63-3-2

NOLTR 63-19

CALIBRATION FOR THE GAP TEST WITH A PENTOLITE DONOR

29 JANUARY 1963

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

NOLTR 63-19

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By

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ABSTRACT: A second calibration of the gap test was made with a pentolite donor replacing the tetryl donor of the standardized test. The calibration consisted of measuring the attenuation of the shock velocity in a Plexiglas rod, and calculating the corresponding shock pressure as a function of gap distance.

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NOLTR 63-19 29 January 1963

This report supersedes NOLTR 62-78 of 15 May 1962.

The work reported here was carried out under Task NOL-323, Polaris Program on the Sensitivity of Solid Propellants. The calibration of the shock sensitivity test (gap test) with a donor which is readily available (pentolite) increases the usefulness and availability of the test. At the same time, the results which have been obtained with the tetryl donor are relevant and may be correlated with a fair degree of confidence with the results attainable with the new donor. The pentolite donor described has been adopted by the Armed Services Explosives Safety Board as the standard donor to be used in the hazard classification of solid propellants.

R. E. ODENING
Captain, USN
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By direction

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I. INTRODUCTION

The NOL large-scale shock sensitivity test (gap test) was originally calibrated with a tetryl donor (1) to interpret the 50% point gap in terms of absolute pressure. The pressure amplitude at the 50% point, assuming the shape of the pressure pulse to be defined by the amplitude, should be an intrinsic property of a propellant tested under standardized conditions, and should be reproducible regardless of the donor used. To determine the validity of this assumption a standard pentolite donor was made and used in a second calibration. This donor was also used to determine the 50% point of various substances; the pressures obtained at the 50% point were compared to those obtained with the standard tetryl donor.

II. EXPERIMENTAL

A. Pentolite Donor

The chemical and physical properties of trinitrotoluene (TNT-Grade I) and pentaerythrite tetranitrate (PETN), which were used to formulate pentolite, are specified in the Joint Army-Navy Specification (2,3). A quantity of these ingredients were sieved separately, using a No. 70 and a No. 100 sieve (U.S. Standard Sieve Series - ASTM specification). That fraction of material which passed the No. 70 sieve and remained on the No. 100 sieve (particle size ranging from 150 microns to 210 microns) was used. One thousand grams of the sieved TNT and an equal amount of PETN was added to a "V"-blender and dry blended for a period of one hour to insure a homogeneous mixture.

The TNT-PETN mixture (pentolite) was placed in a mold, which measured 2 inches inside diameter, and was pressed on a hydraulic press to a length of 1 ± 0.003 inches and to a density of 1.56 - 1.57 g/cc which is 91 - 92% of the theoretical maximum density, 1.71 g/cc.

B. Experimental Procedure

The attenuation of a shock generated by two pentolite pellets in a Plexiglas rod was measured by a streak camera. Figure 1 is a schematic of the experimental assembly. A

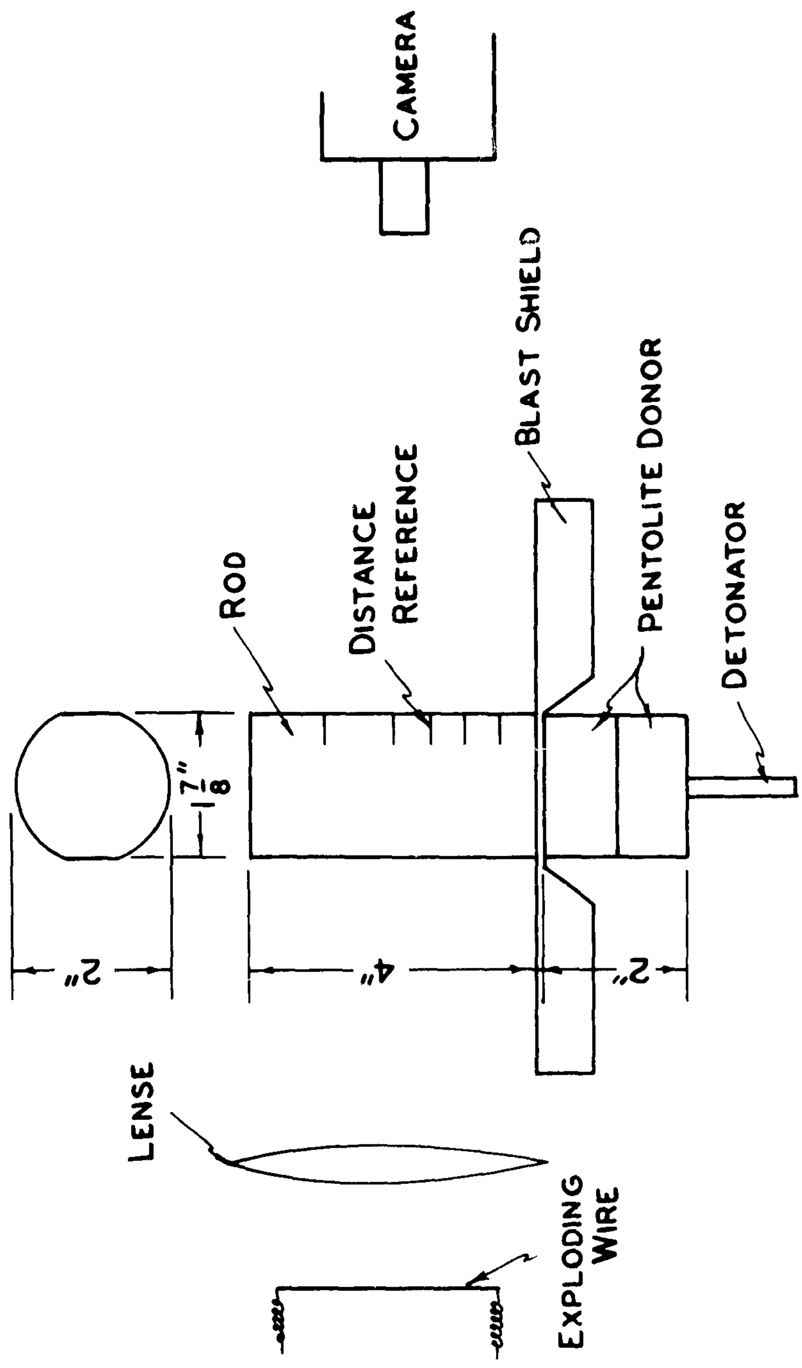

FIG. 1 EXPERIMENTAL SET-UP

Plexiglas rod 2 inches in diameter and 4 inches long was machined from 1 7/8 inches sheet Plexiglas. The resulting rod contained two parallel opposing flat surfaces 1 7/8 inches apart (see Figure 1) through which the camera could view the shock front as it progressed up the rod. The flat surfaces eliminate any distortion of the light. Calibration lines were inscribed at known distances on the rod.

The rod was set upon two pentolite pellets which were conditioned at 25°C. A blast shield of known thickness was provided to prevent the products of the reaction, resulting from the detonating pentolite pellets, from obscuring the view of the camera. A detonator, used to initiate the reaction, was placed in contact with the donor. The entire assembly was backlighted by an exploding wire. The approximate speed of the camera was 1.32 mm per microsecond.

III. RESULTS

Figure 2 is a typical record (Expt. No. 2) taken from the series of four experiments performed. The data obtained from these records are listed in Table I and plotted in Figure 3.

The equation which relates the shock pressure and the shock velocity is

$$P = \rho_o u U$$

where

P = shock pressure

ρ_o = initial density of the material

u = particle velocity

U = shock velocity

To determine a corresponding pressure both the shock velocity and particle velocity must be known. The shock velocity and particle velocities for Plexiglas (4, 5) and similar substances such as Lucite (1, 6) and Perspex (7) have been determined experimentally. These data were combined to give a relationship between shock velocity and particle velocity (1) which was used to calculate a corresponding pressure for each shock velocity determined experimentally under the conditions described above.

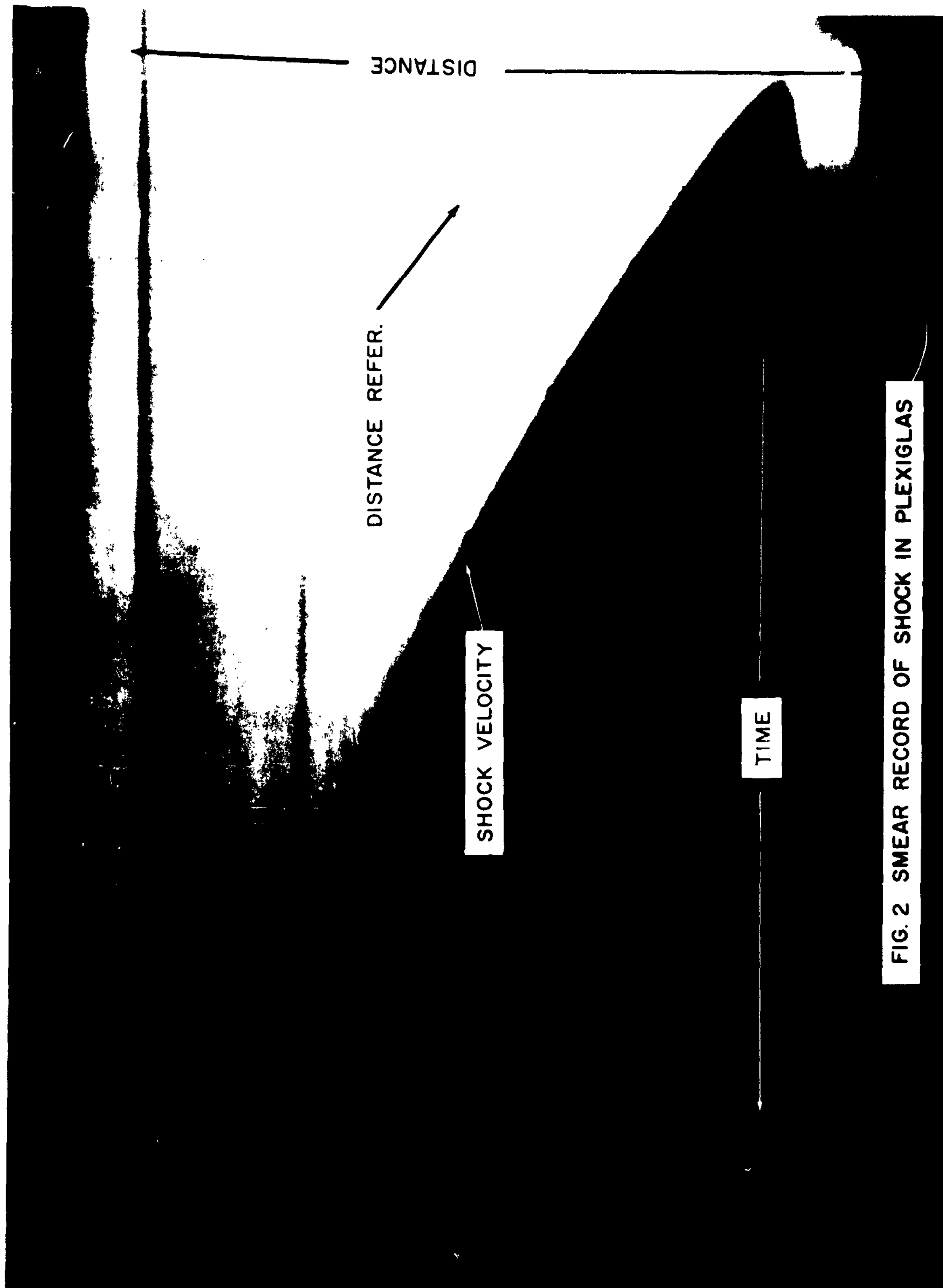

FIG. 2 SMEAR RECORD OF SHOCK IN PLEXIGLAS

TABLE I

Distance vs Time in Plexiglas Rod

Expt. 1		Expt. 2		Expt. 3		Expt. 4	
Time µsec	Distance mm	Time µsec	Distance mm	Time µsec	Distance mm	Time µsec	Distance mm
1.21	7.2	1.87	10.4	1.31	8.0	1.18	7.2
3.83	20.0	3.76	18.9	2.89	16.0	2.01	11.5
5.69	28.0	5.82	28.1	5.85	28.9	4.08	21.2
7.71	35.7	7.70	35.3	7.75	35.9	7.64	36.0
10.26	44.5	10.36	45.0	10.19	44.3	10.19	45.5
12.68	52.4	12.84	53.6	13.14	53.1	13.88	58.0
15.73	62.0	16.07	64.2	17.69	68.5	18.07	71.3
23.40	85.7	20.74	79.0	19.99	75.5	21.63	82.80
25.53	92.2	23.84	89.0	22.23	82.3	24.53	92.00
27.43	97.7	26.96	98.6	25.78	93.6	27.34	100.50
28.87	102.2			28.86	102.8		

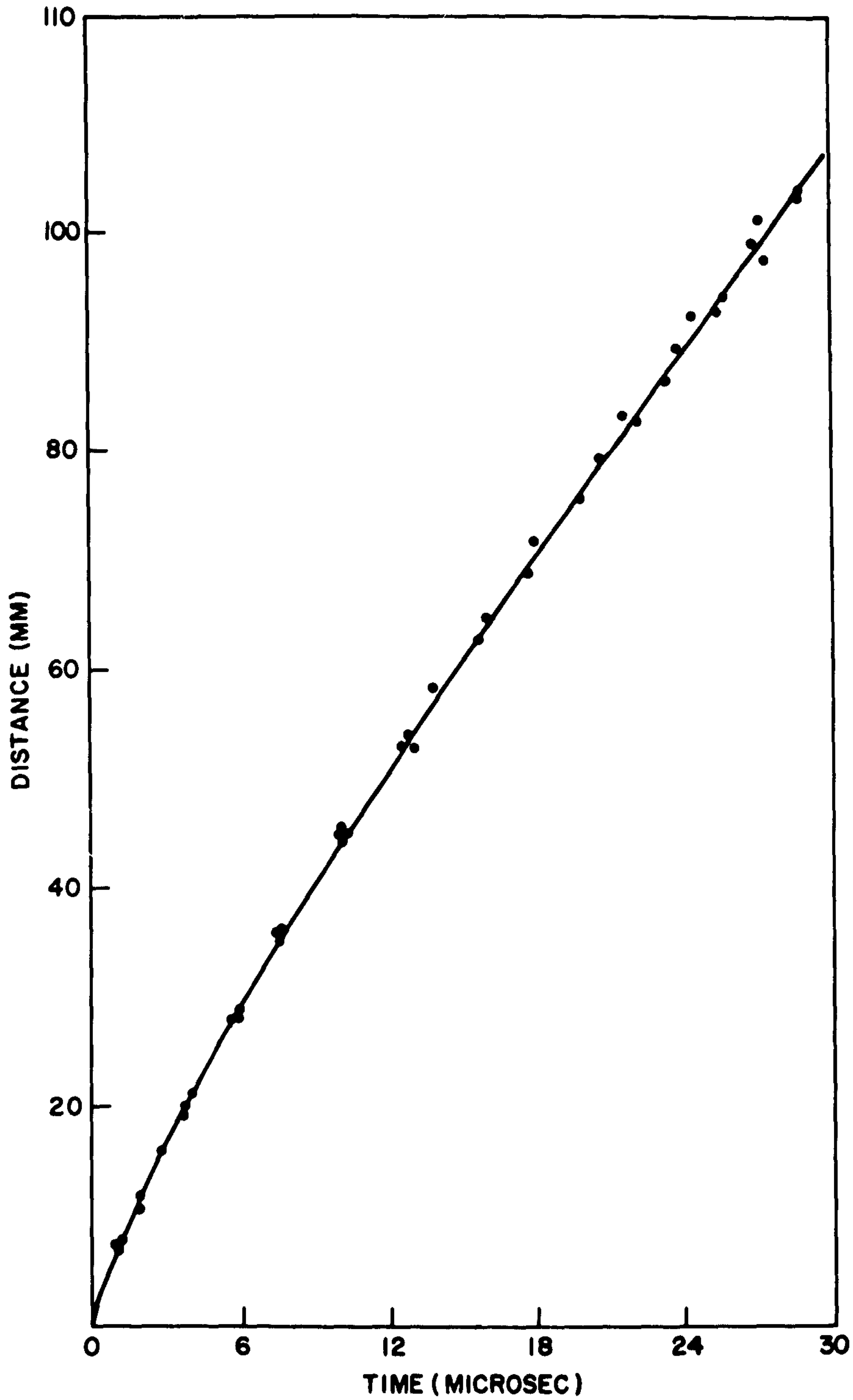

FIG. 3 SHOCK IN PLEXIGLAS

It is difficult to determine the velocity precisely for the first ten to fifteen millimeters of the gap. A slight change in the interpretation of the data in this region (shape of the curve) makes for a fairly large change in the calculated shock pressure. The error may be compounded further by the inaccuracies in the determination of the slope and in the equation of state used to obtain the shock pressure. To obtain the best interpretation, the shock velocities were obtained graphically from the distance-time curve (Figure 3) and compared to the velocities obtained from a number of equations ranging from a second to a seventh degree polynomial which were fitted in turn to the experimental data by an electronic computer (IBM-7090). A fifth degree equation was obtained which reproduced the experimental data to a fair degree of accuracy. A more detailed discussion of the equation is given in the appendix.

Figures 4 and 5 are plots of Pressure vs Distance for Plexiglas in which the curves obtained by both methods are compared to an analogous curve obtained with tetryl. The tetryl curve of Figure 4 was derived from graphical treatment of the data because an analytically fitted cubic in the range 5 - 25 µsec gave velocities only a few percent higher than those determined graphically (1).

IV. DISCUSSION

The gap used in the NOL shock sensitivity test is composed of Plexiglas, Lucite, cellulose acetate or some combination of these materials. These substances are quite similar and it has been demonstrated (1) that they are equivalent as attenuators in the gap test. Figures 4 and 5 show the relationship between pressure and distance (gap) for both pentolite and tetryl. Both donors were calibrated under similar conditions with one exception: the Plexiglas rod used here was slightly smaller, 1 7/8 inches between the flat parallel surfaces as against two inches in the earlier work with tetryl. This should not affect the results obtained to any noticeable degree. The same equation of state was used in both calibrations to calculate the pressure-distance relationship for the gap.

It is apparent that the pentolite donor initially generates a larger pressure (using either pentolite curve) than the tetryl. It is somewhat improbable that the initial pentolite pressure amplitude would be larger by a factor of two than that of the tetryl; this casts some doubt on the validity of the upper part of the curve constructed with graphically determined values of U. Moreover the variation of shock pressure with distance represented by the analytical curve is a more reasonable one compared with the tetryl curve. This similarity in the general configuration of the curve is evident in Figures 4, 5, and 6 (log P vs X). In Fig. 6, curves are shown for Tetryl (log P vs X, linear) and for pentolite, the analytical polynomial. In addition, the unconnected data points are shown for pentolite. In the tetryl work (1) the data points fell below the extrapolated linear log P vs X curve at values of X less than about 18.5 mm. This is not the case for pentolite. The graphical and analytical curves are both non-linear and intersect at about 5.0 mm; for smaller X the data points are above the analytical curve.

Table II contains the smoothed data for the shock velocities and the shock pressures obtained by both methods. The degree to which the calculated shock pressure depends upon the velocity (slope of X-t curve) and the equation of state for Plexiglas can be seen by comparing the shock velocities and the corresponding calculated shock pressures at 2 millimeters. For a 5% change in velocity there is a 15% difference in the shock pressure, which is due primarily to the difference in particle velocity (2.3 compared to 2.1 mm/μsec) used to calculate the shock pressures. It is believed that the analytical approach minimizes the inherent inaccuracies involved in the graphical interpretation of the data at this point, and should be used to represent the pressure for the first 30 mm of the Plexiglas. Beyond this point both methods give essentially the same results.

The larger pressure generated by the pentolite donor is attenuated rapidly. After 10 mm it is within the tetryl pressure range and after 25 mm (1 inch) of travel its curve is similar to that of the tetryl. From this point on both donors may be considered to give the same pressure amplitude within the precision of the experimental data.

The pressure amplitude at the 50% point as a quantitative measure of sensitivity was further studied by making a series of shock sensitivity tests on several different materials. A number of charges were made from the same batch of materials and the 50% point gap was determined using first a tetryl donor and then a pentolite donor. The results are listed in Table III.

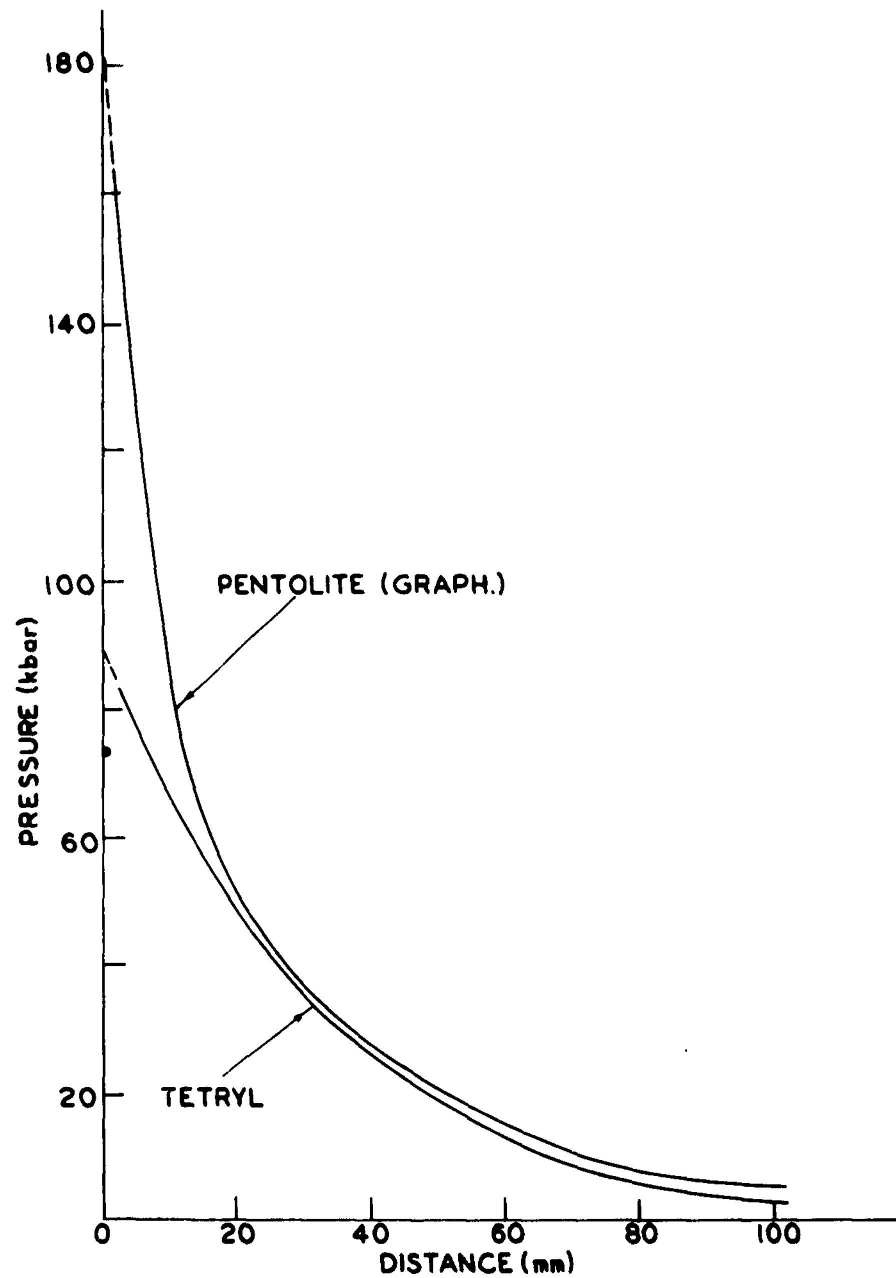

FIG. 4 PRESSURE vs GAP

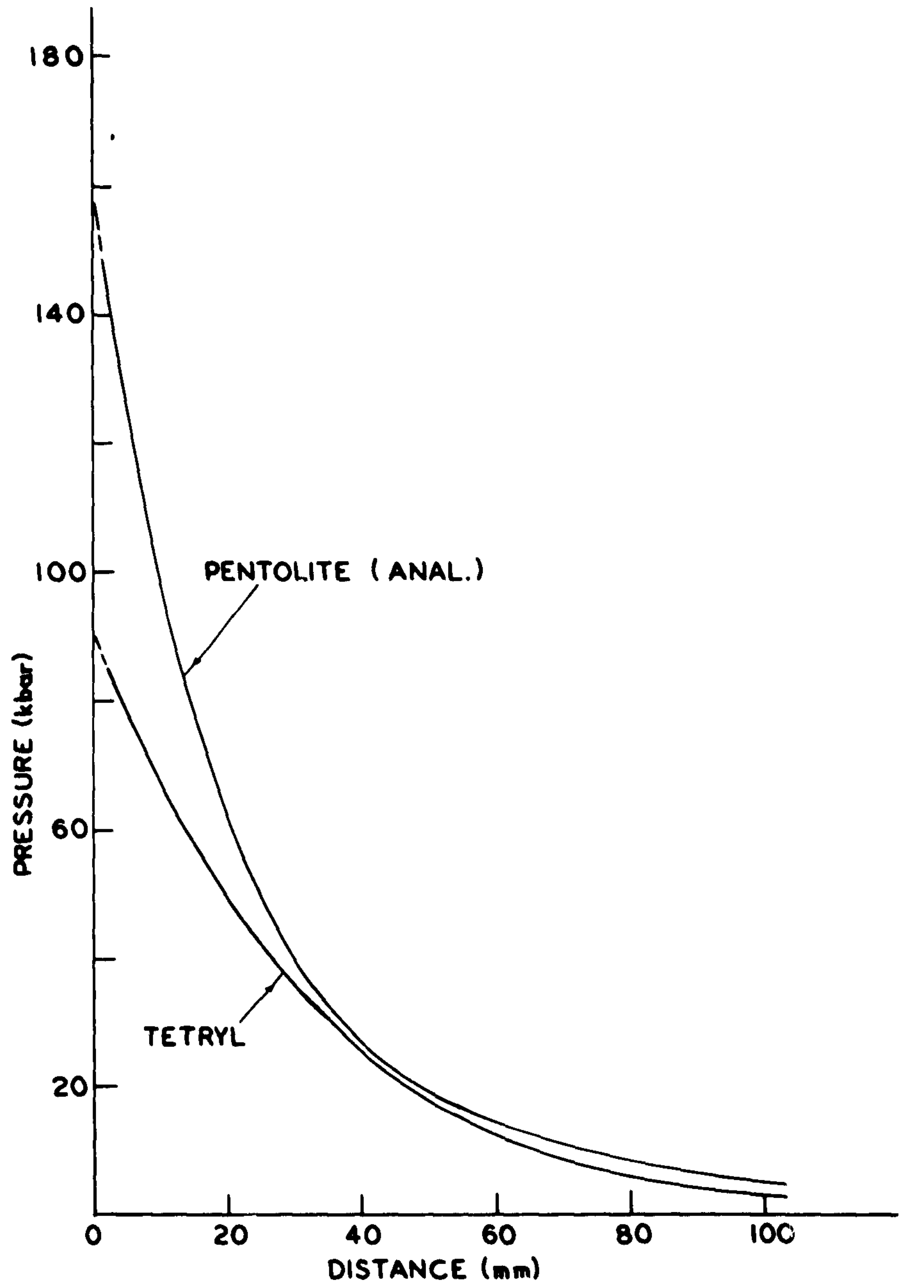

FIG. 5 PRESSURE vs GAP

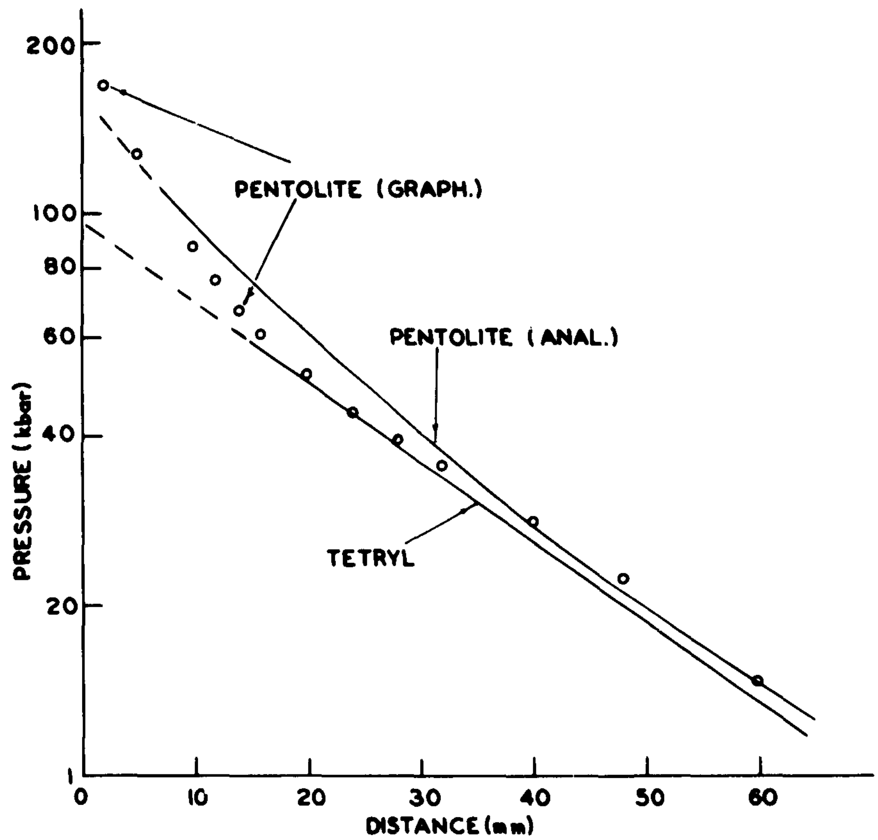

FIG. 6 LOG P vs X

TABLE II

Pressure and Shock Velocity as a Function of Distance

Distance mm	Shock Velocity mm/µsec		Pressure kbar	
	Graph	Analytical	Graph	Analytical
2	6.13	5.82	169.3	146.1
5	5.54	5.52	126.8	125.9
7	5.24	5.33	108.2	114.1
10	4.87	5.08	86.8	99.1
12	4.67	4.92	75.5	89.5
14	4.50	4.76	66.9	80.9
16	4.37	4.63	60.9	73.6
20	4.16	4.38	51.1	61.3
24	4.01	4.16	44.0	51.2
28	3.89	3.98	39.5	43.0
32	3.79	3.82	35.3	36.7
40	3.58	3.57	27.9	27.5
48	3.41	3.37	22.1	20.6
60	3.18	3.18	14.6	14.6
70	3.03	3.06	10.7	11.0
80	2.93	2.97	8.0	8.9
90	2.86	2.90	6.1	7.3
100	2.82	2.84	5.3	5.7

TABLE III

Pentolite vs Tetryl - Shock Sensitivity

Material	Donor	Gap 50% Point	Pressure kbar	Mean kbar
Comp B-3 (cast)	Tetryl	209	16.4	
	Pentolite	209	18.0	17.2
Nitroguanidine ρ_o = 1.59 g/cc	Tetryl	46	63.0	
	Pentolite	53	83.2	73.1
Nitroguanidine/Wax 95/5 ρ_o = 1.55 g/cc	Tetryl	16	78.8	
	Pentolite	25	119.7	99.3

The pressure amplitude for the same substance measured by the tetryl system and the pentolite system differ by ± 5% for gaps larger than 50 cards (13 mm). For gaps less than 50 cards the values differ by ± 13 to 20%, with increasing difference for decreasing gap length (see Table III).

It can be concluded that the same initiating pressure (to within 5%) is measured by either donor at large gaps. For smaller gaps, agreement between the donors is not obtained because the calibration curves in this region are inaccurate or because the pressure-time loading curves (not measured) affect the results or because both of these factors are operative. For the smallest gaps (highest pressures) it seems that the pressure-time histories of the two donors differ, and that this factor is having a major effect on inducing detonation of the acceptor. In other words, at the highest pressures, pressure amplitude alone does not sufficiently define the shock.

APPENDIX I

The Analytical Reduction of the P vs X Data

The equation determined analytically from the experimental data relating distance and time is:

$$X = 0.377 + 5.903t - 0.250t^2 + 0.012t^3 - 0.297 \times 10^{-3}t^4 + 0.281 \times 10^{-5}t^5$$

where

X = distance (mm)

t = time (μsec)

The velocity was obtained from the first derivative of the above equation.

$$U = \frac{dx}{dt} = 5.90 - 5.00t + 0.036t^2 - 0.119 \times 10^{-2}t^3 + 0.141 \times 10^{-4}t^4$$

Table AI contains a comparison between the smoothed experimental data, and the data calculated by the equation for the initial 60 mm of Plexiglas. Also in the table are the velocities calculated from the equation for the corresponding time. The equation obtained for the tetryl donor (1) gives a more precise fit than the equation for pentolite obtained in the present investigation. To arrive at the equation for tetryl, the data from the single best experiment were used, while for pentolite the data from all four experiments were used. In this respect, one would assume the equation for pentolite to be a more accurate description of P vs X than the equation for tetryl.

TABLE AI

Comparison Between the Experimental Data and the Analytical Results

Experimental		Calculated	
Time mm/μsec	Distance mm	Distance mm	Velocity mm/μsec
1.00	5.98	6.04	5.44
2.00	11.50	11.28	5.04
3.00	16.20	16.14	4.70
4.00	20.70	20.69	4.41
5.00	24.90	24.98	4.17
6.00	29.00	29.05	3.97
7.00	32.90	32.94	3.81
8.00	36.70	36.68	3.67
9.00	40.30	40.30	3.57
10.00	43.70	43.82	3.48
11.00	47.20	47.26	3.41
12.00	50.60	50.65	3.36
13.00	54.10	53.98	3.32
14.00	57.40	57.28	3.28
15.00	60.70	60.55	3.25

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REPORT NUMBER	63-19	63ØØ19	CIRCULATION LIMITATION		
REPORT DATE	29 January 1963	Ø163	CIRCULATION LIMITATION OR BIBLIOGRAPHIC	Supersedes	SUPD
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SUBJECT ANALYSIS OF REPORT

DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Calibration	CALB	Computation	COMA	Particle	PART
Gap test	GAPT	Pressure	PRES	Equations	EQUA
Pentolite	PENI	Function	FUNC	Nitro	NITRO
Donor	DONR	Gap	GAPE	Guanidine	GUAN
Explosives	EXPL	Distance	DIST	Wax	WAXE
Measurement	MEAU	Sensitivity	SENV		
Attenuation	ATTE	Solid	SOLI		
Shock wave	SHWV	Propellants	FUEL		
Shock	SHOC	Tetryl	TETY		
Velocity	VELC	Comparison	CMRI		
Plexiglas	PLEX	Experiment	EXPE		
Rod	RODS	Analysis	ANAL		

PRNC-NOL-5070/28 (5-62)

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