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MEMORANDUM REPORT NO. 1778

DETONATION PRESSURE MEASUREMENTS IN TNT AND OCTOL

by

Robert L. Jameson
Albert Hawkins

August 1966

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BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 1778

AUGUST 1966

DETONATION PRESSURE MEASUREMENTS IN TNT AND OCTOL

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Terminal Ballistics Laboratory

RDT&E Project No. 1C014501A32B

ABERDEEN PROVING GROUND, MARYLAND

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RLJameson/ALHawkins/blw
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DETONATION PRESSURE MEASUREMENTS IN TNT AND OCTOL

ABSTRACT

Measurements have been made of the von Neumann spike pressure and Chapman-Jouguet pressure in TNT and Octol by a modification of the technique of Duff and Houston. Spike pressures of 259 kilobars in TNT and 452 kilobars in Octol and Chapman-Jouguet pressures of 213 kilobars in TNT and 314 kilobars in Octol are reported. Comparisons are made to previous data for TNT; no previous measurements for Octol were found for comparison.

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INTRODUCTION

In the measurements of the shock properties of unreacted explosive materials it is important to know the degree to which reaction behind the shock front is contributing to the measurements. The two extremes of a non-reacting shock Hugoniot for an explosive are: the bulk sound velocity at $u = 0$ (u = shock particle velocity) and the von Neumann shock conditions at detonation velocity. The technique reported here is a variation of that of Duff and Houston[1*] which was developed to determine the von Neumann spike conditions and pressure profile behind the spike. Direct measurement of the pressure profile in a steady detonation is not feasible at this time. The dynamic properties in the reacting explosive must be inferred from observation made in a medium placed in contact with the explosive. In this case, optical measurements were made in Plexiglas placed in contact with the face of the TNT and Octol charges which were initiated by plane-wave lenses.

The optical technique described in this report is used for the measurement of shock velocities in Plexiglas as thin as twenty-thousandths of an inch. Results for the inferred shock measurements in TNT and Octol are given.

Theory

According to the widely accepted von Neumann theory of detonation,[2] a detonation is pictured as a non-reactive shock followed by a steady state reaction zone ending in the Chapman-Jouguet plane which is followed by the Taylor wave. When an inert material is placed in intimate contact on the end of a detonating charge, the shock followed by a rarefaction wave is transmitted into the inert material.

In a one-dimensional case, the continuity of pressure and particle velocity at the interface can be used to show that

---

[*] *Superscript numbers denote references which may be found on page 16.*

$$\frac{p_1}{p_2} = \frac{\rho_1 U_1}{\rho_2 U_2}\left(\frac{\rho_2 U_2 + \rho_3 U_3'}{\rho_1 U_1 + \rho_3 U_3'}\right) , \qquad (1)$$

where $U_3' = U_3 + u_1$, p = pressure, ρ = density, U = shock velocity and u = particle velocity.[1] The subscript 1 indicates the conditions in the explosive, 2 indicates the conditions in the inert material and 3 indicates the reflected wave condition in the explosive. If it is assumed that, on reflection, the density behind the reflected wave returns to its initial value ρ_1 then it can be shown that $\rho_3 U_3' = \rho_1 U_1$. Substitution of $\rho_1 U_1$ for $\rho_3 U_3'$ in the preceding equation produces the equation:

$$\frac{p_1}{p_2} = \frac{\rho_2 U_2 + \rho_1 U_1}{2\rho_2 U_2} . \qquad (2)$$

When the densities of both materials are known, and the Hugoniot data for the inert material is also known, it is necessary only to determine the shock velocities at the interface in order to use this approximation.

Experimental Procedure

If measurements of the transit time through various thicknesses of Plexiglas material are made, it is possible to extrapolate U_2 to $\tau = 0$, (where τ is transit time) to determine the value of U_2 at the explosive-Plexiglas interface. Separate measurements of U_1, the steady detonation velocity, were also made. The transit time through the Plexiglas is recorded using a Beckman-Whitley model 339B streak camera which is capable of a writing speed of 9.0 mm/μsec with a resolution of 5 nsec when exposure is made through a 3 mil slit. Samples of Plexiglas discs were prepared by cutting discs from sheet stock and final finishing by rubbing on 600 grit coated abrasive paper. This lapping process is used to produce a flat slightly abraded surface. Only one face of each disc is lapped. The other face is left in the "as received" condition. The discs are thoroughly cleaned in ethyl alcohol and inspected under a 45 power stereo microscope for surface condition. The lapped side is then aluminized by an evaporative coating process.

Explosive charges used in this experiment are carefully examined for surface condition and cavities. The charges are lapped on 600 grit paper under water, when it is necessary to improve the surface condition. The test charges were right cylinders four inches in diameter and one inch high initiated by four-inch diameter plane-wave boosters.

The Plexiglas discs were gauged to one ten-thousandth of an inch and placed on the face of the charge as shown in Figure 1. While held under pressure they were cemented at points on the edges with fast-curing epoxy cement. Thin Plexiglas samples which did not exceed 0.060 inch thickness were 0.375 inch in diameter. It was therefore possible to assemble five discs across the face of each explosive sample. When the thickness exceeded 0.060 inch the diameter was increased such that there would be a 0.250 inch center section free of the effects of side rarefaction. Care was then taken to avoid trapping air under the Plexiglas pellets. Despite these precautions it was necessary to reject some data because of the effect of some trapped air.

The assembled charge was aligned so that the light from an argon flash bomb, used as front lighting, was specularly reflected to the camera as shown in Figure 2. Eastman Kodak Double X film was used in the camera and was processed in undiluted D76R used as a developer. A typical record is shown in Figure 3.

All film records were read on an optical comparator to the closest ten-thousandth of an inch. Times are determined by converting measured distances in the writing direction along the film by a functional relationship with the writing speed of the camera measured at the time of actual recording of the shot.

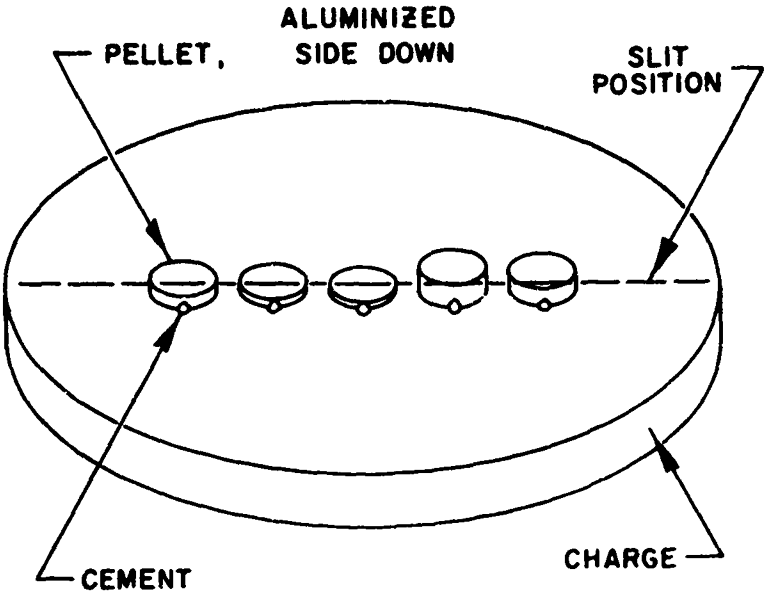

FIG. 1

ARRANGEMENT OF PLEXIGLAS PELLETS ON CHARGE FACE

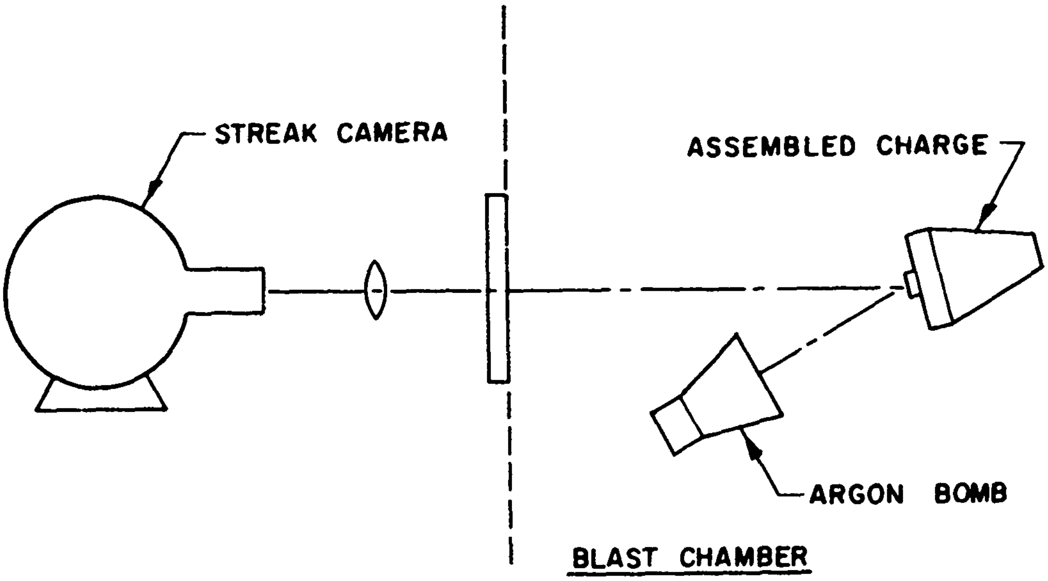

FIG. 2

SKETCH OF ALIGNMENT OF CHARGE WITH REFERENCE TO CAMERA AND ARGON BOMB LIGHTING

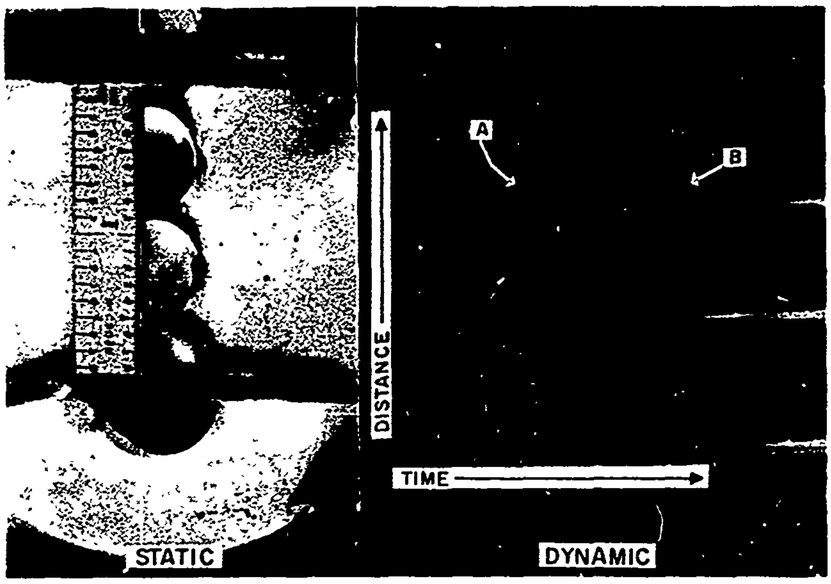

FIGURE 3 - PRINT OF HIGH-SPEED ROTATING MIRROR STREAK CAMERA RECORD OF A SHOCK THROUGH PLEXIGLAS MOUNTED ON THE FACE OF A TNT CHARGE.
A - ARRIVAL OF DETONATION WAVE AT EXPLOSIVE - PLEXIGLAS INTERFACE
B - ARRIVAL OF SHOCK WAVE AT PLEXIGLAS FREE SURFACE

Results

Distance (S) versus time (τ) plots of the shock transit data for TNT and Octol are shown in Figures 4 and 5. Smoothing by least square of the data in this form is useful in determining the end points of the relation $dS/d\tau$ versus τ. In order to better indicate the profile of the pressure wave it is best to plot average velocities through the disc versus average thickness. The most significant least squares fit to the data generated by the spike and the rarefaction wave (Taylor wave) was used to smooth the data in this form, the points in each set being determined by eye. The resulting straight line is the most statistically significant, but should not be viewed as absolutely definitive of the slope of the pressure fall off from the spike. Figures 6 and 7 are plots for TNT and Octol. This data may be refined further by replotting the smoothed data, taking into account the time necessary for the shock to traverse the previous thickness of Plexiglas:

$$U_a = \frac{S_a}{t_a} \text{ at } \frac{S_a}{2} = \bar{S}$$

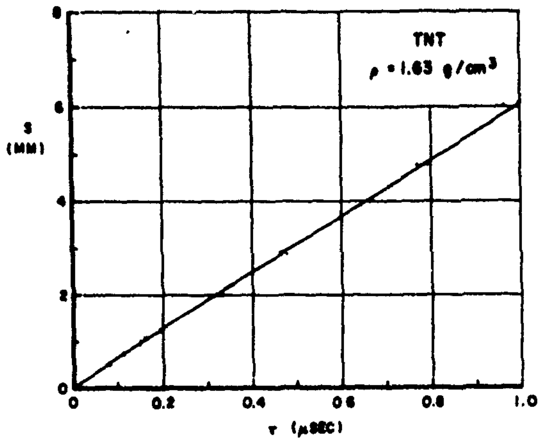

FIGURE 4 - DISTANCE-TIME PLOT FOR SHOCKS IN PLEXIGLAS ON THE SURFACE OF A TNT CHARGE.

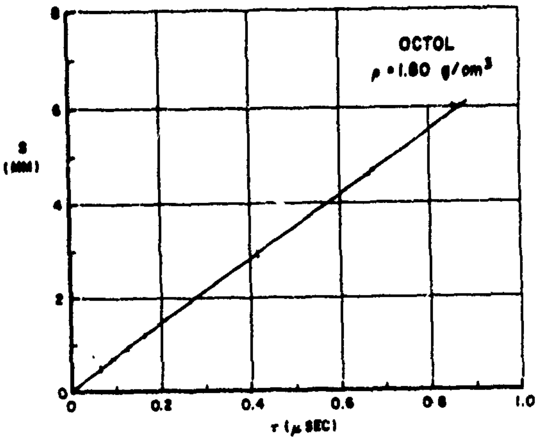

FIGURE 5 - DISTANCE-TIME PLOT FOR SHOCKS IN PLEXIGLAS ON THE SURFACE OF AN OCTOL CHARGE

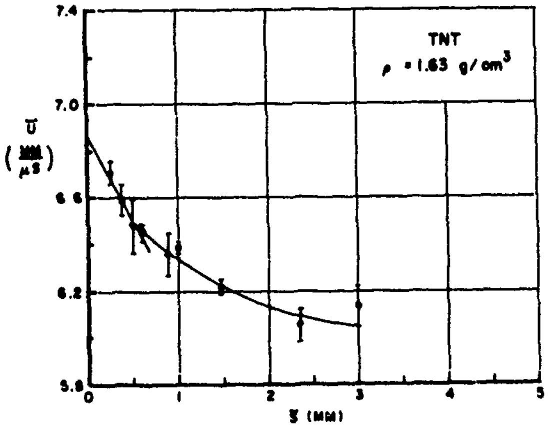

FIGURE 6 - AVERAGE SHOCK VELOCITY PLOTTED AGAINST AVERAGE DISTANCE FROM THE PLEXIGLAS-EXPLOSIVE INTERFACE FOR PLEXIGLAS ON A TNT CHARG

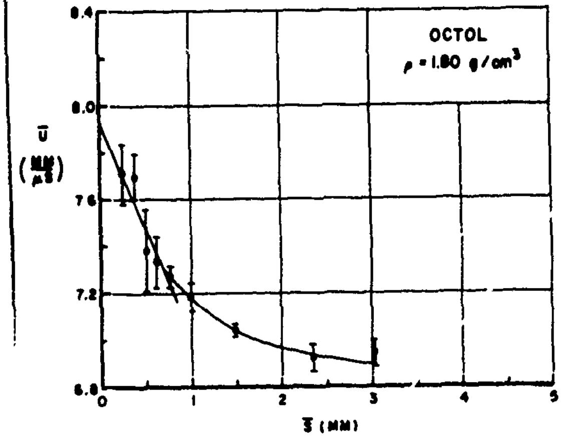

FIGURE 7 - AVERAGE SHOCK VELOCITY PLOTTED AGAINST AVERAGE DISTANCE FROM THE PLEXIGLAS-EXPLOSIVE INTERFACE FOR PLEXIGLAS ON AN OCTOL CHARGE.

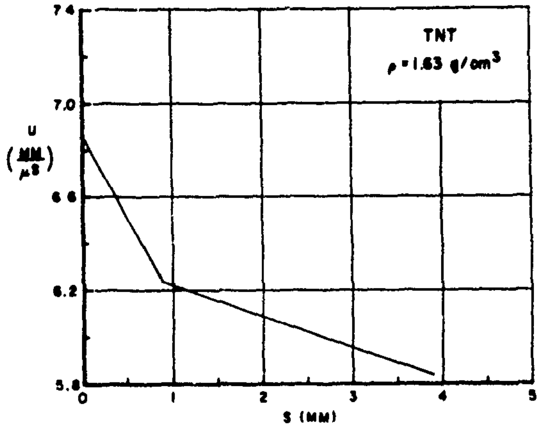

FIGURE 8 - SHOCK VELOCITY IN PLEXIGLAS PLOTTED AGAINST DISTANCE FROM THE PLEXIGLAS-EXPLOSIVE INTERFACE FOR PLEXIGLAS ON A TNT CHARGE.

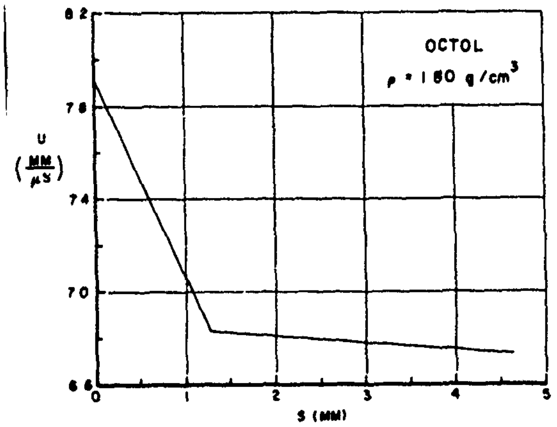

FIGURE 9 - SHOCK VELOCITY IN PLEXIGLAS PLOTTED AGAINST DISTANCE FROM THE PLEXIGLAS-EXPLOSIVE INTERFACE FOR PLEXIGLAS ON AN OCTOL CHARGE

$$U_b = \frac{(S_b - S_a)}{(t_b - t_a)} \text{ at } S_a + \frac{1}{2}(S_b - S_a)$$

where a is the first increment and b is the second. This data is plotted in Figures 8 and 9.

Using the intercept values of Figures 8 and 9, and the Hugoniot equations for Plexiglas[3] which are:

$$U_s = 2.702 + 1.544\, u_p \qquad u_p < 2.6 \tag{3}$$

$$U_s = 3.754 + 1.141\, u_p \qquad 2.7 < u_p < 3.9 \tag{4}$$

$$\rho = 1.184 \qquad u_p \text{ in mm/}\mu\text{sec}$$

where U_s is shock velocity and up particle velocity. The pressure in TNT and Octol can be calculated from Equation (2).

The values for the spike pressure are calculated to be 259 kilobars in TNT and 452 kilobars in Octol. The values of U at the break in the U versus S curve indicates the value associated with the Chapman-Jouguet plane. Using these values with the Plexiglas Hugoniots and Equation (2), the C-J pressure was calculated to be 213 kilobars for TNT and 314 kilobars for Octol. When the pressures, densities and shock velocities are known, the particle velocities can be calculated from the equation

$$u = \frac{P}{\rho U} \quad . \tag{5}$$

The parameters at the spike and at the Chapman-Jouguet plane are shown in Table 1.

TABLE 1

DETONATION PARAMETERS FOR TNT AND OCTOL

	ρ g/cm^3	P kilobars	U mm/μsec	u mm/μsec
TNT Spike	1.630 ± .015	259 ± 5	6.86 ± .03	2.31 ± .05
C-J	1.630 ± .015	213 ± 4	6.86 ± .03	1.90 ± .04
Octol Spike	1.800 ± .015	452 ± 10	8.55 ± .03	2.93 ± .07
C-J	1.800 ± .015	314 ± 7	8.55 ± .03	2.04 ± .05

DISCUSSION OF RESULTS

In the calculation of detonation parameters by the method used in this report the error in P_1, the detonation pressure, is subject to the errors in U_1, ρ_1, U_2 and ρ_2. An error analysis of Equation (2) gives the total differential.

$$dP_1 = \frac{\partial P_1}{\partial U_1} dU_1 + \frac{\partial P_1}{\partial \rho_1} d\rho_1 + \frac{\partial P_1}{\partial U_2} dU_2 + \frac{\partial P_1}{\partial \rho_2} d\rho_2 \; . \tag{6}$$

The partials of P_1 are found using Equations (2), (3) or (4), and (5). We may now write Equation (6) for small variations in P as

$$\Delta P = \frac{\rho_1}{2b}\left[U_2 - a\right] \Delta U_1 + \frac{U_1}{2b}\left[U_2 - a\right] \Delta\rho_1 + \frac{1}{2b}\left[\rho_1 U_1 + \rho_2(2U_2 - a)\right] \Delta U_2 + \frac{U_2}{2b}\left[U_2 - a\right] \Delta\rho_2 \tag{7}$$

where a and b are the coefficients in Equation (3) or (4). For errors in measurement which follow the normal distribution law the error in P can be written

$$(\Delta P_1)^2 = \left[\frac{\rho_1}{2b}(U_2 - a)\right]^2 \left[\Delta U_1\right]^2 + \left[\frac{U_1}{2b}(U_2 - a)\right]^2 \left[\Delta\rho_1\right]^2 + \left[\frac{1}{2b}(\rho_1 U_1 + \rho_2(2U_2 - a))\right]^2 \left[\Delta U_2\right]^2 + \left[\frac{U_2}{2b}(U_2 - a)\right]^2 \left[\Delta\rho_2\right]^2 \tag{8}$$

The evaluation of Equation (8) for the calculation of the total error gives 1.9 percent and 2.3 percent for the spike pressures of TNT and Octol respectively. The errors in calculating the C-J pressures are about the same as for the spike pressure for each explosive.

Some of the previous measurements of C-J pressure in TNT[4,5,6,7] and some measurements and estimates of the spike pressure[4,5,7,8] are compared in Table II.

TABLE II

SPIKE AND C-J PRESSURE COMPARISONS FOR TNT

	Deal[4]	Ilyukhin[5]*	Dremin[6]*	Coleburn[7]	Coleburn[8]	This Work
Spike kilobars	194	326	---	---	237	259
C-J kilobars	178	210	210	187.2	189	213
D mm/μsec	6.951	---	---	6.790	6.81	6.86
ρ g/cm3	1.64	1.62	1.62	1.622	1.614	1.63
Cast		x	x	x	x	x
Pressed	x					

* May be from same experiment

Good agreement between the Soviet C-J work and these measurements is noted. However, Coleburn's[7] pressures are lower than the results reported here. Octol measurements, for comparison to those we have reported could not be found in available literature.

ROBERT L. JAMESON ALBERT HAWKINS

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2a. REPORT SECURITY CLASSIFICATION Unclassified

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3 REPORT TITLE

DETONATION PRESSURE MEASUREMENTS IN TNT AND OCTOL

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

Jameson, Robert L. and Hawkins, Albert

6. REPORT DATE August 1966

7a. TOTAL NO. OF PAGES 19

7b. NO. OF REFS 8

8a. CONTRACT OR GRANT NO.

b PROJECT NO. RDT&E No. 1C014501A32B

c.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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