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WASHINGTON, D.C.

PERFORMANCE OF CONCUSSION VALVES IN VENTILATION DUCTS

by

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~~RESTRICTED~~

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~~U.S. Navy Regulations, 1920, Art. 76(11).~~

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ABSTRACT

This report gives the results of gun-blast tests made to determine the effectiveness of concussion valves in ventilation ducts. A simplified theory of the action of a shock wave at the corner of a ventilation duct is given and correlated with the data, and it is shown that no valve can offer more than limited relief from a shock wave traveling down the duct. The responses of the test valves to the test pressures are shown in time-displacement curves. These curves indicate that the action of the test valves was slow and ineffective in preventing damage to the duct.

INTRODUCTION

The idea of a concussion valve to eliminate the damage sustained by ship ventilation ducts when subjected to the blast of nearby guns was proposed to the Navy Beneficial Suggestion Committee. On the basis of this suggestion several of the valves were built, installed in ducts, and tested under service conditions (1).* The reports of their performance were for the most part favorable (1) (2), but in order to obtain a detailed analysis of their performance characteristics a controlled test was arranged (3). This test was made at the Naval Proving Ground, Dahlgren, Virginia, and included measurements of the blast-pressure load at the valves, as well as the displacement of the valves under the load.

TEST SETUP

A drawing of the concussion valve is shown in Figure 1. Not shown are the specially designed scratch gages which were mounted on the valves and used as a means of recording the displacement of the valve piston relative to the valve case under the blast loading encountered on these tests. Three scratch gages were mounted on each valve at equidistant points around the periphery. This was considered necessary both to distribute symmetrically the friction load applied by the gages and to indicate the maximum displacement of the piston as a plane.

Preparatory to testing, two valves, with scratch gages attached, were mounted in a simulated ventilation duct; see Figure 2. It will be noted that part of the duct is enclosed in a box-like steel structure, which represented a ship compartment in so far as behavior of the duct under blast was concerned. The end of the duct which was inside this compartment was closed by a cover plate. The valve locations in the duct were those which had been suggested originally with submittal of the idea for the valve. Access to these locations was obtained through openings in both ends of the enclosing structure. During firing these openings were sealed with bolted cover plates.

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* Numbers in parentheses indicate references on page 15 of this report.

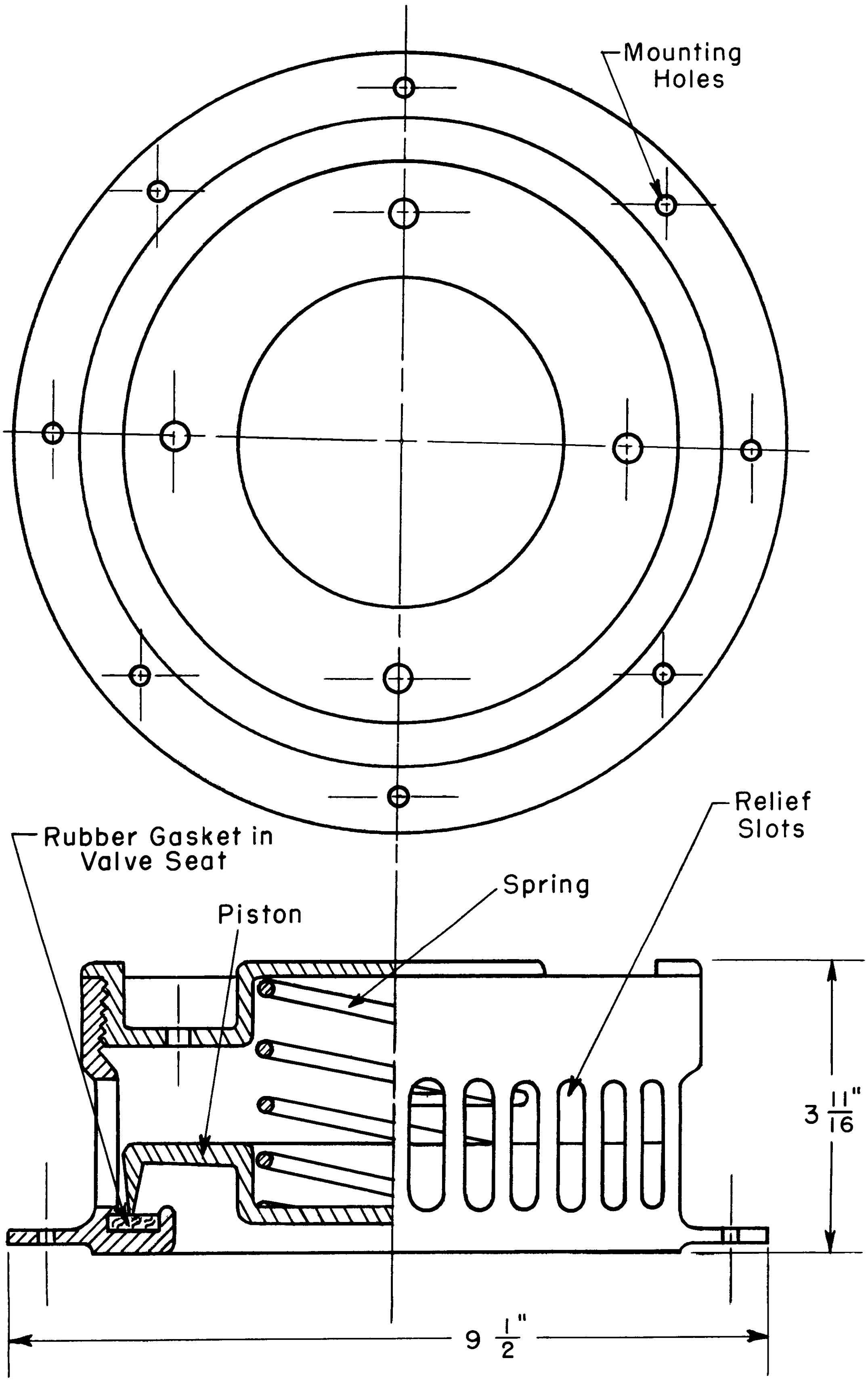

Figure 1 - Simplified Drawing of Concussion Valve Showing Overall Dimensions and Parts

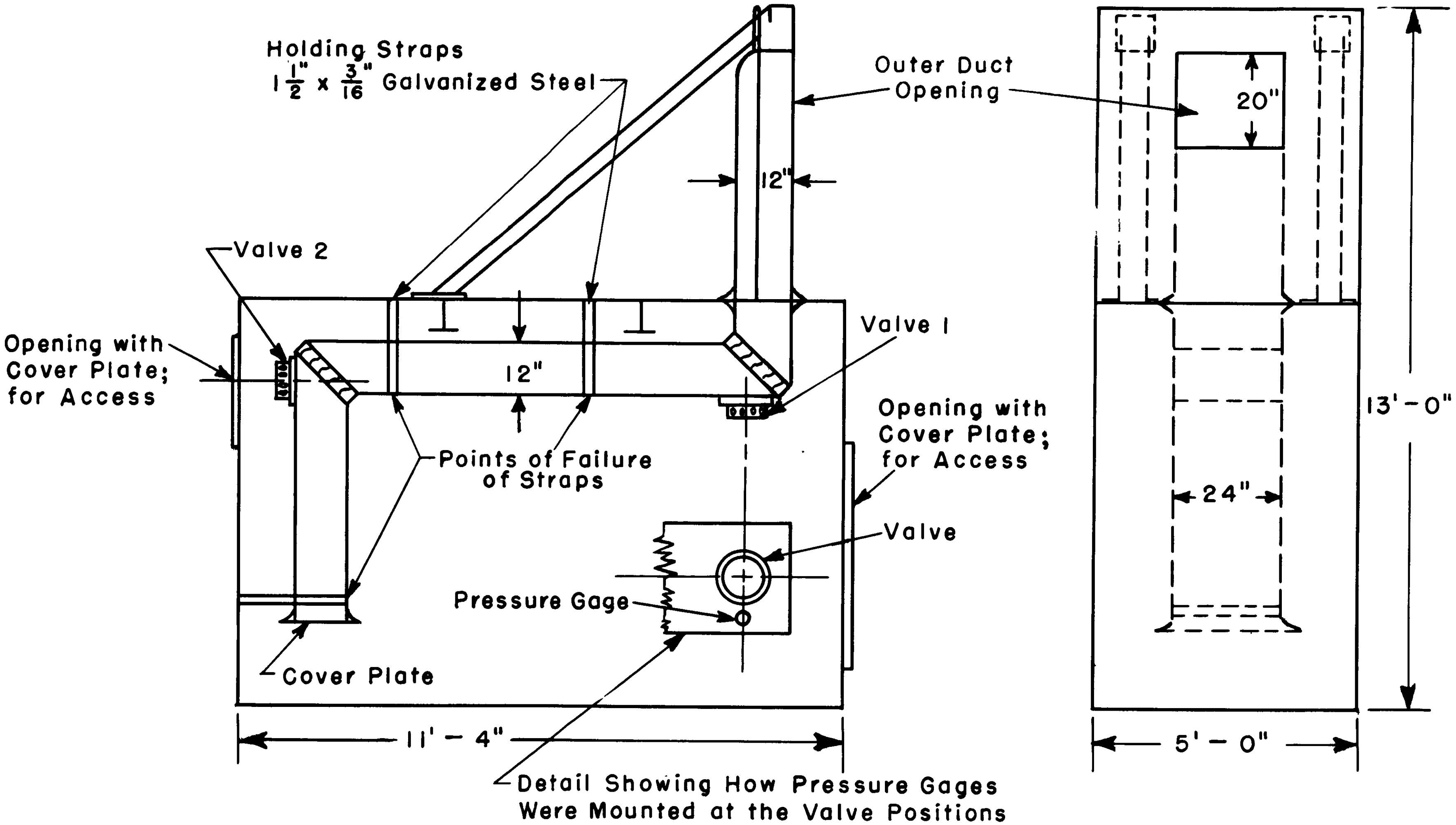

Figure 2 - Simplified Drawing of Simulated Duct

Two TMB diaphragm blast gages (4) were mounted at the valve positions as shown in Figure 2 and recordings of the pressure at each of these two positions were made by connecting the gage to a circuit which included a ballast box, a filter-amplifier, and a Du Mont Type 208 cathode-ray oscilloscope. Time bases were obtained with an electronic sweep generator, and Ektra cameras were mounted on the oscilloscopes for photographing the records.

Three 6-inch guns, mounted as in a turret and firing service charges, were used to produce the shock waves for the test. The position of the guns with respect to the test structure is shown in Figure 3.

TEST PROCEDURE

The original plan for the test had called for three salvos for each of three sets of test conditions, making a total of nine salvos. On the first three salvos the Number 1 concussion valve was to be equipped with a spring designed to permit a 2-inch displacement of the piston at a total static load of 55 pounds on the piston, and the Number 2 valve was to be equipped with a 100-pound spring rated in the same manner.* On the next three salvos both valves were to be equipped with 100-pound springs, and on the final three salvos both valves were to be removed and replaced with cover plates.

The results obtained on the first salvo, however, caused a change of plan and only one more salvo was deemed necessary to complete the test. For this second salvo both concussion valves were replaced by the cover plates.

TEST RESULTS

After the first salvo had been fired, the concussion valves were examined and it was found from the scratch gage records that both valves had reached the maximum possible displacement at all scratch gage positions. This displacement was limited to 1 3/16 inch by the arms of the scratch gages. The ventilation duct had expanded cross-sectionally in the horizontal and short vertical sections inside the compartment, but no other damage was apparent. Only one pressure record was obtained on this salvo, that from the gage at Valve 2. The electrical leads on the gage at Valve 1 were torn off by the high acceleration produced by the ground shock before the pressure was recorded. The record obtained at Valve 2 is shown in Figure 4.

It was thought inadvisable to fire more salvos with the first set of test conditions because of the expansion of the duct. Succeeding salvos would have increased the damage and made it more difficult to obtain comparative damage results with another set of test conditions. Also, since both valves had opened to their maximum displacement on this salvo, it was deemed unnecessary to interchange the valve springs for additional salvos as had

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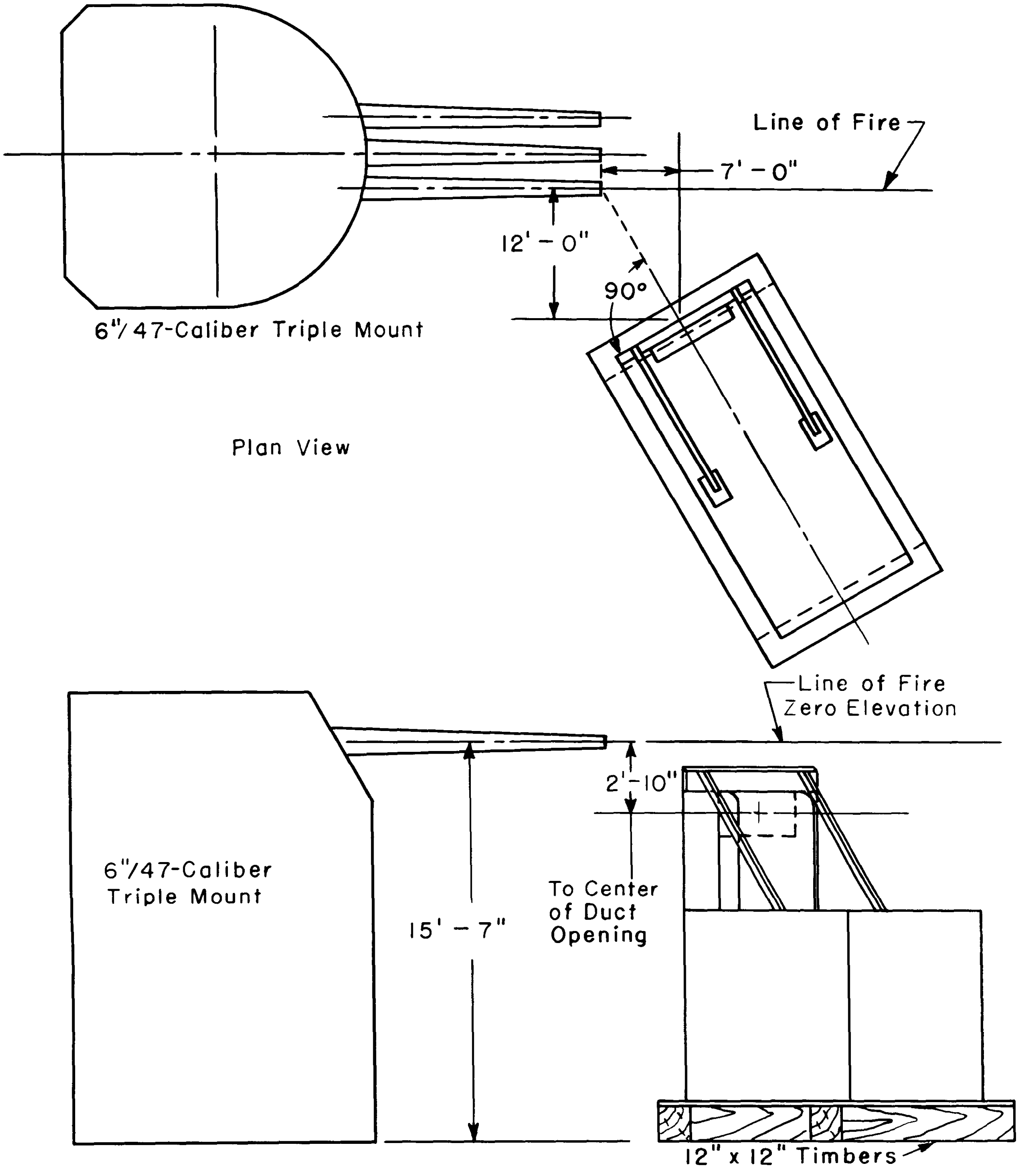
* These design ratings did not agree exactly with the results obtained from a static calibration which gave 47 pounds and 96 pounds, respectively.



Plan View

Elevation View

Figure 3 – Location of Gun Mount with Respect to Simulated Duct

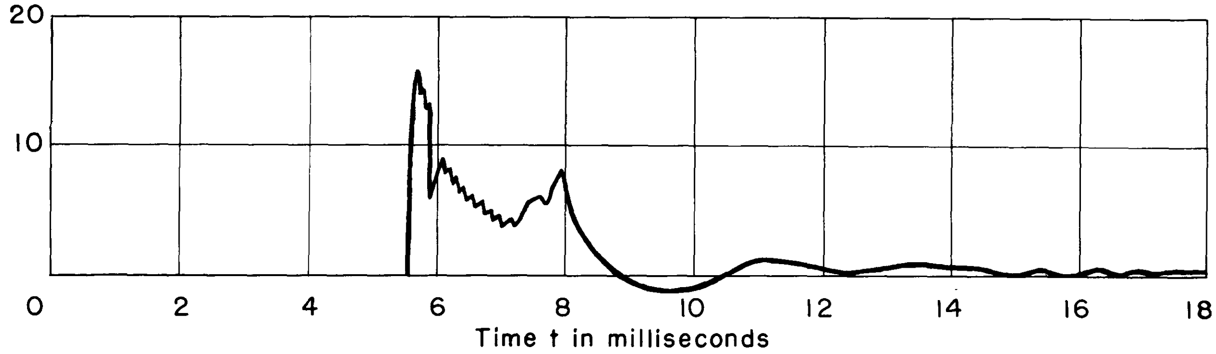


Figure 4a - Curve 1, Pressure at Valve 2 on First Salvo, with Both Valves Present

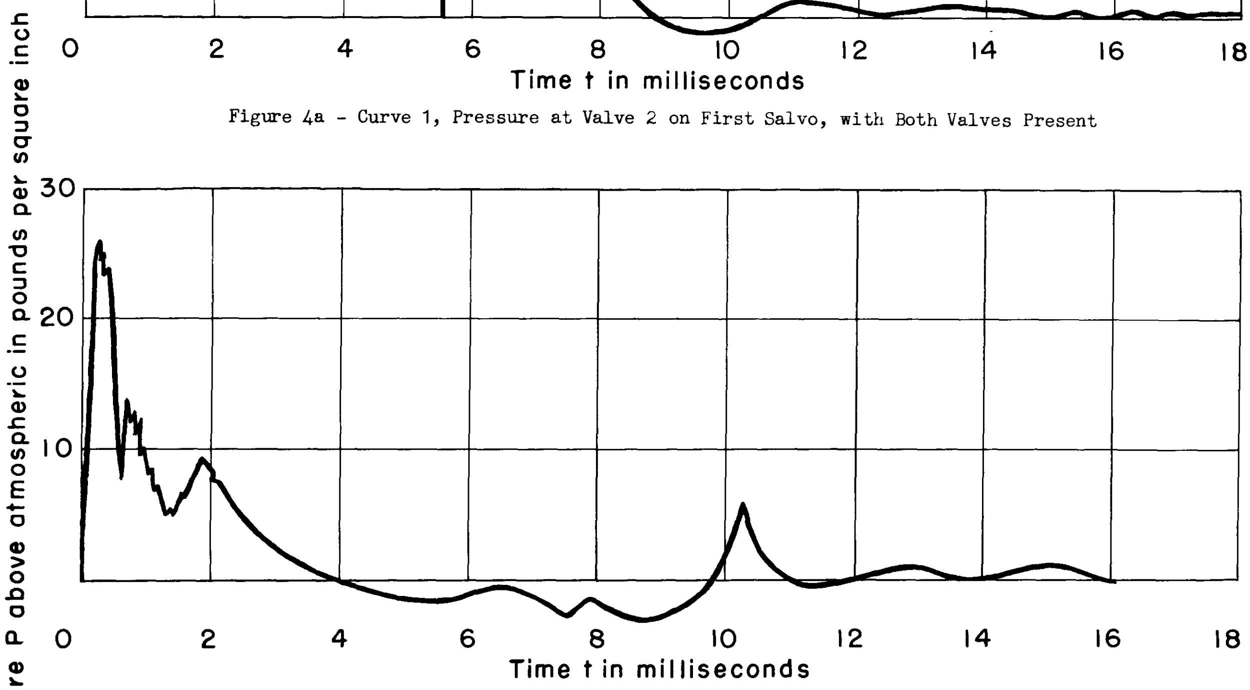


Figure 4b - Curve 2, Pressure at Valve 1 on Second Salvo, with Both Valves Removed

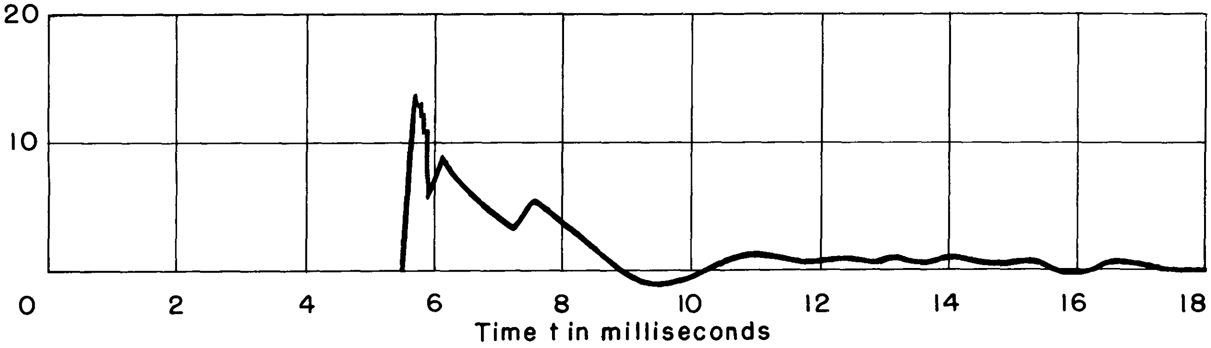


Figure 4c - Curve 3, Pressure at Valve 2 on Second Salvo, with Both Valves Removed

Figure 4 - Pressure-Time Relations at Valve Positions

originally been planned. Therefore, at this time, the valves were removed and replaced with the cover plates. After a salvo had been fired, the duct was again examined. It was found that the damage had been increased; all the steel straps which held the inside sections of the duct to the compartment had been broken. The locations and dimensions of these straps and the points of failure are given in Figure 2. The pressure records obtained from the gages at both cover plates are given in Figure 4.

DISCUSSION

The data taken on this test are sufficient to describe the action of the valves under the blast-pressure loads encountered, but are not sufficient to describe accurately the action of the shock wave in the duct. A detailed analysis of this phase of the problem would require actual photographs of the shock wave taken at numerous positions along the duct at frequent time intervals.

It is possible, however, to set up a simplified theory of the action of the shock wave which agrees reasonably well with the data obtained from the pressure gages if some probable complications are disregarded. Such complications would include possible multiple reflection effects, Mach wave formation (5), and the pressure changes which occur when the angles of incidence and reflection of a shock wave are not normal to the reflecting surfaces.

In the simplified theory it will be assumed that the shock wave from the guns is normally incident at the top of the duct. This assumption will simplify the discussion without invalidating any of the conclusions. The wave will then travel vertically down the duct with a horizontal wave front characterized by an abrupt change in pressure, high particle velocity, and a speed of propagation exceeding the velocity of sound according to well-established laws (6) (7). When the wave reaches and crosses the opening to the horizontal section of the duct, as portrayed in Figure 5, diffraction will occur because of the excess pressure in the wave, and a new front will be formed which will travel at right angles to the original wave. A small fraction of a second later the descending wave will strike the duct at Valve 1 and be reflected. The degree to which it is reflected will depend on the efficiency of the valve, but it is to be noted that no matter how efficient the valve is, the peak pressure of the diffracted wave already set up and traveling down the horizontal section of the duct will not be affected.

The pressure gages near the relief valves will measure the pressures actually existing at these points. These pressures, however, are greater than the pressures in the shock waves because they have been enhanced by the effect of reflection and may be two or more times as large. The pressures acting to expand the duct cross-sectionally will therefore be only about one-half the values of the pressures measured by the gages (6).

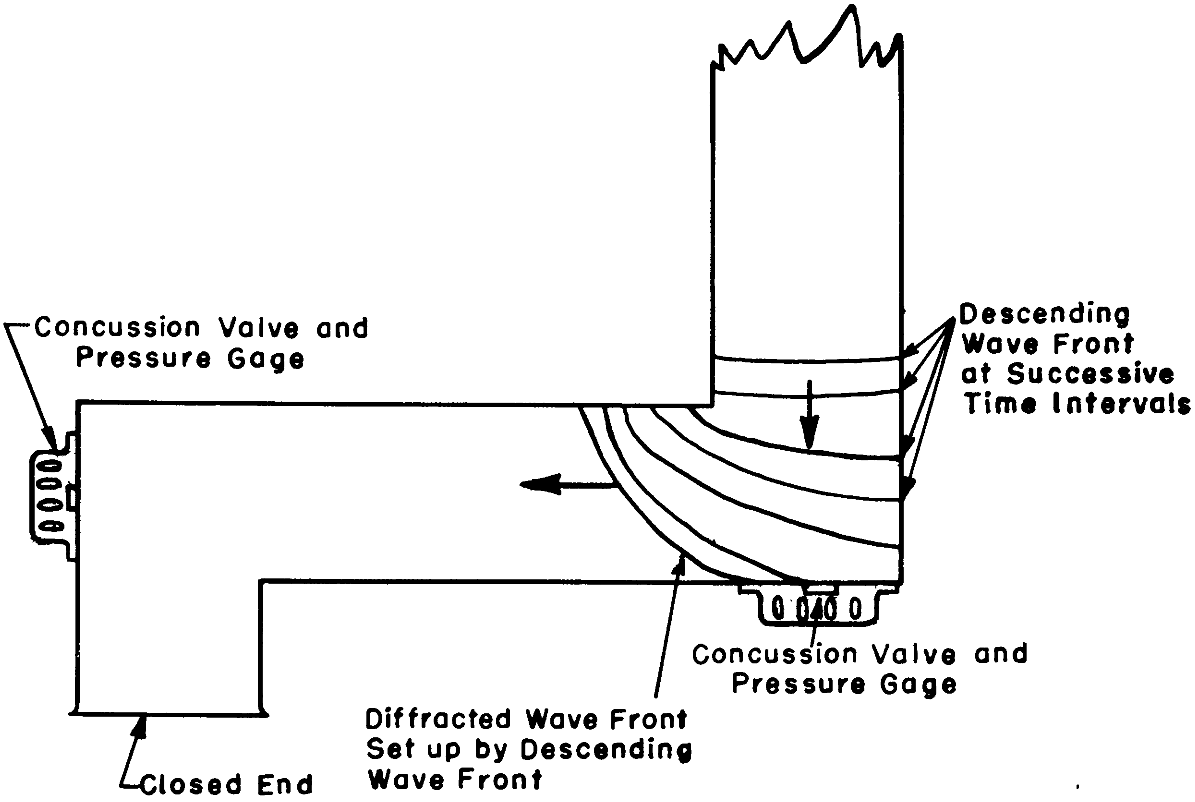


Figure 5 – Simplified Diagram of Ventilation Duct, with Deflection Vanes Omitted, Showing How Shock Wave in Horizontal Section of Duct Could Be Set Up

If the pressure records of Figure 4 are examined in the light of this theory, it will be noted, first, that the record taken at Valve 2 when the valves were present and were known to have opened (Curve 1) is almost identical in both amplitude (16 and 14 pounds per square inch, respectively) and shape to the record taken at the same position when the valves were absent (Curve 3). This tends to bear out the hypothesis that a diffracted wave is formed in the horizontal section of duct which is not affected by the action of Valve 1. The similarity of the pressure-time contours for the wave at Gage 1 (as shown in Curve 2) and those at Gage 2 (as shown in Curves 1 and 3), except for the differences in pressure magnitudes, should also be noted.

One other rough check of the theory can be made from the time of travel of the wave. Reference (6) shows that a shock wave of the amplitude indicated would take 5.9 milliseconds to traverse the horizontal section of the duct. The time difference shown experimentally between occurrence of pressures at Valves 1 and 2 is shown by Figure 4~~5~~ to be 5.6 milliseconds.

RESPONSE TIME OF VALVES

The foregoing discussion has shown that the opening of a concussion valve at a corner of a ventilation duct does not prevent a shock wave from being set up in following sections of the duct. It is possible, however, that valves may give some local relief at the corners. A measure of this relief can be found by calculating the response of the piston to the pressure impulse which strikes it. This can be done simply if the spring and piston are considered as a single-degree-of-freedom system with negligible damping; see Figure 6. Some damping, primarily that caused by the scratch gages, was present, but static tests indicated that this was small.

Neglecting damping, the equation for the above system when acted upon by a force p is

$$m \frac{d^2x}{dt^2} + kx = p(t) \qquad [1]$$

where x is the displacement,
m is the mass,
k is the spring constant, and
t is the time.

The initial conditions of the system described are that the system starts from rest at $t(0) = 0$, $x(0) = 0$, and $dx/dt = 0$. Both concussion valves fit these conditions, but it is necessary to add constants to Equation [1] to take into account the spring preload on the pistons, and the effect of the weight of the spring and piston of Valve 1, which is mounted vertically. With constants added for preload and weight, the equation for Valve 1 is

$$m \frac{d^2x}{dt^2} + (kx + A) = p + w \qquad [2]$$

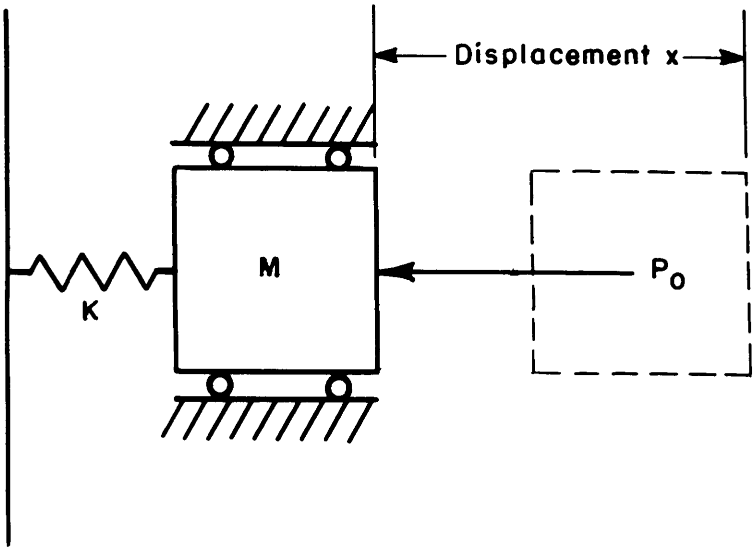


Figure 6 – Single-Degree-of-Freedom System Showing Dynamic Displacement x of the Mass by a Disturbing Force p Whose Peak Value Is P_0

where A is the static preload force on the piston,

- m is the effective mass, equal to the mass of the piston plus one-third the mass of the spring, and
- w is the effective weight, equal to the weight of the piston plus one-half the weight of the spring.

Transposing and dividing by k gives

$$\frac{m}{k}\frac{d^2x}{dt^2} + x = \frac{p + (w - A)}{k}$$

The solution of this equation is given in Reference (8) as

$$x = \sqrt{\frac{k}{m}} \int_0^t \frac{p + (w - A)}{k} \sin\left[\sqrt{\frac{k}{m}}\,(t - \alpha)\right] d\alpha \qquad [3]$$

where p is equal to p_α, where α is the variable of integration. The equation for Valve 2 is

$$\frac{m}{\cancel{k}}\frac{d^2x}{dt^2} + (kx + A) = p \qquad [4]$$

Transposing and dividing by k gives an equation whose solution is

$$x = \sqrt{\frac{k}{m}} \int_0^t \frac{p - A}{k} \sin\left[\sqrt{\frac{k}{m}}\,(t - \alpha)\right] d\alpha \qquad [5]$$

The numerical values of the constants were found experimentally and are

Valve 1	Valve 2
$k = 18$ pounds per inch	$k = 41$ pounds per inch
$m = \frac{0.874}{386}$ pound-second^2 per inch	$m = \frac{0.936}{386}$ pound-second^2 per inch
$w = 0.954$ pounds	$A = 14$ pounds
$A = 10.7$ pounds	

The total force p which acts on the valve at any instant is the unit pressure P* of Figure 4 multiplied by the area of the piston, which is 35.8 square inches. By substituting the numerical constants and performing a numerical integration using the information obtained from the pressure-time curves of Figure 4, the time-displacement relationships of pistons to valve cases are obtained as shown in Figures 7 and 8.

These curves show that neither valve had opened fully before the positive pressure phase was over and that at the end of a millisecond, which is the approximate duration of the first and highest pressure peak recorded, Valves 1 and 2 had opened only 0.12 and 0.7 inch, respectively. Obviously, therefore, no appreciable relief of any kind is furnished by the valves until the first and major pressure peak is past. Pressure relief after the first peak will be greater, but the data are insufficient to indicate exactly how much relief occurs.

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* P is used here as unit pressure to distinguish from the force of Equation [1].

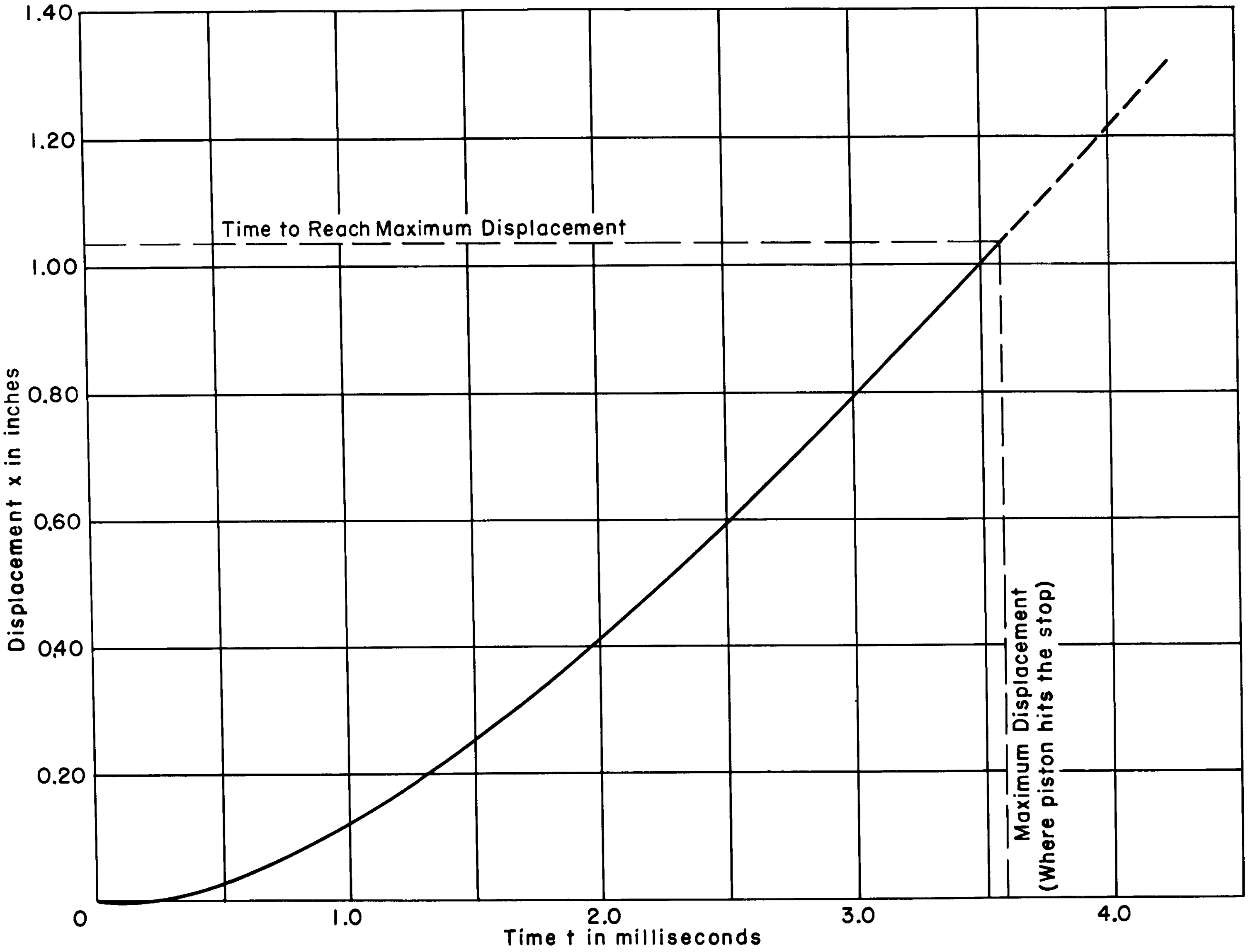

Figure 7 – Displacement of Valve Relative to Case for Valve I When Acted Upon by Pressure Shown in Figure 4, Curve 2

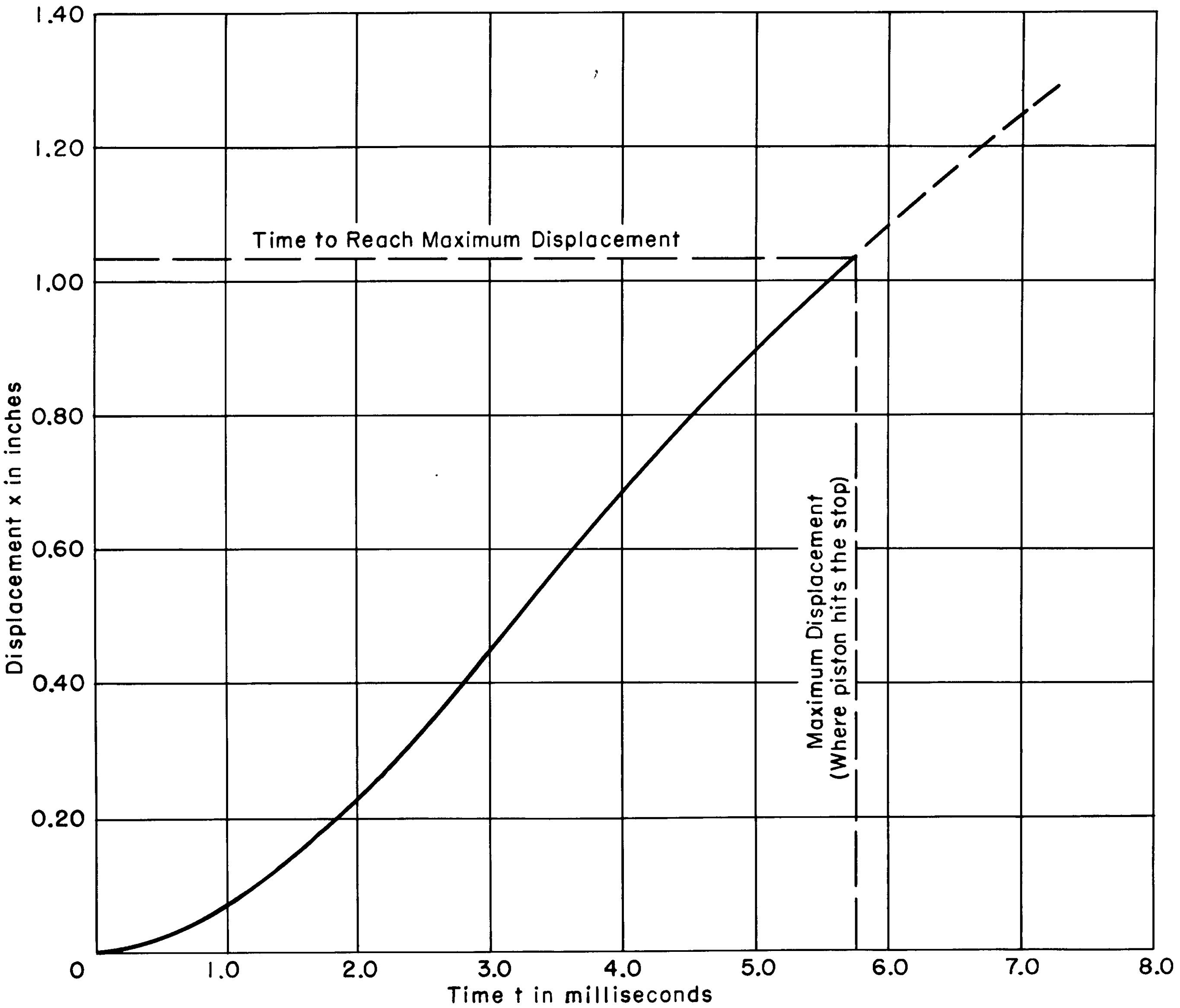

Figure 8 – Displacement of Valve Relative to Case for Valve 2 When Acted Upon by Pressure Shown in Figure 4, Curve I

DISCUSSION OF DAMAGE

The unenclosed vertical section of the duct was not seriously damaged on either salvo, Figure 3, because it was constructed of heavier material than the sections inside the compartment. After the second salvo, however, this section did have a slight inward bulge which was caused by the pressure which acted on the structure from the outside. The breaking, on the second salvo, of the holding straps which both reinforced and supported the section of the duct inside the compartment cannot be attributed to the fact that the valves were absent on this salvo because of the evidence of the pressure records. This damage, therefore, must have resulted from the cumulative weakening action of the two salvos, and not from a larger pressure on the second. This is understandable when it is considered that on the first salvo the duct walls were capable of absorbing considerable energy in their expansion without putting excessive stress on the straps, but on the second salvo, when the duct walls had already received a large permanent set, the strain was put on the straps and they were ruptured in consequence. It is quite possible that on this particular test setup the fracture of the straps was precipitated by the fact that the bends in the straps had too small a radius.

CONCLUSIONS

The foregoing discussion of the nature of a shock wave, its action in a ventilation duct, the damage sustained by the duct, and the action of the concussion valves leads to the following conclusions:

1. The blast or shock wave from a gun does not set up the same pressures in all parts of a duct simultaneously, but applies local pressure at whatever section of the duct the wave is traveling. When a concussion valve opens, therefore, its action is not analagous to that of a safety valve in a pressure tank where the opening of the safety valve relieves the entire tank.

2. Concussion valves at the duct locations of these tests cannot attenuate appreciably the shock waves set up in adjoining sections of the duct no matter how fast their response time.

3. The response times of the valves used on this test were too slow to make the valves very effective in any way.

4. The chief value of a concussion valve probably lies in its action as a shock absorber at the corners of a duct. A valve will absorb some of the energy of a shock wave in its spring and return this energy back to the corner at a much slower rate of application. The value of this type of relief would probably not become apparent until the ventilation duct had been subjected to a large number of salvos and therefore is indeterminate from these tests.

5. The positive pressure phase of the shock wave was responsible for all major damage which occurred on this test. The pressure records show a negative phase existed, but there was no evidence that it caused any damage.

REFERENCES

(1) U.S. Naval Drydocks, Terminal Island, San Pedro, California, letter S38-1, serial 7227 of 26 November 1945 to BuShips, Code 332.

(2) Commanding Officer, USS ST. LOUIS, letter CL49/S38, serial 639 of 28 November 1945 to BuShips.

(3) BuShips letter S38-1-(2) (332) of 15 March 1946 to TMB.

(4) TMB CONFIDENTIAL Report 508, December 1943.

(5) OSRD CONFIDENTIAL Report 6053, September 1945.

(6) CONFIDENTIAL Technical Memorandum 108 of Princeton University Station, Division 2, NDRC, of 27 April 1945.

(7) TMB CONFIDENTIAL Memorandum C-L5-2(163) of 4 July 1945 to Gun Blast Committee.

(8) "Effects of Impact on Simple Elastic Structures," by J.M. Frankland, Ph.D., TMB Report 481, April 1942.

DISCUSSION OF DAMAGE

The unanchored vertical section of the duct was not seriously damaged on either salvo, largely because it was constructed of heavier steel than the sections inside the compartment. After the second salvo, however, this section did have a slight inward bulge which was caused by the pressure which acted on the structure from the outside. The breaking, on the second salvo, of the holding straps which reinforced and supported the section of the duct inside the compartment cannot be attributed to the fact that the valves were absent on this salvo because of the evidence of the pressure records. This damage, therefore, must have resulted from the cumulative weakening action of the two salvos, and not from a larger pressure on the second. This is understandable when it is considered that on the first salvo the duct walls were capable of absorbing considerable energy in their expansion without putting excessive stress on the straps, but on the second salvo, when the duct walls had already received a large permanent set, the stress was put on the straps and they were ruptured in consequence. It is quite possible that on this particular test setup the failure of the straps was precipitated by the fact that the bends in the straps had too small a radius.

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