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THE EXPLOSIVE RELEASE OF
GAS GUN DIAPHRAGMS

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THE EXPLOSIVE RELEASE OF GAS GUN DIAPHRAGMS

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ABSTRACT: An experimental investigation was conducted to determine the feasibility of using explosive materials to open the diaphragm used for the release of the chamber pressure in a 4-inch gas model launcher. A method was developed, using linear-shaped mild detonating fuse for controlled rupture of the stainless steel diaphragm. The diaphragm is ruptured at a predetermined delay time after the gas propellant has reached a given pressure. The tests show that diaphragms can be ruptured at chamber pressures up to 10,500 psi under the ultimate rupture pressure for the diaphragm.

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THE EXPLOSIVE RELEASE OF GAS GUN DIAPHRAGMS

This investigation was undertaken to determine the feasibility of using explosives to reliably open the chamber diaphragm of a 4-inch gas gun under hangfire conditions. This work was performed, under NOL Task 363, as a joint effort between the Ballistics Design and Operations Division of the Ballistics Department and the Explosive Dynamics Division of the Explosions Research Department.

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Captain, USN
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By direction

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REFERENCES

- (1) NOLR 1111: "Ordnance Explosive Train Designers Handbook," NOL Laboratory Staff, April 1952 (Confidential)
- (2) Navord Report 6251: "Piston-Type Strain Gages," V. C. D. Dawson, January 1959 (Unclassified)

INTRODUCTION

This report describes an experimental investigation of a system to explosively rupture metal diaphragms at a predetermined time delay after a given chamber pressure has been reached. The system includes an explosive train, delay unit and triggering circuit, diaphragm assembly, and pressure switch.

In the launching of models at hypersonic speeds for ballistic research, a light-gas gun is used in the NOL Ballistics Ranges. The propellant consists of a mixture of helium, hydrogen, and oxygen. Experience has indicated that detonations or serious over-pressures in the gun chamber after ignition may occur if the gas is released prematurely. This is of major concern in the 4-inch gas gun, which has a considerably larger chamber volume than the smaller gas guns.

One of the means of controlling the release of the high-pressure chamber gas is through the use of explosives to rupture the diaphragms. Of the explosive methods considered, it appeared that an explosive train, using as a basic element, (1) a miniature cone-lined shaped charge or (2) a linear-shaped mild detonating fuse, would provide the necessary penetrating action required to open the metal diaphragms.

Preliminary testing of the miniature lined conical shaped charge indicated that this type of charge was not feasible for this operation. The lined conical shaped charge did not remove sufficient metal from the diaphragm to allow it to open under pressure. The method using the linear-shaped mild detonating fuse was found to be a feasible way of removing metal from the diaphragm while the diaphragm was under pressure. It was found that the 4-inch gas gun diaphragm could be reliably opened by this method at approximately two-thirds of its theoretical burst pressure.

To control the release time of chamber pressure, or burst of the diaphragm, a pressure switch that triggered a time delay unit was developed. The high-pressure switch designed and tested also functioned as a safety device. Operation of the pressure switch and a subsequent time delay, prevents premature firing of the explosive charge (MDF) and insures complete combustion of propellant in the chamber. This switch was found to function reliably at the desired pressures.

The organization of the project was as follows:

a. Explosive Train Investigation. Preliminary testing of the miniature lined conical shaped charge and the linear-shaped mild detonating fuse.

b. Test Equipment. Fabrication of the pressure vessel, the pressure monitoring system, and the firing circuits for the explosive train.

c. Pressure Switch. Design and preliminary testing of the pressure switch.

d. Diaphragm Preparation and Rupture. Prebulging of the various thicknesses of stainless steel diaphragms, mounting of the explosive on the diaphragm, and rupture tests.

e. System Test. Controlled opening of the diaphragm with the use of the pressure switch and explosive train. Figure 1 shows the test assembly used in the final tests of the system.

EXPLOSIVE TRAIN INVESTIGATIONS

First, a miniature shaped charge was investigated since this would be the most efficient use of explosives for penetration purposes. The technique involved the use of a conical liner (copper or stainless steel) driven by 1.6 grams of explosive. The cones were of 0.014-inch wall thickness with a 53-degree apex angle with a base diameter of 0.400 inch. The explosive used was EL-506 A-8 Sheet Explosive* which was detonated by a short piece of duPont EL506 C Sheet Explosive* and a Mk 70-0 Detonator. This assembly of explosive and cone was cemented to the stainless steel plate by Eastman Kodak 910 Adhesive**. A typical setup and examples of penetration of the miniature shaped charge are shown in Figures 2 and 3. This method of penetration was satisfactory for the 0.187-inch thickness plate. At a thickness of 0.375 inch, a jet from the cone had penetrated through the plate but the slug remained in the hole. This latter thickness of 0.375 inch represents the heaviest of the diaphragms presently used. Table 1 shows the penetrations of several steel cones with two explosive stand-off distances and stainless steel specimens backed up with wood or steel.

The second technique was that of using a linear-shaped mild detonating fuse (250 grains per foot of PETN or RDX explosive charge). This lead-coated explosive charge has the same type of cutting ability as a regular shaped charge but cuts in a linear fashion. The mild detonating fuse was cemented to a steel plate in the same manner as the miniature shaped charge. The explosive was detonated by a lead of duPont EL-506 C Sheet Explosive and a Mk 70-0 Detonator. A typical arrangement of the linear-shaped MDF and the steel plate is shown in Figure 4. The photograph shows the cutting ability of the explosive charge.

* E. I. duPont or equivalent

** Eastman Kodak or equivalent

The results of both methods of cutting were considered to be preliminary. The investigation was continued with the linear-shaped charge. This method appeared to provide a more effective means of controlling diaphragm rupture.

The surface temperature on the diaphragm following a hangfire condition was measured to determine the compatibility of this system with a hangfire. A thermocouple placed on the outer side of the diaphragm showed no temperature rise until 1.5 seconds after chamber ignition. Then the temperature increased at the rate of 37 degrees centigrade per second. The peak temperature was 113.0 \pm 2 degrees centigrade after 6.4 seconds. This test indicates that no premature ignition of the cutting charge should be expected since the cook-off temperatures of the RDX and PETN, respectively, are 360 and 215 degrees centigrade (see ref. (1)).

TEST EQUIPMENT

PRESSURE VESSEL. For reasons of economy and so as not to interfere with the operation of the 4-inch gas gun, a pressure vessel was designed and manufactured for this investigation. This vessel was of sufficient volume to produce complete diaphragm opening. It was designed with a chamber of approximately 108 cubic inches and to sustain a safe pressure of 30,000 psi. By the use of spacer and transition piece, testing of diaphragms of various flange configurations was possible. Electrical inserts and an exhaust vent were conveniently located. An outlet was provided for the purpose of installing a pressure-measuring device.

PRESSURE-MONITORING SYSTEM. Because of its good frequency response and sensitivity, the piston-type strain gage was used to monitor the chamber pressures (see ref. (2)). This type of pressure-measuring device has been very reliable in its past use to measure dynamic pressures in the shocktube wind tunnels and the chamber pressures of the light-gas launchers. This system was used to record diaphragm prebulging and rupturing pressures. A schematic of the electrical circuit may be seen in Figure 5.

PRESSURE SWITCH

A pressure switch, Figure 6, was designed to operate on the pressure built up from the combustion gases in the chamber. The resulting force moves a piston which opens the contacts of the electric switch. The electric switch was designed to operate from a normally closed position. The pressure range at which the switch operates is controlled by the size of the swaging skirt on the piston. When the designed pressure is reached, the plunger pushes the contact piston skirt through the swage block breaking the circuit. The normally closed contacts on the switch are

incorporated in the pressure monitoring system so as to record actual pressure at time of functioning. This switch is normally used to arm the external explosive charge. This device was used and functioned properly fourteen times at pressures in excess of 10,000 psi.

DIAPHRAGM PREPARATION AND RUPTURE

The diaphragms used for these tests were of the type, style, and material that had been used in the 4-inch gas guns. No attempt was made to redesign the diaphragms. Figure 7 shows a typical diaphragm. These diaphragms are made from stainless steel plate, AISI Type 304, annealed. Preparation of the diaphragm includes a prebulging process, and cementing of the explosive. These steps are shown in Figure 8. The primary reason for the prebulging operation is to facilitate the placing of the explosive over the desired area and also to eliminate any further yielding of the steel at these pressures. The prebulging operation in this investigation was essentially a closed-bomb experiment. An extension of the calculations made by the Universal Match Corporation, indicated that pressures from 10,000 to 30,000 psi could be obtained with 100 and 265 grams, respectively, of Unique Powder (see ref. (3)). Smokeless powder was chosen because it was convenient and available. A plot of the calculated values appears in Figure 9 with a comparison of the empirical data collected from the pressure measurements in the pressure vessel. Various thicknesses of diaphragms were prebulged for the high-pressure release tests. Typical prebulge pressures for these diaphragms are shown in Table 2.

Following the prebulge operation, the explosives were attached to the prebulge section of the diaphragm. The shaped mild detonating fuse was cut in 1-3/8-inch lengths and cemented in position with Eastman Kodak 910 Adhesive. Typical arrangement is shown in Figure 10. The explosive was mounted directly opposite the previously machined groove. This explosive does not cut through the stainless steel but only weakens it. The preliminary tests also included a lined conical shaped charge in the center of the diaphragm. Later tests indicated that this charge was superfluous and that the linear shaped charge was sufficient to cut the diaphragm. The versatility of this method can be seen by comparing the large difference between hangfire and explosive rupture pressures. The data (see Table 2) indicate pressure differentials up to 10,500 psi can be obtained by this method and still maintain satisfactory opening.

THE SYSTEM TEST

To determine the performance of the system (Explosive Train,

Delay Unit, Triggering Circuit, Diaphragm Assembly, and Pressure Switch) six tests were performed. In these tests, diaphragm thicknesses varied from 0.250 to 0.389 inch and hangfire pressures from 8,700 to 16,500 psi. The sequence of the operation was as follows:

a. The pressure chamber was pressurized by the ignition of Unique Powder with an XE-68A Squib.

b. The pressure switch functioned when the desired pressure was obtained in the pressure vessel.

c. The pressure switch triggers a delay circuit, with a predetermined time delay sufficient to insure complete combustion of propellant in the chamber. The output of the delay unit is fed to a thyatron firing circuit.

d. The firing circuit then fires the explosive train placed on the stainless steel diaphragm.

e. For the tests conducted the delay time for firing the explosive train was set for 40 milliseconds following the pressure switch functioning. The cutting action of the explosive material weakens the diaphragm which ruptures and releases the chamber pressure.

f. In each test, oscilloscope traces were taken. These traces provided hangfire and explosive rupture pressures with respect to time.

The typical ruptured diaphragm is shown in Figure 11 as compared with the diaphragm which was burst by a large over-pressure in the pressure chamber. Typical pressure traces, showing peak pressure, delay time and explosive rupture, are also shown in Figure 11.

CONCLUSIONS

From the limited tests conducted, it appears that the system for controlled rupture of a 4-inch gas gun diaphragm, by the use of a high-explosive charge, is feasible. In the various tests performed it was found that:

a. The linear-shaped MDF provides an efficient method of removing metal from the diaphragms.

b. The system using a high-pressure switch, explosive train, and pressure-monitoring equipment, operated satisfactorily and reliably.

c. A diaphragm can be ruptured by this method at approximately two-thirds of its burst pressure.

This system has the advantage of not requiring the close manufacturing tolerances of the present diaphragm. It may be expanded so that it may be adaptable to the gas gun facility utilizing either the single or double diaphragm system as indicated in Figure 12.

Table 1

THE PENETRATION BY MINIATURE STAINLESS STEEL
LINED CONICAL SHAPED CHARGES

TEST*	EXPLOSIVE	SHEET EXPLO- SIVE WEIGHT (GMS)	STAND- OFF DIS- TANCE (INS)	BACK-UP MATE- RIAL	STEEL BLOCK THICK- NESS (INS)	PENETRA- TION (INS)
A	EL-506 A-8	1.57	0.156	Steel	0.375	0.300
B	EL-506 A-8	1.57	0.156	Wood	0.375	0.375
C	EL-506 A-8	1.57	0.020	Steel	0.625	0.160
D	EL-506.A-8	3.20	0.156	Wood	0.375	0.375

* Refer to Figure 3 for detailed results

TABLE 2
EXPLOSIVE RUPTURE OF VARIOUS THICKNESS STAINLESS STEEL DIAPHRAGMS

DIAPHRAGM TYPE*	THEORETICAL BURST PRESSURE (PSI)	EMPIRICAL BURST PRESS. (PSI)	PREBULGE PRESSURE (PSI)	HANGFIRE PRESSURE AT EXPL. (PSI)	RUPTURE PRESSURE** (PSI)	DIFFERENTIAL PRESSURE** (PSI)
A 250/170	10,700	11,350	9,350 8,450	8,700 9,230	2,650 2,120	
C 300/265	20,300	22,700	12,900 17,500	12,200 15,780	10,500 6,920	
E 389/315	25,000	26,700/***	23,200 21,000	16,200 16,500	10,500/ 10,200/	

* Type A diaphragms were 0.250-inch thick with 0.170-inch metal under the groove
 Type C diaphragms were 0.300-inch thick with 0.265-inch metal under the groove
 Type E diaphragms were 0.389-inch thick with 0.315-inch metal under the groove

** Differential pressures were obtained by subtracting hangfire pressures from Empirical burst pressures

*** Type E diaphragms held 26,700 psi. No Empirical burst pressure was obtained

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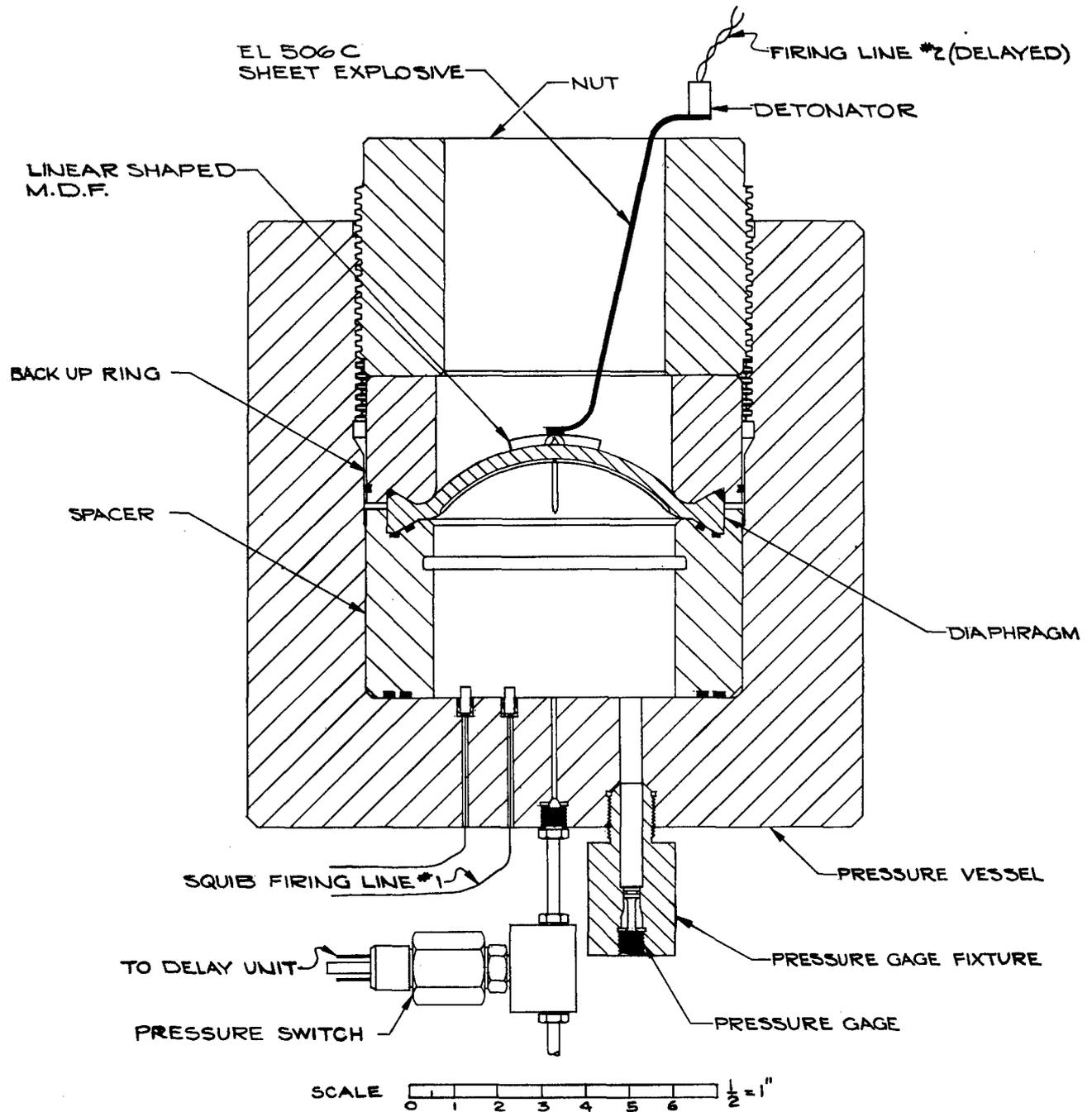
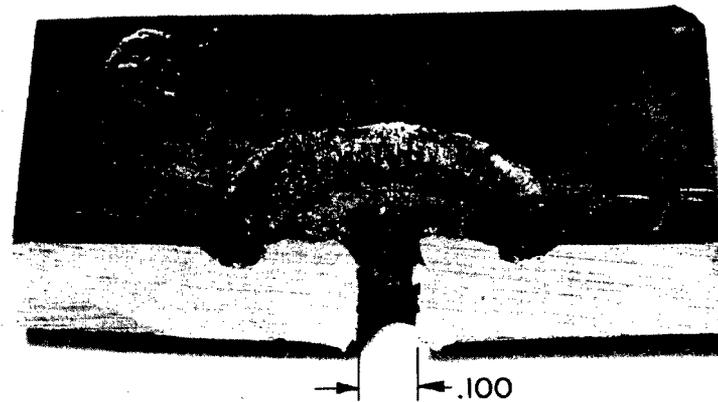
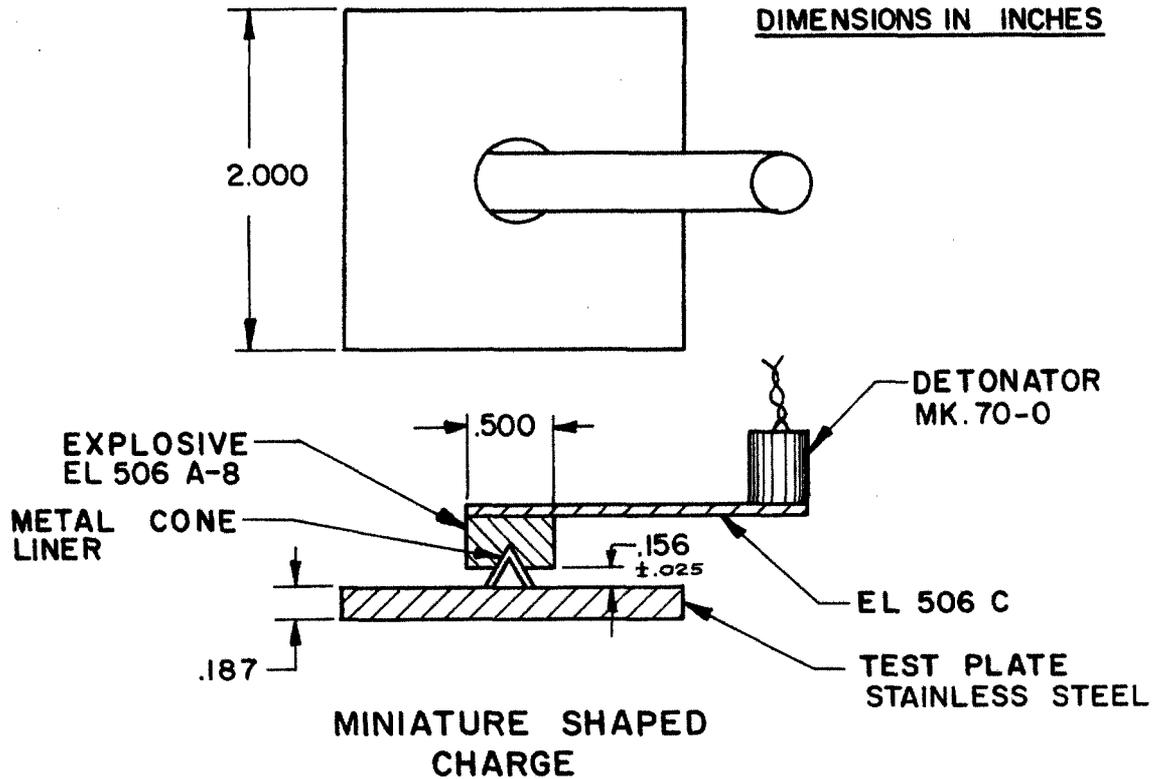


FIG. 1 EXPLOSIVE HIGH PRESSURE RELEASE TEST ASSEMBLY



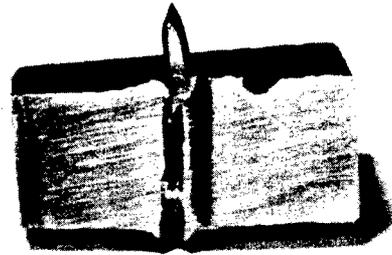
A $\frac{3}{16}$ TEST PLATE SHOWING TYPICAL PENETRATION OF A CONE-LINED SHAPE CHARGE.

FIG. 2 TYPICAL ARRANGEMENT AND PENETRATION OF A LINED CONICAL SHAPED CHARGE.



CONE: .400 DIA. X.014 THICK
EXPLOSIVE: 1.6 GMS
BLOCK: .375 THICK

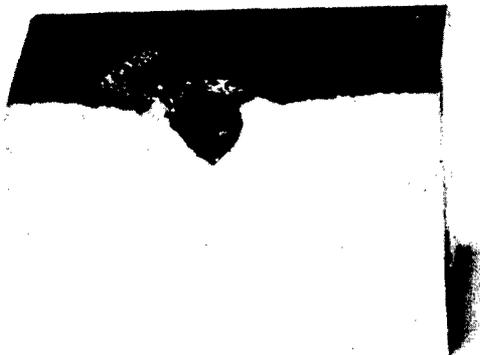
A



CONE: .400 DIA X .014 THICK
EXPLOSIVE: 1.6 GMS
BLOCK: .375 THICK

B

DIMENSIONS IN INCHES



CONE: .300 DIA X.010 THICK
EXPLOSIVE: 1.6 GMS
BLOCK: .650 THICK

C



CONE: .400 DIA X.014 THICK
EXPLOSIVE: 3.2 GMS
BLOCK: .375 THICK

D

FIG. 3 SPECIMENS SHOWING PENETRATION BY LINED CONICAL SHAPED CHARGES

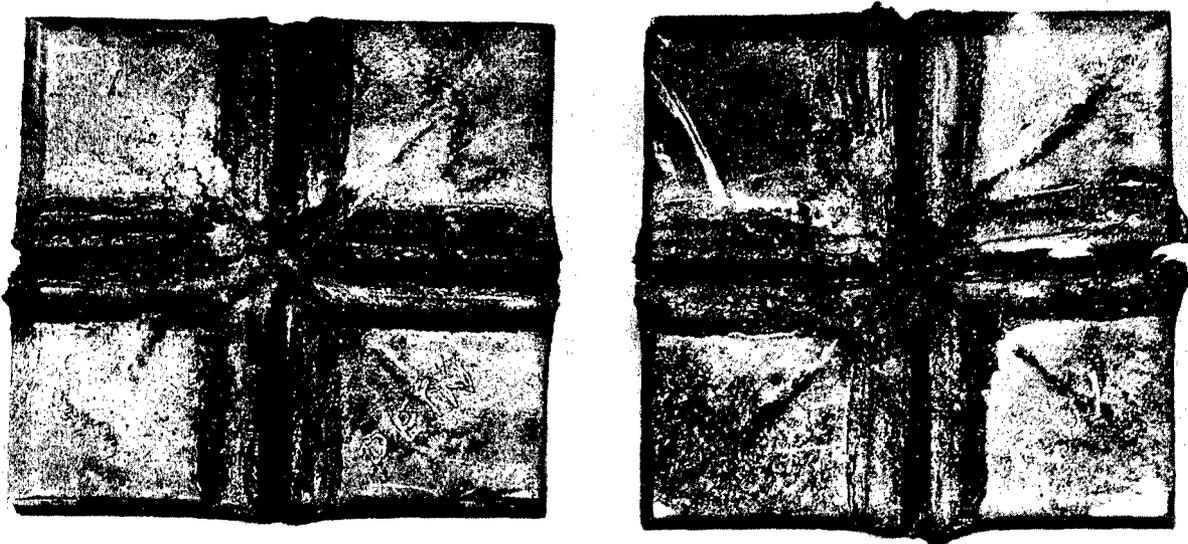
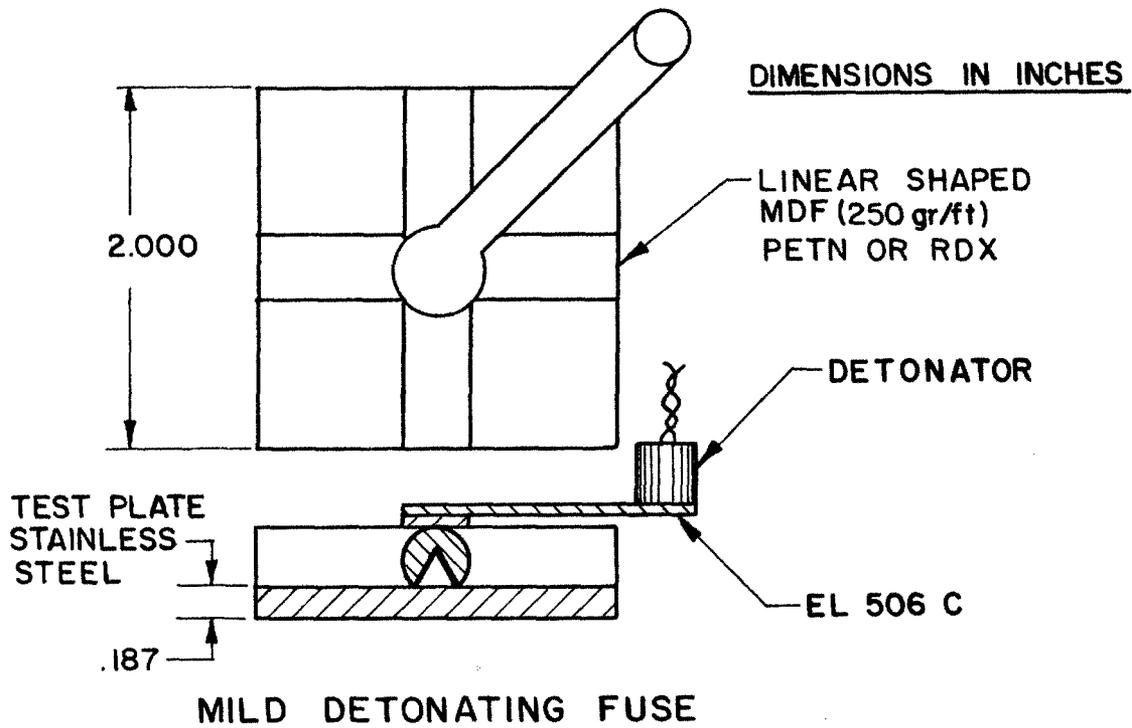
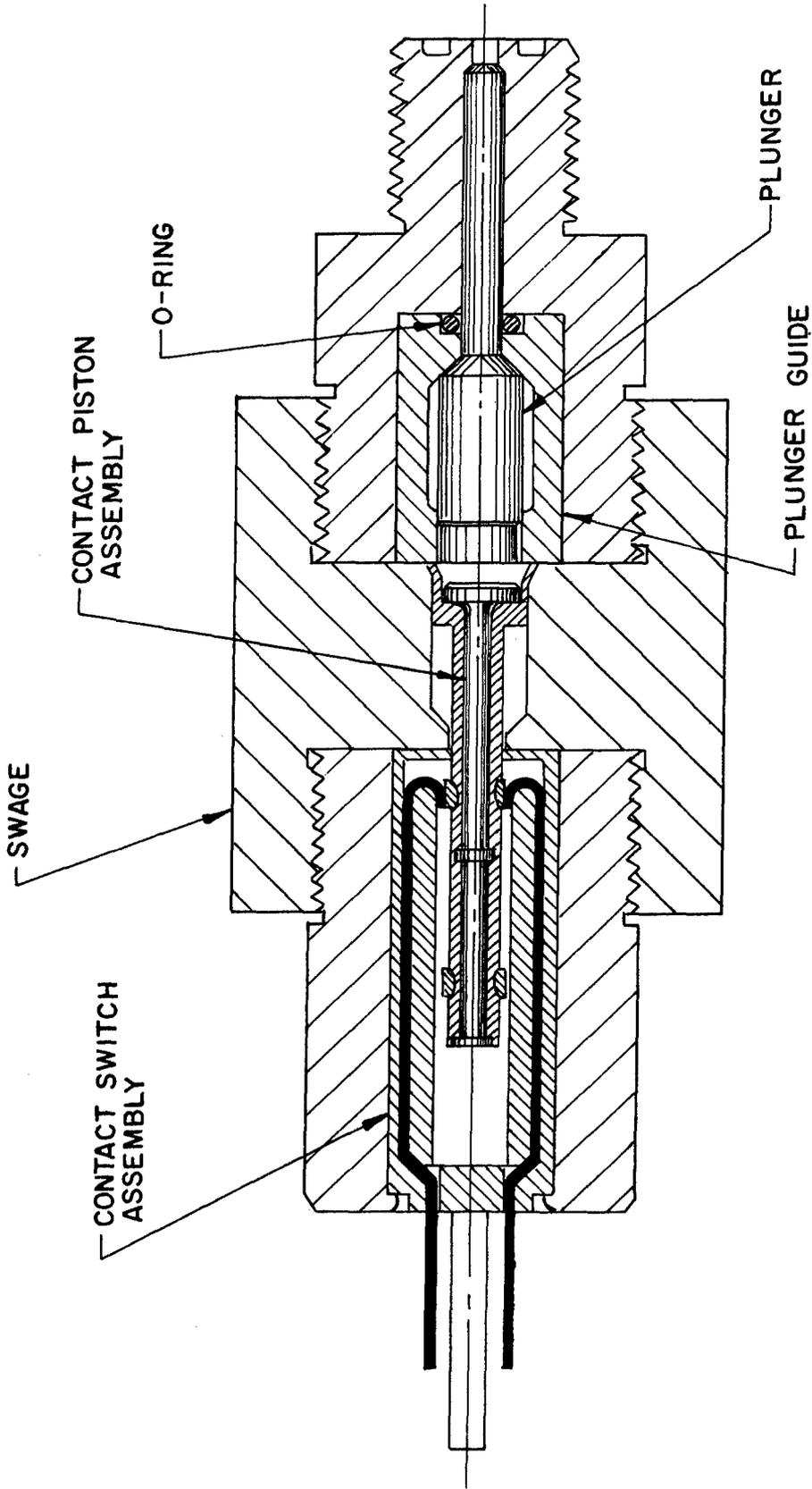


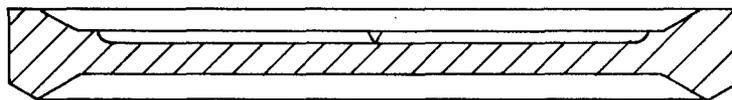
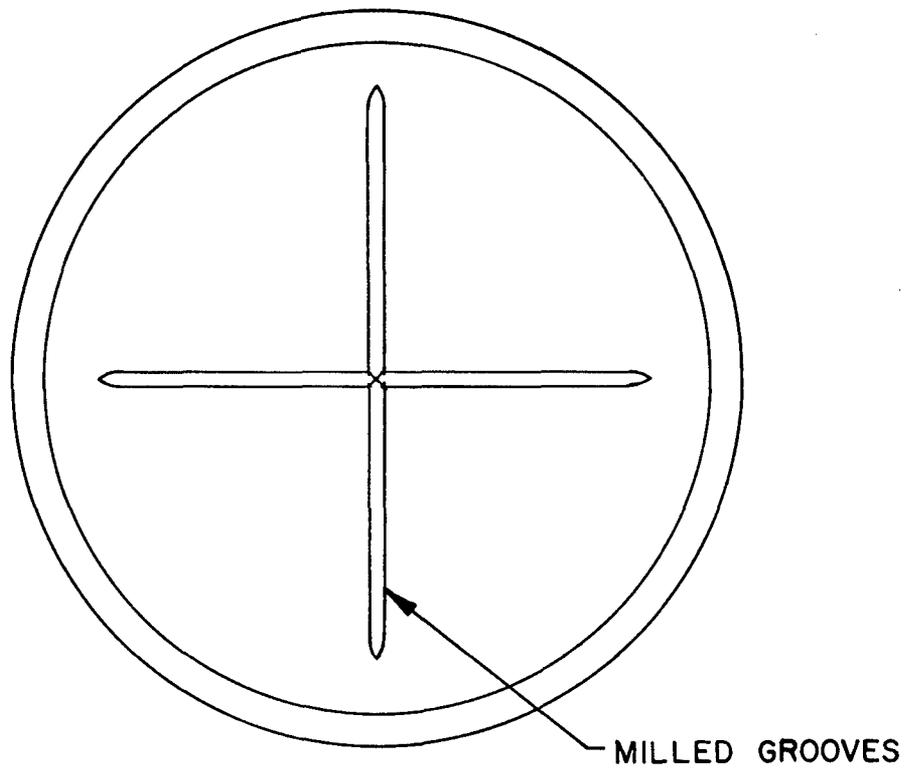
FIG. 4 TYPICAL ARRANGEMENT AND STAINLESS
STEEL PLATES SCORED BY SHAPED
MILD DETONATING FUSE

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SCALE $\frac{2}{1}$

FIG. 6 PRESSURE SWITCH ASSEMBLY



SCALE $\frac{1}{2}$

A TYPICAL 4" GUN DIAPHRAGM

FIG. 7

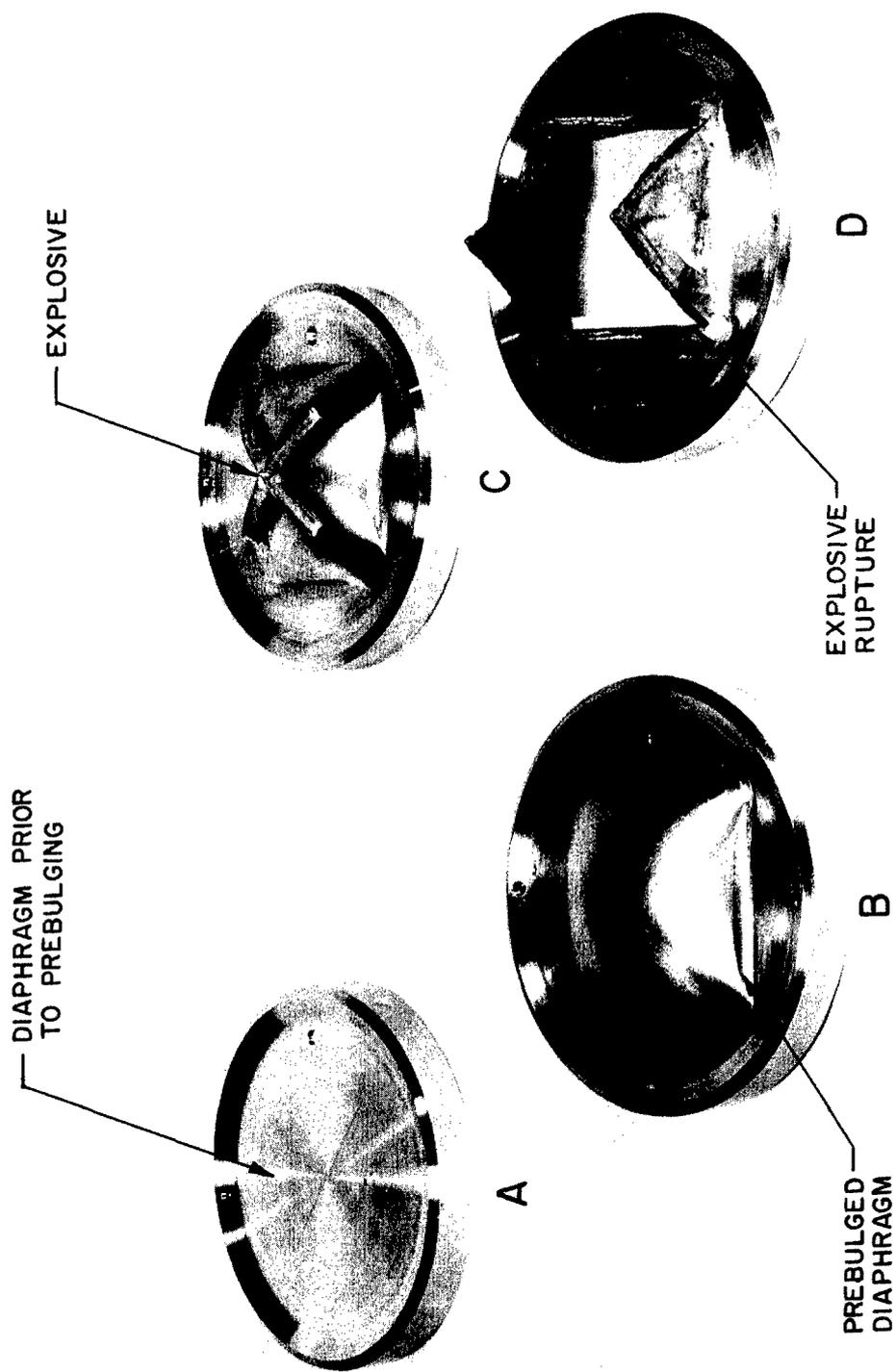


FIG. 8 STEPS IN THE FABRICATION OF THE EXPLOSIVE HIGH PRESSURE RELEASE.

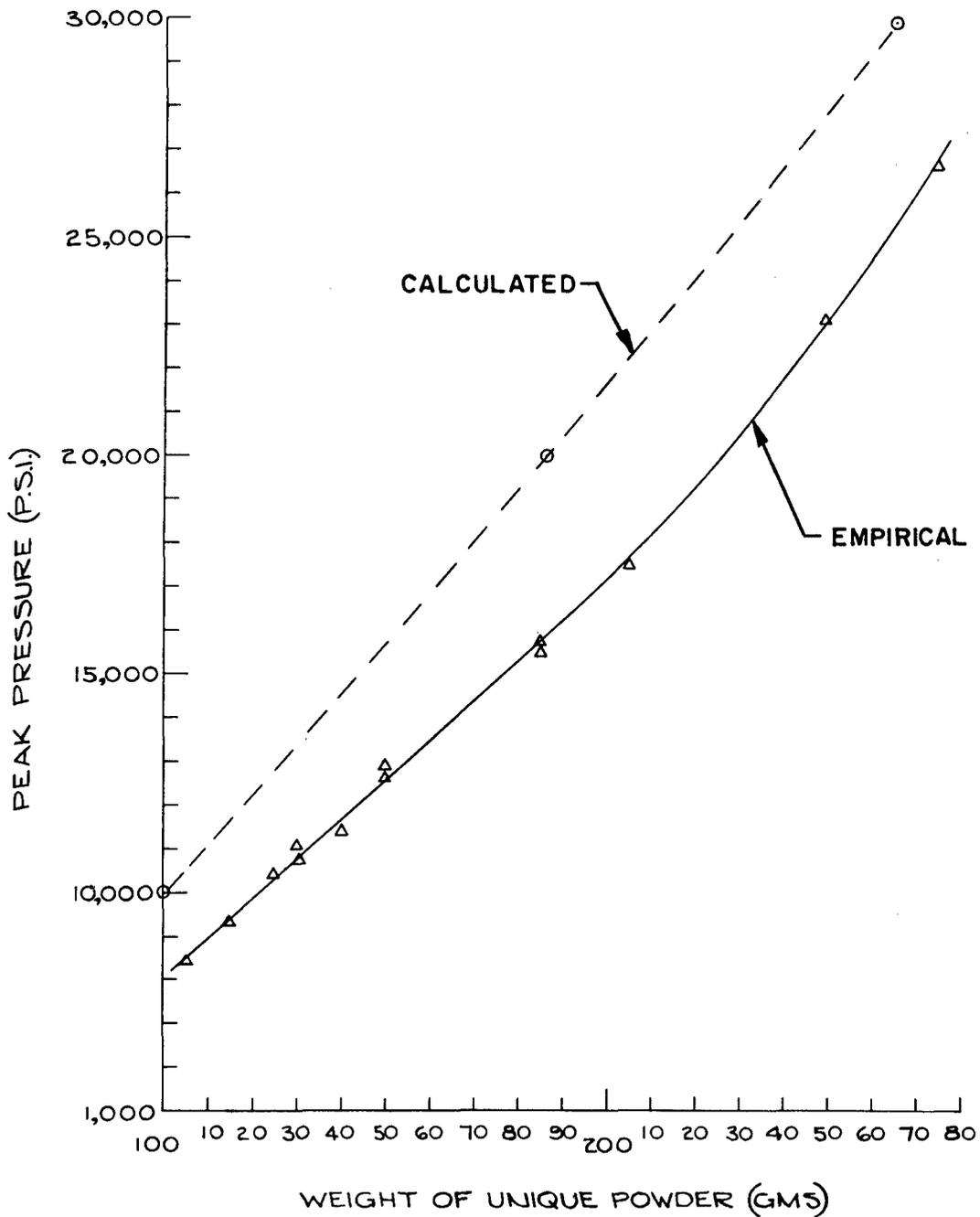
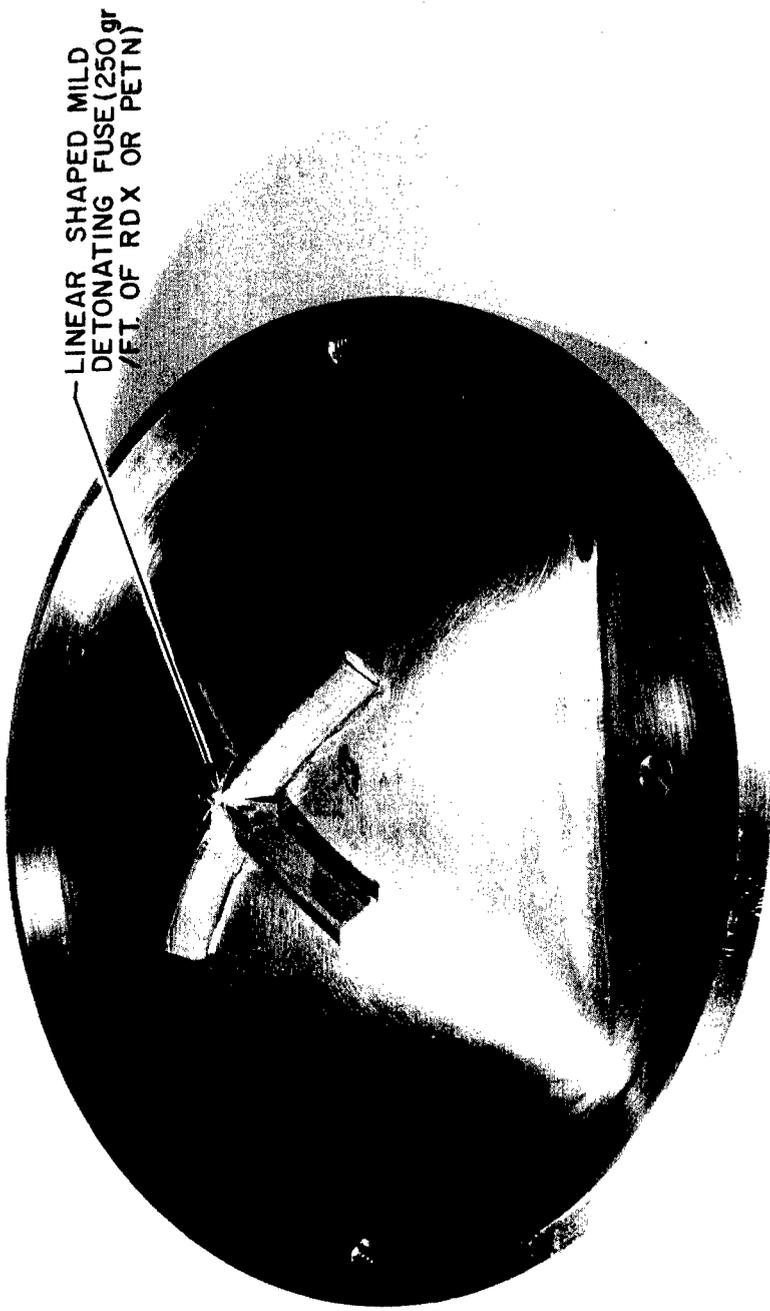


FIG. 9 PEAK PRESSURE VS THE WEIGHT OF UNIQUE POWDER FOR CHAMBER VOLUME OF 108 CUBIC INCHES.



LINEAR SHAPED MILD
DETONATING FUSE (250 gr
/FT OF RDX OR PETN)

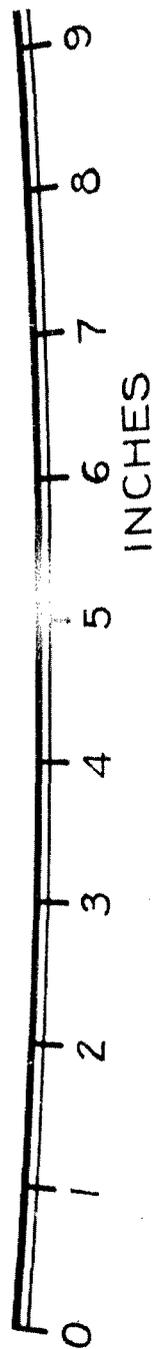
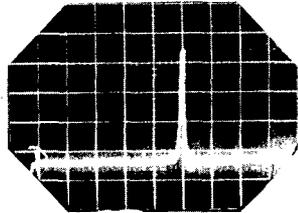


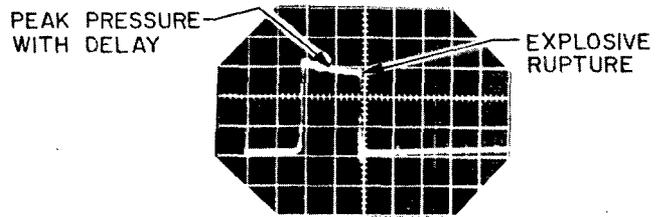
FIG. 10 MDF ARRANGEMENT ON THE PRE-STRESSED
STAINLESS STEEL DIAPHRAGM.

TYPICAL OSCILLOSCOPE TRACES

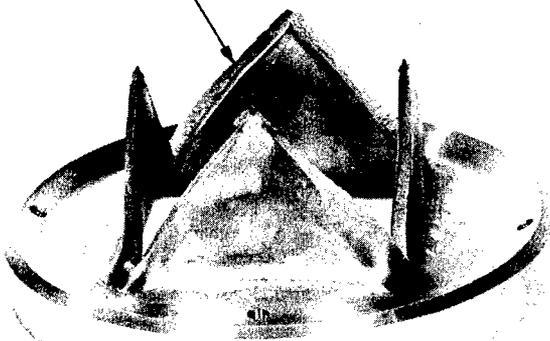
A SWEEP TIME
10 MILLISECONDS/UNIT



B SWEEP TIME
20 MILLISECONDS/UNIT



OVERPRESSURE RUPTURE A



EXPLOSIVE RUPTURE B

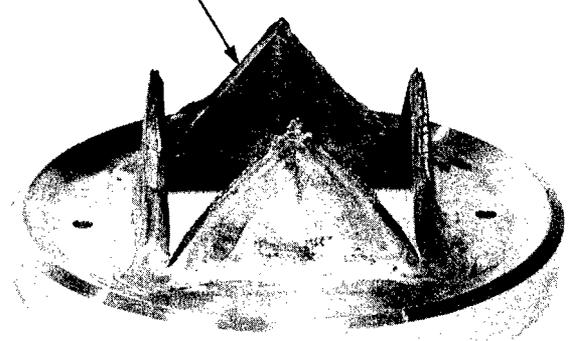


FIG. II COMPARISON OF THE DIAPHRAGM
EXPLOSIVE AND OVERPRESSURE RUPTURES

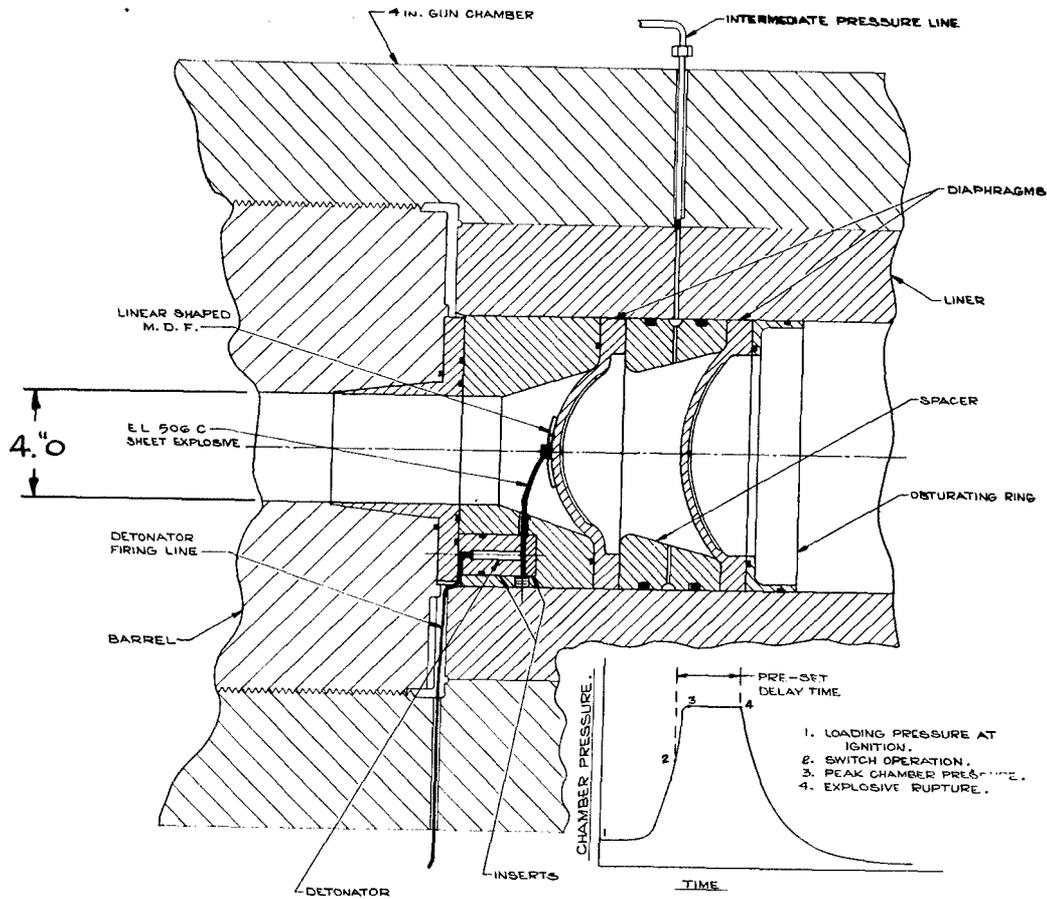


FIG. 12 PROPOSED EXPLOSIVE RUPTURING SYSTEM FOR 4 in. GAS GUN OPERATION.

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