LABORATORY TESTS OF AIR VALVE PERFORMANCE (2-Inch Combination Air and Vacuum Relief Valves)

by

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The test apparatus was designed to simulate the conditions encountered in Reclamation's applications. The valves may perform differently under different conditions.

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CONTENTS

INTRODUCTION

Combination air and vacuum valves often experience problems during operations in the field. One problem of primary concern occurs when lateral pipelines are filled faster than the designer's criteria recommends. Manufacturers' stated design criteria and air discharge capacities are often exceeded, causing air valves to close prematurely under high air velocities. This can occur as a result of intentional or unintentional operations, or because of equipment malfunction. This results in large quantities of trapped air within the pipeline which may lead to pipeline damage or waterhammer, causing damage when valve closure occurs.

The Grand Junction Projects Office, which is involved in the operation of PVC pipeline laterals, felt there was a need to determine actual performance limits for 2-in combination air and vacuum valves (including those currently designated in design standards). Eight of these valves were supplied by the Grand Junction Projects Office to be tested. The objectives included determination of :

1. Actual air valve performance curves.
2. Discharge coefficients.
3. Pressures and flow rates at which the air valve blows closed.
4. Pipeline transients caused by valve closure.

These data could then be used to assess the applicability of the valves for various situations. Combination air and vacuum release valves are designed to release large quantities of air through a large orifice during pipeline filling and will continuously discharge air through a separate smaller orifice even after the pipeline is under full operating pressure. This type of valve will also allow air to enter the pipeline if the pressure becomes negative (to prevent it from collapsing inward). This occurs during the pipeline draining procedure.

Note that only 2-in combination air and vacuum valves were tested in this study. The results of this study are not applicable to valves of any other size, since the mechanism design is often changed for different size valves.

TEST SETUP

This study consisted of two separate test setups; one to determine air valve discharge curves and coefficients, and a separate setup to determine pressure transients associated with the instantaneous closure of the air valve during rapid filling.

The test apparatus was designed to simulate the conditions encountered in Reclamation's applications. The valves may perform differently under different conditions.

Test Setup 1. The first test setup or "Air Discharge Test" is shown in figure 1. A compressed air line was run into a large tank (113 ft^3) to store a reservoir of constant pressure compressed air ranging from 0.5 lb/in^2 to 10 lb/in^2. A butterfly valve was used to release air from the tank into the 4-in pipeline. Each air valve was mounted on the 4-in pipeline. A pressure transducer located on the air valve riser was used to measure the differential pressure across the air valve.

Pressure transducers connected across orifice plate flange taps were used to determine the corresponding flow rate. In addition, a pressure transducer was connected directly to a tap on the air valve (when a tap was available). Data from this transducer will be used to compare to field tests if they are performed in the future. Pressures and flow rates were also noted when each valve was blown closed under high air velocities. The data from this test were recorded manually.

Test Setup 2. The second test setup or "Transient Test" is shown in figure 2. With the downstream butterfly and gate valves closed, the pump fed water into the pipeline where the air valve was mounted. The prototype fill velocities of interest ranged from 1 ft/sec to 30 ft/sec. At the point where either water or high air velocities caused the air valve to close, pressure transients were measured with three dynamic pressure transducers and recorded on a strip chart for each fill velocity. One transducer was located on the air valve, with another transducer located 20 ft downstream, and a third transducer located 40 ft downstream. From these data it was possible to determine the maximum transients that would occur due to valve closure in PVC pipes ranging from 6-in to 36-in diameter.

TRANSIENT MODEL SCALING

For the transient test, Froude scaling was used to determine pipeline fill velocities into the 4-in-diameter model steel pipeline where the air valves were mounted. This resulted in a 1:1.22 velocity ratio in modeling a 6-in-diameter prototype pipeline and a 1:3 velocity ratio for a 36-in-diameter prototype pipeline. In order to account for the effects of PVC piping in the prototype as opposed to the steel pipe used in the model, the downstream transients had to be scaled according to wave speed ratios as shown in Appendix B.

Reynolds numbers versus pressure drop coefficients for the model were plotted (fig. 16 and 17) in order to determine at what flows viscous effects may affect model scaling of pressures. For fill velocities that correspond to Reynolds number values where the pressure drop coefficient becomes constant, the viscous effects are negligible for scaled values of pressure; therefore, these values were used for the analysis.

Pressure drop coefficients for the transient model were calculated from:

$$C_p = \frac{P}{\frac{1}{2}\rho V^2}$$

where C_p = Pressure drop coefficient
V = Velocity (ft/sec)
P = Differential pressure across air valve (lb/in^2)
ρ = Air density (lb$_m$/ft^3)

In figures 12 through 15, which show dynamic pressure as a function of fill velocity, an arrow is used to indicate the fill velocities that correspond to the region where viscous effects are negligible. For fill velocities below these values, viscous effects may cause scaled values of pressure to be too high; therefore, these values were not used in the analysis. This demonstrates one of the limitations in scaling. However, since the main objective in this study was to determine the effects of higher fill velocities, this didn't present a limitation to the test results.

Appendices A through C demonstrate how values for pressure and velocity, measured from the model (Table 3), were scaled to give the values for 6-in and 36-in PVC piping (Table 2). Figure 18 shows a sample of the data that were collected for one test run.

RESULTS

Air Discharge Test Results. Test discharge curves for all eight valves are shown for comparison in figure 3. Test and manufacturers' discharge curves, as well as test discharge coefficients (C_d), are shown in figures 4 through 11. Test curves do not follow the manufacturers' curves very closely and in most cases actual performance is less than advertised. Pressures at which each valve blows closed, and values for C_d, are given in Table 1. Tests were repeated, several times in some cases, to identify the position where the valve blows closed. It is important to note over what flows these discharge coefficients apply, since a valve with a high value of C_d may actually blow closed at a very low pressure, thereby making the valve useless. Discharge coefficients were calculated from:

$$C_d = 1.905 \frac{Q}{d^2}\sqrt{\frac{\rho}{P}} \qquad (2)$$

where C_d = Discharge coefficient
Q = Flow rate (ft^3/s)
P = Differential pressure across air valve (lb/in^2)
d = Inlet diameter (in) of air valve
ρ = Air density (lb_m/ft^3)

Six of the eight valves tested blew closed (due to high air velocities) at pressures ranging from 0.35 lb/in^2 to 5.6 lb/in^2 as shown in Table 1. None of the manufacturer's curves anticipate this phenomena.

Transient Test Results. Dynamic pressures due to valve closure versus fill velocity for 6-in-diameter PVC piping are shown in figures 12 and 13. Dynamic pressures due to valve closure versus fill velocity for 36-in-diameter PVC piping are shown in figures 14 and 15. The maximum of these dynamic pressures and the flow rates at which they occurred are given in Table 2. The maximum dynamic pressures for a 36-in-diameter pipeline range from 10.1 lb/in^2 to 25.0 lb/in^2 for a range of fill velocities of 1 ft/sec to 30 ft/sec. The maximum dynamic pressures for a 6-in-diameter pipeline range from 2.8 lb/in^2 to 7.2 lb/in^2 over the same range of fill velocities. Note that the pressures shown in Table 2 and on figures 12 through 15 are dynamic pressures only and must be added to actual static filling pressures (as determined by field tests) in order to determine the total pressure experienced by the pipeline.

Valve E and valve G leaked excessively at all test flows (maximum pressure of 11 lb/in^2). Valves D and H leaked at pressures less than 4 lb/in^2 and 3 lb/in^2, respectively. Valves A, B, C, and F demonstrated no leakage for any test flows.

CONCLUSIONS and DISCUSSION

Valve overall performance should be based on the following criteria:

1. The higher the discharge capacity the better the performance.

This capacity can be based on discharge coefficients and inlet diameter, and can be readily seen by comparing performance curves in figure 3.

2. The valve should not blow closed.

Any valve that has the tendency to blow closed could present a problem in the field. As the pipeline gets close to being filled, the surrounding air becomes compressed, causing the pipeline pressure to rise rapidly. This can cause premature valve closure for some valves, which leads to large quantities of air becoming trapped in the pipeline and possible pipeline damage or failure.

3. Leakage should be minimal.

Based on these criteria the following valves should be considered for selection:

1. Valve C.
   The discharge capacity for this valve is very low. It has a discharge coefficient ranging from .20 to .23, based on an inlet diameter of 1.747. However, over the range of test pressures, this valve neither leaked nor blew closed and would therefore be considered the most reliable of the valves tested.

2. Valve A.
   Although valve A blows closed around 4 lb/in^2, it may still be used if consideration is given to its limitations. This valve does not leak and has a larger inlet diameter and higher discharge coefficient than Valve C. Its efficiency in expelling air is quite good with an inlet diameter of 2.08 and a discharge coefficient ranging from .33 to .45. Therefore, most of the surrounding air may be expelled before it blows closed at 4 lb/in^2. Also, if static pipeline filling pressures remain below 4 lb/in^2 this valve would be a very good selection.

3. Valve G.
   This valve may also be useful for some applications since it did not blow closed over the range of test pressures and has a higher discharge coefficient than either valves A or C, based on an inlet diameter of 2.08 in. However, this valve leaked up to the maximum test pressure of 11 lb/in^2. Since field operating pressures generally range from 40 to 100 lb/in^2, the valve may seal under prototype pressures. This would make valve G an excellent selection. The valve seating pressures should be tested in the future.

The remaining valves were not considered good choices for the following reasons:

1. Valves E, H, D, and F blow closed at very low pressures. Because of this, too much air may remain trapped when valve closure occurs.

2. Valve B does not leak and does not blow closed until a pressure of 5.6 lb/in^2 is reached. However, the inlet diameter is

small (1.34 in) and its discharge capacity isn't as great as that of valve C. Also, because of its smaller discharge capacity, the surrounding pressure will rise more rapidly towards closing pressure.

In addition to the tests performed, valves functioning by similar mechanisms were compared. However, no direct correlation was found between type of mechanism design and valve performance.

Once a valve is selected, dynamic pressure due to valve closure will need to be evaluated to be sure that the allowable pipeline pressure is not exceeded at the desired fill velocity (see fig. 12 through 15). In general, the pipeline transient pressures were not a problem in the model tests. However, compression of large amounts of air in the prototype under larger static heads may cause high pipeline pressures.

TABLE 1. Summary of Information Obtained from Air Discharge Model.

Valve	Discharge Coefficients (Cd)	Cd Inlet Diameter (in)	Conditions at which Valve Blows Closed	
			Pressure across Valve (lb/in^2)	Air Flow Rate (ft^3/s)
Valve A	.45 to .33	2.08	4.3	5.1
Valve B	.21 to .27	1.34	5.6	1.9
Valve C	.23 to .20	1.747	Does not blow closed up to maximum test conditions of:	
			10.2	3.1
Valve D	.56 to .61	1.707	.5	2.6
Valve E	.08 to .05	2.08	1.0	0.7
Valve F	.81 to .91	2.08	.35	3.8
Valve G	.53 to .31	2.08	Does not blow closed up to maximum test conditions of:	
			7.3	5.5
Valve H	.24 to .34	2.08	1.5	2.5

TABLE 2. Summary of Transient Test Information for 6-in and 36-in Diameter Prototype Pipeline.

Valve	Maximum Dynamic Closure Pressure (lb/in^2) and Fill Rate (ft/s) - 6-in Pipe				Maximum Dynamic Closure Pressure (lb/in^2) and Fill Rate (ft/sec) - 36-in Pipe				Leakage
	Peak	Fill Rate	Peak to Peak	Fill Rate	Peak	Fill Rate	Peak to Peak	Fill Rate	
Valve A	4	30	5.7	30	11.5	27	11.5	27	None
Valve B	4.2	24.5	4.2	12	17	30	25	30	None
Valve C	3.8	30	6.0	30	9.8	30	15.8	18	None
Valve D	2.8	30	3.8	30	11	18	12.1	15	Leakage occurs below 4 lb/in^2
Valve E	3.8	30	6.0	30	22	19	22	19	Leakage at All Test Flows
Valve F	3.4	30	3.4	30	9.7	21	12	18	None
Valve G	4.2	30	6.6	30	10.1	15	12.4	15	Leakage at All Test Flows
Valve H	4.8	30	7.2	30	9.5	24	10.4	15	Leakage occurs below 3 lb/in^2

TABLE 3. Summary of Original Transient Information Obtained from 4-in Model.

Valve	Maximum Dynamic Closure Pressure (lb/in^2) and Fill Rate (ft/sec) for 6 in. Pipe converted back to original 4-in model pipe data				Maximum Dynamic Closure Pressure (lb/in^2) and Fill Rate (ft/sec) for 36-in Pipe converted to original 4-in model pipe data				Leakage
	Peak	Fill Rate	Peak to Peak	Fill Rate	Peak	Fill Rate	Peak to Peak	Fill Rate	
Valve A	2.7	25	3.8	25	1.3	9	1.3	9	None
Valve B	2.8	20	2.8	10	1.9	10	2.8	10	None
Valve C	2.6	25	4	25	1.1	10	1.8	6	None
Valve D	1.9	25	2.5	25	1.2	6	1.3	5	Leakage occurs below 4 lb/in^2
Valve E	2.6	25	4	25	2.4	6	2.4	6	Leakage at All Test Flows
Valve F	2.2	25	2.2	25	1.1	7	1.3	6	None
Valve G	2.8	25	4.4	25	1.1	5	1.4	5	Leakage at All Test Flows
Valve H	3.2	25	4.8	25	1.1	8	1.1	5	Leakage occurs below 3 lb/in^2

TABLE 4. Combination Air and Vacuum Valve Identification.

Air Valve Letter Designation	Air Valve Identification	
	Manufacturer	Model No.
Valve A	Apco.	145C.1
Valve B	Netafim	65-ARI-B-2-B
Valve C	Bermad	4415 (plastic)
Valve D	Bermad	4415M (cast)
Valve E	Crispin	IC10A
Valve F	Fresno	35
Valve G	Val-Matic	202C
Valve H	Waterman	CR-100

APPENDIX A
Froude Scaling for Transient Model

Velocities are scaled using Froude scaling as follows:

$$\frac{V_{36}}{V_4} = \frac{\left(\frac{L_{36}\gamma_{36}}{\rho_{36}}\right)^{\frac{1}{2}}}{\left(\frac{L_4\gamma_4}{\rho_4}\right)^{\frac{1}{2}}}$$

Where V = Pipeline velocity for 36-in (V_{36}) or 4-in (V_4) diameter pipe
L = Pipeline diameter for 36-in (L_{36}) or 4-in (L_4) diameter pipe
ρ = Density
γ = Specific weight

Since $\rho_{36} = \rho_4$ and $\gamma_{36} = \gamma_4$:

$$\frac{V_{36}}{V_4} = \frac{[L_{36}]^{.5}}{[L_4]^{.5}}$$

For L_{36} = 36 in and L_4 = 4 in:

$$\frac{V_{36}}{V_4} = \frac{[36]^{.5}}{[4]^{.5}} = 3$$

So

$$V_{36} = 3V_4$$

Froude scaling of pressure gives:

$$\frac{P_{36}}{P_4} = \frac{L_{36}}{L_4}$$

Where P_4 = Pressure measured in 4-in pipeline model
P_{36} = Scaled pressure for 36-in pipeline

For L_{36} = 36 in and L_4 = 4 in:

$$P_{36} = 9P_4$$

APPENDIX B
Adjustments in Dynamic Pressure Accounting for Pipe Material

The following analysis was taken from "Pipeline Protection"[1] by Dr. Charles M. Burt of Cal Poly State University (1992):

"Pressure surges are caused by a sudden velocity change of the water in a pipeline. The additional pressure caused by a surge due to a sudden velocity change is:

$$P = .01345aV$$

Where P = Surge pressure, lb/in^2
a = Pressure wave velocity, ft/s
V = Initial velocity of the stopped water, ft/s

The wave velocity (a) is not the same as the water velocity (V). The wave velocity is the speed at which a pressure surge is transmitted by the pipe walls.

$$a = \frac{4660}{\left(1 + \frac{k(SDR-2)}{E}\right)^{.5}}$$

Where a = Wave velocity, ft/sec
k = Fluid bulk modulus (300,000 lb/in^2 for water)
SDR = Standard dimension ratio of the pipe (pipe OD/wall thickness)
E = Modulus of elasticity of the pipe:
400,000 lb/in^2 for PVC
30,000,000 lb/in^2 for steel."

Since P = .01345aV, then:

$$V = \frac{P}{.01345a}$$

For $V_{PVC} = V_{steel}$:

$$\left(\frac{P}{.01345a}\right)_{PVC} = \left(\frac{P}{.01345a}\right)_{steel}$$

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[1] This text is part of a to be published book for Waterman Industries [Exeter, California] entitled "Surface Irrigation" by Charles Burt of Cal Poly State University, San Luis Obispo, California 93407.

So

$$P_{PVC} = \frac{a_{PVC}}{a_{steel}} P_{steel}$$

For the model:

$$SDR_m = \frac{4''}{.115''} = 34.78$$

This gives a value of: $a_{steel} = 4044$ ft/sec

For the prototype:

$SDR_p = 32.5$

This gives a value of: $a_{PVC} = 953$ ft/sec

This means that:

$$P_{PVC} = \frac{953\ ft/sec}{4044\ ft/sec} P_{steel}$$

$$P_{PVC} = .236\ P_{steel}$$

APPENDIX C
Example of Transient Model Scaling

The following example illustrates how transients measured from the model are converted to prototype values using the equations developed in Appendices A and B:

Let's say that a 2-ft/sec fill velocity in the 4-in steel pipeline model produces pressure transients as follows:

On air valve:	$P_{AV} = 3\ \text{lb/in}^2$
20 ft downstream:	$P_{20D} = 2\ \text{lb/in}^2$
40 ft downstream:	$P_{40D} = 1\ \text{lb/in}^2$

First, the scaled velocity for a 36-in-diameter pipeline would be:

$$V_{36} = 3V_4$$
$$V_{36} = 6\ \text{ft/sec}$$

So a velocity of 6 ft/sec would produce the following pressure transients (P') in a 36-in steel pipeline:

$$P' = 9P$$

So

$$P'_{AV} = 27\ \text{lb/in}^2$$
$$P'_{20D} = 18\ \text{lb/in}^2$$
$$P'_{40D} = 9\ \text{lb/in}^2$$

Now for 36-in-diameter prototype piping made of PVC, the pressure transients (P") are as follows:

$$P''_{AV} = P' = 27\ \text{lb/in}^2$$
$$P''_{20D} = .236P'_{20D} = 4.25\ \text{lb/in}^2$$
$$P''_{40D} = .236P'_{40D} = 2.12\ \text{lb/in}^2$$

The downstream pressure transient for a 36-in-diameter PVC pipe is approximately 24 percent of that of a 36-in-diameter steel pipe.

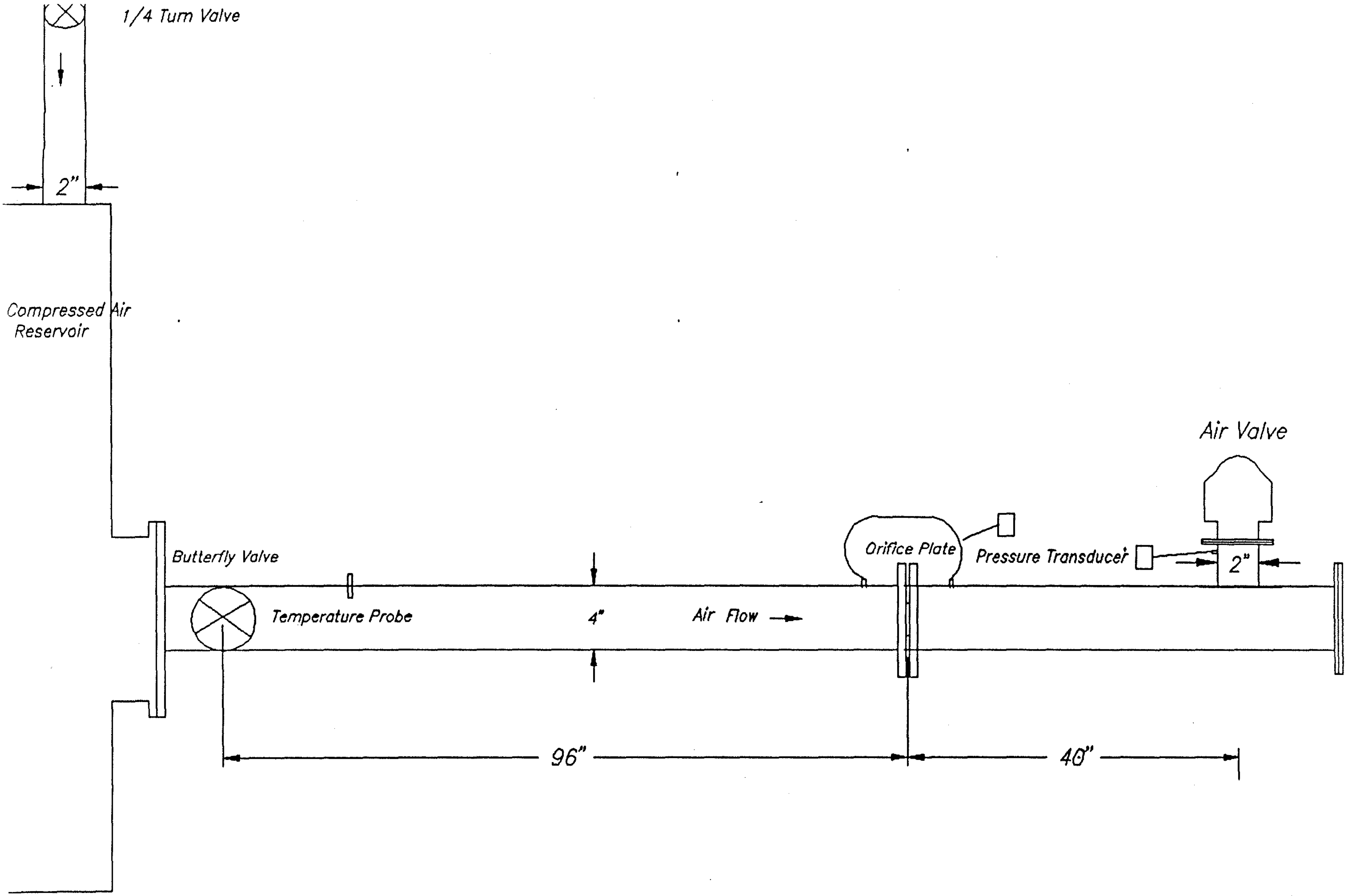


Fig. 1 Air Discharge Test Set-Up

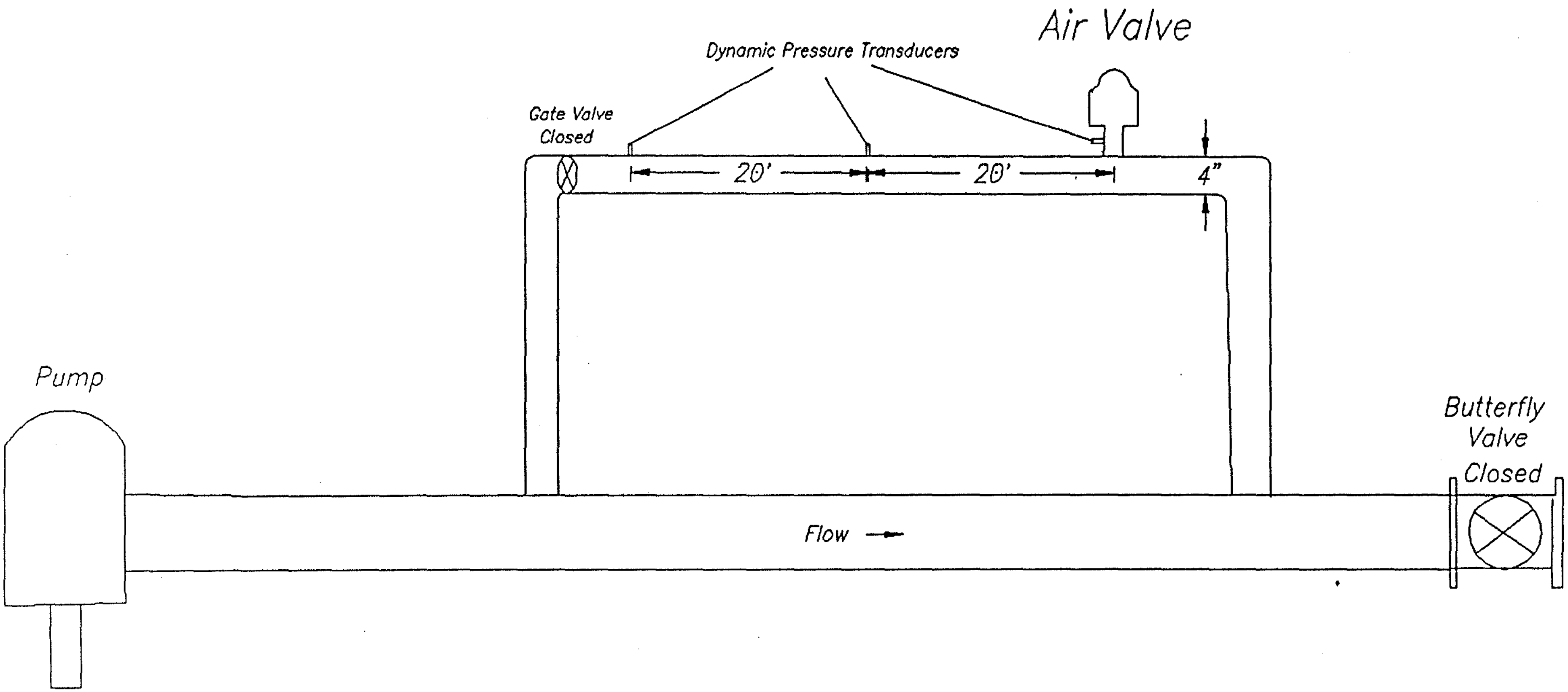


Fig. 2 Air Valve Transients Test Set-Up

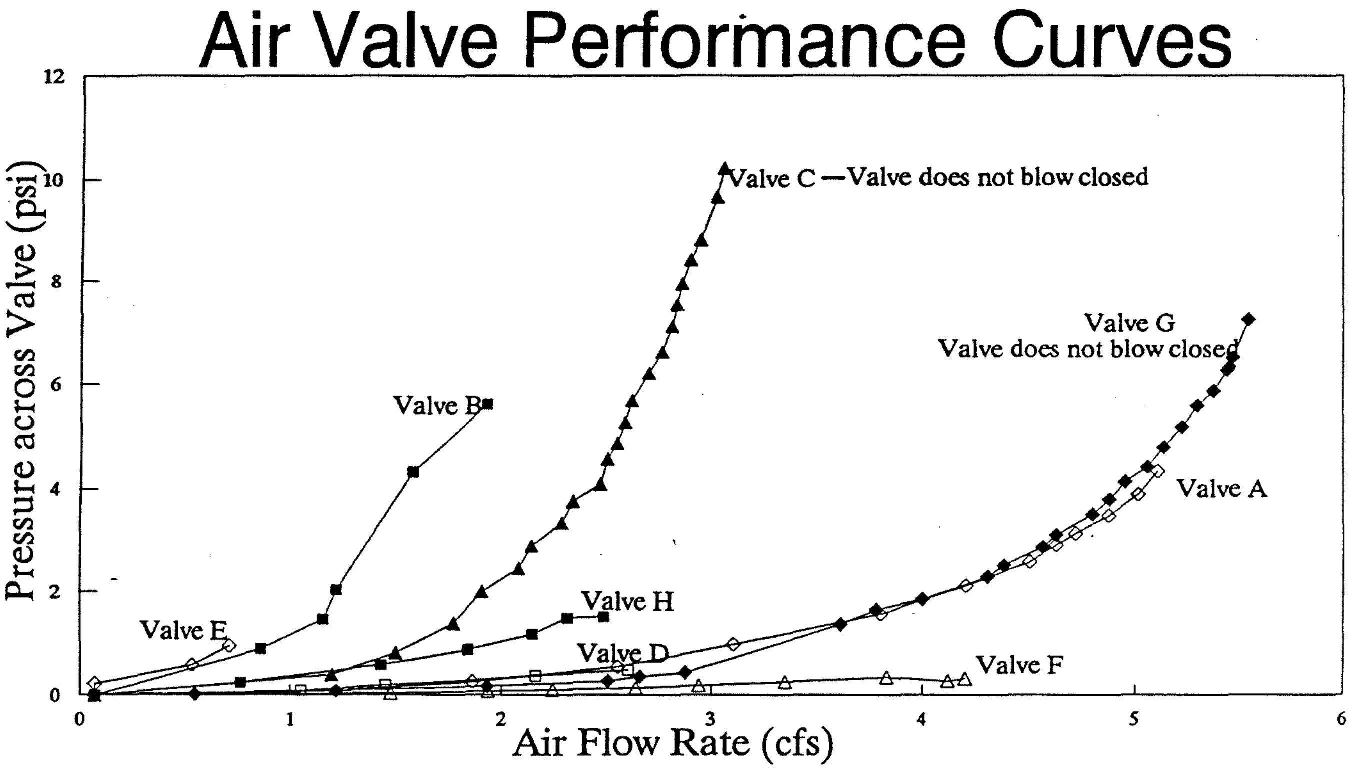
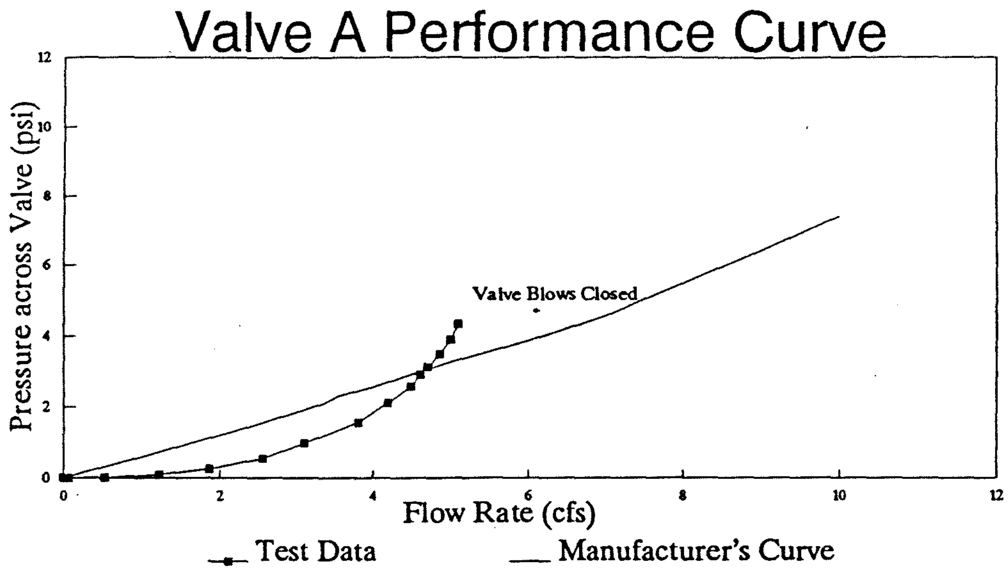


Figure 3. Disharge Curves for Valves A through H



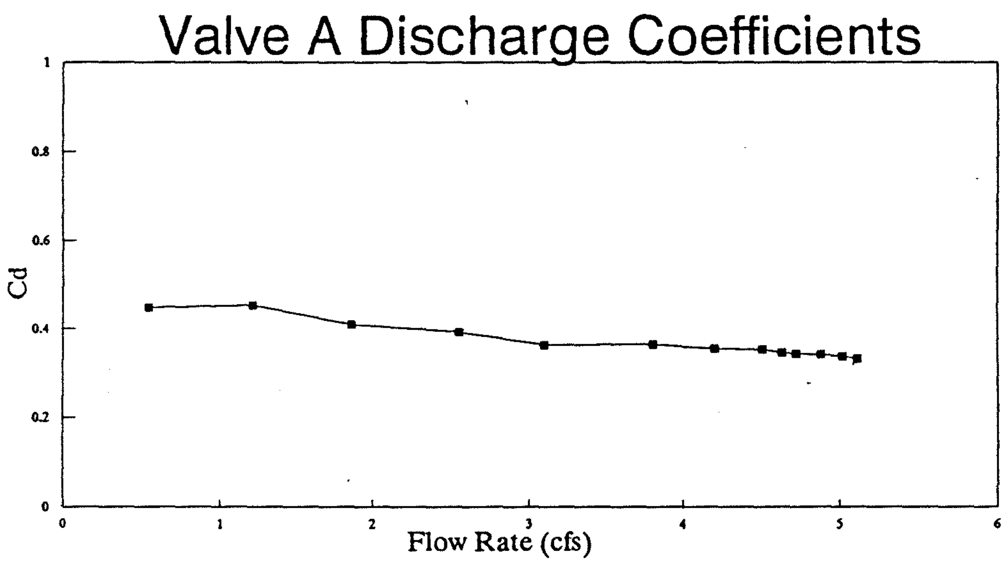
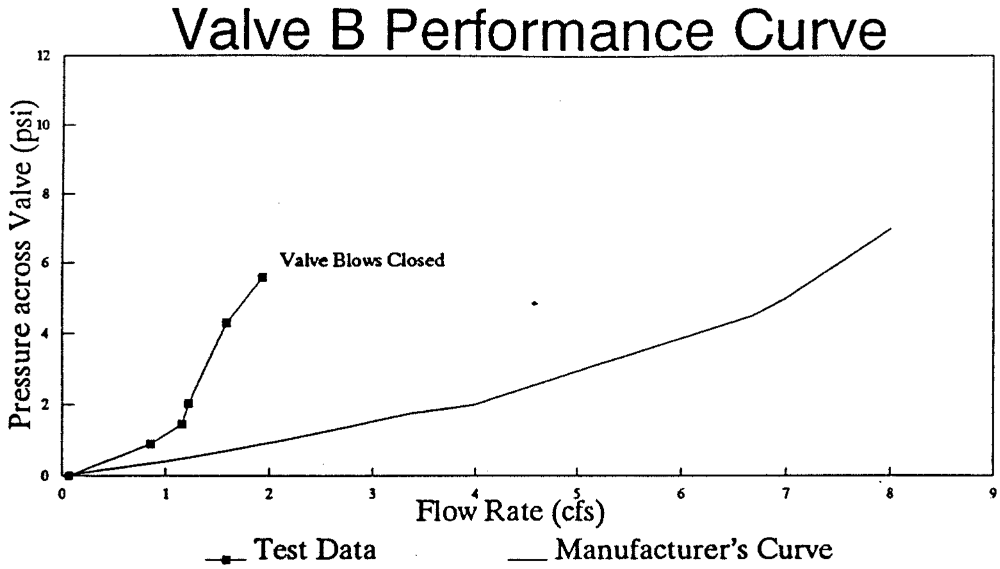


Figure 4. Flow Capacity and Discharge Coefficients for Valve A.



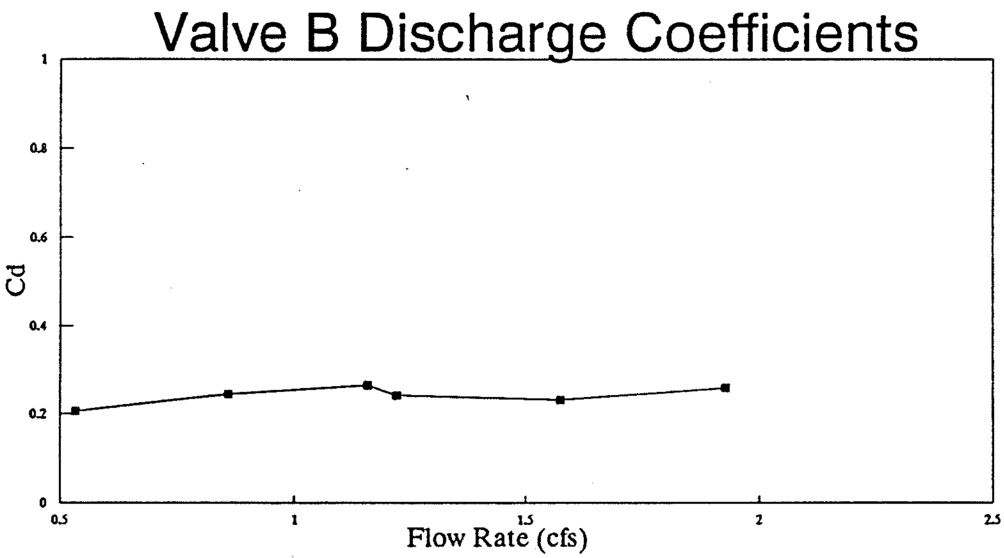


Figure 5. Flow Capacity and Discharge Coefficients for Valve B.

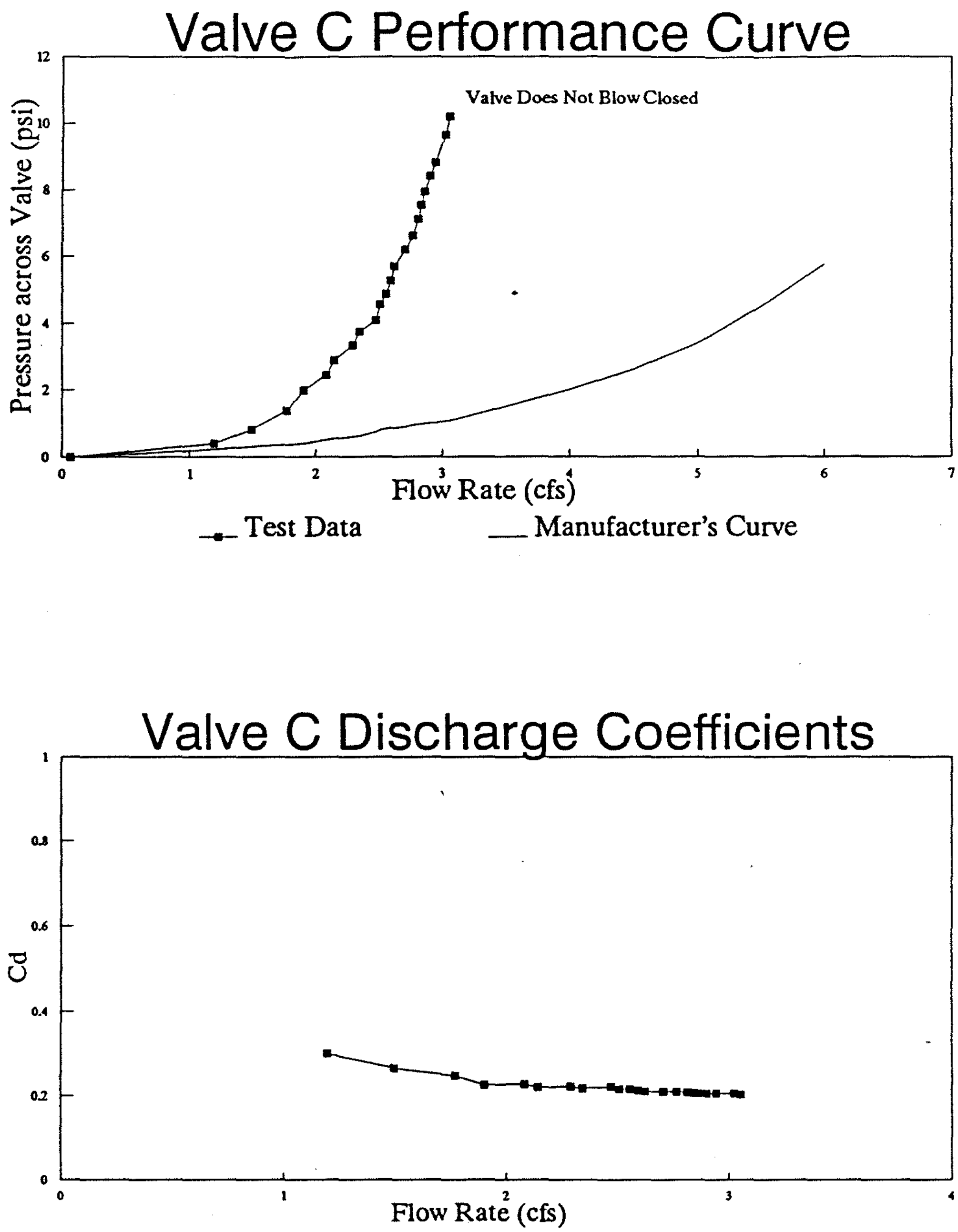
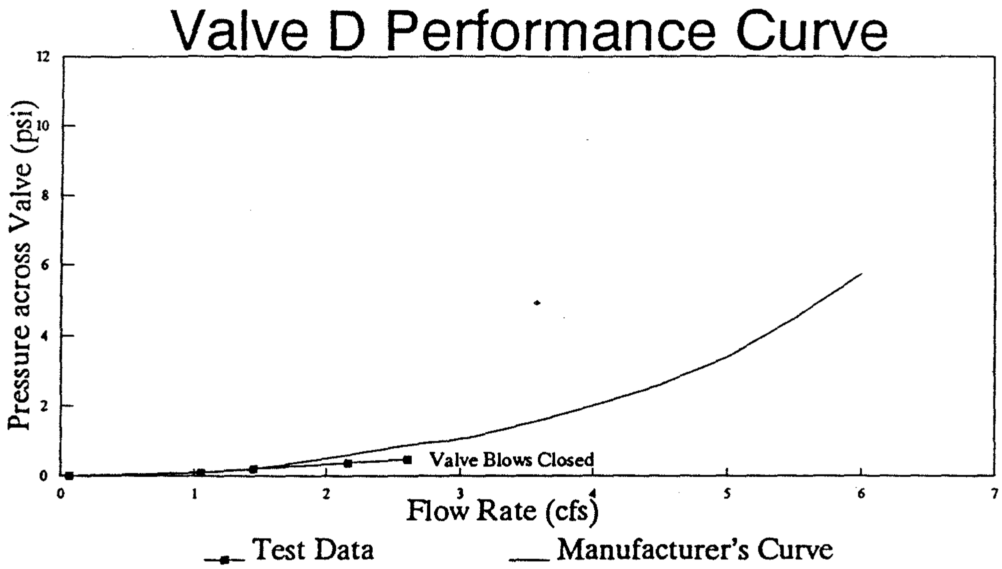


Figure 6. Flow Capacity and Discharge Coefficients for Valve C.



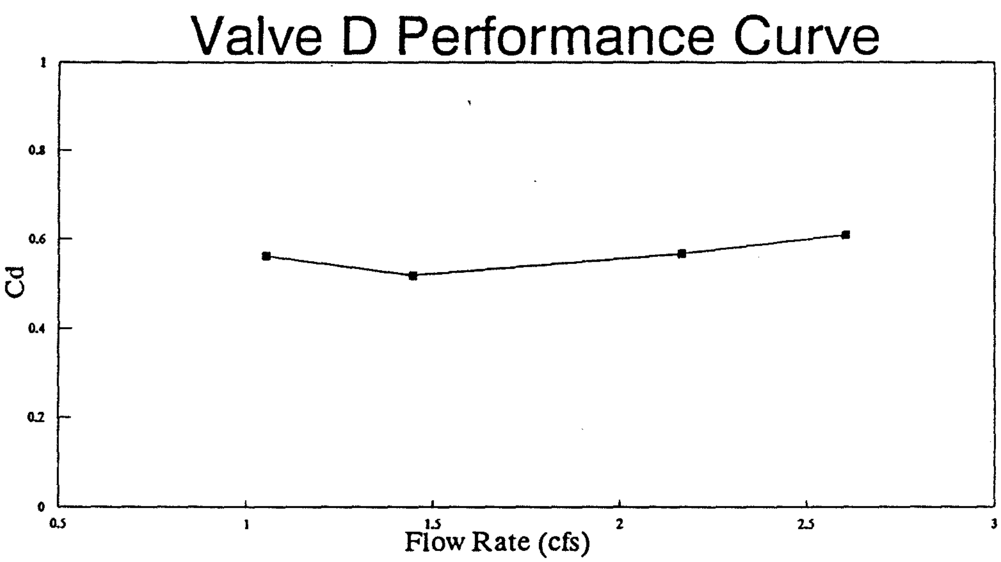
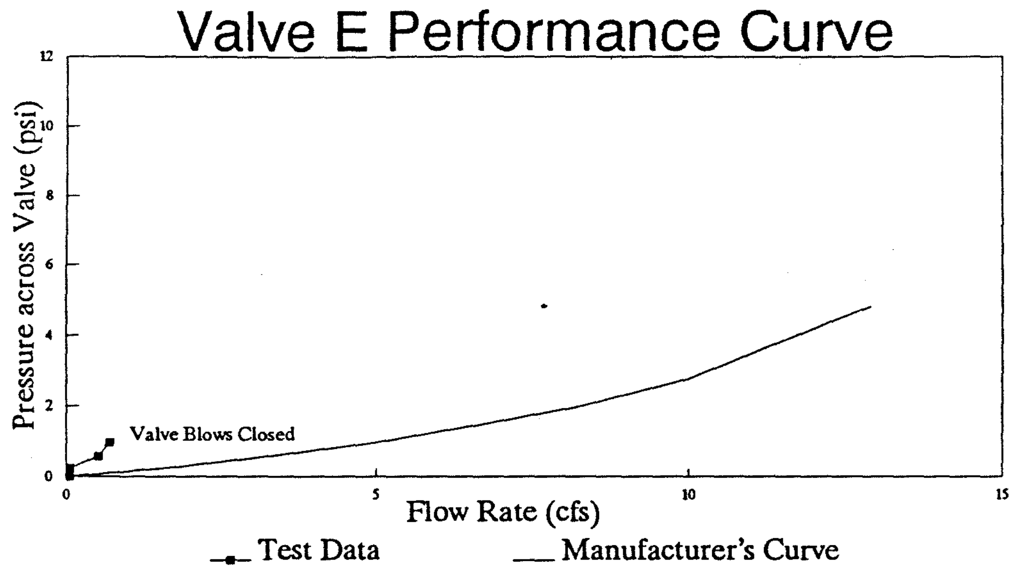


Figure 7. Flow Capacity and Discharge Coefficients for Valve D



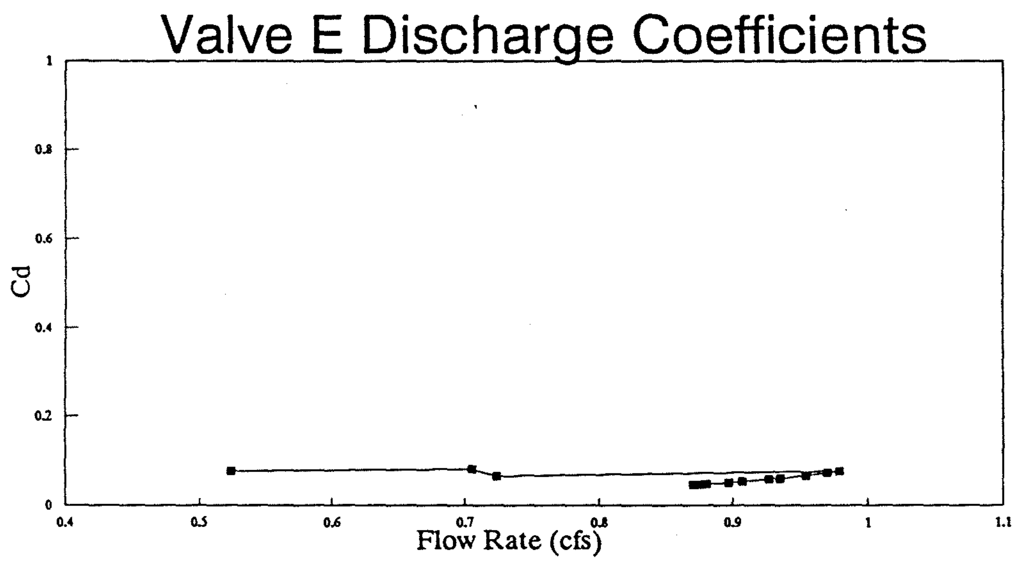
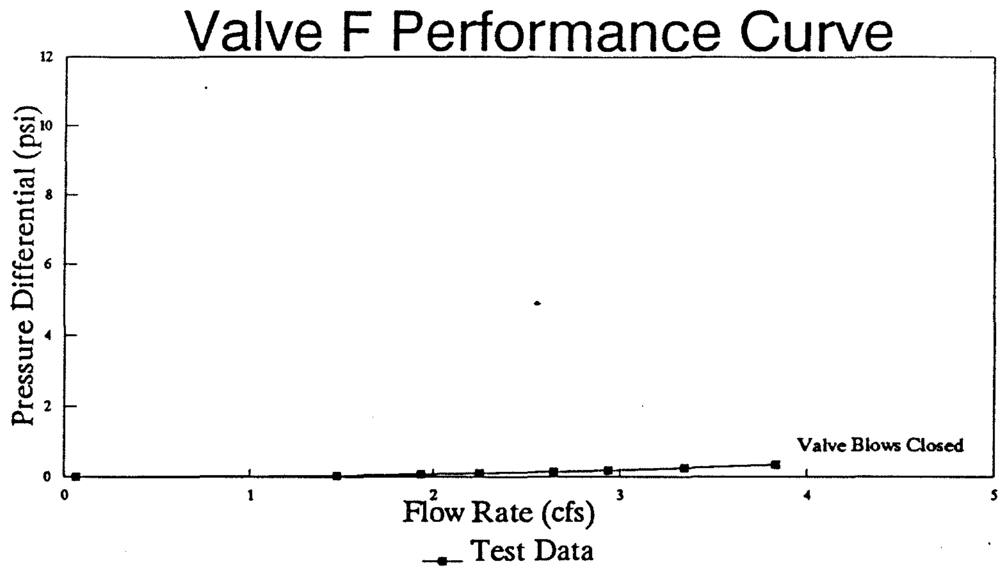


Figure 8. Flow Capacity and Discharge Coefficients for Valve E



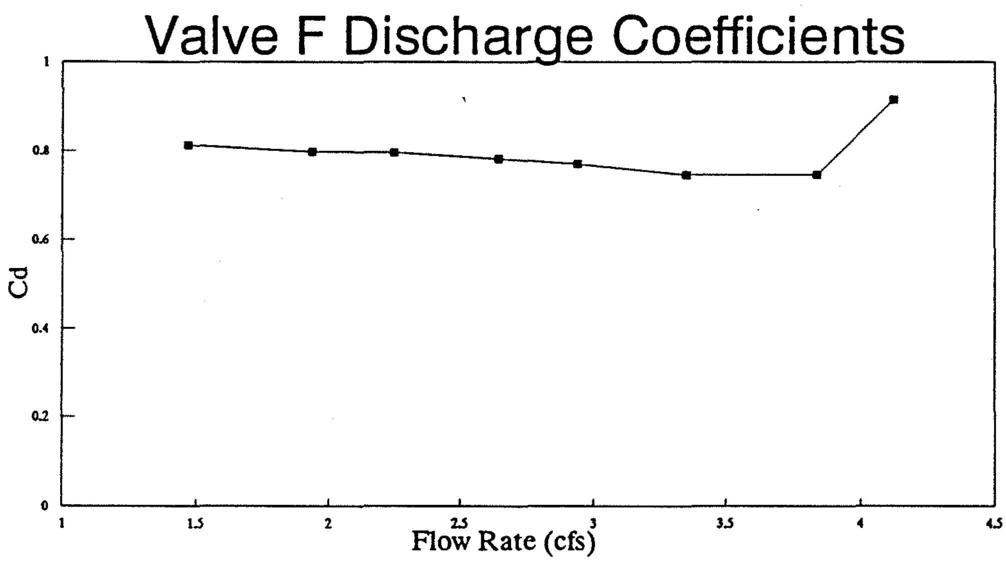
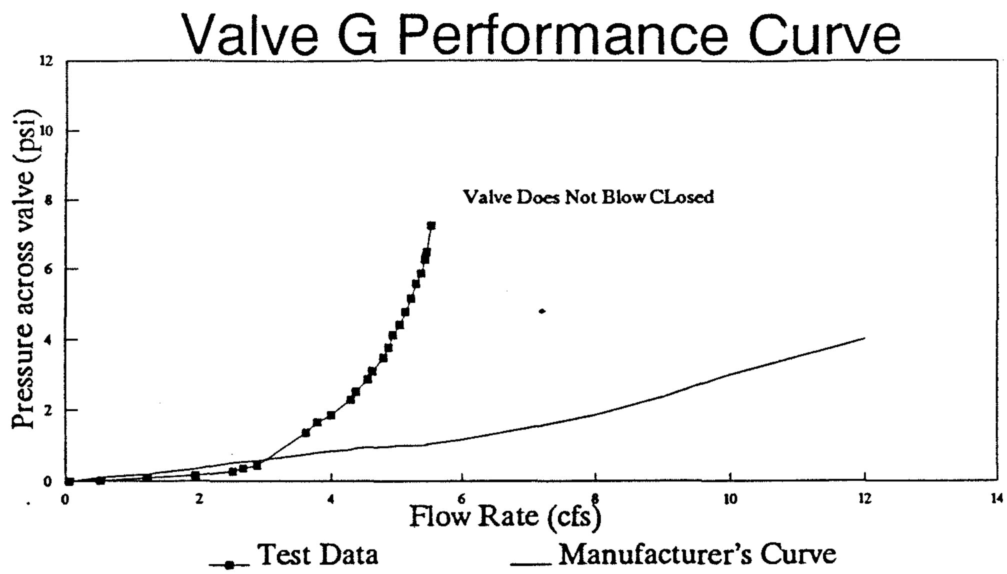


Figure 9. Flow Capacity and Discharge Coefficients for Valve F



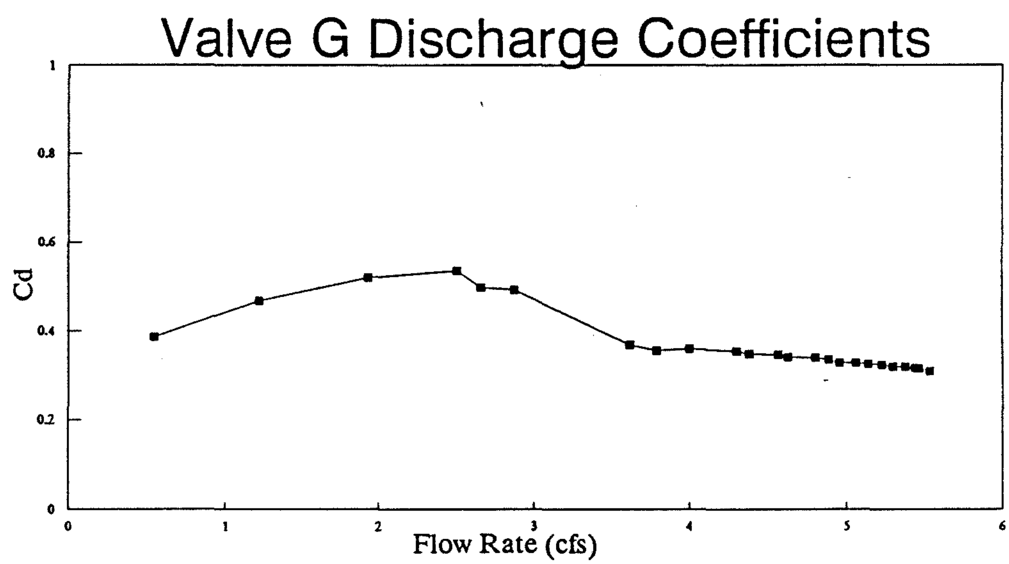
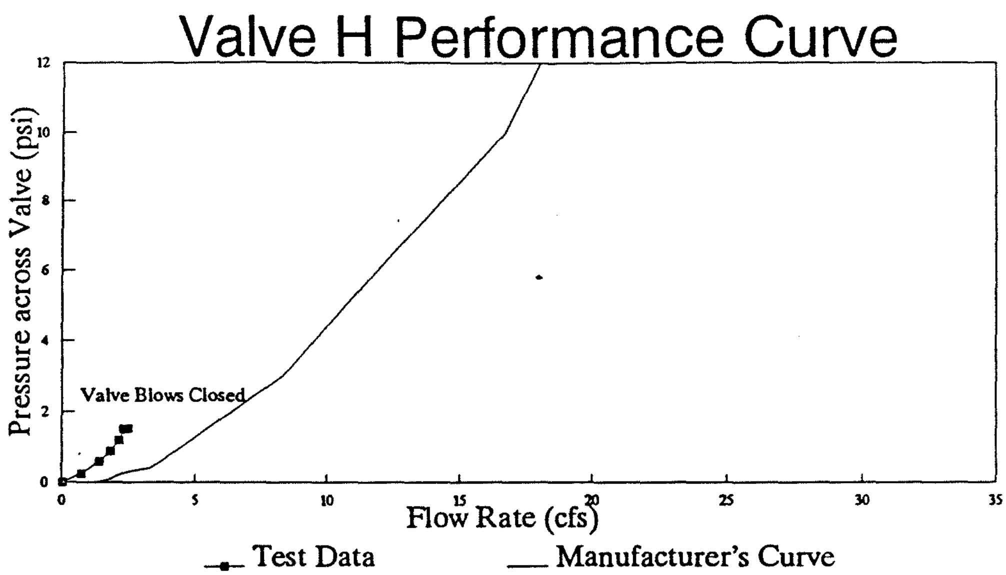


Figure 10. Flow Capacity and Discharge Coefficients for Valve G



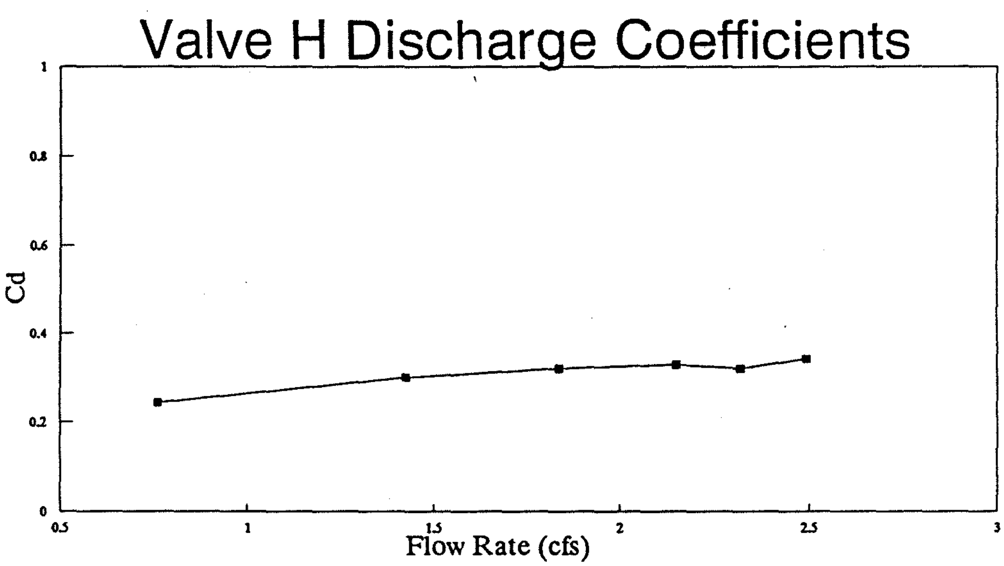


Figure 11. Flow Capacity and Discharge Coefficients For Valve H.

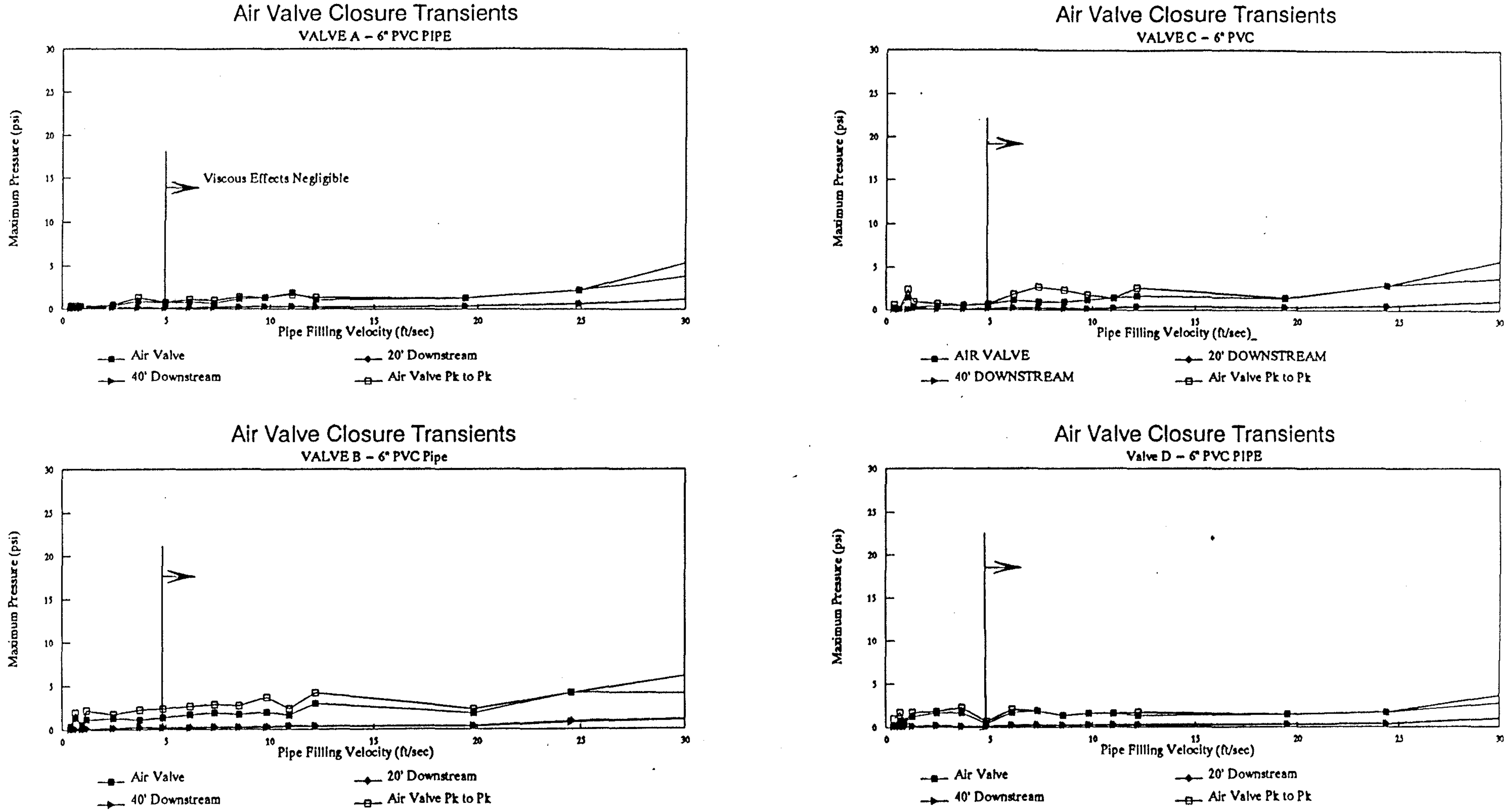


Figure 12. Closure Transients as a function of Fill Velocity for 6" pipeline.

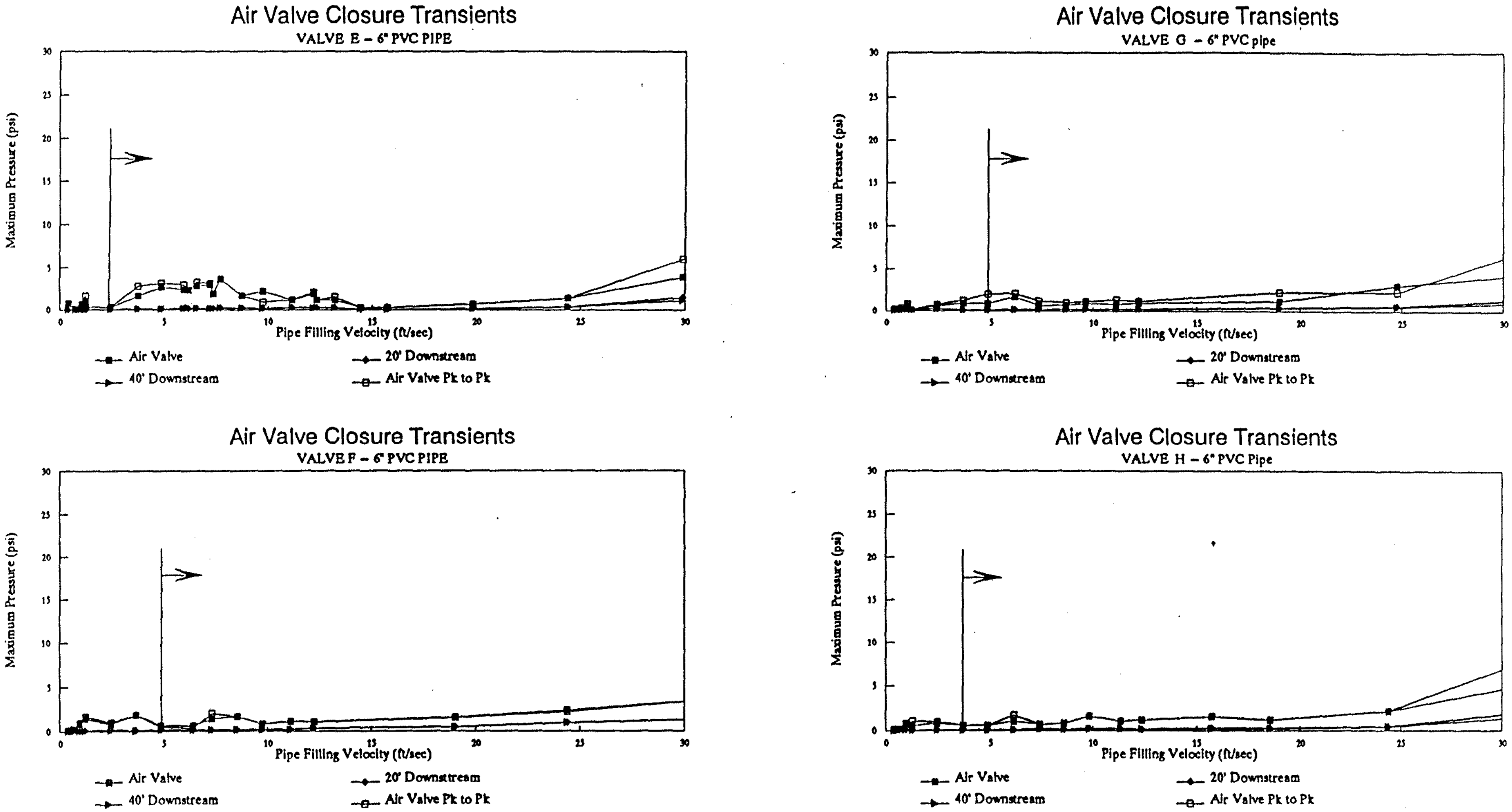


Figure 13. Closure Transients as a function of Fill Velocity for 6" pipeline.

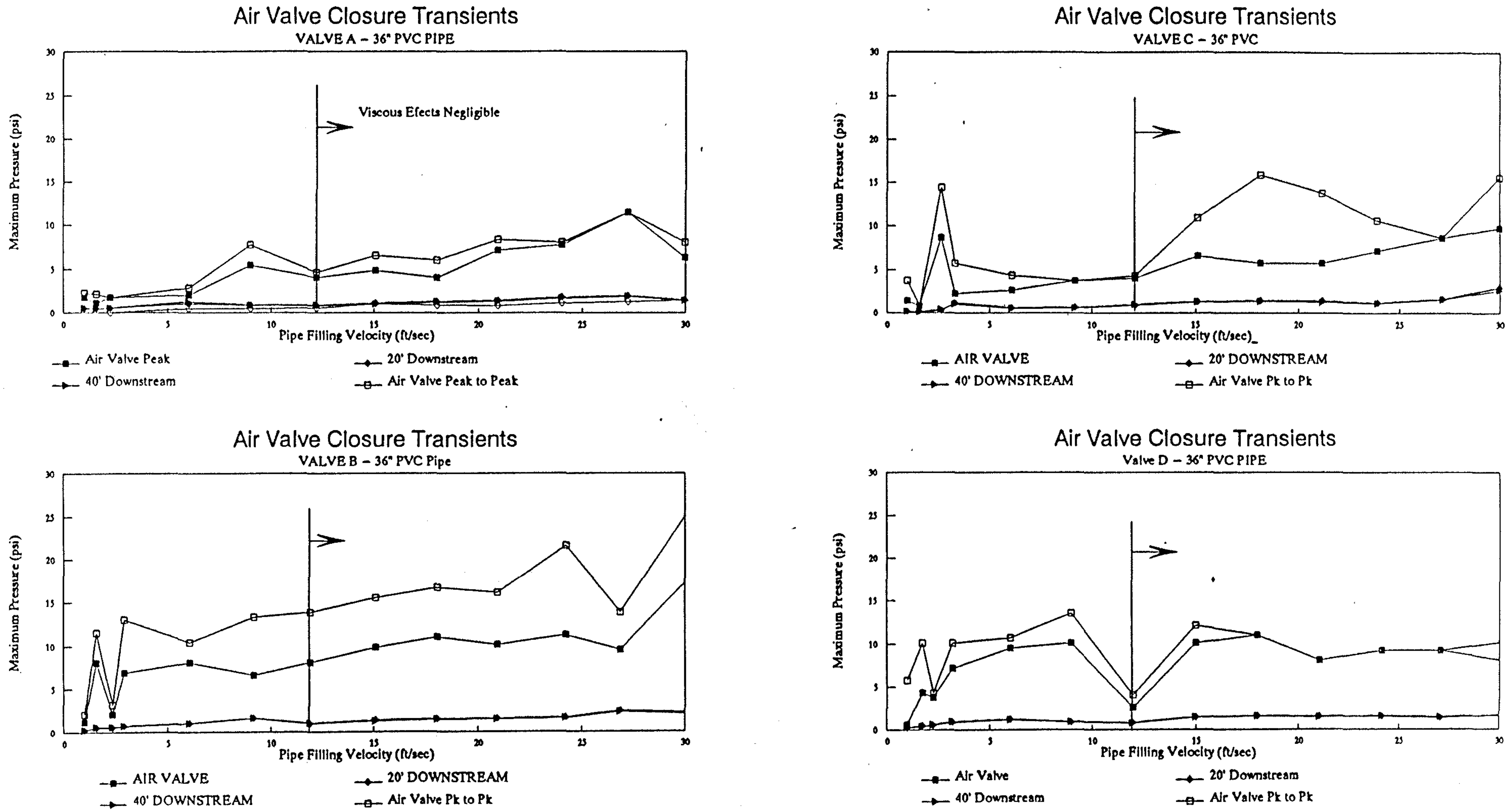


Figure 14. Closure Transients as a function of Fill Velocity for 36" pipeline.

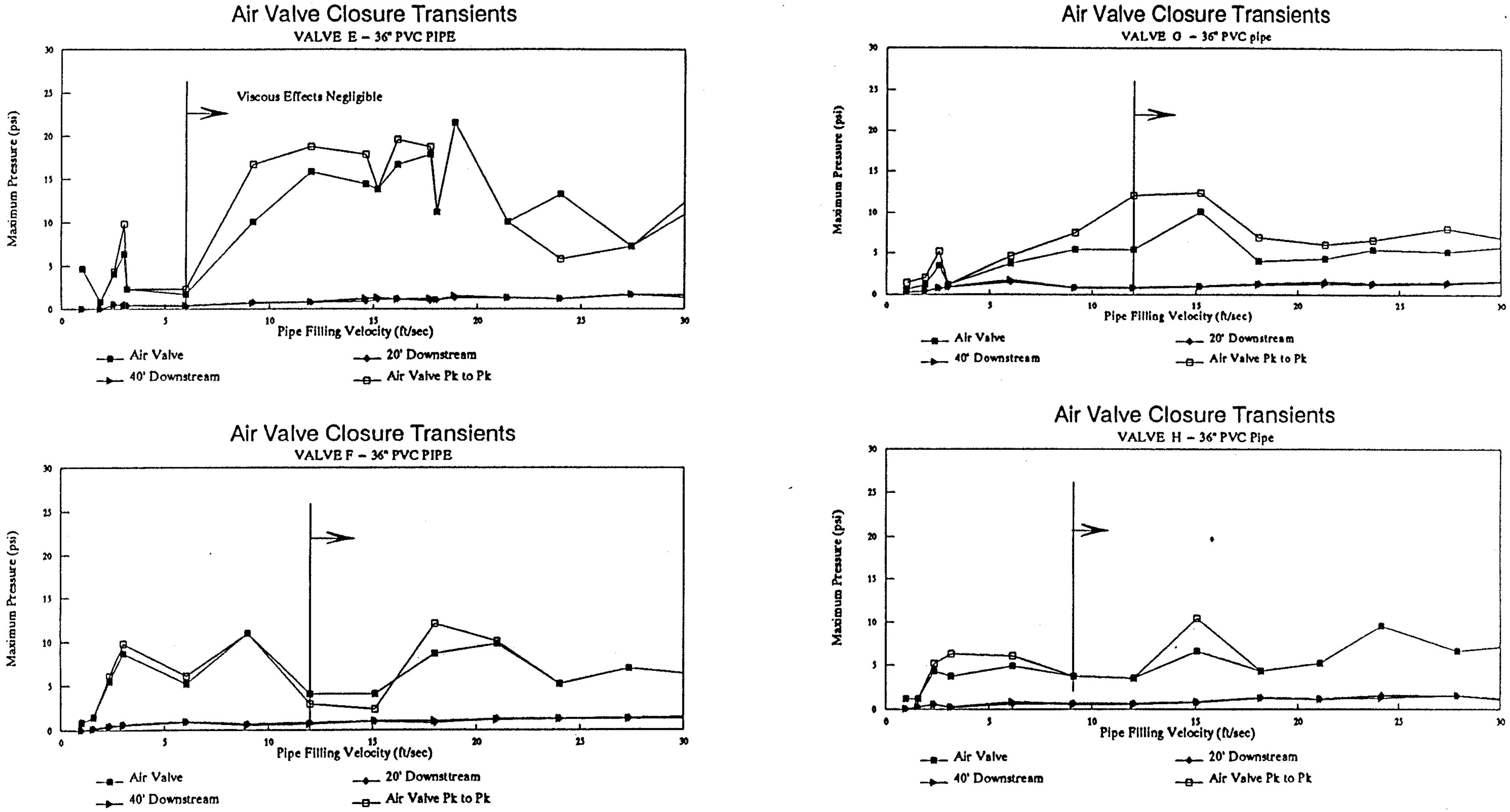


Figure 15. Closure Transients as a function of Fill Velocity for 36" pipeline.

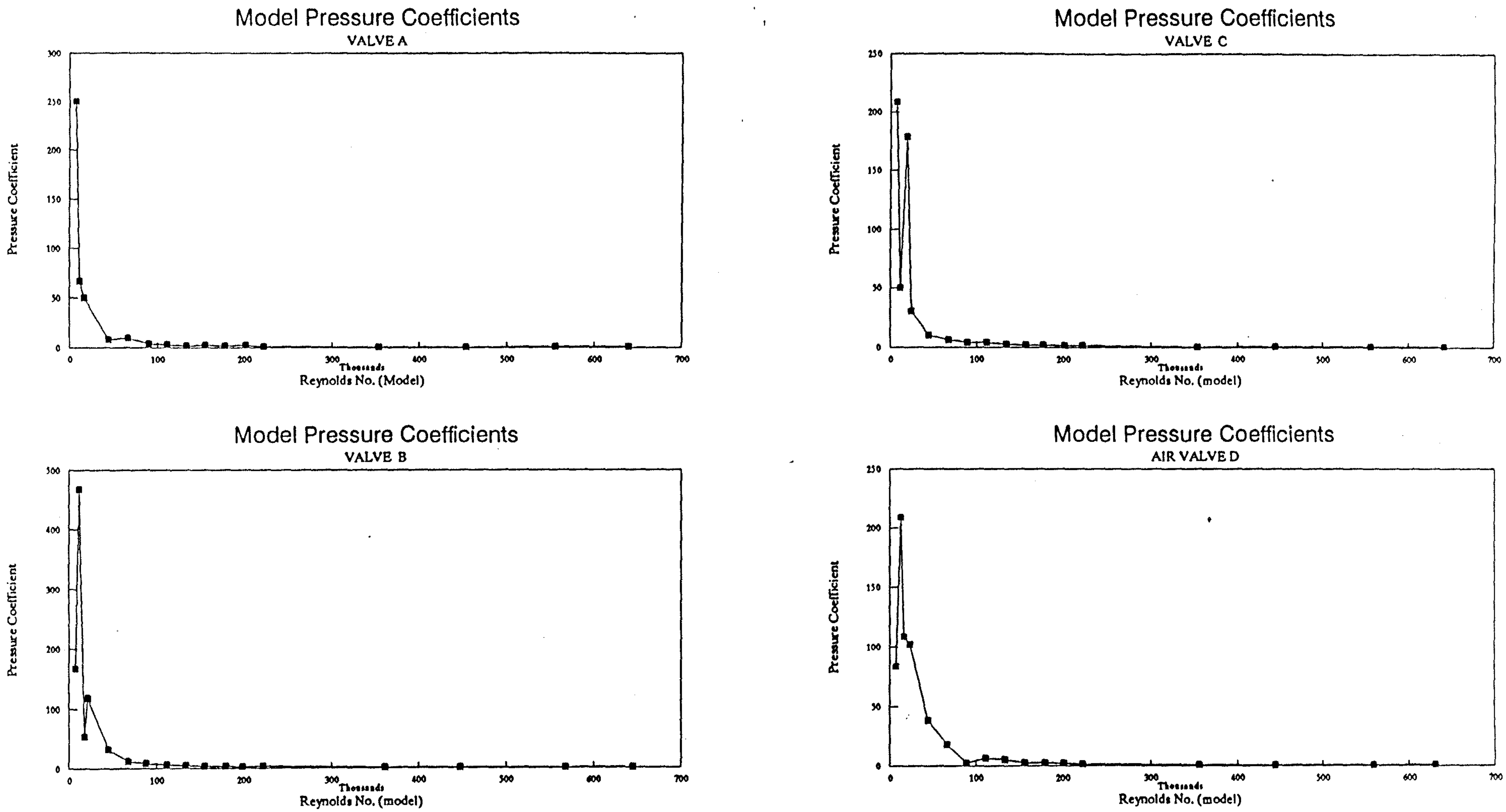


Figure 16. Pressure Coefficient as a function of Reynolds Number for the Model

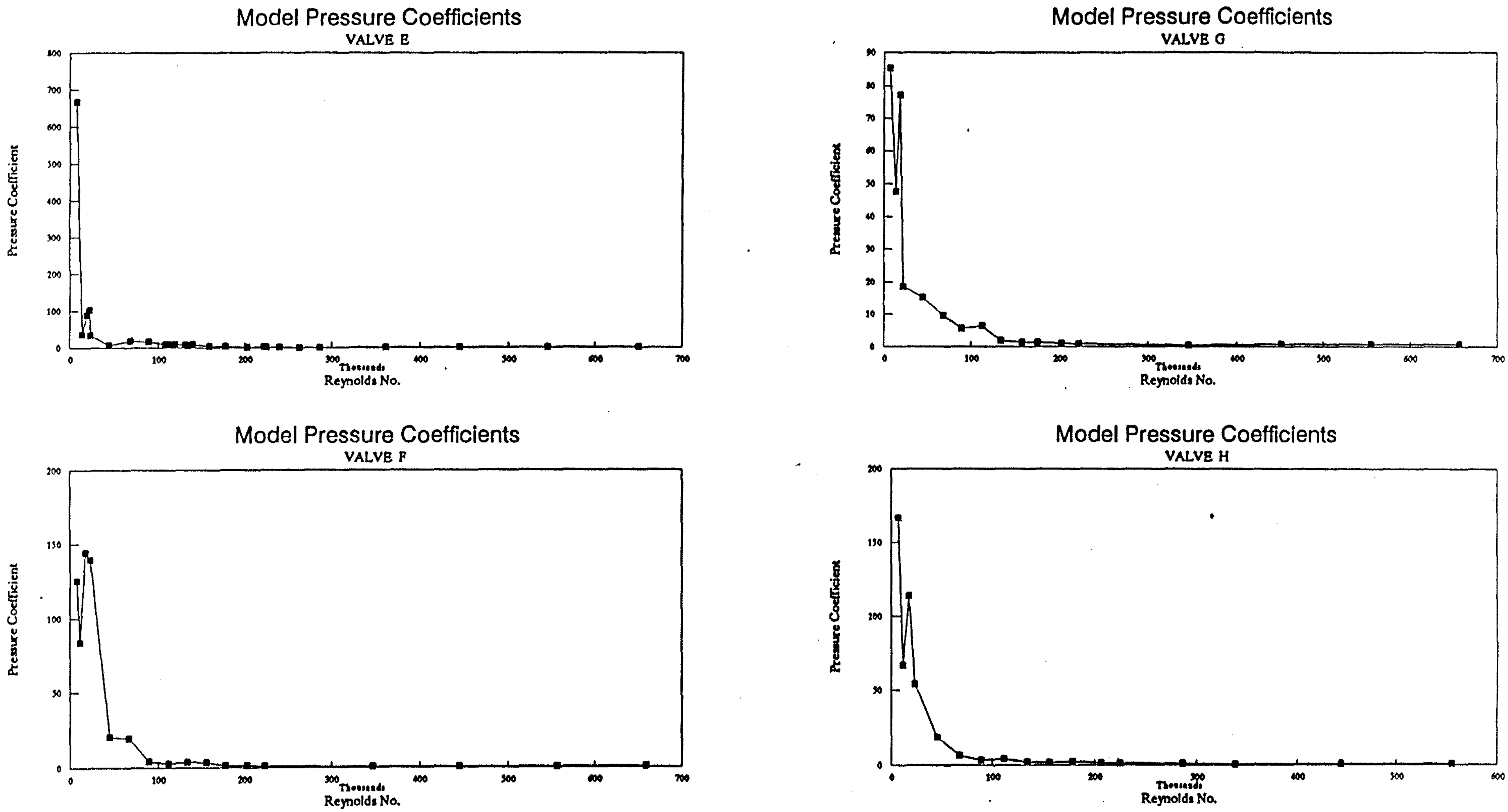


Figure 17. Pressure Coefficient as a function of Reynolds Number for the Model

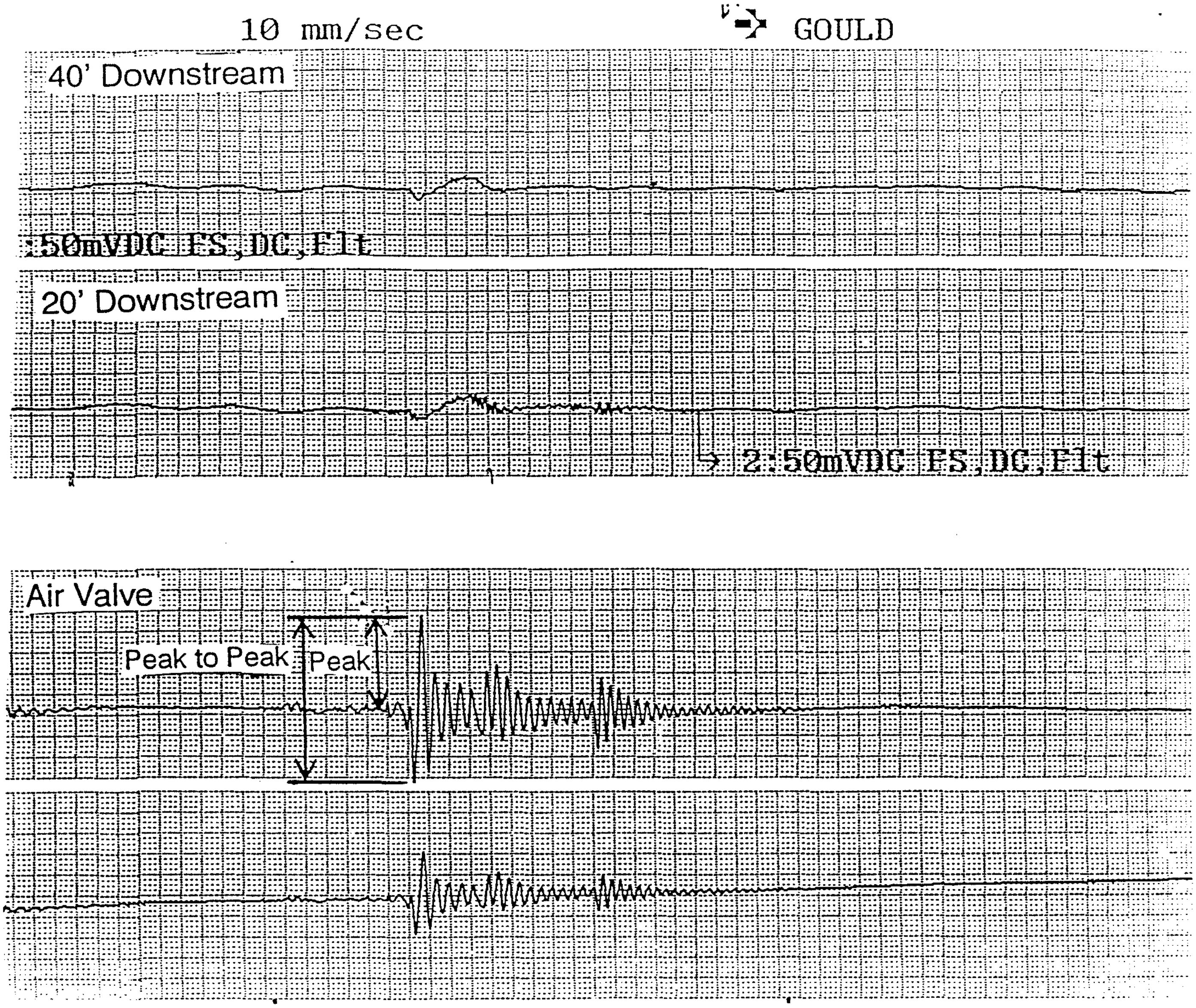


Figure 18. Data Sample from Transient Test Run.