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GENERAL AMERICAN TRANSPORTATION CORPORATION

FRICTION LOSS IN FLEXIBLE PLASTIC AIR DUCT

by

R. B. Neveril
H. F. Behls

OCD Work Unit 1423A

GARD Report 1278-2 October 1965

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REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

FOREWORD

The General American Research Division (GARD) of General American Transportation Corporation (GATX) was contracted by Stanford Research Institute (SRI) for the Office of Civil Defense to design, fabricate, and test flexible plastic tubing and fittings which would provide a system for handling ventilation air in fallout shelters when used with the shelter ventilator (shown below) specified in MIL-V-40645, "Package Ventilation Kit, 20-Inch Fan, Modular Drive (Civil Defense)". This program was performed under SRI Subcontract B-70925(4949A-28)-US with Mr. C. A. Grubb serving as project monitor.

PACKAGE VENTILATION KIT IN OPERATION

ABSTRACT

Tests were conducted to determine the pressure drop characteristics of 20-inch diameter, 4-mil thick, polyethylene tubing and both factory and shelter fabricated 90-degree elbows. The tests were performed at flow rates ranging from 1300 to 4100 cubic feet per minute. These plastic components are part of a portable ventilation system that has been developed for Civil Defense fallout shelters, Specification MIL-V-40645.

Fully inflated 20-inch diameter plastic tubing has about three-quarters of the pressure drop of sheet-metal duct. However, the last fifty feet of a plastic duct system, which is not completely inflated, has 1-1/2 to 3 times the pressure drop per foot of fully inflated plastic tubing. The result is that for duct systems over 100 feet long the pressure drops for sheet-metal and plastic tubing are approximately the same.

The friction losses for both factory fabricated and shelter fabricated elbows were established. A 40-inch, smooth radius, 90-degree factory fabricated elbow is recommended for use with the Civil Defense Package Ventilation Kit. This elbow develops a pressure drop equivalent to 50 feet of straight tubing. The best shelter fabricated elbow is a three-piece elbow with a radius of 60 inches that can be fabricated from the straight tubing and tape stocked in the Package Ventilation Kit. This elbow develops a pressure drop equivalent to 90 feet of straight tubing.

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Fan Package

Drive Module Package

Figure 1 PACKAGE VENTILATION KIT (PVK)

SECTION 1

INTRODUCTION

A Package Ventilation Kit (PVK) was developed (see Figure 1 and Ref. 1) for use as an inexpensive method of exhausting stale, hot and humid air from fallout shelters. This ventilator is intended for use with flexible plastic duct systems (see Figure 2) and, therefore, flexible plastic tubing and fittings are supplied with the Kit. The objectives of this program are to determine the friction loss of flexible tubing and fittings, and to recommend the best fittings, based on cost and pressure drop, for use in fabricating shelter duct systems.

Figure 2 PVK DUCT SYSTEMS

SECTION 2

TEST PROCEDURES

2.1 Apparatus

The test apparatus consisted of an 8,000 cfm centrifugal blower connected by a flexible wire-reinforced cloth duct to a 47 foot long, 20-inch diameter test stand which was fabricated from 24 U.S. Gage, zinc coated steel spiral conduit duct with 6 inch seams (see Figures 3 and 4). The design of the test stand is based on recommendations of the National Electrical Manufacturers Association (Ref. 2). Air flow rates were measured with a 14-inch diameter aperture sharp-edge orifice plate which was calibrated with a pitot tube five feet upstream from the orifice. Two air straighteners were located approximately 14 feet and 28 feet upstream of the orifice plate to reduce turbulence. A piezometer ring was located 14 feet downstream from the orifice and 5 feet from the end of the test stand. Inclined manometers were used to measure the pressure drop across the orifice, and the static pressure drop of the test specimens.

2.2 Methods

The specimens were first taped to the test stand. The blower was adjusted to provide the desired flow rates, and the static pressure loss and flow rate (orifice differential pressure) were recorded. Barometric pressure, dry-bulb temperature, and wet-bulb temperature were recorded before each test to provide the flow rate correction factor to standard air (ρ = 0.075 lbs/cu ft). The tare pressure drop of the test apparatus, i.e., the pressure drop caused by the 5 foot length of spiral duct between the plane of the measuring station and the plastic specimens, was subtracted from the test data after its correction to standard air. To establish the tare pressure drop, the friction loss for 100 feet of 20-inch spiral duct -- as measured from the static pressure measuring station -- was determined with the apparatus described above, and the results are shown in Figure 5. The tare pressure drop for the length of spiral conduit between the static pressure measuring station and the test specimen was calculated by multiplying the values of Figure 5 by 0.05 (see Table I); i.e., the ratio of the five foot length to the total 100 feet spiral duct tested.

Table I

Tare Pressure Drop of the Test Apparatus

Air Flow (cfm)	Tare Pressure Drop (inches of water gage)
1200	0.0010
1400	0.0013
1600	0.0018
1800	0.0022
2000	0.0028
2200	0.0033
2400	0.0039
2600	0.0045
2800	0.0052
3000	0.0059
3200	0.0066
3400	0.0075
3600	0.0083
3800	0.0091
4000	0.0100
4200	0.0110

As shown in Figure 5 the friction of air in straight spiral duct, as manufactured by the Carrier Corporation, is approximately five per cent lower than the theoretical values recommended in the friction chart of the ASHRAE Guide and Data Book (Ref. 3).

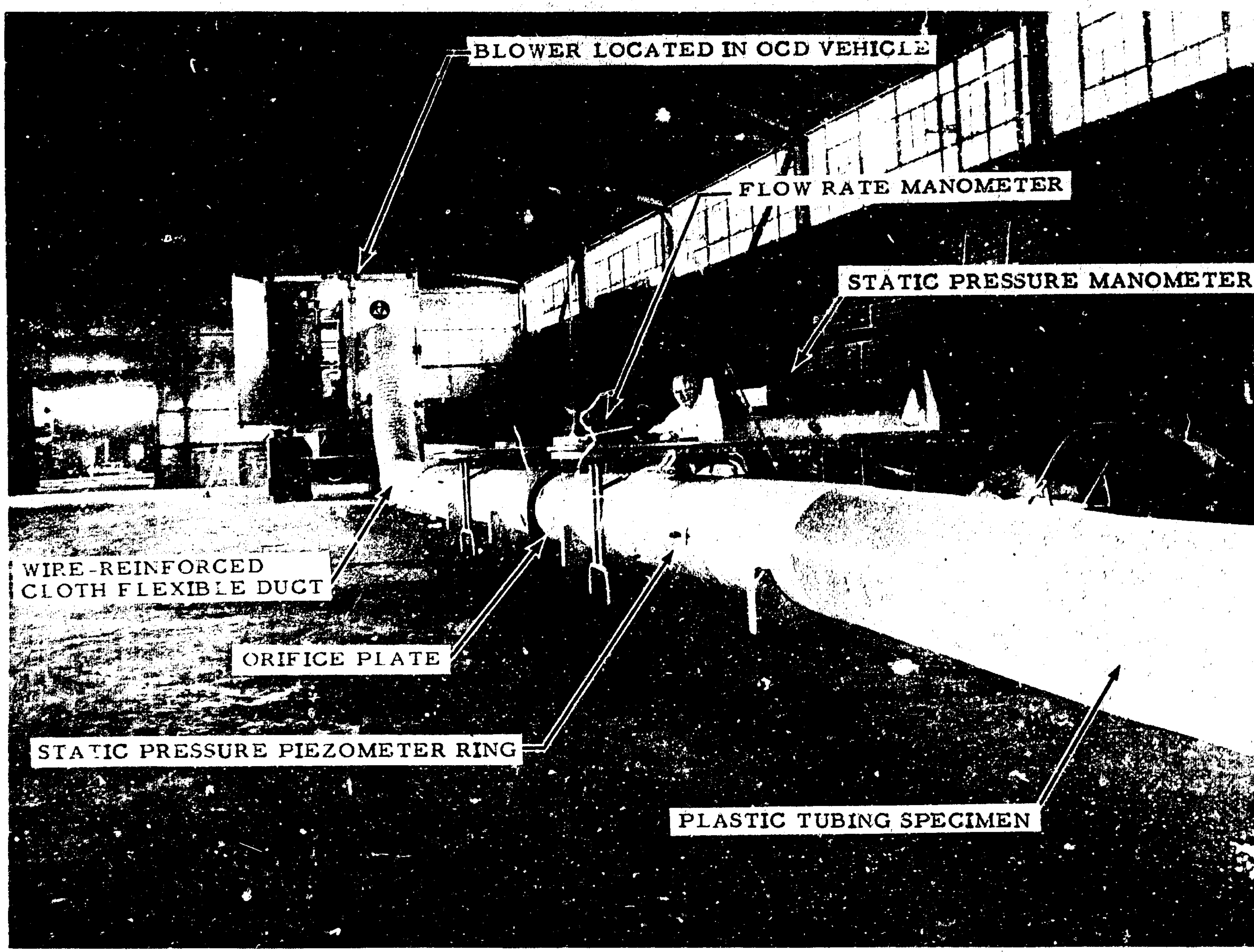


Figure 3 TEST APPARATUS

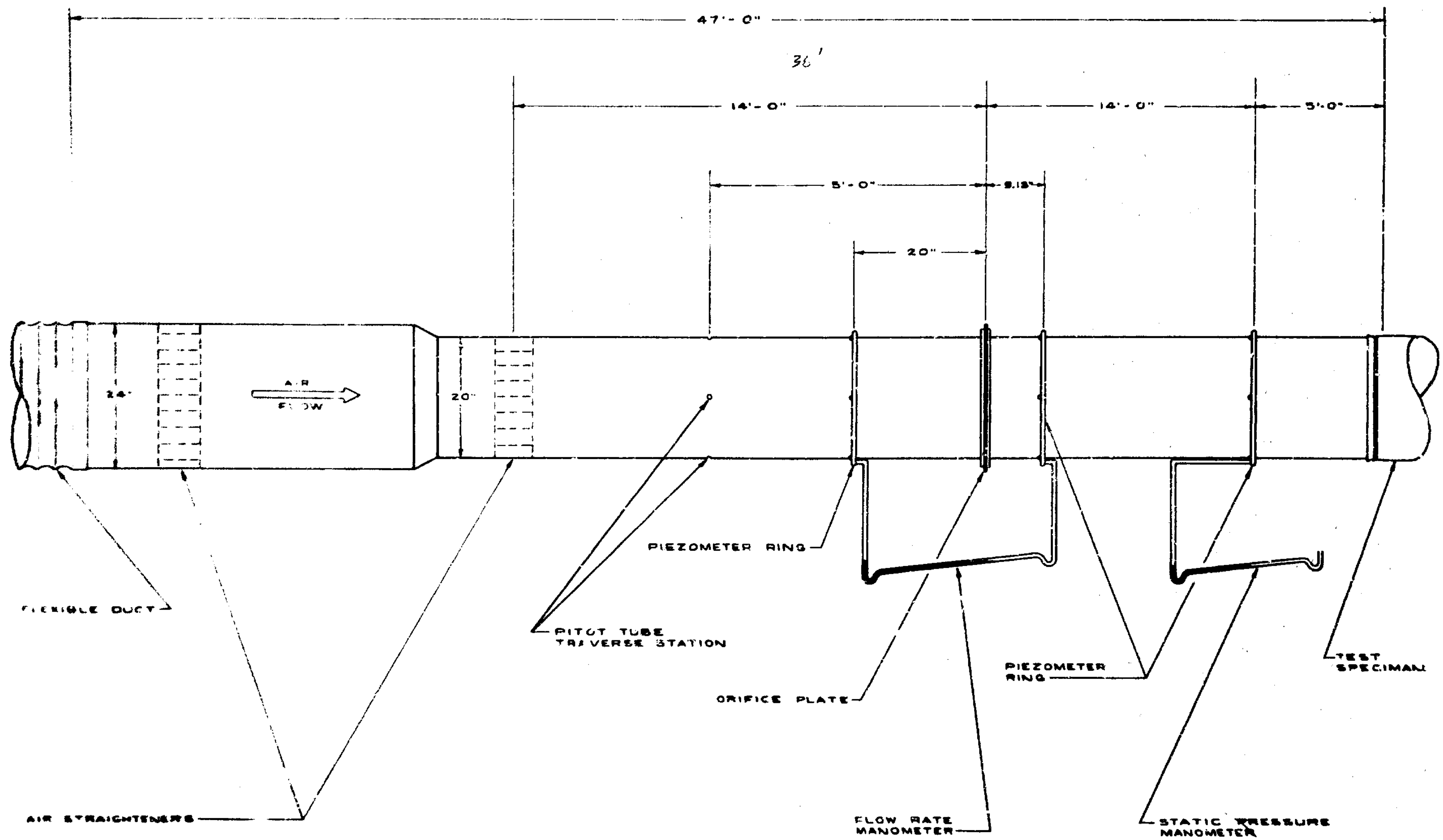


Figure 4 SCHEMATIC LAYOUT OF TEST APPARATUS

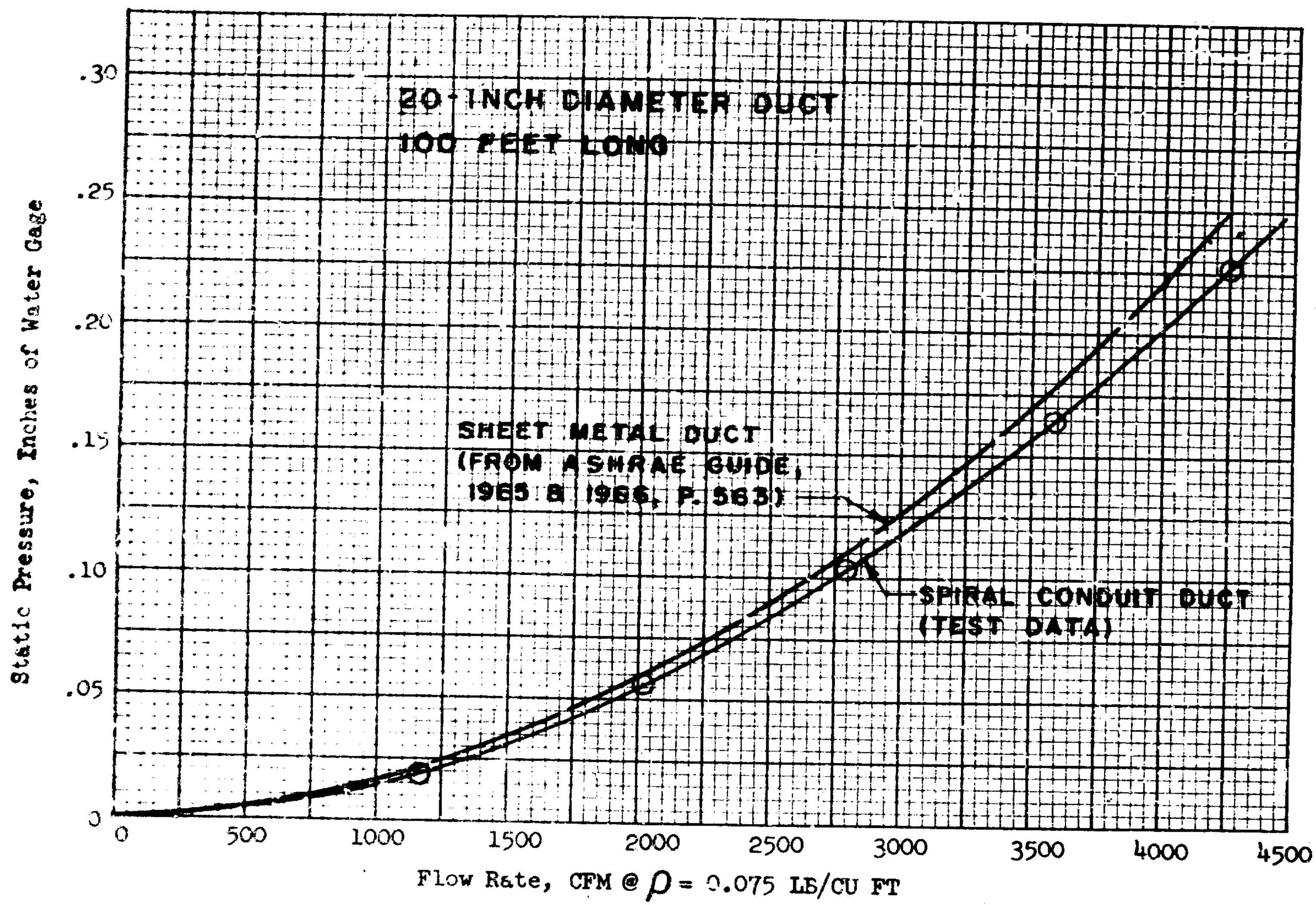


Figure 5 FRICTION OF AIR IN STRAIGHT SPIRAL CONDUIT DUCT

2.2.1 Tubing

Plastic tubing lengths from 450 to 50 feet in increments of 50 feet were tested at flow rates from 1300 to 4100 SCFM (standard air) with the discharge end of the tubing unrestrained (see Figure 6).

Five high impact strength (Type II), untreated (Finish 1) tubing specimens were tested. Of these samples one was low slip* (Grade A), three were medium slip (Grade B), and one was high slip (Grade C). The diameter is 19.75 ± 0.25 inches, and the thickness 0.004 (4-mil) ± 0.0008 inches. The samples were furnished by the Sinclair-Koppers Company, Inc. and the National Poly Products, Inc. Thin gage polyethylene films are classified as follows (Ref. 4):

Type I	Normal impact strength.
Type II	High impact strength.
Grade A	Low slip.
Grade B	Medium slip.
Grade C	High slip.
Finish 1	Untreated.
Finish 2	Treated.

2.2.1.1 Duct Adaptor

After determining the friction loss of a plastic tubing specimen, the duct was tested with the duct adaptor attached to the free-end (see Figure 7).

*The test apparatus and methods for determining the impact strength and slip (kinetic coefficient of friction) are presented in Federal Specification L-P-378. Finish 2 film is treated to allow printing ink to adhere.

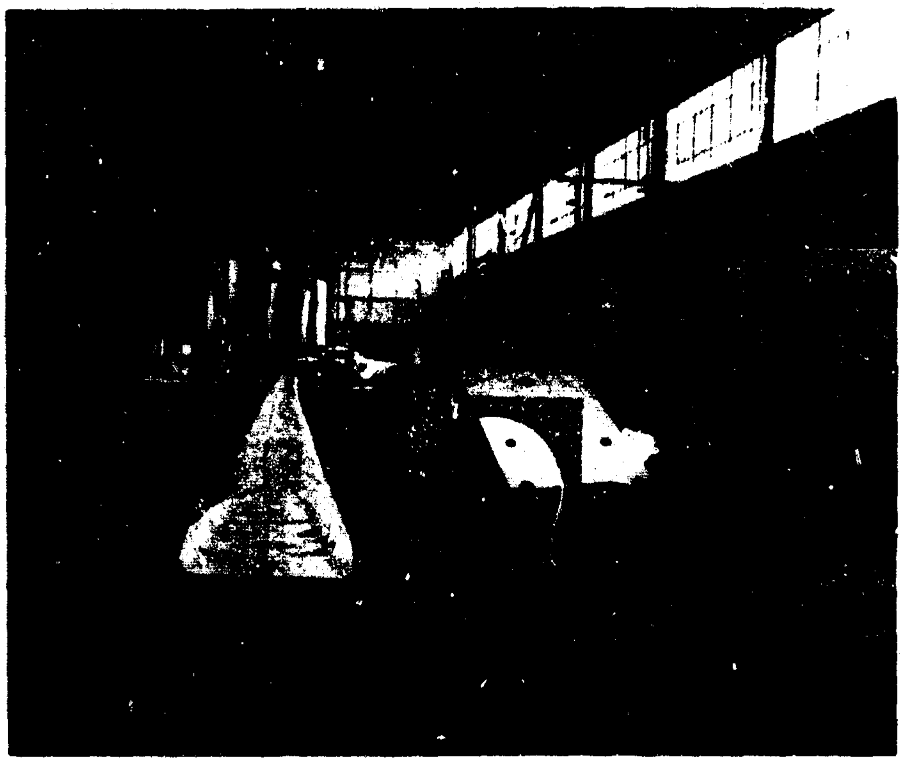


Figure 6 TEST OF THE TUBING WITH THE END UNRESTRAINED (FREE AIR DISCHARGE)

Figure 7 TEST OF THE TUBING WITH THE DUCT ADAPTOR

The purpose of this test was to determine the friction loss of the system with and without the duct adaptor for those duct systems where its use is optional.

2.2.1.2 PVK Application

After determining the friction loss of plastic tubing specimens these same specimens were attached to a calibrated Civil Defense Package Ventilation Kit ventilator and the power input was measured (see Figure 8). Knowing the wattage input to the system the air flow and pressure drop were determined from the fan motor performance curve (Ref. 5). The air flow obtained by this method agreed within three percent of the values obtained with the test set-up. Therefore, the friction loss for tubing and fittings determined herein can be applied to the Civil Defense propeller-type ventilator as specified in MIL-V-40645.

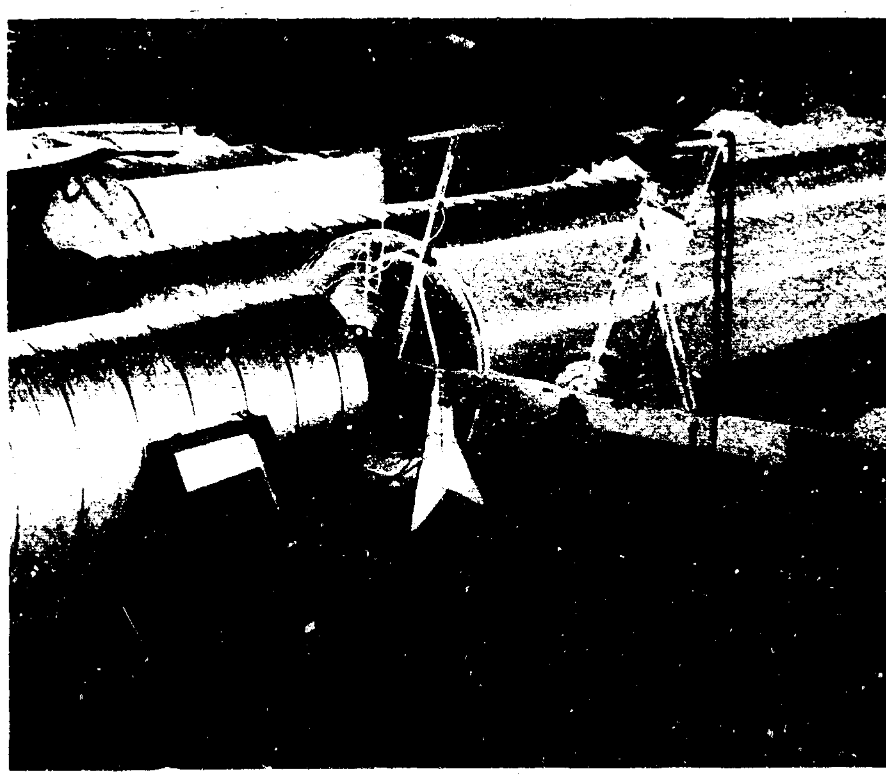


Figure 8 PVK-DUCT TEST

2.2.2 Elbows

The friction loss of all fittings with 100 feet of straight tubing on the downstream end of the system were compared to each other. Testing with a duct on the discharge end of the elbows was necessary to fully inflate the fittings, and the results are therefore only applicable to fully inflated fittings. The best factory fabricated and shelter fabricated elbows were then further tested with duct lengths of 100, 200, and 300 feet to determine the effect of static pressure on the elbow pressure drop or equivalent duct length (EDL).

2.2.2.1 Factory Fabricated Elbows

A preliminary specification for flexible plastic elbows which might be used in constructing a shelter duct system to be attached to a portable ventilator was sent to eight fabricators. This specification is included as Appendix B. The temperature range, flow rate, and internal pressure were specified to incorporate the most adverse conditions expected during storage and operation. Cost quotations were requested for the fabrication of elbows in seven configurations with varying centerline radii from 20-inches to 60-inches. Table II shows the relative production costs of the 20-inch diameter, 90-degree, smooth radius elbow with a 40-inch centerline radius.

The majority of fabricators preferred the use of polyvinyl chloride (PVC) because it is easily heat sealed and less expensive. All manufacturers indicated that the smooth and miter elbows were the simplest and least expensive to fabricate in flexible plastic. The cost of the miter elbow was essentially the same as a smooth elbow with a centerline radius of 20

Table II

Costs of Smooth Elbow

Manufacturer	Material	Thickness mils	Quantity			
			500	350,000	700,000	1,050,000
1	Polyvinyl Chloride	4	$2.00	$1.28	$1.26	$1.24
2	Poly-ethylene	4	$15.35	$3.00	$3.00	$3.00
3	Polyvinyl Chloride	8	$3.10	$2.75	$2.60	$2.55
4*	Polyvinyl Chloride	4	$2.08	$0.43	$0.38	$0.37

*Outside seams of full production units would not be trimmed.

inches. Therefore, 90-degree smooth and miter elbows of 4- and 8-mil thick PVC with centerline radii of 20, 30, 40, and 60 inches were selected for testing.

A wire-reinforced elbow was also tested (see Figure 9). This elbow was constructed by inserting a helical coil of 0.072 inch dia. tinned music wire inside a straight length of four-mil, 20-inch diameter, polyethylene tubing. The wire was taped to the inside of the duct every 90-degrees around the periphery of the tubing, and the distance between hoops was six inches.

2.2.2.2 Shelter Fabricated Elbows

The shelter fabricated elbows that were tested were hand-tucked, 3-piece, and packing boxes taped together. The hand-tucked elbow was constructed by forming tucks or pleats on one side of the tubing and taping the tucks so that a gradual radius of curvature was developed (see Figure 10).

Figure 9 WIRE-REINFORCED ELBOW

Figure 10 HAND-TUCKED ELBOW

The excess material inside of the duct, formed by the tucks, was placed downstream to reduce the resistance to air flow. This elbow is difficult to construct, and in most cases requires a relatively large floor area when inflated as compared to the other elbows.

A three-piece elbow was fabricated from polyethylene tubing by cutting two 32 x 16-1/2 x 32 inch triangular-shaped sections 58 inches apart (see Figure 11). The tubing was taped after overlapping the downstream seam (relative to the direction of the air flow) approximately one inch. This provided an elbow with an approximate centerline radius of 60 inches (see Figure 12). This elbow is easily constructed with a template.

A rigid elbow was constructed from a corrugated fiberboard box (see Figures 13 and 14) and tested. The packing box elbow, especially one less than 90-degrees, is very difficult to construct and requires materials which in many cases will not be found in shelters.

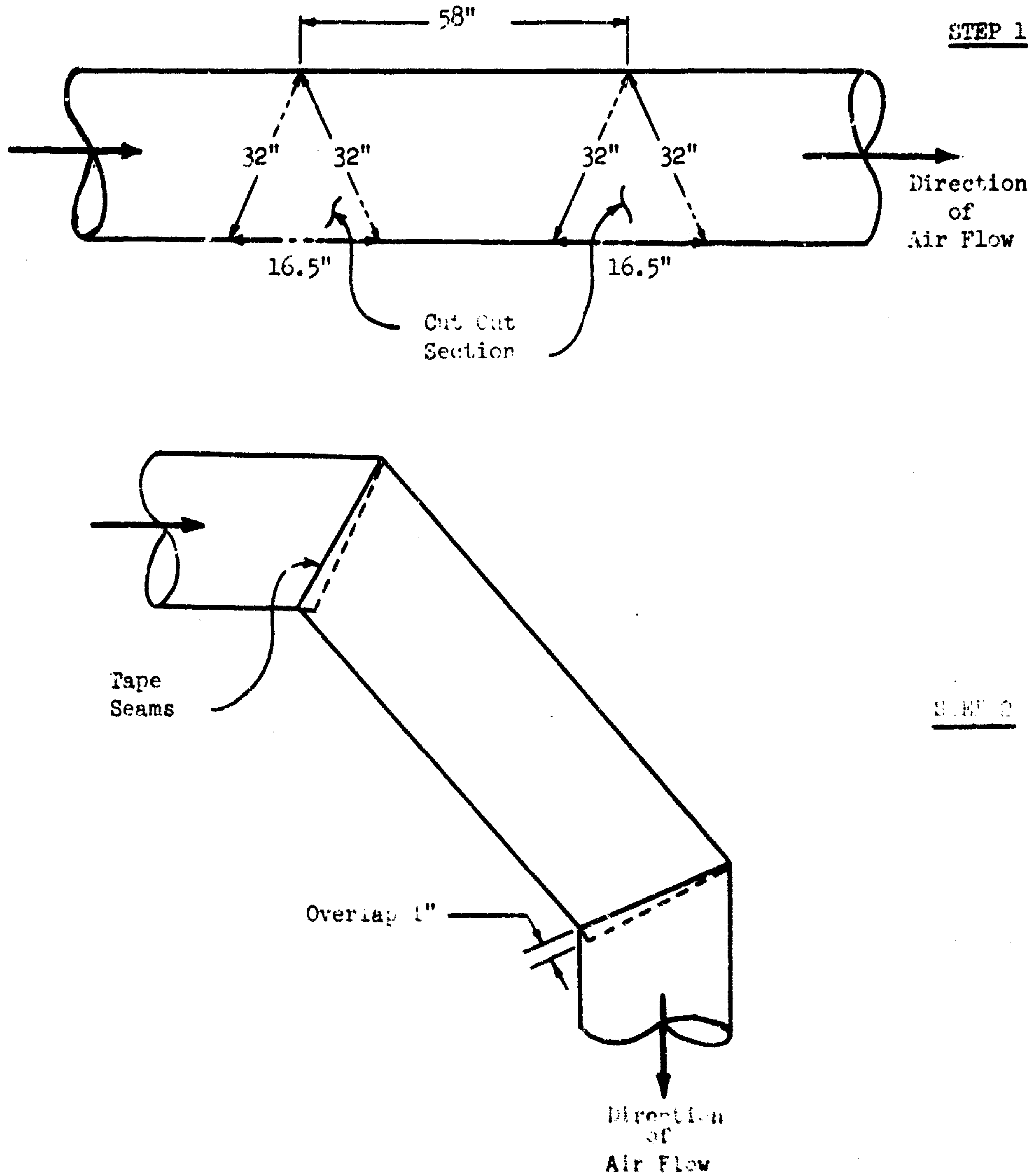


Figure 11 SHELTER FABRICATION OF A 60-INCH RADIUS, 90-DEGREE, THREE-PIECE ELBOW

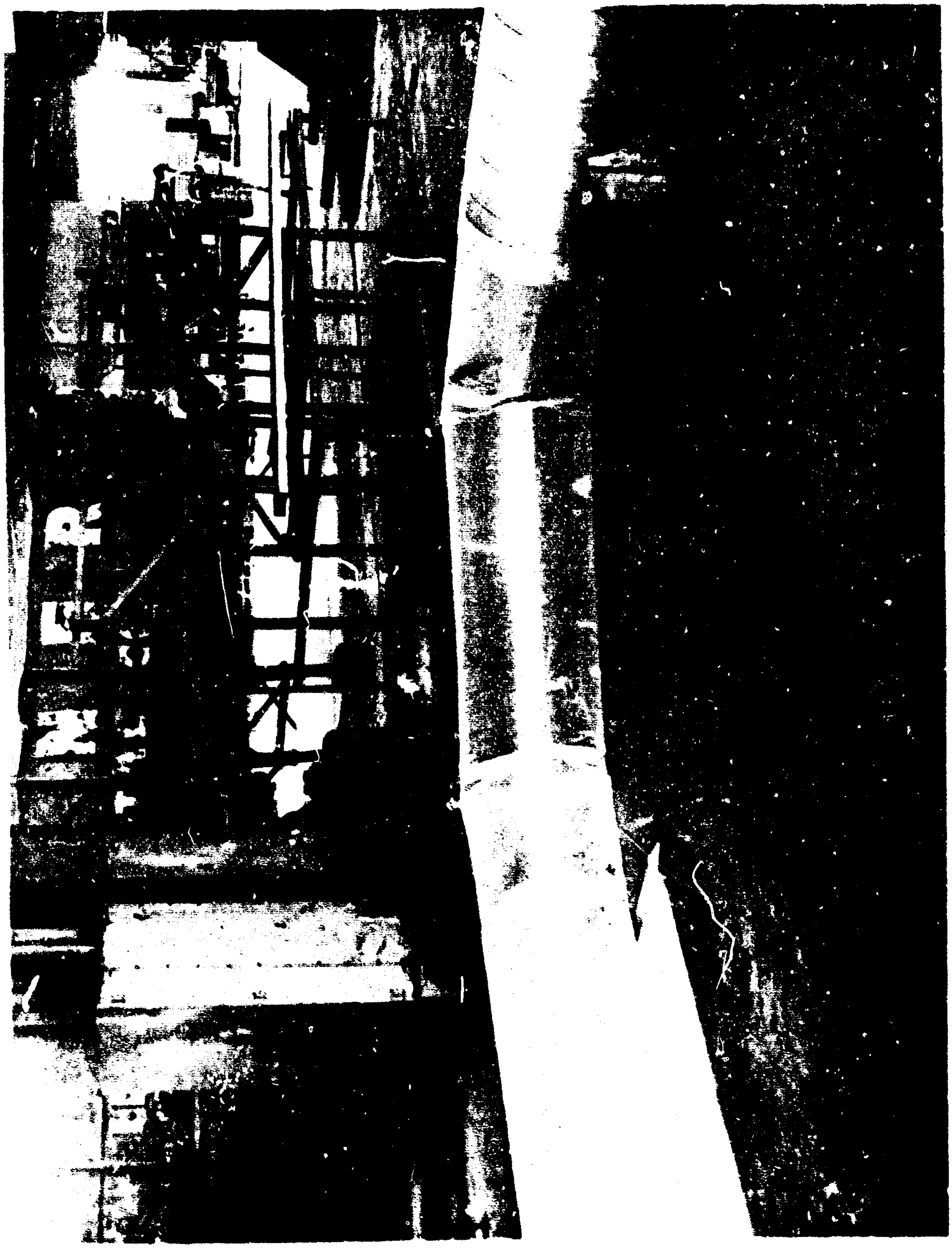


Figure 12 SHELTER FABRICATED THREE-PIECE ELBOW IN OPERATION

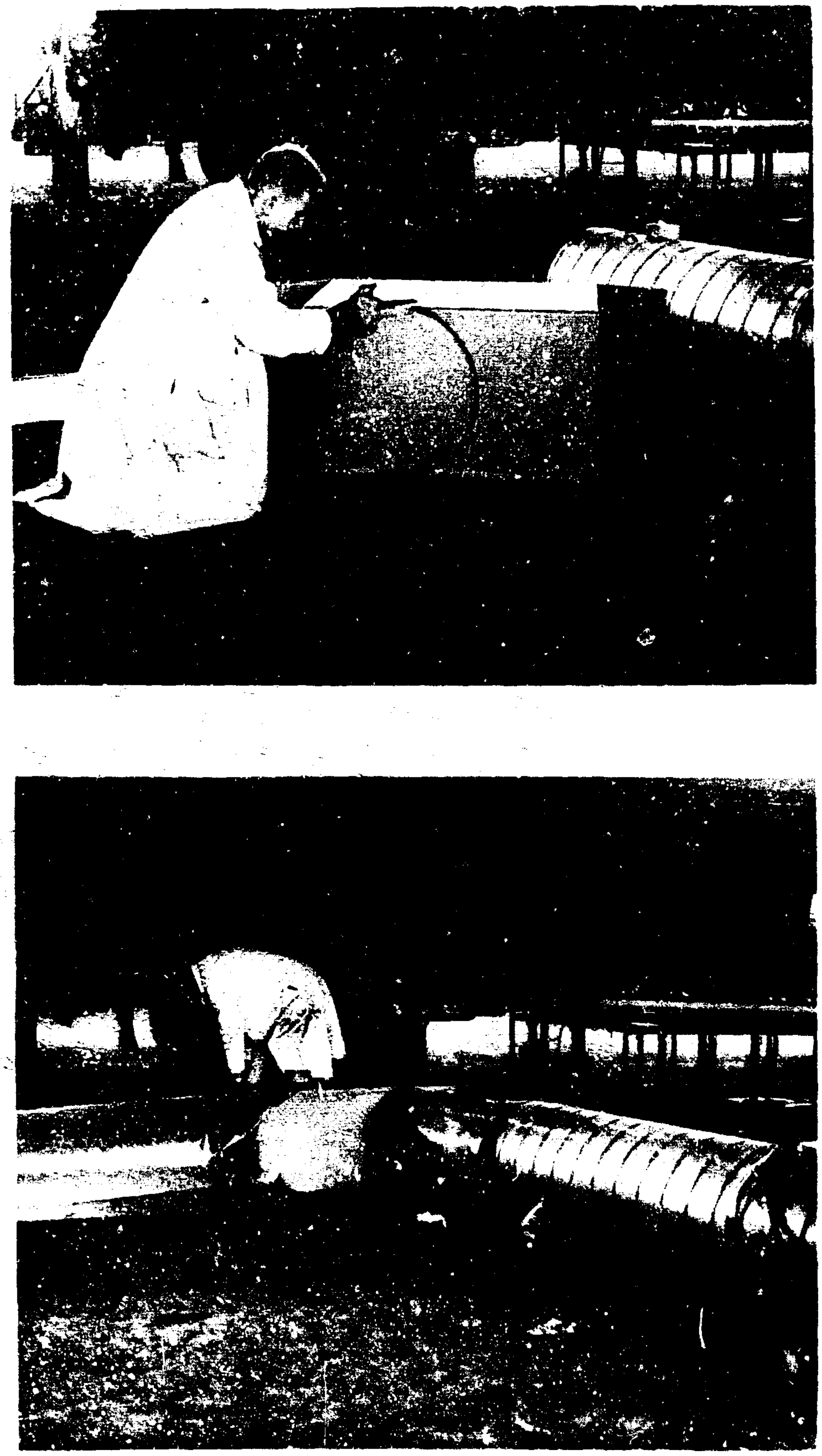


Figure 13 SHELTER CONSTRUCTION OF THE PACKING BOX ELBOW

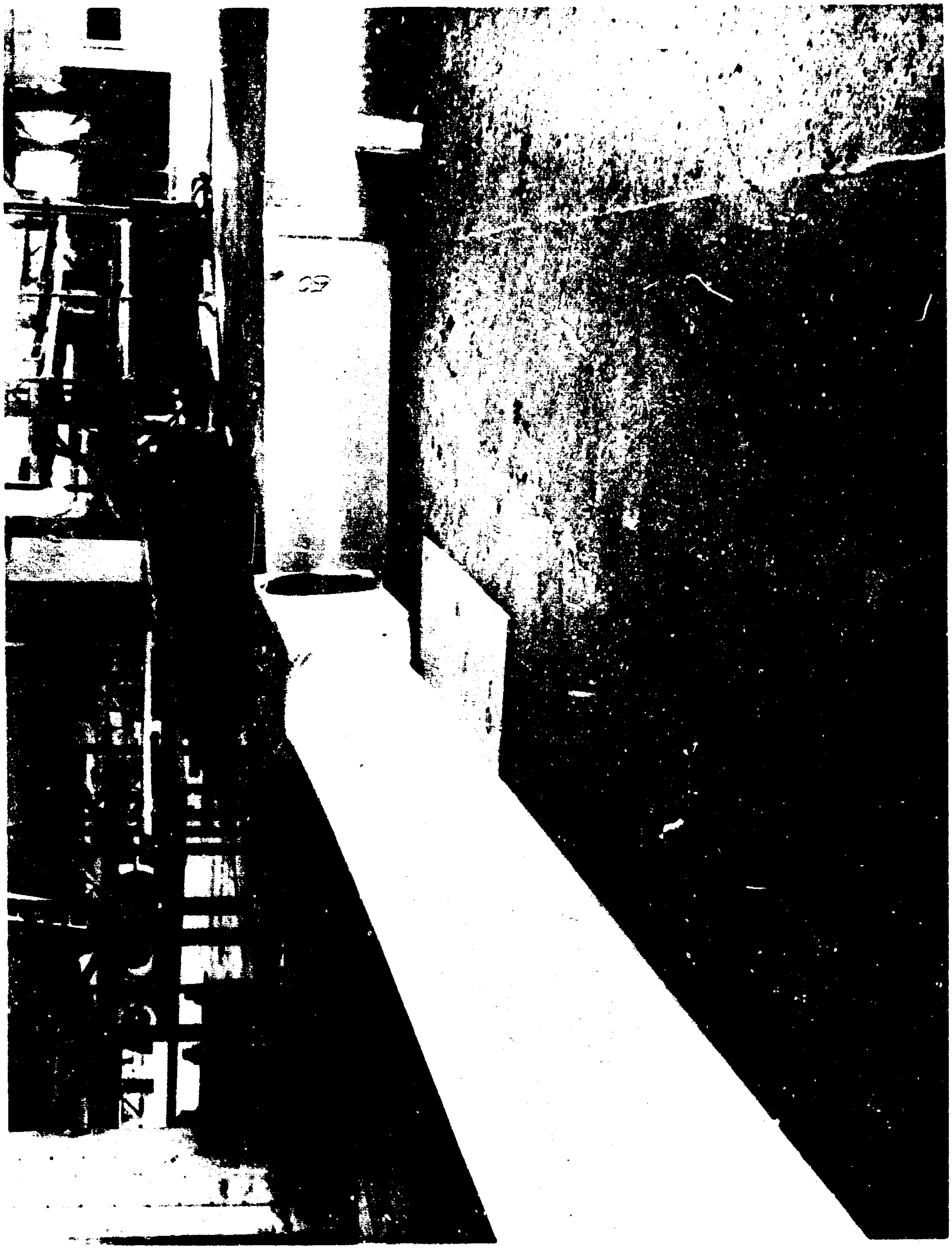


Figure 14 PACKING BOX ELBOW IN OPERATION

SECTION 3

RESULTS AND ANALYSIS

3.1 Tubing

The friction of air in straight polyethylene tubing for lengths from 50 to 450 feet are shown in Figure 15. These curves are based on a least squares regression of the test data as shown in Appendix A. The standard error of estimate; i.e. the mean of the square of the differences between the data and the fitted curve ranges from 0.007 inches of water gage (iwg) for the 150 foot length to 0.023 iwg for the 400 foot length. As indicated by the data presented in the Appendix, the low slip specimen has the least friction loss for all lengths except the 50 foot length. It was expected that this specimen would have the highest friction loss, and the high slip specimen the minimum friction loss. It is felt that an insufficient number of samples were tested to establish if friction loss can be correlated to slip since only one lot of the low and high slip specimens was used.

Figure 15 and Table III show that the pressure drop for the last 50 feet of tubing in a duct system is from 1-1/2 to 3 times as great as that for duct elsewhere in a system. As shown in Figure 6, page 9, the last 50 feet of tubing in a duct system is not completely inflated due to the weight of material and decreased static pressure in this part of the system. The air velocity in a partially deflated duct is greater than that in an inflated duct since the cross-sectional area is less than that of a fully inflated or circular duct. Since the pressure drop due to friction is approximately proportional to the velocity squared, the increased velocity in partially inflated duct results in an increased pressure drop in this section of duct. As the flow rate increases, the length of uninflated tubing in a system decreases. As shown in Table III the friction loss for the polyethylene tubing other than the last fifty feet in the system is approximately proportional to the length. For example: at 1000 scfm the pressure drop increases 0.007 iwg (range: 0.006 to 0.007) for every fifty feet additional tubing; at 3000 scfm it increases 0.049 iwg (range: 0.047 to 0.051) for the same length increments. The friction losses of polyethylene tubing and sheet-metal ducts are also compared in this table. In general, the friction loss of inflated polyethylene tubing is less than that for the same diameter sheet-metal ducts, whose pressure drop is directly proportional to length. At 1000 scfm the friction loss of inflated plastic tubing is 0.007 iwg per fifty feet as compared to 0.008 for the sheet-metal duct; at 3000 scfm the friction losses of plastic tubing and sheet-metal ducts are 0.049 and 0.065 iwg per fifty feet, respectively.

A mathematical expression derived from the least squares fitted curves of the data (see Appendix A) is:

$$P = 1.915 \times 10^{-6} \left[Q^{1.349} + 0.01096 \left(\frac{L}{50} - 1\right) Q^{1.833} \right] \qquad (1)$$

where:

P = static pressure loss, inches of water gage

Q = air flow rate, standard cubic feet per minute (scfm)

L = tubing length (for lengths of 50 feet and longer)

The solid curves in the Appendix are based on the test data, while the dotted portions of the curves were generated with Equation 1.

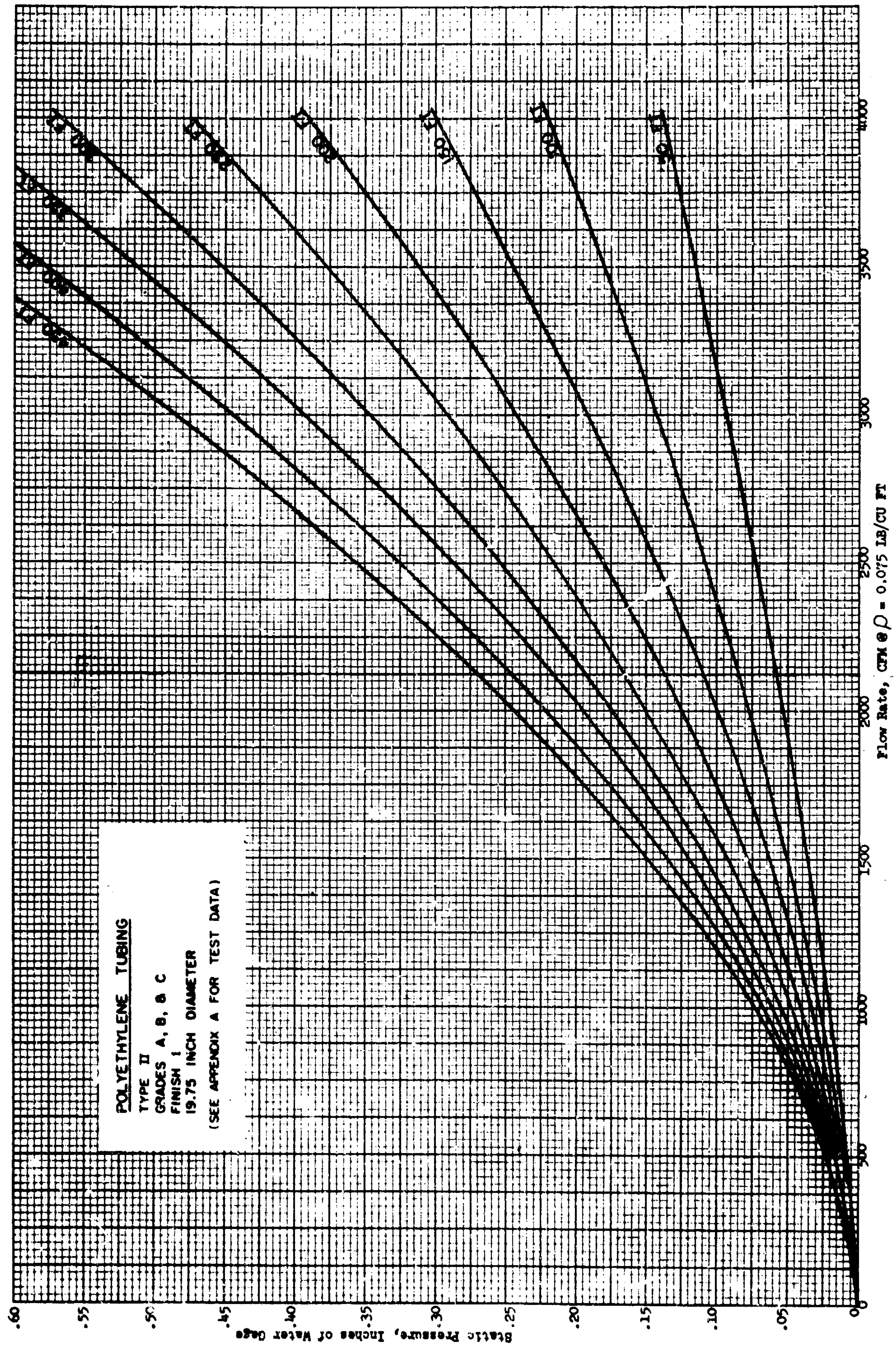


Figure 15 FRICTION OF AIR IN STRAIGHT POLYETHYLENE TUBING

Table III

Pressure Drop Variations for 20-inch Diameter Polyethylene Tubing

Duct Material	Station, Feet	Air Flow, SCFM						
		1000	1500	2000	2500	3000	3500	4000
		Pressure Drop per Fifty Feet, Inches of Water Gage						
Poly-ethylene (From Figure 15)	0-50	0.21	0.036	0.054	0.072	0.093	0.115	0.138
	50-100	0.007	0.015	0.024	0.036	0.049	0.065	0.082
	100-150	0.006	0.012	0.022	0.034	0.049	0.065	0.076
	150-200	0.007	0.015	0.025	0.037	0.050	0.067	0.091
	200-250	0.007	0.015	0.026	0.035	0.049	0.066	[illegible]
	250-300	0.007	0.015	0.024	0.037	0.055	0.075	0.093
	300-350	0.007	0.013	0.021	0.034	0.047	0.062	--
	350-400	0.007	0.016	0.026	0.039	0.051	0.065	--
	400-450	0.006	0.015	0.023	0.031	0.041	--	--
	Mean 50 to 450	0.007	0.014	0.024	0.035	0.049	0.066	0.085
Sheet-Metal (Ref. 3)	Each 50 Feet	0.008	0.017	0.029	0.045	0.065	0.085	0.111

3.1.1 Duct Adaptor

The PVK includes a Duct Adaptor which is used to seal the plastic ducting to a window or doorway opening in a shelter. This adaptor was tested with plastic duct to determine if it could support the discharge end of the duct, and thus reduce the high friction loss of the final fifty feet of tubing in a system. The Duct Adaptor increased the static pressure loss through the duct system since a negative pressure occurs upstream of the adaptor. This additional pressure loss results from the converging and expanding air stream through the reduced flow area (see Figure 7, page 9). Therefore, the Duct Adaptor specified for the Kit (MIL-V-40645) does not include legs, and is intended for use in windows, doorways, or partitions only. When the air supply for the shelter enters the duct exit opening, or other nearby air supply openings, the duct should extend at least 35 feet from the building, and should not include the Duct Adaptor (free air discharge).

3.1.2 Condition of Duct

Creases are formed in the tubing during fabrication by rolling the tubing on a cylindrical core. Tests with these creases in both the horizontal and vertical positions produced the same static pressure losses. The tubing that was walked on and crushed, however, did indicate a decrease in static pressure loss and less "whipping" and "flutter" at the discharge end. Ripples are formed in new tubing when it is first inflated (see Figure 16). After the tubing is crushed, wrinkled, and generally abused, these ripples diminish, thus accounting for the decrease in static pressure losses.

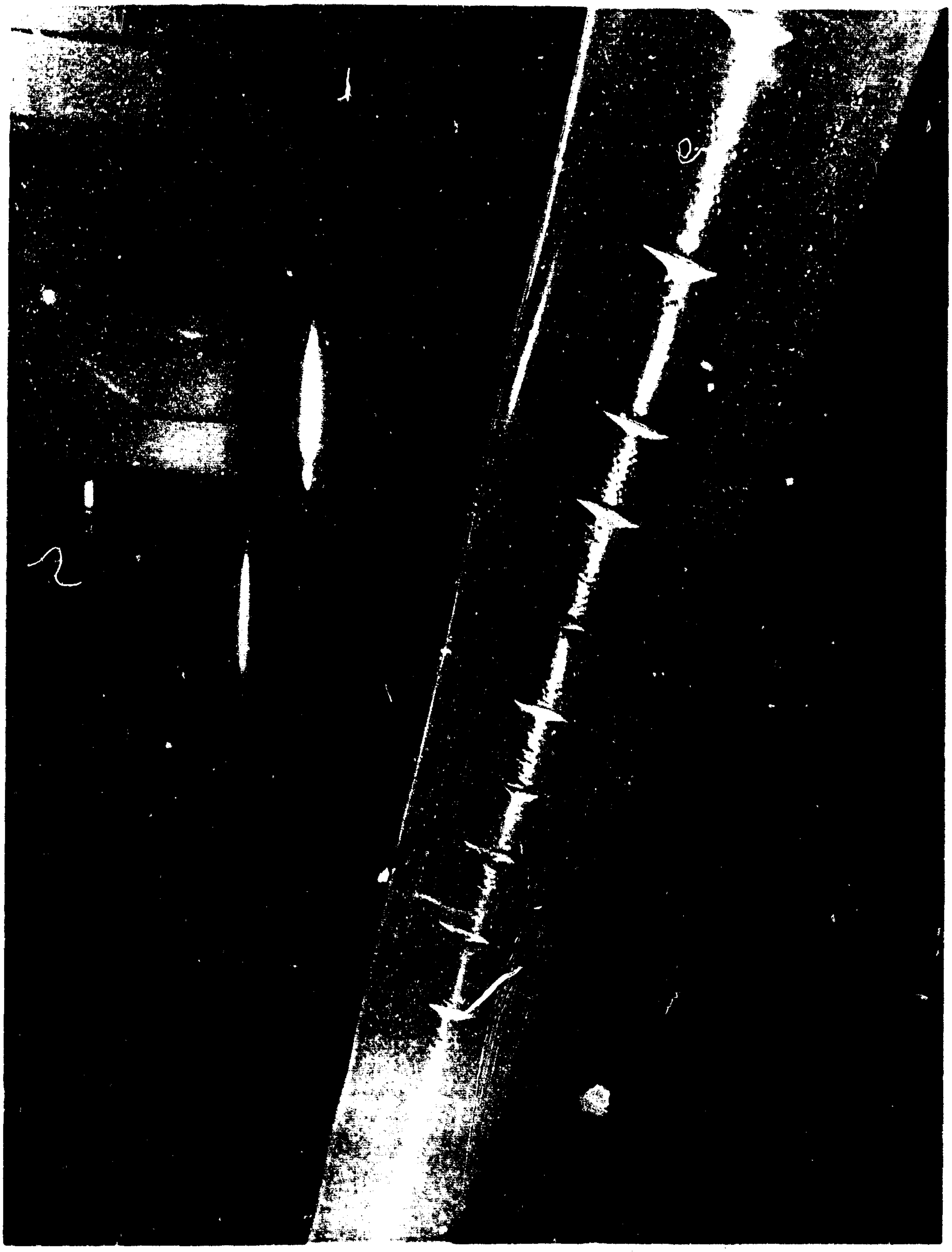


Figure 16 WRINKLES IN NEW TUBING

3.2 Elbows

Each of the factory and shelter fabricated candidate elbows was tested by fastening it to the test stand and taping a 100 foot section of polyethylene duct to the downstream end of the elbow to assure that the elbow is fully inflated. The pressure losses measured for these systems are presented in Figure 17. Based on the results of this comparison of factory and shelter fabricated elbows, a series of tests were conducted to determine the length of straight duct equivalent to the pressure drop for the recommended factory and shelter fabricated elbows when fully inflated. These tests evaluated the elbows with straight lengths of tubing. The tubing was attached directly to the elbow by overlapping approximately one inch of the end of the elbow and taping the seam. When inflated these elbows produced a total curvature or bend of approximately 110 degrees. This phenomenon is caused by stretching of the plastic material due to the elbow internal pressure. Since the surface at the outer radius of the elbow contains more material than the surface at the inside radius, the effect of the stretching produced an angular bend of more than 90-degrees. Prior to recording data, all elbows were inflated and trimmed to form a 90-degree angle. No attempt was made to determine the equivalent duct length for partially inflated elbows.

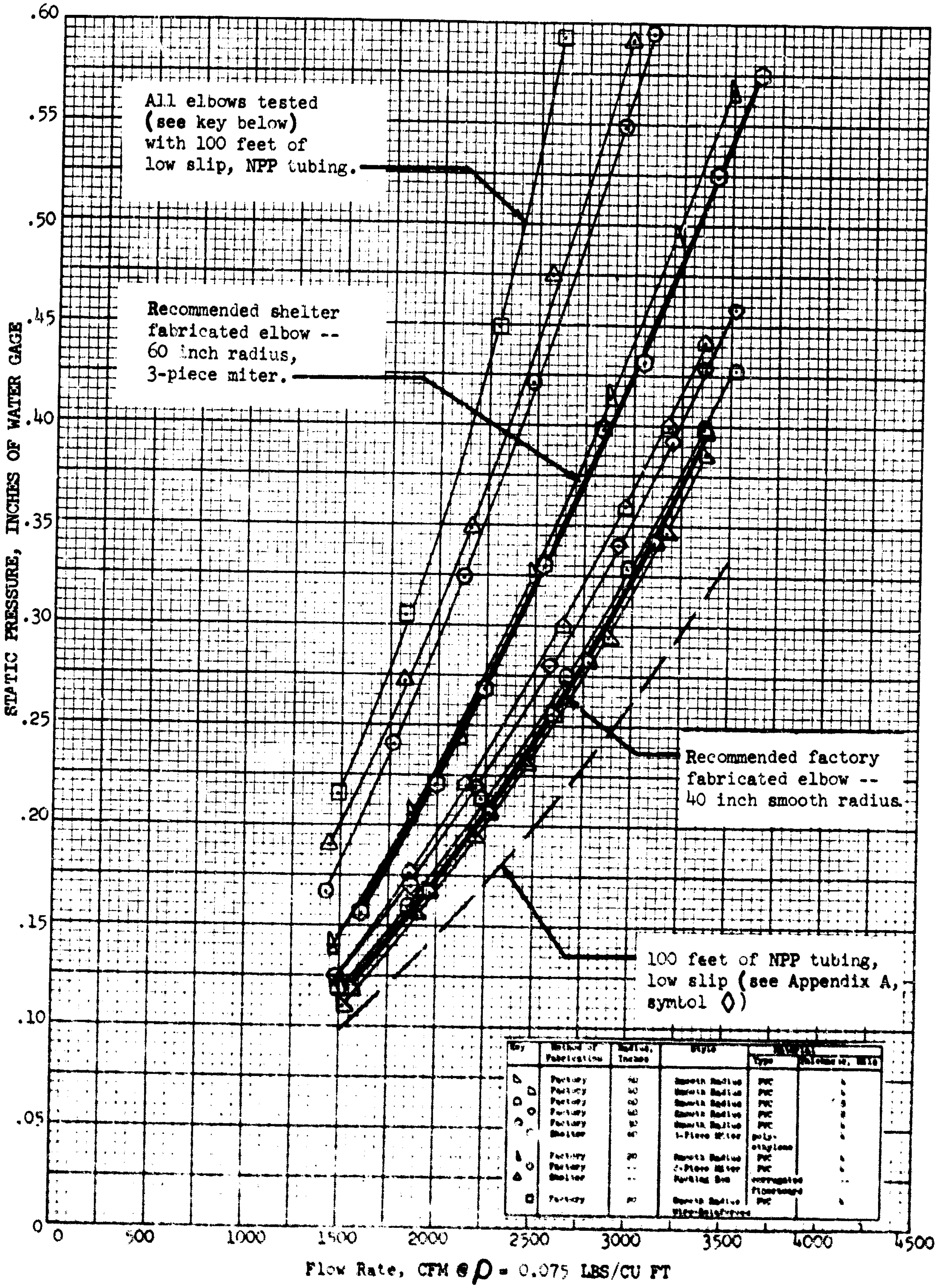


Figure 17 PRESSURE DROP COMPARISON OF 90-DEGREE ELBOWS

3.2.1 Factory Fabricated Elbows

The elbows with the lowest pressure losses are factory fabricated smooth radius elbows (see Figure 17). For a given configuration, the elbows fabricated from four-mil plastic had lower pressure losses than those fabricated from eight-mil plastic. The change in pressure loss with centerline radius decreased as the centerline radius approached 60 inches. The elbows with centerline radii of 40-inches and 60-inches have nearly identical pressure losses, indicating that the trade-off point for centerline radius versus pressure loss is approximately 40 inches. Increasing the centerline radius beyond this point provides only a minimal decrease in pressure loss, and requires considerably more shelter floor area when inflated.

The mitered elbow had a considerable pressure drop, even greater than the shelter fabricated three-piece elbow, because of the extreme flutter and vibration which developed. Figure 18 is "stop-action" photographs of the miter elbow illustrating the amplitude of the pulsation in the tubing and elbow.

The wire-reinforced elbow (see Figure 9, page 13) developed excessive pressure losses. This elbow had to be restrained at flow rates above 2000 cfm to keep it from straightening out. With the restraint, the elbow tended to kink into a short radius elbow such as a miter elbow. This instability resulted in the high pressure losses.

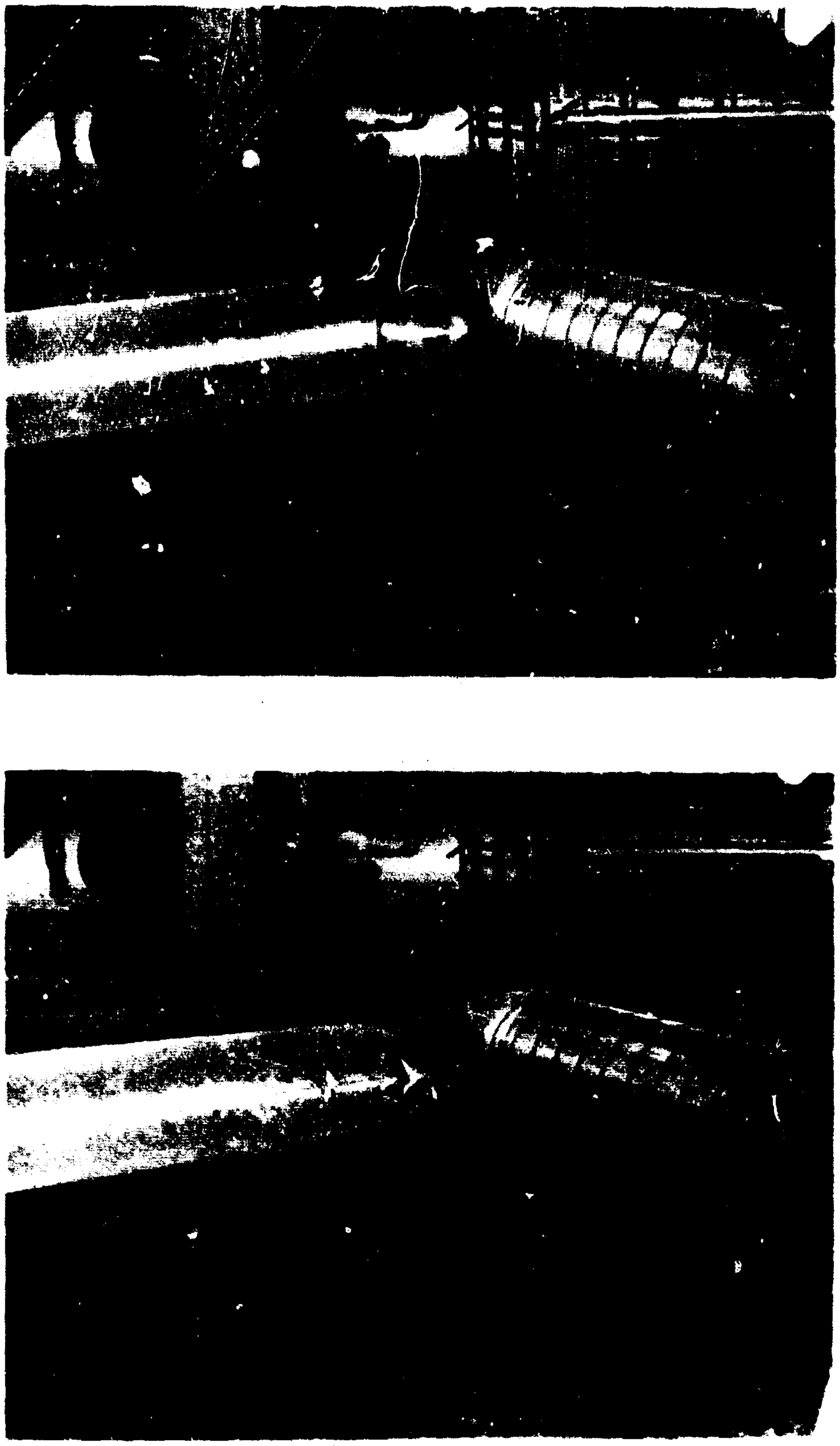


Figure 1[illegible] INSTABILITY IN MITER ELBOW

The four-mil polyvinyl chloride 40-inch smooth radius elbow is the best factory elbow when considering pressure drop, space requirements, material and cost. Figure 19 shows the results of further tests performed on this elbow. The solid lines show the pressure losses for the elbow with straight lengths of tubing attached to the downstream side, the broken lines show the pressure losses for the straight lengths only. It can be seen that <u>the equivalent length of straight tubing for the 40-inch smooth radius elbow is approximately 50 feet</u> when fully inflated. For the elbow to be fully inflated fifty feet of straight tubing must be on the downstream side.

3.2.2 Shelter Fabricated Elbows

Of the shelter fabricated elbows (see Figure 20) the three-piece elbow results in the least pressure loss. The elbow made from packing boxes produced the largest pressure loss. This elbow was extremely stable at all flow rates; however, the exit and entrance losses of the air stream in the plenum-like box produced the high pressure loss. The best hand-tucked elbow resulted in pressure drops considerably higher than those shown in Figure 17. Since the results were erratic (due to the elbow being unstable) no curve is presented.

Since the three-piece elbow has the least pressure loss this elbow was further tested with 100, 200, and 300 feet of tubing (see Figure 21). It can be seen that <u>the pressure loss of the three-piece elbow with a centerline radius of 60-inches is equivalent to 90 feet of straight tubing</u> when fully inflated. For the elbow to be fully inflated fifty feet of straight tubing must be on the downstream side.

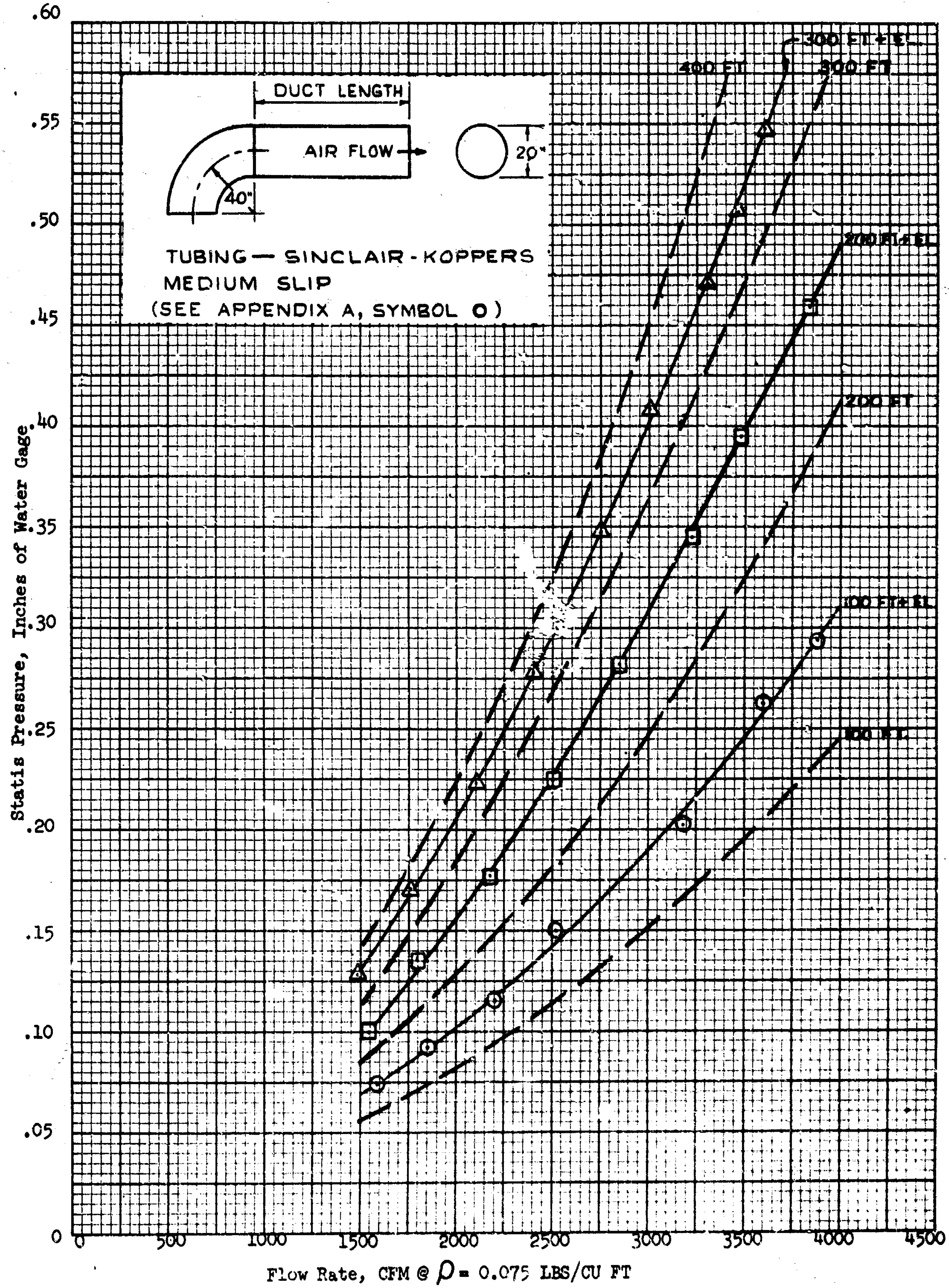
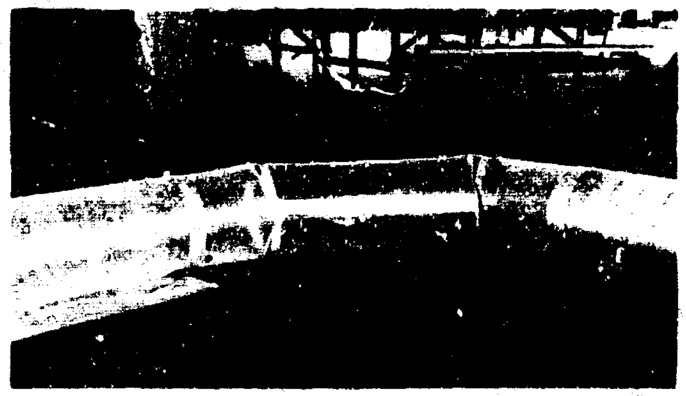
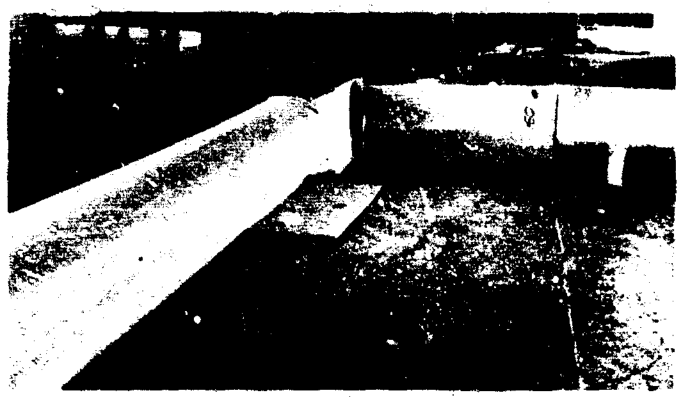


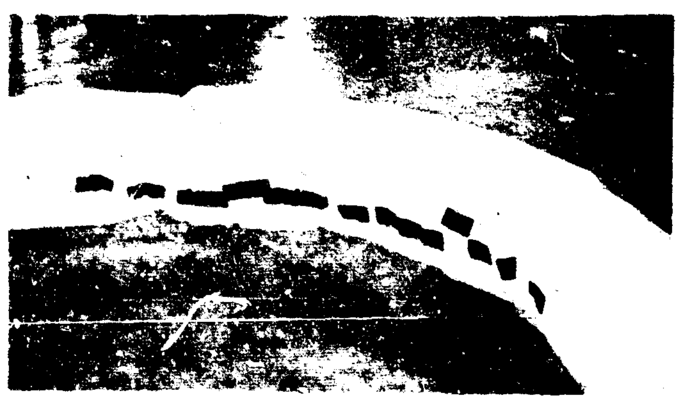
Figure 19 FRICTION LOSS OF THE 40-INCH SMOOTH RADIUS ELBOW



Three-piece, 60° Radius, Elbow



Packing Box Elbow



Hand-tucked Elbow

Figure 20 SHELTER FABRICATED ELBOWS IN OPERATION

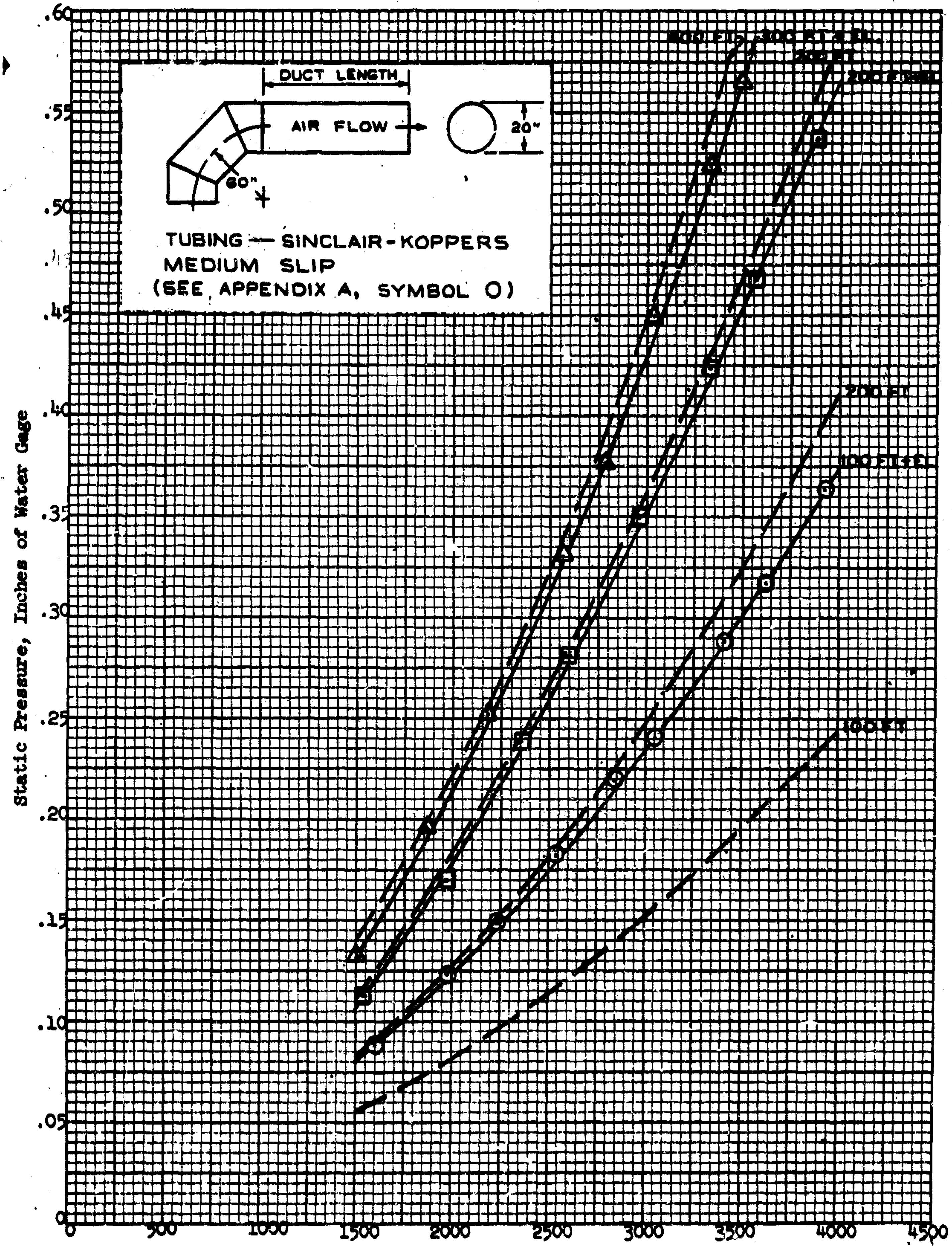


Figure 21 FRICTION LOSS OF THE THREE-PIECE, 60-INCH RADIUS, ELBOW

SECTION 4

SUMMARY AND RECOMMENDATIONS

The friction losses of the 4-mil polyethylene tubing specified for the Package Ventilation Kit, MIL-V-40645, have been determined (see Figure 15 and Equation 1), and have been incorporated into the PVK rating (Ref. 6). Fully inflated 20-inch diameter plastic tubing has about three-quarters of the pressure drop of sheet-metal duct. However, the last fifty feet of a plastic duct system which is not completely inflated has 1-1/2 to 3 times the pressure drop per foot of fully inflated plastic tubing. The result is that for duct systems over 100 feet long the pressure drops for sheet-metal and plastic tubing are approximately the same.

The Duct Adaptor supplied with the PVK should be used to prevent recirculation in windows and doorways when the duct system terminates there, and when necessary in corridors and partitions for developing systems which control the flow or distribution of air. The Duct Adaptor should not be used elsewhere, such as the end of the duct outside of a building, since its use increases the system pressure drop.

The smooth 40-inch radius plastic elbow is the best of the factory fabricated elbows. This elbow when fully inflated results in a pressure drop equivalent to 50 feet of straight tubing. For the elbow to be fully inflated at least 50 feet of tubing must be on its downstream side. Since this elbow must be cut at 75-degrees when uninflated so that the resulting inflated elbow is 90-degrees, it is recommended that "Figure 8 of MIL-V-

40645" be modified as shown in Figure 22. The cuffs have been removed since they are of no value for taping the tubing to the elbow, and in most cases produce wrinkles and distortion. Since polyvinyl chloride material is easily heat sealed it is recommended that this material be specified in paragraph 3.7.3 of MIL-V-40645; therefore, the second sentence of this paragraph should read as follows:

"The elbows shall be fabricated from 4-mil thick polyvinyl chloride or type II, grade C, finish 1 polyethylene conforming to Specification L-P-378 with a minimum flat dimension of 31 inches."

The most efficient shelter fabricated elbow is the 60-inch radius three-piece elbow. This elbow when fully inflated produces a pressure drop equivalent to 90 feet of straight tubing. For the elbow to be fully inflated at least 50 feet of tubing must be on the downstream side.

Factors that should be considered in the selection of elbows for use in shelters are the simplicity of assembly, floor space required when inflated, stability in operation, and cost. Assembly of the factory fabricated elbow in a duct system is a simple matter of cutting straight lengths of tubing at the appropriate length, inserting the elbow, and taping the components together. Any angle between zero and ninety degrees can be obtained by cutting the elbow at the angle desired. The shelter fabricated elbow can be fabricated from materials in the PVK, and the required number of 90-degree elbows can be fabricated to develop a suitable ventilation duct system for any shelter. The three-piece, 90-degree, elbow can probably be constructed by the shelterees with a template and instructions; however, fabrication

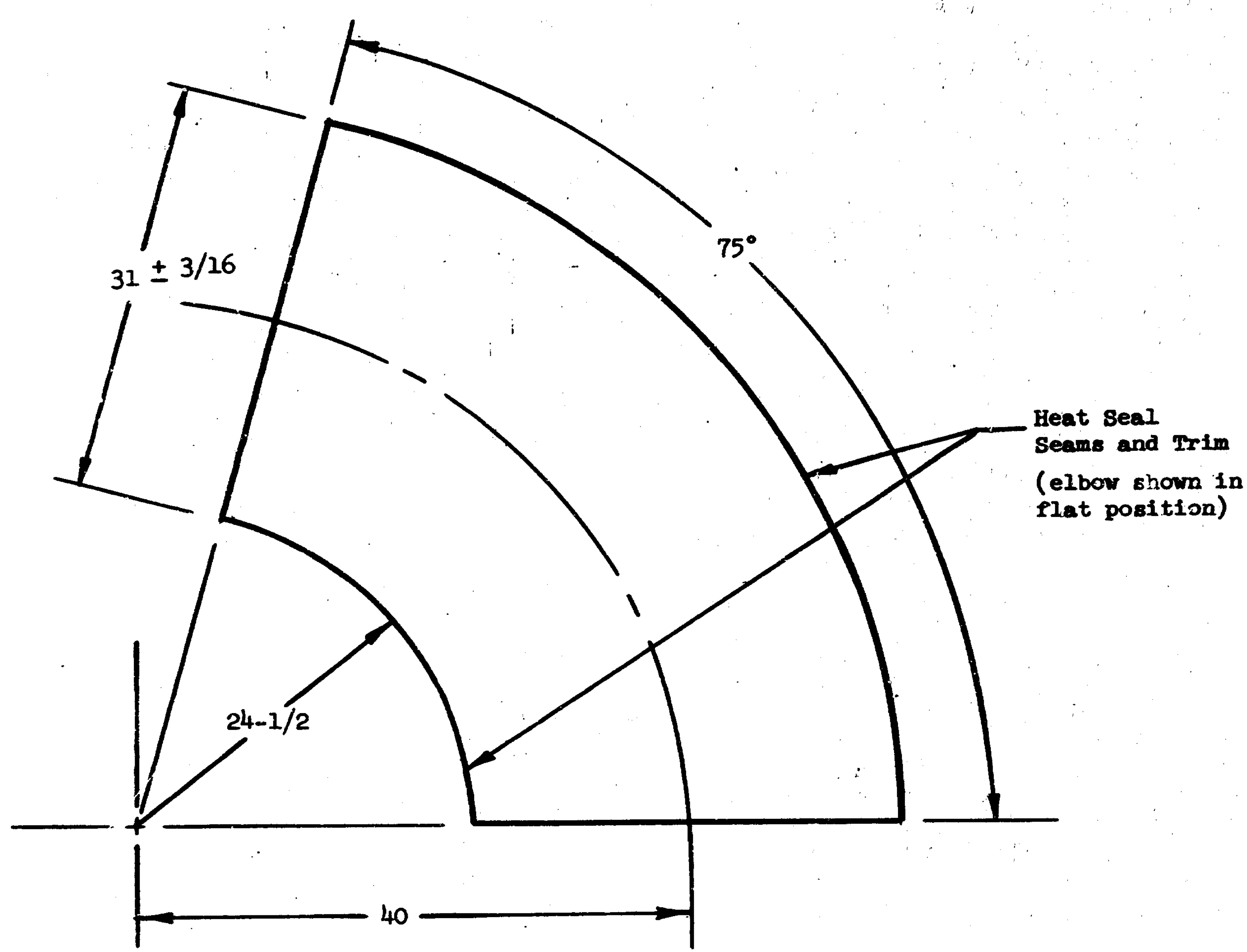


Figure 22 FACTORY FABRICATED ELBOW (MODIFIED)

of an elbow with angles other than 90-degrees would most likely be difficult and confusing. Therefore, it is recommended that:

1) One factory fabricated elbow be furnished with the PVK. One elbow should satisfy the majority of shelter duct systems.

2) A 90-degree elbow template should be included with the PVK for those systems requiring more than one elbow. If a system requires elbows with an angle less than 90-degrees a factory fabricated elbow should be cut for the desired angle, thus eliminating most cases of shelter fabrication of an elbow other than 90-degrees.

The equivalent duct length of any plastic tubing system can be determined by adding the total length of straight tubing plus the number of elbows times their respective equivalent duct length (see Equation 2) -- 50 feet for the factory fabricated elbow and 90 feet for the shelter fabricated elbow.

$$EDL_s = L + 50\,N_f + 90\,N_s \qquad (2)$$

where:

EDL_s = Equivalent Duct Length of the system, feet

L = length of straight duct in the system, feet

N_f = number of factory fabricated elbows, dimensionless

N_s = number of shelter fabricated elbows, dimensionless

The pressure drop of these systems may be determined using the following equation.

$$\Delta P = 1.915 \times 10^{-6} \left[Q^{1.349} + 0.01996 \left(\frac{EDL_s}{50} - 1 \right) Q^{1.833} \right] \qquad (3)$$

where:

ΔP = static pressure drop, inches of water gage

Q = air flow rate, standard cubic feet per minute (scfm)

EDL_s = Equivalent Duct Length of the system (for lengths of 50 feet and longer), feet

Equations 2 and 3 have been experimentally verified for straight tubing, and for elbows located anywhere in a duct system except within 50 feet of the discharge end. Future tests should be performed to verify the generality of equations 2 and 3 to a system with the elbow(s) partially inflated (within the last 50 feet of a system). Tests on other diameter plastic ducting and ducting fabricated from different thicknesses of plastic should also be performed to establish a general relationship for plastic duct pressure drop in order to evaluate the performance of shelter ventilators of other diameters.

REFERENCES

1. B. A. Libovicz and H. F. Behls, "Shelter Package Ventilation Kit", prepared for the Office of Civil Defense under Contract OCD-PS-64-22, OCD Work Unit 1423A, General American Transportation Corporation (GARD Report 1244), Niles, Illinois, October 1965.

2. National Electrical Manufacturers Association (NEMA) Standards Publication No. FM1-1955, "Electric Fans", 155 East 44th Street, New York, New York.

3. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Guide and Data Book, 1965 and 1966, New York, Chapter 31, Figures 2 and 3, pp. 562-3.

4. Federal Specification L-P-378, "Plastic Film (Polyethylene Thin Gage)".

5. Libovicz, op. cit., Figure 36, p. 65.

6. Libovicz, op. cit., Figure 31, p. 55.

APPENDIX A

TEST DATA

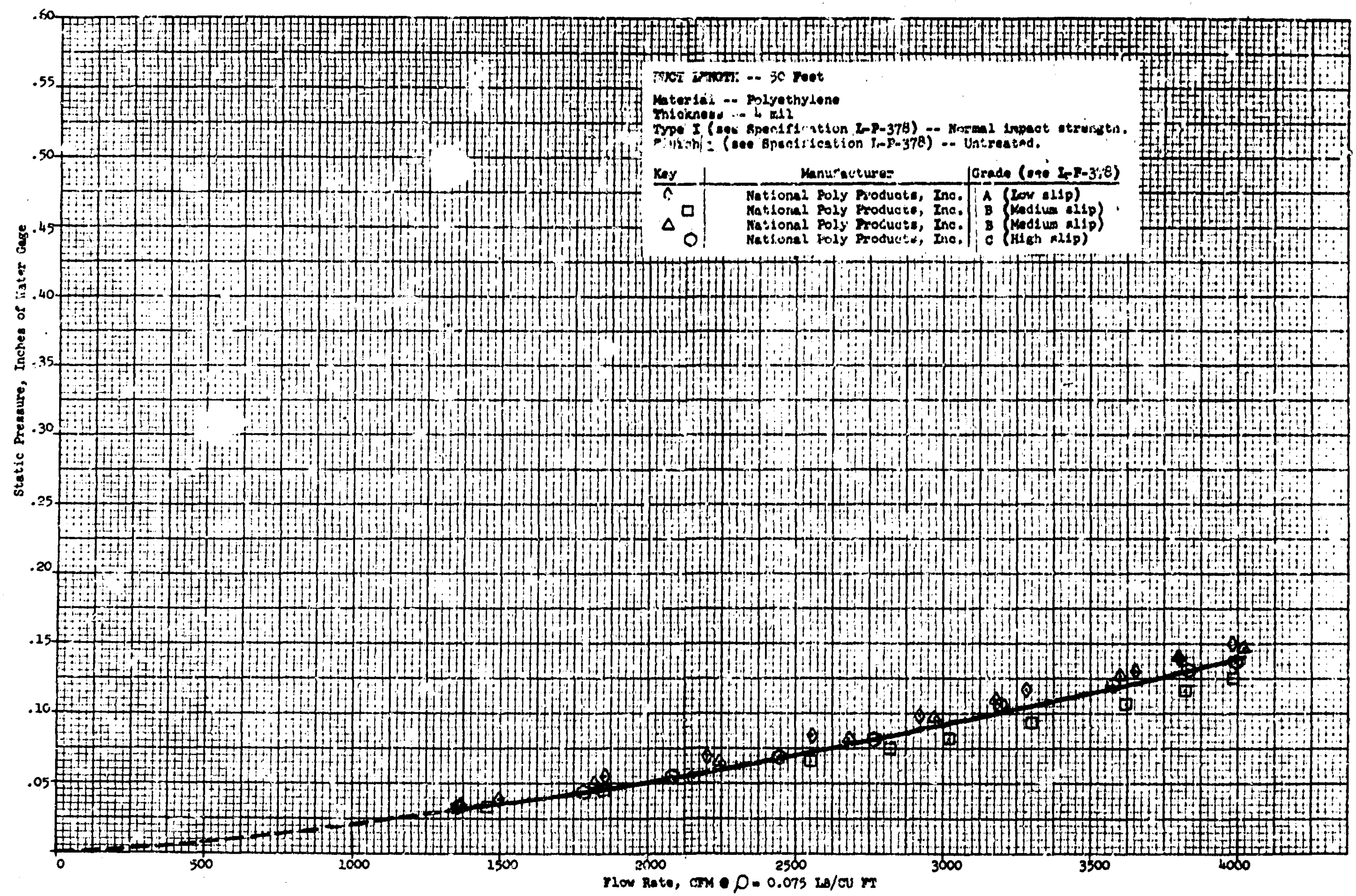


Figure 23 TEST DATA -- 50 FEET OF TUBING

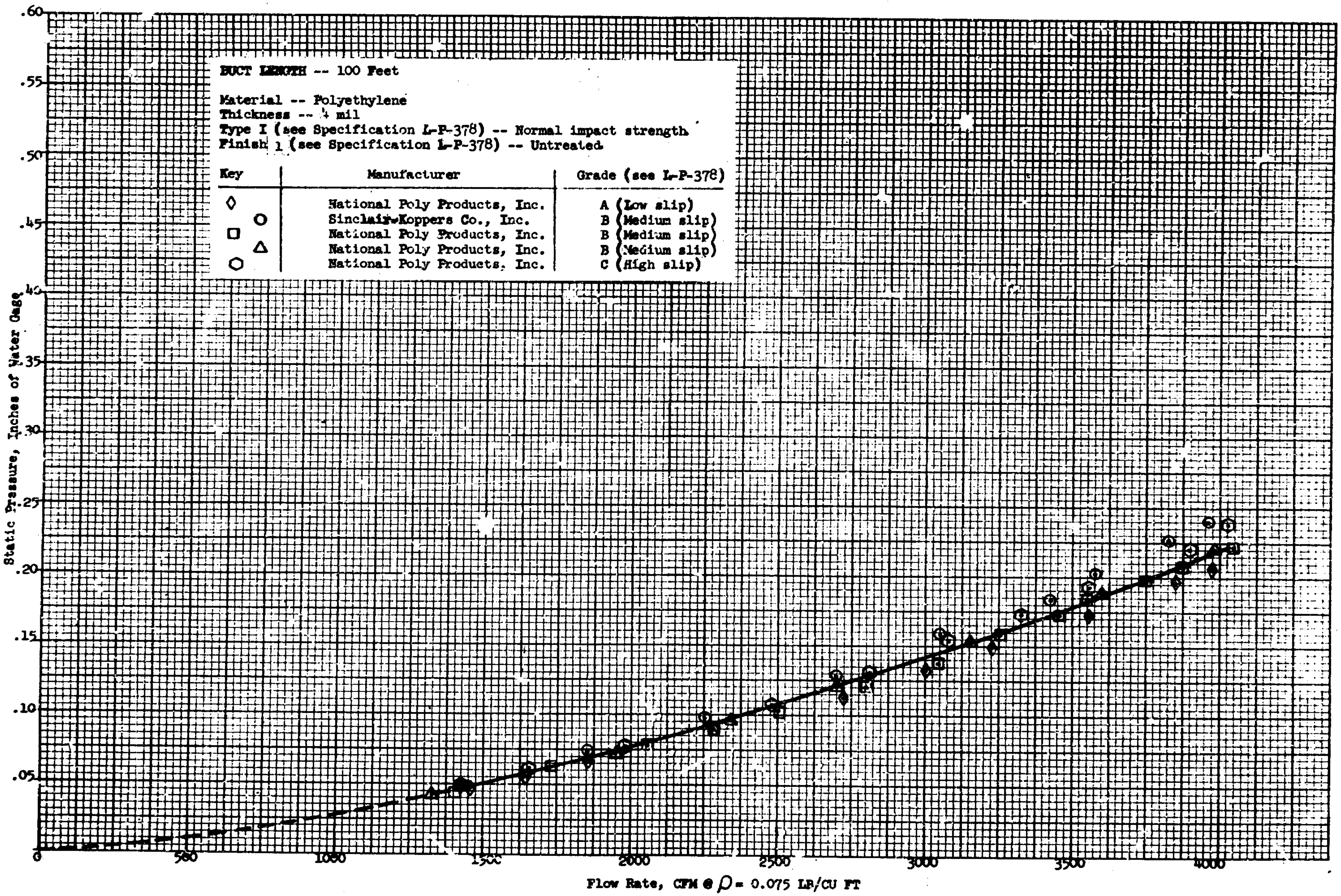


Figure 24 TEST DATA -- 100 FEET OF TUBING

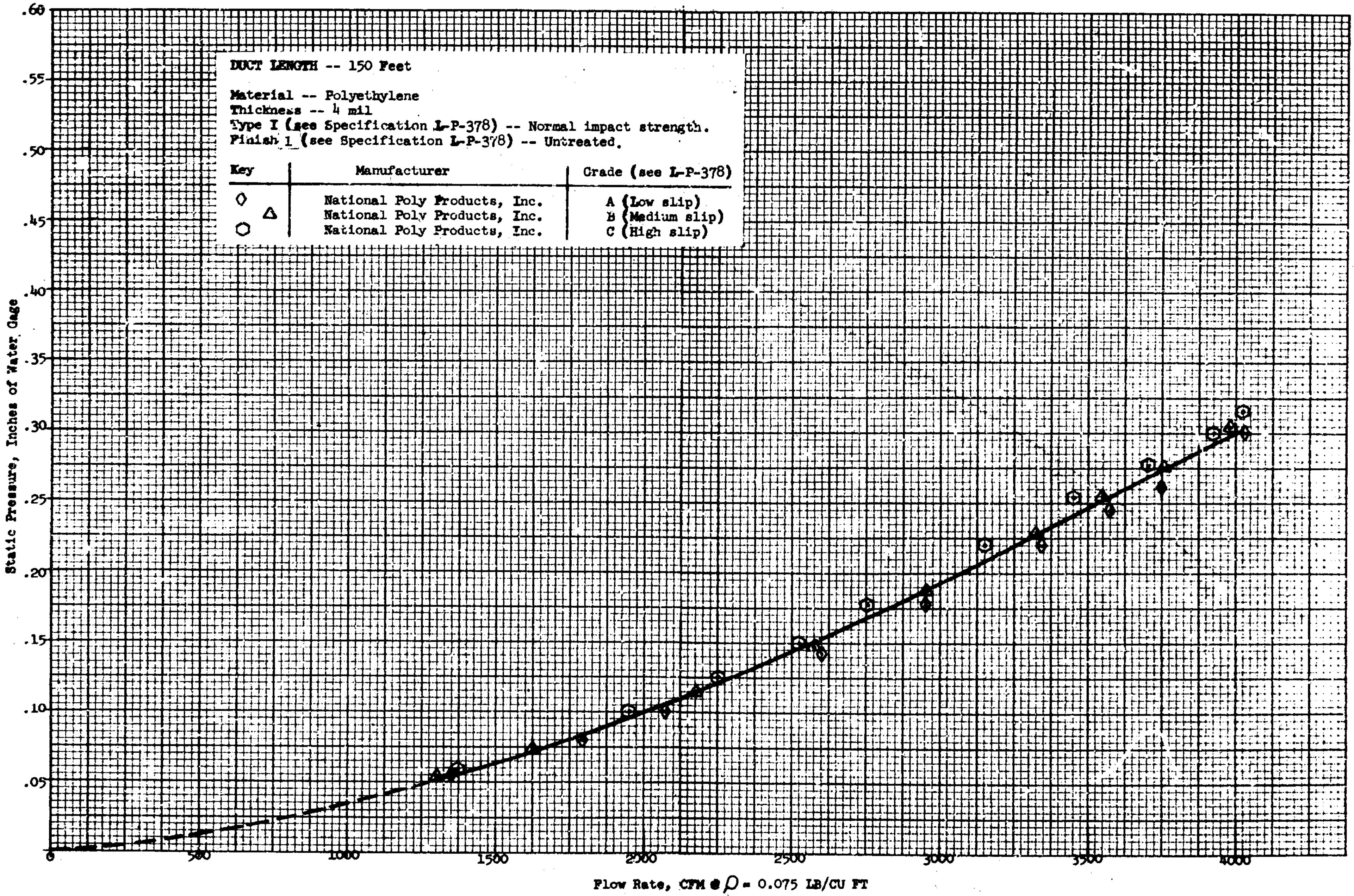


Figure 25 TEST DATA -- 150 FEET OF TUBING

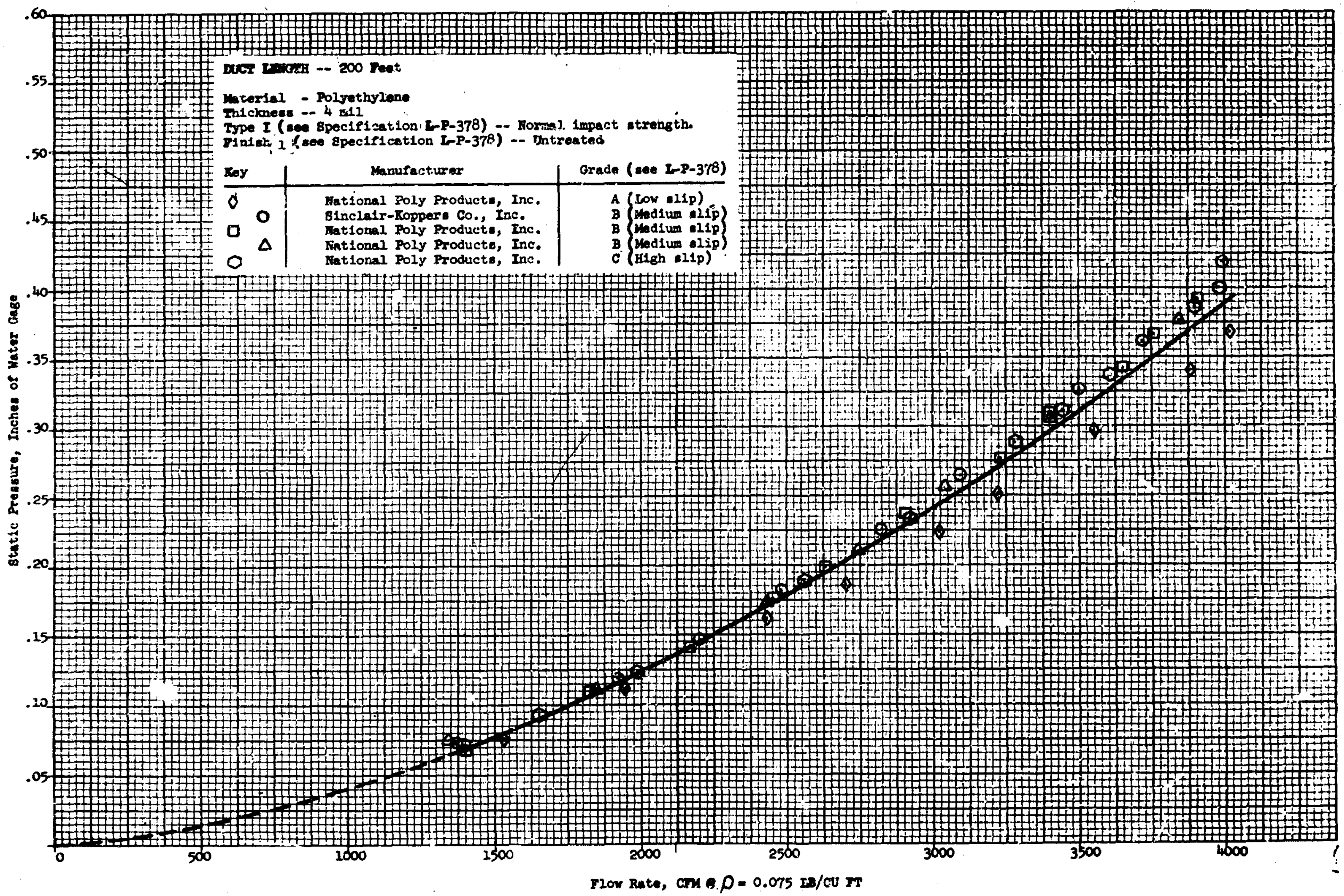


Figure 26 TEST DATA -- 200 FEET OF TUBING

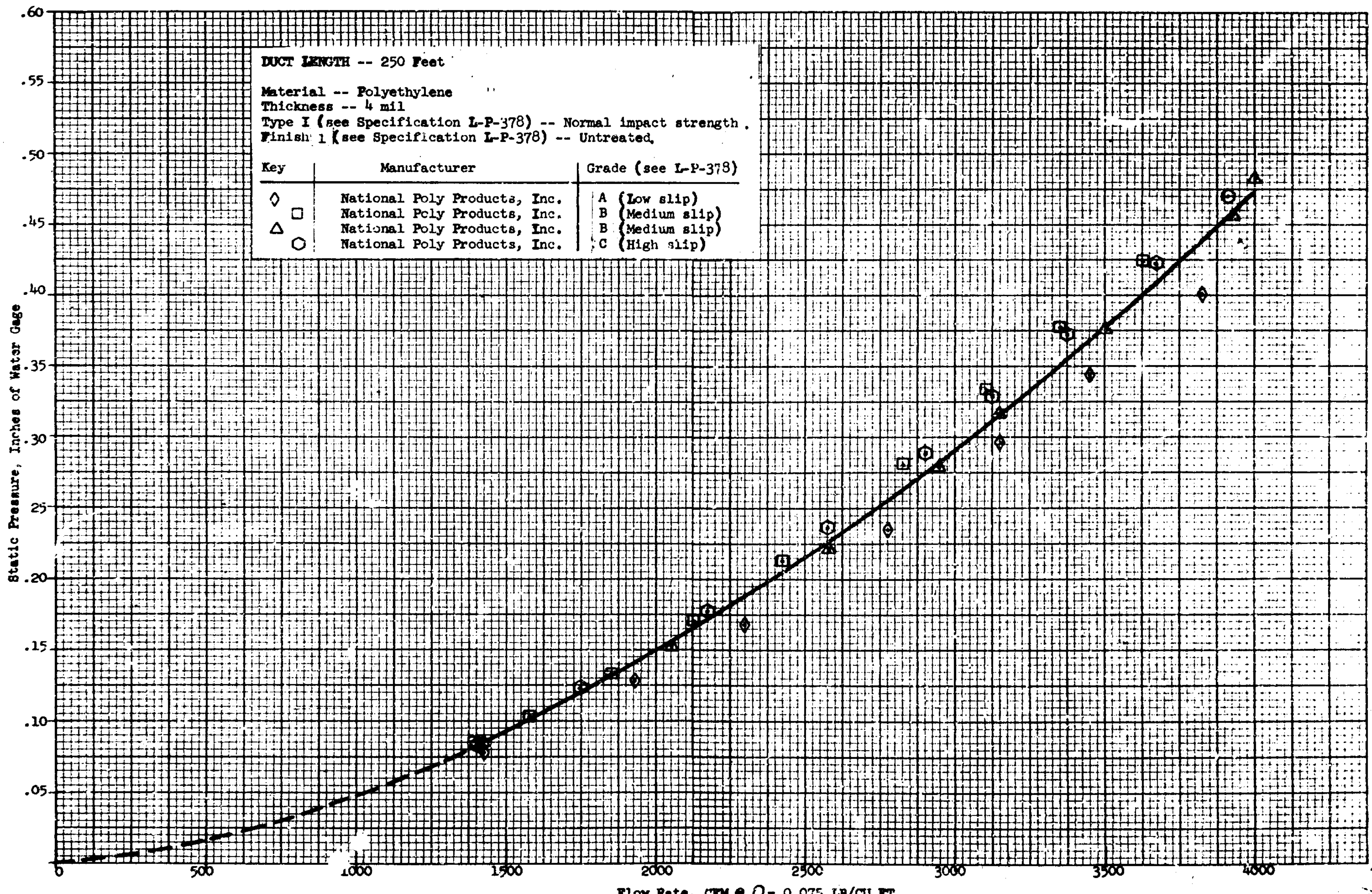


Figure 27 TEST DATA -- 250 FEET OF TUBING

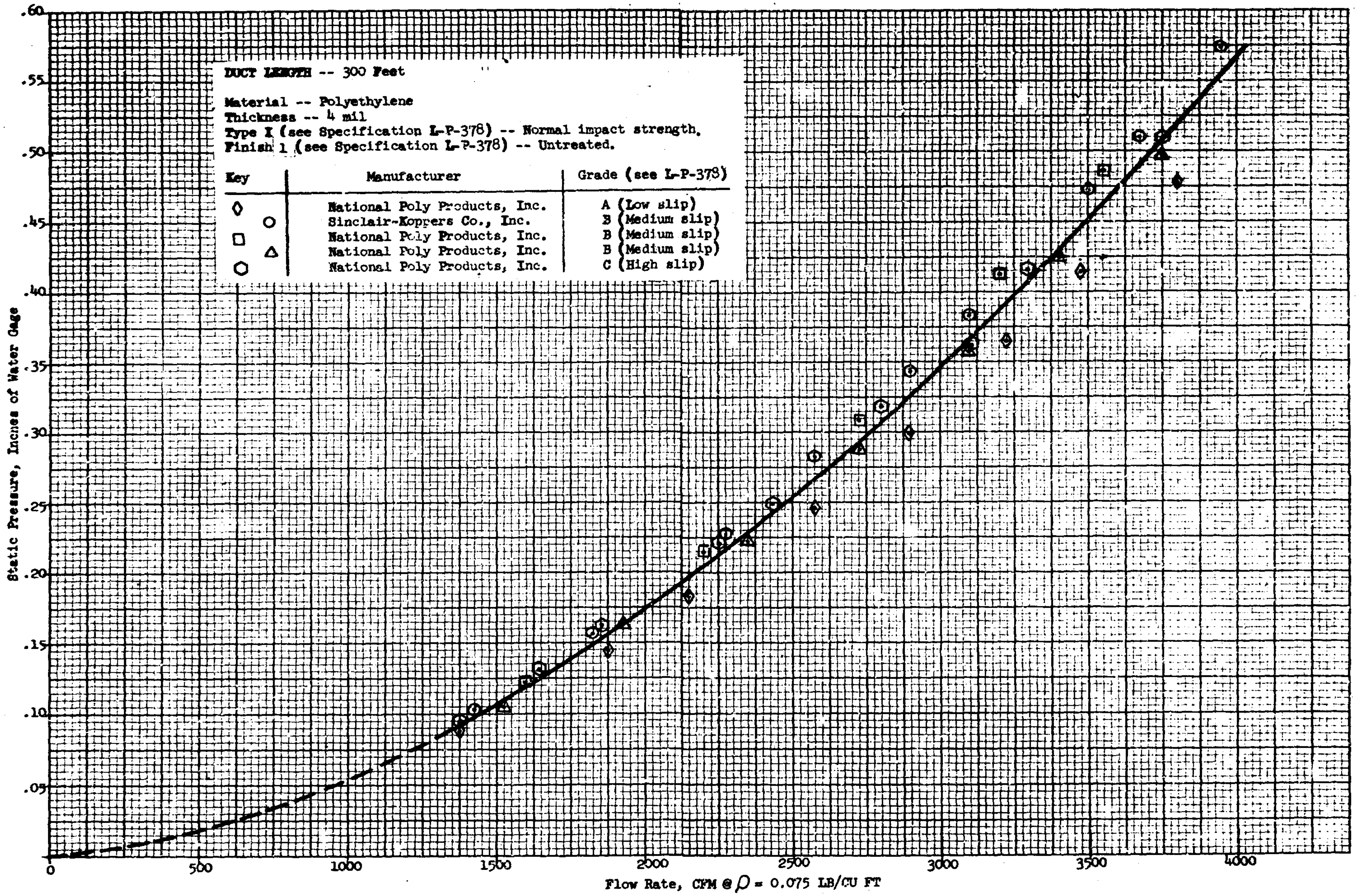


Figure 28 TEST DATA -- 300 FEET OF TUBING

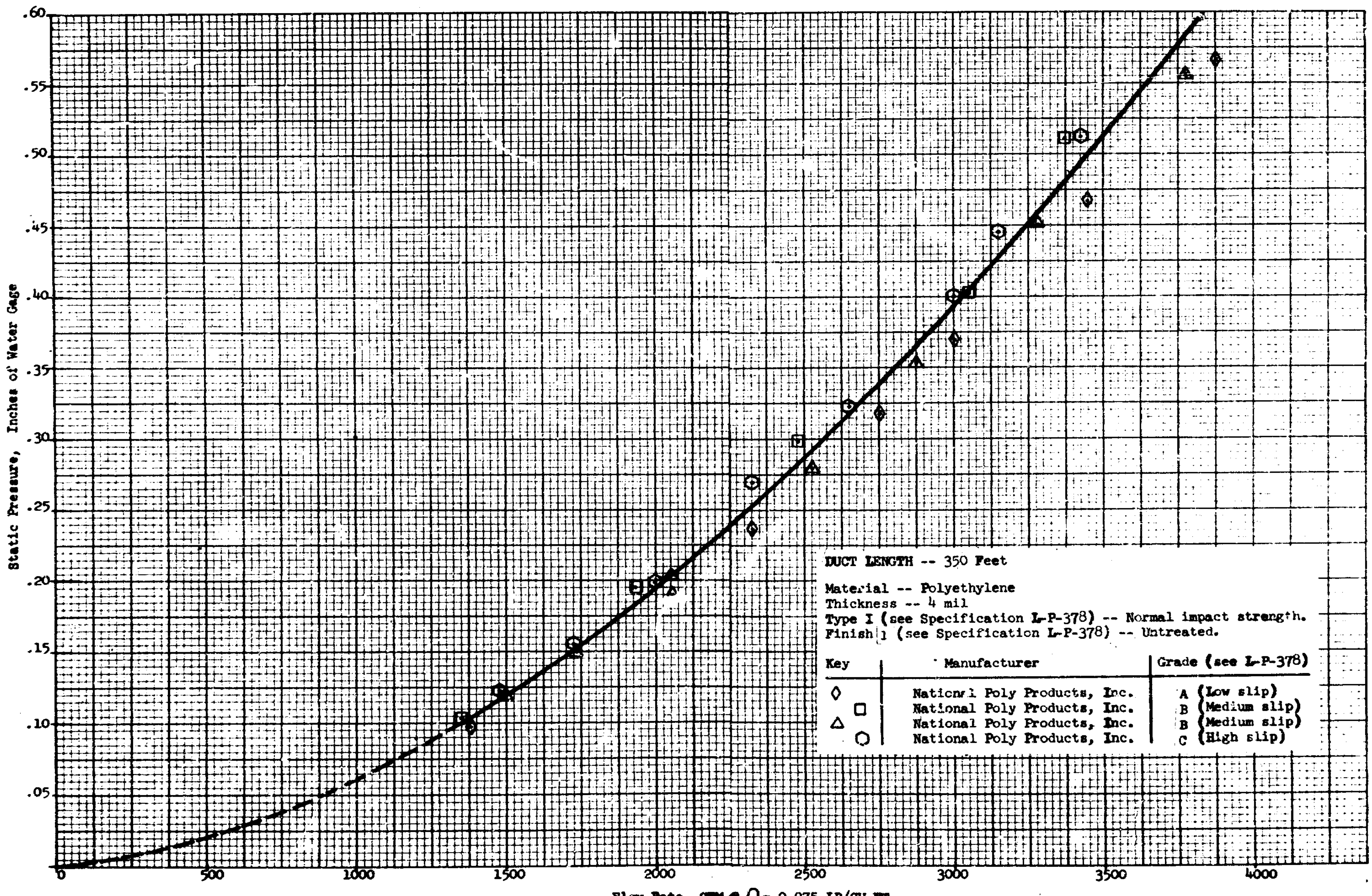


Figure 29 TEST DATA -- 350 FEET OF TUBING

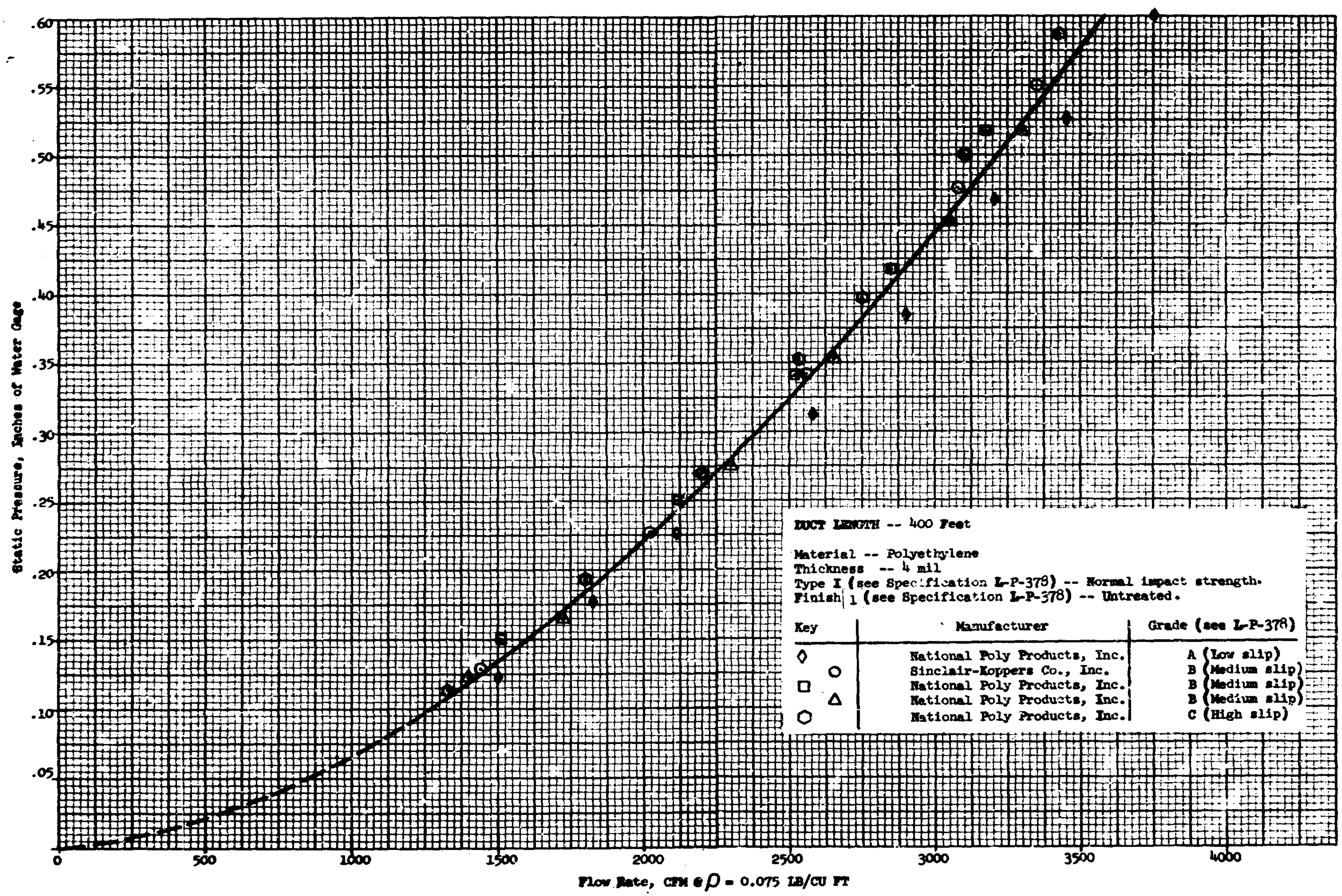


Figure 30 TEST DATA -- 400 FEET OF TUBING

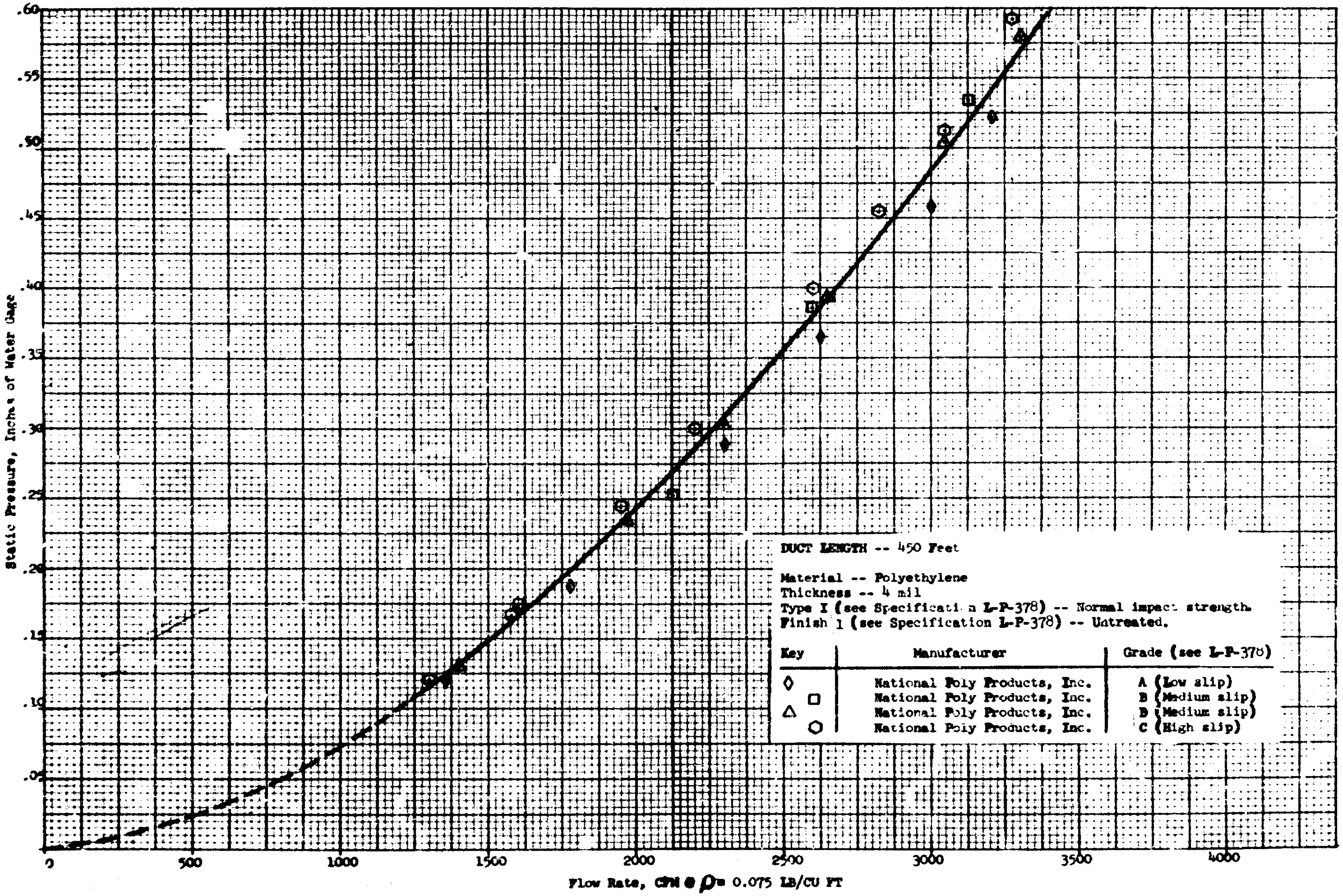


Figure 31 TEST DATA -- 450 FEET OF TUBING

APPENDIX B

SPECIFICATION USED
FOR DETERMINING COST
OF FITTINGS

Spec. No. 1278-1
Date: 13 April 1965

General American Transportation Corporation

Specification for Plastic Duct Elbows

1. Scope

A study is being conducted to determine the type, quantity, material, and configuration of plastic duct fittings which will be required in a portable Package Ventilation Kit suitable for Civil Defense fallout shelters. At present it is anticipated that at least three 90° elbows or three 45° elbows will be required per kit. This study will include fabrication of various 45° and 90° elbow configurations with subsequent tests and analysis of each configuration. Selection of the optimum elbow will be based on efficiency (low pressure drop), stability, and production costs. A production run of the package ventilation kit will be on the order of 350,000 units in which at least three of the selected elbows will be supplied per unit.

2. Requirements

2.1 Description

The elbows are to be fabricated from 4 mil (.004) minimum plastic film such as polyethylene or polyvinylchloride, etc. with a 20 inch nominal diameter (equivalent to tubing 31 x .004). The maximum stati pressure within the elbows will be 1.0 inches W.G. The maximum air velocity within the elbow will be 2000 feet per minute. The elbows must be capable of being stored (but not necessarily operated) at ambient temperatures of -60°F to 120°F and relative humidities of 0 to 100%. Operational temperature of elbows in a ventilation duct will be approximately 85°F. The cuffs of the elbow will be assembled to straight lengths of polyethylene tubing 31 x .004 by means of a coupling to form the ventilation duct. Material for the elbows must be flexible, unsupported plastic film in natural color and odorless. Type, grade, and finish of plastic material can be specified by the fabricator. The method of sealing or bonding the seams is left to the discretion of the fabricator.

2.2 Elbow Configurations

Seven elbow configurations under consideration are shown in drawing number Spec. 1278-1. Each configuration is dimensioned in respect to a radius R, nominal diameter D, and a cuff length C. Preproduction models of each configuration are required for testing and will have the following dimensions.

90° smooth elbow (4 elbows in total)

C = 4"; D = 20"; R = 20"
C = 4"; D = 20"; R = 30"
C = 4"; D = 20"; R = 40"
C = 4"; D = 20"; R = 60"

90° 3-piece elbow (4 elbows in total)

C = 4"; D = 20"; R = 20"
C = 4"; D = 20"; R = 30"
C = 4"; D = 20"; R = 40"
C = 4"; D = 20"; R = 60"

90° 5-piece elbow (4 elbows in total)

C = 4"; D = 20"; R = 20"
C = 4"; D = 20"; R = 30"
C = 4"; D = 20"; R = 40"
C = 4"; D = 20"; R = 60"

90° mitered elbow (1 elbow in total)

C = 6"; D = 20"

45° smooth elbow (4 elbows in total)

C = 4"; D = 20"; R = 20"
C = 4"; D = 20"; R = 30"
C = 4"; D = 20"; R = 40"
C = 4"; D = 20"; R = 60"

45° 3-piece elbow (4 elbows in total)

C = 4"; D = 20"; R = 20"
C = 4"; D = 20"; R = 30"
C = 4"; D = 20"; R = 40"
C = 4"; D = 20"; R = 60"

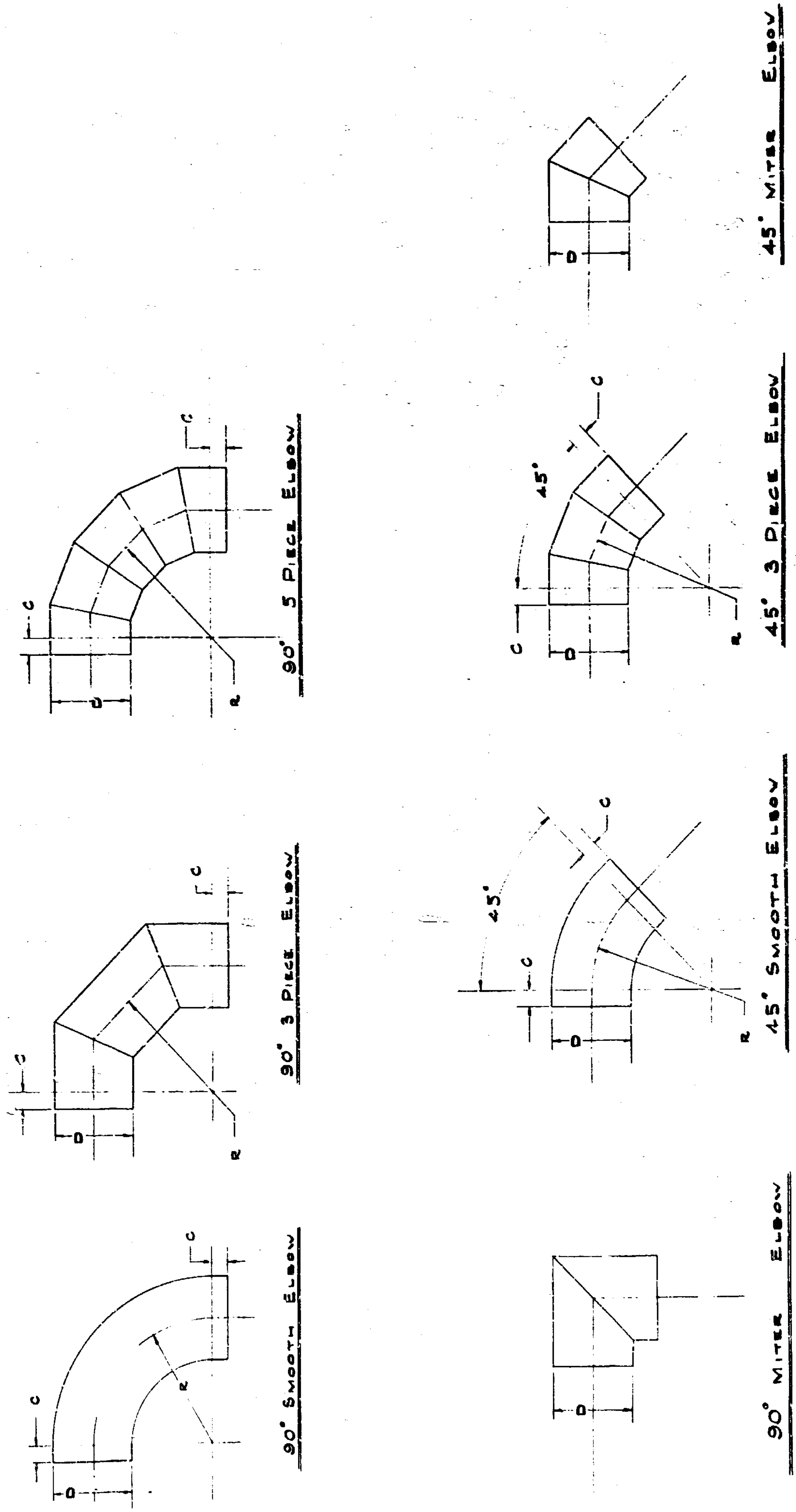
45° mitered elbow (1 elbow in total)

C = 6"; D = 20"

The dimension D is nominal and is equivalent to the diameter of extruded tubing 31" x .004.

3. Quantity

Preproduction elbows for testing purposes will consist of one elbow per size per configuration or a total of 22 elbows. After testing, a cost versus performance analysis will be conducted to determine the optimum elbow configuration and size. A production run of the selected elbow will then be made in quantity of 500 units. A follow-up production run will consist of either 350,000, 700,000, or 1,050,000 units to be fabricated over a two year period. Cost estimates of preproduction elbows as well as estimates of each size and elbow configuration in quantities of 500, 350,000, 700,000, and 1,050,000 should be submitted by the fabricator.



Drawing Spec. 1278-1

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final

5. AUTHOR(S) (Last name, first name, initial)

Neveril, Robert B.
Behls, Herman F.

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13. ABSTRACT

The friction losses for 20-inch diameter, 4-mil thick, flexible polyethylene tubing and plastic elbows are presented in this report. This type of ducting is intended for use with the Civil Defense fallout shelter ventilator specified in MIL-V-40645. (U)

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Friction Loss In Flexible Plastic Air Duct
OCD Work Unit 1423A
Final Report 1278-2
By R. B. Neveril and H. F. Behls
October 1965 (UNCLASSIFIED) pp. 57

The friction losses for 20-inch diameter, 4-mil thick, flexible polyethylene tubing and plastic elbows are presented in this report. This type of ducting is intended for use with the Civil Defense fallout shelter ventilator specified in MIL-V-40645. (U)

CIVIL DEFENSE SYSTEMS, FALLOUT SHELTERS, SPECIFICATIONS, COOLING & VENTILATING EQUIPMENT, VENTILATION, ENVIRONMENT, TESTS, MATERIALS, PLASTICS

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Prepared for
Office of Civil Defense
Department of the Army, OSA
under
OCD Work Unit 1423A
SRI Subcontract No. B-70925(4949A-28)-US

SUMMARY
OF
RESEARCH REPORT

FRICTION LOSS IN FLEXIBLE PLASTIC AIR DUCT

GARD Report 1278-2 October 1965

by

General American Transportation Corporation
General American Research Division
Environmental Research Group
Niles, Illinois

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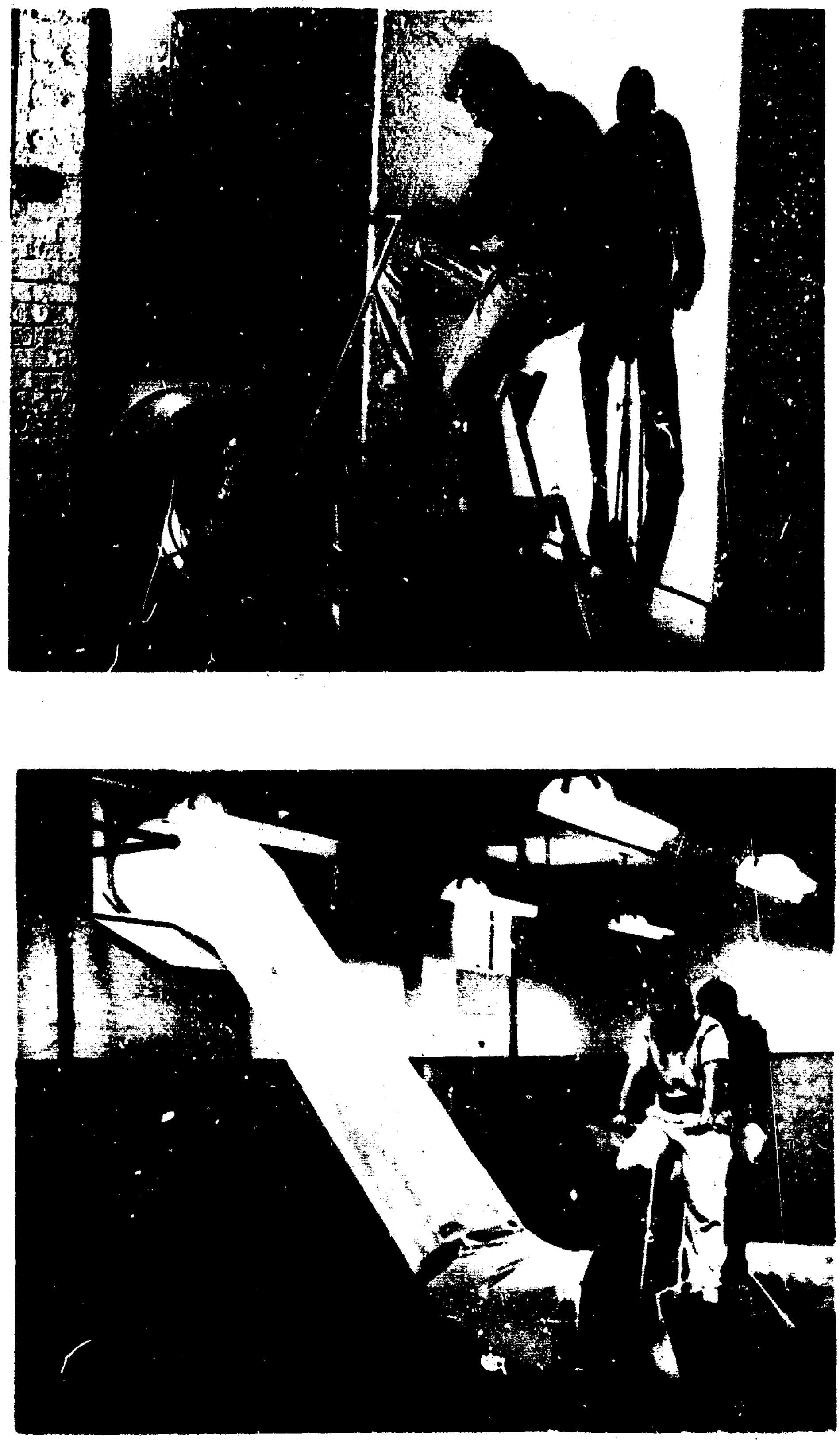


Figure 1 PACKAGE VENTILATION KITS IN OPERATION

INTRODUCTION

A Package Ventilation Kit (PVK) was developed[1] for use as an inexpensive method of exhausting stale, hot and humid air from fallout shelters (see Figure 1). This ventilator is intended for use with flexible plastic duct systems (see Figure 2) and, therefore, flexible plastic tubing and fittings are supplied with the Kit. The objectives of this program are to determine the friction loss of flexible tubing and fittings, and to recommend the best fittings, based on cost and pressure drop, for use in fabricating shelter duct systems.

Figure 2 PVK DUCT SYSTEMS

[1] B. A. Libovicz and H. F. Behls, "Shelter Package Ventilation Kit", prepared for the Office of Civil Defense under Contract OCD-PS-64-22, OCD Work Unit 1423A, General American Transportation Corporation (GARD Report 1244), Niles, Illinois, October 1965.

TEST PROCEDURES

Apparatus.--The test apparatus consisted of an 8,000 cfm centrifugal blower connected by a flexible wire-reinforced cloth duct to a 47 foot long, 20-inch diameter test stand which was fabricated from 24 U.S. Gage, zinc coated steel spiral conduit duct with 6 inch seams (see Figures 3 and 4). The design of the test stand is based on recommendations of the National Electrical Manufacturers Association.[2] Air flow rates were measured with a 14-inch diameter aperture sharp-edge orifice plate which was calibrated with a pitot tube five feet upstream from the orifice. Two air straighteners were located approximately 14 feet and 28 feet upstream of the orifice plate to reduce turbulence. A piezometer ring was located 14 feet downstream from the orifice and 5 feet from the end of the test stand. Inclined manometers were used to measure the pressure drop across the orifice, and the static pressure drop of the test specimens.

Methods.--The specimens were first taped to the test stand. The blower was adjusted to provide the desired flow rates, and the static pressure loss and flow rate (orifice differential pressure) were recorded. Barometric pressure, dry-bulb temperature, and wet-bulb temperature were recorded before each test to provide the flow rate correction factor to standard air (ρ = 0.075 lbs/cu ft). The tare pressure drop of the test apparatus, i.e., the pressure drop caused by the 5 foot length of spiral duct between the plane of the measuring station and the plastic specimens, was subtracted from the test data after its correction to standard air.

---

[2] National Electrical Manufacturers Association (NEMA) Standards Publication No. FM1-1955, "Electric Fans", 155 East 44th Street, New York, New York.

Tubing.--Plastic tubing lengths from 450 to 50 feet in increments of 50 feet were tested at flow rates from 1300 to 4100 SCFM (standard air) with the discharge end of the tubing unrestrained. Five high impact strength (Type II), untreated (Finish 1) tubing specimens were tested. Of these samples one was low slip* (Grade A), three were medium slip (Grade B), and one was high slip (Grade C). The diameter is 19.75 ± 0.25 inches, and the thickness 0.004 (4-mil) ± 0.0008 inches.

Elbows.--The friction loss of the fittings listed below were tested with 100 feet of straight tubing on the downstream end of the system and the results were compared to each other. Testing with a duct on the discharge end of the elbows was necessary to fully inflate the fittings, and the results are therefore only applicable to fully inflated fittings. The best factory fabricated and shelter fabricated elbows were then further tested with duct lengths of 100, 200, and 300 feet to determine the effect of static pressure on the elbow pressure drop or equivalent duct length (EDL).

Key	Method of Fabrication	Radius, Inches	Style	Material	
				Type	Thickness, Mils
◺	Factory	60	Smooth Radius	PVC	4
D	Factory	40	Smooth Radius	PVC	4
⌂	Factory	60	Smooth Radius	PVC	8
◇	Factory	40	Smooth Radius	PVC	8
⌂	Factory	30	Smooth Radius	PVC	4
○	Shelter	60	3-Piece Miter	poly-ethylene	4
▲	Factory	20	Smooth Radius	PVC	4
ɔ	Factory	--	2-Piece Miter	PVC	4
△	Shelter	--	Packing Box	corrugated fiberboard	--
□	Factory	20	Smooth Radius Wire-Reinforced	PVC	4

Table I

Summary of Elbows Tested

*The test apparatus and methods for determining the impact strength and slip (kinetic coefficient of friction) are presented in Federal Specification L-P-378, "Plastic Film (Polyethylene Thin Gage)". Finish 2 film is treated to allow printing ink to adhere.

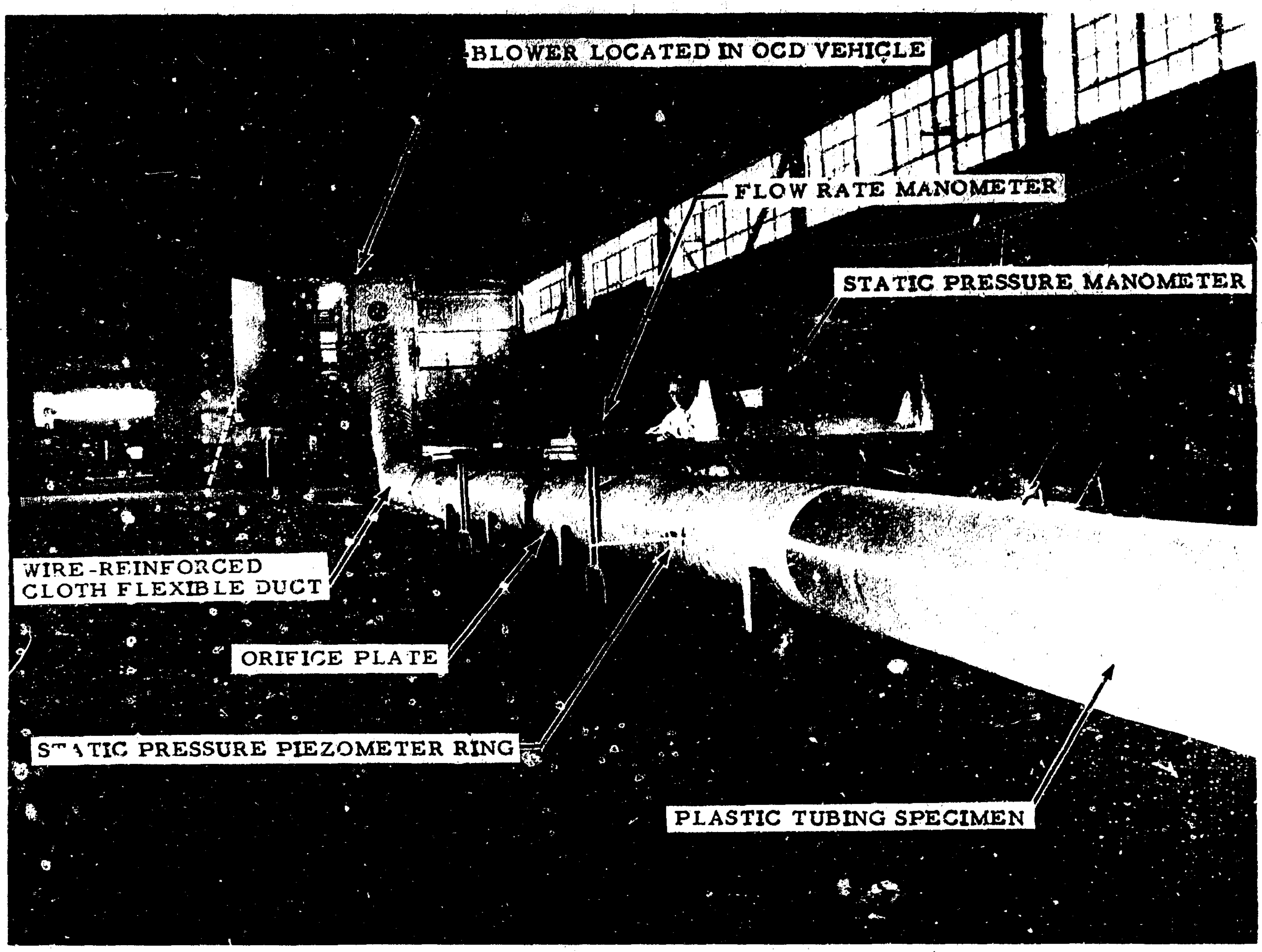


Figure 3 TEST APPARATUS

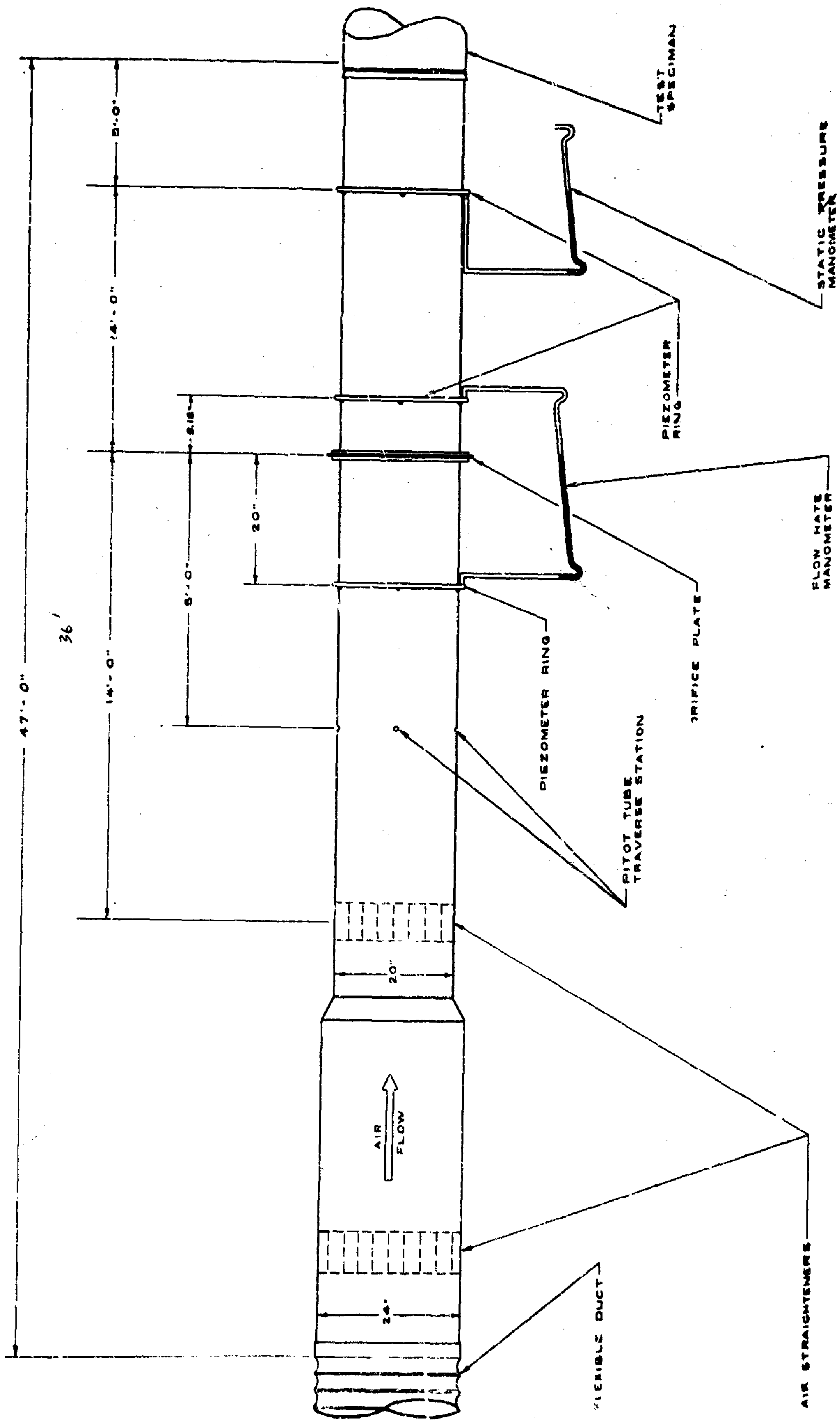


Figure 4 SCHEMATIC LAYOUT OF TEST APPARATUS

RESULTS AND ANALYSIS

Tubing.--The friction of air in straight polyethylene tubing for lengths from 50 to 450 feet are shown in Figure 5. These curves are based on a least squares linear logarithmic regression of the test data. The standard error of estimate; i.e., the mean of the square of the differences between the data and the fitted curve ranges from 0.007 inches of water gage (iwg) for the 150 foot length to 0.023 iwg for the 400 foot length. Fully inflated 20-inch diameter plastic tubing has about three-quarters of the pressure drop of sheet-metal duct. However, the last fifty feet of a plastic duct system which is not completely inflated has 1-1/2 to 3 times the pressure drop per foot of fully inflated plastic tubing. The result is that for duct systems over 100 feet long the pressure drops for sheet-metal and plastic tubing are approximately the same.

A mathematical expression derived from the least squares fitted curves of the data is:

$$P = 1.915 \times 10^{-6} \left[Q^{1.349} + 0.01096 \left(\frac{L}{50} - 1\right) Q^{1.833} \right] \qquad (1)$$

where:

P = static pressure loss, inches of water gage

Q = air flow rate, standard cubic feet per minute (scfm)

L = tubing length (for lengths of 50 feet and longer)

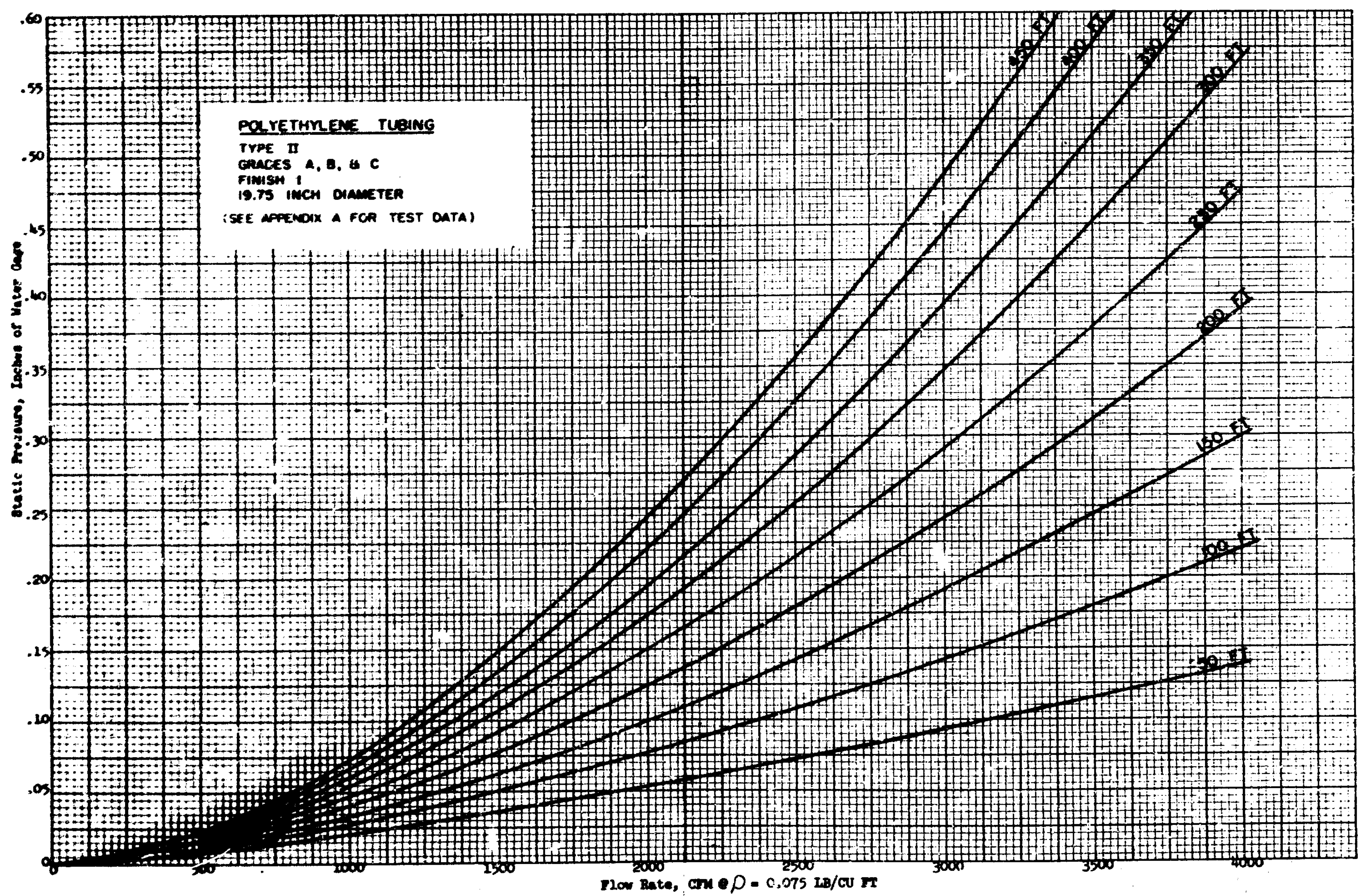


Figure 5 FRICTION OF AIR IN STRAIGHT POLYETHYLENE TUBING

Factory Fabricated Elbows.--The elbows with the lowest pressure losses are factory fabricated smooth radius elbows. The elbows fabricated from four-mil plastic had lower pressure losses than those fabricated from eight-mil plastic. The change in pressure loss with centerline radius decreased as the centerline radius approached 60 inches. The elbows with centerline radii of 40-inches and 60-inches have nearly identical pressure losses, indicating that the trade-off point for centerline radius versus pressure loss is approximately 40 inches. The mitered elbow had a considerable pressure drop, and the wire-reinforced elbow developed excessive pressure losses.

The four-mil polyvinyl chloride (PVC) 40-inch smooth radius elbow is the best factory elbow when considering pressure drop, space requirements, material and cost. Figure 6 shows the results of tests performed with this elbow. The solid lines show the pressure losses for the elbow with straight lengths of tubing attached to the downstream side, the broken lines show the pressure losses for the straight lengths only. It can be seen that the equivalent length of straight tubing for the 40-inch smooth radius elbow is approximately 50 feet when fully inflated. For the elbow to be fully inflated fifty feet of straight tubing must be on the downstream side.

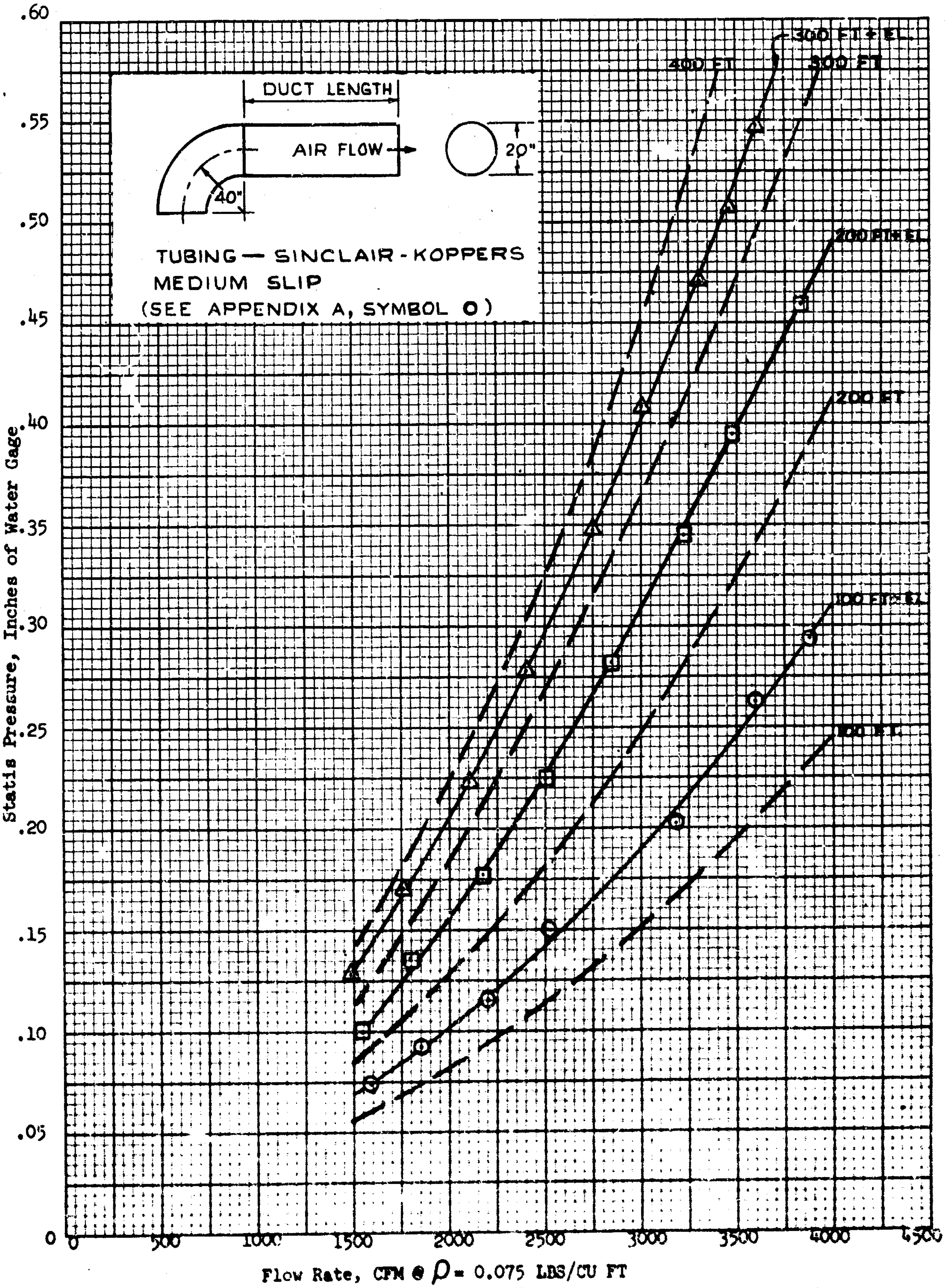


Figure 6 FRICTION LOSS OF THE 40-INCH SMOOTH RADIUS ELBOW

Shelter Fabricated Elbows.--Of the shelter fabricated elbows (see Table I) the three-piece elbow results in the least pressure loss. The elbow made from packing boxes produced the largest pressure loss. This elbow was extremely stable at all flow rates; however, the exit and entrance losses of the air stream in the plenum-like box produced the high pressure loss. The best hand-tucked elbow results in pressure drops considerably higher than any of the other elbows, and the results were erratic.

Since the three-piece elbow has the least pressure loss this elbow was further tested with 100, 200, and 300 feet of tubing (see Figure 7). It can be seen that the pressure loss of the three-piece elbow with a centerline radius of 60-inches is equivalent to 90 feet of straight tubing when fully inflated. For the elbow to be fully inflated fifty feet of straight tubing must be on the downstream side.

Application.--The equivalent duct length of any plastic tubing system can be determined by adding the total length of straight tubing plus the number of elbows times their respective equivalent duct length (see Equation 2) -- 50 feet for the factory fabricated elbow and 90 feet for the shelter fabricated elbow.

$$EDL_s = L + 50 N_f + 90 N_s \qquad (2)$$

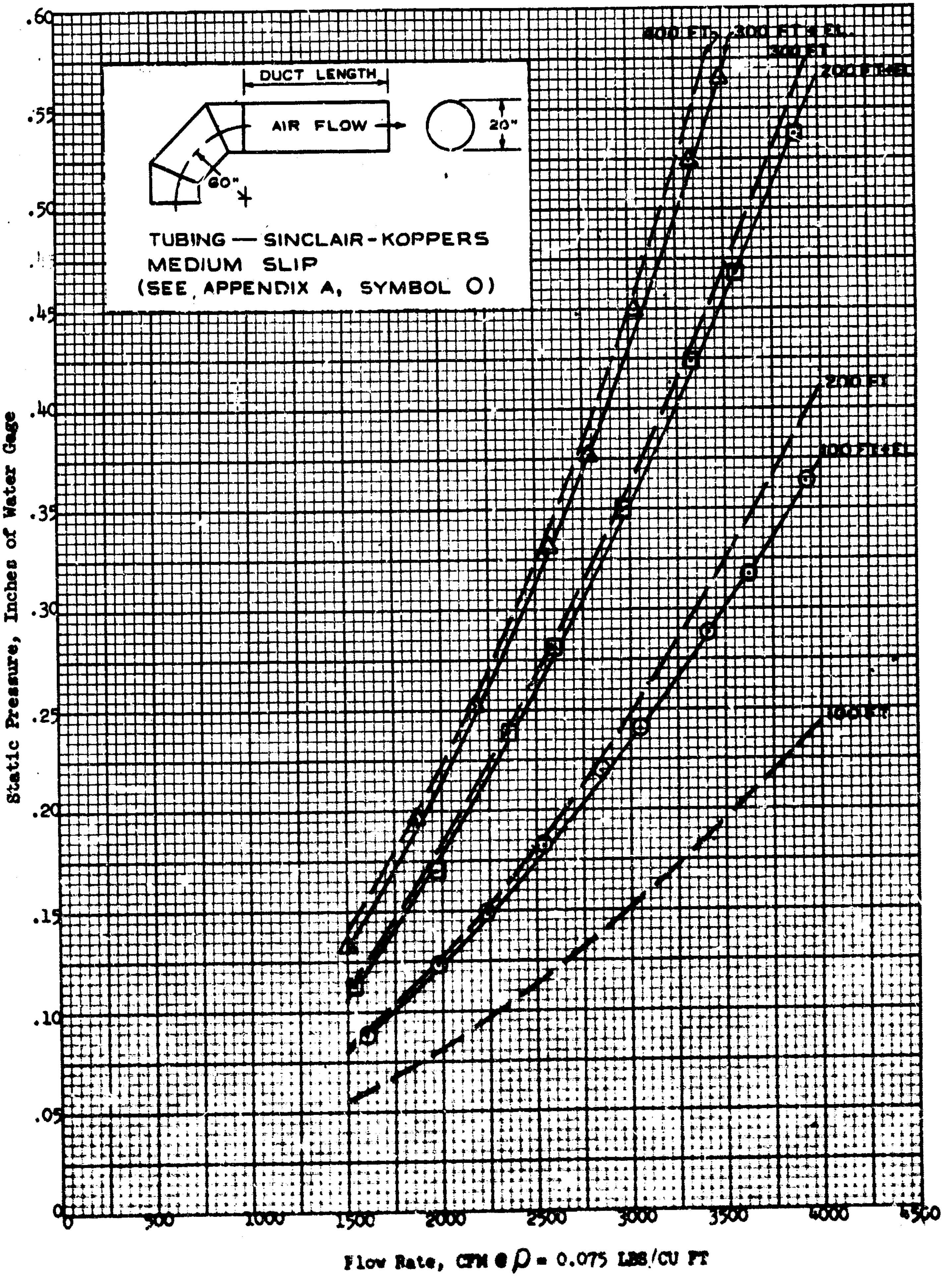
where:

EDL_s = Equivalent Duct Length of the system, feet

L = length of straight duct in the system, feet

N_f = number of factory fabricated elbows, dimensionless

N_s = number of shelter fabricated elbows, dimensionless


DUCT LENGTH
AIR FLOW
20"
60"
TUBING — SINCLAIR-KOPPERS
MEDIUM SLIP
(SEE APPENDIX A, SYMBOL O)
400 FT
300 FT + EL
300 FT
200 FT + EL
200 FT
100 FT + EL
100 FT
Static Pressure, Inches of Water Gage
.60
.55
.50
.45
.40
.35
.30
.25
.20
.15
.10
.05
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Flow Rate, CFM @ ρ = 0.075 LBS/CU FT

[illegible]

ERRATA

Subject Report: R. B. Neveril and H. F. Behls, "Friction Loss in Flexible Plastic Air Duct", OCD Work Unit 1423A, GARD Report 1278-2, October, 1965.

Page 26, Figure 17

The ordinate scale of Figure 17 which ranges from 0 to .60 inch of water gage, static pressure is double the actual value and should be changed to indicate a scale range of 0 to .30 inch of water gage.