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Technical Report

BRECKENRIDGE BLAST-ACTUATED
CLOSURE VALVE

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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BRECKENRIDGE BLAST-ACTUATED CLOSURE VALVE

Technical Report R-481

Y-F011-05-02-302

by

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ABSTRACT

The ventilation systems of shelters providing blast protection must have automatic valves to prevent ingress of damaging pressure waves through the air ducts. This report discusses a blast-actuated closure valve developed, tested, and evaluated at the U. S. Naval Civil Engineering Laboratory.

For ventilation the valve has a rated airflow of 700 cfm. It provides protection from blast overpressures up to 150 psi. It also provides protection during the negative phase following any blast wave. When installed as intended, the valve should be relatively insensitive to the thermal pulse and ground accelerations associated with nuclear explosions. It is also insensitive to environmental conditions. Its operation is simple and reliable, and resetting is unnecessary because of the valve's automatic response. It requires no maintenance.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

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INTRODUCTION

Statement of Problem

All personnel shelters which are going to be occupied for more than a few hours must have ventilation. This normally requires air intake and exhaust ducts to the outside atmosphere. If the shelter is to provide blast protection, the ducts must be equipped with some sort of device to prevent a blast wave from entering the sheltered area through the ventilation system.

A blast closure device should be automatic, reliable, reusable, maintenance free, and inexpensive. It should not allow large pressure impulses to pass by the valve before closure, cause excessive obstruction to the rated airflow either before or after the passage of a blast wave, nor should it require personnel to expose themselves to a hostile environment to service the device after each operation. Also, it should prevent excessive amounts of air loss from the shelter during periods of negative pressure. Inasmuch as a device meeting all of the desirable characteristics was not available, the Naval Civil Engineering Laboratory (NCEL) undertook the development of a closure device conceived by the author.

Approach

In order to avoid the complexities of thermal or radiation detecting and triggering systems, it was decided to use the blast wave itself to activate the closure device and provide the necessary source of power. There is a disadvantage to a blast-actuated closure valve, however, in that it takes at least a few milliseconds to close. During this time a portion of the blast wave which has activated the valve bypasses (i.e., flows through) the incompletely closed valve. The pressure impulse which passes is normally large enough to cause filters in the ventilation system to rupture or to harm personnel directly exposed. The usual solution to this problem has been to provide large plenum chambers in which the wave could expand and be attenuated. Large plenums, however, are expensive. To avoid this disadvantage, a blast-actuated valve was conceived in which the blast wave had to travel through a pipe loop after actuating the valve and before reaching the shelter port as shown in Figure 1. The bypassing wave could thereby be considerably reduced and, therefore, would require only a very small and relatively inexpensive plenum made of plywood.

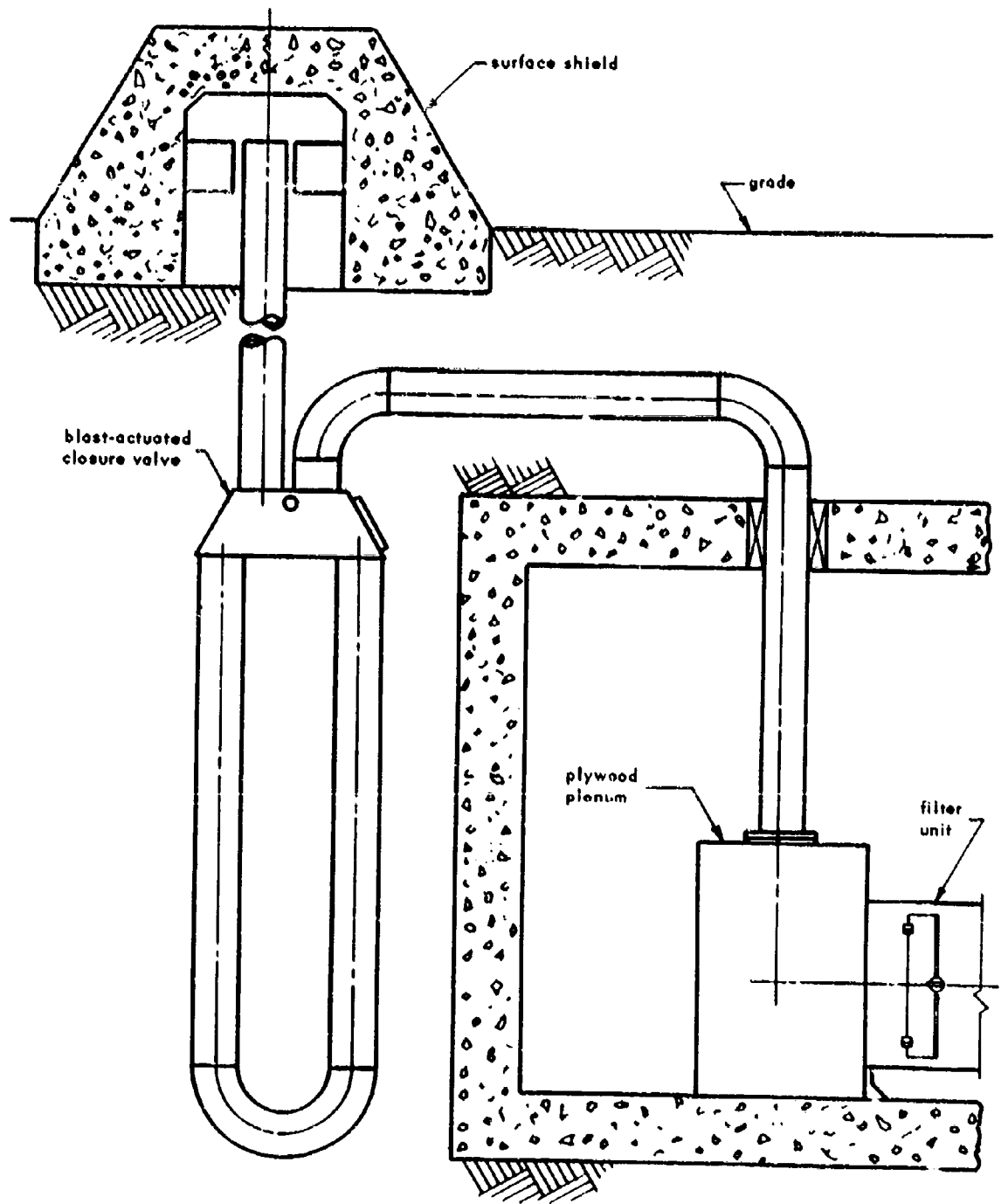


Figure 1. Typical installation of the Breckenridge Blast-Actuated Closure Valve.

The blast-actuated valve developed is very simple and maintains efficiency under a number of repeated overpressures. A prototype of the valve was tested to determine basic operational characteristics and optimal mechanical suspension.

Following this, two more prototypes were built, one of welded construction and the other cast. With these valves, an effort was made to simulate normal procurement procedures and quality control in all phases of component fabrication. In this way it was hoped that difficulties in commercial production could be discovered and that the suitability of the drawings and specifications could be evaluated. In addition, further testing of valve-closure and bypassing-wave characteristics was conducted on the two new valves.

DESCRIPTION OF VALVE

Size and Operation

The valve was developed for a rated ventilation of 700 cfm and for use with 8-inch-diameter steel pipe. It would probably be installed in the duct system external to the shelter as shown in Figure 1, but could be placed within the shelter. The valve is about 12 inches high, 10 inches deep, and 34 inches wide.

The housing of the valve consists of two adjacent chambers which are connected at the bottom by a loop pipe. The loop provides a distance through which the blast wave must travel after actuating the valve and while the valve is closing. The only moving part is a V-shaped flap that is hinged at the apex with one arm hanging in each chamber. Figure 2 shows a full-scale wooden and plastic model of the valve ready for the initial airflow tests. Figure 3 shows a full-scale prototype of the valve as received from the fabricator, and Figure 4 shows a flap with its internal parts disassembled.

The valve is installed so that the flap is held open by the combined forces of gravity and spring action. The springs shown in Figure 4 are installed inside the flap on its axis and produce a restraining torque that helps hold the flap open during normal airflow. An airflow greater than about 1,150 cfm will cause the flap to close.

The valve is actuated when the incoming pressure wave impinges on the flap arm in the outer chamber. As this arm of the flap swings away from the outside port to allow the blast wave to pass into the pipe loop, the other arm necessarily swings simultaneously to cover the shelter port of the inner chamber. Thus, by the time the wave has traveled through the pipe loop and into the inner chamber, the flap is very nearly, and sometimes completely, closed. The pressure wave then impinges on the flap arm in the inner chamber, causing it to rapidly snap shut, and holds it tightly shut so that a pressure wave of only very small impulse continues into the protected area. For the negative phase, the flap flips over and closes the other port. Thus, in effect, any abnormal pressure differential on either side of the valve causes it to close and remain closed as long as that pressure differential exists.

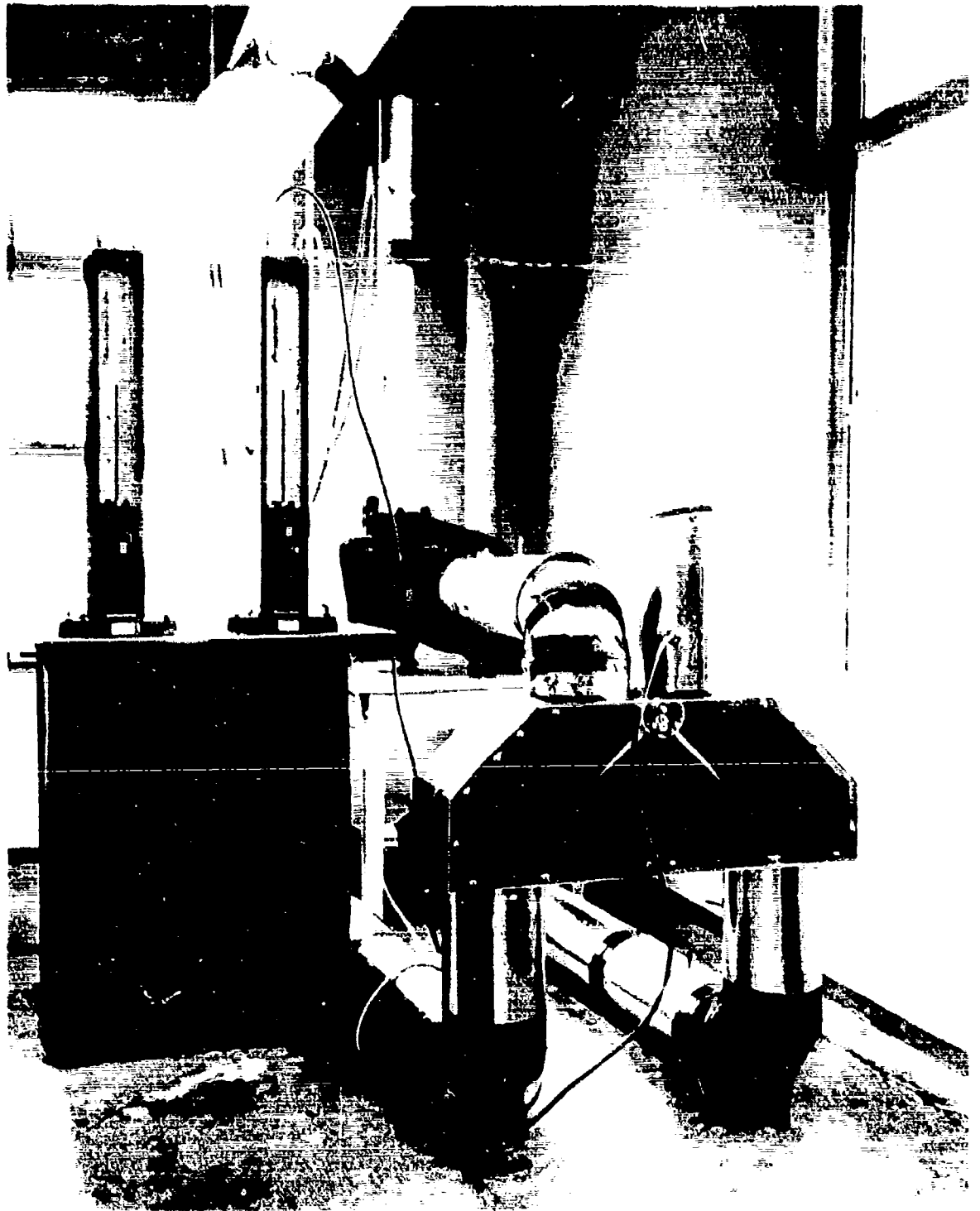


Figure 2. Mockup of valve ready for initial airflow tests.

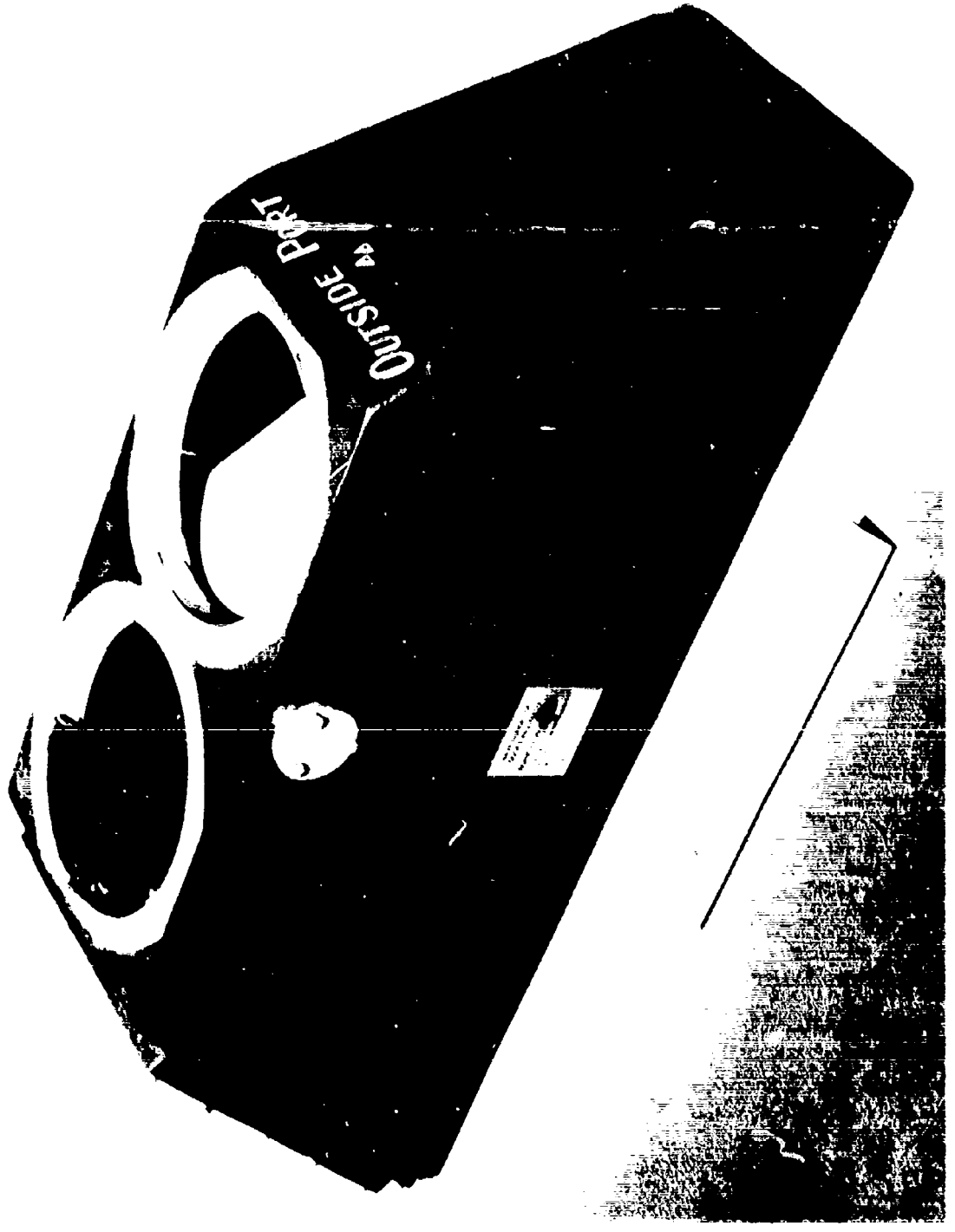


Figure 3. A prototype blast closure valve as received from the fabricator.

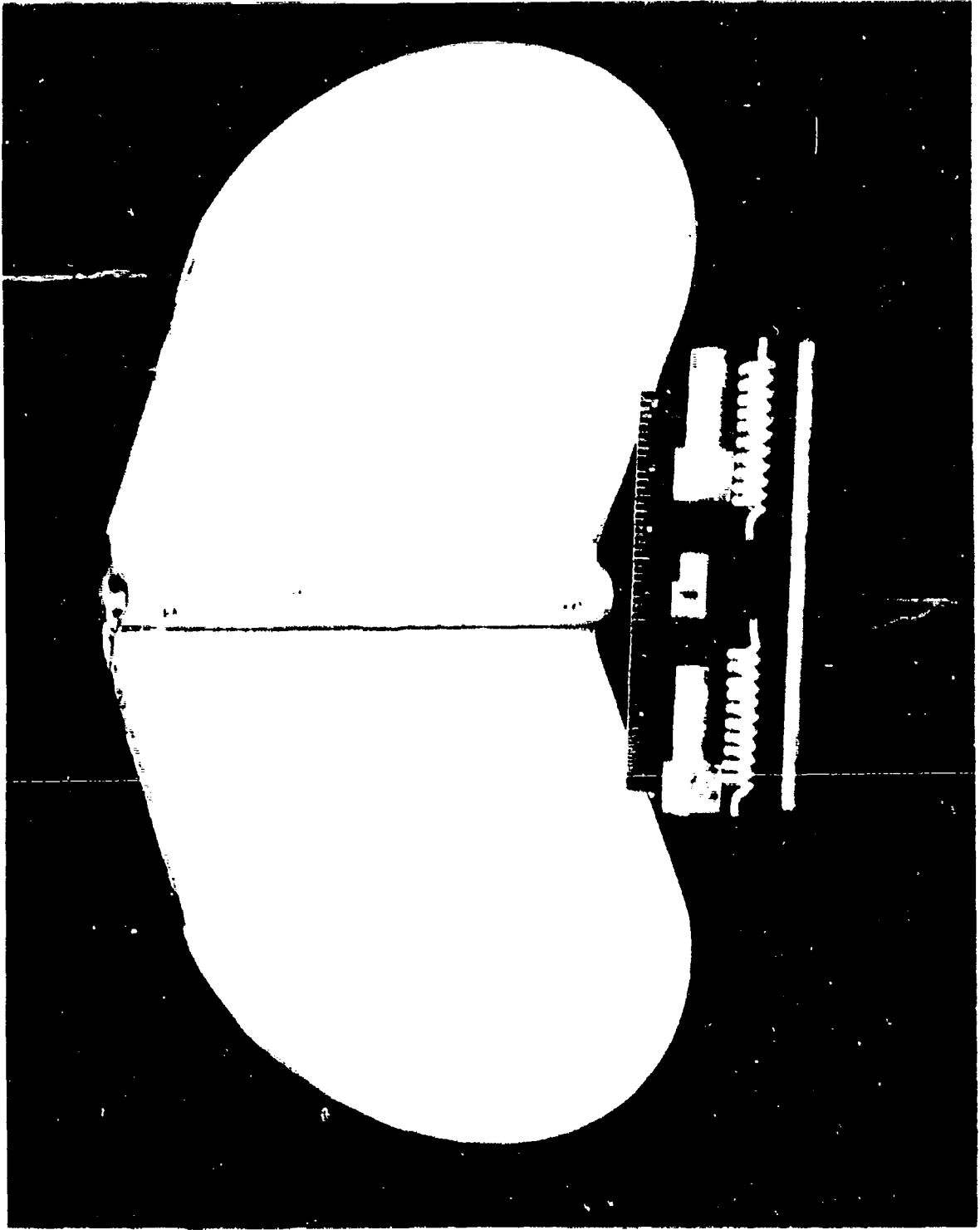


Figure 4. A welded and machined 110-degree flap with its shafts, torsion springs, keeper, and spacer.

Construction and Material

Three prototype valves were constructed in addition to the airflow model shown in Figure 2. Two of them were fabricated (i.e., welded), and the third was cast.

The housings of the fabricated valves were made from 5/8-inch-thick steel plate (ASTM A-242) welded together. The first valve was made at NCEI from sketches prepared by the task engineer. The second valve was fabricated commercially in accordance with drawings and specifications similar to those in Appendixes A and B. The commercial valve cost \$688.75 and weighed 245 pounds.

The housing of the third valve was cast in conformance with Y & D Drawing No. 993669. Five housings were cast before an acceptable one was obtained. This was accomplished by changing the steel specifications from ASTM A-217 to A-27, grade 70-40. Even then, a radiographic inspection revealed two small spots that needed to be repaired. Also, the final casting did not conform to the requirement that the inside surface of the top ports be flat. This surface had a crown of about 1/8 inch. To accommodate minimum radius requirements for corners, the cast housing was slightly larger than the fabricated housing, and the complete valve weighed 280 pounds. The two types of housings cost about the same. Because of the difficulty encountered in casting, the dimensional problems, and the greater weight when cast, it is recommended that only the fabricated housing be used in all future procurement of this valve.

Five prototype flaps were constructed. All of them were made of aluminum. The first flap was for the airflow tests only and did not receive any special treatment. The second flap was fabricated from 6061-T6 plate and rod, welded with 4043 filler, and given a solution and precipitation heat treatment to a T6 condition. It had a 90-degree angle between the faces of the flap. The third flap was made of the same material and was given the same type of heat treatment, but had a slightly different design at the apex; it had a 110-degree angle between the faces of the flap. After a number of tests, it was modified to accommodate the torsion springs to help hold it open during normal airflow. The fourth flap was similar to the third, but was fabricated commercially. The fifth flap was sand-cast from TENS-50 aluminum alloy and received special heat treatment in order to obtain as much ductility as possible without too large a sacrifice in strength. The flaps weighed about 5-1/2 pounds each.

To prevent galvanic action between the aluminum flap and the steel parts with which it is in contact, the steel parts are cadmium plated and covered with grease. The housing is given an initial protective coating of zinc inorganic silicate.

AIRFLOW TESTS

Test Setups

Before the steel prototypes of the valve were constructed, a wooden and plastic mockup of the valve was made to determine the effects on airflow of various modifications. A number of airflow tests were conducted with the test setup shown in Figure 2. The model was attached to the air-intake side of a centrifugal blower. All joints and seams of the blower and duct-work were sealed to prevent leakage and to ensure accurate airflow measurements. The original 90-degree flap was used for all tests conducted on the model.

Similar test setups were used to make airflow tests of the prototype valves. These tests were all performed in the NCEL blast simulator pit just prior to the over-pressure tests. Figure 5 shows one of the setups. Tests were first made using a 90-degree flap, then using a 110-degree flap with ball plungers to hold it open, and finally with a 110-degree flap with torque springs such as shown in Appendix A. Airflows were started as low as possible and were increased in increments until the valve closed or the capacity of the blower was reached. The pressure drop through the valve and the pipe loop was recorded at each increment.

Instrumentation

Airflow was measured with either an Ellison Pitot tube or with a Hastings Precision Air-Meter, model B-16. The readings were taken in the center of the duct and were reduced by 9% to account for the theoretically parabolic shape of the flow.

Pressure drops were measured to the nearest 0.001 inch of water with a Merian Instrument Co. Precision Manometer, model A-750.

Results and Discussion

The airflow tests using the easily modified wooden and plastic model showed that a very simple housing with flat sloping ends resulted in the lowest pressure drop across the valve. The detailed results of this study are presented and discussed in Reference 1.

Tests with the first prototype valve showed that the 90-degree flap would stay open because of its own weight during airflows of 600 cfm. The 110-degree flap, however, required something to restrain it from closing. Ball plungers bearing against a groove in the side of the flap had too much friction and were unsatisfactory. Magnetic restraints on the flap shafts also did not work properly. It was therefore decided to design torque springs that would fit inside the flap and act on its shafts. After a few modifications the springs produced the desired results.

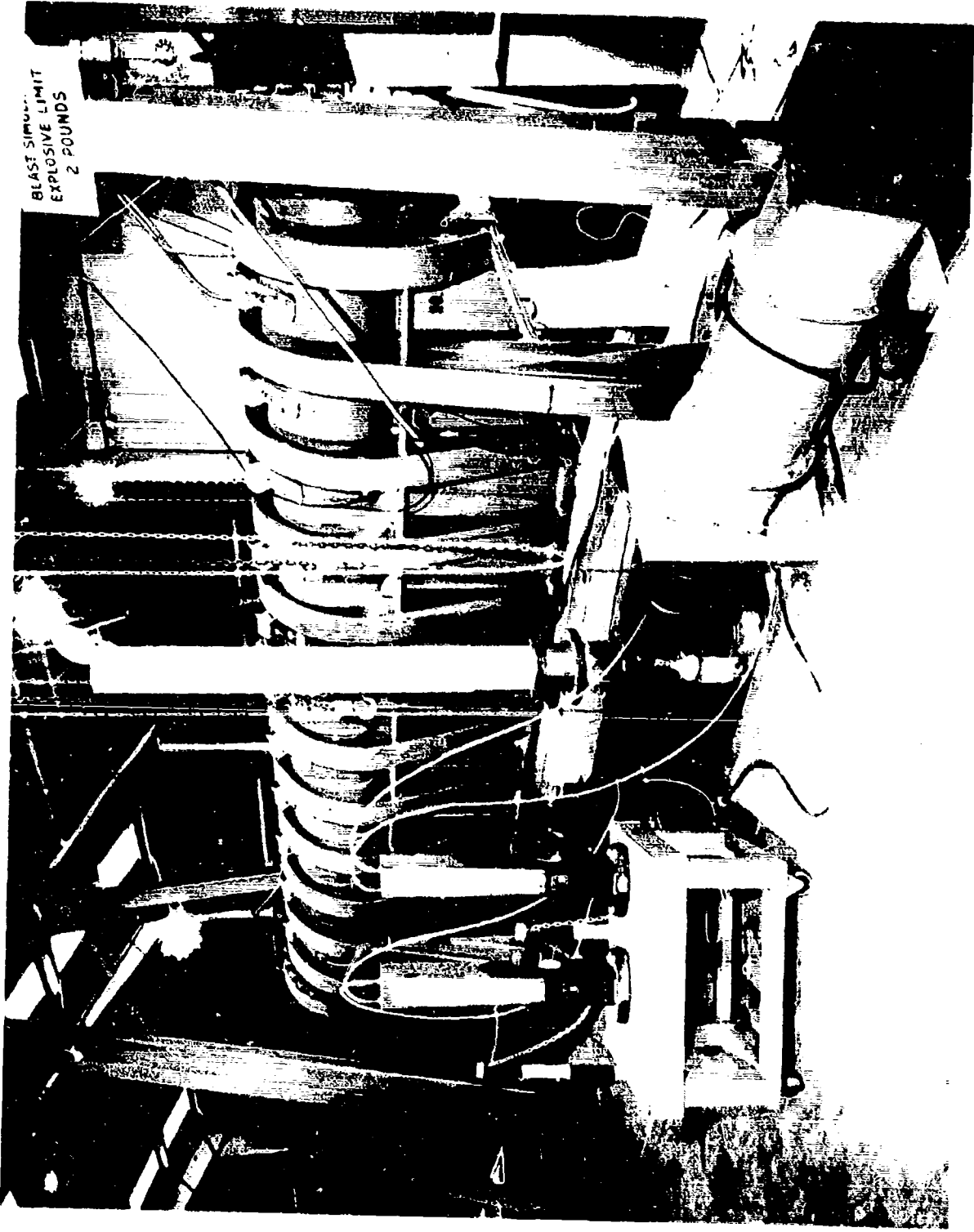


Figure 5. Airflow-test setup in blast simulator pit.

The loss of pressure across the valve (i.e., through the valve and pipe loop) increased logarithmically with the rate of airflow. There was some variation in the results between different instrumentation, test setups, and prototype valves, as indicated in Figure 6. The results show, however, that the valve can be rated at an airflow of 700 cfm for a pressure drop of 1 inch of water. An airflow of about 1,150 cfm caused the valve to close.

OVERPRESSURE TESTS

Test Setups

The NCEL blast simulator was used to apply overpressures ranging from 2 to 159 psi. Numerous tests were performed, and many variables were investigated. Figure 7 shows one of the typical setups. The blast simulator was sealed except for an 8-inch opening to which a pipe, acting as the outside connection to the ventilation system, was attached. The blast wave then passed through the first chamber of the valve and the pipe loop and into the second chamber of the valve. During the preliminary tests any wave that bypassed the valve was exhausted to the atmosphere.

These tests included an investigation of the following:

1. Relative peak pressures and impulses to which various portions of the valve and associated pipes would be subjected.
2. Closure times under a range of overpressures.
3. Magnitude of the flap rebound.
4. Effect of different flap angles.
5. Angular acceleration of the flap.
6. Strains in the valve body and the flap as related to time.
7. Magnitude and duration of any portion of the blast wave which bypassed the valve.

During subsequent tests the shelter side of the valve was connected to a 600-cfm collective protector, simulating a typical installation. Two of these test setups are shown in Figures 8 and 9. Most of the tests were conducted, however, with only the prefilter portion of the collective protector, as shown in Figure 10.

The prefilter is expendable and is the weakest part of the filter system. It is a 2x2x20-inch fiberglass filter that removes about 60% of the dust. Some of these filters are very weak and are easily blown out of their frame. This type of filter was provided with some additional support. There are prefilters, however, that are manufactured with greater strength and which do not need any additional support. This is discussed further in Appendix C.

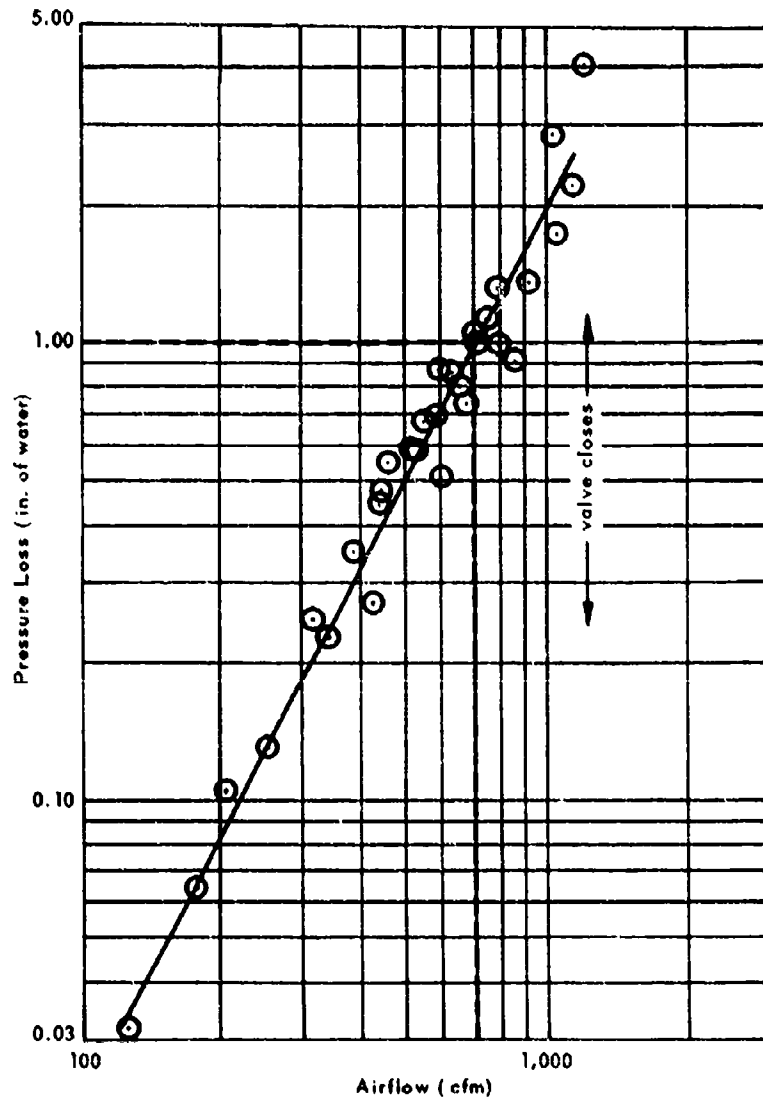


Figure 6. Pressure loss versus airflow through fabricated valves with 110-degree flap.

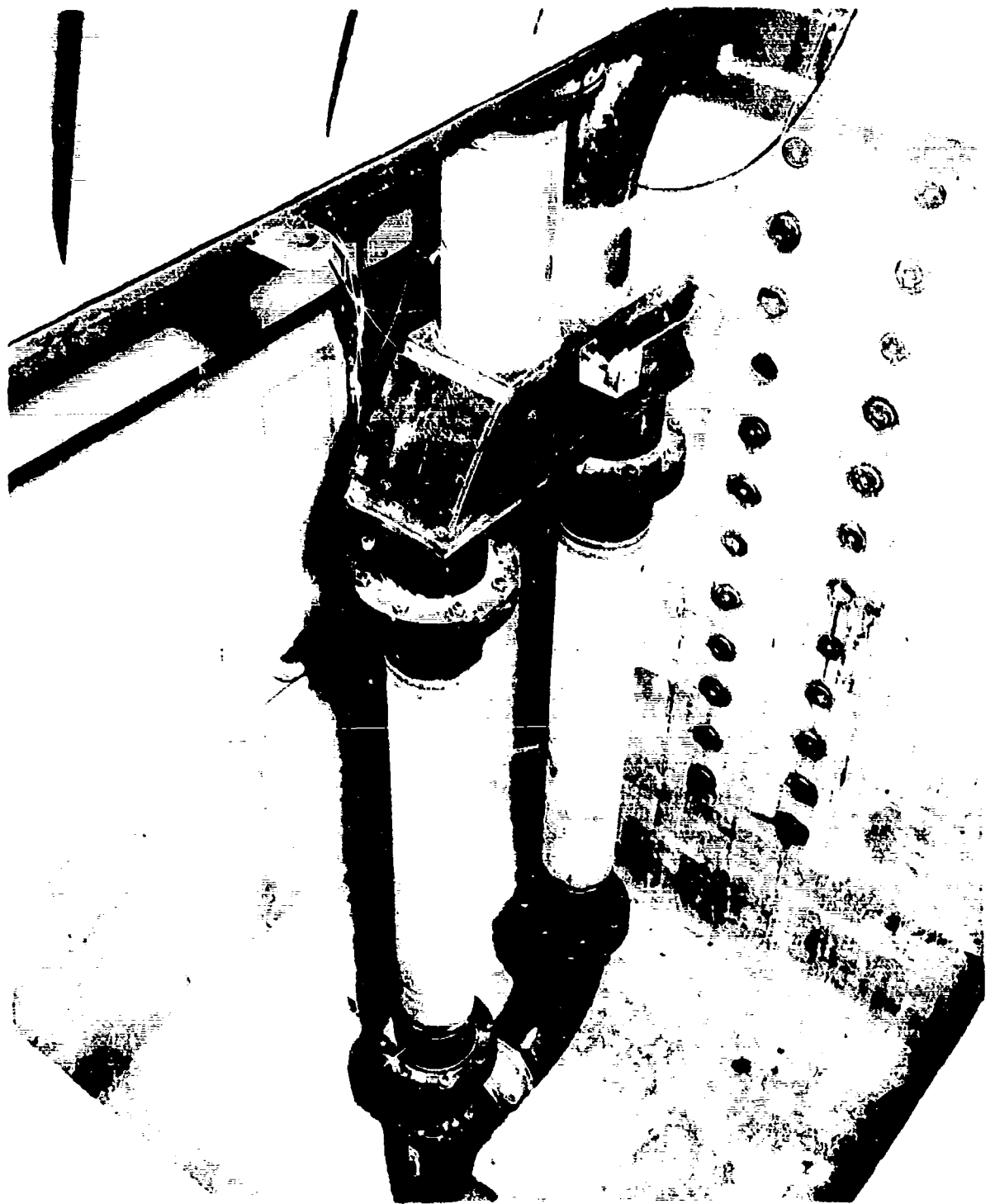


Figure 7. Original prototype valve setup for overpressure tests.

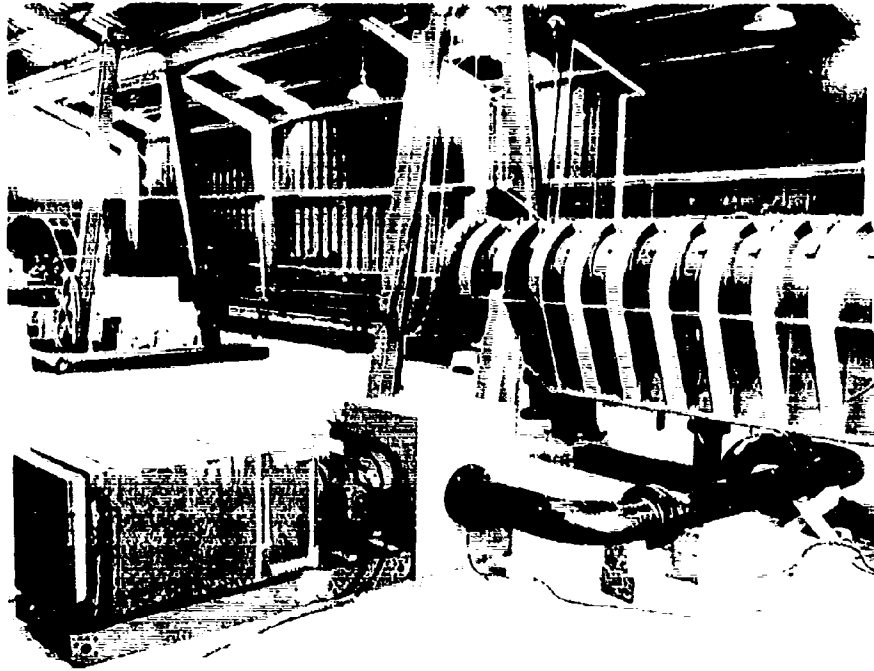


Figure 8. Overpressure tests with blast closure valve connected to plenum and 600-cfm collective protector.

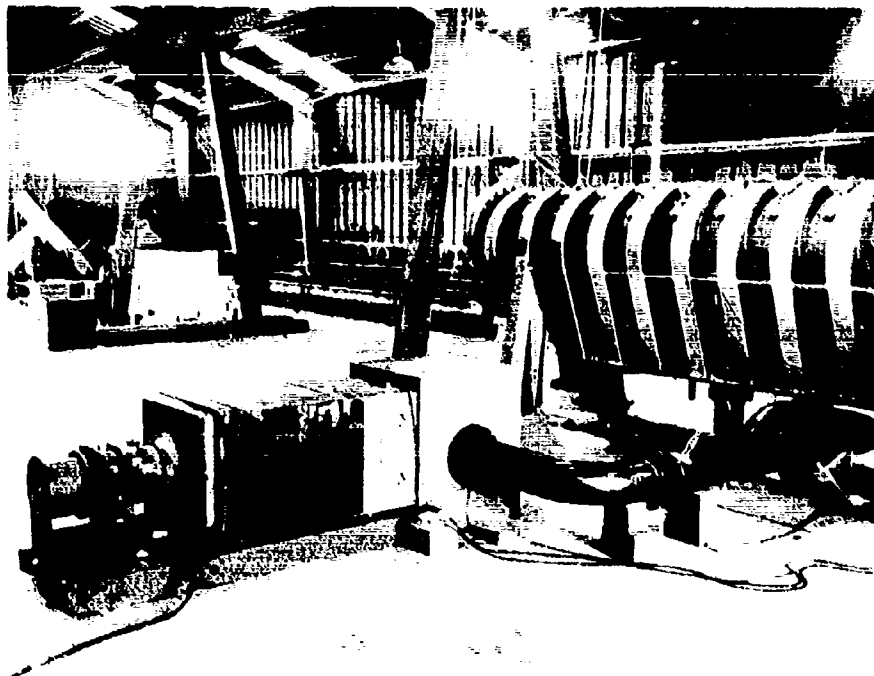


Figure 9. Overpressure tests with sequence of collective protector units switched.

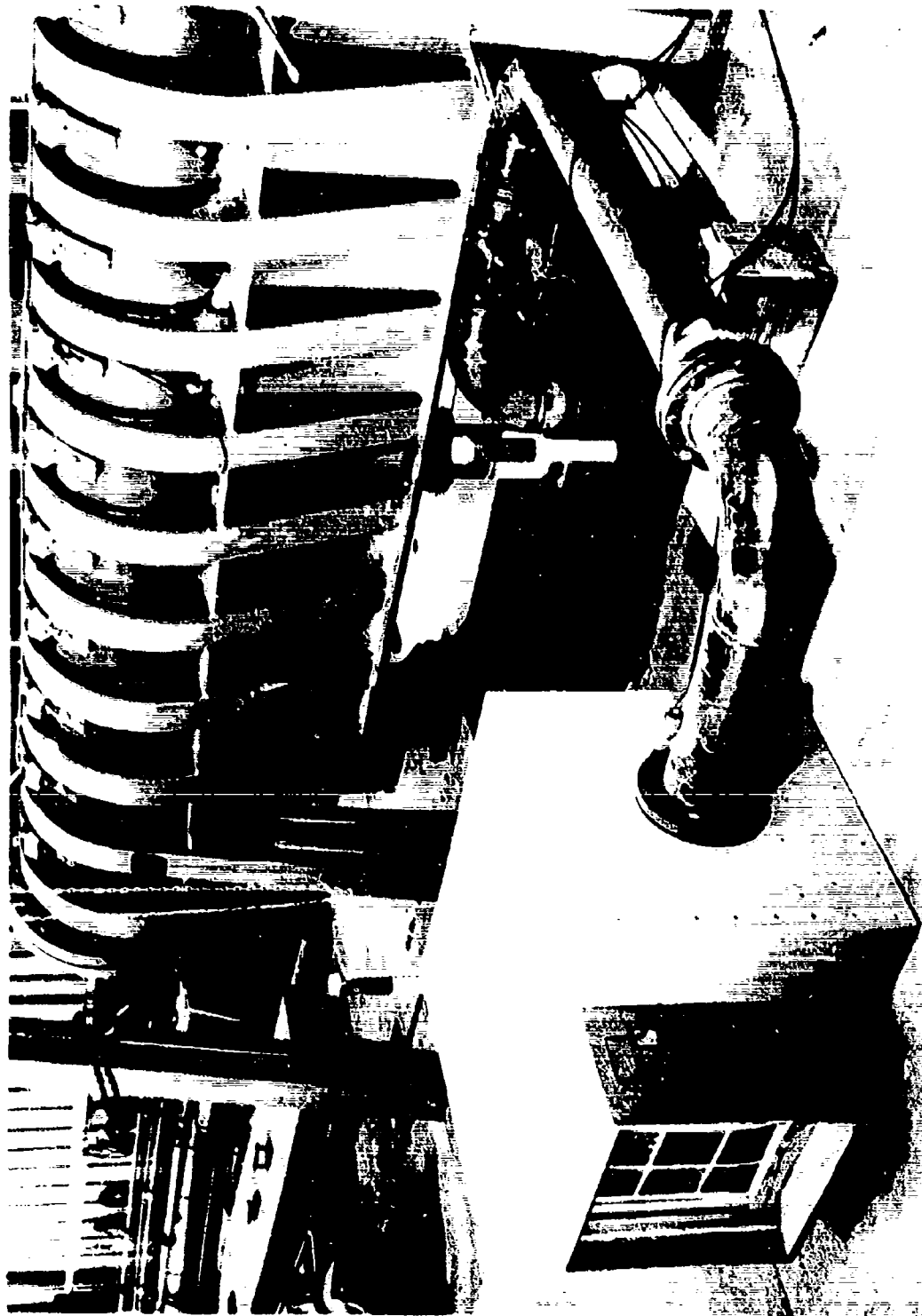


Figure 10. Overpressure test setup with plywood plenum and prefilter section of collective protector.

The subsequent tests were conducted to accomplish the following:

1. Further investigate some of the previously mentioned problems.
2. Study various means of mitigating the bypassing wave (e.g., direct connection to filter unit, use of a tapered plenum, effect of a muffler device, and use of a relatively small plywood plenum).
3. Determine the ability of the system to function properly under very low overpressures.
4. Investigate the effects of different lengths of pipe loop.
5. Establish the maximum overpressure which the valve could repeatedly withstand.
6. Determine the effects of the torque springs on flap closure and the strength of the springs under dynamic loads.
7. Evaluate two commercially manufactured prototype valves — one fabricated (i.e., welded) and one cast.

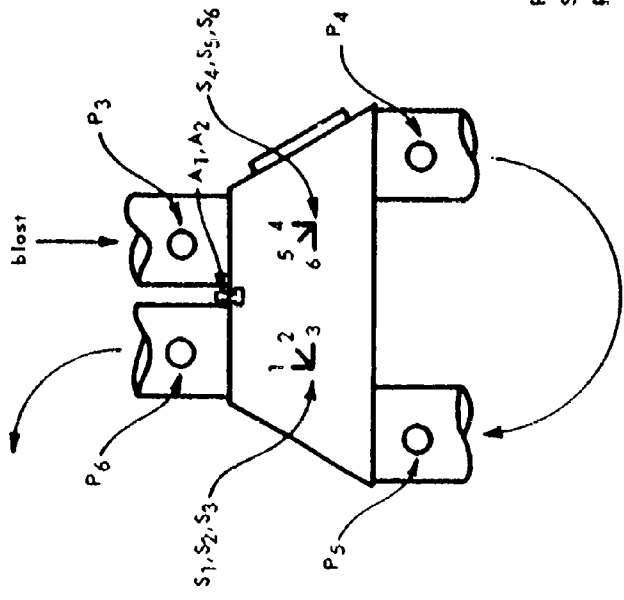
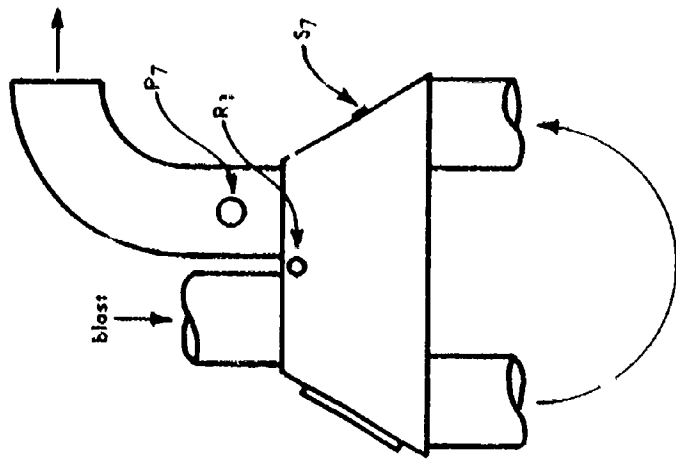
The strength of the blast wave that reached the prefilter was dependent on three basic variables: the blast closure valve, the pipe-loop length (this is discussed in Appendix D), and a device for mitigating the bypassing wave. An effort was made to keep the blast valve simple, the pipe loop short, and the mitigating device inexpensive.

Instrumentation

In the preliminary tests the instrumentation consisted of six Statham pressure cells, two Filpup pressure transducers, eight SR-4 strain gages, two Statham accelerometers, and one device on the axle of the flap to measure rotation. These nineteen channels of information were connected with CEC System-D power supplies and amplifiers and were recorded on two CEC oscillographs. Figure 11 shows the location of most of the instrumentation. There were also two pressure cells located in the skirts of the simulator, and a strain gage located on the flap.

In the subsequent tests, pressure cells 4 and 5 were usually omitted, all of the strain gages were omitted, and pressure cell 8 was moved downstream to a location 2 feet 10 inches from the valve's shelter port. Additional pressure transducers were sometimes placed in the pipe 11 feet 5 inches and 15 feet 3 inches from the valve's shelter port. Also, pressure transducers were sometimes placed in the plywood plenum and in the plenum for the prefilter.

For the last nine tests an FM tape system was used to record the data. The information was then fed through an analog-to-digital converter and into an IBM 1620 computer for reduction.



P = Pressure cell
 S = SR-4 strain gage
 R = Rotation of flap
 A = Accelerometer

Figure 11. Instrumentation for blast simulator tests.

Results and Discussion

A total of 63 tests were performed in the NCEL blast simulator. Of these, 15 were at less than 10 psi overpressure as measured between the skirts of the simulator, 15 were between 100 and 150 psi, and three were greater than 150 psi. The largest overpressure to which the valve was subjected was 159 psi.

The blast waves generated by the simulator had a decay typical of the idealized wave form from a nuclear weapon. The pressures measured at points three, four, and five (Figure 11) also had about the same peak value as that measured in the simulator, but a considerably different wave form. When a given wave traveled through the blast-closure system, it was attenuated until it reached the closure port on the shelter side of the valve. At that point it was reflected back through the entire system. The peak values of the reflected wave were about equal to the initial peak pressures measured in the simulator.

The welded housing and flap performed well. Overpressure tests showed, however, that the cast flap was too brittle. It failed with almost no sign of yielding when subjected to a peak overpressure of 100 psi. The cast steel housing withstood the 100-psi overpressure, but for the reasons discussed previously it is not recommended. The following results and discussion, therefore, will be primarily concerned with the fabricated flap and housing.

The time required for the 110-degree welded flap to close initially is shown in Figure 12. It can be seen that the time required to close decreased as overpressure increased up to peak values of about 80 psi. As the peak overpressure increased above 80 psi, the initial closure time was constant at about 4-1/2 milliseconds. At the lower overpressures the closure time increased rapidly as shown by the curves. The flap did close, however, at overpressures as low as 2 psi, and the valve functioned as intended over the complete range of overpressures from 2 psi through 159 psi.

The torque springs that help to hold the flap open during normal airflow did not significantly affect the response of the flap when the valve was subjected to overpressures within the above range. At overpressures of 2 to 6 psi the average effect was a delay in closing of about 2 milliseconds. At higher overpressures there was no delay caused by the springs.

After initially closing, the flap would usually rebound. The duration of the rebound for the 110-degree flap was 5 to 10 milliseconds and was essentially independent of the peak overpressure. The magnitude of the rebound did, however, depend on the magnitude of the peak overpressure. The flap rebounded about 6-1/2 degrees at 15 psi, about 13 degrees at 100 psi, and roughly 19 degrees at 150 psi. The first time the flap was subjected to a significantly larger overpressure than it ever had received, it would undergo some local plastic deformation where it contacted the closure port, and the magnitude and duration of the rebound would be considerably less than the values indicated above — sometimes almost nonexistent.

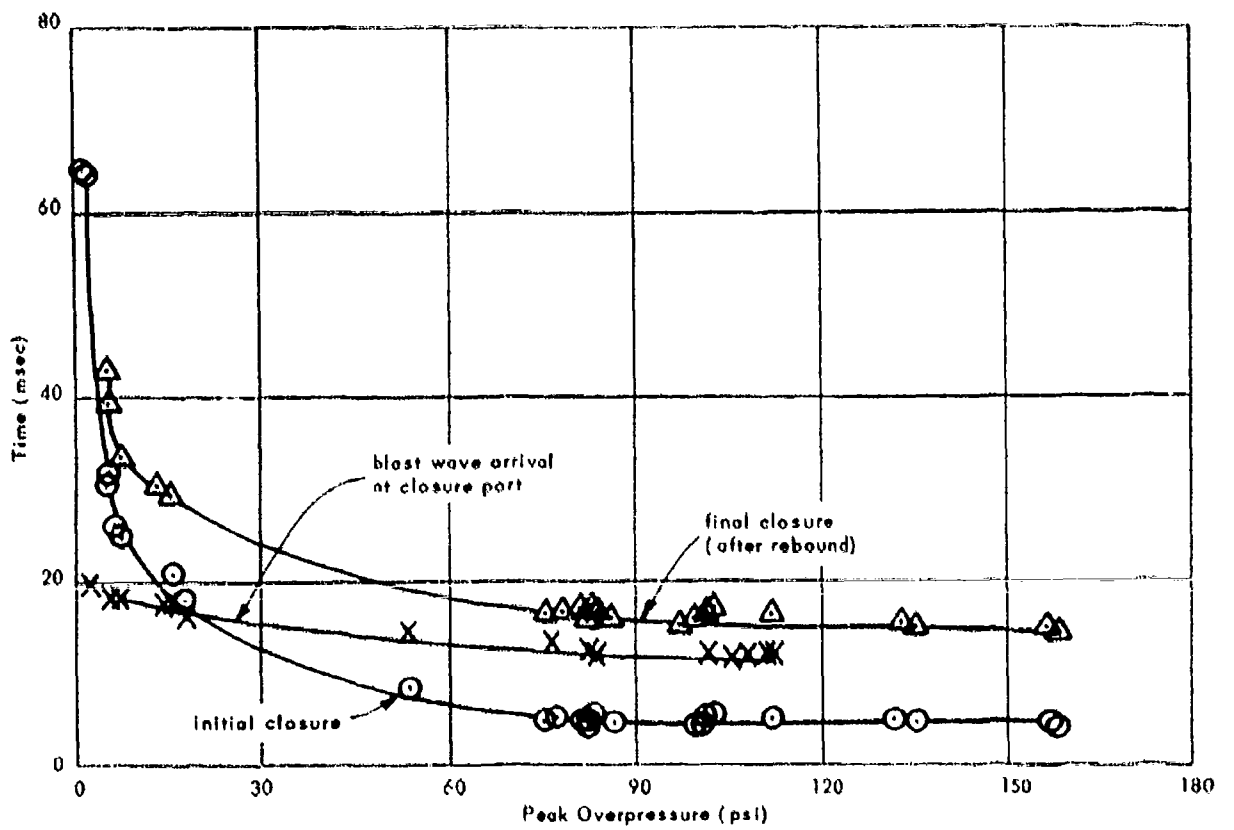


Figure 12. Time required for 110-degree flap to close and for blast wave to reach the closure port through 21.8-foot pipe loop.

Flaps with two different dihedral angles were tested. The following data show that the initial closure time for the 90-degree flap was considerably greater than for the 110-degree flap:

Initial Closure		
Peak Overpressure (psi)	Average for 110-Deg Flap (msec)	Average for 90-Deg Flap (msec)
6	28	44
16	16	26
97	4.2	8.4
99	4.2	8.7

Data for flap rotation versus time are of poor quality because of the effects of the extremely high accelerations on the transducers used to measure the rotation. Quantitatively, however, the rebound of the 90-degree flap seemed to be less than the rebound of the 110-degree flap. At peak overpressures of about 100 psi, this results in a net reduction in any pressure tending to bypass the valve before it was completely closed. At lower overpressures, however, the longer time required to initially close the 90-degree flap resulted in larger bypassing pressures. These bypassing pressures for the 90-degree flap were sufficient to cause damage to the prefilter shown in Figure 10. This same filter was undamaged when the 110-degree flap was used. Most of the tests were therefore conducted using the 110-degree flap.

A few measurements were made of the strains in one of the 110-degree flaps. The arm first loaded by the blast wave would initially deflect in the direction of rotation. While continuing to rotate, it would then spring back in the opposite direction and continue to oscillate until the other arm hit the closure port. At that time it would make a large deflection in the direction of rotation, and then spring back again in the opposite direction. For an overpressure of 102 psi, the largest strain recorded before closure was 2,450 microinches per inch.

During preliminary tests in which the valve was subjected to overpressures up to 113 psi, the valve housing was instrumented with seven strain gages. The recorded strains were all very small. The largest, about 280 μ in./in., was in the center of the end plate, gage 7 (Figure 11).

The valve was subjected to three tests in which the peak overpressure was greater than 150 psi. At no time did any part of the valve housing or the pipe loop show any permanent deformation.

The original 110-degree flap withstood a total of 44 overpressure tests. Fourteen of these were greater than 100 psi, and three were greater than 150 psi. The arms of the flap are relatively thin, tapering from 1/2 inch to 1/8 inch, and, as

was expected, the arm of the flap on the closure side was dished by the high overpressures. The total dishing for the 44 tests was 3/4 inch, but this did not impair the operation or effectiveness of the flap. Also, it is very unlikely that any shelter would be subjected to this number of blasts. The condition of the flap before and after the 44 tests is shown in Figures 13 and 14.

During all the tests the angular accelerations and decelerations of the flaps were very high. But at overpressures less than 113 psi, the inertial effects were not large enough to cause any permanent reduction of the dihedral angle between the arms. The original 110-degree flap was subjected, however, to three tests between 154 and 159 psi. During these tests the dihedral angle between the arms was reduced a total of 6-1/2 degrees, and there was slight permanent bending of the arm first loaded by the blast wave (e.g., a total of about 1/8 inch for three tests).

The 110-degree flap that was fabricated commercially did not perform as well as the original flap welded at NCEL. The commercial flap cracked at a welding imperfection during the sixth test. This was, however, during the third test at about 150 psi. The commercial flap was not fabricated in the same manner as the NCEL flap. The drawings and specifications have been changed to require the proper fabrication procedures in future commercial procurement. Also, the weld size was increased slightly to add a factor of safety. These changes are included in the drawings and specifications given in Appendixes A and B. If there is any question regarding the soundness of the weld it would be advisable to have it X-rayed.

Probably the most important measurements made were those of the magnitude and duration of any portion of the blast wave which bypassed the valve. Because the flap was not completely closed at the time the blast wave arrived at the closure port (Figure 12), fairly high peak values of pressure did bypass the valve. The durations were very short, however, and the total impulses were very small. A typical bypassing wave is compared with the applied overpressure in Figure 15. The positive phase of the bypassing wave was followed by a negative phase which usually had a significantly smaller peak value but a somewhat longer duration. Then there was usually some oscillation of the wave about atmospheric pressure before it damped out.

The magnitude of the positive pressure which bypassed the valve with the 110-degree flap is shown in Figure 16 for three locations: two downstream from the valve in the 8-inch pipe and one in the plywood plenum. There is some scatter in the data, but it can be seen that the peak of the positive wave generally increases as the applied peak overpressure increases. The rate of the increase is smaller, however, further downstream. The peak negative pressure is not shown. It appeared to be relatively independent of the applied peak overpressure and seldom exceeded 4 psi at the gage location closest to the valve.



Figure 13. Original 110-degree flap before tests.

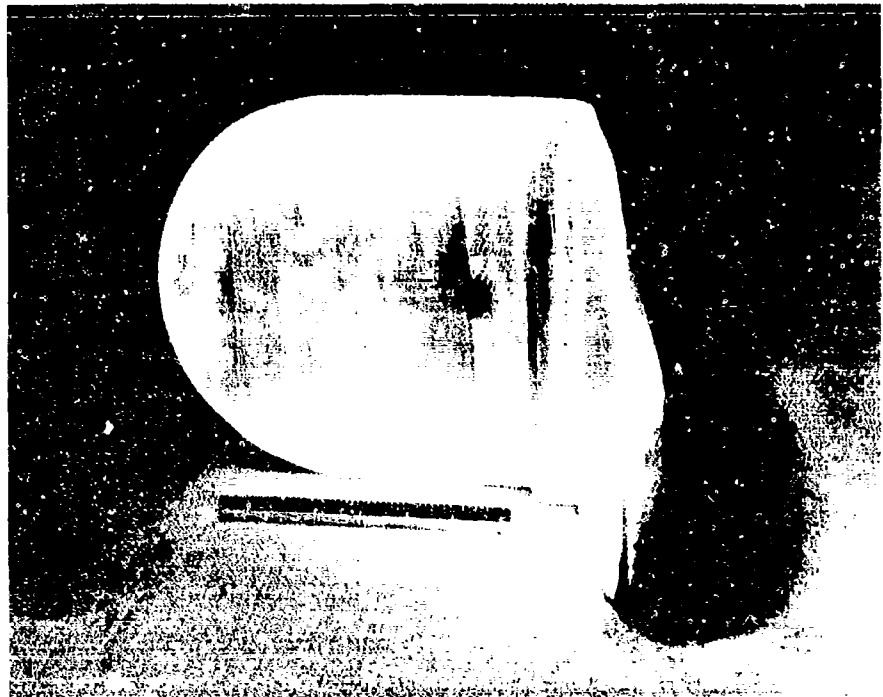


Figure 14. Original 110-degree flap after 44 overpressure tests.

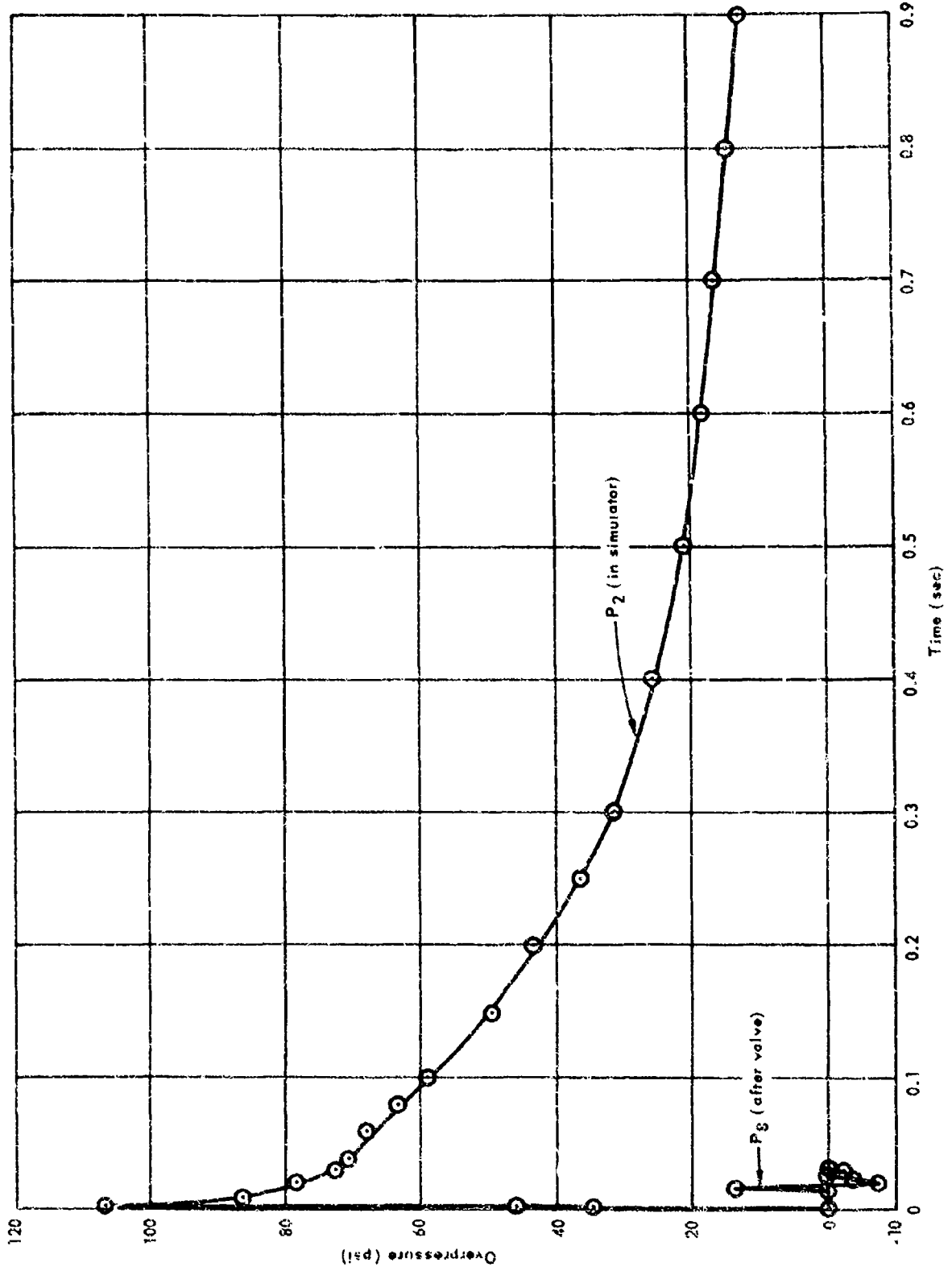


Figure 15. Bypassing pressure wave compared to applied pressure wave.

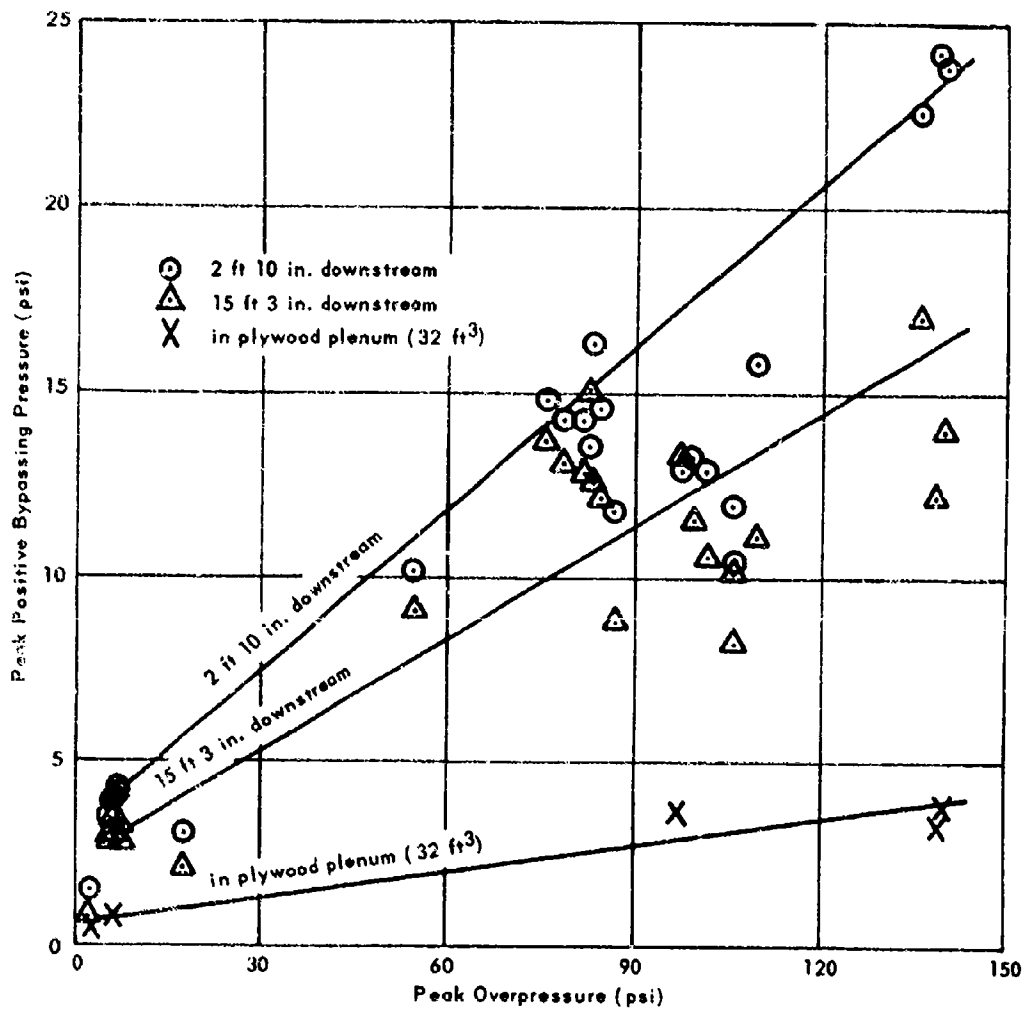


Figure 16. Peak positive pressure bypassing the valve (110-degree flap and 21.8-foot pipe loop).

The damage that a blast wave can cause is dependent on its duration as well as its peak overpressure. The bypassing pressures had very short durations. The peak positive pressure usually had a duration of 2 to 4 milliseconds at a point 15 feet 3 inches downstream from the valve. The maximum positive impulses of the bypassing pressures were, therefore, also very small as can be seen in Figure 17. The maximum negative impulses were even smaller. At a point 15 feet 3 inches downstream, they were only a fraction of the positive impulse.

There were two primary questions regarding the bypassing wave:

1. What was the best means of mitigating it?
2. How much did it have to be attenuated?

The wave bypassing the valve could have been reduced by various means. For example, the rebound of the flap could have been prevented by a latch mechanism, but this would not have been of too much help at overpressures of less than approximately 20 psi. Figure 12 shows that at overpressures of less than this value the flap has not yet initially closed when the blast wave arrives.

Other approaches were also considered, but the simplest and most economical solution was to attenuate the bypassing wave itself by means of a relatively small plywood plenum such as shown in Figures 10 and 18. The plenum shown in Figure 10 (15 cubic feet) was good for overpressures up to 109 psi. Higher overpressures began to damage it. The plenum shown in Figure 18 (32 cubic feet) was good for overpressures up to 159 psi.

The effectiveness of the 32-cubic-foot plywood plenum in reducing the magnitude and impulse of the bypassing wave is shown in Figures 16 and 17. The peak positive bypassing pressure was reduced to less than 4 psi in the plenum, and the maximum positive impulse was reduced to less than 0.008 psi-sec.

The weakest part of a ventilation system which utilizes a Navy standard 600-cfm collective protector (i.e., M9A1 gas-particulate filter unit) is the expendable dust-stop-type prefilter discussed previously. In many installations the prefilter plenum will be connected to the plywood plenum as shown in Figure 9. Under these conditions it is desirable that the bypassing wave be attenuated sufficiently so that it does not damage the prefilter even though it is expendable. It was found that the bypassing pressure remaining after being attenuated by the 15-cubic-foot plenum would not damage a typical unsupported prefilter at peak overpressures of less than about 80 psi. At higher overpressures the bypassing wave would not cause any damage if a stronger prefilter was used (e.g., Fram/Glass G7) or if some simple support was provided as indicated in Appendix C.

The degree to which the bypassing pressure was attenuated by the time it reached the prefilter is indicated in Figure 19. These data were taken with the test setup shown in Figure 10. When the rest of the collective protector was added to the system, it appeared to impede the progress of the bypassing wave beyond the prefilter, and thereby higher indicated pressures were developed on the front of the prefilter. The differential pressure across the prefilter, however, was probably lower.

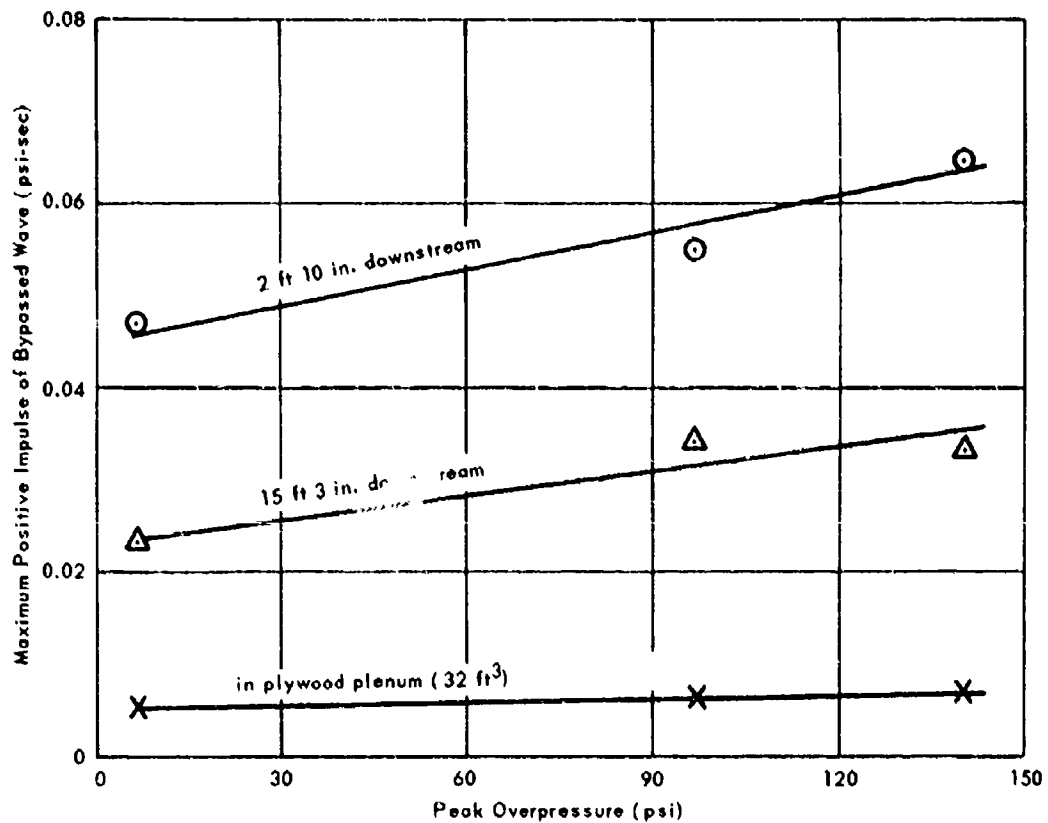


Figure 17. Maximum positive impulse of bypassing wave at three locations (110-degree flap and 21.8-foot pipe loop).

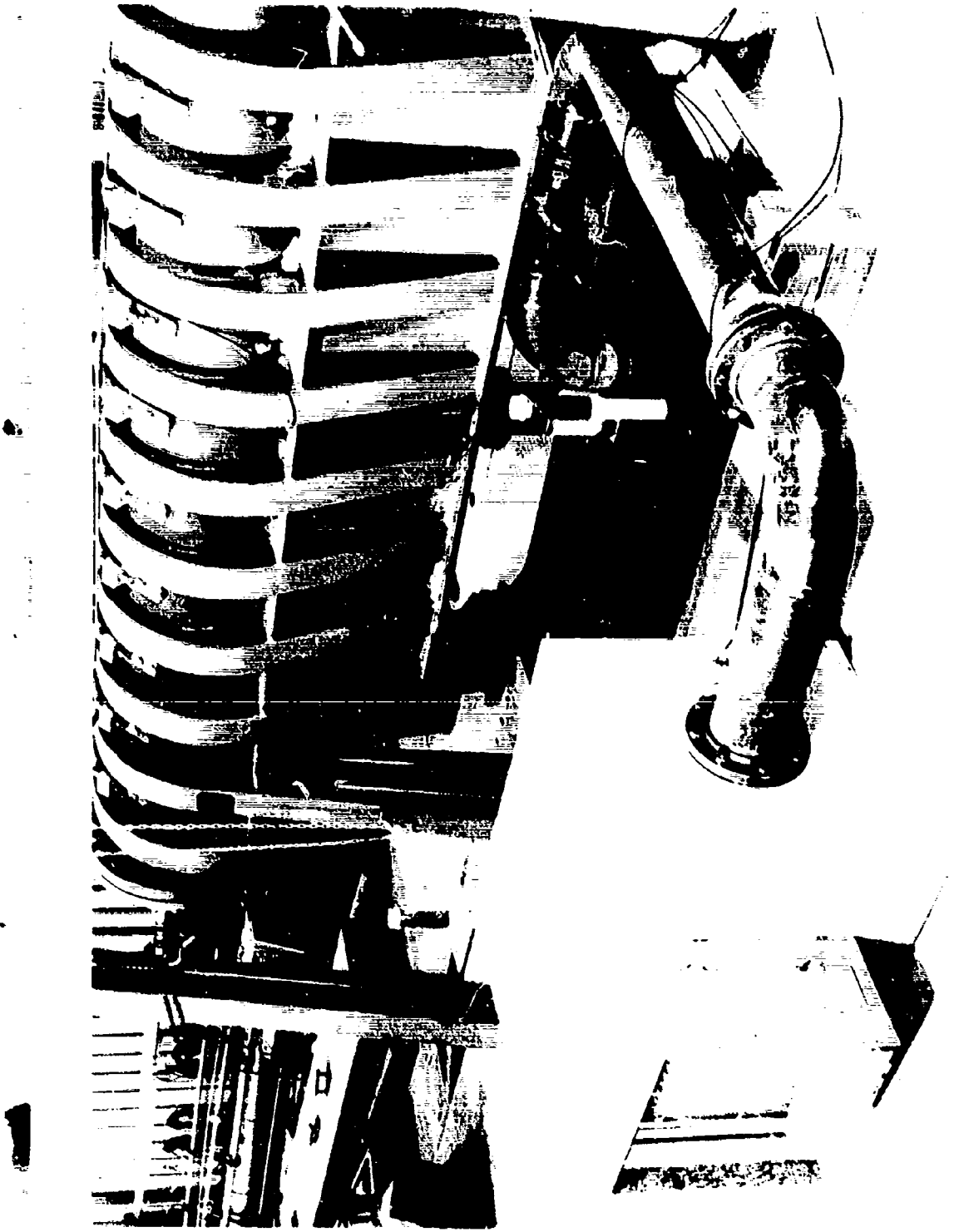


Figure 18. Blast simulator test setup using 32-cubic-foot plenum.

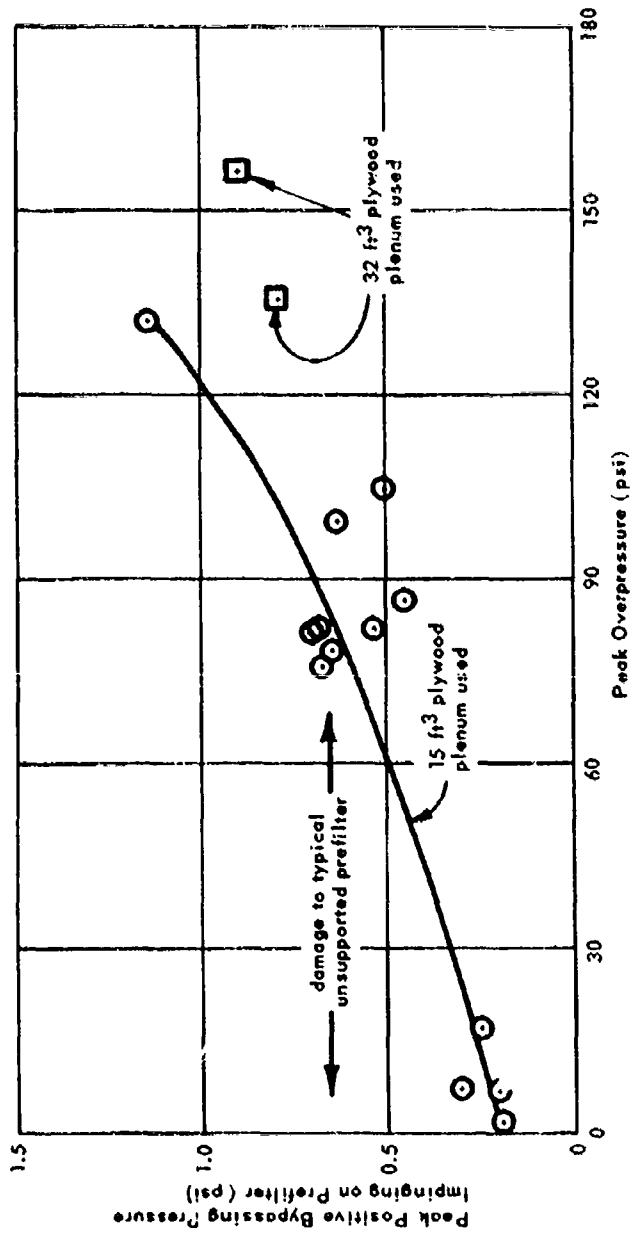


Figure 19. Peak positive bypassing pressure impinging on prefilter (110-degree flap and 21.8-foot pipe loop).

Some installations may have the intake or exhaust pipes for the ventilation system open directly into a room. In these installations the room itself could act as a large plenum for the bypassing wave.

During the overpressure tests the blast simulator and the attached valve were subjected to accelerations due to the onset of the pressure wave. The accelerations were dependent upon the test setup: how the bottom of the simulator skirts were sealed and insulated, how the valve was attached, and how the valve was supported. The vertical accelerations have been plotted in Figure 20. They were roughly 40% larger than the horizontal accelerations.

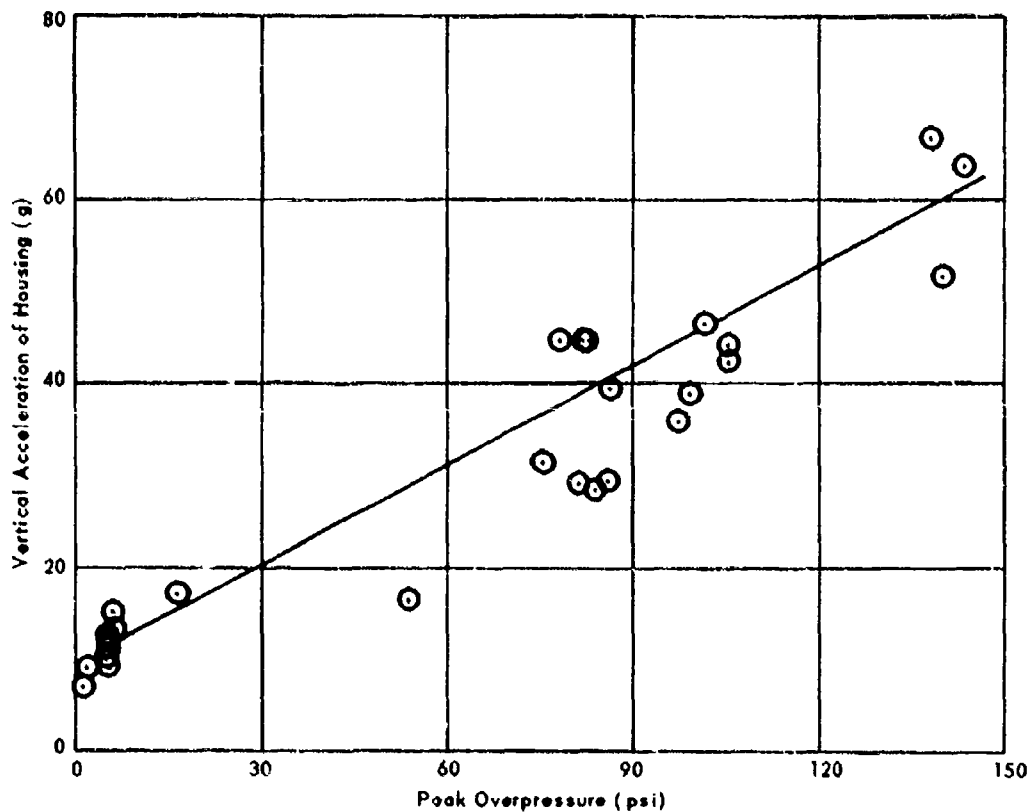


Figure 20. Maximum vertical acceleration of valve housing under given test conditions.

FINDINGS AND CONCLUSIONS

Airflow

1. The blast closure valve described herein and shown in the drawings of Appendix A has a rated airflow of 700 cfm at a pressure drop of 1 inch of water across the valve (including the pipe loop).
2. At the rated airflow of the M9A1 collective protector (i.e., 600 cfm) the valve has a pressure drop of 0.7 inch of water.
3. An airflow of about 1,150 cfm will cause the valve to close.

Overpressure

1. The valve may be rated as providing blast protection from peak overpressures of 2 to 150 psi.
2. The overpressures developed in the valve, including reflected values, are equal to or less than the outside air overpressures. The wave forms, however, are somewhat different.
3. The valve housing and flap should be made by welding rather than casting.
4. The welded valve housing is strong enough to withstand numerous blast loadings from peak overpressures up to 150 psi.
5. The welded flap possesses adequate strength but is the weakest part of the valve. If the overpressures are about 100 psi or less, the valve flap will provide the desired protection for numerous blasts — at least 44. At overpressures of about 150 psi the valve flap will provide the desired protection for at least three blasts.
6. At overpressures greater than 80 psi the valve initially closed in about 4-1/2 milliseconds, but at lower peak overpressures it normally took increasingly longer.
7. After initially closing, the valve flap would normally rebound for 5 to 10 milliseconds before final closure.
8. Because the flap is not completely closed when the pressure wave reaches the closure port, a relatively small pressure wave bypasses the valve. It will, however, have a very short duration (e.g., 3 milliseconds) and therefore a very small impulse.
9. This bypassing wave has a negative as well as a positive phase and may be easily damped out. For example, a plenum smaller than the size of an M9A1 collective protector can reduce the maximum bypassing impulse to less than 0.008 psi-sec.

10. The bypassing pressure wave from the valve has such a small impulse that the valve could be connected directly to a room (e.g., equipment room) without resulting in any damage to equipment or personnel, provided that they were a reasonable distance (e.g., 2 feet or more) from the air duct terminal.

11. The valve is not sensitive to accelerations.

12. When installed as indicated in Appendix A, the valve will provide complete blast protection to an M9A1 collective protector for peak overpressures up to 159 psi.

Appendix A

BRECKENRIDGE BLAST-ACTUATED CLOSURE VALVE DRAWINGS

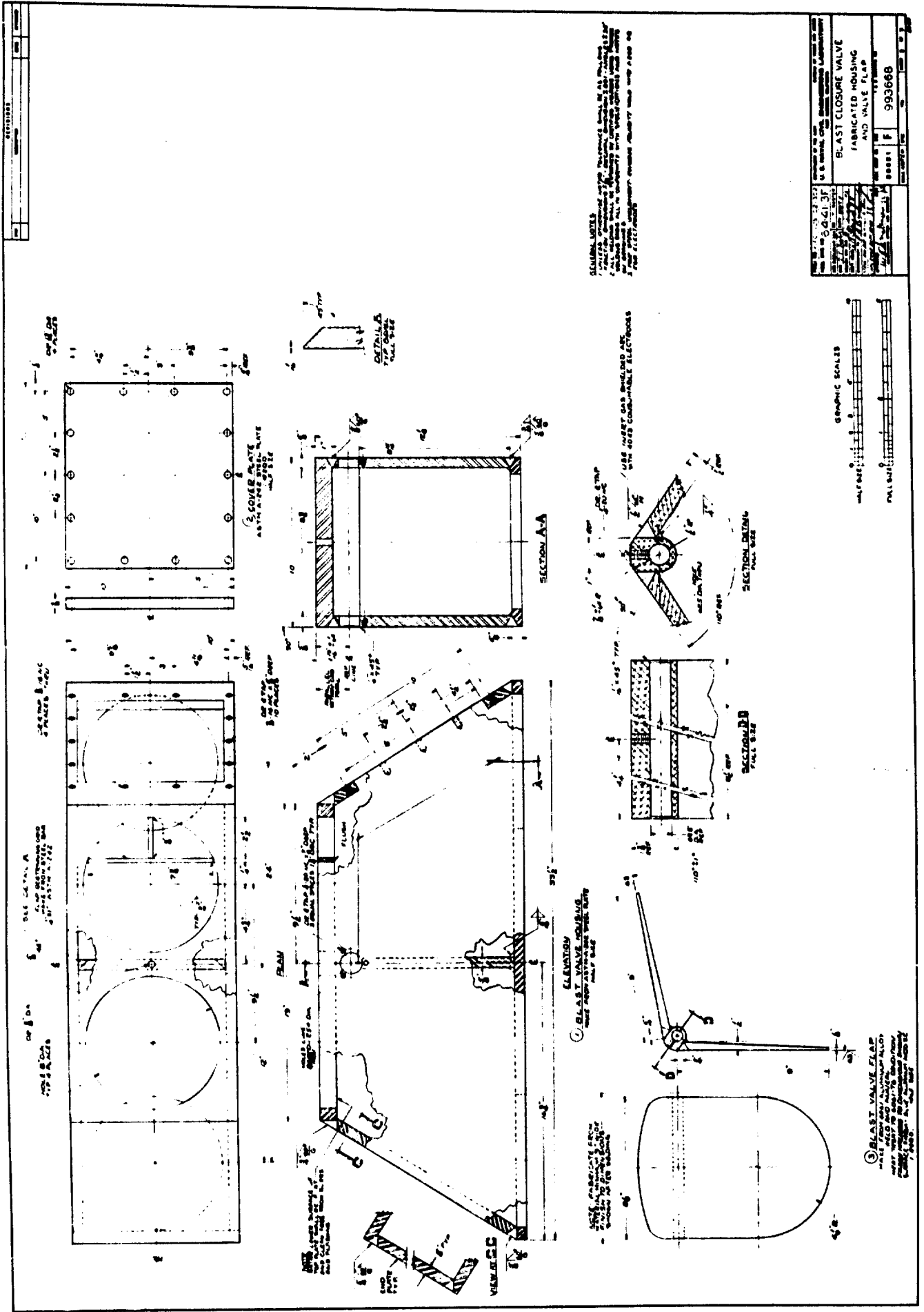


Figure A-3. Bureau of Yards and Docks Drawing No. 993668, blast closure valve fabricated housing and valve flap.

Appendix B

BRECKENRIDGE BLAST-ACTUATED CLOSURE VALVE SPECIFICATIONS

SECTION 1. SCOPE

1.1 The work shall include all labor, equipment, and material necessary for the complete fabrication, protective coating, and assembly of all component parts for the Breckenridge blast-actuated closure valve. The blast closure valves will be used by the Government to prevent overpressures from entering the ventilation systems of buried shelters.

SECTION 2. APPLICABLE DOCUMENTS

2.1 The following specifications, standards, and drawings of the issue in effect on the date of invitations for bids form a part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

QQ-A-250/11c	Aluminum Alloy 6061, Plate and Sheet
QQ-P-416a	Plating, Cadmium (Electrodeposited)
QQ-S-633a	Steel Bars, Carbon, Cold Finished and Hot Rolled (General Purpose)
QQ-W-470a	Wire, Steel, High Carbon, Spring, Bright, Music

Military

MIL-C-6183A	Cork and Rubber Composition Sheet; for Aromatic Fuel and Oil Resistant Gaskets
MIL-H-6088C	Heat Treatment of Aluminum Alloys
MIL-S-6758A	Steel, Chrome-Molybdenum (4130) Bars and Reforging Stock (Aircraft Quality)
MIL-P-23236	Paint Coating Systems, Steel Ship Tank, Fuel and Salt Water Ballast

STANDARDS

Military

MS-90725 Screw, Cap, Hexagon Head (Finished Hexagon Bolts)
Medium Carbon Steel, Cadmium Plated, UNC-2A.

DRAWINGS

Bureau of Yards and Docks

993666 Blast Closure Valve Typical Installation
993667 Blast Closure Valve Assembly and Fabricated Details
993668 Blast Closure Valve Fabricated Housing and Valve
Flap

(Copies of specifications, standards, and drawings required by suppliers in connection with specific procurement functions should be obtained from the procuring activity.)

2.2 Other publications. The following documents form a part of this specification. Unless otherwise indicated, the issue in effect on the date of invitation for bids shall apply.

American Society for Testing Materials

ASTM Designation A242 High-Strength Low Alloy Structural Steel

(Application for copies should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

American Welding Society

Standard Qualification Procedure

(Application for copies should be addressed to the American Welding Society, United Engineering Center, 345 East 47th Street, New York, New York 10017.)

American Society of Mechanical Engineers

Welding Qualifications of the ASME

(Application for copies should be addressed to the Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, New York 10017.)

National Bureau of Standards

Handbook H-28 Screw-Thread Standards for Federal Services

(Application for copies should be addressed to the Superintendent of Documents, Government Printing Office, Washington, D. C.)

SECTION 3. REQUIREMENTS

3.1 Description. Each blast closure valve shall include a housing with overall approximate dimensions as follows: 10 inches wide by 33 inches long by 12 inches high. The detail parts for each valve shall include a housing, a blast valve flap, a flap-restraining grid, a cover plate, two (2) insert hubs, a spacer, two (2) valve-flap shafts, two (2) torsion springs, a keeper, two (2) shaft covers, and gaskets. Each housing and the required detail parts shall be fabricated complete. The detail parts and housing shall be assembled with the required screws to make a complete and usable blast closure valve all as specified herein and shown on Drawings Y & D 993667 and Y & D 993668. Drawing Y & D 993666 shows the intended use of the valve in a typical installation.

3.2 Material. Material shall be as specified herein and as shown on the applicable drawings and parts lists. All material shall be new and unused. Material shall be of uniform quality and first-class condition, sound, free from seams, cracks, or other defects which might adversely affect the appearance, strength, endurance, or wear resistance of the finished parts and assemblies. Material not definitely specified shall be of standard commercial quality suitable for the intended use. Commercial materials are defined as materials which are in accordance with the National Society or Association Specifications. The material to be furnished under this specification shall be subject to inspection and tests in the mill, shop, and field by Government inspectors. Inspections in the mill or shop shall not relieve the supplier of his responsibility to furnish satisfactory materials. The Government reserves the right to reject any material at any time before final acceptance of the work, when, in the opinion of the Government inspector, the materials do not conform to the specification requirements.

3.3 Construction. The blast closure valves shall have the dimensions, characteristics, and construction details specified herein and shown on Drawings Y & D 993667 through Y & D 993668 and the associated parts lists. The torsion springs shall be installed as specified on the drawings to operate the blast valve flap in the manner intended. The springs act against one another and therefore require the application of some torque during installation.

3.4 Housing. The housing shall be fabricated using high-strength low-alloy structural steel conforming to ASTM A242. The housing shall be fabricated according to Drawing Y & D 993668 and shall conform to all tolerances and finishes specified. The lower surface of the top plate shall be flat and clean — free from burrs and flashing as specified on the drawing.

3.5 Blast valve flap. The valve flap shall be fabricated using 6061 aluminum conforming to Specification QQ-A-250/11c. The flap shall be fabricated according to Drawing Y & D 993668 and shall conform to all tolerances and finishes specified. The flap shall be welded by inert-gas-shielded metal-arc welding with 4043 aluminum, consumable electrodes. Strict cleanliness shall be observed in preparing joints. The axial length of the flap during welding shall be sufficiently larger than the finished dimension to permit the weld to be started and stopped in an area to be later machined away so that the finished flap does not contain any blemishes, cracks, voids, or other imperfections. The flap shall be heat-treated after welding and prior to machining to final dimensions. Heat treatment shall be full annealing and tempering to a T6 condition conforming to Specification MIL-H-6088A. The flap shall be given an anodized finish.

3.6 Flap-restraining grid. The flap-restraining grid shall be fabricated using high-strength steel conforming to ASTM A242. The grid shall be fabricated according to Drawing Y & D 993668 and shall conform to all tolerances and finishes specified. The lower surfaces of the top plate and the grid shall be kept flat and flush and free from weld material and flashing.

3.7 Cover plate. The cover plate shall be fabricated using high-strength low-alloy structural steel conforming to ASTM A242. The cover plate shall be fabricated according to Drawing Y & D 993668 and shall conform to all tolerances and finishes specified.

3.8 Insert hubs. The insert hubs shall be fabricated from C1144 steel conforming to Specification QQ-S-633a. The hubs shall be fabricated according to Drawing Y & D 993667 and shall conform to all tolerances and finishes specified. Plating shall be cadmium conforming to Specification QQ-P-416a Class 1, Type I. The word "TOP" shall be steel stamped as indicated on the drawing.

3.9 Spacer. The spacer shall be fabricated from C1018C.F. steel rod conforming to Specification QQ-S-633a. The spacer shall be fabricated according to Drawing 993667 and shall conform to all tolerances and finishes specified. Plating shall be cadmium conforming to Specification QQ-P-416a Class 1, Type I.

3.10 Valve-flap shafts. The valve-flap shafts shall be fabricated from E4130 steel conforming to MIL-S-6758A, Condition D4. The shafts shall be fabricated according to Drawing Y & D 993667 and shall conform to all tolerances and finishes specified. Plating shall be cadmium conforming to Specification QQ-P-416a, Class 1, Type I.

3.11 Torsion springs. The torsion springs shall be fabricated according to Drawing Y & D 993667 and shall conform to all tolerances and finishes specified. Plating shall be cadmium conforming to Specification QQ-P-416a, Class 1, Type I.

3.12 Keeper. The keeper shall be fabricated from E4130 steel conforming to MIL-S-6758A. Fabrication shall be according to Drawing Y & D 993667 and shall conform to all tolerances and finishes specified. The hole for the set screw shall not be drilled in the keeper until after the valve has been temporarily assembled, the flap located in the center of its swing, and the location of the hole marked by tightening the set screw. The valve will then be disassembled, the 3/8-inch access hole in the top of the housing plugged, and the shallow hole for the set screw drilled in the keeper. Plating shall be cadmium conforming to Specification QQ-P-416a, Class 1, Type I.

3.13 Shaft cover. The shaft cover shall be fabricated from AISI C1010 Condition 4 steel. Fabrication shall be according to Drawing Y & D 993667 and shall conform to all tolerances and finishes specified. Plating shall be cadmium conforming to Specification QQ-P-416a, Class 1, Type I.

3.14 Gaskets. The gaskets shall be fabricated from sheet gasket stock conforming to MIL-C-6183A. The gaskets shall be fabricated on assembly and installed under the insert hubs, the shaft covers, and the cover plate as shown on the Drawing Y & D 993667.

3.15 Fasteners. Capscrews and setscrews shall be of the dimension, length of threads, finish, and quality indicated on the applicable drawings and the associated parts lists. The capscrews shall conform to Standard MS-90725, and the setscrews shall conform to AN565 as specified on Drawing Y & D 993667.

3.16 Dimensions. The following tolerances shall be conformed to unless specified otherwise on the drawings:

3.16.1 Fractional tolerances. Fractional tolerances shall be 1/64 inch.

3.16.2 Angular tolerances. Angular tolerances shall be as specified on drawings.

3.16.3 Three place decimals. Three place decimals shall be 0.001 inch.

3.17 Painting. All interior and exterior surfaces of the blast valve housing, flap-restraining grid, and cover plate (except threaded surfaces and surfaces of the 1.253-inch-diameter bored holes in the housing) shall be cleaned, treated, and painted with one coat (0.003 inch thick) of zinc conforming to MIL-P-23236, Type I, Class 3. The 8-inch-diameter port containing the flap-restraining grid shall be stenciled "SHELTER PORT" and the other 8-inch-diameter port in the top shall be stenciled "OUTSIDE PORT" in accordance with Drawing Y & D 993667.

3.18 Finish. All sharp edges shall be broken and all burrs removed. The minimum finish for all machined parts shall be 63. Other finish requirements shall be as specified on the drawings.

3.19 Identification marking. A brass nameplate containing the following information shall be permanently affixed to the closed end of the blast closure valve: Blast Closure Valve, Navy Y & D Drawing No. 993667 & 8, Rated Design Pressure 150 psi, Rated Air Flow 700 cfm at 1 inch, Contract No., and Serial No.

3.20 Workmanship. The quality of workmanship shall meet the standards prevalent among manufacturers who normally produce parts similar to the type specified herein. The valve shall be free from contamination and damage such as dents, cracks or deformations which would impair its use.

3.20.1 Metal fabrication. Metal used in the fabrication of the valves shall be free from kinks and sharp bends. The straightening of material shall be done by methods that will not cause injury to the metal. Flame cutting, using a tip suitable for the thickness of metal, may be employed instead of shearing or sawing. Precautions shall be taken to avoid overheating, and heated metal shall be allowed to cool slowly.

3.20.2 Screwed connections. Screw holes shall be accurately drilled and shall have the burrs removed. All screws shall be tight. Threads shall conform to the National Bureau of Standards Handbook H-28.

3.20.3 Welding. The surface of parts to be welded shall be free from rust, scale, paint, grease, or other foreign matter. Spot, tack, or intermittent welds for strength will not be permitted. Weld penetration shall be such as to provide transfer of maximum design stress through the base metal juncture. Steel welds shall be made using reverse-polarity with A233 or E60 electrodes. Aluminum welds shall be made using inert-gas-shielded metal-arc welding with 4043 consumable electrodes. All welding shall be done by welders who have passed the qualification tests as prescribed by any of the following codes for the type of welding operation to be performed:

Standard Qualification Procedure of the American Welding Society

Welding Qualification of the American Society of Mechanical Engineers

3.20.4 Machine work. Quality of machine work shall meet or exceed the highest standard of the manufacturing industry. Where machined surfaces are required, adequate thicknesses of stock shall be used so that final thicknesses shall be as shown on the drawings, without holidays. Machining shall be performed to the sizes and dimensions shown on the drawings, making due allowances for heat treating, hardening, finish grinding, and plating or coating based on shop experience and judgment.

SECTION 4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility of inspection. The supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Inspection procedure. Each of the blast closure valves shall be examined on the supplier's premises for the following defects:

- 101 Dimensions not as specified
- 102 Assembly not complete or incorrect
- 103 Detail parts missing
- 104 Material not as specified
- 105 Treatment and painting not as specified

4.3 Reinspection. If a rejection occurs, the blast closure valves shall be reworked to have parts replaced to correct defects. Before reinspection, full particulars concerning reinspection of the blast closure valves and the action taken to correct defects shall be furnished.

SECTION 5. PREPARATION FOR DELIVERY

5.1 Packing. The blast closure valve shall be packed in a manner that will insure arrival at destination in satisfactory condition and be acceptable to the carrier at the lowest cost.

5.2 Marking. In addition to any special marking required by the contract or purchase order, the shipping container shall be marked "Blast Closure Valve, Y & D Dwg. No. 993667 & 8" and shall show the shipping address, contract or purchase number, gross weight and cubic feet. All markings shall be clear, nonfading, and durable.

SECTION 6. RIGHTS

6.1 Right of inspection. The Government shall have the right at any time to visit the premises of the supplier to inspect the work in progress.

6.2 Patent. The design and application of the blast closure valves is covered by U. S. Patent No. 3,111,078.

Appendix C

INSTALLATION

A blast-actuated closure device is only part of a ventilation system. Such a system contains a minimum of two blast closure valves, some filters, and an air blower. Larger shelters will also require an air-distribution system, and blast-actuated closure devices will usually require some type of plenum. Blast closure devices are usually placed outside the shelter to conserve space. The filtering system normally consists of a prefilter, an "absolute" particulate filter, and a gas filter.² The filtering system is connected in some manner to the air-intake duct and must be protected from significant overpressures as discussed in the main body of this report. A blower forces the air through the system and pressurizes the sheltered area. A typical installation is shown in Figure A-1.

When installing the blast closure valve, it is important that the proper ports be connected to the outside air and to the shelter. One of the ports has two bars welded in it to provide support for the flap when closed. This port is marked "shelter" and is to be welded to a pipe leading to the inside of the shelter. The other port is marked "outside" and is to be welded to a pipe leading to the outside.

After being welded to the 8-inch pipe, the valve and welds should be painted with a coal tar compound conforming to MIL-C-18480A (coating compound, Bituminous, Solvent, Coal Tar Base) using the procedures given in NAVDOCKS Specification 34Yd (Bituminous Coating Systems for Steel Surfaces).

The prefilter is the weakest part of the ventilation system. The filtering medium is fiberglass. It is held between two perforated thin metal grilles and supported by a cardboard frame. Two such filters are shown in Figure C-1. The prefilter on the right (20x20x2 Fram/Glass Air Filter G7, Fram Aire Co., Div. Fram Corp., Henderson, N. C.) has its fiberglass and its metal grilles continuously secured to its holding frame for maximum structural integrity. This prefilter can be used with the Breckenridge blast valve without any additional support if the system is installed as shown in Figure A-1. The prefilter on the left (Figure C-1) is secured to its holding frame with only a few staples and perhaps an occasional dab of glue. It is strong enough for its intended purpose (i.e., normal commercial applications), but will be damaged by pressure waves larger than about 0.65 psi as indicated in Figure 19. It is therefore recommended that if prefilters of this latter type are used they be provided with some type of reinforcement or support. This is easy to do and is recommended even for installations designed for relatively low overpressures. For shelters designed for peak overpressures greater than 80 psi, the prefilters of this latter type must be reinforced or supported. They can be reinforced with fiberglass tape as shown in Figure C-1, or support can be provided by wires secured to the wooden frame of the collective protector. New models of collective protectors will probably incorporate a 1/2-inch-mesh wire cloth to back up the prefilter.³

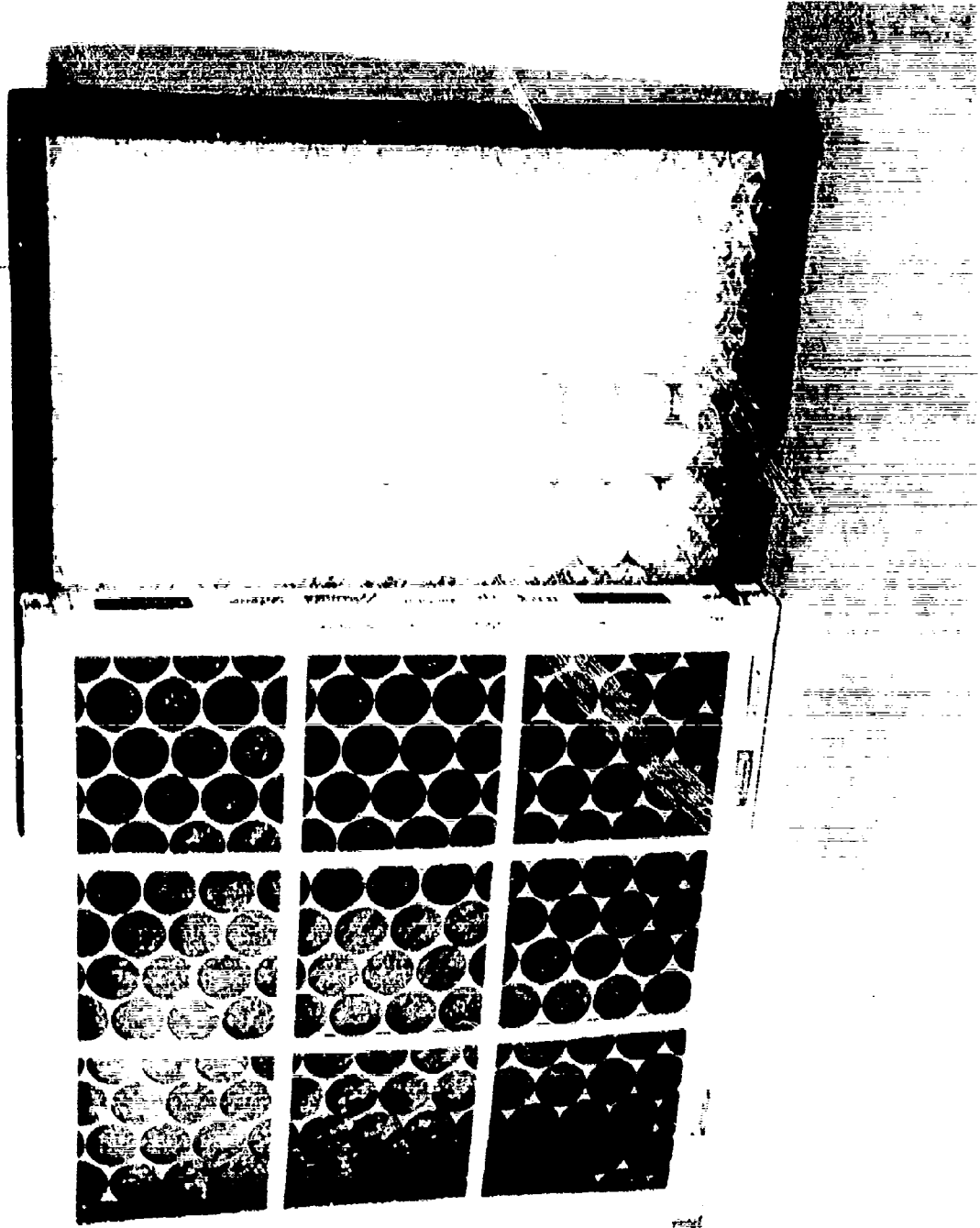


Figure C-1. Two types of prefilters.

The blower provided with the M9A1 Gas-Particulate Filter Unit will be unable to supply 600 cfm of air to most installations. This blower can produce a static pressure of only 4.5 inches H₂O at 600 cfm.³ The pressure drop through a typical installation might be as follows:

<u>Inches H₂O</u>	<u>Item Causing Loss</u>	
0.80	Intake pipes and entrance losses (estimate)	
0.70	Blast closure valve in intake	
?	Plenum	
0.75	Damper	} M9A1 Collective Protector
1.05	Clean particulate filter	
0.95	Clean gas filter	
0.40	Miscellaneous	
?	Dirt on filters	
?	Distribution system	
0.70	Blast closure valve in exhaust	
<u>0.85</u>	Exhaust pipes and entrance losses (estimate)	
6.20 + ? + ? + ?	Total inches H ₂ O pressure drop	

During installation, provisions should be made to close the ventilation system during fire storms by closing dampers, securing blind flanges, or other simple devices within the shelter.

Appendix D

POTENTIAL MODIFICATIONS

There are two potential modifications discussed in this appendix: (1) the shortening of the pipe loop responsible for the time delay while the flap is closing, and (2) the possibility of increasing the airflow capacity of the present valve.

Six tests were performed with shorter pipe loops. The test results shown in the main body of this report are for a loop length of 21.8 feet. The drawings of Appendix A show a loop length of 21.1 feet. Four tests were performed with loop lengths of 17.1 feet and two with loop lengths of 10.8 feet. These tests were performed with the same setup as shown in Figure 10.

The applied overpressures and the resulting bypassing pressures are given in the following table:

Peak Positive Bypassing Pressure

Peak Applied Overpressure (psi)	Loop Length (ft)	2 Ft 10 In. Downstream (psi)	15 Ft 3 In. Downstream (psi)	On Prefilter (psi)
91.0	17.1	10.1	1.75	0.37
95.9	10.8	1.5	0.55	0.10
16.8	10.8	7.3	6.10	0.45
17.4	17.1	5.5	5.25	0.28
6.2	17.1	4.3	3.20	0.25
6.8	17.1	4.6	3.25	0.30

These results can be compared with those plotted in Figures 16 and 19. Such a comparison shows that for the shortest length loop, 10.8 feet, the peak bypassing pressures were reduced by about 80% at 95.9 psi peak overpressure, but were increased by about 50% at 16.8 psi. This latter test caused some damage to the plenum side of a weaker prefilter which was not reinforced or supported on that side.

A similar comparison shows that for the medium length loop, 17.1 feet, the peak bypassing pressures were reduced by about 50% for 91.0 psi peak applied overpressure, and were generally just slightly higher at lower overpressures. The prefilters were the weaker type and were not reinforced or supported on the plenum side. They were slightly damaged on the plenum side by the 6-psi tests.

The time required for the 110-degree flap to close and for the blast wave to reach the closure port is shown in the following table:

<u>Peak Applied Overpressure (psi)</u>	<u>Loop Length (ft)</u>	<u>Initial Closure (msec)</u>	<u>Duration Closed (msec)</u>	<u>Duration of Rebound (msec)</u>	<u>Final Closure (msec)</u>	<u>Blast Wave Arrival (msec)</u>
91.0	17.1	5.9	1.3	6.2	13.4	9.6
95.9	10.8	4.6	3.6	3.0	11.2	6.3
16.8	10.8	15.0	2.0	4.1	21.1	8.1
17.4	17.1	16.4	1.5	4.5	22.4	12.7
6.2	17.1	28.3	3.5	5.2	37.0	14.2
6.8	17.1	27.9	2.3	6.2	36.4	14.1

A comparison of these data with those plotted in Figure 12 for the 21.8-foot loop shows that, as expected, the blast wave arrived sooner at the closure port through the shorter pipe loops. It also shows that the time required for initial closure of the flap was unchanged. For overpressures greater than about 7 psi, however, the flap did not rebound as long, and the complete closure of the flap was sooner.

The important consideration in the above data is the length of time during which the pressure can bypass the open flap. This is shown in the following table:

<u>93 psi Approximate Peak Overpressure</u>	<u>17 psi Approximate Peak Overpressure</u>	<u>6 psi Approximate Peak Overpressure</u>
<u>10.8-ft loop, 3.0 msec</u>	10.8-ft loop, 11.0 msec	—
17.1-ft loop, 3.8 msec	<u>17.1-ft loop, 8.2 msec</u>	17.1-ft loop, 16.8 msec
21.8-ft loop, 4.5 msec	21.8-ft loop, 10.0 msec	<u>21.8-ft loop, 15.9 msec</u>

The shortest time during which the pressure could bypass the valve, and therefore the best loop length, has been indicated for each peak overpressure. It can be seen that the longer loops are best for small peak overpressures and that shorter loops are best for higher overpressures. The flap has not yet initially closed at the lower overpressures and is in the rebound phase at the higher overpressures. Apparently, the arrival of the blast wave at the closure port during the rebound phase helps to inhibit the rebound.

The above tables and discussion indicate that if the stronger type prefilter were used or if the weaker type were reinforced or supported on both sides so that the low applied peak overpressures would not damage it, then it would probably be possible to reduce the loop length and thereby reduce the maximum pressure bypassing the valve at higher applied peak overpressures. The capability of the valve to perform under these conditions has not been tested at applied peak overpressures greater than 96 psi.

The other potential modification to be discussed in this appendix is the increasing of the airflow capacity of the valve. It is unlikely that the present valve could be merely scaled up or the dimensions merely increased to increase the airflow capacity. This is because of inertial problems with the flap. If the length of the flap arm were increased, the inertia of the flap would go up rapidly; therefore, the time the flap took to close and the magnitude and duration of the bypassing wave would rapidly increase. This would be particularly true at low overpressures. A possible solution to this problem would be to make the flap and the ports rectangular for any larger capacity valve. This would allow the arm of the flap to be kept to a reasonable length. The axial distance could probably be increased as necessary.

REFERENCES

1. U. S. Naval Civil Engineering Laboratory. Technical Note N-460: Preliminary development and tests of a blast-closure valve, by R. A. Breckenridge. Port Hueneme, Calif., Sept. 1962.
2. U. S. Navy. Bureau of Yards and Docks. NAVDOCKS P-92: Operation and maintenance manual: Gas-particulate filter units M9A1 and M10A1. Washington, D. C., May 1962.
3. U. S. Naval Civil Engineering Laboratory. Technical Note N-783: Collective protector design and development, interim report, by N. P. Oldson and R. J. Zablodil. Port Hueneme, Calif., Nov. 1965.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Blast shelters Ventilation Closure valve Blast-actuated Overpressures Bypassing impulses Negative impulse Attenuation Mitigation						

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