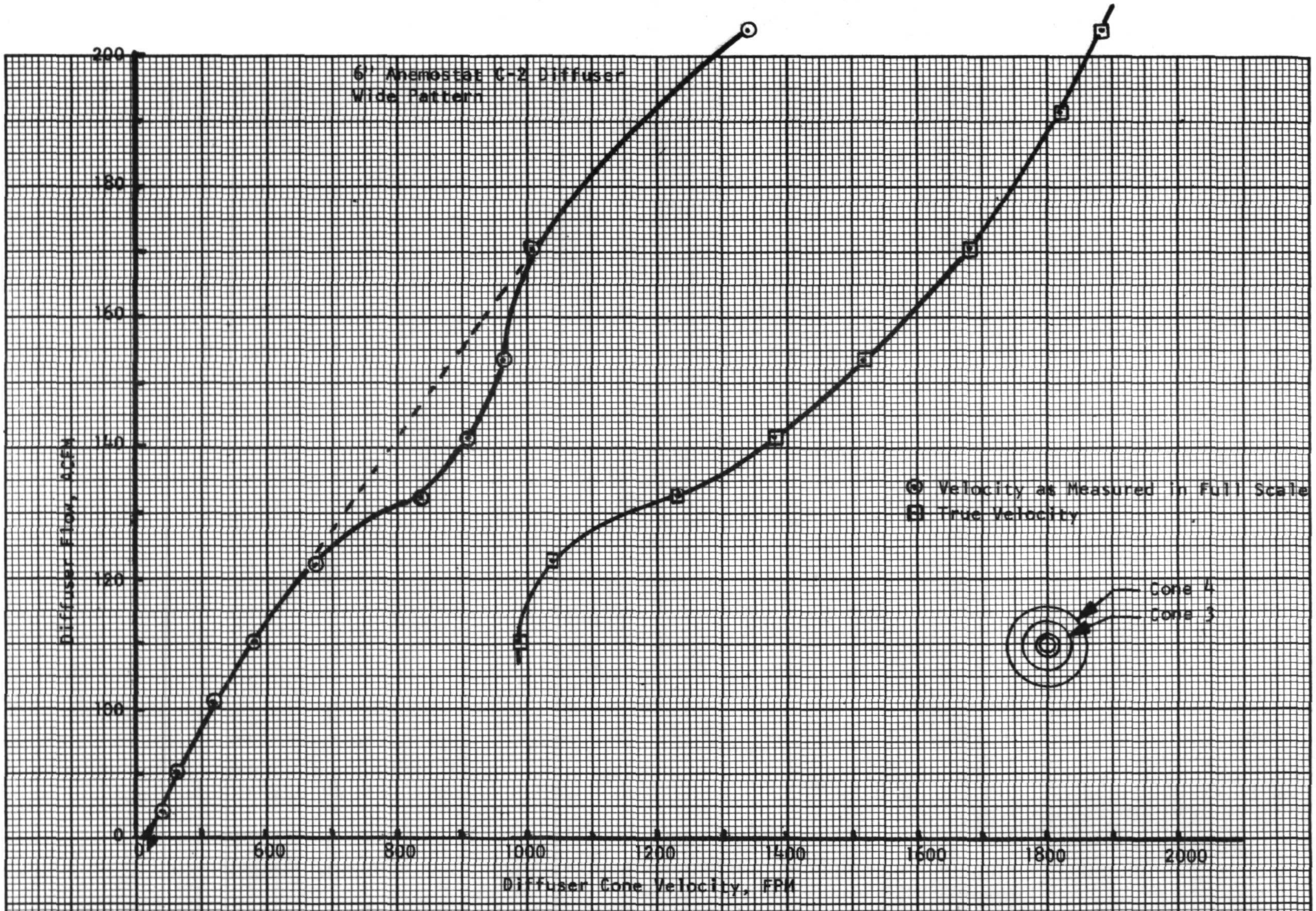

FIGURE 38. DIFFUSER CONE VELOCITY VS DIFFUSER FLOW

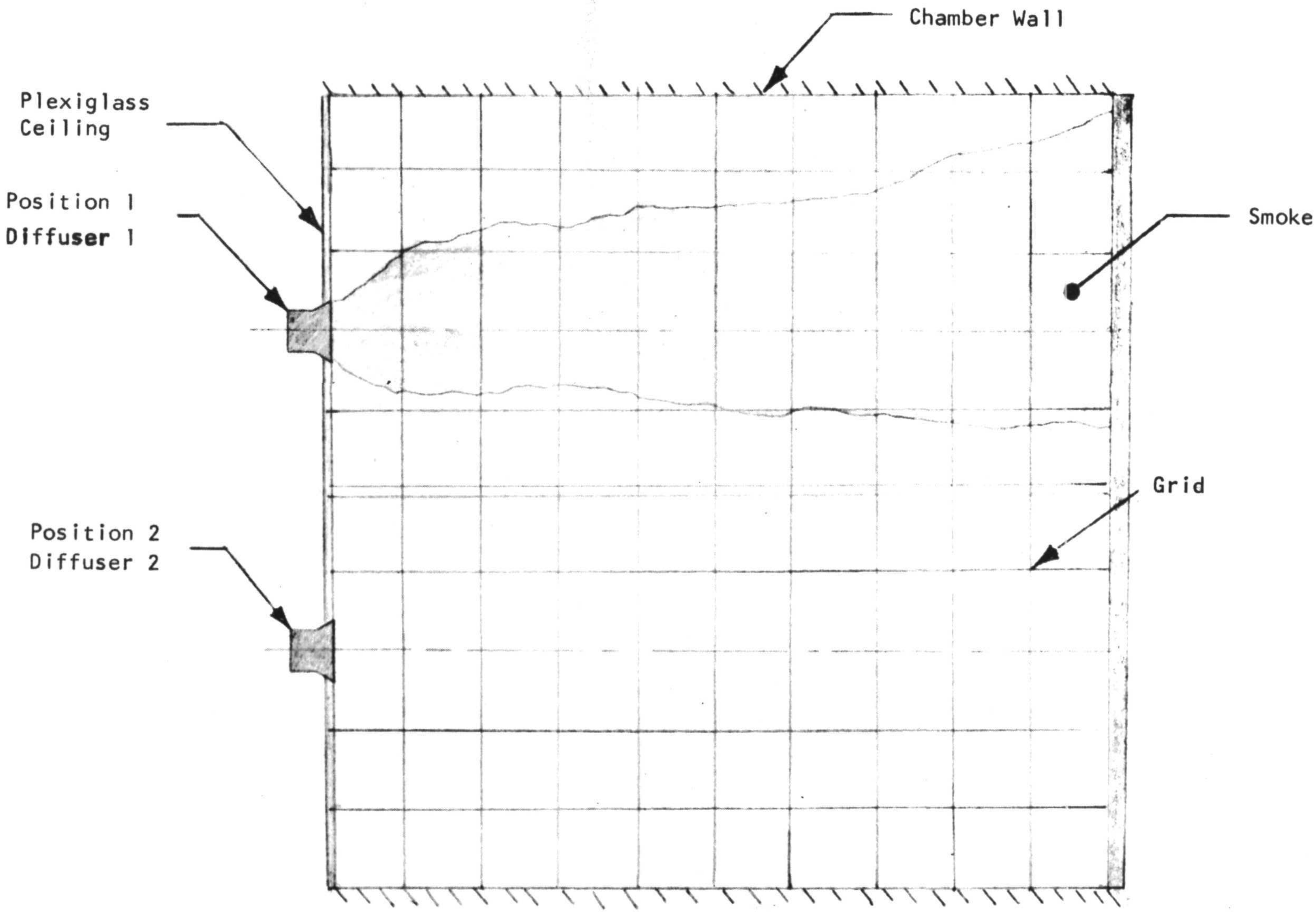

FIGURE 39. 6" DIFFUSER FLOWING WITH CENTER BODY REMOVED

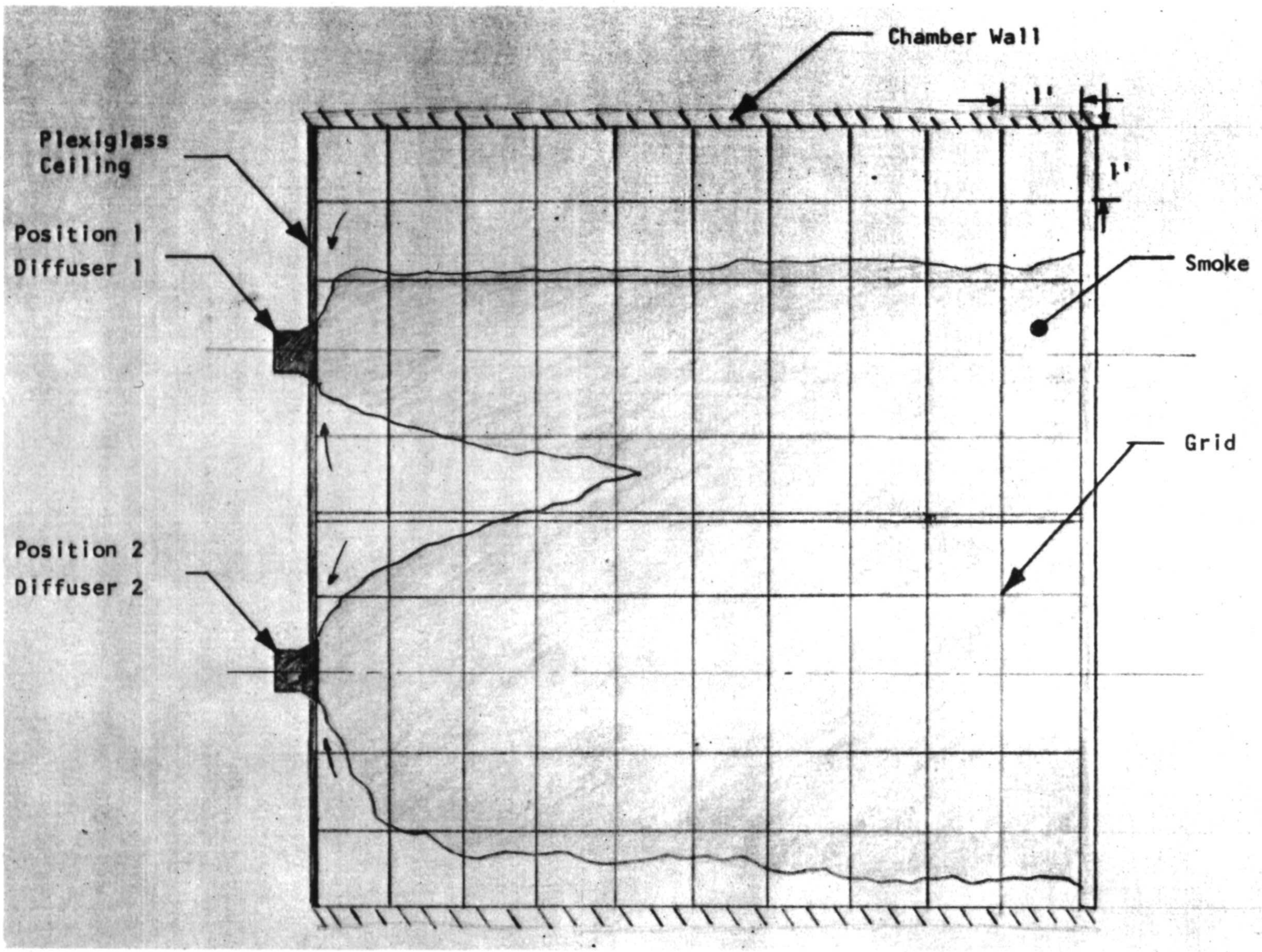

FIGURE 40. DUAL DIFFUSERS SET IN PROJECTION PATTERN

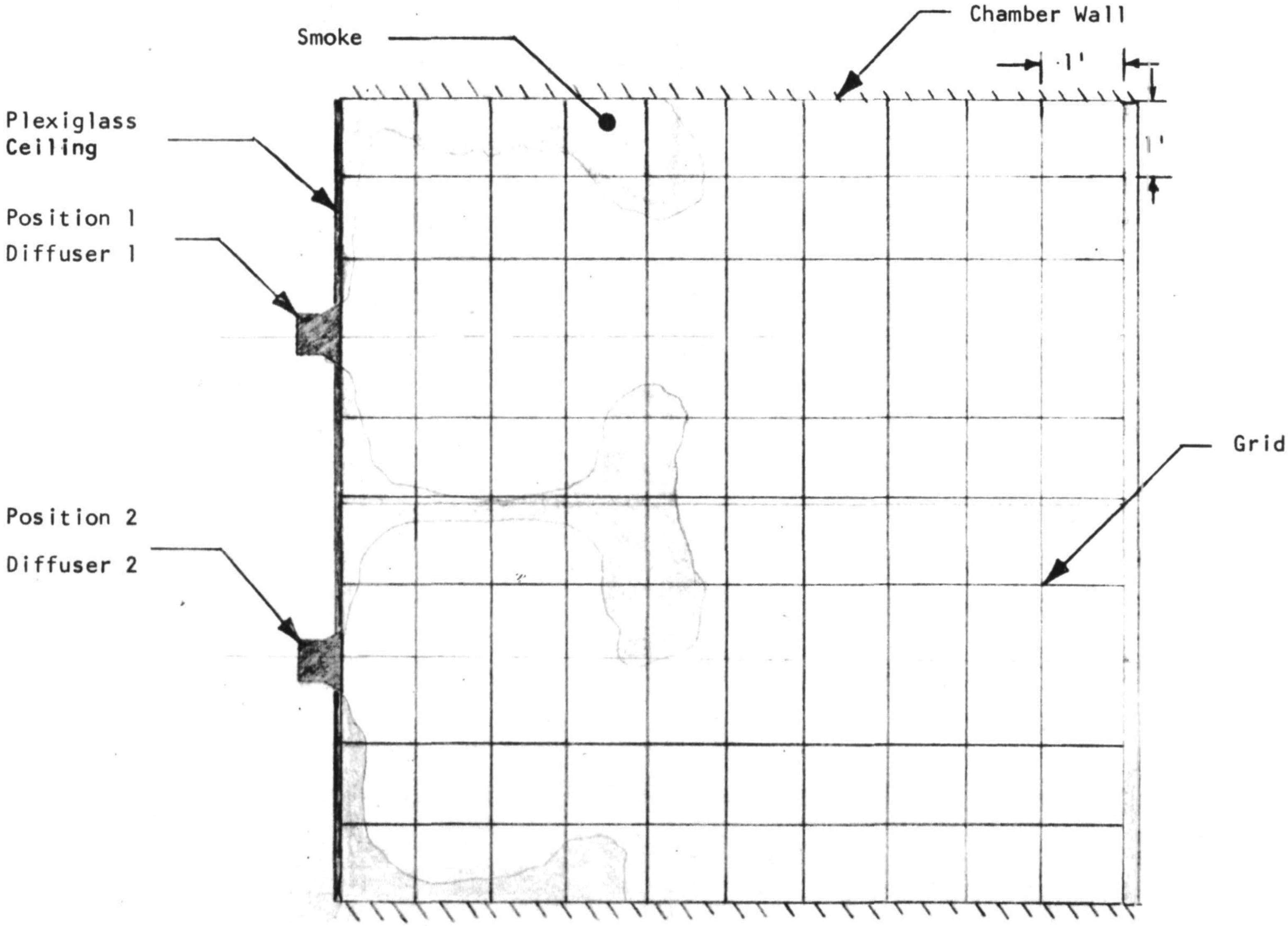

FIGURE 41. DUAL DIFFUSER SET IN PROJECTION PATTERN

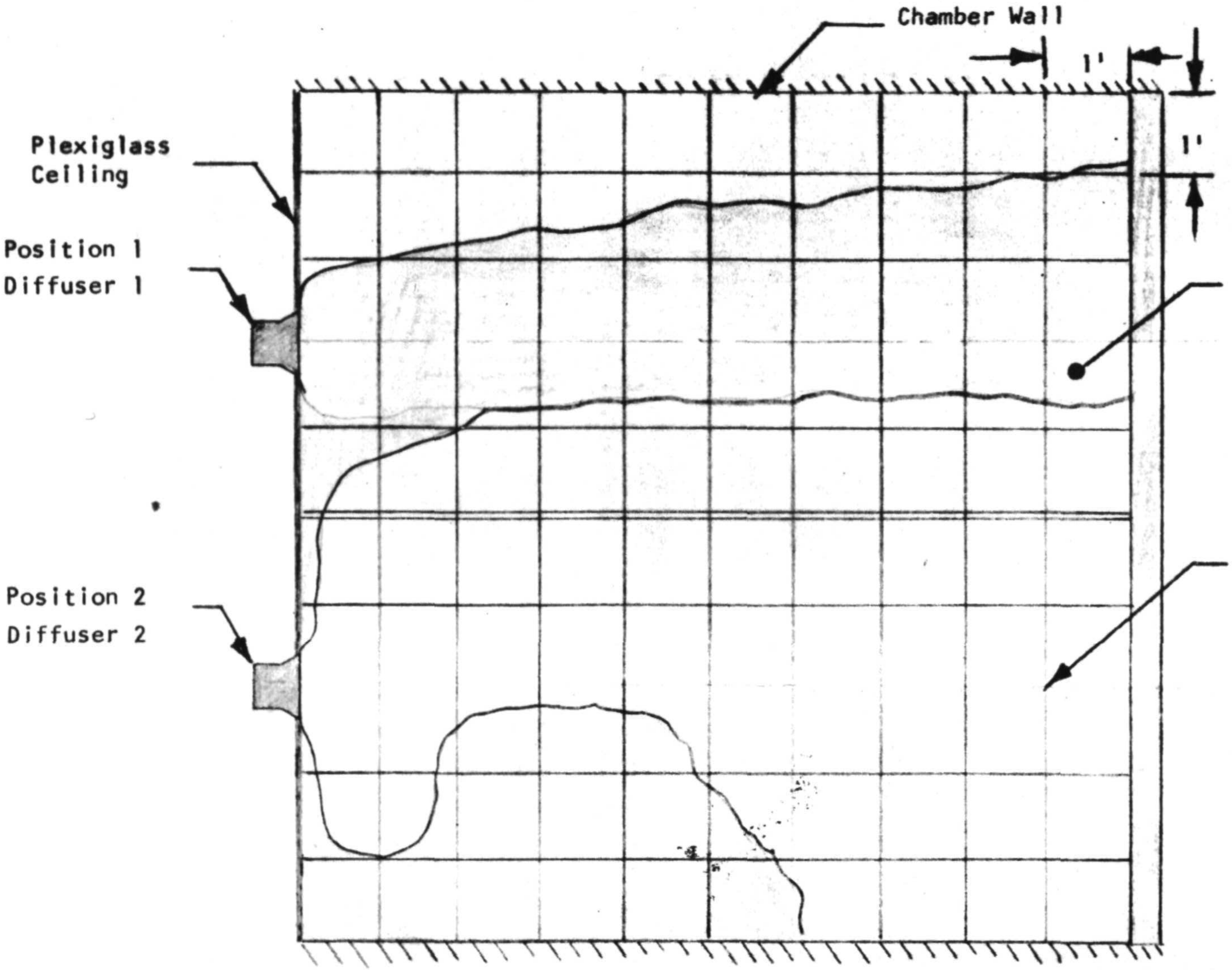

FIGURE 42. DUAL DIFFUSERS SET IN WIDE AND PROJECTION PATTERN

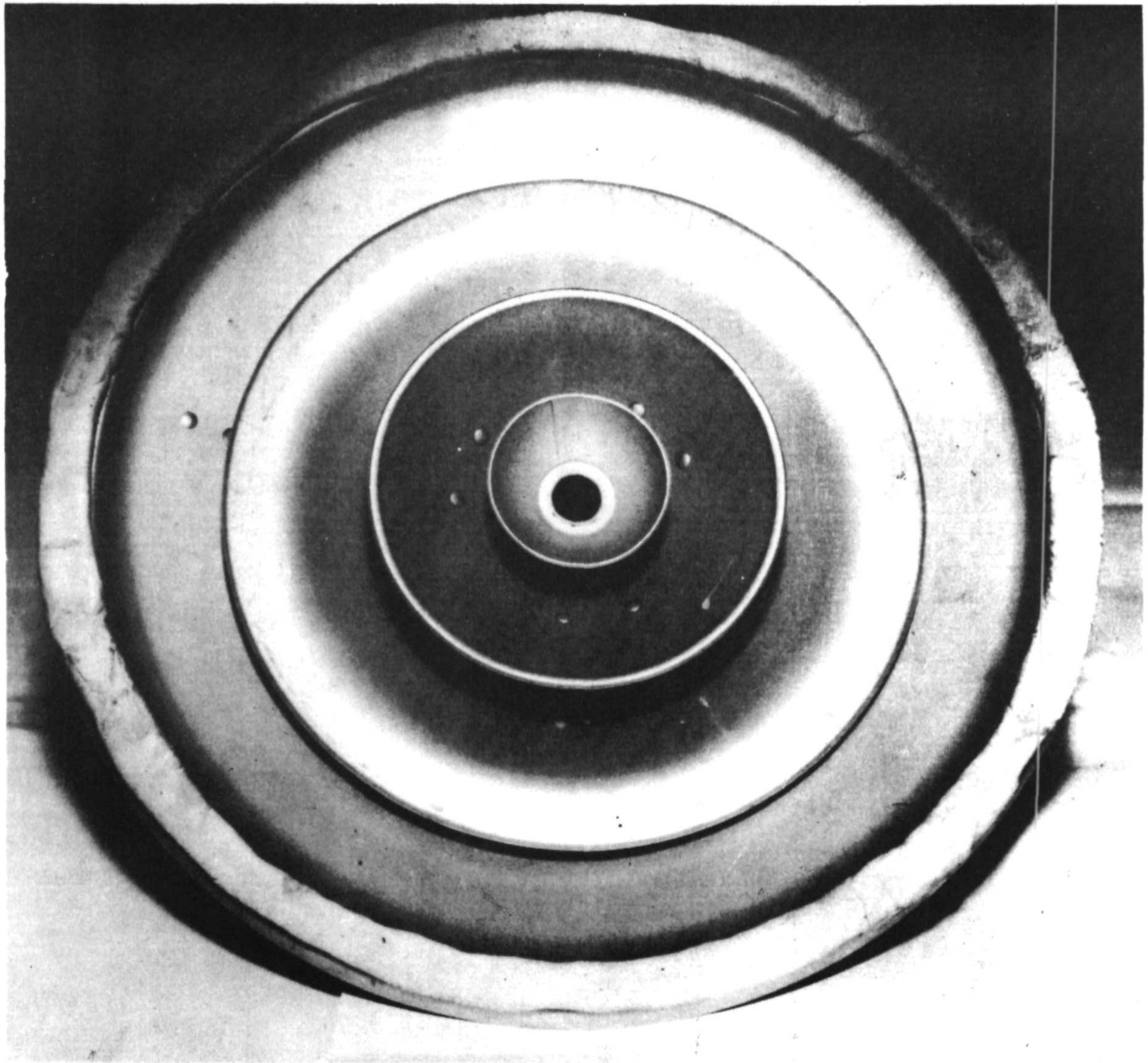

FIGURE 43. ANEMOSTAT 6" C-2 IN-HOUSE MODIFIED DIFFUSER NO. 4

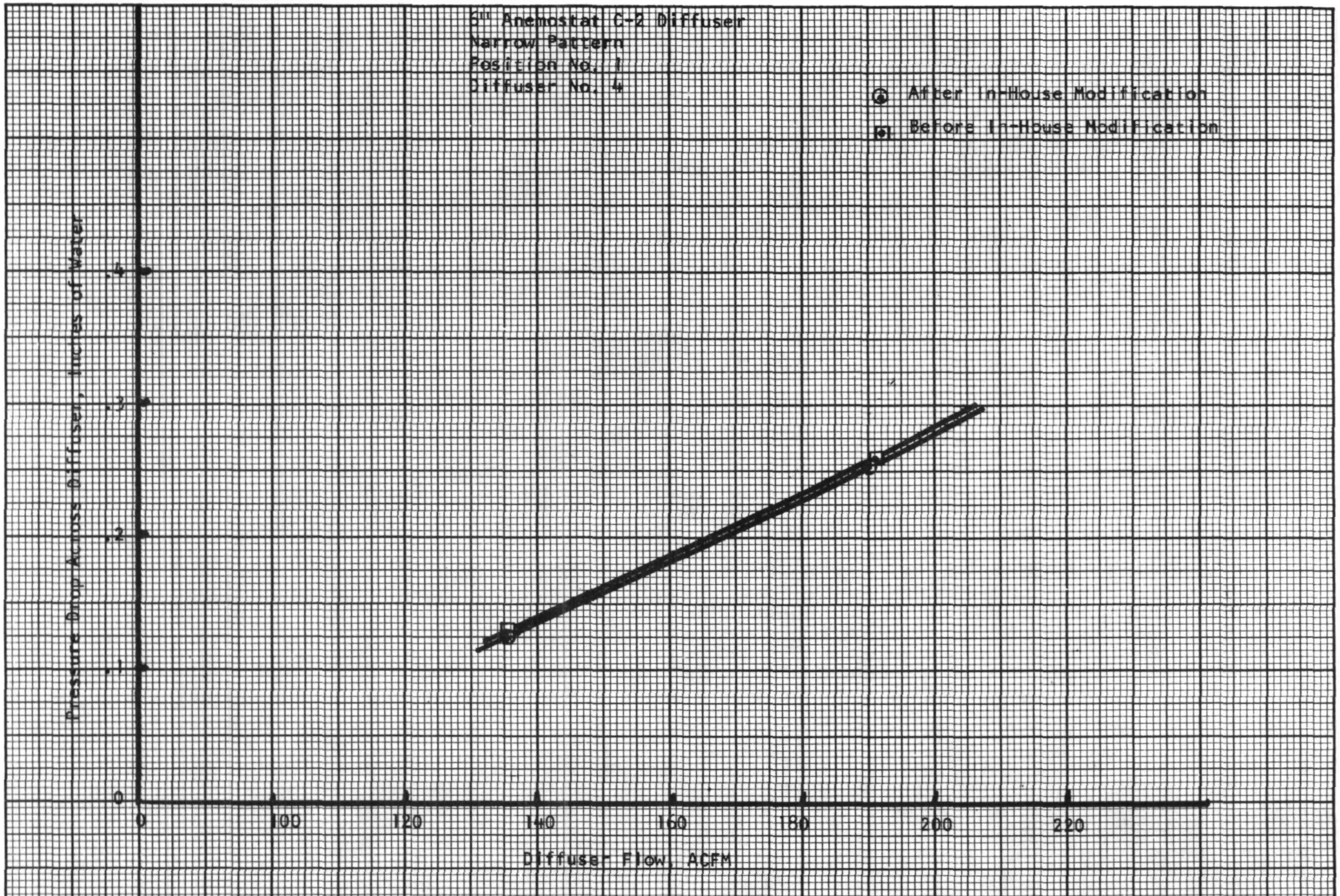

FIGURE 44. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

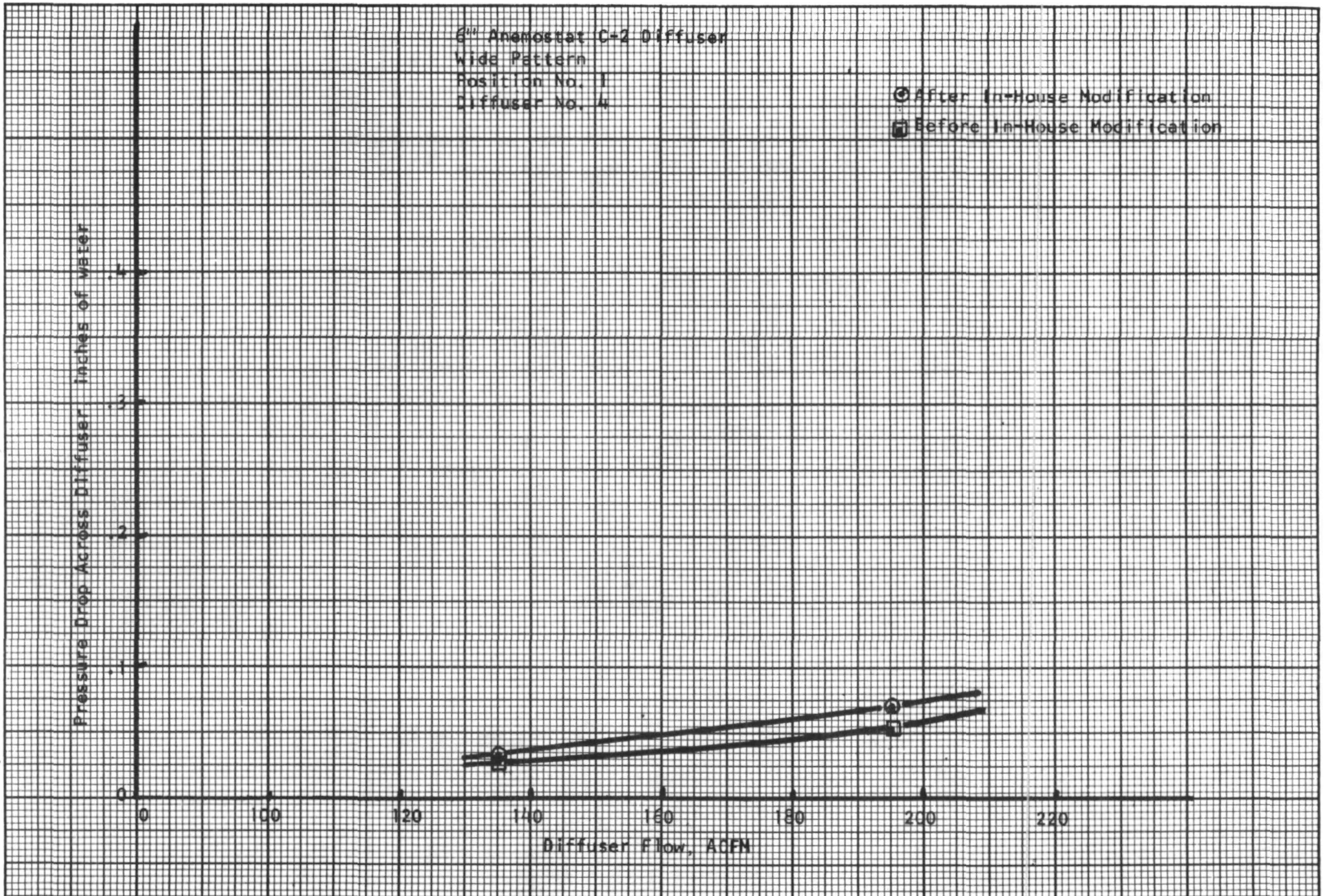

FIGURE 45. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

APPENDIX C

RESULTS OF THE ORBITAL WORKSHOP 6-INCH ANEMOSTAT MODIFIED DIFFUSER TESTS

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FILE 3.12.60

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

Memorandum

TO : Chief, Fluid Mechanics Section
S&E-ASTN-PFE PFA

DATE: Oct. 6, 1969
In reply refer to:
S&E-ASTN-TF-45-69

FROM : Chief, Environmental Test Section
S&E-ASTN-TFE

GDP
WLG

SUBJECT: Results of the Orbital Workshop 6" Anemostat Modified Diffuser Tests

Reference: Test Request Memorandum R-P&VE-PT-60-M-42-F

1. Introduction

Previous tests verified that the 6" Anemostat diffuser performance in a 5-p.s.i.a. environment correlates with the performance in a 14.7-p.s.i.a. environment (reference test report S&E-ASTN-TF-29-69). However, during these tests an unstable flow pattern was experienced with the standard 6" diffuser. Therefore, a modified diffuser was provided by the manufacturer to correct this problem. S&E-ASTN-TFE conducted the tests of this report to determine the correlation of performance between the standard and modified 6" Anemostat C-2 diffuser and to determine the effect, if any, of mounting the diffusers in a plenum - a configuration simulating the workshop mockup test setup.

2. Test Hardware and Setup

For these tests, S&E-ASTN-P furnished 5 Anemostat 6" modified C-2 circular diffusers (see Figure 1) and a 6" standard C-2 diffuser. Each diffuser was installed in a 6-foot cube plenum (see Figure 2) in the west-end of the Redstone Vacuum Drying Chamber (see Figure 3).

A duct and fan system was connected in the plenum so that a flow path would be established which would not disturb the diffuser outlet pattern (Figure 4). A Joy Manufacturing Company fan in the duct provided flow up to 200 ACFM through each diffuser. The diffuser flow patterns were recorded by motion picture cameras using yellow smoke as a tracer gas and a grid network as a dimensional reference. The smoke was generated by a smoke candle (Figure 5) ignited remotely by a Nichrome wire coil (Figures 6 and 7). The candle generated yellow smoke for a minimum of 30 seconds, and the smoke was pulled directly into the suction-end of the duct by the fan.

The grid network was constructed of white electrical wire held in place by the tension of rubber bands on each end of each wire (Figure 8). The grid was installed on a horizontal plane coinciding with the longitudinal centerline of the diffusers. Therefore, even with the distortion of the fish-eye camera, accurate measurements could be taken from the film.

3. Instrumentation

Instrumentation for the test program consisted of a Dwyer inclined manometer, a Cox gas flowmeter, three copper constantan thermocouples, one C.E.C. pressure transducer, and one T.T. smoke gun as shown in Figures 9, 10, and 11. Two movie cameras were used to record the smoke patterns. One 140° lens camera and one semi-fish-eye 160° lens camera, with a frame speed of 64 frames-per-second, were used at locations shown in Figure 4. Timing blips of 60 cycles-per-second were incorporated on all film.

4. Test Discussion and Results

A test was conducted to determine the effects on the differential pressure of a plenum-mounted standard diffuser relative to the differential pressure of a duct-mounted standard diffuser. The graphs of Figures 12 and 13 show a significant increase in differential pressure for the plenum-mounted standard diffuser, especially in the horizontal pattern. To further investigate the affects of the mounting configuration, a 2' straight section of pipe was added to the diffuser (Figure 14) and differential pressure profiles were plotted (Figures 15 and 16). Again, a significant increase in the pressure drop across the diffuser was observed. Then, a bell-shaped inlet was added to the 2' straight pipe inlet (Figure 17). This lowered the pressure drop across the diffuser significantly (Figures 18 and 19). With this set-up, the pressure drop across the diffuser agreed closely to that quoted by the manufacturer for the wide and projection patterns.

During the aforementioned test it was found that regardless of the pattern configuration in which the standard diffuser was set (horizontal or projection), a horizontal pattern always occurred. The standard diffuser was removed from the plenum and a modified diffuser was installed. Again, no projection pattern could be obtained. Subsequently, an "in-house" modified diffuser (see report S&E-ASTN-TF-29-69) was installed. With this diffuser installed in the plenum a semi-projection pattern was obtained. A second in-house modified diffuser (see Figure 20) was tested with the result that only a horizontal pattern could be achieved.

During the conduct of these tests, a conversation was held with the diffuser manufacturer in which he stated that the type flow out of the diffuser (projection or horizontal) was dependent upon the mounting method (flush-to-ceiling mount or exposed-duct mount) and whether the diffuser was being used for a heating or cooling application. The following is the basics of the conversation:

a. In a flush-to-ceiling mount, with the third cone flush with the outside cone, a horizontal pattern is expected in heating applications. However, in cooling applications, a projection pattern is possible.

b. In an exposed-duct mount, a horizontal pattern can be obtained by setting the third cone in the lowest position, next to the inside cone. For a projection pattern the third cone is raised to its highest position, against the outer cone.

From this conversation an explanation for the "flip-flop" flow (see report S&E-ASTN-TF-29-69) phenomenon can be deduced. In previous tests the diffuser was mounted in a flush-to-ceiling application. Therefore, with the third cone flush with the outside cone, a projection or horizontal pattern could be obtained, depending upon the temperature of the gas flowing through the diffuser.

Because of the problem encountered in getting a projection pattern with the diffuser mounted flush on the plenum, a study was undertaken to determine how far off the plenum the diffusers would have to be mounted to simulate an exposed-duct mounting. Utilizing a 1/16" spacer behind the modified diffuser, and a 2-foot straight pipe inlet on the diffuser (see Figure 21), a projection pattern was observed. Attempts to flip this narrow pattern to a wide pattern were unsuccessful.

With the section of straight pipe removed from the inlet of the diffuser, a spacer of approximately $1\frac{1}{2}$ inches was required to yield a projection pattern. Therefore, it was found that the diffuser pattern is not only influenced by the position of the third cone, but it is also influenced by the mounting configuration of the diffuser and the inlet configuration of the diffuser.

There was no significant difference in performance between the standard Anemostat C-2 diffuser and the modified Anemostat C-2 diffuser.

In a plenum-mount set-up, five modified diffusers were checked for pressure drop. The results, plotted in Figures 22 and 23, show no significant difference in the differential pressure profile of one diffuser relative to another.

As stated in an earlier report a stable projection pattern can be established and maintained (even with the diffuser mounted in the plenum) by removing the center body of the diffuser. A pressure profile of pressure drop across the diffuser in this configuration is shown in Figure 24.

Data from the nineteen tests were transmitted to S&E-ASTN-PT with copies of all film data. The test data also are enclosed in Table I of this report. The nineteen tests complete the evaluation of the circular diffusers.

5. Summary

Any future testing on diffusers should be performed with the diffuser mounted in a configuration to simulate its expected application.

A projection and horizontal pattern was obtained with the Anemostat 6" modified diffuser mounted on a plenum with a 1/16" spacer between the diffuser and plenum surface, and a straight 2' pipe section used on the diffuser inlet. A bell-shaped inlet should be used to keep the pressure drop across the diffuser as low as possible.

The pressure drop across the diffuser set for a wide pattern is more than doubled when the diffuser is mounted in a plenum relative to the pressure drop when the diffuser is mounted on a duct.

The pressure drop across the diffuser set for a projection pattern is essentially constant regardless of the mounting configuration.

For either pattern setting, with the diffuser mounted in the plenum, the pressure drop across the diffuser was close to that quoted by the manufacturer.

It has been found that the diffuser pattern is not only influenced by the position of the third cone, but it is also influenced by the mounting configuration of the diffuser and the inlet configuration of the diffuser.

There was no significant difference in performance between the standard Anemostat C-2 diffuser and the modified Anemostat C-2 diffuser.

The lowest pressure drop for a projection pattern setting can be obtained with the center body of the diffuser removed. In this case the pressure drop across the diffuser is close to that of a horizontal pattern.

6. Any questions or comments concerning this series of tests or the enclosed data should be addressed to Mr. Robinson, S&E-ASTN-TFE, Phone 3-1704.

J. T. Ralston

J. T. Ralston

24 Enc:
a/s

cc:
S&E-ASTN-PL, Mr. Hopson
S&E-ASTN-PF, Mr. Worlund
S&E-ASTN-T, Mr. Grafton/Mr. Verschoore
S&E-ASTN-TF, Mr. Perry/Mr. Harsh
S&E-ASTN-TF, File 3.12.60.4

S&E-ASTN-TFE:GARobinson: lb 10-6-69 bAR

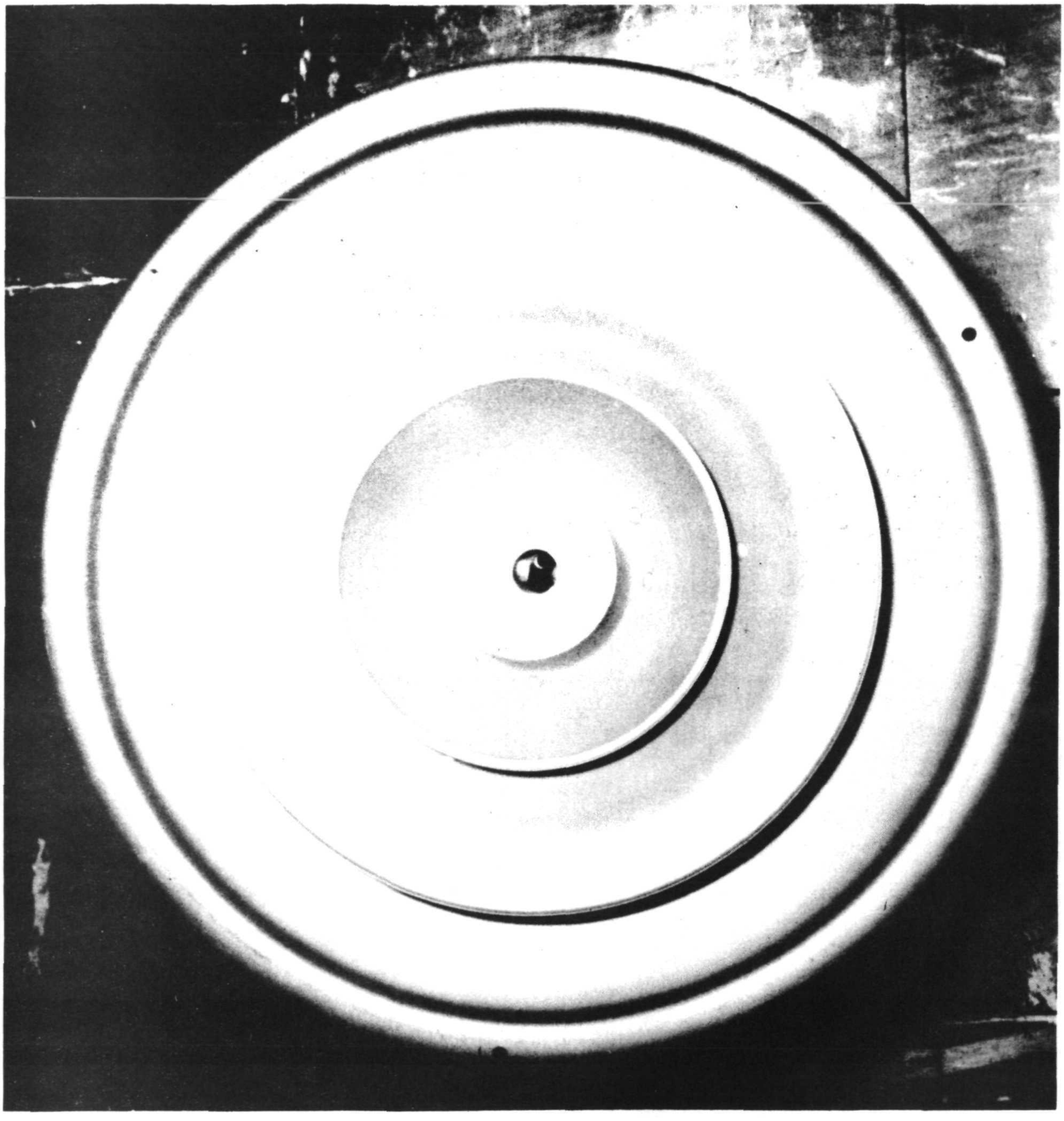


FIGURE 1. ANEMOSTAT 6" C-2 MODIFIED DIFFUSER

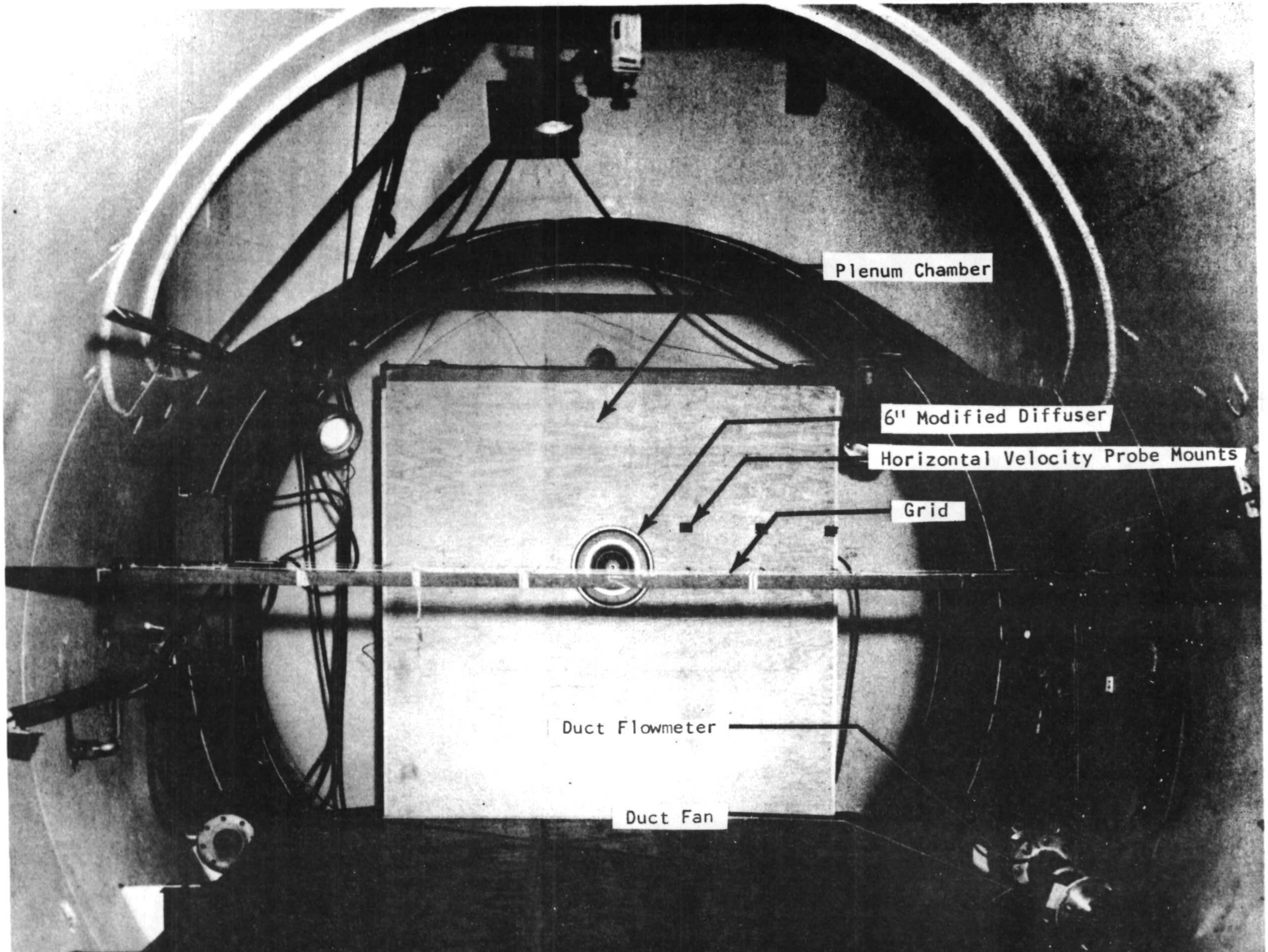


FIGURE 2. PLENUM CHAMBER TEST SETUP

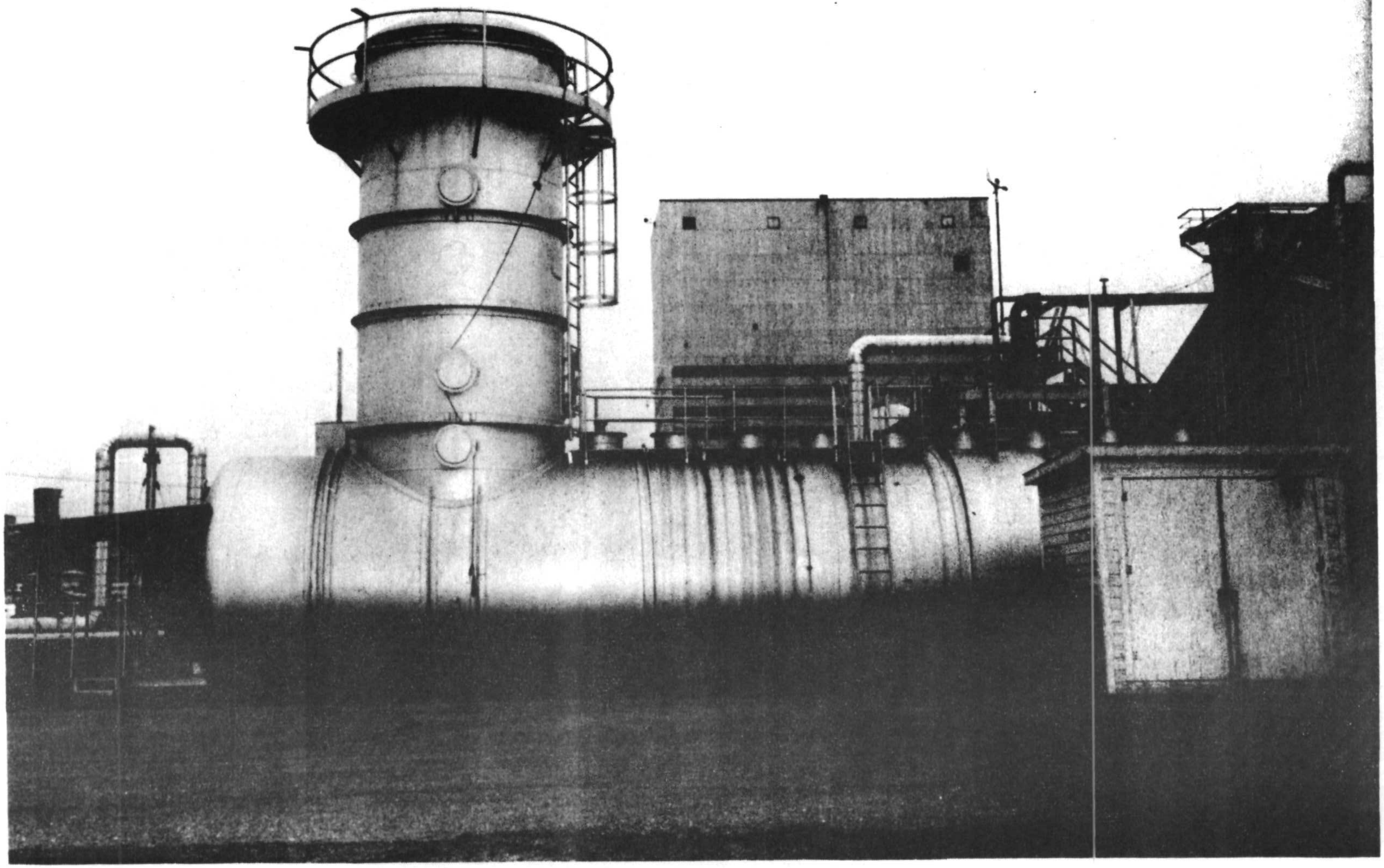


FIGURE 3. REDSTONE VACUUM CHAMBER

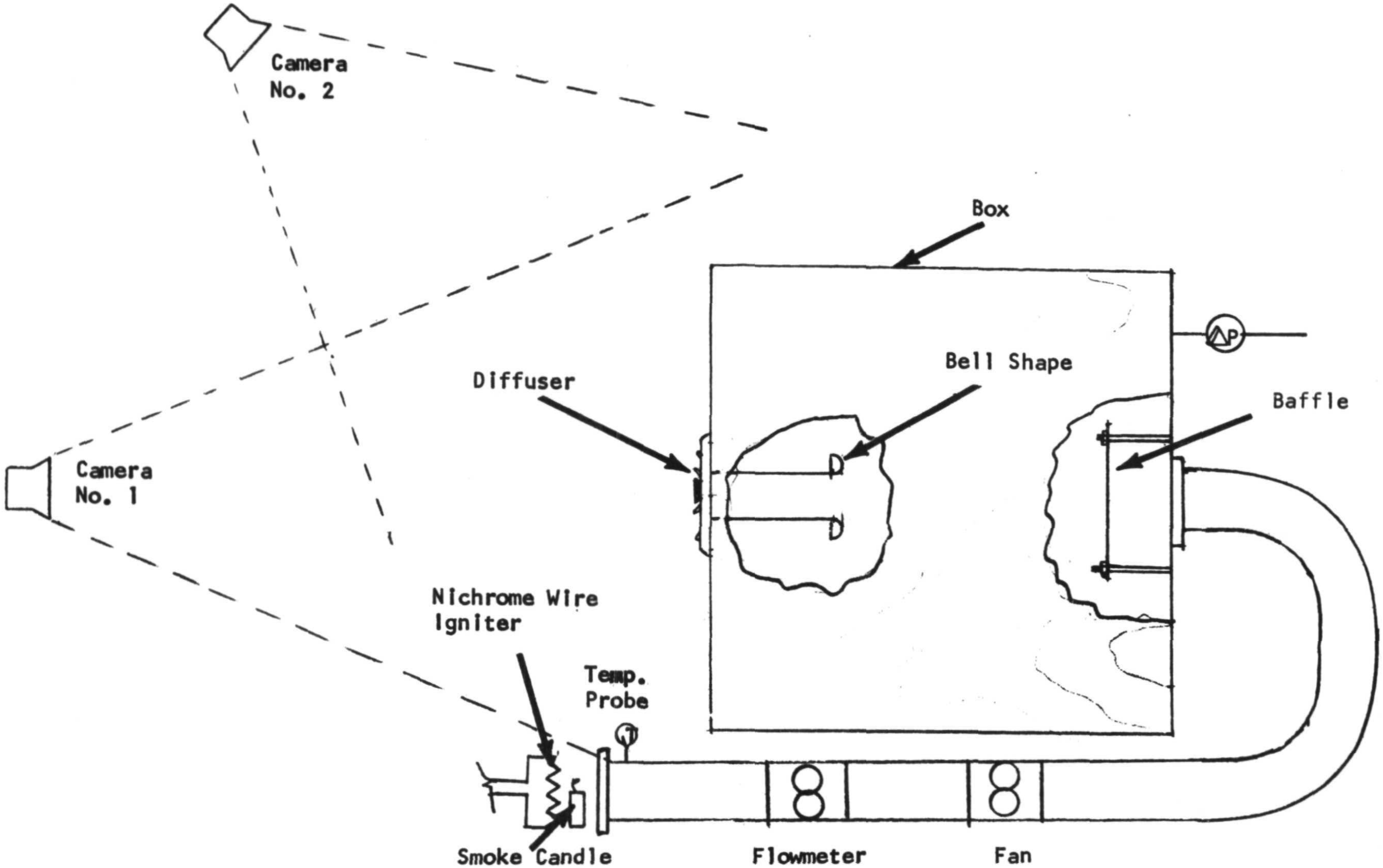


FIGURE 4. TEST SETUP

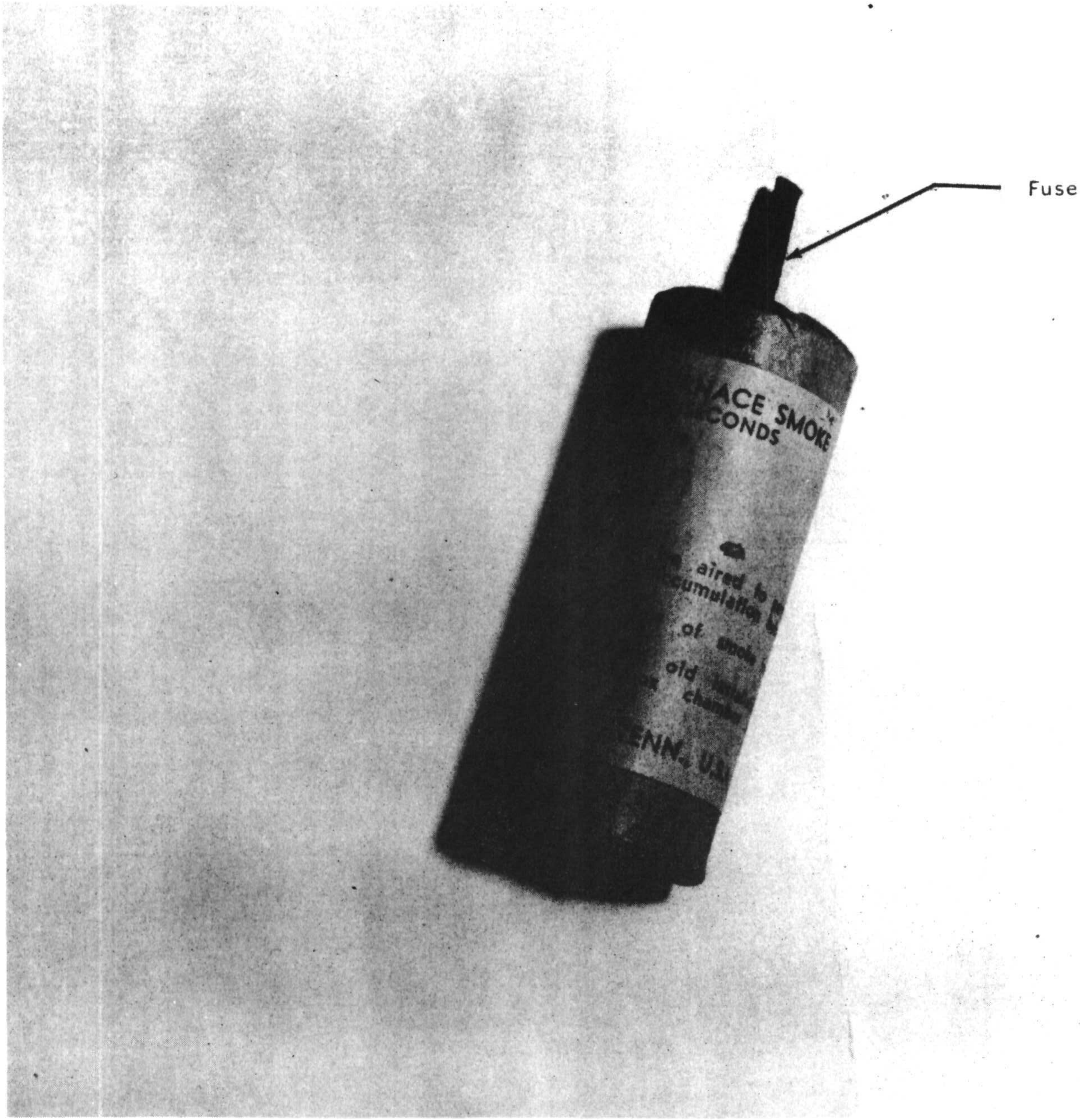


FIGURE 5. SMOKE CANDLE

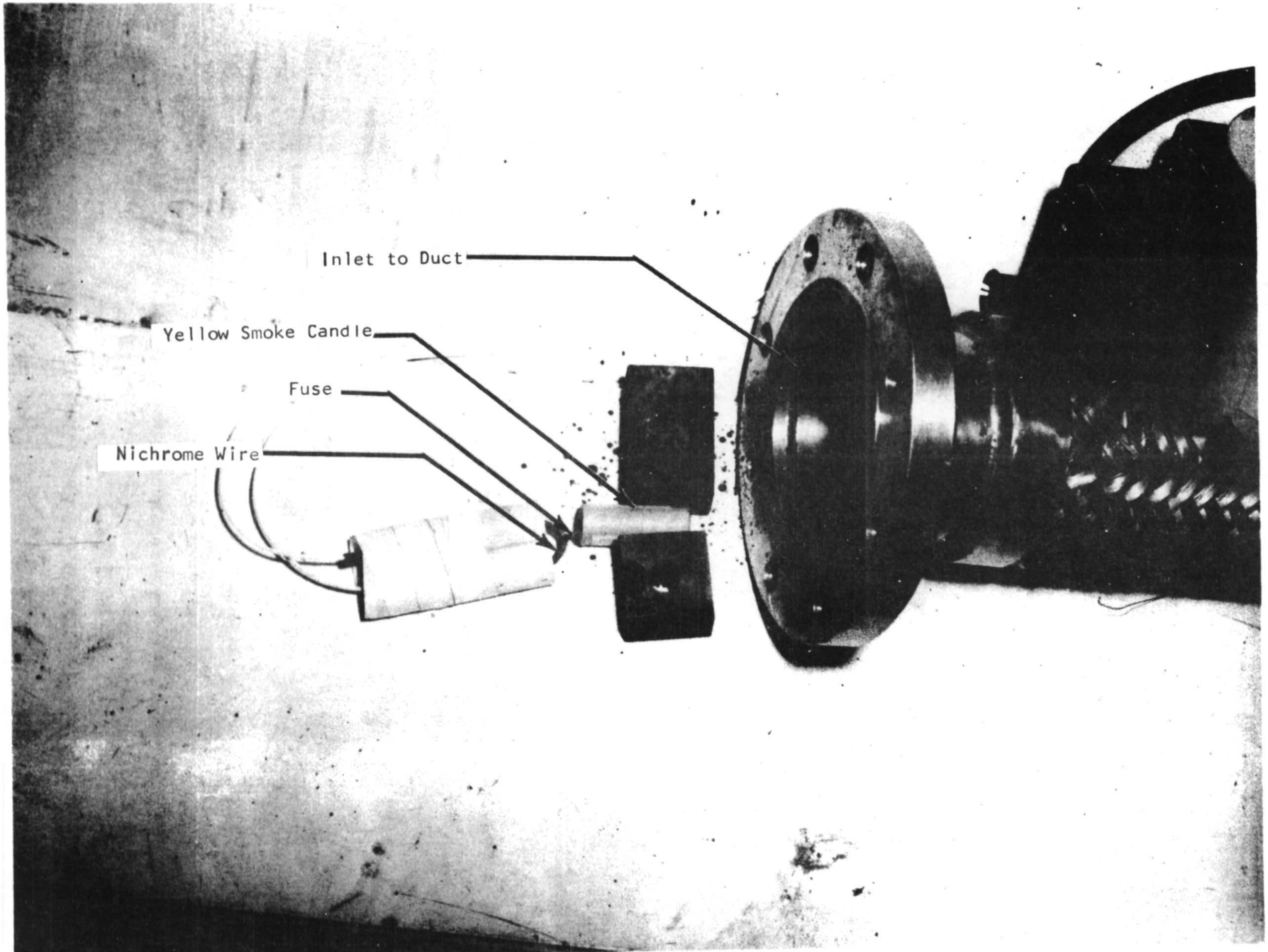


FIGURE 6. SMOKE CANDLE IGNITER

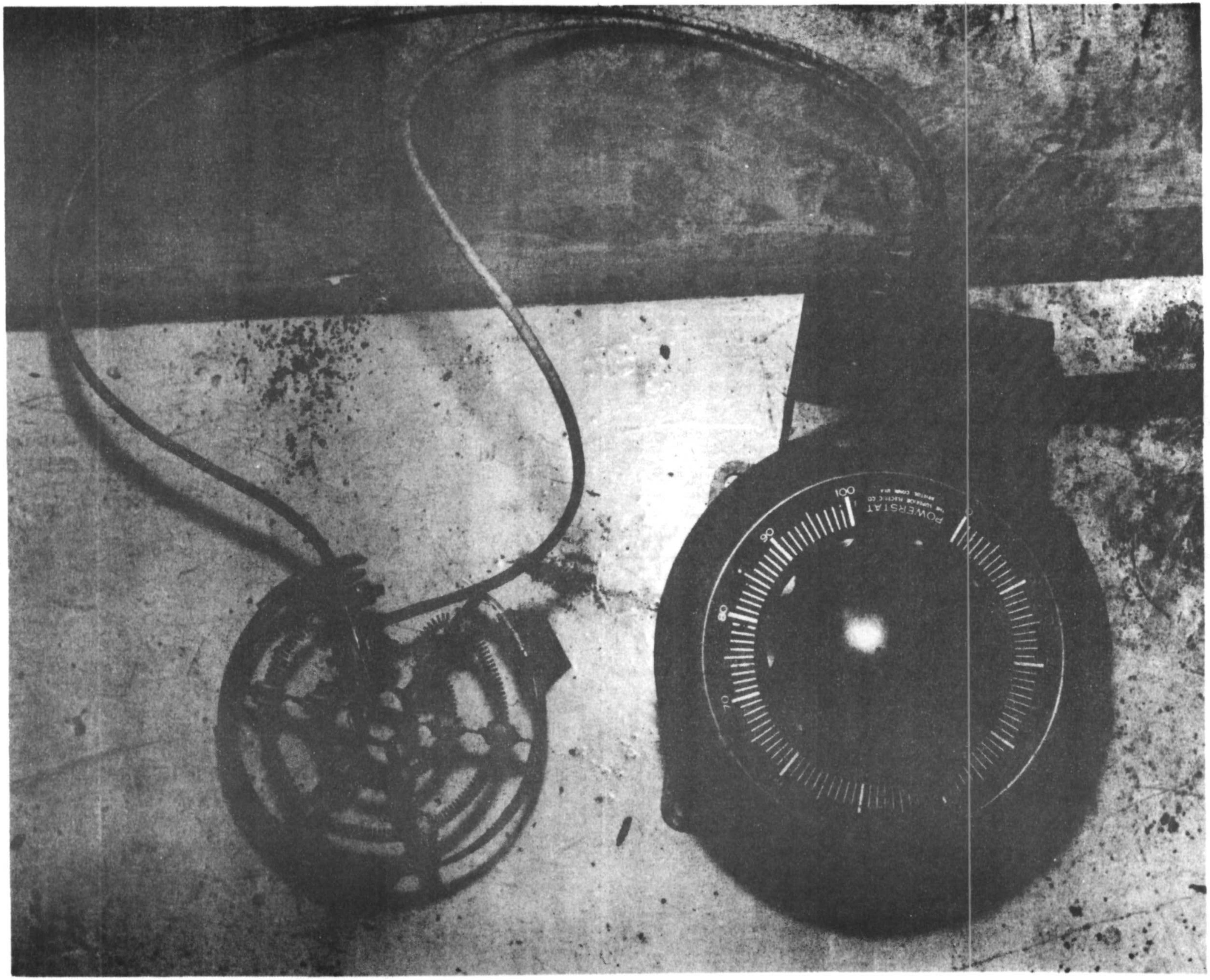


FIGURE 7. SMOKE CANDLE IGNITER

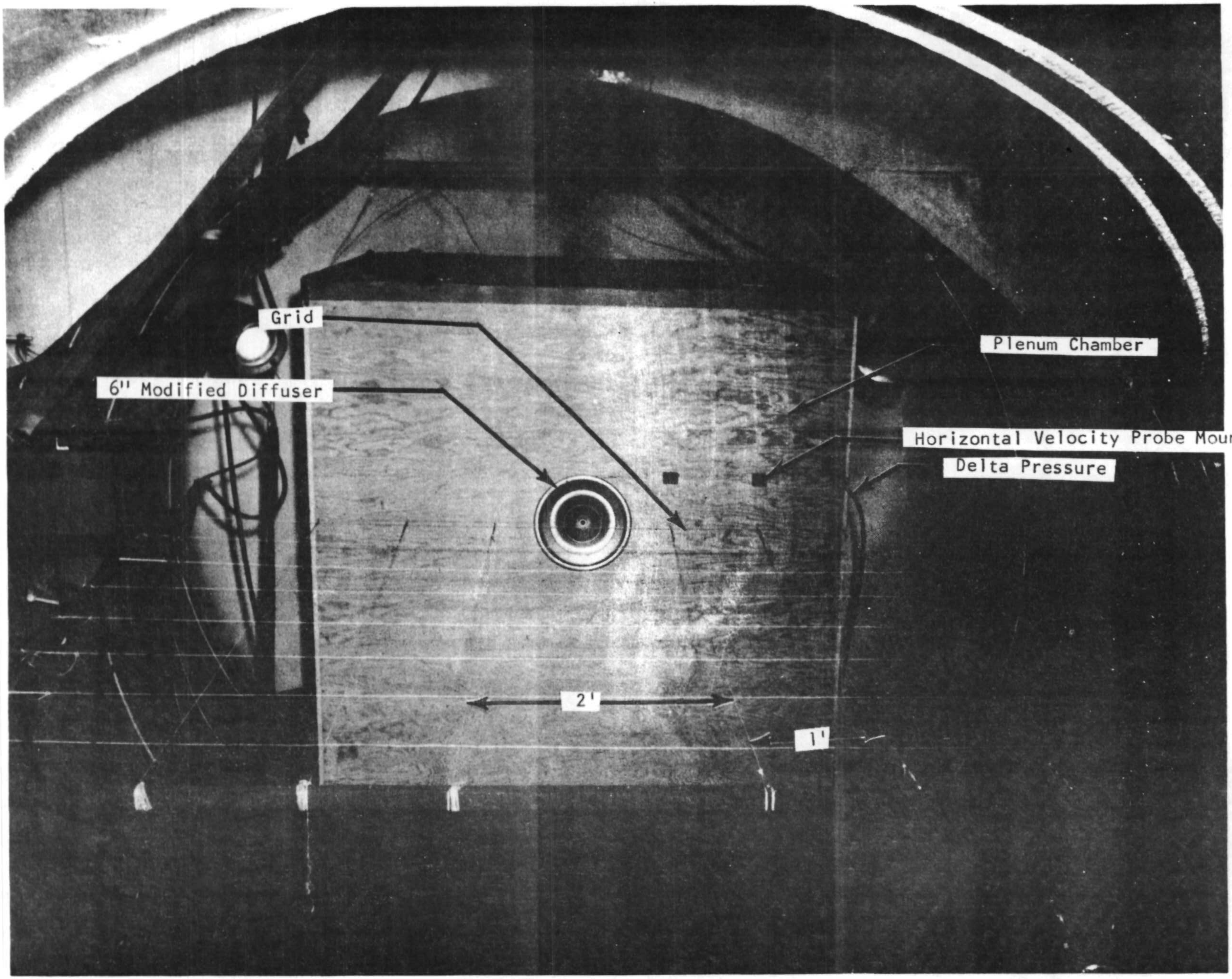


FIGURE 8. PLENUM CHAMBER TEST SETUP

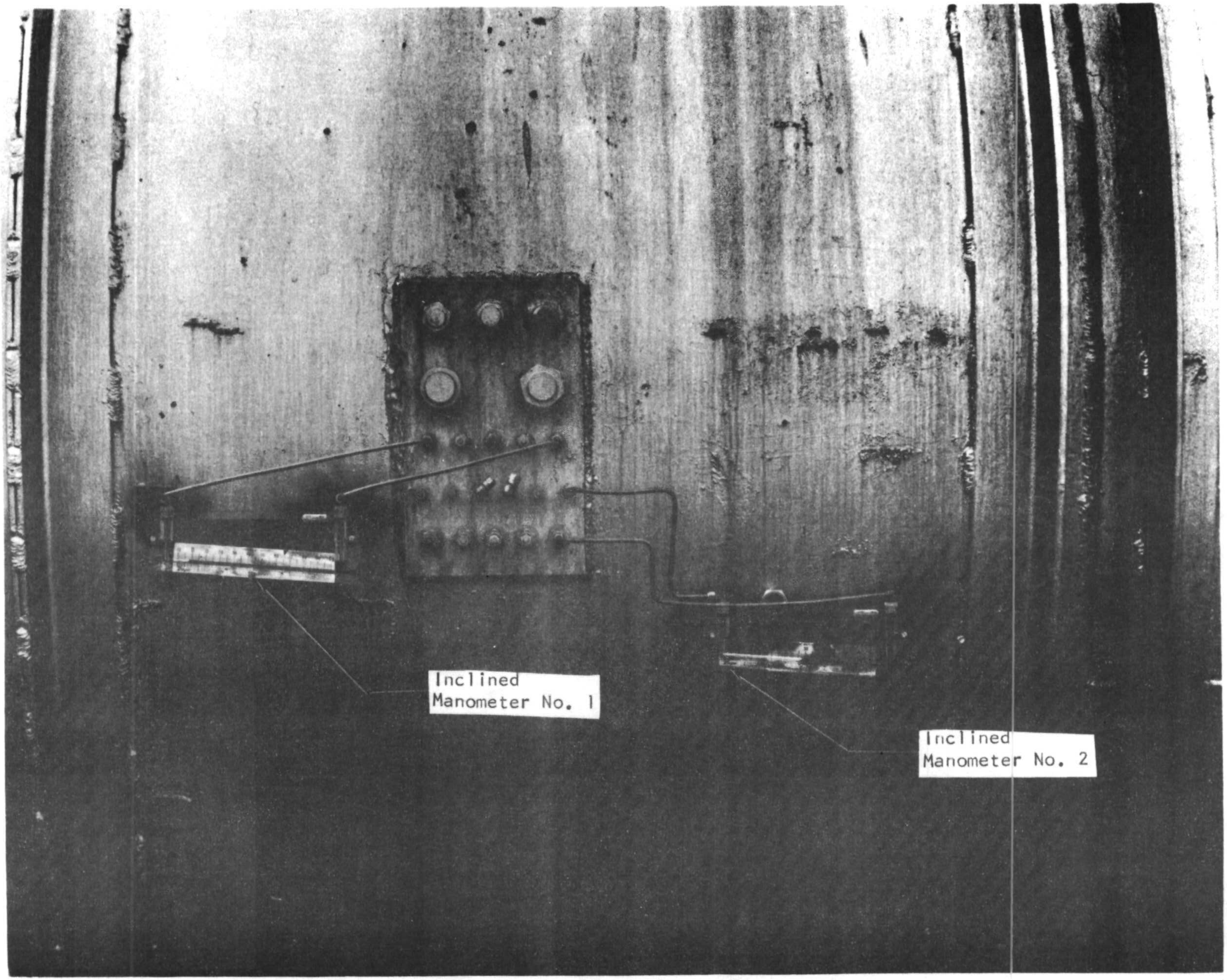


FIGURE 9. INCLINED MANOMETERS

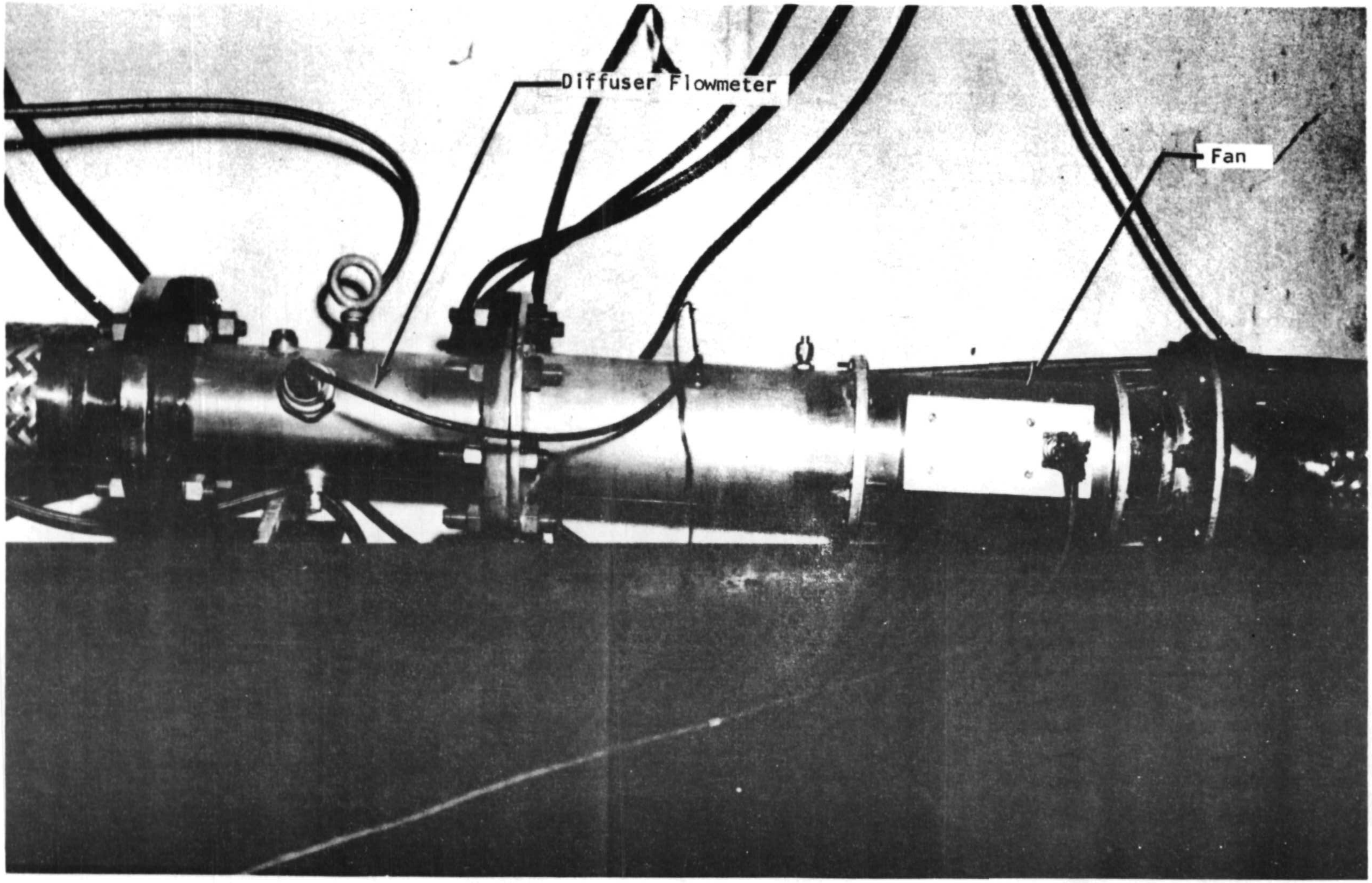


FIGURE 10. PLENUM CHAMBER FAN

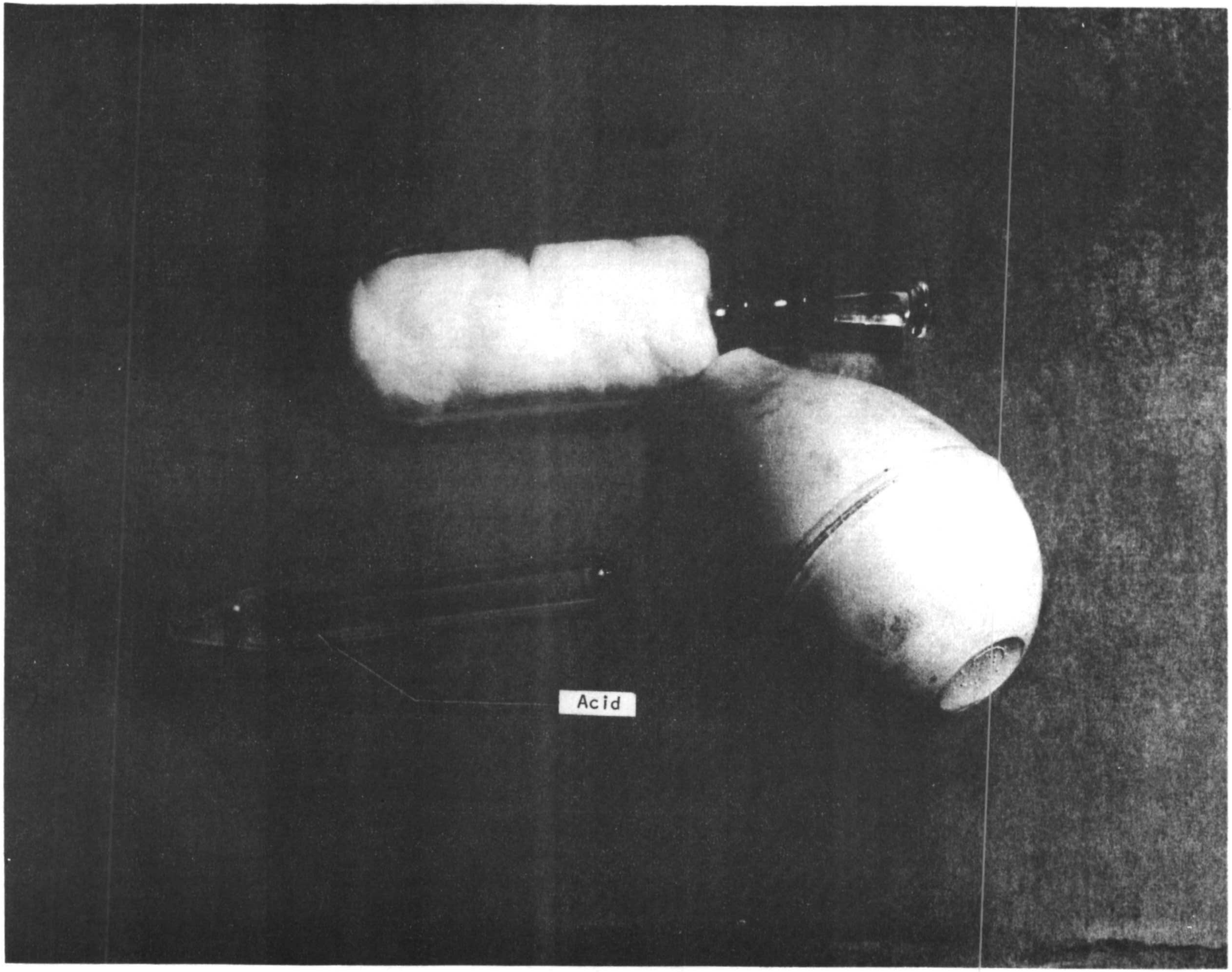


FIGURE 11. T.T. SMOKE GUN

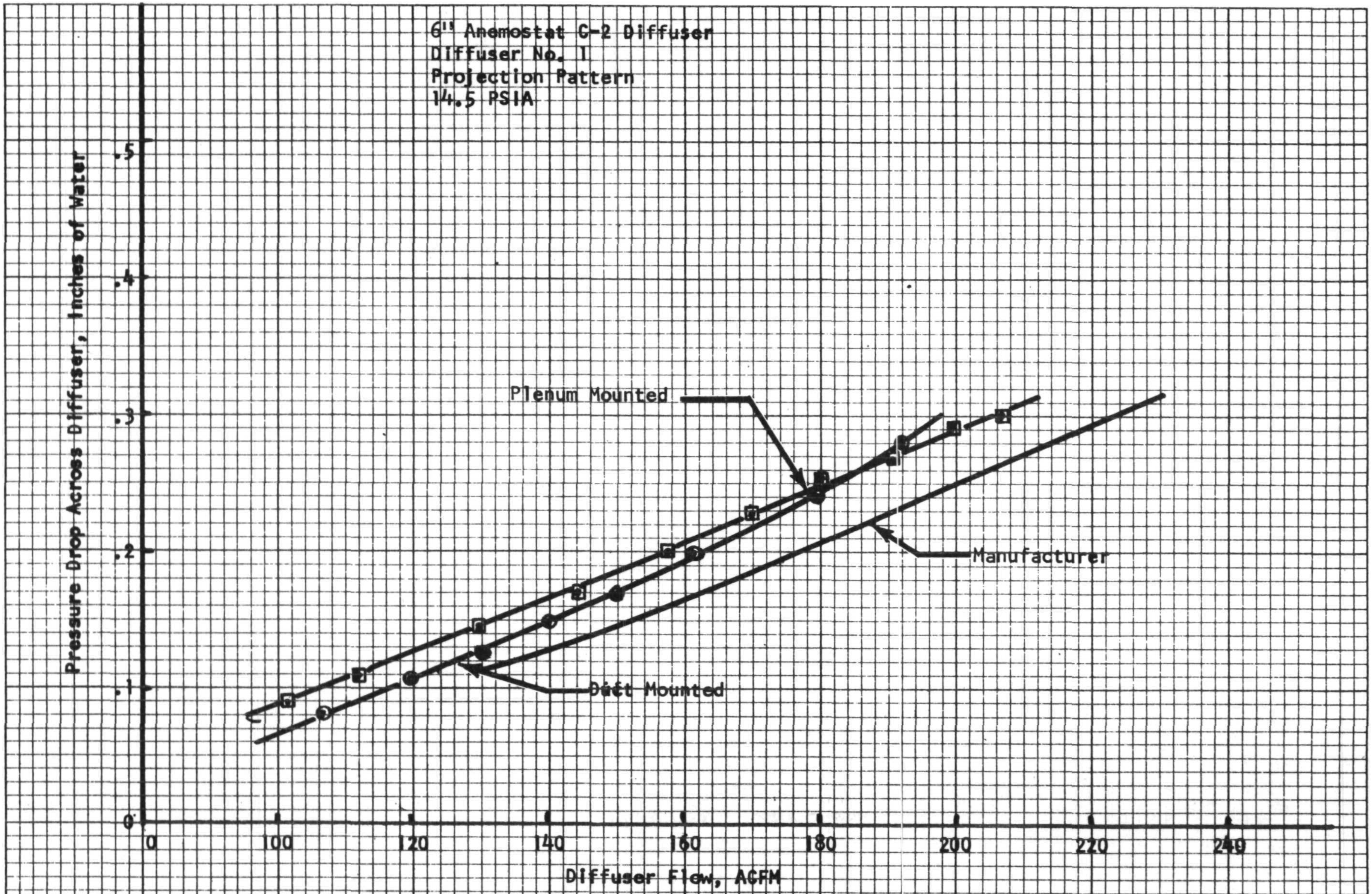


FIGURE 12. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

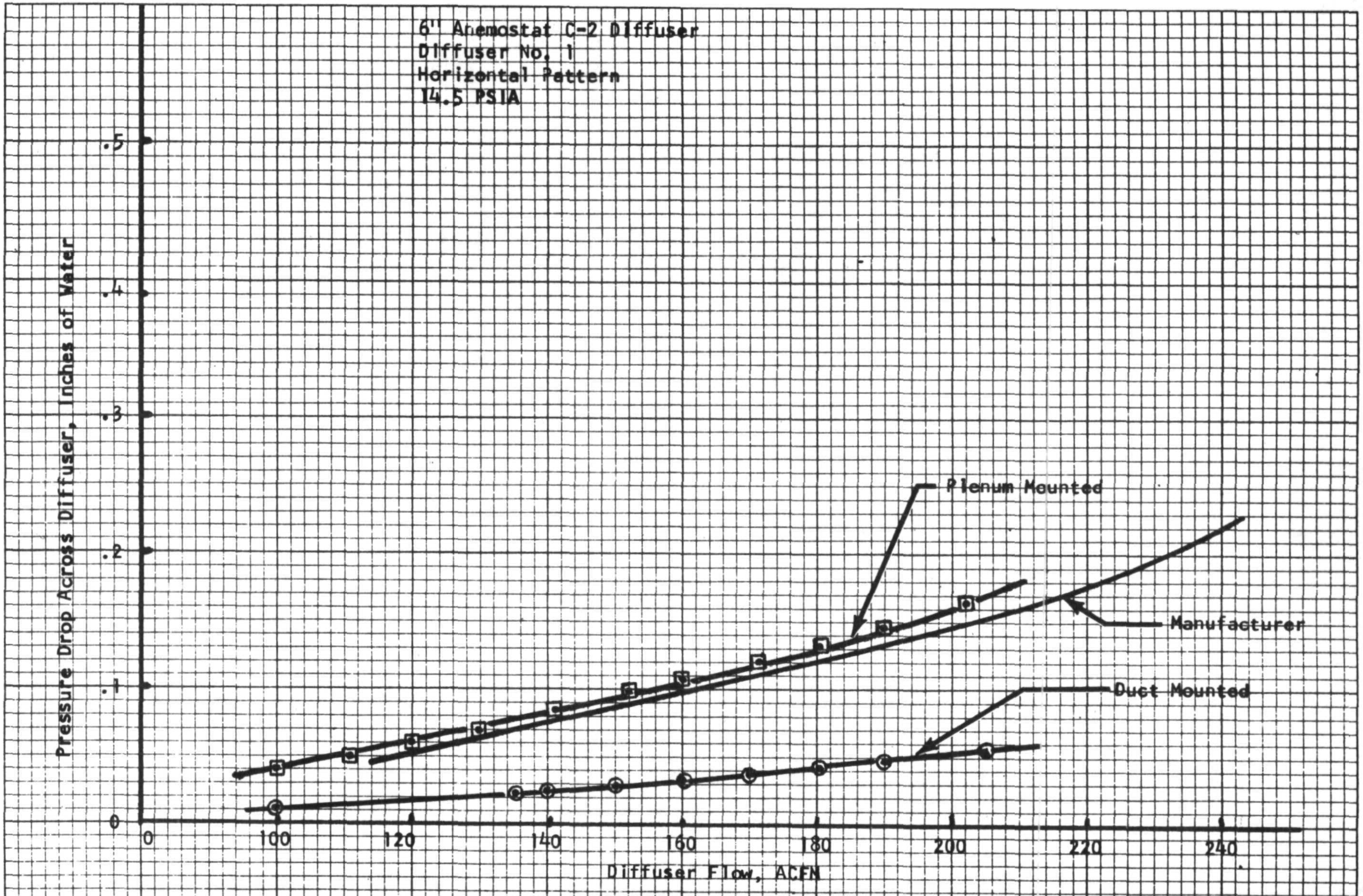


FIGURE 13. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

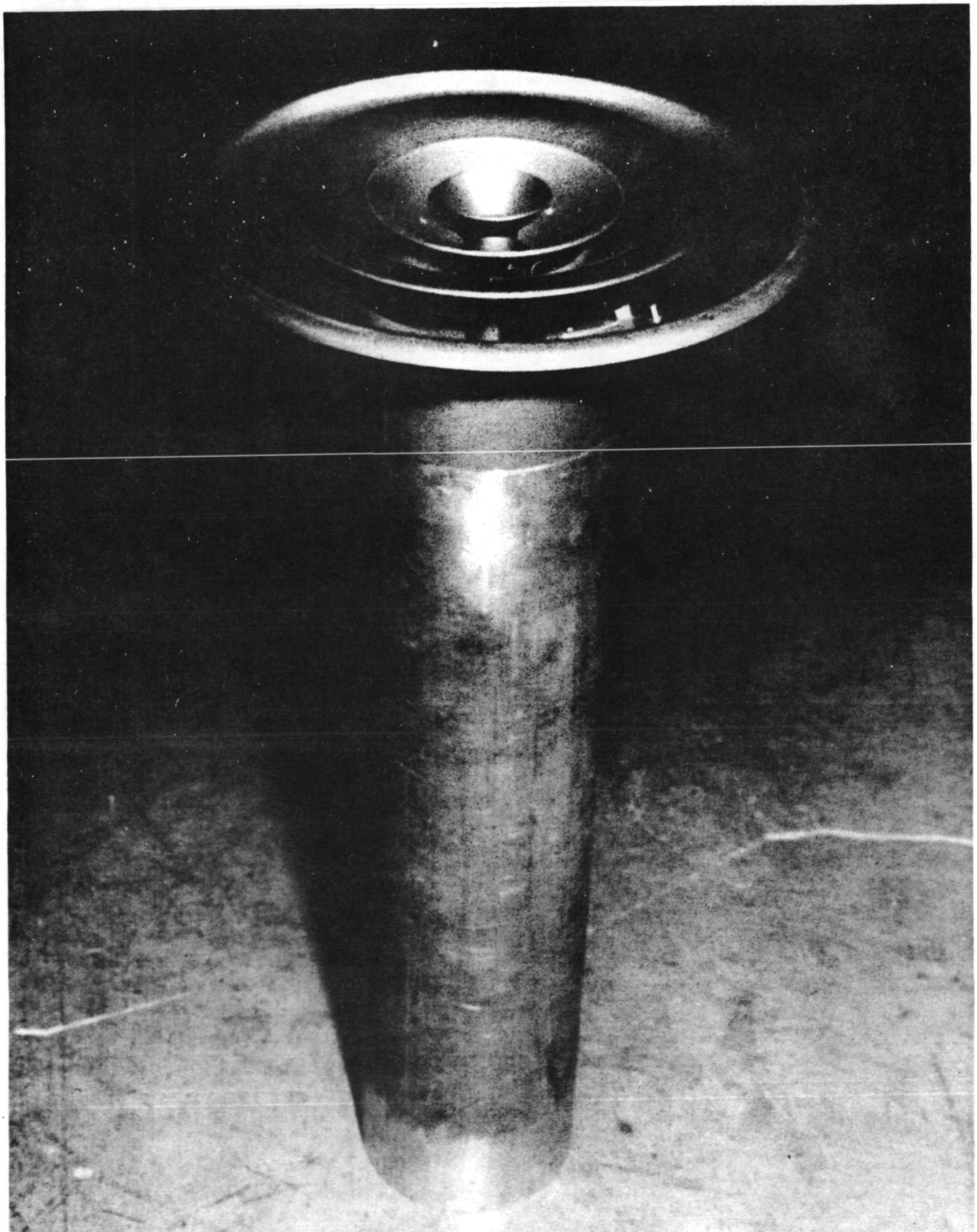


FIGURE 14. STRAIGHT PIPE INLET

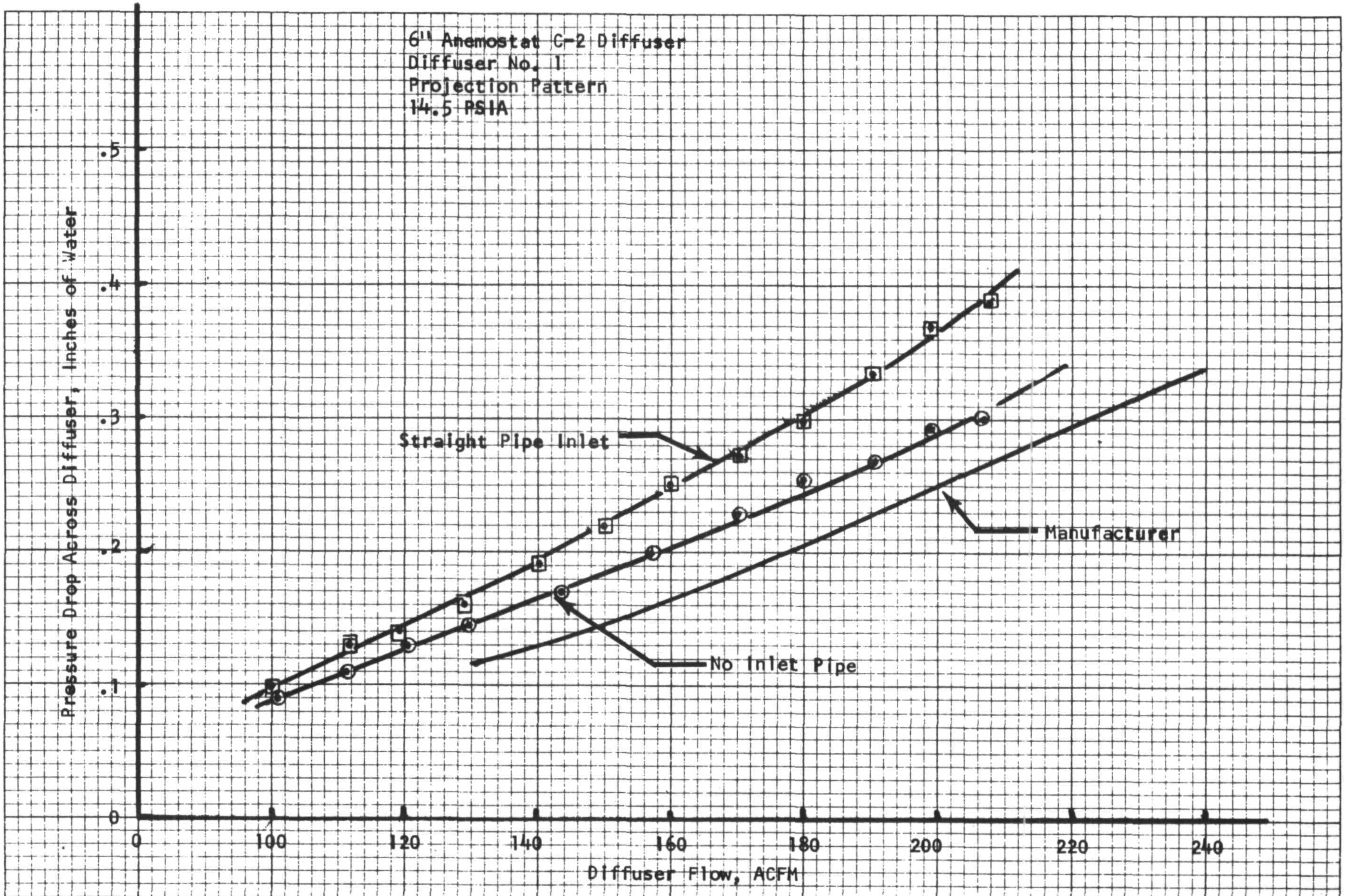


FIGURE 15. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

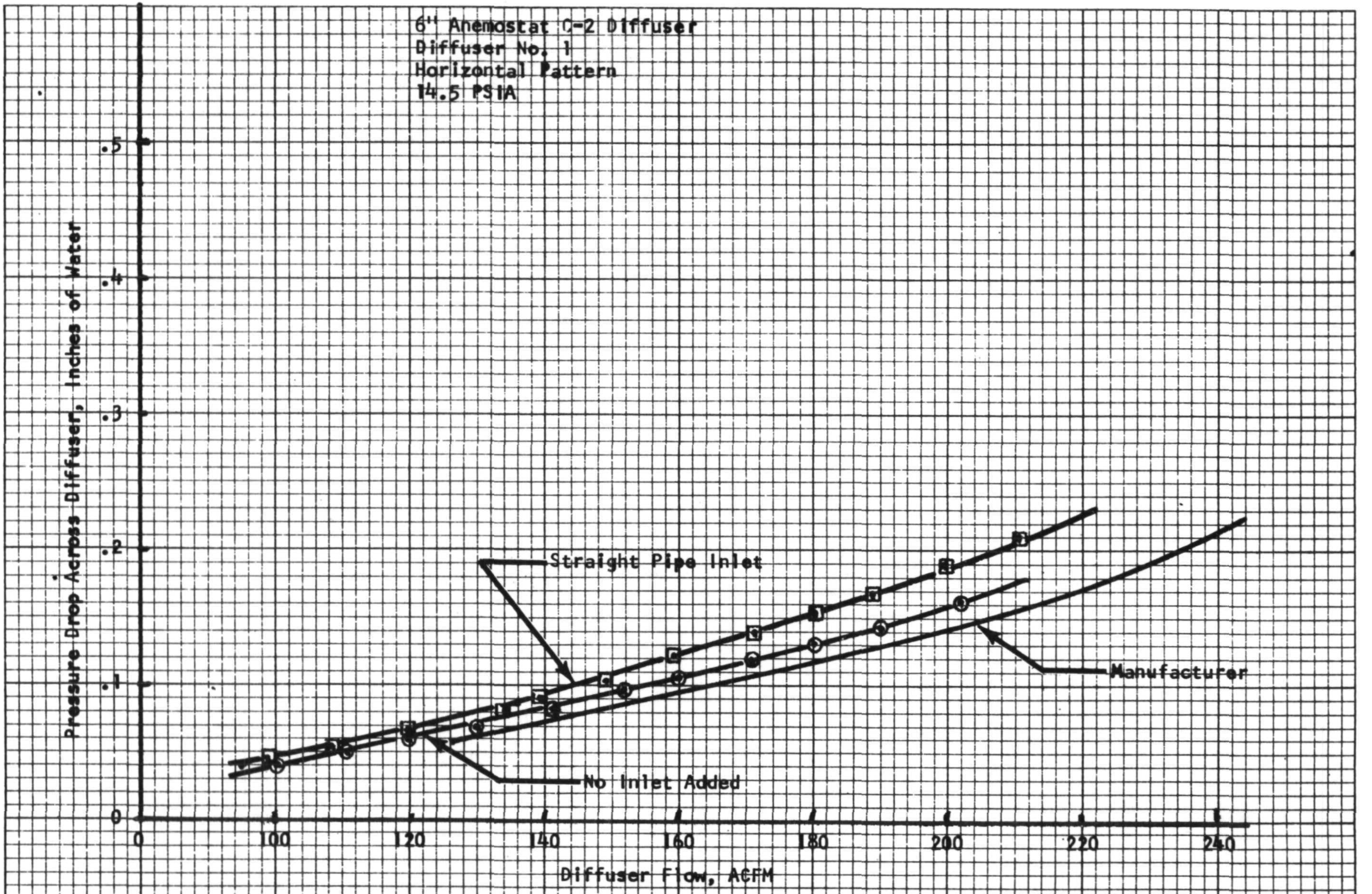


FIGURE 16. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

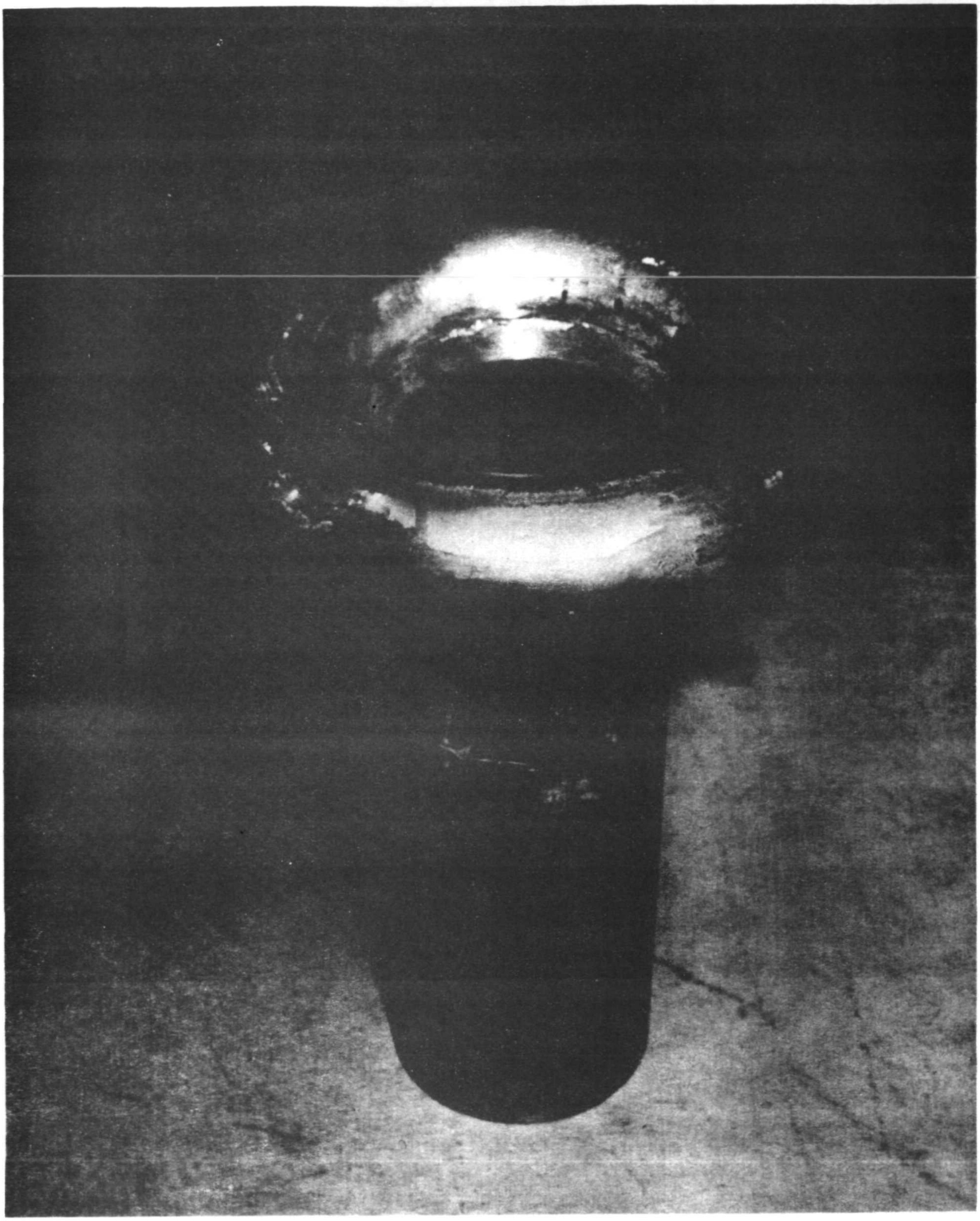


FIGURE 17. BELL-SHAPED INLET

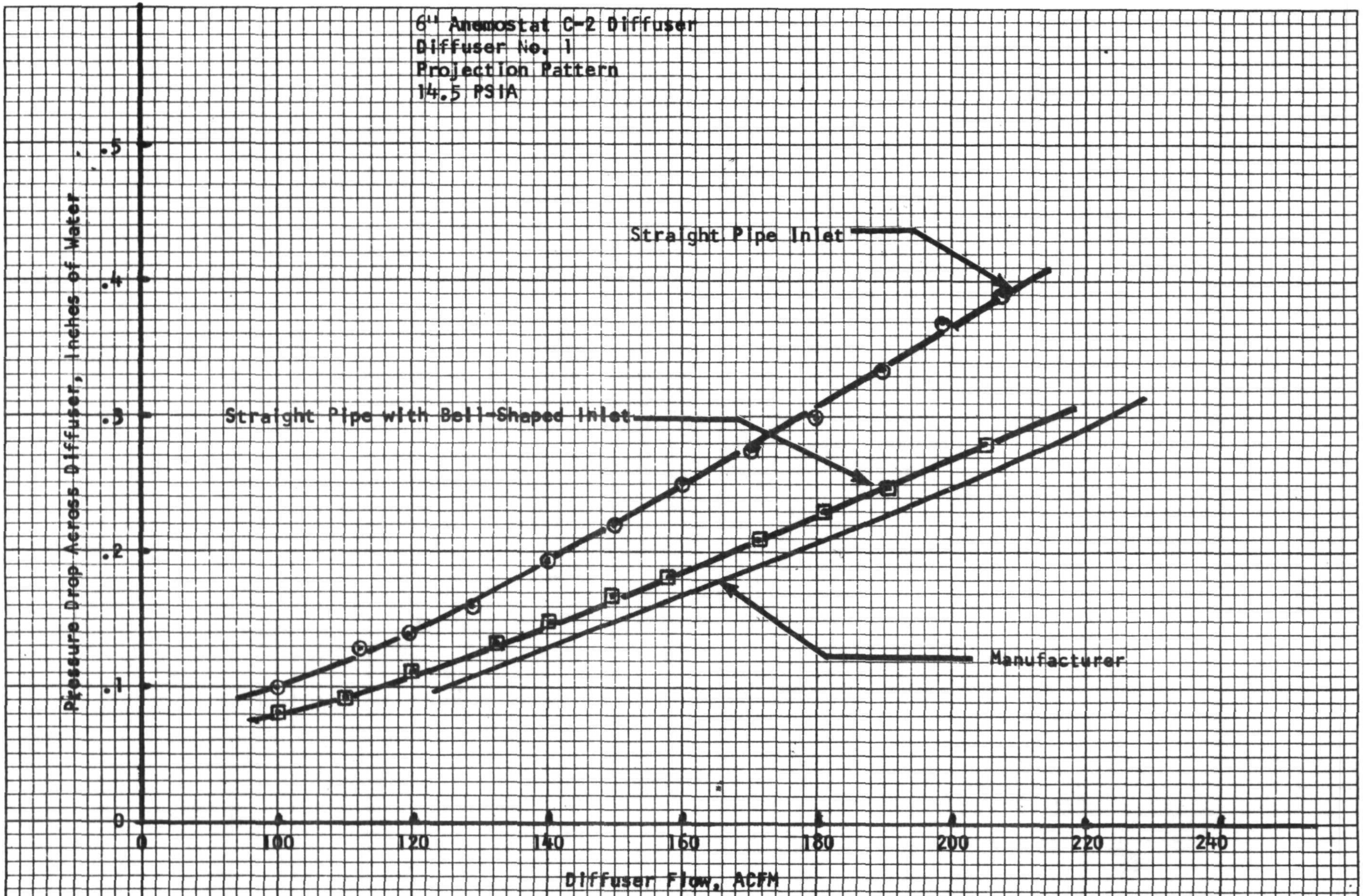


FIGURE 18. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

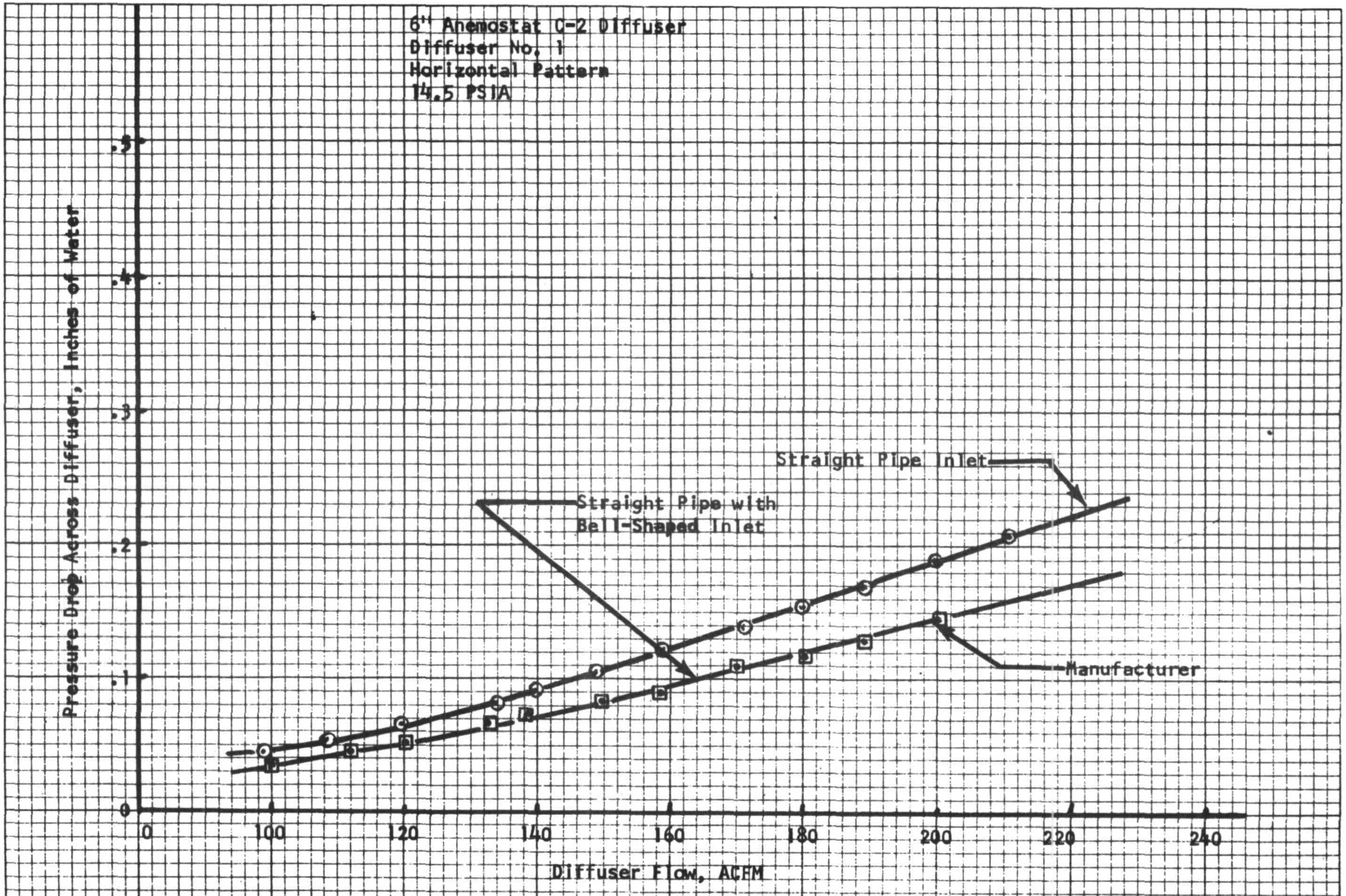


FIGURE 19. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

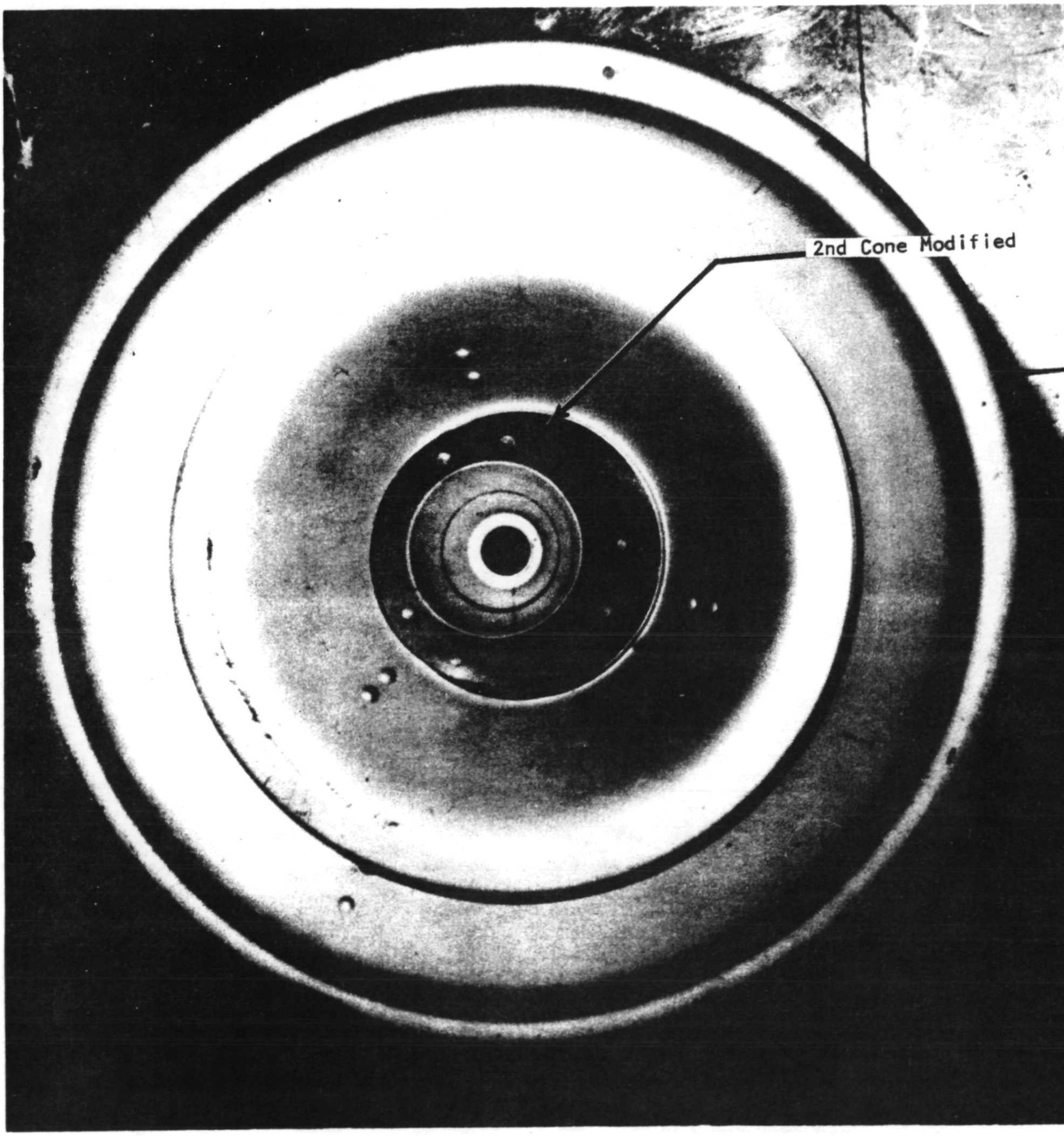
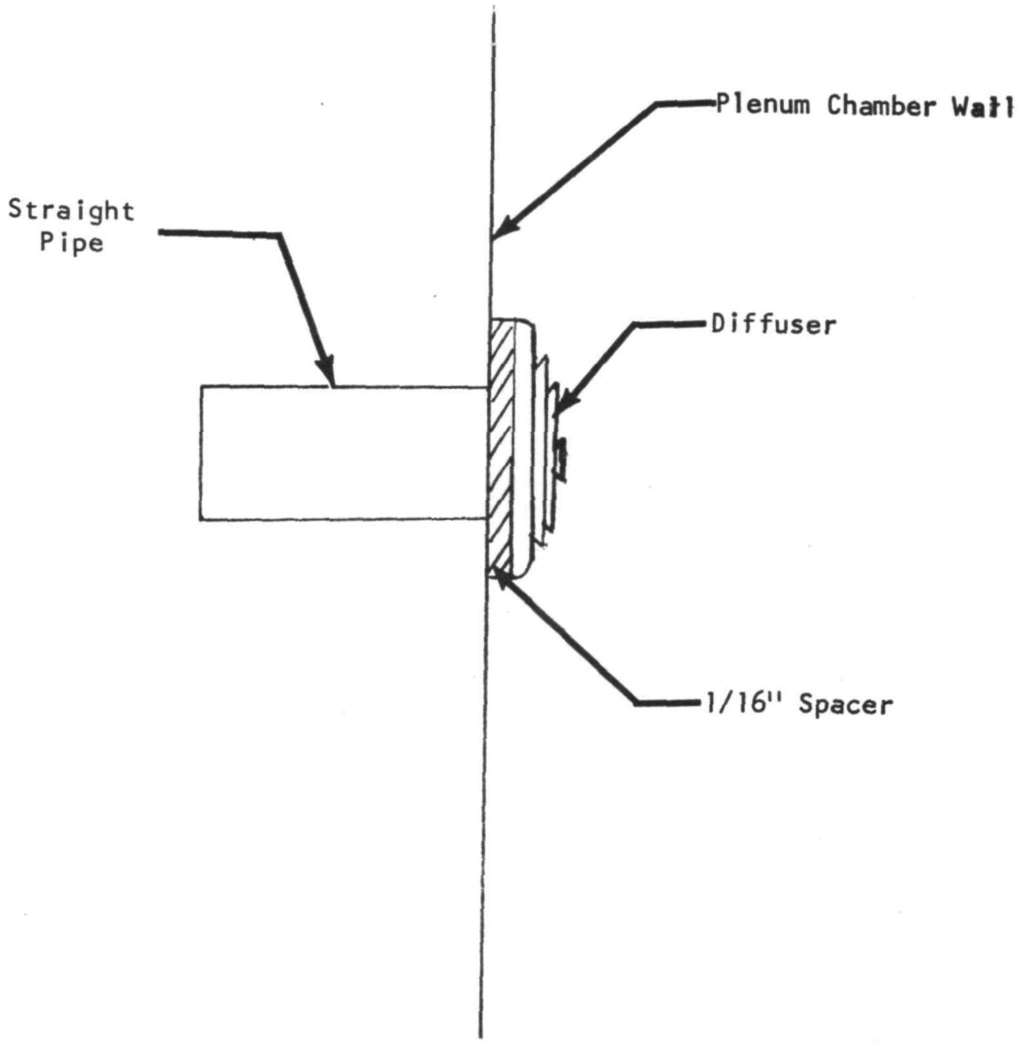


FIGURE 20. IN-HOUSE MODIFIED 6" DIFFUSER



(Not to Scale)

FIGURE 21. DIFFUSER MOUNT WITH SPACER

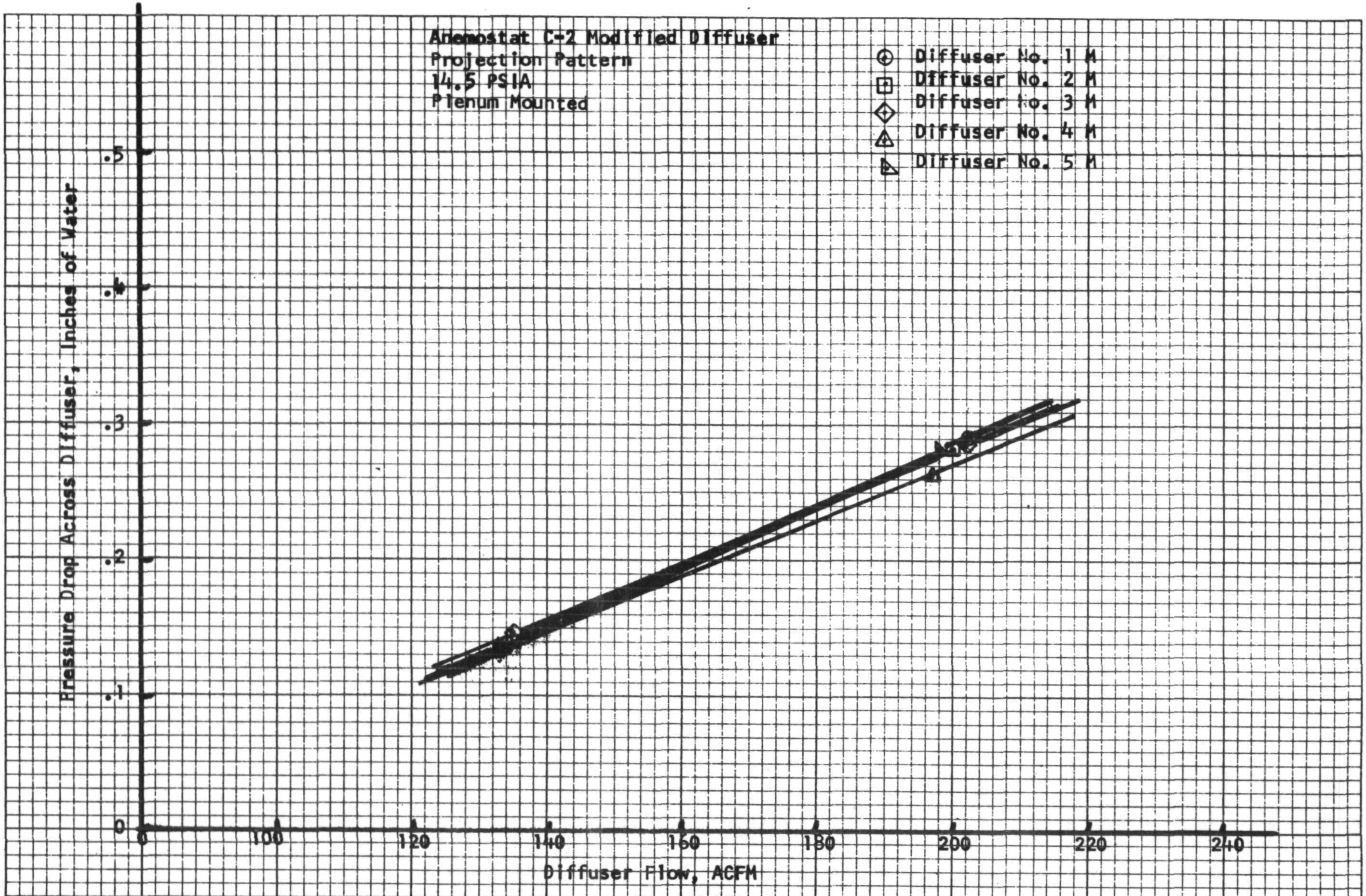


FIGURE 22. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

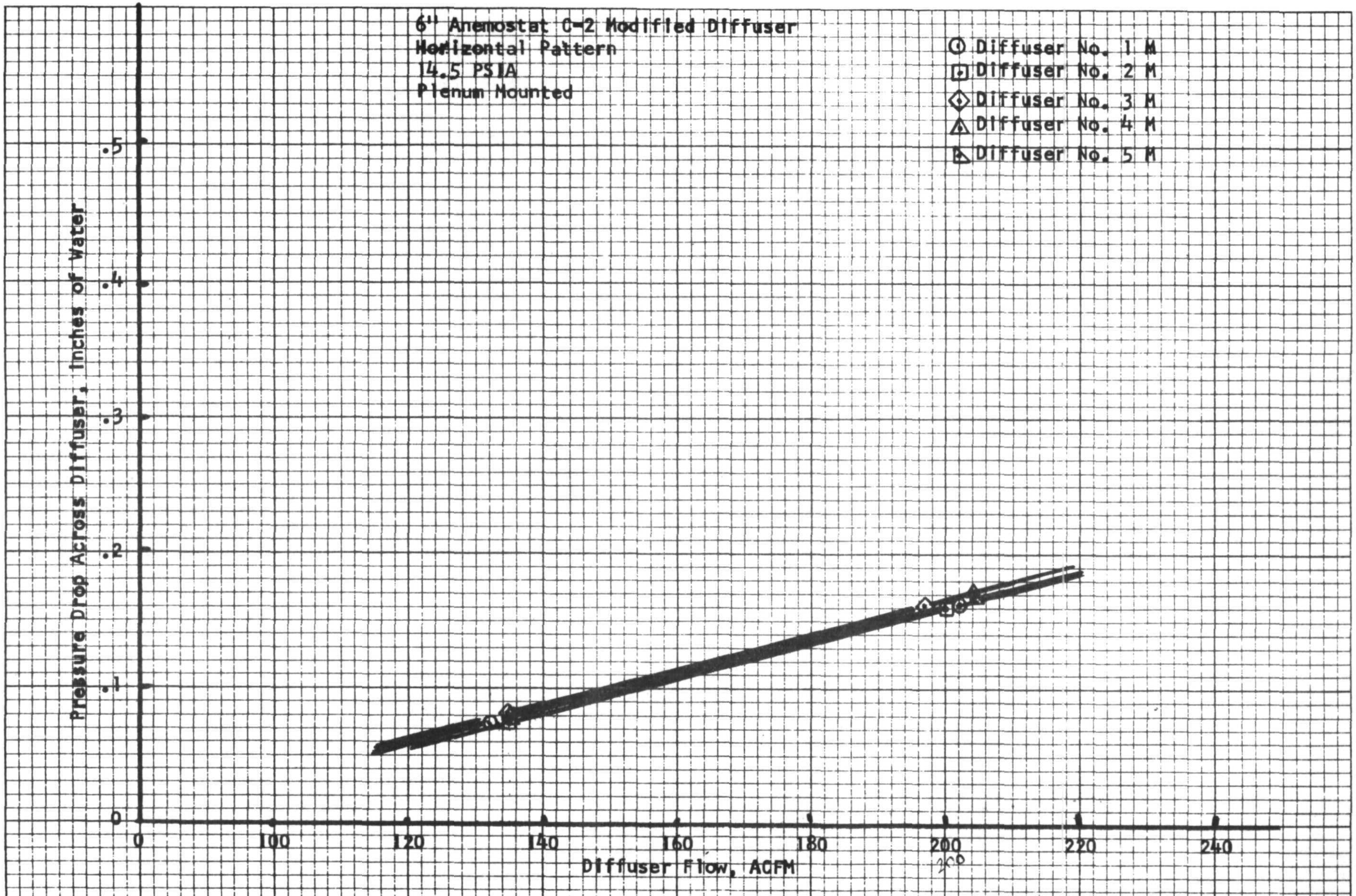


FIGURE 23. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

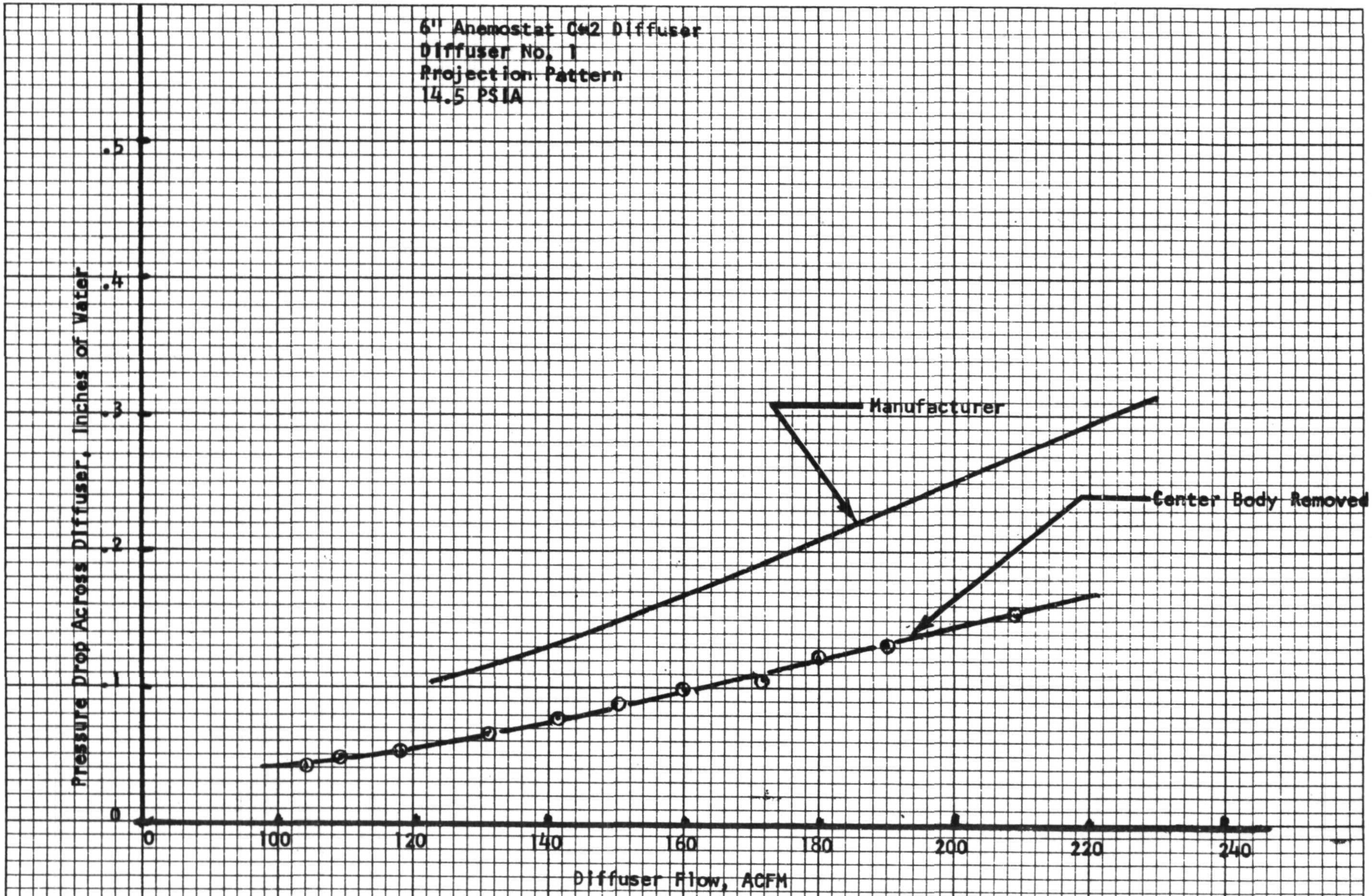


FIGURE 24. DIFFUSER FLOW VS PRESSURE DROP ACROSS DIFFUSER

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APPENDIX D

RESULTS OF VENTILATION TESTS CONDUCTED ON THE SKYLAB I ORBITAL WORKSHOP FULL-SCALE MOCKUP

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

REPLY TO ATTN OF: S&E-ASTN-TF-09-71

February 22, 1971

GDP
CPV
EJC

TO See List Attached

FROM Chief, Environmental Test Section
S&E-ASTN-TFE

SUBJECT Results of Ventilation Tests Conducted on the Skylab I Orbital Workshop Full-Scale Mockup

1. References: (a) Memorandum S&E-ASTN-PF-70-M-76, "Saturn V Workshop Ventilation Test Plan for Full Scale Mockup," dated May 1, 1970, (b) BECO Memorandum TD-A2-P-P-3-001-42, "Minutes of Saturn V Workshop Ventilation Working Group Meeting on April 8, 1970," dated April 16, 1970.

2. Introduction:

A full-scale engineering mockup of the Skylab I OWS (Orbital Workshop) located in Building 4619, Marshall Space Flight Center, was utilized for testing of the OWS ventilation system. The subject tests, requested by the Propulsion and Thermodynamics Division, Astronautics Laboratory, MSFC (S&E-ASTN-P), were conducted during the period June 15, 1970 through August 12, 1970, by the Environmental Test Section, Test Division, Astronautics Laboratory, MSFC (S&E-ASTN-TFE).

The objectives of the ventilation tests were twofold: (1) to determine system performance relative to delivered flowrates and system differential pressure, with various combinations of component adjustments, and (2) to demonstrate the capability of the system to provide satisfactory air distribution in the workshop.

The voltage setting of the ventilation system fans, in orbit, is 28 ± 2 VDC. System performance tests and air distribution tests were conducted at 24, 28 and 32 VDC fan voltage settings to allow a test operational voltage span inclusive of orbital voltage tolerances. Performance of the fans at 26 VDC in an 0.028 lb/ft^3 (1/3 atmosphere) density environment is equivalent to performance at 28 VDC in an 0.073 lb/ft^3 (1 atmosphere) density environment (reference memorandum S&E-ASTN-TF-68-70). Performance data in this report, taken at 28 VDC - 0.073 lb/ft^3 conditions, therefore, represent the minimal orbital conditions of 26 VDC - 0.028 lb/ft^3.

The OWS mockup configuration was, basically, flight-type and the test environmental conditions were ambient. Specifically; air density was essentially 0.07 lb/ft^3 and air temperature in the mockup varied from 65°F at the beginning of a test day to 95°F at the end of a test day. Note: To avoid one-g bouyancy effects, no air conditioning equipment was installed. The flexible ducting in the mockup was not flight-type. It's relative roughness was greater than flight-type ducting and, therefore, system resistance data in this report are conservative.

A general matrix of the ventilation test program is presented in Figure 1. This report contains all component performance data and subsystem performance data used in support of analysis of the system.

It is recommended that the reader refer to the definitions of symbols and abbreviations, Page 14, before proceeding further.

3. Description:

The OWS is to be a manned earth-orbiting space station consisting of an S-IVB stage modified to provide a life-support environment, an air lock/STS (Structural Transition Section) and an MDA (Multiple Docking Adapter) (See Figure 2). The air lock/STS contains the equipment for conditioning air in the OWS and, with the MDA, provides a means of ingress and egress for the crew. The entire assembly will provide a zero-gravity space station in which, and from which, a variety of scientific experiments are to be conducted.

Modification of the S-IVB stage includes installation of two floors, perpendicular to the stage longitudinal axis, in the liquid hydrogen tank. One floor, approximately one foot above the apex of the lox dome, is sealed on the lox dome side, providing an aft plenum, and contains a triangular grid-work on the crew-quarters side. (Note: The terms aft and forward noted herein apply to the S-IVB stage in the launch attitude.) Seventy-eight inches above the grid-work is the second floor (more appropriately, the floor/ceiling) containing identical triangular grid-work on each of its' surfaces. The volume between the floors contains the ward room, work area, sleep area, and waste management area. The volume between the floor/ceiling and the forward end of the liquid hydrogen tank is designated the forward plenum and contains various scientific experiment packages and life-support equipment. A port in the forward plenum dome provides access to the air lock and MDA.

Three 12-inch diameter ducts diverge from a common mixing chamber on the hydrogen tank dome (See Figure 3), connect to three four-fan clusters in the forward plenum (see Figures 4 and 5), then continue through the crew quarters into the aft plenum. Conditioned air from the air lock enters the mixing chamber along with recirculated air from the crew quarters and forward plenum. This air mixture is circulated continuously through the aft plenum, by the fan clusters, and exits the aft plenum into the crew quarters through nine, 6-inch Anemostat, Type C-2, circular diffusers (see Figure 6), and three, $3\frac{1}{2}$ x $5\frac{1}{2}$-inch Air Devices, Inc., rectangular diffusers (see Figure 7).

Each of the three clusters contains four, brushless DC-motor-driven vaneaxial fans, P/N 826070-4, manufactured by the Airesearch Corporation (see Figure 8).

The circular diffusers are adjustable to provide air-distribution pattern flexibility from a wide, along the floor, distribution to a narrow (projection) distribution with generally a cylindrical shape. Note: Memorandum S&E-ASTN-TF-25-70 documents, in detail, ventilation tests of the circular diffuser.

Three circular diffusers are located in the ward room floor, five in the work area floor, and one in the WMA (waste management area) floor (see Figure 21). Each circular diffuser contains a manually-adjustable damper to allow control of the volume of air flowing into the crew quarters. The WMA diffuser also contains a 3 7/8" orifice to limit the WMA pressure to a value less than that of the remaining crew quarters. Any airflow, therefore, would be <u>from</u> the crew quarters rather than <u>into</u> the crew quarters. Note: Tests in the WMA were conducted with the orifice and with the orifice replaced by a damper. Air from the WMA is exhausted through an odor removal filter by means of a vaneaxial fan identical to those used in the clusters.

A rectangular diffuser, located in the floor in each of the three sleep compartments, is adjustable from the standpoint of volumetric flow (closed, open and in-between) and provides control of jet stream direction.

4. Instrumentation:

a. Air velocity (flowrate) in each duct was initially measured utilizing a Hastings Air Meter, Model AM-12X, with Hastings-Radist Probe Type S-22A; Range 0 to 1000 feet/minute (see Figure 9). This method, however, proved unacceptable and was replaced by other methods discussed later in this report.

b. Air velocity in the crew quarters was measured utilizing:

(1) Hastings Air Meter, Model AM-12X, with Hastings-Radist Probe, Type S-22A; Range 0 to 100 feet/minute.

(2) Hastings, Air Meter, Model AM-12X, with Hastings-Radist Probe, Type S-22A; Range 30 to 300 feet/minute.

(3) Hastings Precision Air Meter, Model B-22-1, with Hastings-Radist Probe, Type S-22A; dual range 0 to 5 mph and 5 to 100 mph.

c. Ambient pressure in the OWS was measured utilizing an MB Electronics pressure transducer, Model No. 151-HAC-227, S/N 51103, range 0 to 25 p.s.i.a., and a strip chart recorder.

d. Temperature in the OWS, and in Building 4619 adjacent to the OWS, was measured utilizing thermocouples and strip chart recorders.

e. Differential pressure across each fan cluster and across the aft plenum floor was measured utilizing F.W. Dwyer Mfg. Co., 0 to 1-inch of water, slant-tube manometers with 0.826 specific gravity oil.

5. Test Criteria:

Test criteria was provided to S&E-ASTN-TFE in the form of design criteria and are attached to this report as Appendix A.

6. Test Plan:

a. System Performance Tests

Tests were conducted to determine the operating characteristics (differential pressure vs. flowrate) of the air circulation system under various conditions of fan voltage, number of operating fans, circular diffuser settings, damper settings, and rectangular diffuser settings.

b. Air Distribution Tests

Tests were conducted to determine the average air velocity in the crew quarters, under various system operating conditions, and the velocity profiles of a typical circular diffuser and portable fan.

c. Component Performance Tests

Problems with the duct flow measuring system necessitated that tests be conducted on various ventilation system components. Specifically, tests were conducted on each PLV (Post Landing Ventilation) fan, a typical circular diffuser, and a typical rectangular diffuser to determine the differential pressure vs. flowrate characteristics of the component. Data from these tests were required to support analyses of the system with respect to performance.

7. Test Results and Observations:

Performance data from all system tests are contained in Tables 1 and 2.

a. System Performance Tests

In the initial part of the test program, Hastings hot-wire anemometers were installed in the 12-inch ventilation ducts to obtain duct air velocity measurements for conversion to duct flowrate. Use of the anemometer was abandoned when experiments showed that the velocity profile across the ducts was very erratic and unrepeatable, from test-to-test, under identical flow conditions. Two alternative methods of determining flow through the floor were therefore utilized with significantly agreeable results:

Method 1 - Determination of Q_T:

Performance curves were prepared to allow determination of the flowrate through each fan cluster with the clusters operating in the following modes (see Figures 10, 11, and 12):

(1) Three clusters fully operative

(2) Two clusters fully operative, one cluster inoperative

(3) Two clusters fully operative, one cluster with three fans operative

(4) Two clusters fully operative, one cluster with two fans operative

(5) One cluster fully operative, one cluster inoperative, one cluster with two fans operative

(6) Two clusters with three fans operative (each cluster),one cluster inoperative.

Data for preparation of the curves were obtained by conducting performance tests on each fan; by conducting performance tests on a cluster with three fans operating, one fan freewheeling (see Figure 13), and two fans operating, two fans freewheeling (see Figure 14); and by calibrating the inoperative cluster for backflow (see Figure 15). Assuming no leakage, the flow through the floor, Q_T, was the flow produced by the operating clusters minus the backflow (where applicable) through the inoperative cluster. In each system test, the ΔP across each fan cluster was recorded. By using the measured ΔP and the appropriate curve, the flow through each duct was determined for each condition. Note: Tests conducted during a four-fan cluster test program showed this method to be entirely adequate (reference memorandum S&E-ASTN-TF-68-70).

Method 2 - Determination of Q_4:

Component tests of a typical circular diffuser and a typical rectangular diffuser were conducted to determine flowrate vs ▲P. The combined performance of all circular and rectangular diffusers is shown in Figures 16, 17 and 18. In each system test, the ▲P across the floor was recorded and the summation of the flowrates through each diffuser, at that floor ▲P, was taken as the total flow, Q_4, through the floor.

The total flowrate by methods 1 and 2 agreed within 9%, except for test configurations in which the dampers and rectangular diffusers were closed at the same time, and for test configurations in which more than four fans were inoperative. Although the component tests were conducted on assumed-typical diffusers rather than on each individual diffuser, each diffuser is known (from previous test programs) to differ slightly in its flow characteristics relative to others. Test time was not available for conducting tests on each diffuser at each damper and pattern setting to allow a more precise determination of Q_4. The flowrates obtained by method 1 are, therefore, of greater integrity and should be taken as correct.

The floor resistance (▲P_4) was measured for each test conducted. Figure 19 shows the worst and best flow conditions obtainable relative to damper and diffuser settings, and, the variation in floor resistance caused by setting the circular diffusers from full-wide to full-narrow. Also shown in Figure 19 (by dashed line) is the predicted floor resistance at orbital density. Note: Prior to testing, the floor was sealed to prevent flow other than through the ventilation system components.

Tests were conducted to determine the airflow through the WMA. Figure 20 shows the test setup in which velocity measurements were made at five positions across the fan exit. The five velocity values were averaged, and converted to flowrate, for two cases: (1) with the WMA diffuser containing a 3 7/8-inch orifice, and (2) with the WMA diffuser containing an open damper but no orifice. The flowrate for case (1) was 135 ACFM, and for case (2), 138 ACFM.

b. Air Distribution Tests

Dampers were not available for OWS installation until the last 20% of the test program. Because the OWS flight configuration ventilation system is to contain dampers, data from the air distribution tests with dampers are particularly significant; however, data obtained without dampers are included for comparison purposes and are considered pertinent with respect to air distribution as a function of system flowrate (see Figure 35).

Figure 21 shows the locations of the circular and rectangular diffusers and the locations at which velocity measurements were taken.

A test was conducted to determine an air-velocity baseline to assure that convective effects on air velocity were negligible. The workshop was undisturbed, overnight (13.7 hours), with the fans and lights deactivated. At the end of this period, before disturbances, the temperature was measured at seven internal locations and one external location. The workshop was then carefully and slowly entered, to minimize disturbance of the internal environment, and air velocity measurements were made at eight locations 39 inches above the crew quarters floor, and at five locations 60 inches above the floor/ceiling. The temperature ranged from 83.7°F at the lox-dome apex to 87.3°F at the mixing chamber (outside air temperature, near the workshop, was 82.8°F). After three hours of fan operation, the temperature ranged from 86.4°F to 87.3°F (outside 86.3°F). Measured air velocity, with minimal disturbances and no ventilation equipment operating, was below the readability of the air meter and therefore negligible. To summarize, convection effects on air velocity were negligible.

Air distribution in the forward plenum, the WMA, the sleep area, and the work area and ward room are treated separately in the following paragraphs:

(1) Forward Plenum

Single-diffuser velocity profile tests (discussed later in this report) showed that the best projection pattern (highest velocities along and near the diffuser longitudinal centerline) was obtained with a diffuser setting of 5TN (5 turns from the full-narrow pattern).

Figure 22 shows the velocity measurements (values and locations), at levels 39 inches and 96 inches above the floor/ceiling, with the best obtainable operating condition. The best condition would entail operation of all cluster fans at 32 VDC with three portable fans operating at 32 VDC. In this test program, however, only 13 fans were available. Hence, the best obtainable condition utilized 10 operational fans in the clusters, with two fan ports sealed and three portable fans operating. The flow produced by the 10 fans at 32VDC (operating in a 1-atmosphere environment) corresponds approximately to the flow obtainable by operating, under the same conditions, 12 fans at 26 VDC.

Figure 23 shows the results obtained with no cluster fans operating and air velocity produced solely by the portable fans. Measurements were taken at the same locations as those shown in Figure 22.

Figures 24 and 25 show the measurement locations and the velocity values obtained in the forward plenum with only the cluster fans providing air movement. The measurement locations shown were selected relative to experiment activity positions. Three tests were conducted to determine the influence of the diffuser pattern setting on air velocity in the forward plenum. The test results shown in the figures verify that higher forward-plenum velocities are obtained with the 5TN pattern setting than with the full-narrow or the wide pattern setting. Figure 25 also shows the effect of fan voltage on air velocity in the forward plenum.

(2) Waste Management Area

Tests were conducted to determine the average air velocity in the WMA with a dampered diffuser and with an orificed diffuser. Figure 26 shows the test results with the orificed diffuser set for the NARR, 4TW, and WIDE patterns. Figure 27 shows the results with the damper open and closed. The WMA air velocities were higher with the damper open than with the damper closed or with the orifice installed, except in the vicinity of the exhaust fan port where the exhaust-fan suction was the predominant influence on velocity.

(3) Sleep Area

The velocity in each of the three sleep compartments varied from 5 to 800 FPM, as measured over the diffuser six feet from the floor, depending upon the setting of the louvers. The lower value was obtained with all louvers closed and the higher value was obtained with all louvers open. Intermediate values were obtained by partially or fully opening one or more of the three louvers. In all sleep-area velocity tests the circular diffuser dampers were open. Closing the circular diffuser dampers would increase the sleep-compartment velocities.

(4) Circular Diffuser Air-Velocity Profile

Results of testing to determine the influence of configuration changes on air velocity from a typical circular diffuser are shown in Figures 28 through 32. The figures are self-explanatory. For these tests, the ventilation system was set as noted on the figures.

(5) Portable Fan Air-Velocity Profile

An unshrouded PLV fan was equipped with a 5 1/8-inch (length) extension, to simulate a portable fan, and positioned in the forward plenum as shown in Figure 33. The data indicate that the jetstream produced by the fan is relatively narrow and generally symmetrical. Although the fan was tested only in the high speed mode, a low-speed mode could be utilized in the event that the velocities produced by the high-speed mode were undesirable. Operation of the fan in this mode should result in velocities reduced by approximately 35% of that achieved with high-speed operation.

(6) Work Area and Ward Room

Eighty per cent of the test program was conducted without dampers in the circular diffusers (the OWS was available for ventilation testing only one week after receipt of the dampers). Therefore, after damper installation, emphasis was placed on tests of worst-case conditions. Relative to air distribution the worst cases were those in which the dampers were closed, yielding the lowest flowrates through the floor.

Prior to receipt of the dampers, nineteen air distribution tests were conducted with velocity measurements taken at sixteen selected stations (stations 1 through 16, Figure 21) at levels six inches above the floor, 39 inches above the floor and six inches below the floor/ceiling. These measurement stations were selected prior to testing and were anticipated, at that time, to be of adequate number and location to yield representative average-velocity results. When the velocity data from these stations were analyzed however, it was determined that the average velocity was biased toward the low side, for pattern settings other than the wide setting, and additional measurement stations were needed to take into account the relatively high velocity area directly over the diffusers. In tests -97 and subsequent, velocity measurements were made at station 1 and stations 6 through 24, Figure 21, in the work area and ward room. Because of these additional measurements, the air velocity data of tests prior to -97 are included but subsequent discussion of air-velocity tests is limited to tests -97 and on.

Work-area/ward-room air distribution tests were conducted only with circular diffuser settings of WIDE and 6TW (6 turns from wide). The diffuser profile tests provided air velocity data with the NARR (full narrow) and 5TN pattern settings which are primarily used for spot-cooling and to obtain increased air velocity in the forward plenum. Velocity profile experiments with several circular diffusers indicated that the most desirable intermediate air-distribution pattern - a pattern in which the mainstream of airflow is approximately half-way between the full-narrow and full-wide patterns - was obtained with diffuser settings from 5TW to 7TW, depending on the diffuser tested. An adjustment of 6TW was therefore selected as the intermediate setting for all circular diffusers. Table 3 contains the results of tests with various voltage, diffuser, and damper settings.

Reference to Table 3 allows direct comparison of the average air velocity of tests conducted with and without dampers. The "39-inch level only" data of Table 3 are presented to allow direct comparison of tests -97, -98, and -99 with tests in which velocity measurements were made only at the 39-inch level above the floor (specifically, tests -103, -105, -106, and -108). Data from Table 3 are graphically presented in Figure 34 to show the correlation of average air velocity with system performance. Figure 35 illustrates the insensitivity of average air velocity to system flowrate for wide-pattern settings. The sensitivity of the 6TW pattern to flowrate is also illustrated.

Table 4 contains all air distribution test data.

Color motion pictures were made utilizing Tedlar strips to indicate air movement. All modes of operation which could be selected by the crew members were filmed. Copies of the film are retained by S&E-ASTN-PFA, MSFC.

c. Component Performance Tests

(1) Circular Diffuser

A typical circular diffuser was removed from the OWS and tested to determine its' ΔP vs. flow characteristics with an open damper, with a closed damper, and with a 3 7/8-inch orifice, at pattern settings of NARR, 5TN, 6TW, and WIDE. These performance tests were conducted with the entire diffuser assembly, including the standpipe and bell-mouth inlet, mounted in a 6 x 6 x 6-foot plenum. Standpipe penetration into the plenum was the same as penetration into the OWS aft plenum. The test results are shown in Figures 36, 37 and 38.

(2) Rectangular Diffuser

A typical rectangular diffuser was removed from the OWS and tested to determine its's ΔP vs. flow characteristics with the louvers open and closed. These performance tests were conducted with the entire diffuser assembly, including the standpipe and bell-mouth inlet, mounted in a 6 x 6 x 6-foot plenum. Standpipe penetration into the plenum was the same as penetration into the OWS aft plenum. Figure 39 shows the test results.

(3) PLV Fans

When it became evident that cluster performance could not be determined utilizing the duct-mounted Hastings anemometers, each PLV fan was removed from the OWS and performance tested. The individual fan curves are not included in this report, but Figures 10, 11, and 12 show the performance of each cluster obtained by adding the flowrates of individual fans at given differential pressures.

8. Conclusions and Recommendations:

a. Conclusions - Velocity Criteria for Comfort

(1) The crew quarters average velocity range criterion was 15 to 40 FPM, with velocities in excess of 40 FPM to be provided by portable fans and/or diffuser adjustment to the narrow pattern. Crew quarters average velocity test results were: 26 to 42 FPM with dampers closed, and 47 to 73 without dampers. Portable fans or diffusers set for the narrow pattern provided localized velocities greater than 40 FPM.

(2) The criteria stated that during uncomfortably cold conditions, a 15 FPM average velocity was desirable, and that simultaneous operation of all heaters (one in each duct) was desirable, although one duct could be shut down if necessary to obtain 15 FPM. The lowest average air velocity in the crew quarters, obtained with dampers installed (and closed), was 26 FPM. In this test (Test -121) the configuration was 3/4/28/WIDE/OPEN/CLSD combination.

(3) The criteria did not specify an average air velocity in the forward plenum. Air distribution in this area was to be provided solely by portable fans. The test results show that the average air velocity in the forward plenum was at least 18 FPM at measuring stations up to 10 feet above the floor without the operation of portable fans. Higher velocities are obtainable with the additional operation of portable fans.

b. Conclusions - Velocity Criteria for Safety

Velocities in excess of 2 FPM were considered adequate to prevent localized concentrations of CO_2. No instrument was available to allow direct reading of velocity values less than 5 FPM (with confidence). Therefore, thin tedlar strips strategically located throughout the workshop, were used to indicate air distribution. Based on observation of these strips, the air distribution appeared to be adequate to preclude localized CO_2 concentrations.

c. Conclusions - Minimum Acceptable Flowrate Criteria

(1) Six hundred ACFM was specified as the minimum flowrate (through the diffusers) to assure adequate CO_2 control for crew safety.

In this test program, the lowest flowrate obtained was 505 ACFM with a 2/4-0-4/24/6TW/CLSD/CLSD configuration. The lowest in-orbit flowrate however, would occur at 26 VDC which corresponds to the flowrate obtained at 28 VDC in the mockup. The lowest flowrate at 28 VDC in this test program was 600 ACFM (Test C-091-76).

(2) The minimum acceptable flowrate through each operating fan was 50 ACFM, per the test criteria, to prevent fan over-heat. The lowest flowrate-per-fan experienced during this test program was 88 ACFM with all dampers closed and the voltage set at 24 VDC (Test C-091-105).

(3) The specified minimum acceptable flowrate over each operating duct heater was 100 ACFM. The minimum duct flowrate experienced in this test program was 155 ACFM (Test C-091-102).

(4) The design flowrate through the WMA fan/filter/odor removal unit was 120 ACFM with the WMA fan and clusters operating at 26 VDC. The minimum flowrate during testing was 135 ACFM with the 7/8-inch orifice installed and all fans operating at 28 VDC (simulating 26 VDC in orbit).

d. General Conclusions

Although the majority of tests were conducted without dampers, the following conclusions are based on test data obtained with dampers installed except where comparisons of the two configurations are applicable.

(1) With all parameters constant except voltage, an increase in voltage yielded an increase in system flowrate and average air velocity in the crew quarters.

(2) With all parameters constant except the rectangular diffuser setting, the average air velocity in the crew quarters was increased by closing the rectangular diffusers.

(3) With all parameters constant, installation of the dampers (set open) had no significant affect on flowrate through the diffusers.

(4) The 6TW circular diffuser setting provided the best overall air movement capability of the ventilation system.

(5) The 5TN circular diffuser setting yielded higher average air velocities in the forward plenum than other circular diffuser pattern settings.

(6) Operation of three portable fans at 28 VDC in the forward plenum, with the clusters inoperative, yielded 36 FPM average velocity at the measurement points near experiment locations.

(7) Average air velocity in the sleep compartments may be varied over a wide range by utilizing the flexibility of settings inherent in the rectangular diffuser design.

(8) The flowrate through the WMA exhaust fan was essentially the same with a 3 7/8-inch orifice or with an open damper installed in the WMA circular diffuser.

(9) The average air velocity in the WMA was higher with the dampered circular diffuser than with the 3 7/8-inch orificed diffuser, regardless of the damper setting.

(10) Greater flowrates were obtained with 4-0-2 fans operating than with 3-0-3 fans operating even though six fans were operating in each case.

(11) Air velocity distribution obtained without dampers and with dampers open was not significantly different.

(12) The lowest air velocity obtainable, with the minimum bulk air velocity of 600 ACFM as a constraint, is 20 to 25 feet per minute. An in-orbit operating configuration of 2/4-0-4/26/WIDE/OPEN/CLSD should provide this velocity range and provide a bulk air velocity above the 600 ACFM limitation.

(13) Based on the test criteria and test results, the as-tested configuration of the OWS ventilation system performed adequately to provide satisfactory air distribution in the OWS.

J. T. Ralston

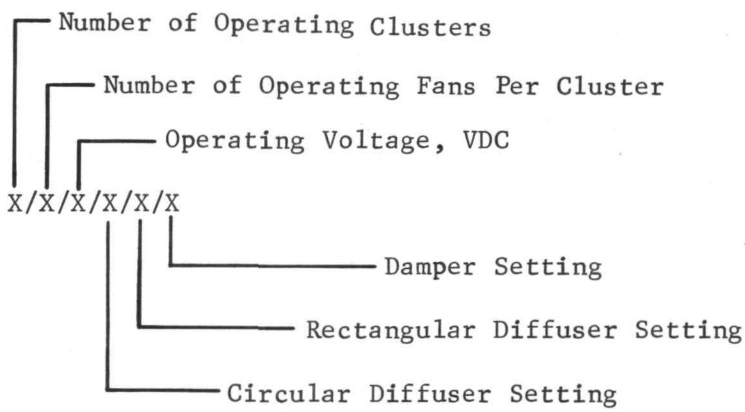
J. T. Ralston

Enc:
a/s

DEFINITIONS OF SYMBOLS & ABBREVIATIONS

NARR	Circular Diffusers in Full-Narrow Pattern
5TN	Circular Diffusers Five Turns From Narrow Pattern
WIDE	Circular Diffusers in Full-Wide Pattern
8TW	Circular Diffusers Eight Turns From Wide Pattern
6TW	Circular Diffusers Six Turns From Wide Pattern
4TW	Circular Diffusers Four Turns From Wide Pattern
ΔP_1, ΔP_2, ΔP_3	Pressure Rise Across Each Fan Cluster
QT	Flowrate Across Floor, Summation of Fan Cluster Flowrates
ΔP_4	Differential Pressure Across Floor
Q4	Flowrate Across Floor, From ΔP_4
NA	Not Applicable
NMT	No Measurement Taken

SYSTEM CONFIGURATION CODE



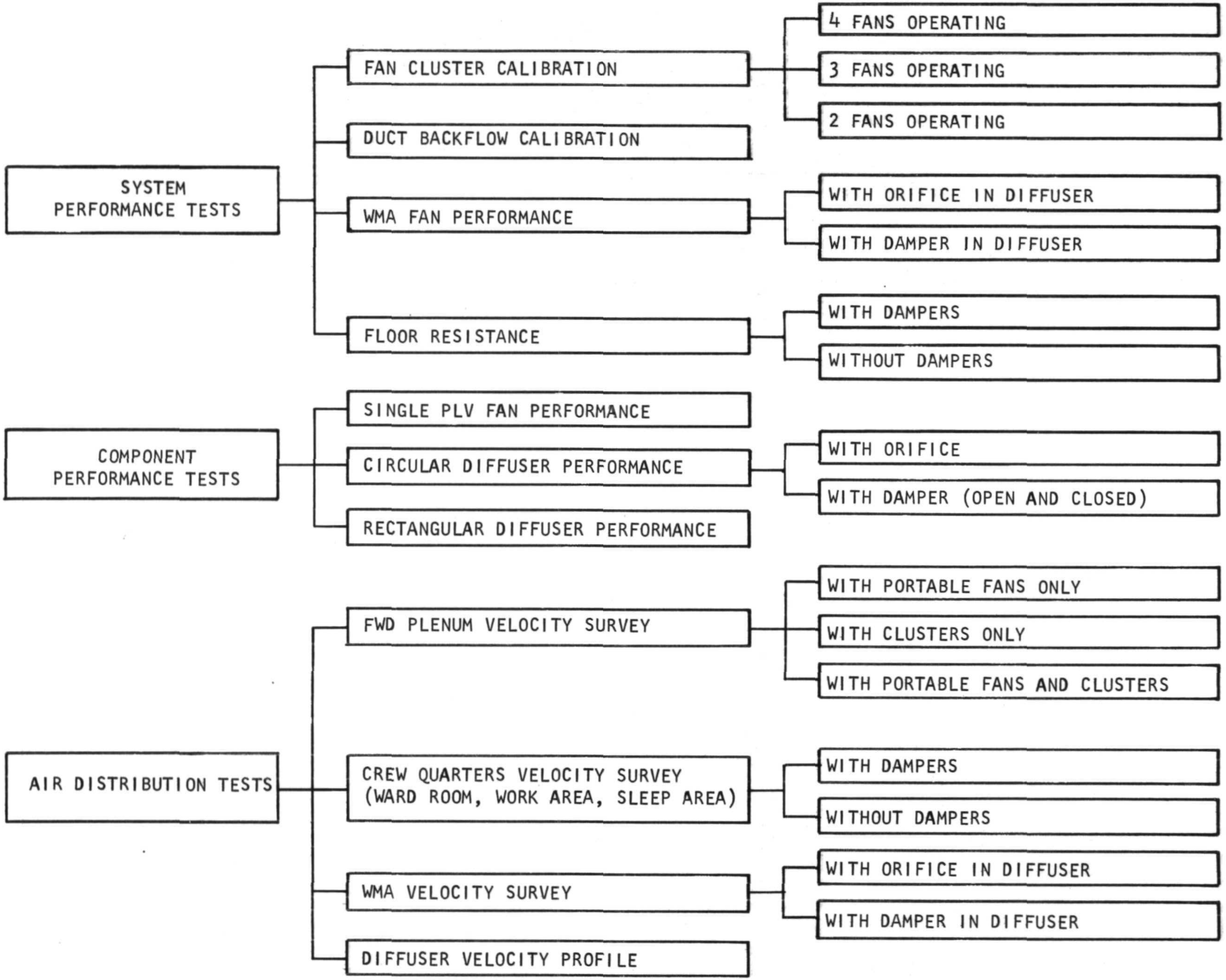


FIGURE 1. SKYLAB I ORBITAL WORKSHOP MOCKUP - VENTILATION TEST PROGRAM

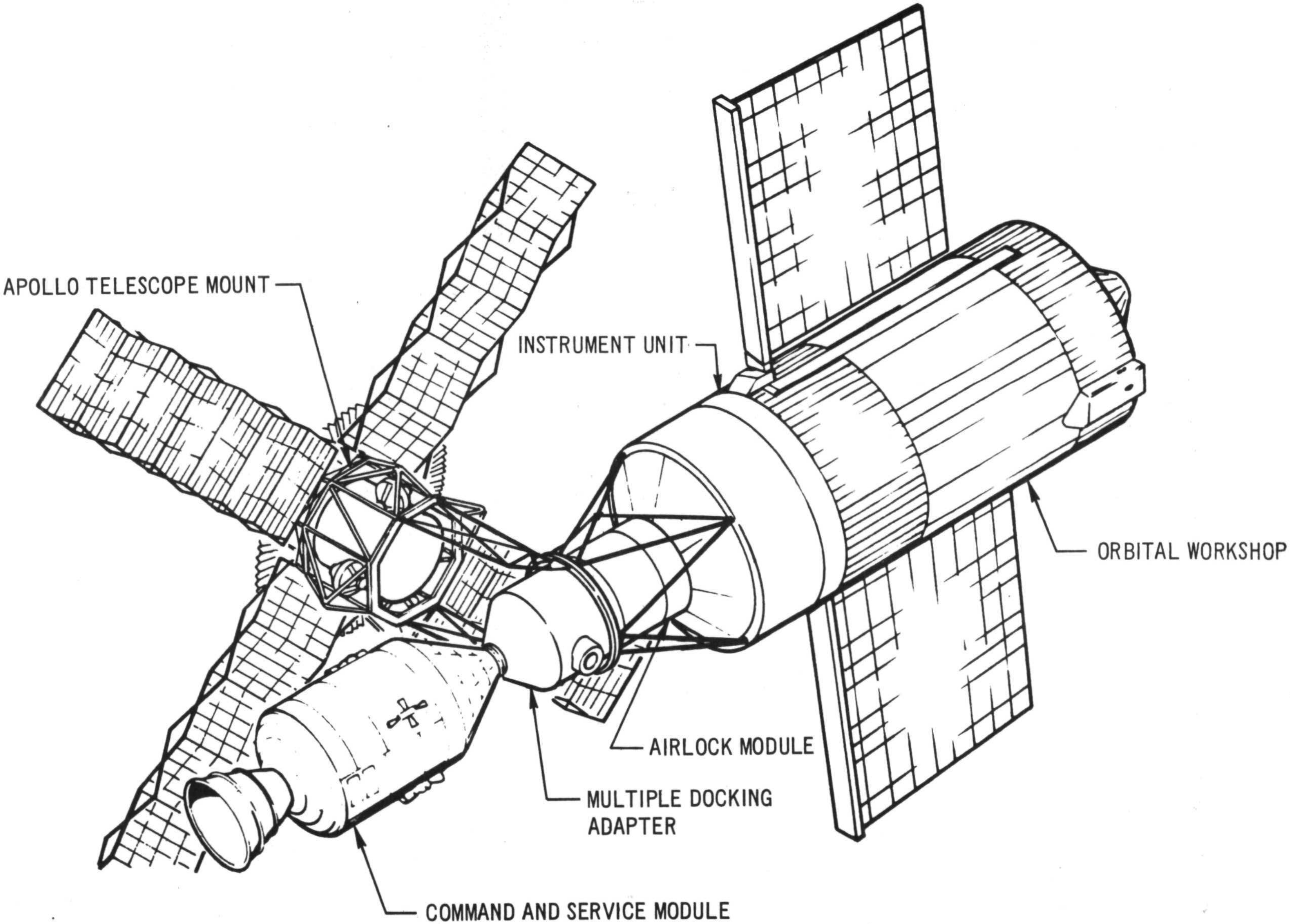


FIGURE 2. SKYLAB ORBITAL ASSEMBLY

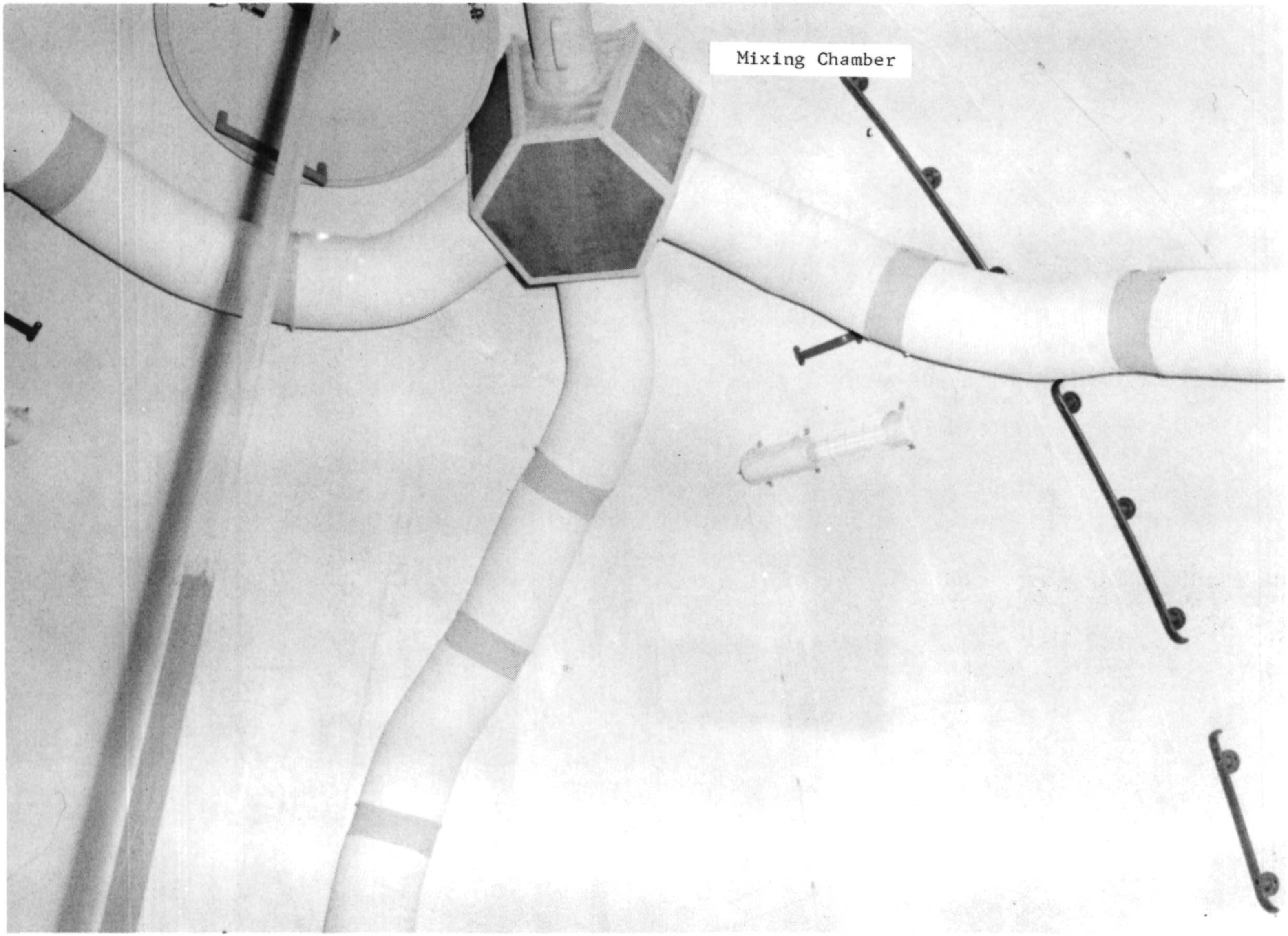
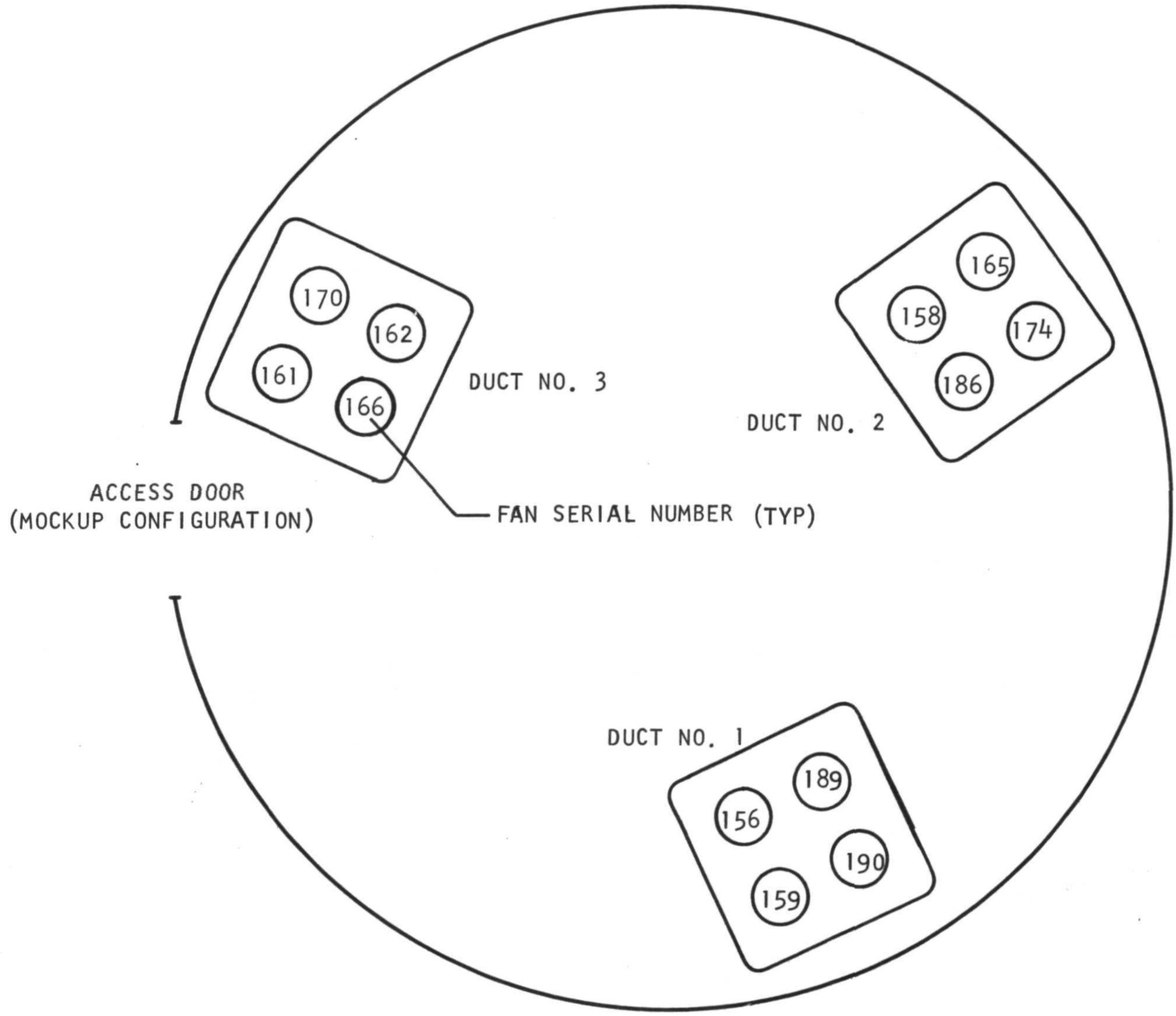


Figure 3. Mixing Chamber and Forward Plenum Ducting



NOTE: FANS S/N'S 97-154 & 97-164
USED AS PORTABLE FANS

FIGURE 4 . FAN/CLUSTER LOCATION AND DESIGNATION

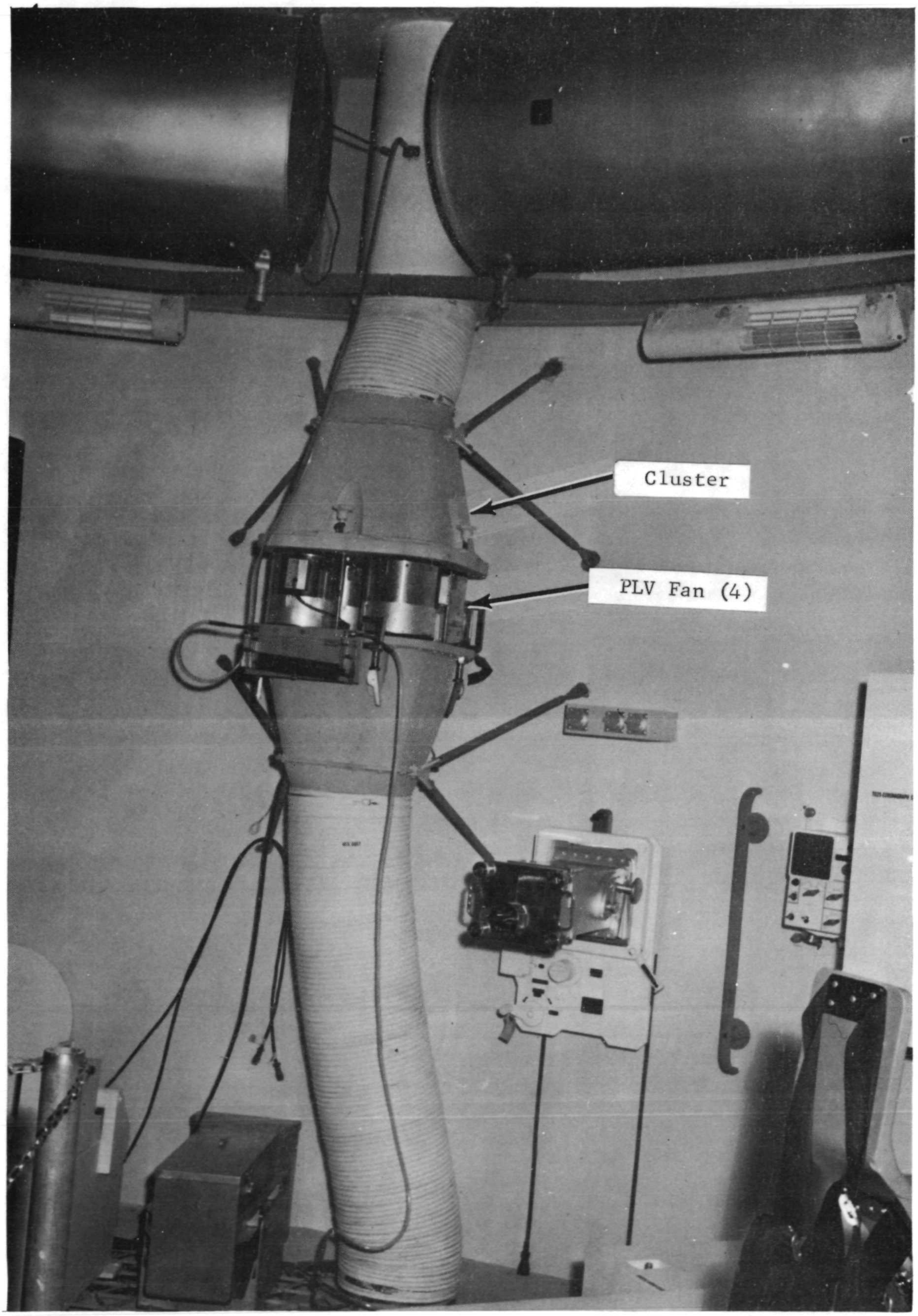


Figure 5. Typical Four-Fan Cluster

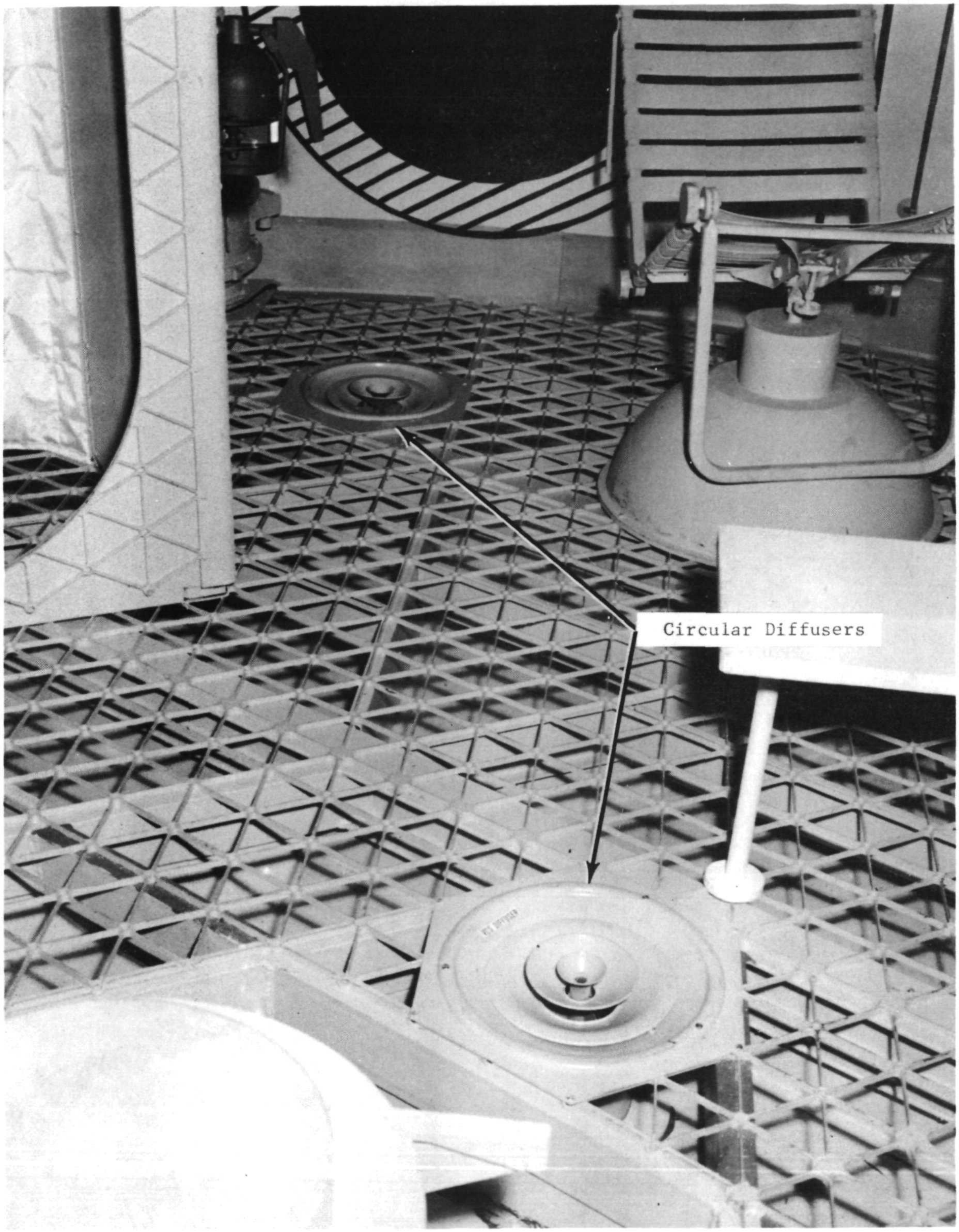


Figure 6. Six-Inch Anemostat Circular Diffusers

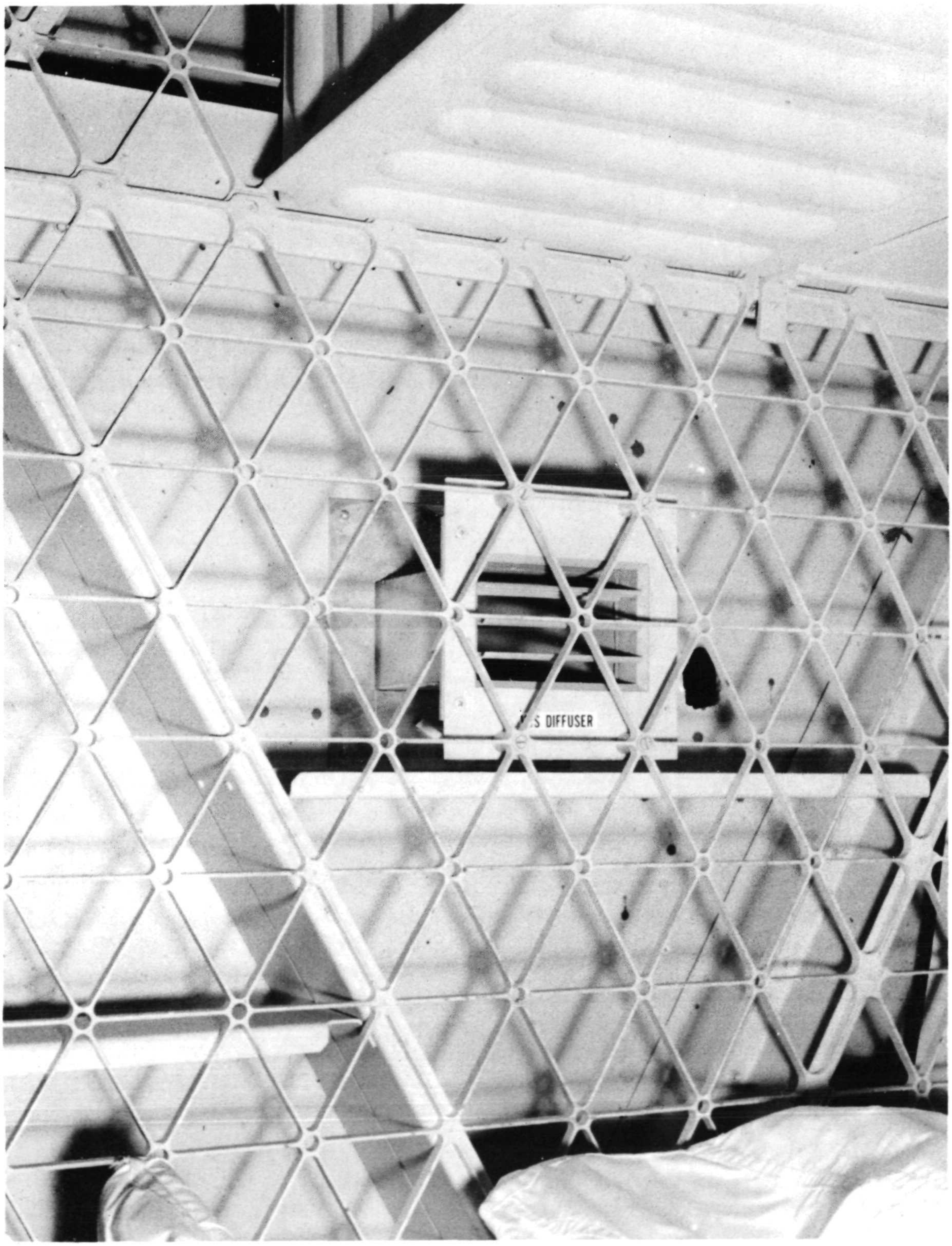


Figure 7. Air Devices Rectangular Diffuser

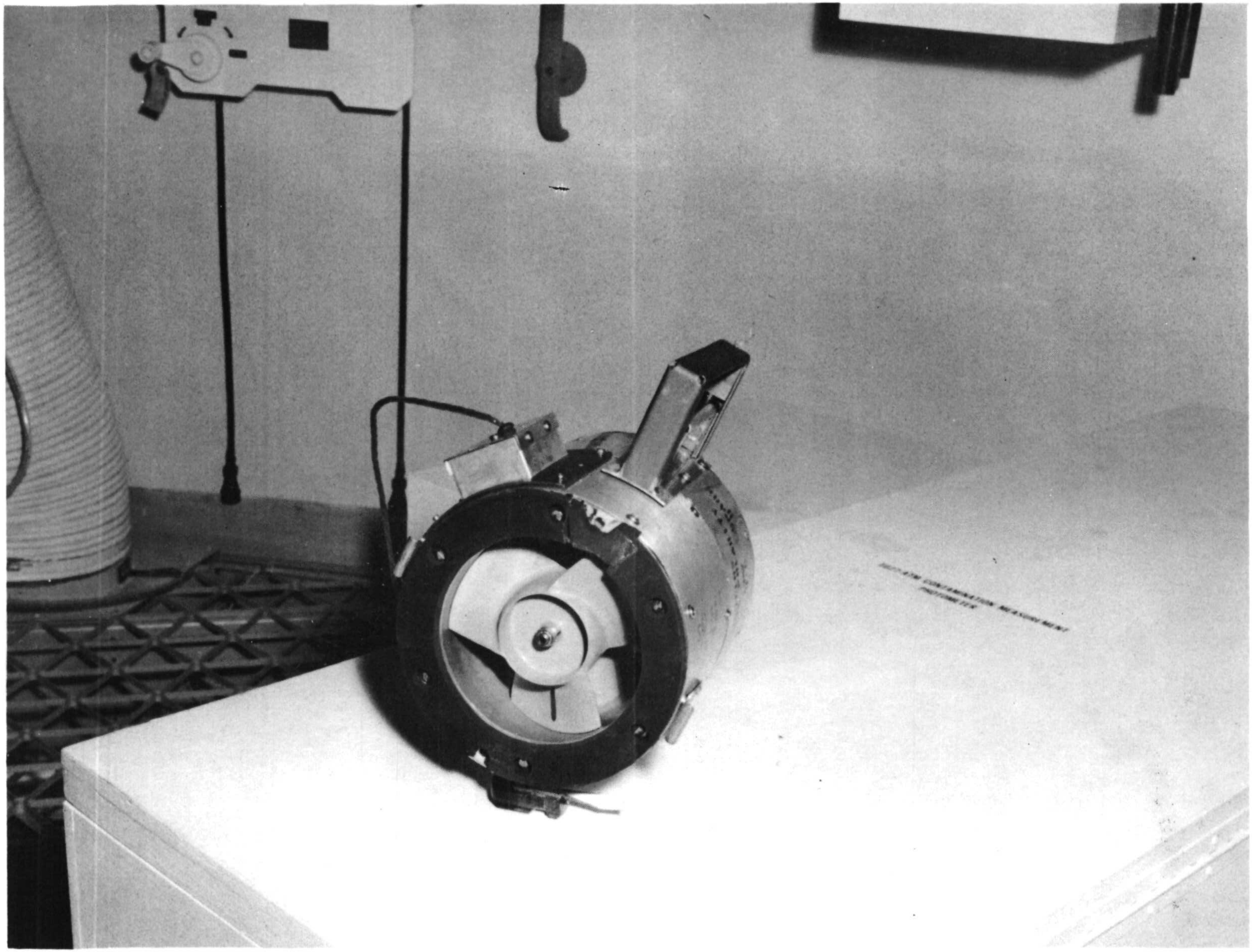


Figure 8. Shrouded PLV Fan

Figure 9. Hastings-Radist Anemometer and Probe

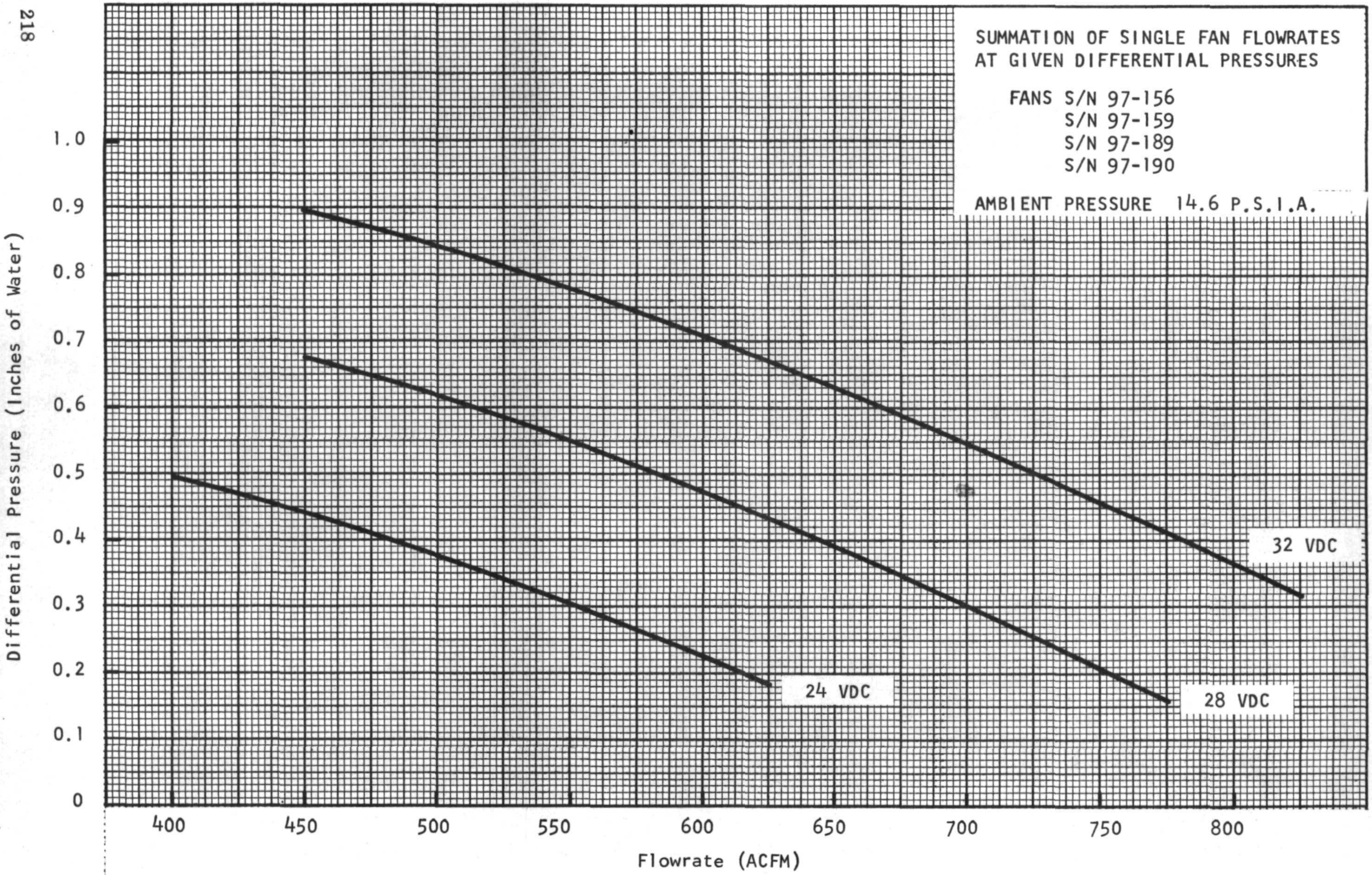


FIGURE 10. CLUSTER NUMBER 1 PERFORMANCE

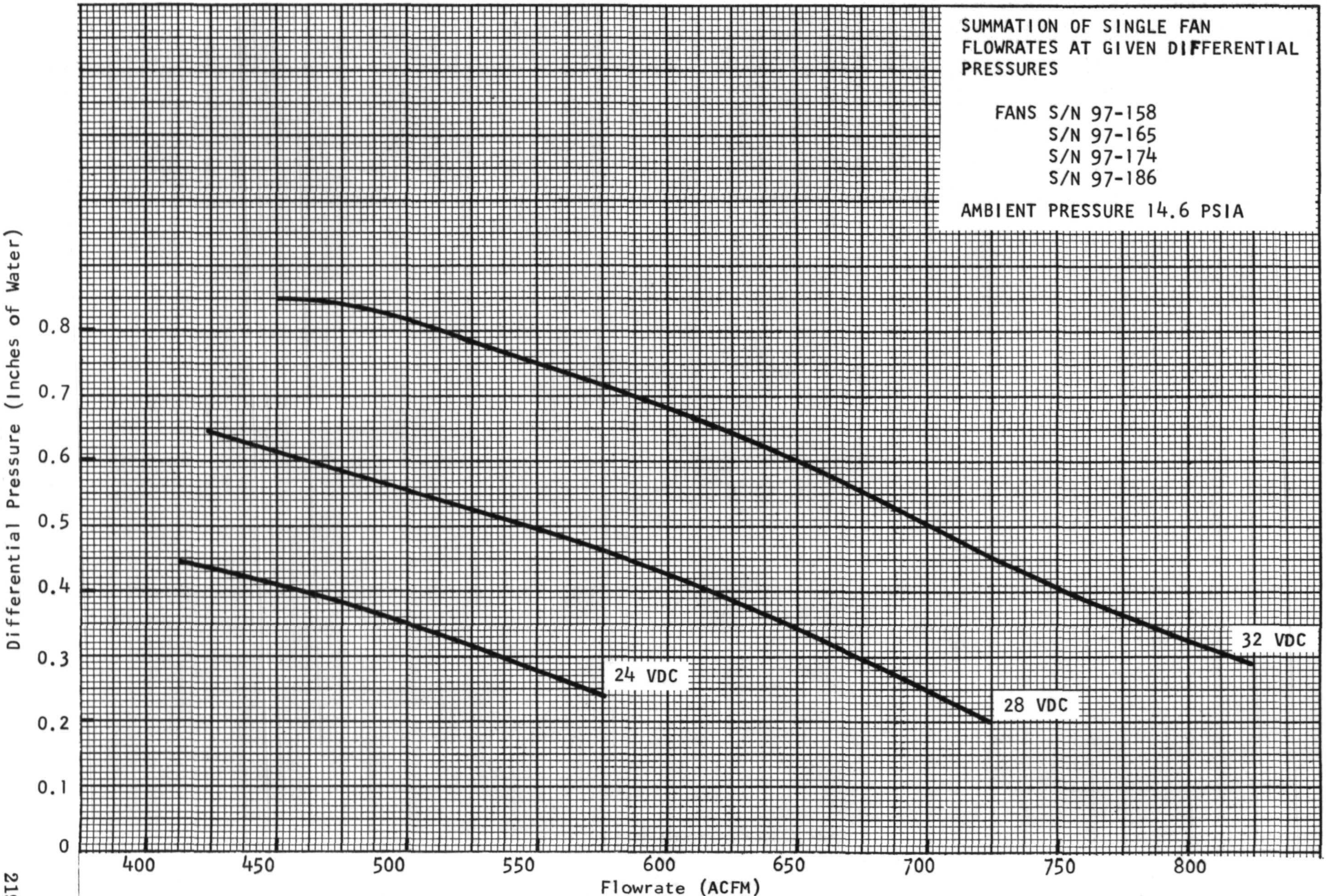


FIGURE 11. CLUSTER NUMBER 2 PERFORMANCE

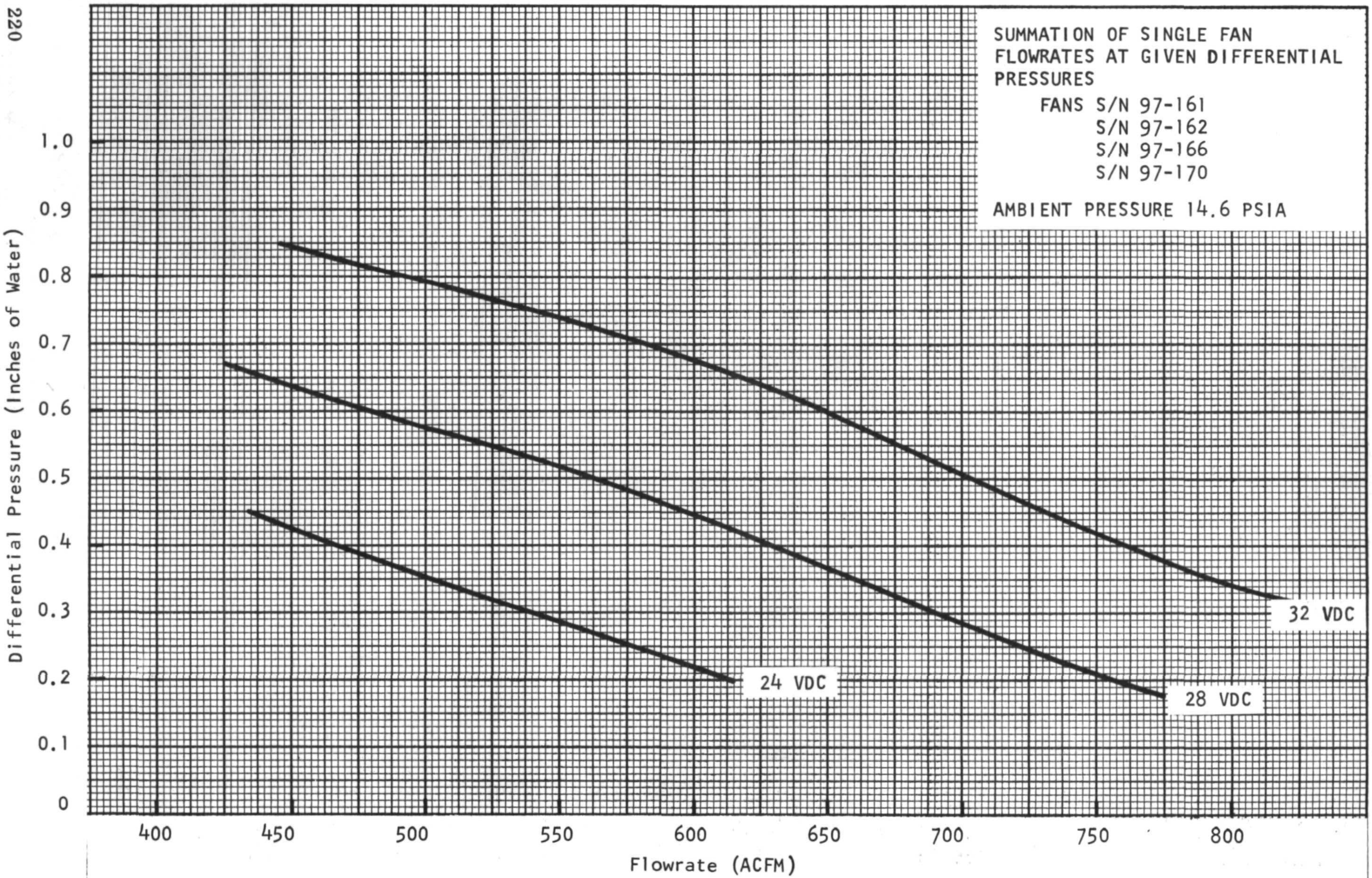


FIGURE 12. CLUSTER NUMBER 3 PERFORMANCE

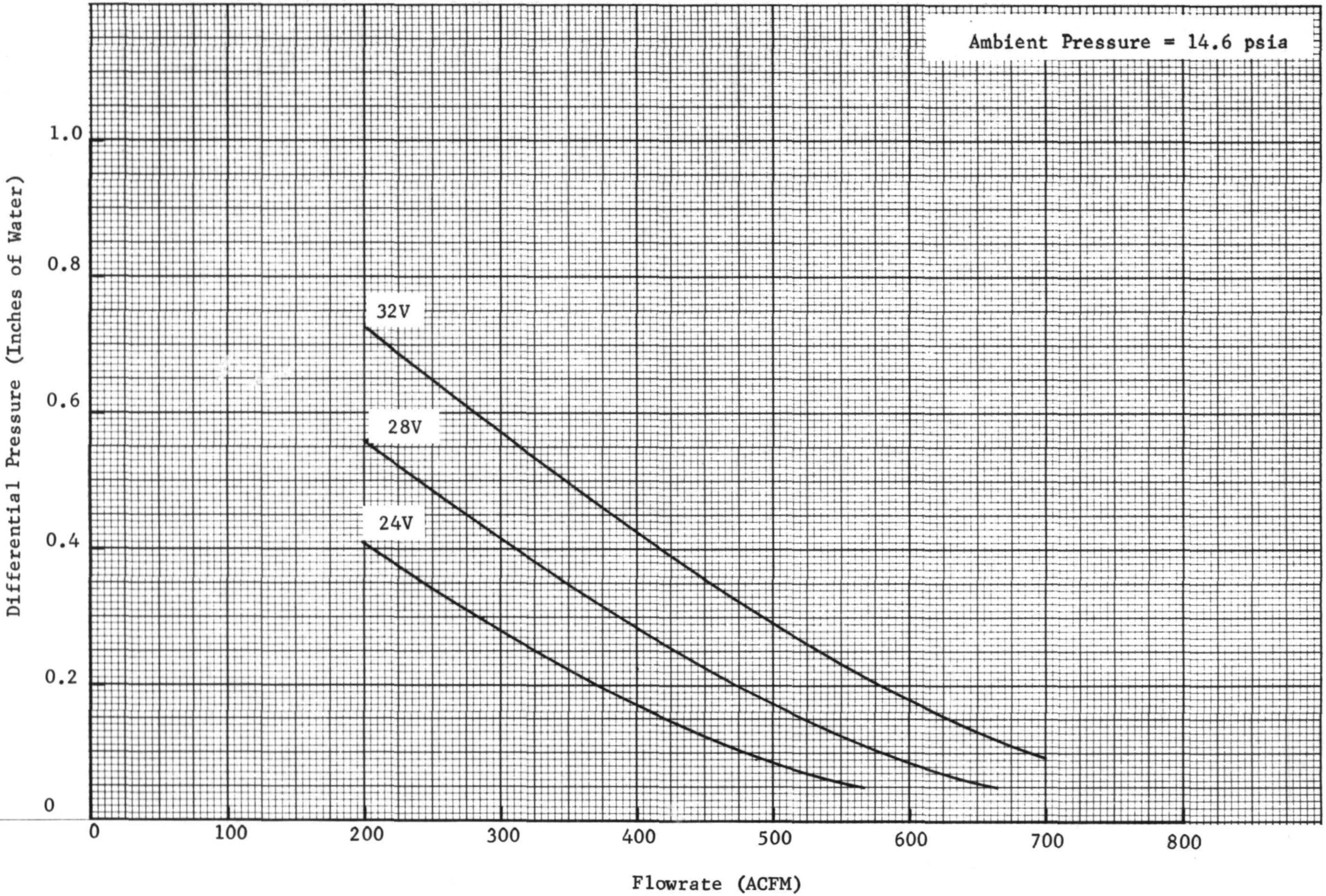


Figure 13. Cluster Performance - 3 Fans Operating/1 Fan Freewheeling

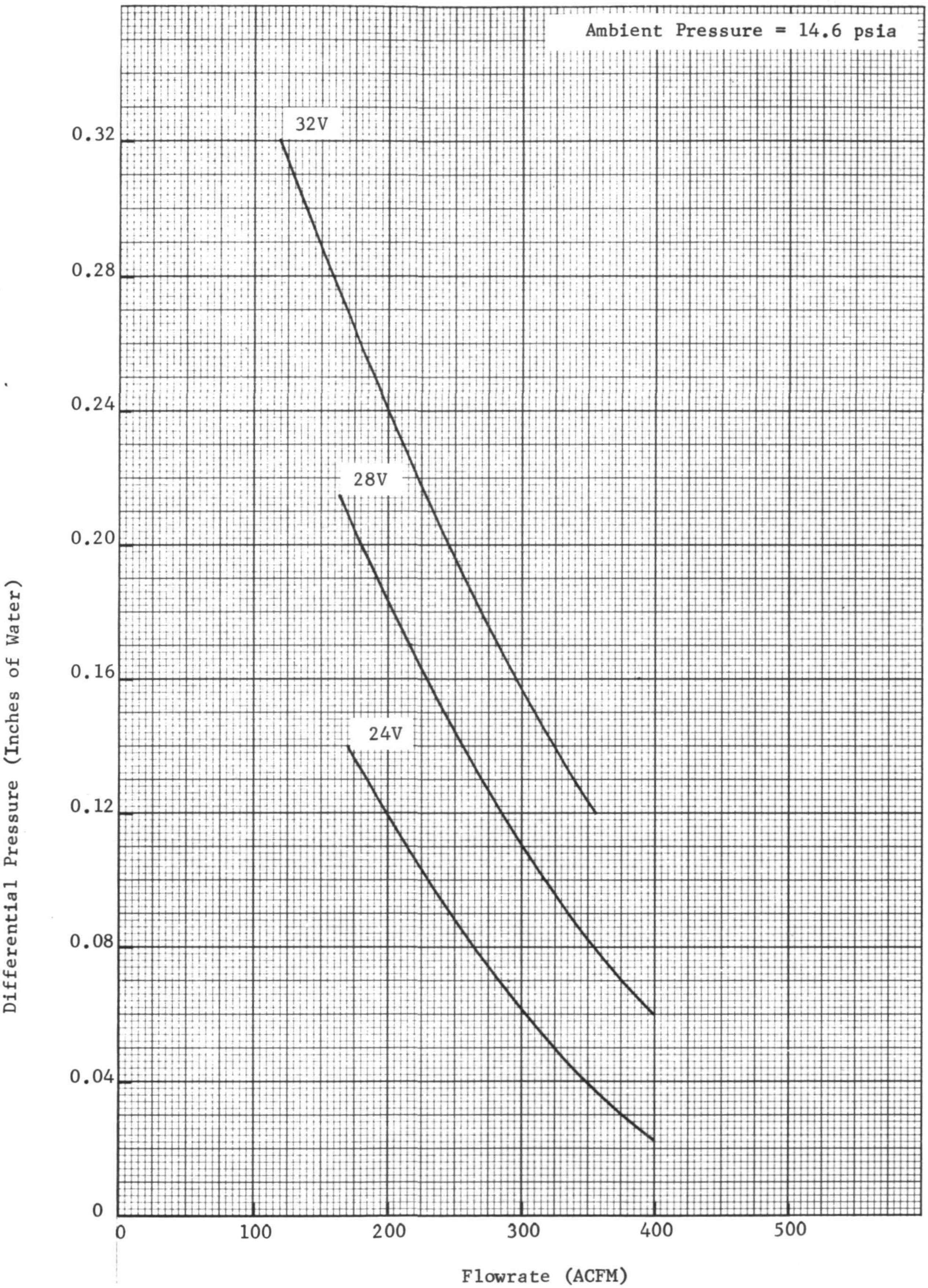


Figure 14. Cluster Performance - 2 Fans Operating/2 Fans Freewheeling

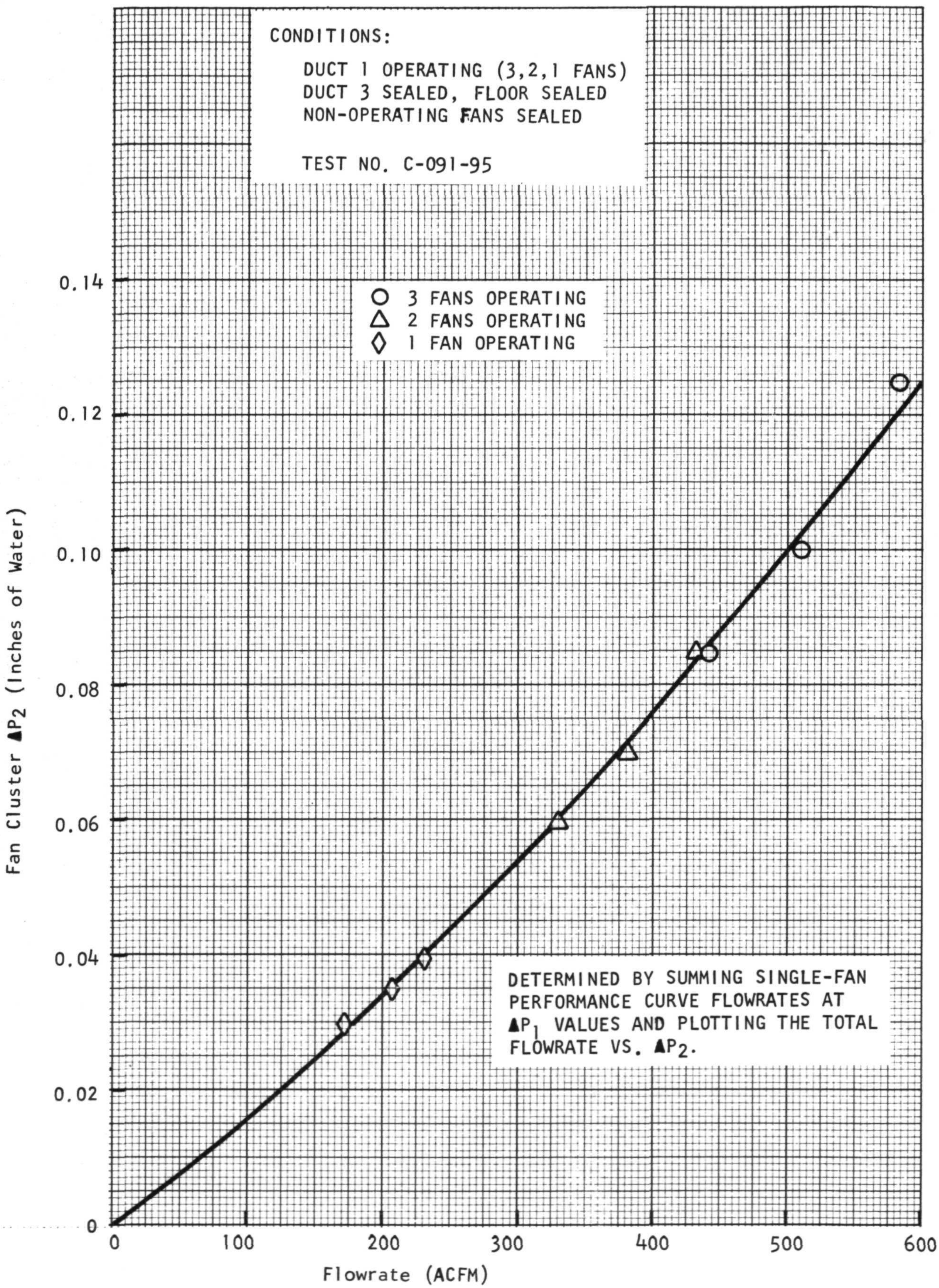


FIGURE 15. BACKFLOW CALIBRATION CURVE FOR DUCT 2

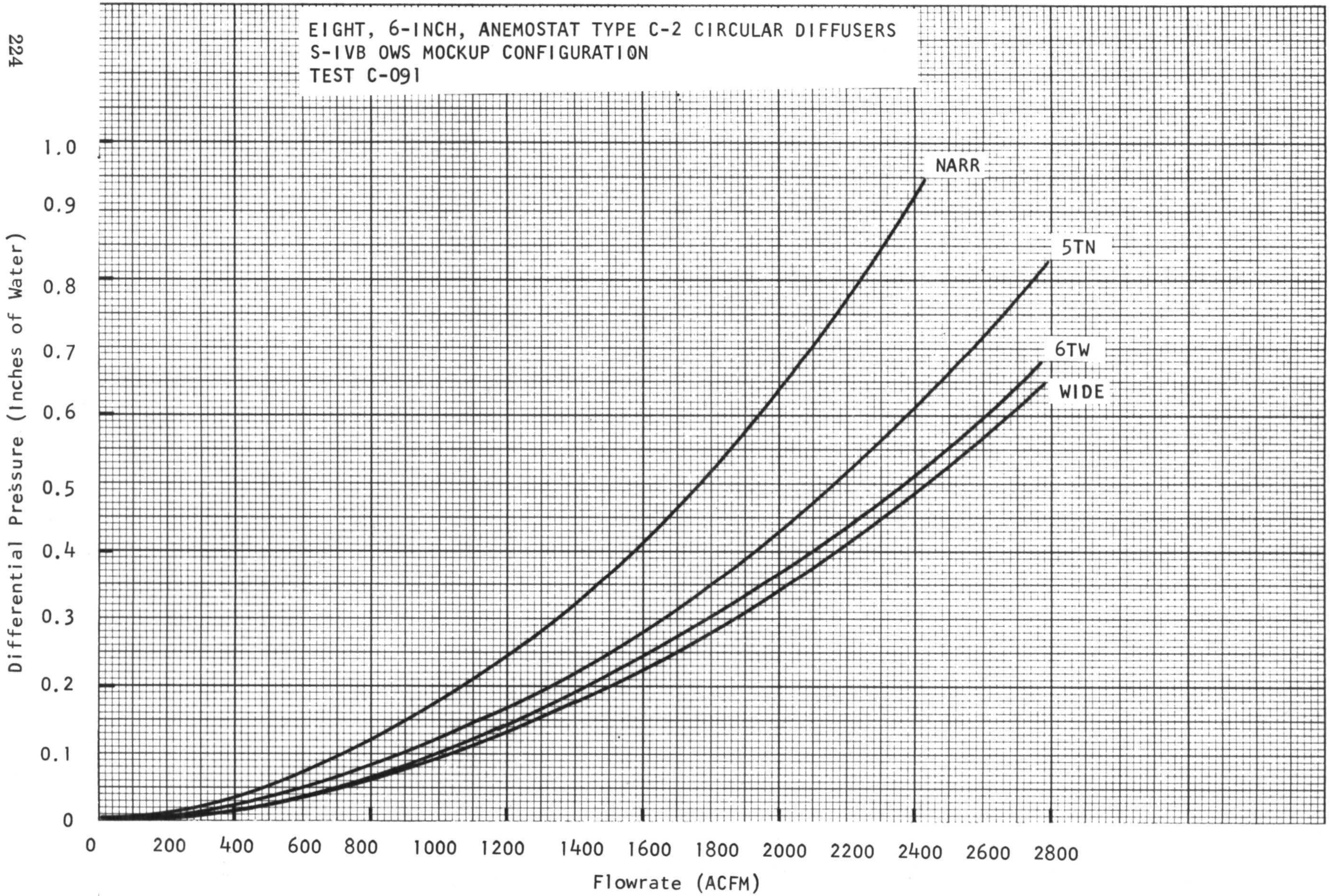


FIGURE 16. WORK AREA AND WARD ROOM DIFFUSER PERFORMANCE - DAMPERS OPEN

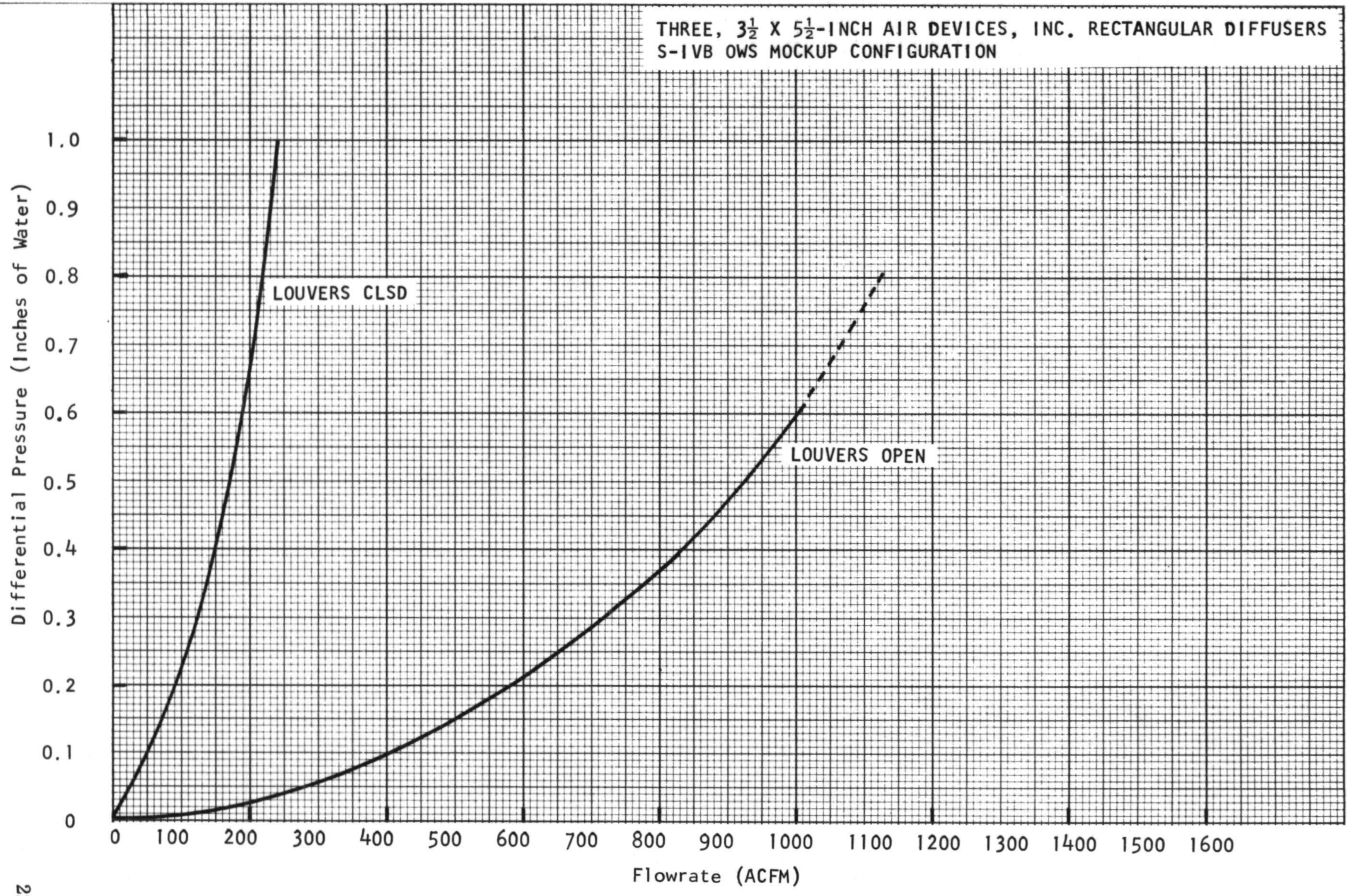


FIGURE 17. SLEEP AREA DIFFUSER PERFORMANCE

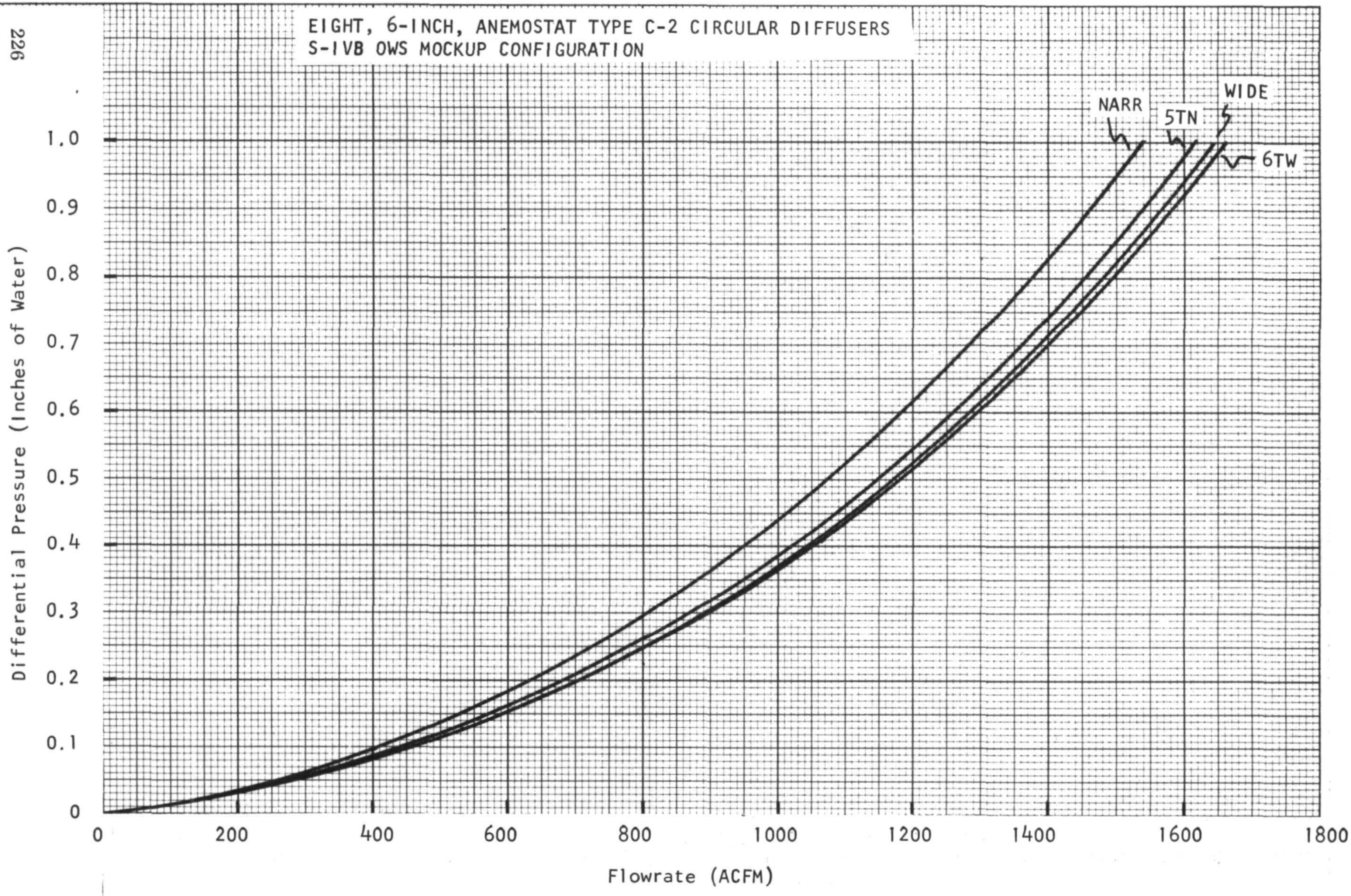


FIGURE 18. WORK AREA AND WARD ROOM DIFFUSER PERFORMANCE - DAMPERS CLOSED

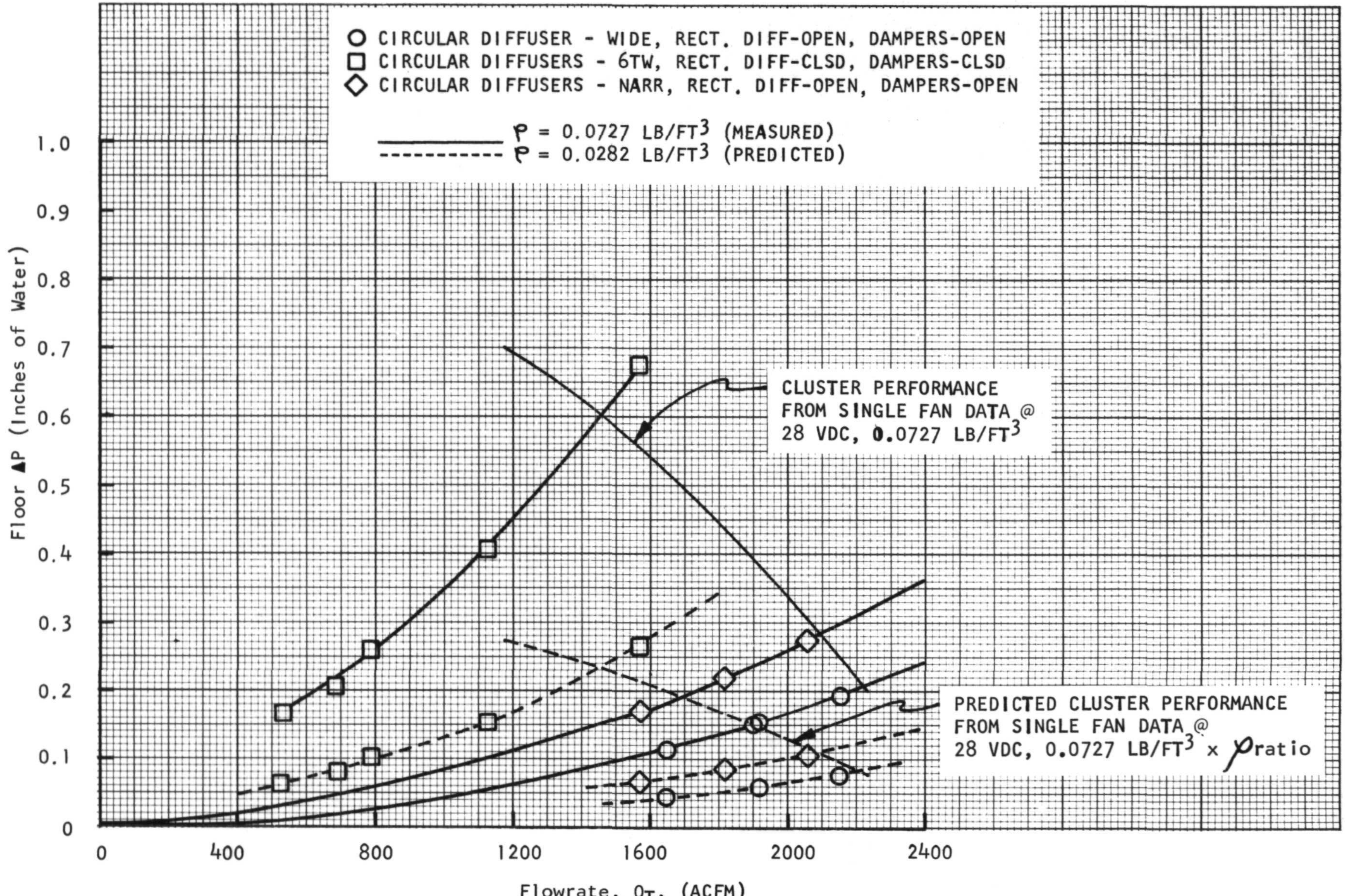
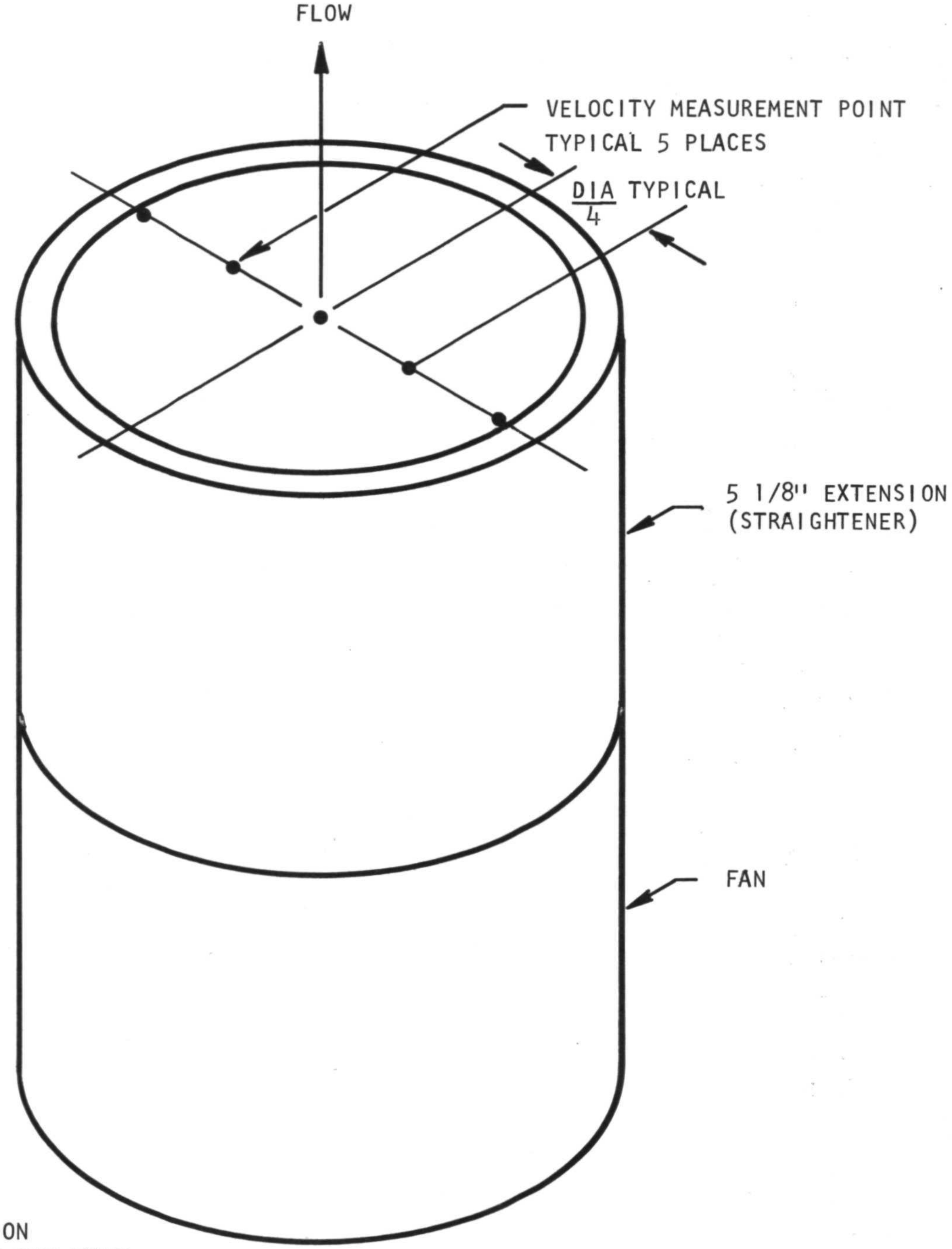


FIGURE 19. VENTILATION SYSTEM PERFORMANCE - FLOOR RESISTANCE & CLUSTER PERFORMANCE



NOTE: I.D. OF EXTENSION
SAME AS I.D. OF FAN EXIT.

FIGURE 20. DETERMINATION OF WMA EXHAUST FAN FLOWRATE

▲ MEASUREMENT LOCATION

● CIRCULAR DIFFUSER LOCATION

■ RECTANGULAR DIFFUSER LOCATION

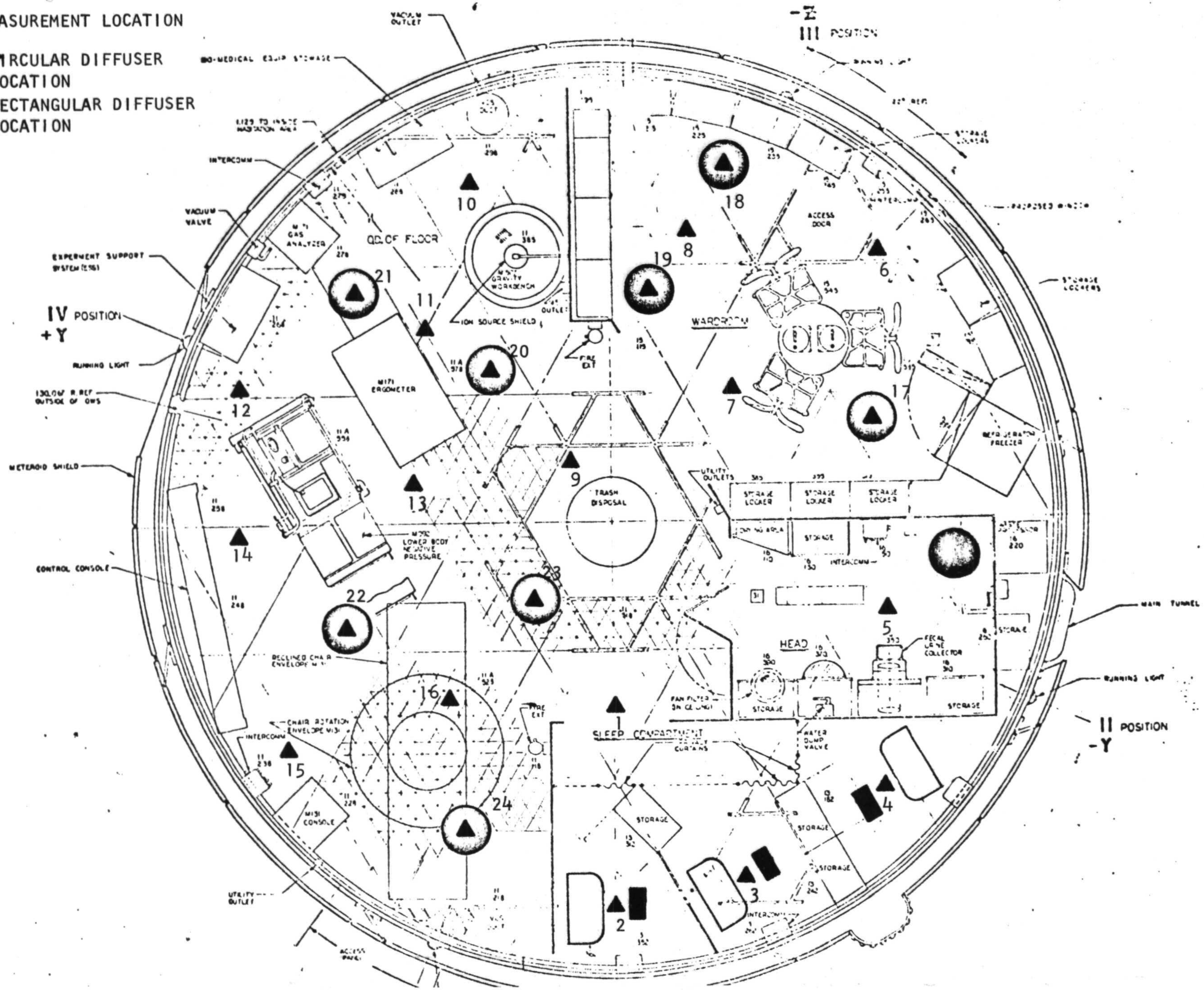


FIGURE 21. VELOCITY SURVEY MEASUREMENT LOCATIONS - CREW QUARTERS

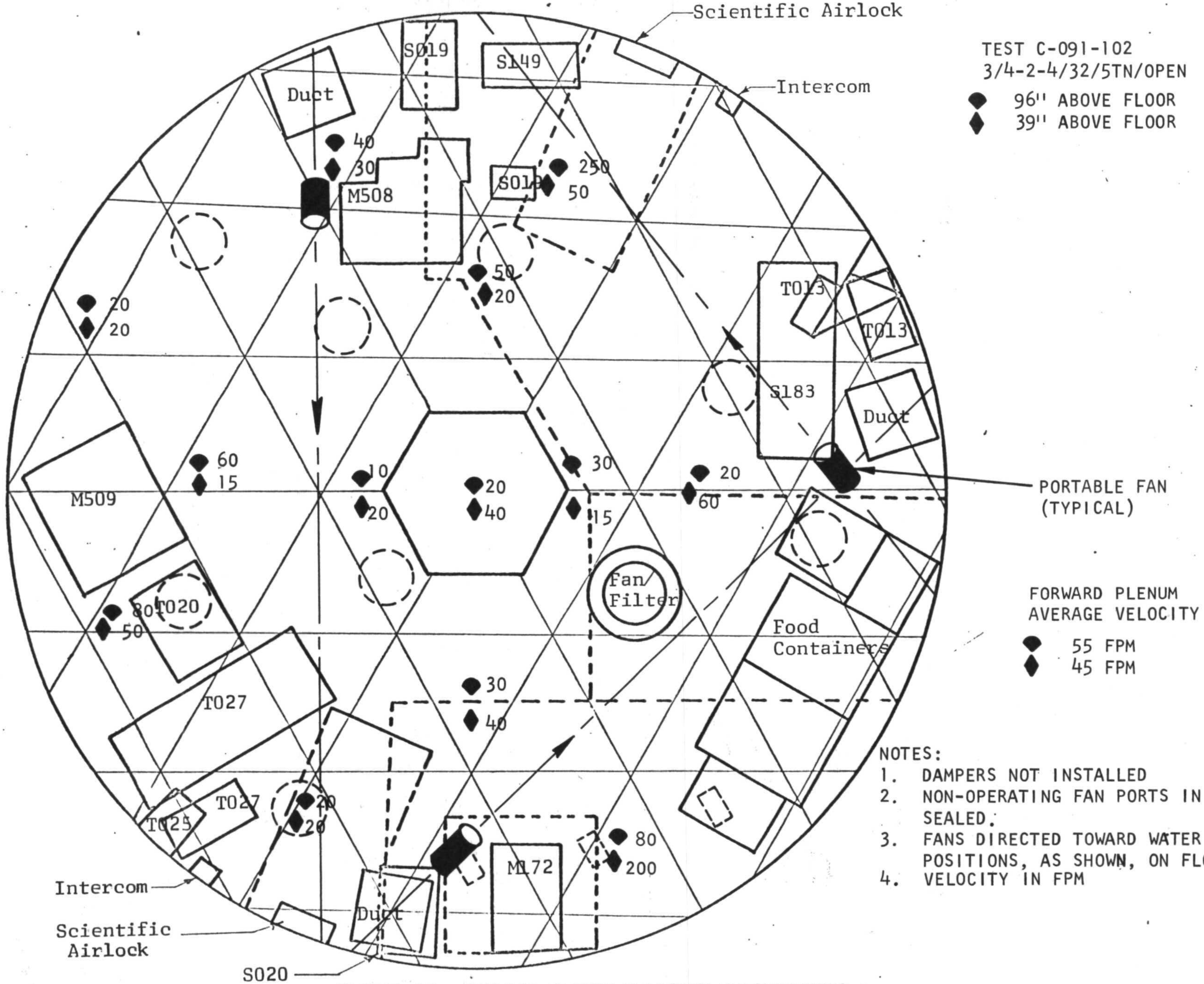


FIGURE 22. FORWARD PLENUM VELOCITY MEASUREMENTS — 3 PORTABLE FANS AND CLUSTERS OPERATING AT 32 VDC

NOTES:
1. DAMPERS NOT INSTALLED
2. NON-OPERATING FAN PORTS IN DUCT 2 SEALED.
3. FANS DIRECTED TOWARD WATER TANKS FROM POSITIONS, AS SHOWN, ON FLOOR
4. VELOCITY IN FPM

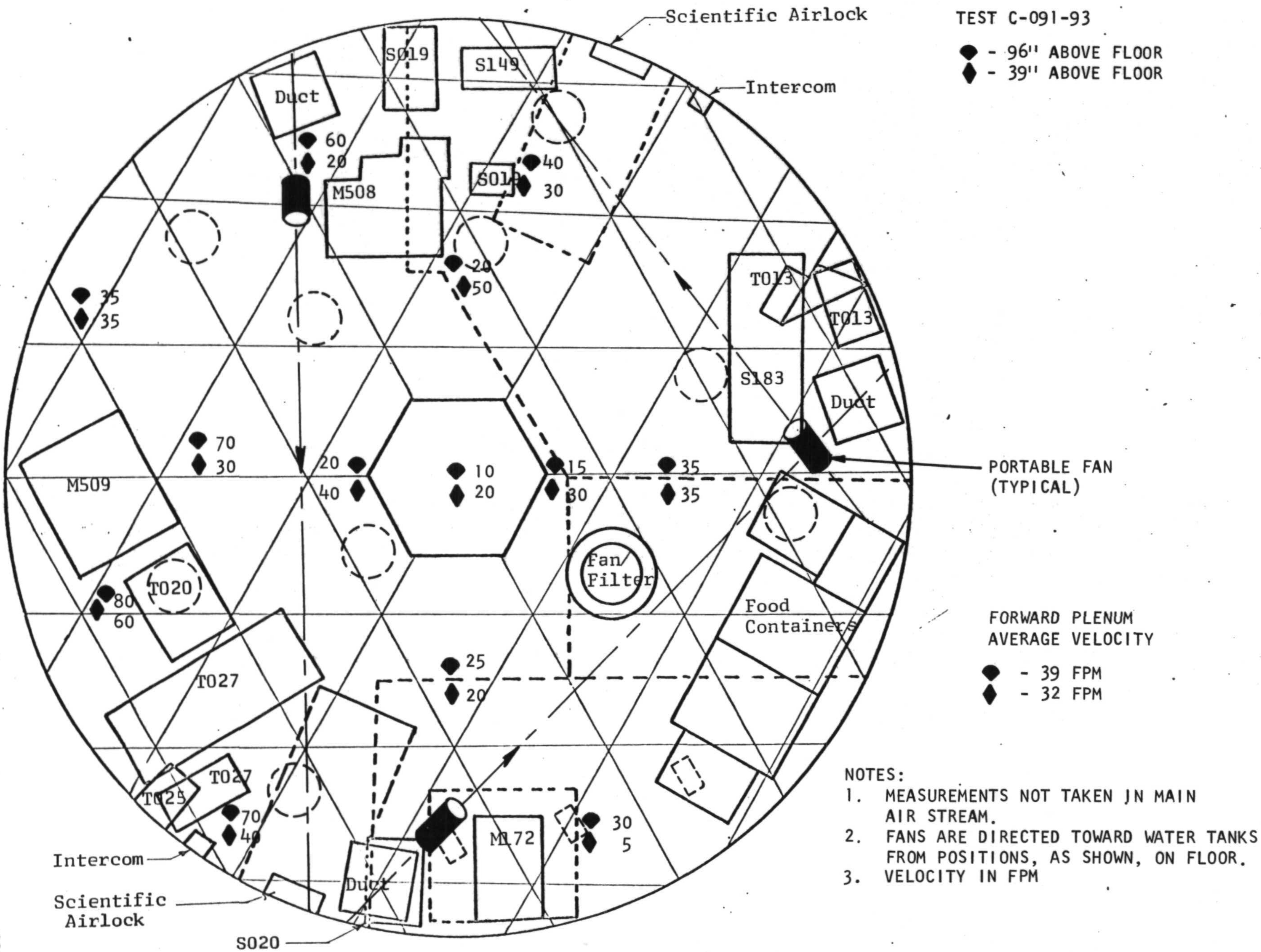
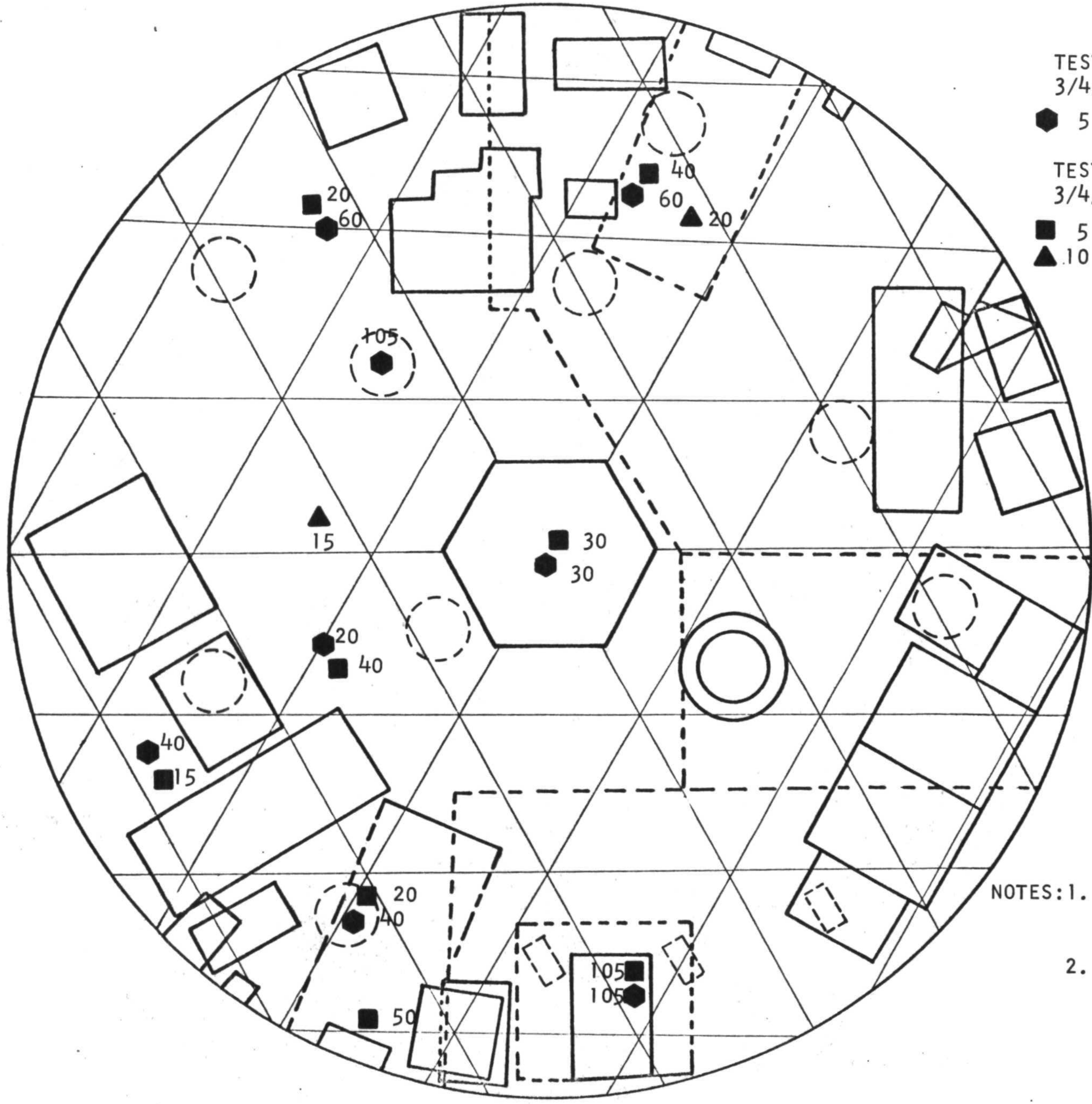


FIGURE 23. FORWARD PLENUM VELOCITY MEASUREMENTS — THREE PORTABLE FANS (ONLY) OPERATING AT 28 VDC



TEST C-091-90
3/4/28/5TN/OPEN

⬢ 5 FT. ABOVE FLOOR

TEST C-091-91
3/4/28/NARR/OPEN

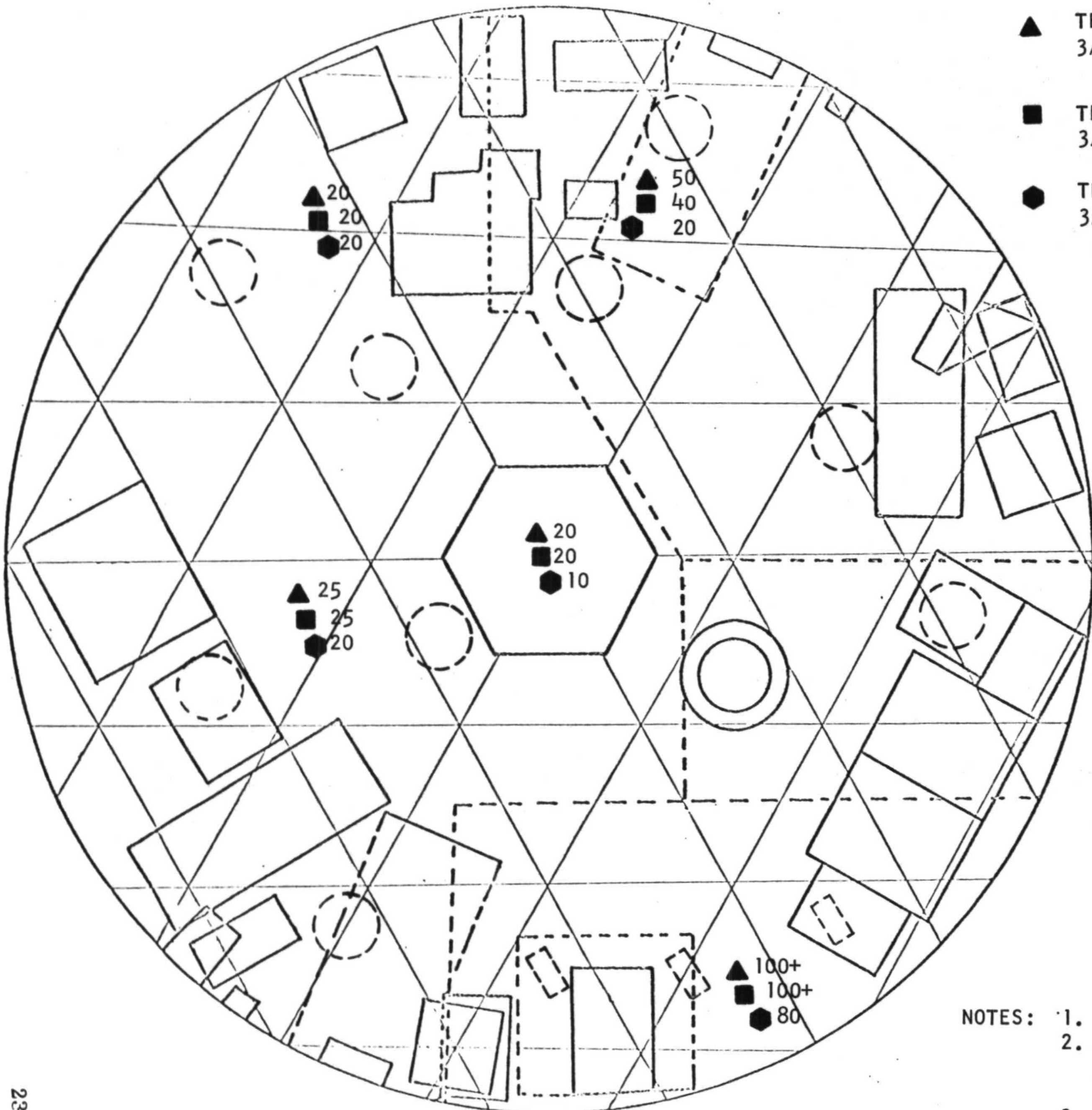
■ 5 FT. ABOVE FLOOR
▲ 10 FT. ABOVE FLOOR

FORWARD PLENUM
AVERAGE VELOCITY

⬢ 54 FPM
■ 39 FPM
▲ 18 FPM

NOTES: 1. ALL MEASUREMENTS TAKEN WITHOUT OPERATION OF PORTABLE FANS OR WMA EXHAUST FAN.
2. VELOCITY IN FPM

FIGURE 24. FORWARD PLENUM VELOCITY MEASUREMENTS WITH OPERATION OF CLUSTERS ONLY AT 28 VDC



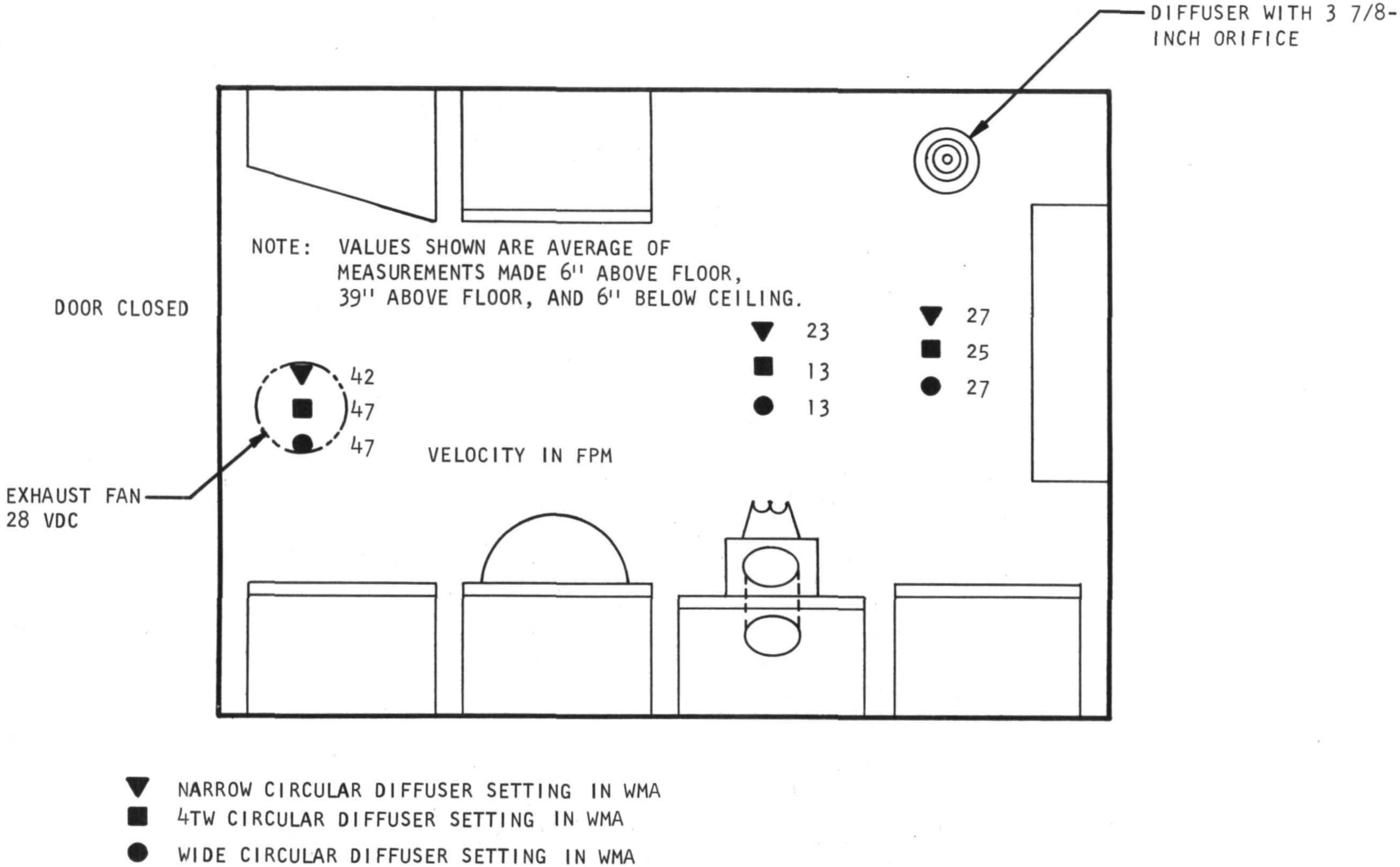
TEST C-091-83
3/4/32/WIDE/OPEN

TEST C-091-84
3/4/28/WIDE/OPEN

TEST C-091-85
3/4/24/WIDE/OPEN

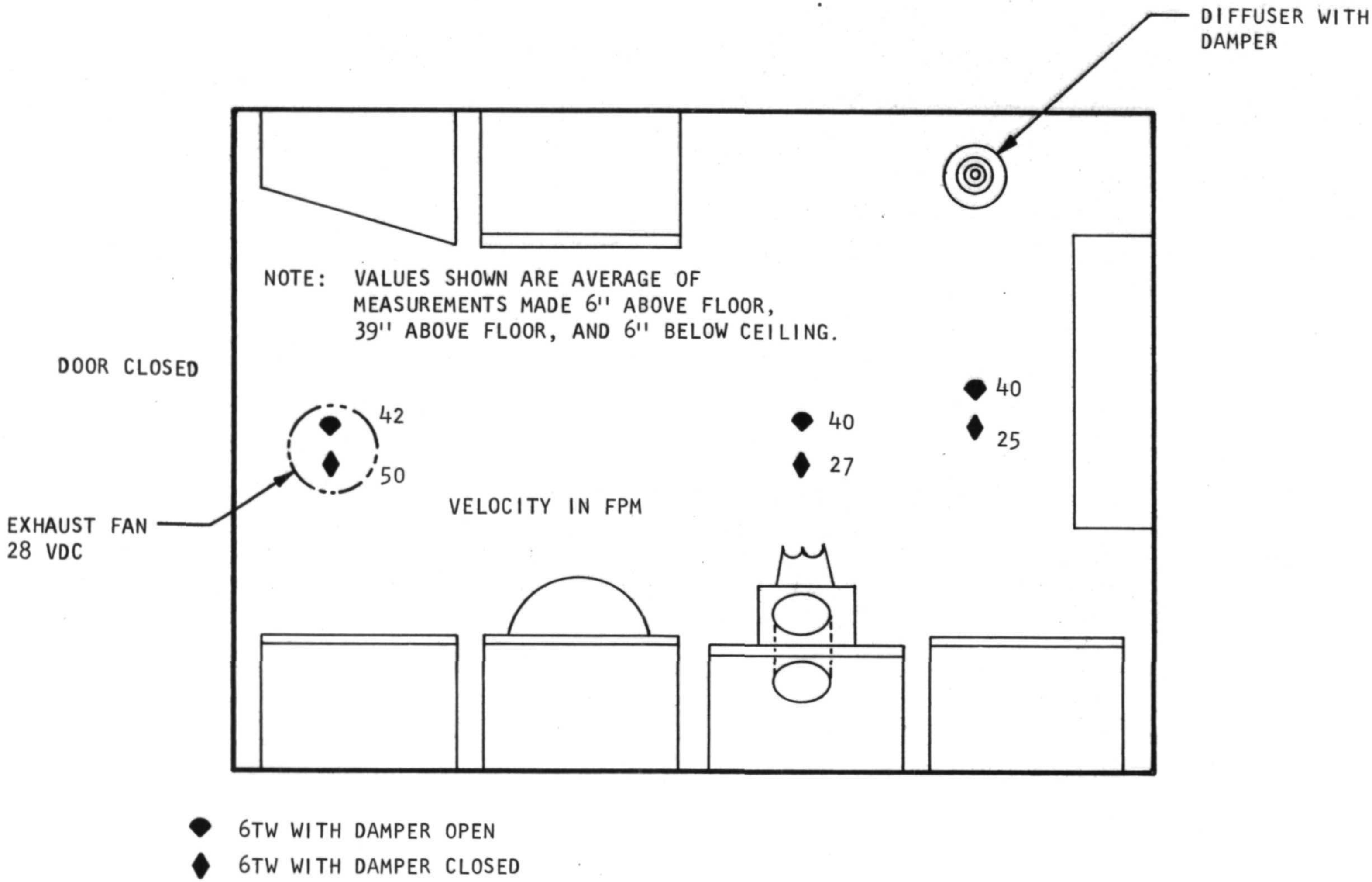
NOTES:
1. Dampers not installed
2. All measurements taken without operation of portable fans or WMA fan.
3. Velocity in FPM
4. All measurements 5' above floor/ceiling.

FIGURE 25. FORWARD PLENUM VELOCITY MEASUREMENTS PRIOR TO DAMPER INSTALLATION



3/4/28/WIDE/OPEN ALL OTHER DIFFUSERS, ALL TESTS

FIGURE 26. WMA AVERAGE VELOCITY WITH ORIFICED DIFFUSER



3/4/28/6TW/OPEN ALL OTHER DIFFUSERS, ALL TESTS

FIGURE 27. WMA AVERAGE VELOCITY WITH DAMPERED DIFFUSER

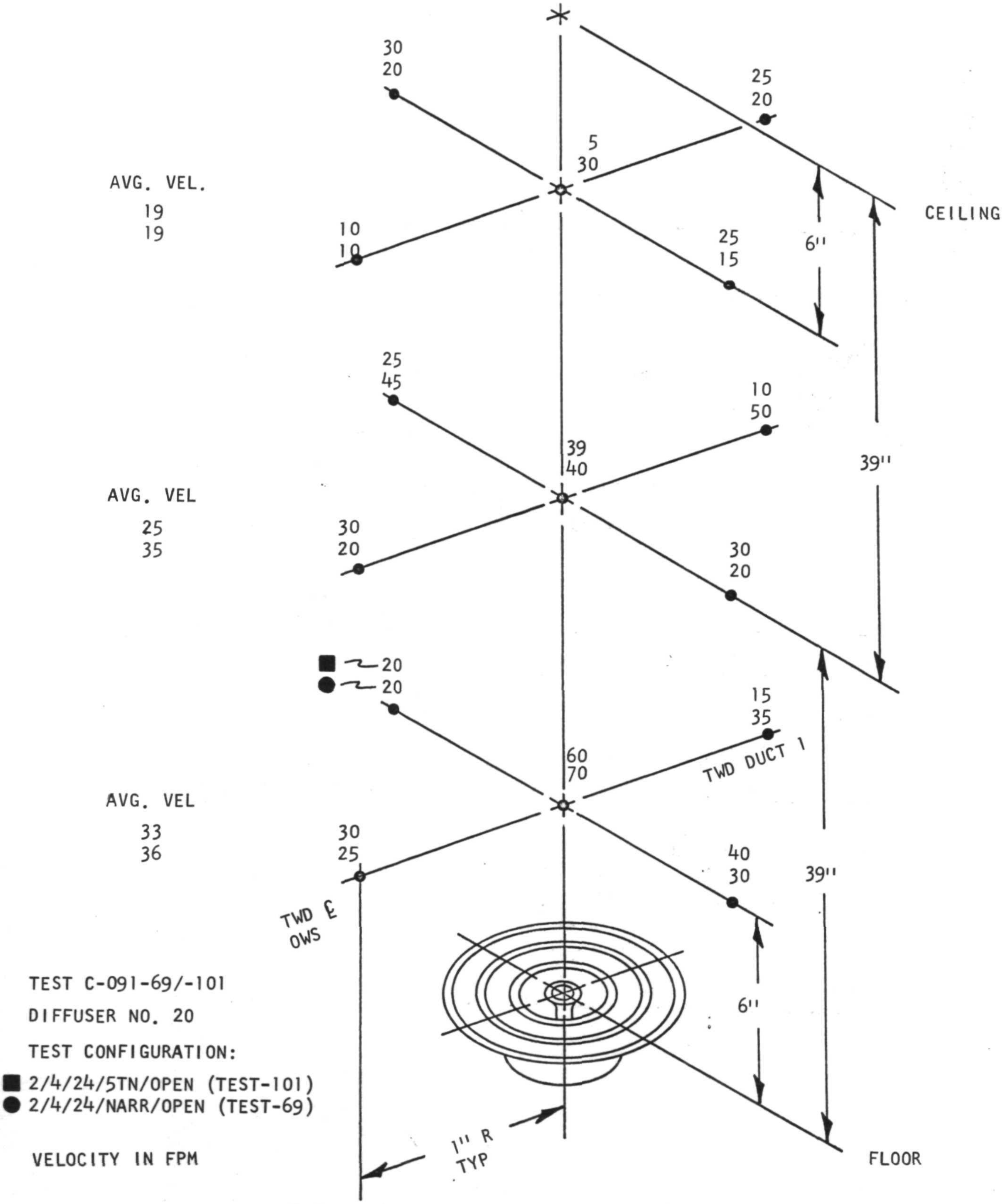


FIGURE 28. CIRCULAR DIFFUSER AIR-VELOCITY PROFILE — COMPARISON OF VELOCITIES AS AFFECTED BY CIRCULAR DIFFUSER PATTERN SETTING

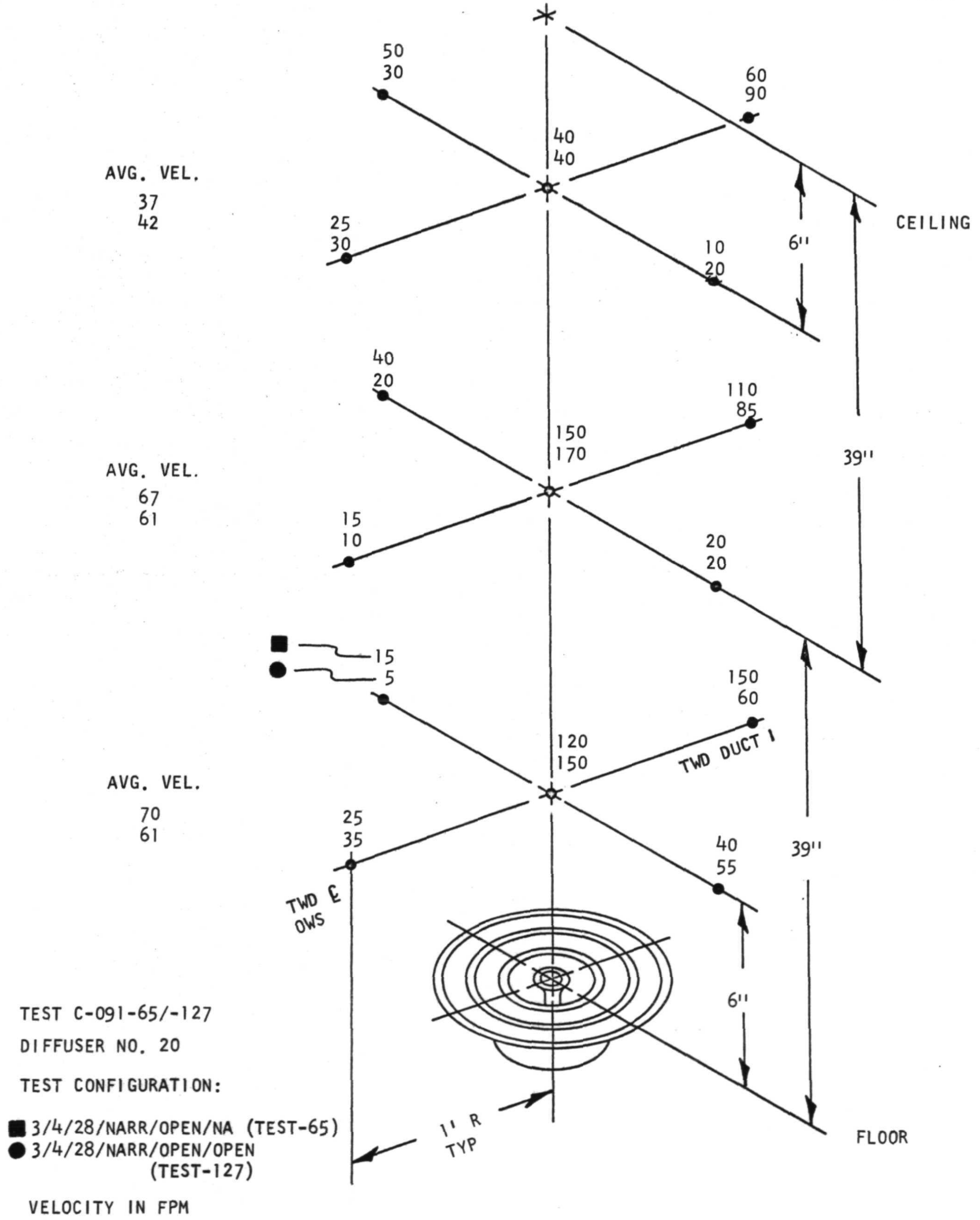
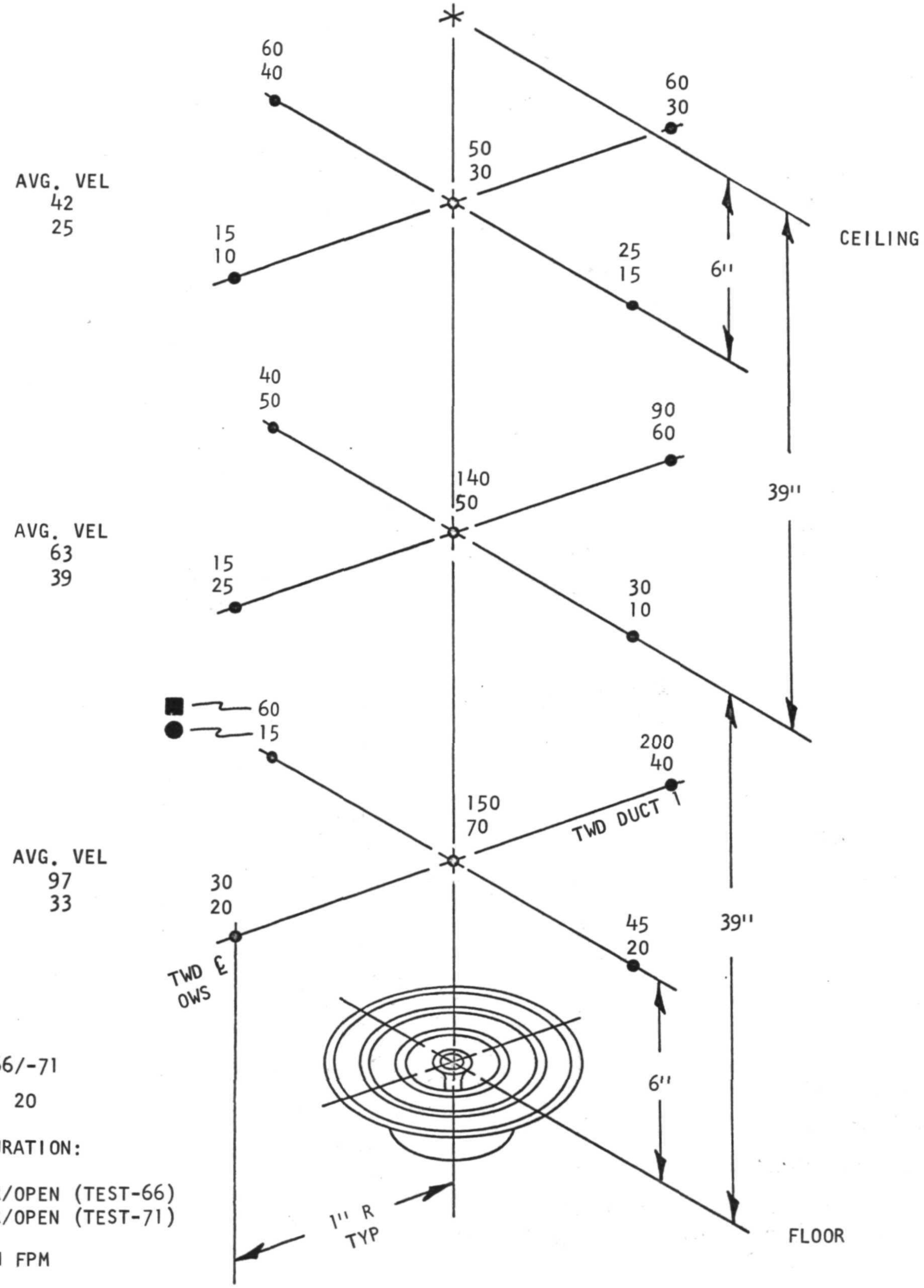


FIGURE 29. CIRCULAR DIFFUSER AIR-VELOCITY PROFILE — COMPARISON OF VELOCITIES AS AFFECTED BY THE INSTALLATION OF DAMPERS



TEST C-091-66/-71

DIFFUSER NO. 20

TEST CONFIGURATION:

■ 3/4/32/NARR/OPEN (TEST-66)
● 2/4/32/NARR/OPEN (TEST-71)

VELOCITY IN FPM

FIGURE 30. CIRCULAR DIFFUSER AIR-VELOCITY PROFILE — COMPARISON OF VELOCITIES AS AFFECTED BY LOSS OF FOUR FANS IN ONE DUCT

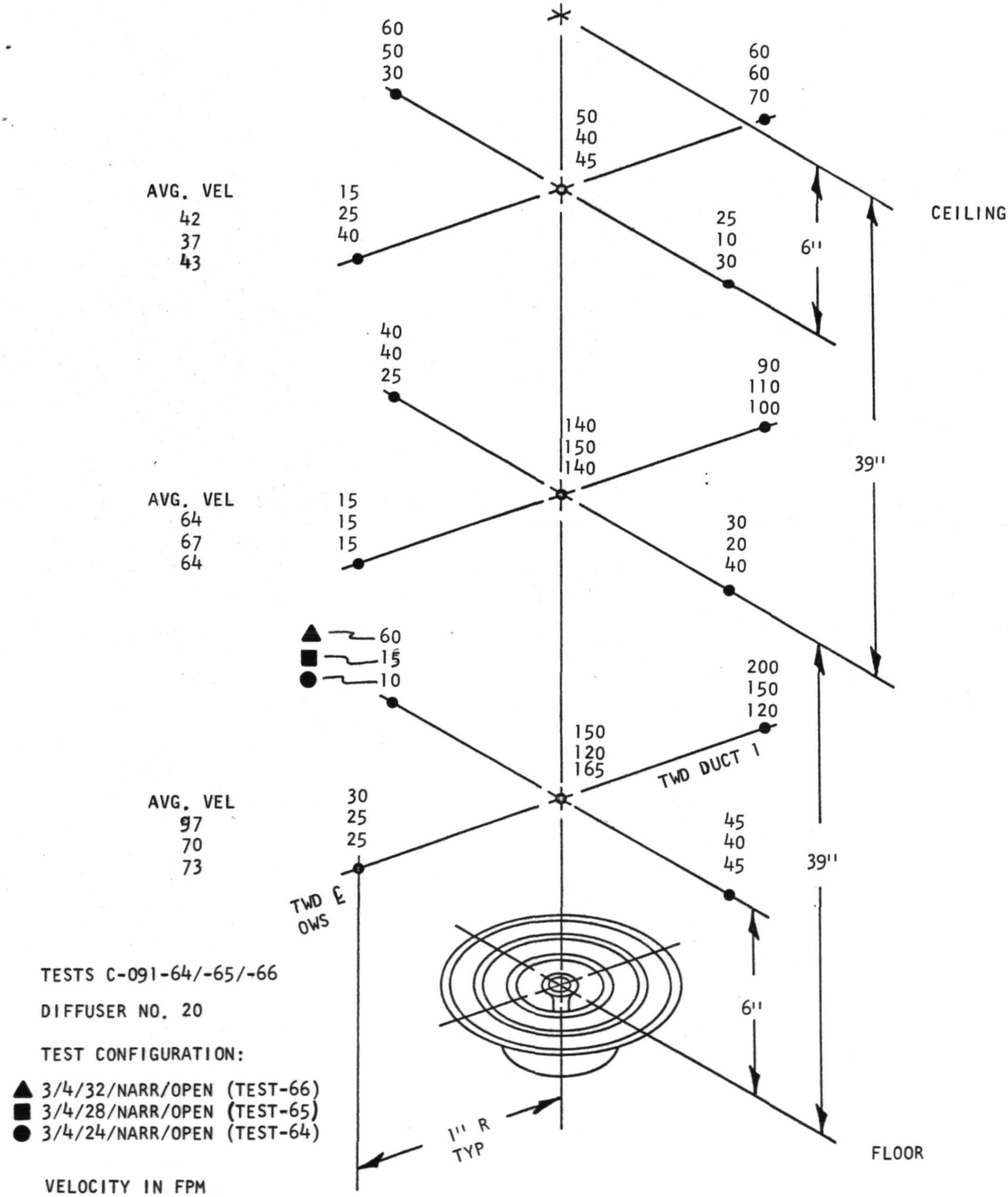


FIGURE 31. CIRCULAR DIFFUSER AIR-VELOCITY PROFILE — COMPARISON OF VELOCITIES AS AFFECTED BY FAN VOLTAGE

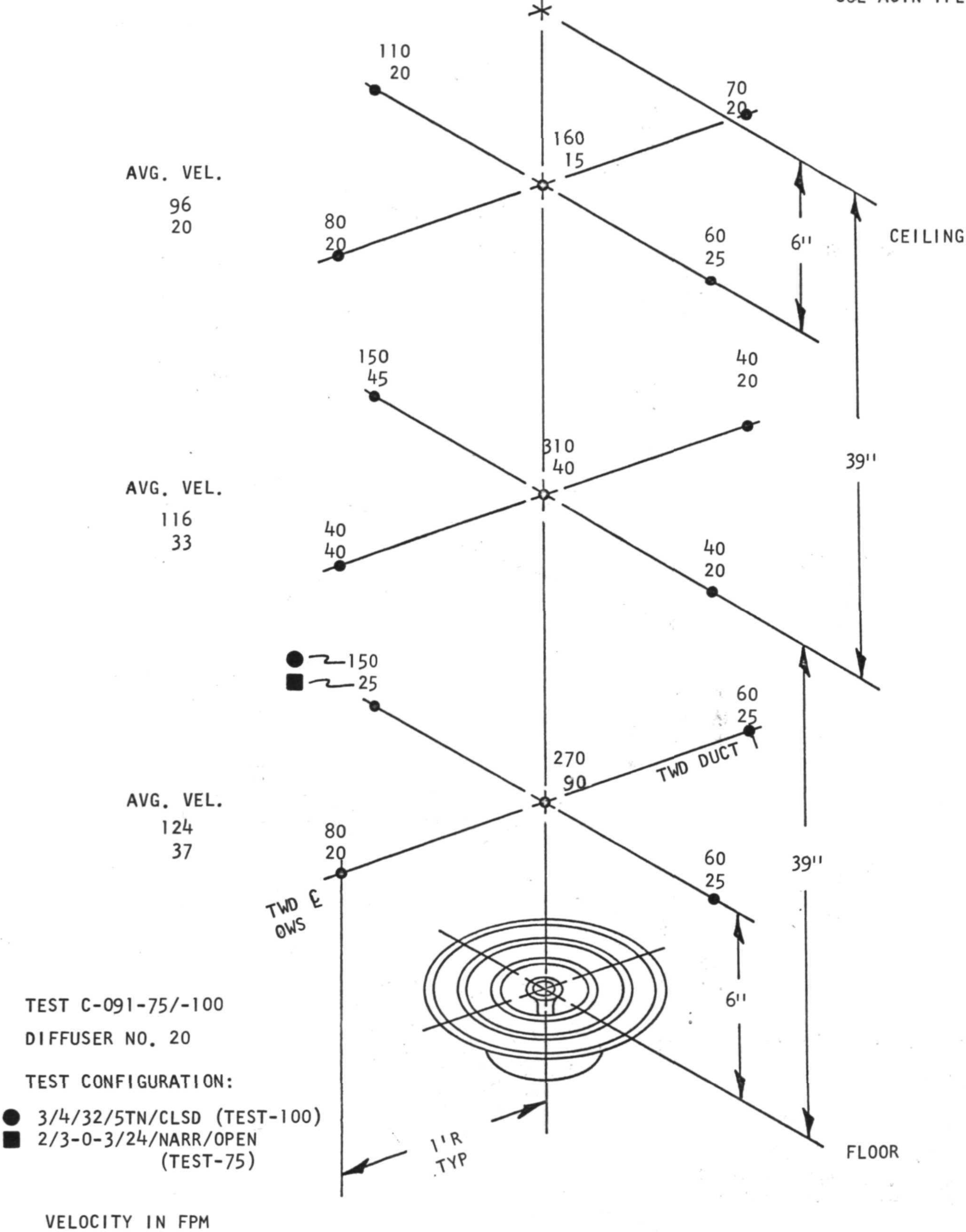


FIGURE 32. CIRCULAR DIFFUSER AIR-VELOCITY PROFILE — COMPARISON OF VELOCITIES PRODUCED BY MAXIMUM AND MINIMUM FLOW CONDITION

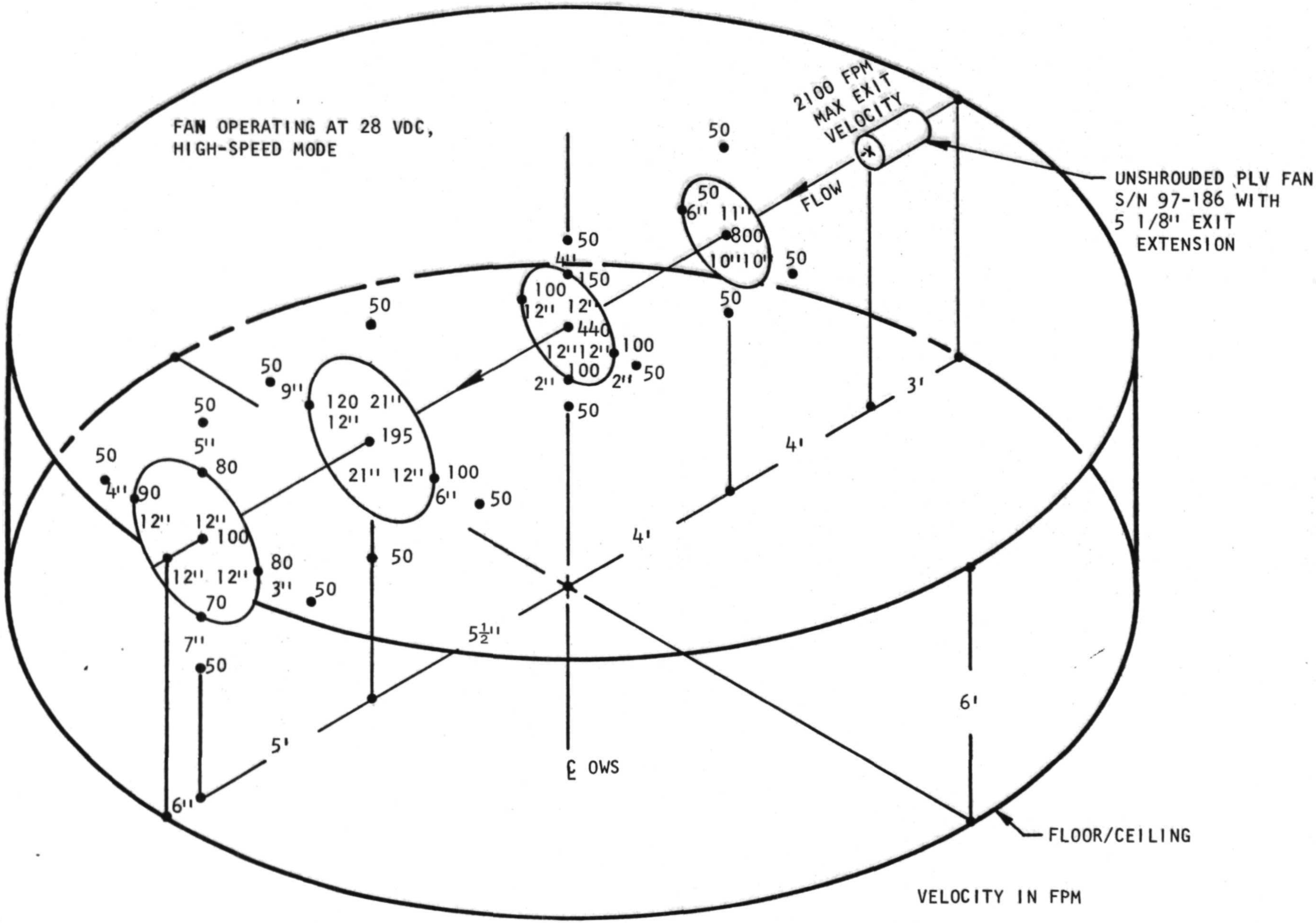


FIGURE 33. PORTABLE FAN VELOCITY PROFILE

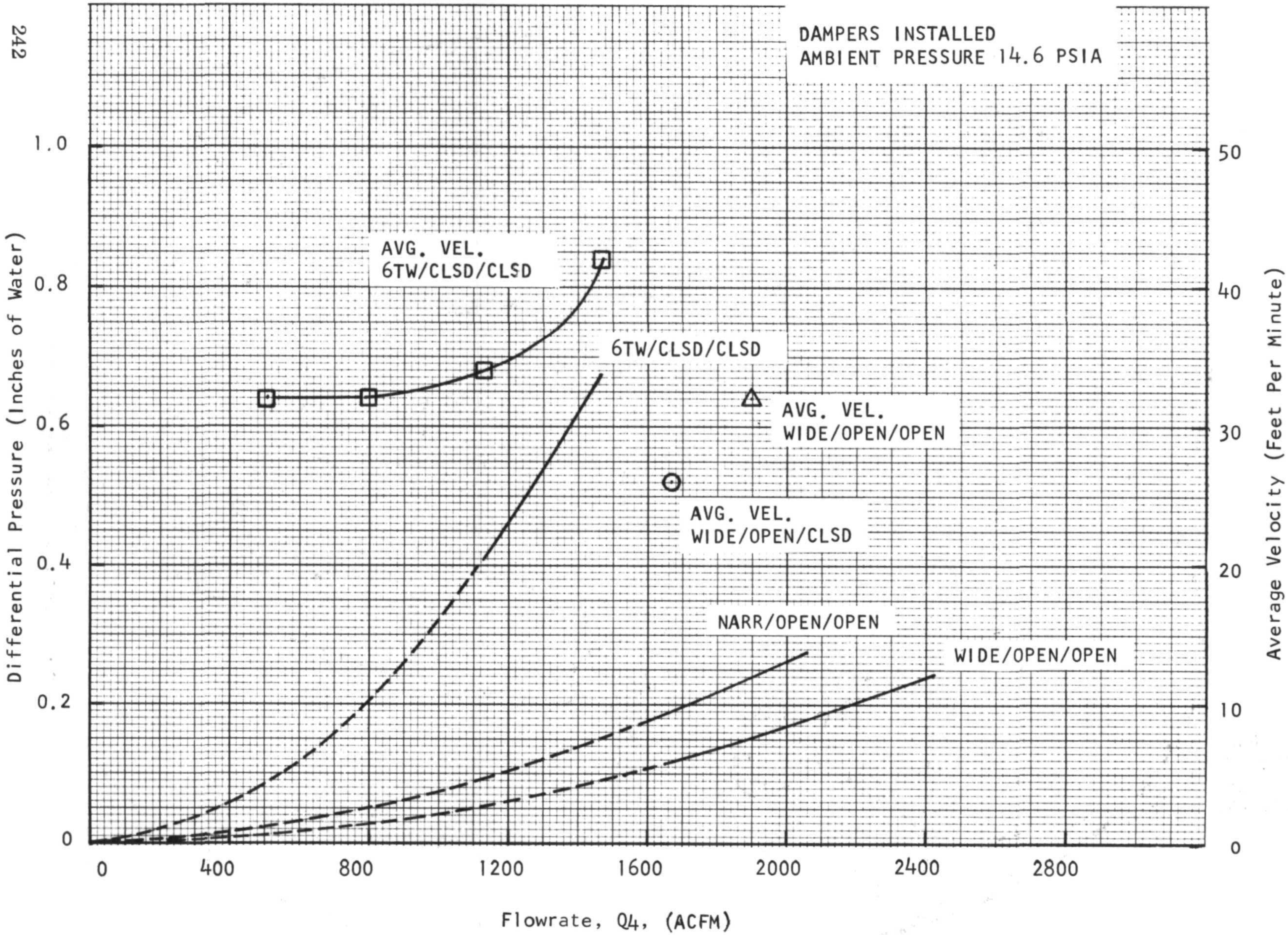


FIGURE 34. CREW QUARTERS VELOCITY RELATIVE TO SYSTEM PERFORMANCE

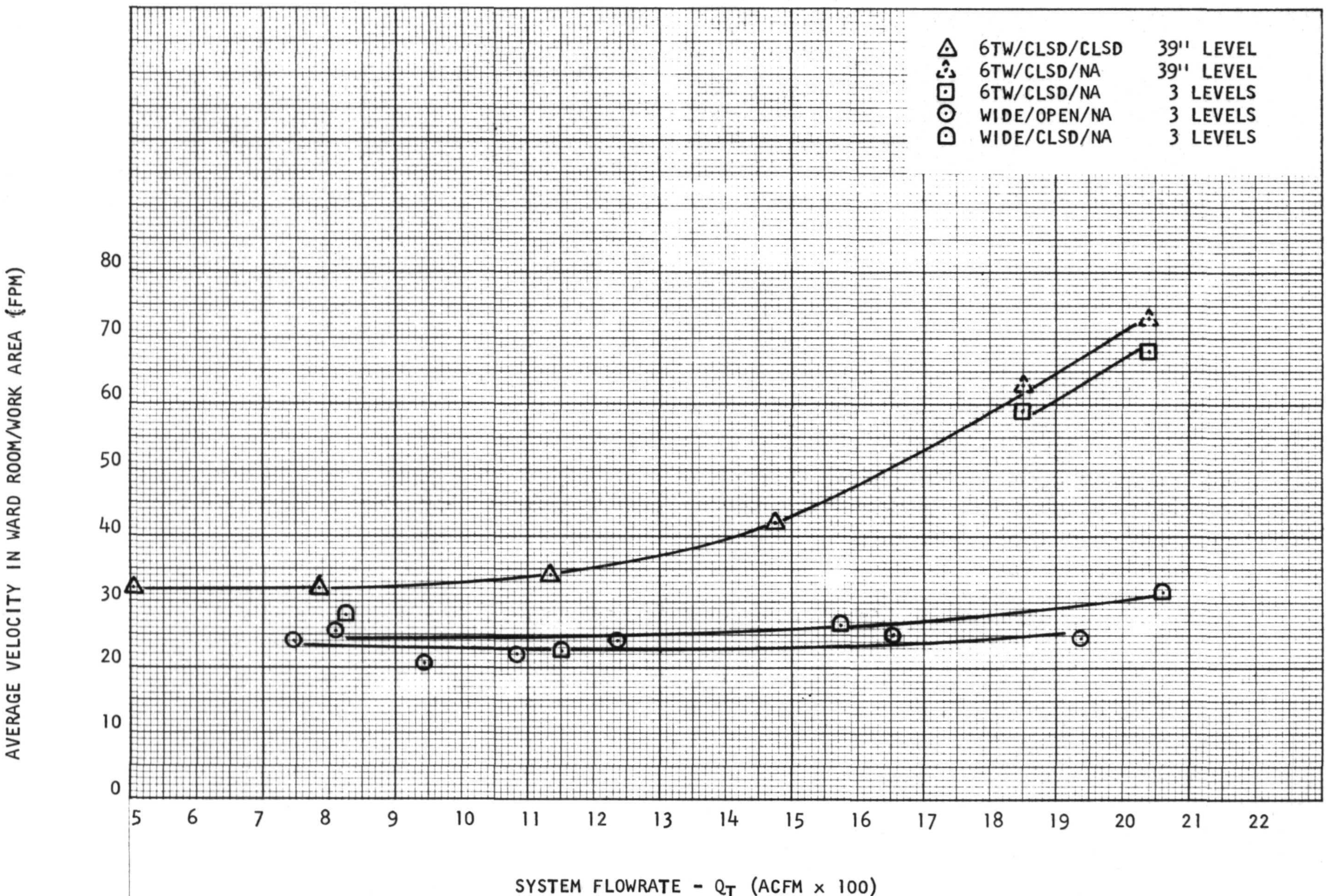


FIGURE 35i. AFFECT OF FLOWRATE AND CIRCULAR DIFFUSER PATTERN SETTING ON AVERAGE VELOCITY

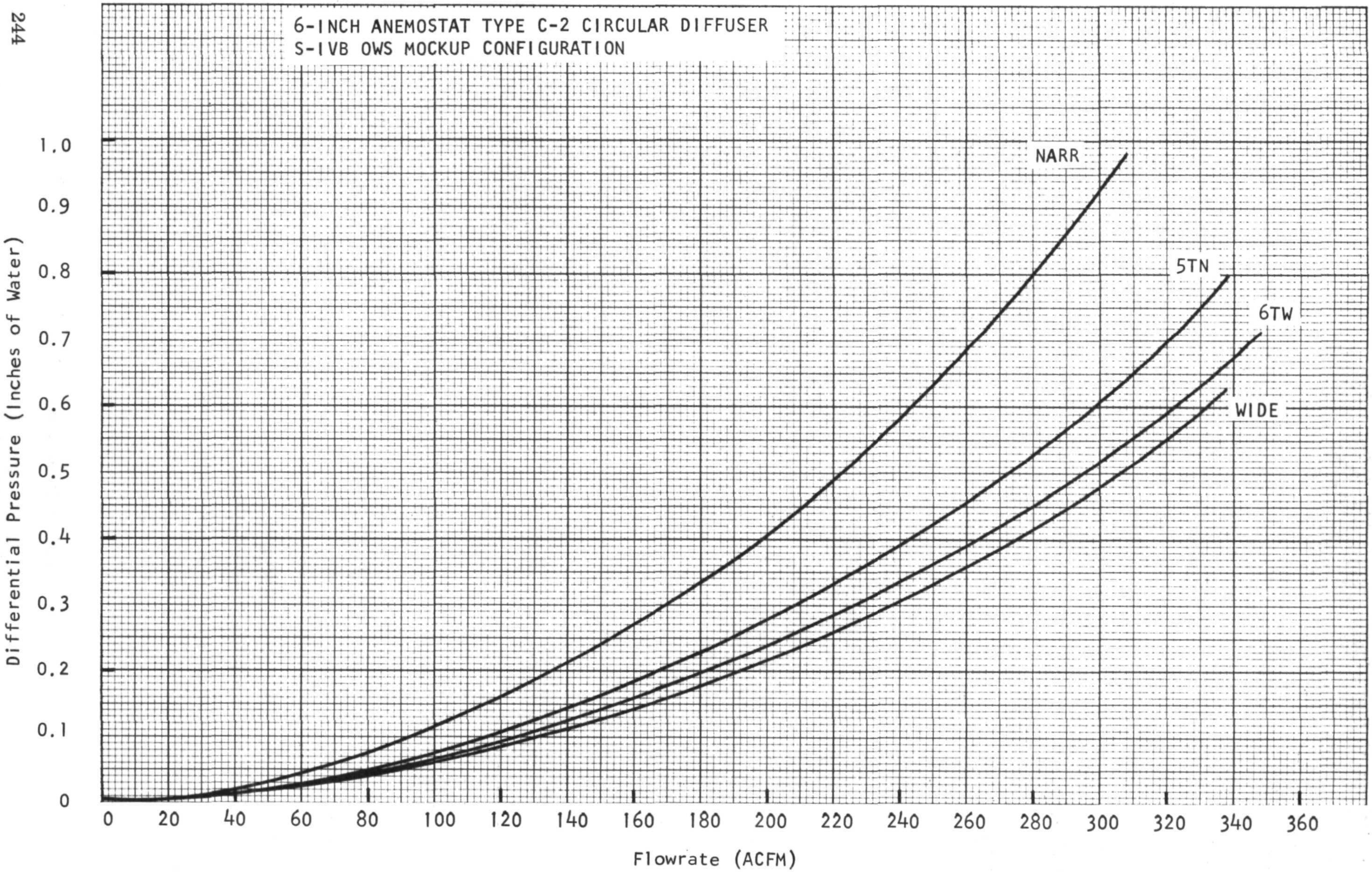


FIGURE 36. SINGLE CIRCULAR DIFFUSER PERFORMANCE - DAMPER OPEN

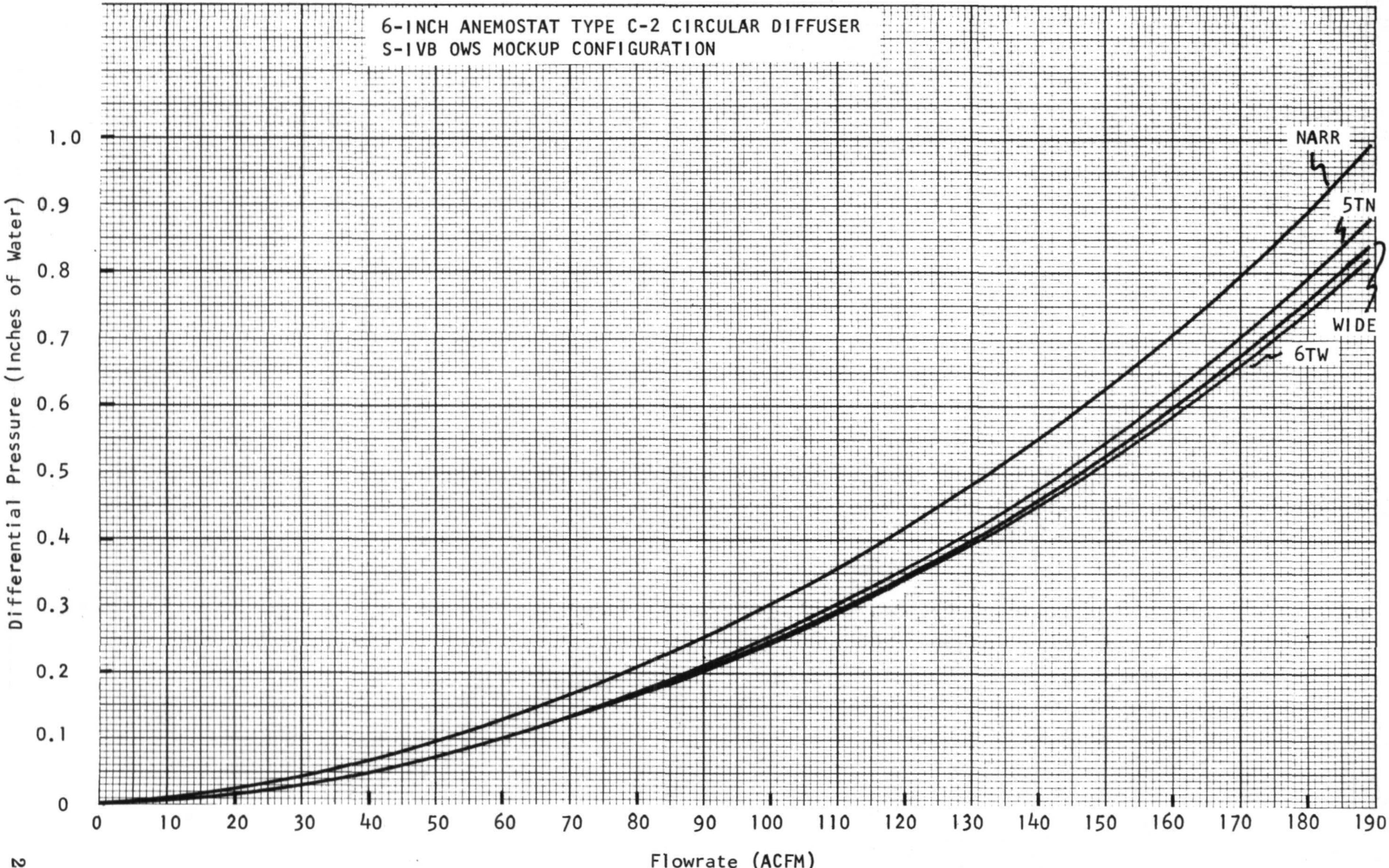


FIGURE 37. SINGLE CIRCULAR DIFFUSER PERFORMANCE - DAMPER CLOSED

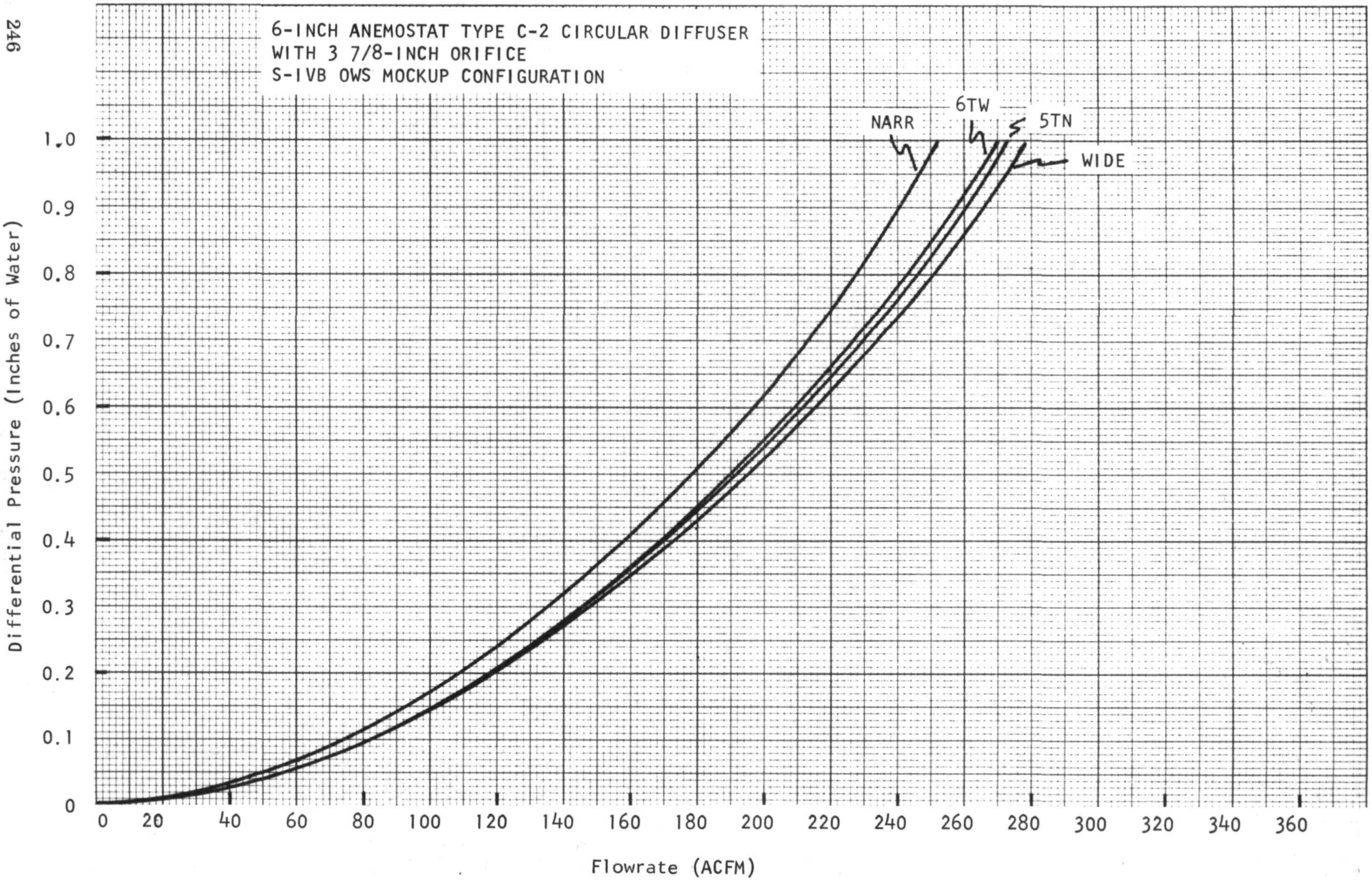


FIGURE 38. SINGLE CIRCULAR DIFFUSER PERFORMANCE - WITH ORIFICE

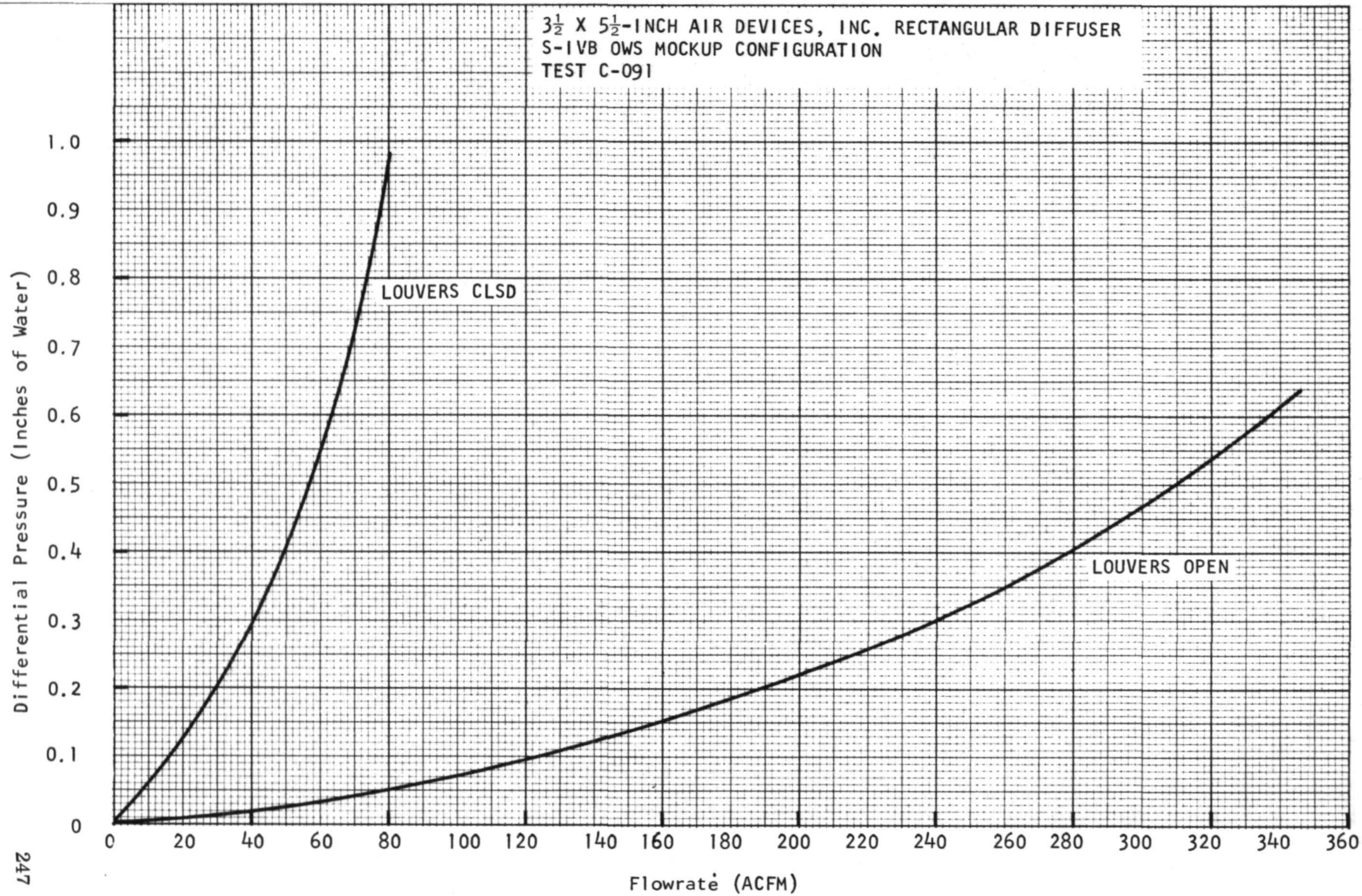


FIGURE 39. SINGLE RECTANGULAR DIFFUSER PERFORMANCE

TEST C-091	DUCTS	FANS PER DUCT	VDC	CIR. DIFF. PATT.	RECT. DIFF. PATT.	WMA FAN	ΔP_1 in. Wg.	Q_1 CFM	ΔP_2 in. Wg.	Q_2 CFM	ΔP_3 in. Wg.	Q_3 CFM	ΔP_4 in. Wg.	Q_4 CFM	Q_T CFM
-55	3	4	24	Wide	Open	Off	.320	542	.290	543	.265	568	.105	1574	1653
-56	3	4	24	Wide	Clsd	Off	.355	517	.330	515	.305	540	.160	1511	1572
-85	3	4	24	Wide	Open	Off	.325	540	.290	545	.260	570	.110	1606	1655
-86	3	4	24	Wide	Open	On	.325	540	.285	548	.255	575	.100	1532	1663
-51	3	4	24	8TW	Open	Off	.315	545	.290	545	.270	565	.115	1598	1655
-52	3	4	24	8TW	Clsd	Off	.360	512	.330	515	.310	535	.175	1539	1562
-64	3	4	24	Narr	Open	Off	.365	510	.330	515	.310	535	.170	1609	1560
-80	3	4/4/3	24	Wide	Open	Off	.295	558	.255	567	.160	410	.080	1368	1535
-57	2	4/0/4	24	Wide	Open	Off	.245	590	.045	-260	.195	613	.040	934	943
-67	2	4/0/4	24	4TW	Open	Off	.250	587	.055	-300	.200	612	.040	888	899
-69	2	4/0/4	24	Narr	Open	Off	.260	580	.055	-300	.215	600	.060	922	850
-101	2	4/0/4	24	5TN	Open	Off	.250	587	.055	-300	.205	607	.050	960	894
-72	2	3/0/3	24	Wide	Open	Off	.135	437	.030	-170	.100	480	.025	724	747
-75	2	3/0/3	24	Narr	Open	Off	.140	430	.045	-250	.115	460	.040	764	640
-58	3	4	28	Wide	Open	Off	.410	638	.370	633	.340	668	.135	1782	1939
-62	3	4	28	4TW	Open	Off	.425	630	.370	635	.345	665	.145	1835	1930
-84	3	4	28	Wide	Open	Off	.425	630	.375	630	.340	668	.140	1830	1928
-87	3	4	28	Wide	Open	On	.420	633	.370	635	.340	668	.140	1830	1936
-97	3	4	28	6TW	Open	Off	.425	630	.375	630	.350	660	.150	1840	1920
-98	3	4	28	6TW	Clsd	Off	.490	590	.450	585	.420	675	.240	1833	1850
-65	3	4	28	Narr	Open	Off	.475	600	.435	594	.405	625	.220	1876	1819
-81	3	4/4/3	28	Wide	Open	Off	.390	648	.340	652	.215	460	.110	1601	1760
-59	2	4/0/4	28	Wide	Open	Off	.325	687	.060	-325	.260	720	.050	1054	1082
-60	2	4/0/4	28	4TW	Open	Off	.325	687	.060	-325	.260	720	.050	1014	1082
-70	2	4/0/4	28	Narr	Open	Off	.340	678	.070	-387	.280	708	.080	1088	999
-78	2	4/0/2	28	Wide	Open	Off	.300	700	.045	-260	.095	330	.030	783	770
-79	2	4/0/2	28	4TW	Open	Off	.300	700	.045	-260	.095	330	.035	838	770
-73	2	3/0/3	28	Wide	Open	Off	.170	500	.040	-230	.135	540	.030	783	810
-76	2	3/0/3	28	Narr	Clsd	Off	.200	475	.070	-375	.170	500	.075	730	600
-61	3	4	32	Wide	Clsd	Off	.590	678	.535	687	.500	706	.260	1998	2061
-83	3	4	32	Wide	Open	Off	.535	708	.470	717	.430	745	.175	2057	2170
-88	3	4	32	Wide	Open	On	.540	705	.475	713	.435	742	.180	2098	2160
-63	3	4	32	4TW	Clsd	Off	.615	662	.550	680	.520	695	.280	2044	2037
-66	3	4	32	Narr	Open	Off	.600	672	.550	680	.515	697	.285	2165	2049
-82	3	4/4/3	32	Wide	Open	Off	.495	730	.430	738	.275	515	.145	1865	1983
-99	3	4	32	6TW	Clsd	Off	.610	665	.550	680	.520	695	.285	2035	2040
-100	3	4	32	5TN	Clsd	Off	.625	655	.570	670	.540	683	.320	2022	2008
-102	3	4/2/4	32	5TN	Open	Off	.500	725	.290	155	.405	762	.150	1755	1642
-53	2	4/0/4	32	Wide	Open	Off	.400	783	.065	-360	.320	815	.065	1227	1238
-54	2	4/0/4	32	Wide	Clsd	Off	.420	773	.080	-415	.350	783	.095	1140	1151
-68	2	4/0/4	32	4TW	Clsd	Off	.435	765	.080	-415	.355	790	.100	1152	1140
-71	2	4/0/4	32	Narr	Open	Off	.430	767	.080	-415	.355	790	.100	1222	1142
-74	2	3/0/3	32	Wide	Clsd	Off	.230	555	.060	-325	.185	595	.060	890	825
-77	2	3/0/3	32	Narr	Open	Off	.230	555	.060	-325	.180	600	.060	930	830

TABLE 1. PERFORMANCE DATA - WITHOUT DAMPERS

TEST C-091	DUCTS	FANS PER DUCT	VDC	CIR. DIFF. PATT.	RECT. DIFF. PATT.	DMPR SET.	WMA FAN	ΔP_1 in. Wg.	Q_1 CFM	ΔP_2 in. Wg.	Q_2 CFM	ΔP_3 in. Wg.	Q_3 CFM	ΔP_4 in. Wg.	Q_4 CFM	Q_T CFM
-111	3	4	24	Wide	Open	Open	Off	.330	535	.295	543	.265	568	.115	1649	1646
-116	3	4	24	Wide	Clsd	Open	Off	.370	505	.340	510	.315	532	.180	1603	1547
-117	3	4	24	Wide	Clsd	Open	On	.330	535	.300	538	.270	565	.120	1281	1638
-105	3	4	24	6TW	Clsd	Clsd	Off	.515	380	.500	350	.480	405	.405	1386	1135
-115	3	4	24	Narr	Open	Open	Off	.360	513	.330	518	.300	543	.170	1627	1574
-108	2	4/0/4	24	6TW	Clsd	Clsd	Off	.330	535	.120	-580	.290	550	.165	805	505
-110	3	4	28	Wide	Open	Open	Off	.430	625	.380	627	.345	665	.155	1924	1917
-118	3	4	28	Wide	Open	Open	On	.430	625	.390	622	.350	660	.155	1924	1907
-120	3	4	28	Wide	Open	Open	Off	.440	620	.395	620	.350	660	.150	1893	1900
-121	3	4	28	Wide	Open	Clsd	Off	.545	555	.520	532	.480	577	.320	1820	1664
-104	3	4	28	6TW	Clsd	Clsd	Off	.690	438	.660	413	.640	448	.540	1564	1299
-114	3	4	28	Narr	Open	Open	Off	.475	600	.435	593	.400	627	.220	1872	1820
-107	2	4/0/4	28	6TW	Clsd	Clsd	Off	.430	625	.130	-582	.375	645	.205	911	688
-128	3	4	28	6TW	Open	Open	Off	.445	618	.410	610	.370	648	.180	2035	1876
-109	3	4	32	Wide	Open	Open	Off	.540	705	.485	710	.440	740	.195	2175	2155
-112	3	4	32	Wide	Clsd	Open	Off	.615	663	.565	672	.520	695	.305	2171	2030
-119	3	4	32	Wide	Open	Open	Off	.540	705	.490	707	.440	740	.195	2175	2152
-103	3	4	32	6TW	Clsd	Clsd	Off	.865	483	.825	492	.800	498	.675	1800	1473
-113	3	4	32	Narr	Open	Open	Off	.595	675	.540	685	.500	705	.275	2113	2065
-106	2	4/0/4	32	6TW	Clsd	Clsd	Off	.540	705	.155	-642	.470	723	.260	1052	786

TABLE 2. PERFORMANCE DATA WITH DAMPERS INSTALLED

TEST C-091	DUCTS	FANS PER DUCT	VOLTS	CIR DIFF PATT.	RECT DIFF. PATT.	DMPR SET	WMA FAN	QT CFM	Measurements @ 3 Levels*			Measurements @ 39" Level		
									AVG. VEL. WORK FPM	AVG. VEL. WARD FPM	OVERALL AVG. VEL. FPM	AVG. VEL. WORK FPM	AVG. VEL. WARD FPM	OVERALL AVG. VEL. FPM
WITHOUT DAMPERS														
-97	3	4	28	6TW	Open	NA	Off	1920	43	53	48	39	55	47
-98	3	4	28	6TW	Clsd	NA	Off	1850	52	66	59	48	78	63
-99	3	4	32	6TW	Clsd	NA	Off	2040	63	73	68	61	85	73
WITH DAMPERS														
-121	3	4	28	WIDE	Open	Clsd	Off	1664	23	29	26	-	-	-
-108	2	4-0-4	24	6TW	Clsd	Clsd	Off	505	-	-	-	33	30	32
-106	2	4-0-4	32	6TW	Clsd	Clsd	Off	786	-	-	-	28	35	32
-120	3	4	28	WIDE	Open	Open	Off	1900	24	40	32	-	-	-
-105	3	4	24	6TW	Clsd	Clsd	Off	1135	-	-	-	37	30	34
-103	3	4	32	6TW	Clsd	Clsd	Off	1473	-	-	-	53	31	42

*Six inches above floor, 39 inches above floor, six inches below floor/ceiling.

TABLE 3. CREW QUARTERS AIR VELOCITY

APPENDIX A

DESIGN CRITERIA

A. Velocity Criteria for Comfort

The average velocity range for the crew area, without portable fans, is 15 to 40 FPM, obtainable on demand. Velocities in excess of 40 FPM are to be provided in localized areas by portable fans and/or diffuser adjustment to the narrow (projection) pattern.

The average velocity range of 15 to 40 FPM is to be provided with three ducts operating at fan voltage settings of 28 ± 2 VDC (in-orbit voltage). One duct may be shut down, if necessary, to obtain the 15 FPM velocity. However, during uncomfortably cold conditions, the simultaneous operation of all heaters (one in each duct) is desirable.

Prior to the ventilation tests, no "guarantee" was made concerning forward plenum ventilation except that air velocity above the bulk air velocity would be provided by portable fans only.

B. Velocity Criteria for Safety

Crew-quarters air velocity less than 2 FPM is considered unsafe relative to CO_2 accumulation. Lower velocities in small, localized areas, however, are not to be of concern; i.e., corners and other isolated areas that the crew members would be unlikely to occupy.

C. Minimum Acceptable Duct Flowrate

Six-hundred ACFM is the minimum "target" bulk flowrate in order to assure adequate CO_2 control for crew safety. Such a minimal-flow condition is not expected to occur except during off-nominal conditions such as closing all ventilation dampers, an electrical bus failure, or multiple fan failures.

Fifty ACFM is the minimum allowable flow through each operating fan to prevent fan over-heating problems.

The minimum acceptable flow over each duct heater is 100 ACFM. This criterion, verbally received from MDAC-WD, is based on tests conducted at MDAC-WD. Flowrates 100 ACFM prevents heater overheat and flowrates 150 ACFM prevents excessive air temperature into the crew quarters.

The design flowrate through the waste management area fan/filter/odor-removal unit is 120 ACFM at 26 VDC.

D. Fan Voltage

Voltage to the fans, in orbit, is to be 28 ± 2 VDC.

Addressees:
S&E-ASTN-P, Mr. Paul/Mr. Wood
S&E-ASTN-E, Mr. Kroll
S&E-ASTN-T, Mr. Connor/Mr. Verschoore
S&E-ASTN-PF, Mr. Worlund
S&E-ASTN-PFA, Mr. Hastings (20)/Mr. Allums
S&E-ASTN-PL, Mr. Hopson/Mr. Moses
S&E-ASTN-PLA, Dr. Littles
S&E-ASTN-PLC, Mr. Mitchell
S&E-ASTN-PLD, Mr. Patterson
S&E-ASTN-PT, Mr. Vaniman
S&E-ASTN-SM, Mr. Thompson
S&E-ASTN-XA, Mr. Griner
S&E-ASTN-TF, Mr. Perry
S&E-ASTN-TI, Mr. Kastanakis
S&E-ASTN-TE, Mr. Bradley
S&E-ASTN-TF, File 3.14.91

S&E-ASTN-TFE:JTR/ha 2-22-71

APPROVAL

EXPERIMENTAL EVALUATION OF THE SKYLAB ORBITAL WORKSHOP VENTILATION SYSTEM CONCEPT

By Steve L. Allums, Leon J. Hastings, and James T. Ralston

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

L. J. HASTINGS
Chief, Fluid Mechanics Section

G. PERRY
Chief, Engineering Technology Branch

A. L. WORLUND
Chief, Fluid Mechanics and Dynamics Branch

K. HILL
Chief, Test Division

H. G. PAUL
Chief, Propulsion & Thermodynamics Division

KARL L. HEIMBURG
Director, Astronautics Laboratory

J. T. RALSTON
Chief, Environmental Section

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Mr. Perry
Mr. Harsh

S&E-ASTN-TFE
Mr. Ralston (10)

S&E ASTN-P
Mr. Paul
Mr. Wood

S&E-ASTN-PL
Mr. Hopson
Mr. Moses

S&E-ASTN-PLA
Dr. Littles
Mr. Humphries

S&E-ASTN-PLC
Mr. Mitchell (3)

INTERNAL (Concluded)

S&E-ASTN-PLD
Mr. Patterson
Mr. Bradford

S&E-ASTN-PLB
Mr. Middleton

S&E-ASTN-PT
Mr. Vaniman

S&E-ASTN-PJ
Mr. Cothran

S&E-ASTN-PF
Mr. Worlund

S&E-ASTN-PFA
Mr. Hastings (5)
Mr. Allums (20)

S&E-P
Mr. Roach

S&E-CSE
Mr. Hagood

PM-SL
Mr. Simmons
Mr. Bowden

EXTERNAL

Scientific and Technical Information
Facility (25)
P. O. Box 33
College Park, Maryland 20740
Attn: NASA Representative (S-AK-RKT)

Manned Spacecraft Center
NASA
Houston, Texas 77058
Attn: G. Mills, Mail Code EC2

Manned Spacecraft Center
NASA
Houston, Texas 77058
Attn: J. Turner

Martin-Marietta Corporation
Denver, Colorado 80201
Attn: Mr. L. Browne (2)
Mail Code 8842

McDonnell Douglas Corporation -
Western Division
Santa Monica, California
Attn: M. J. Hamilton (5)
Mail Station 7

Manned Spacecarft Center
NASA
Houston, Texas 77058
Attn: R. Frost, Mail Code KS (5)