

LA-7158

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Issued: March 1978

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## High-Temperature Shock Initiation of Explosives

J. B. Ramsay  
B. G. Craig  
J. J. Dick



**los alamos**  
**scientific laboratory**  
of the University of California  
LOS ALAMOS, NEW MEXICO 87545

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This work was supported by a contract from the Air Force Armaments Test Laboratory, Eglin Air Force Base, Florida (Authorization AFL-7-33).

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U.S. Department of Commerce  
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Springfield, VA 22161

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# HIGH-TEMPERATURE SHOCK INITIATION OF EXPLOSIVES

by

J. B. Ramsay, B. G. Craig, and J. J. Dick

## ABSTRACT

The detonation sensitivity to plane shock-wave loading of three polycrystalline, high-density explosives (PBX-9501, DATB, and TNT) was measured for runs-to-detonation up to 2.5 cm in the temperature range 25-150°C. Streak camera recording was used to obtain the shock-wave propagation distance, the initial shock velocity in the explosive, and the free-surface velocity of the driver. For PBX-9501 and DATB no significant change in distance-to-detonation was detected between 25 and 100°C, whereas a decrease in the distance-to-detonation of approximately 30% for the same input pressure was noted for shots fired at 150°C. A small decrease in distance-to-detonation was noted for cast TNT between 25 and 73°C. The time-to-detonation for liquid TNT at 150°C for an input shock strength of 13 GPa was measured. Possible mechanisms leading to increased sensitivity in polycrystalline explosives at high temperature are discussed. However, the nonmonotonic nature of the relationship between pressure and distance-to-detonation as a function of temperature indicates that a simple thermal model is not adequate.

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## I. INTRODUCTION

There are increasing applications where explosives are subjected to temperatures that exceed those specified for the usual military qualification tests. In addition, munitions engulfed in flames and other high-temperature sources can present serious hazards to personnel safety. In cases where the intended use might subject an explosive to temperatures above the usual military specifications ( $-55$  to  $+75^{\circ}\text{C}$ ), it may be desirable to change the composition. However, little information exists on the shock sensitivity of explosives above  $75^{\circ}\text{C}$ . We have evaluated the shock sensitivity (2 to 20 GPa) for cast TNT, liquid TNT, PBX-9501, and pressed DATB. This report summarizes the results.

## II. BACKGROUND

We know that low temperatures decrease the reliability of marginal boosters to initiate detonation in common military explosives such as Composition B, PBX-9404, and TNT. The reliability increases at elevated temperatures. The implication is that the shock sensitivity increases with increasing temperature. Two types of effects might be expected to affect the shock sensitivity. The first is melting, which would alter the initiation behavior from a polycrystalline type to that expected for a homogeneous explosive.<sup>1,2</sup> Secondly, the increase in temperature could increase the shock sensitivity because of the decrease in the density or from an increase in the thermal decomposition rate if the thermal contribution were significant to the initiation mechanism.

Some of the first work on sensitivity at elevated temperatures was performed by Urizar<sup>3</sup> even though the work was not published. He studied the impact sensitivity of RDX, HMX, and PETN using a Type-12 impact tool and showed a decrease in the 50% point from 27 cm at  $20^{\circ}\text{C}$  to 15 cm at  $160^{\circ}\text{C}$  for RDX. Similar, though not necessarily parallel, behavior was observed for HMX and PETN. He also noted that the violence of the explosion increased with increasing temperature. Roth<sup>4</sup> published data to show that the shock sensitivity, as measured by a gap test, increases as the initial temperature increases for RDX, PETN, HNS, and NONA. Roth's data for the 50% gap thickness for PBX-9404 showed no decrease with temperature up to  $150^{\circ}\text{C}$ , but his data obtained by the wedge test did show a slight increase in sensitivity. Schwarz<sup>5</sup> showed that a less energetic flyer plate is required to initiate a pellet of TATB when the initial temperature is  $260^{\circ}\text{C}$  compared to that required when the temperature is  $25^{\circ}\text{C}$ .

For this program we have examined the sensitivity to plane-wave shock initiation for three selected explosives in the 25 to 150°C range . TNT was selected because it is thermally stable, but has a phase change at 83°C. PBX-9501 (95 wt% HMX/2.5 wt% Estane/2.5wt% nitroplasticizer) and plastic-bonded DATB (95 wt% diamino-trinitro-benzene/5 wt% Viton A) were selected as thermally stable compositions. Some difficulty was experienced in preparing the DATB charges.

### III. EXPERIMENTAL TECHNIQUE

In a study of the shock sensitivity of an explosive, the initial pressure in the explosive and the distance and time from shock entrance to the transition of the shock wave to a detonation are the variables desired. The wedge technique<sup>6</sup> measures the latter two variables directly, whereas the initial pressure must be inferred from a measure of the initial shock velocity in the explosive and from a knowledge of the equation of state and pressure of the driver system generating the shock in the explosive. Figure 1 shows the wedge test used in this study. The driver system is selected to generate a pressure of the desired magnitude and to provide as plane and simultaneous an impact across the base of the wedge-shaped test specimen as possible. The pressure in the driver is determined by measuring the free-surface velocity of the booster using a reflected image technique.<sup>6,7</sup> A streak camera record obtained from such a test assembly is shown in Fig. 2. The history of the shock wave through the wedge is observed as a phase velocity along the slant face of the wedge using a smear camera. The point of transition-to-detonation is manifest as an abrupt change in the phase velocity. The initial shock velocity in the sample is computed from the phase velocity along the slant face. From a knowledge of the equation of state of the driver and the shock velocity and initial density of the test specimen, the pressure can be estimated by shock matching.<sup>6,8</sup>

Heating the test specimen and final driver plate, using our usual booster/driver systems, would adversely affect the performance of the booster system. We developed a new assembly that incorporated an air gap between the final driver plate and the main booster assembly. A polycarbonate plastic (Lexan®) withstood the temperature and was used for the two plates to form the air gap. The air gap provided sufficient thermal insulation to protect the booster

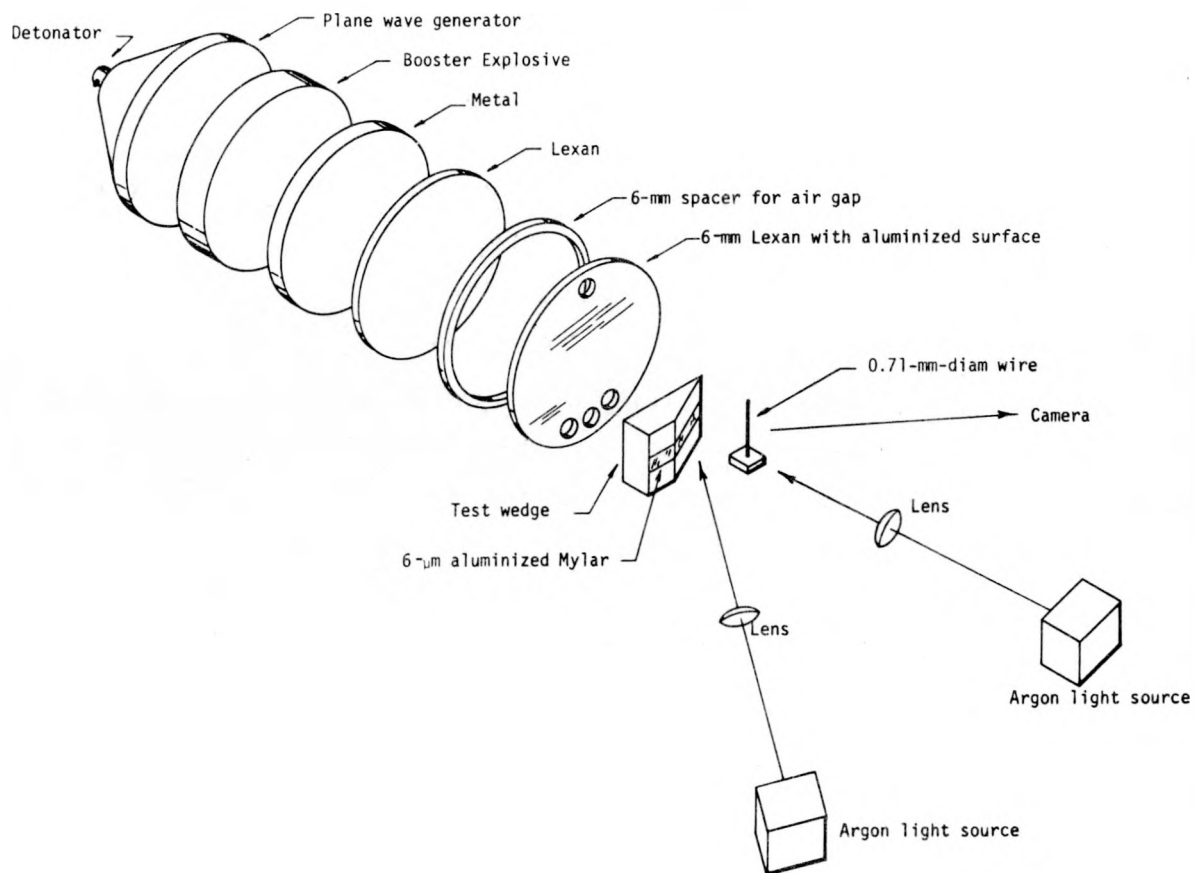


Fig. 1.

Shot assembly and optical design of wedge shots. The wire and its image provide a measure of the free-surface velocity of the driver which, when combined with the initial density and shock velocity in the test specimen, provides an estimate of the pressure in the specimen. The air layer in the booster/driver assembly was used to insulate the main booster charge from the temperature of the test specimen.

explosive. Carter and Marsh<sup>9</sup> have measured the shock Hugoniot for this material. The sample was mounted in an insulated box made of heat-cured rigid foam, and the air in the box was heated with electrical resistance heaters mounted directly in the box. Air was circulated around the explosive sample and behind the last booster plate to minimize temperature variations within the sample. The temperature in the explosive sample could not be monitored directly, but was simulated and monitored with a thermocouple imbedded in a 25-mm-diam by 25-mm-long inert plastic cylinder located in the box adjacent to the explosive. The assembly in the insulated box is shown in Fig. 3. We

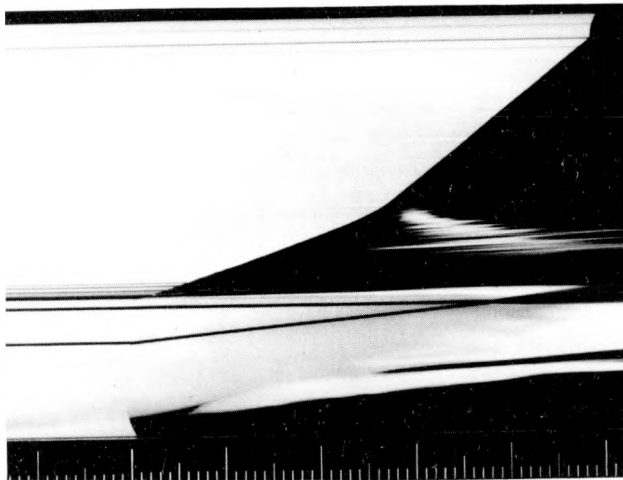


Fig. 2.  
Smear camera record for DATB at 30°C (E-4476). Time increases from left to right with space increasing upwards. Each major division is 1.0  $\mu$ s. The wire and its image for measuring the free-surface velocity of the Lexan<sup>®</sup> driver plate are located below the wedge record.

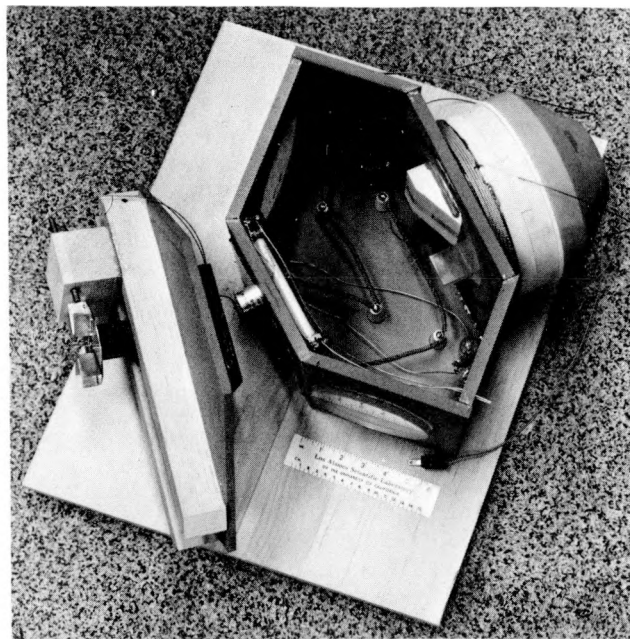


Fig 3.  
Charge assembly for wedge tests between 70 and 150°C.

believe that the thermal gradients in the sample were less than 5°C. It normally required about 2.5 h to raise the temperature to 150°C, and we do not believe that any significant thermal decomposition occurred. However, it should be pointed out that exposure of PBX-9501 to a temperature slightly above 150°C for a few minutes can initiate thermal decomposition of the HMX. When the plastic binder softens or melts, it can dissolve a small amount of HMX. The thermal decomposition rate in solution is higher than in the solid phase. The vapor pressure of the plasticizer at 150°C was estimated to be about 13 Pa (0.1 mm Hg) and there was some evidence of a slight loss of this material. This may be part of the source of the larger variation of the 150°C data.

#### IV. DATA ANALYSIS

The distance and the time-to-detonation in the explosive wedge were read directly from the smear camera record. For a given shot, the distance can be



determined to about 0.05 mm and the time to within 0.03  $\mu$ s. Nonplanarity and nonsimultaneity of the input pressure wave will increase the uncertainty of these values, although probably not more than double. The greatest uncertainty in the analysis of wedge data is the estimation of the initial shock velocity. The toe of the wedge is generally not perfectly tapered to a feather edge and can be obscured by small jets and variations in illumination. Therefore, it is necessary to extrapolate backwards to obtain the initial velocity. The theory of initiation of solid, polycrystalline explosive is not sufficiently advanced to provide a functional relationship to guide in the extrapolation. The extrapolation of the phase velocity to the interface is complicated by irregularities arising from the nonplanarity of the entering shock and by the acceleration of the shock in the test explosive. A number of techniques have been used to make this extrapolation. In this study, we chose to smooth and differentiate the numerical space-time data obtained using a running linear least squares fit of three sequential points, each with equal weight. The slope of each line was assigned as the velocity at the median point. These velocities were then plotted as a function of time and visually extrapolated to zero time. Figure 4 shows a plot in which the extrapolation was reasonably clean and a good estimate of the initial velocity was obtained. A poor record is shown in Fig. 5. Despite the wide range of initial shock velocities that could be obtained from such a record, the range in pressure (the desired quantity) is within about 5% or less, even on the worst records. An error of this size does not affect the results presented here. All data reported here were obtained using the running linear least squares technique. The older data reported were obtained by reanalyzing the records.

The initial density above normal ambient conditions was estimated using an expansion coefficient of  $1.6 \times 10^{-4}/^{\circ}\text{C}$ . This is the reported value<sup>10</sup> for PBX-9501 over the range -60 to 70 $^{\circ}\text{C}$  and is essentially the same for TNT over the same range. Lacking any data above this range and for the DATB/Viton A composition, this value was used for the three materials. Errors from this source are negligible. The initial pressure in the explosive was estimated by assuming that the expansion isentrope and reflected shock Hugoniot for the driver plate material were the mirror-image of the single-shock Hugoniot and that the single-shock Hugoniot was linear in the shock-velocity/particle-velocity plane.<sup>8,11</sup> With these assumptions, the particle velocity and

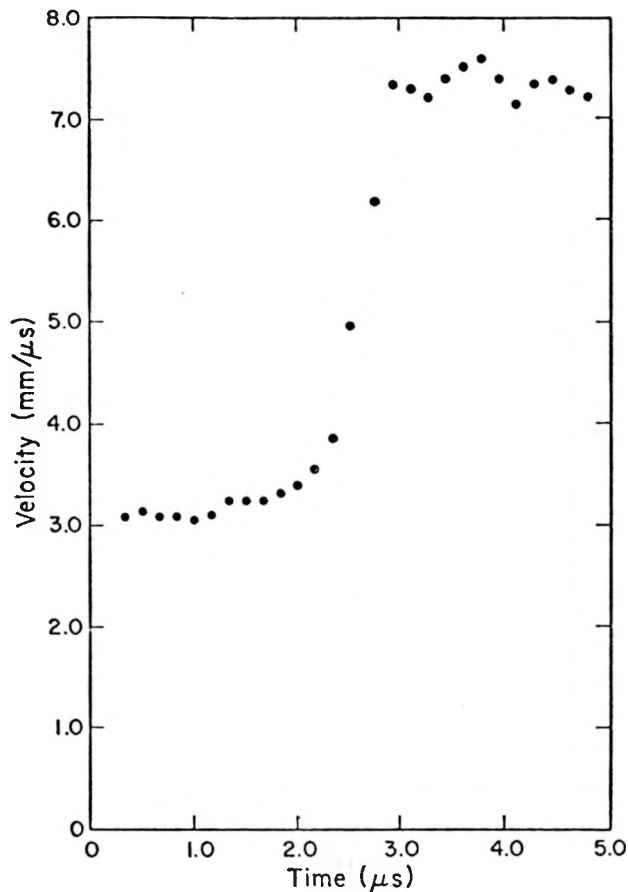


Fig. 4.  
Running linear least squares fit (3 points/line) E4476 (DATB). Example of velocity profile that can be extrapolated cleanly to  $t = 0$ .

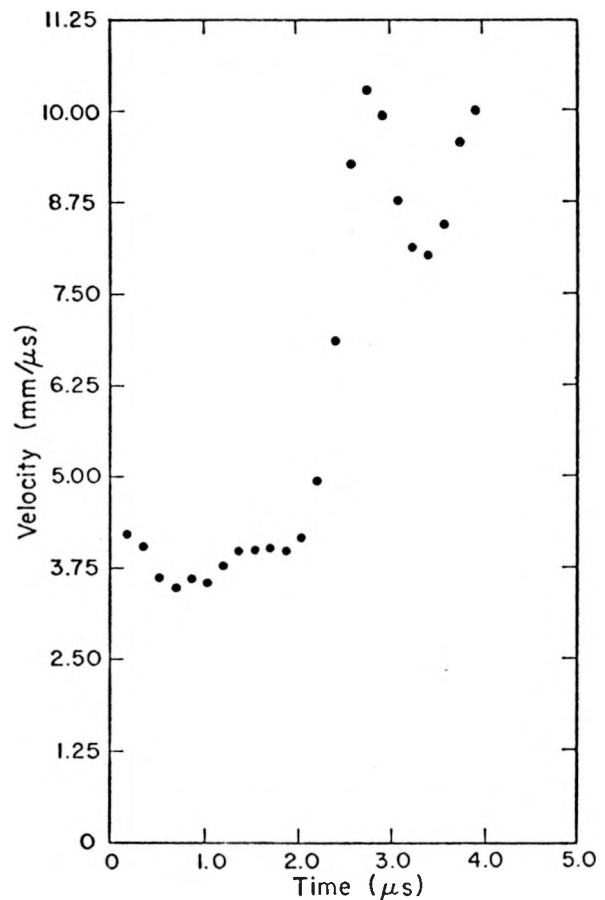


Fig 5.  
Running linear least squares fit (3 points/line) E4411 (PBX-9501). Example of velocity profile that does not extrapolate cleanly to  $t = 0$ .

pressure at the driver/explosive interface were obtained from a solution of the resulting algebraic equations.

## V. EXPERIMENTAL RESULTS

### A. PBX-9501 (95 wt% HMX; 2.5 wt% Estane; 1.25 wt% BDNPA; 1.25 wt% BDNPF)

This material is representative of plastic-bonded HMX explosives. It is more thermally stable than the better known PBX-9404. The differential thermal analysis curve shows an endothermic peak at about  $190^{\circ}\text{C}$ , which is the phase change from  $\beta$  to  $\delta$  HMX.<sup>12,13</sup> An exothermic rise begins at about  $200^{\circ}\text{C}$  rising approximately exponentially to about  $300^{\circ}\text{C}$  where complete

decomposition occurs. Eleven shots were fired using PBX-9501 from current Los Alamos Scientific Laboratory (LASL) production. The nominal density for all charges at 25°C was  $1.833 \pm 0.002 \text{ g/cm}^3$ . The temperatures studied were 25, 100, and 150°C with a pressure range of 2 to 8 GPa. The data obtained are summarized in Table I. The shock Hugoniot in the shock-velocity( $U_s$ )/particle-velocity( $u$ ) plane is shown in Fig. 6 and the initial pressure vs distance-to-detonation data are plotted in Fig. 7. Data obtained from shots fired by Craig<sup>14</sup> in 1972 using PBX-9501 of the same nominal density are also plotted in the two figures. The data for  $U_s$ - $u$  from both sets of experiments at 24°C agree within the expected experimental error. Both data points taken at 100°C lie above the line defined by the 24°C data, though possibly not significantly above. All five points obtained at 150°C lie below the line, and although there is more scatter than normal, we believe this difference is significant. In the plot showing shock sensitivity, no distinction among the older data, the new 24°C data, and the 100°C data can be detected. The data obtained at 150°C show an increase in shock sensitivity with the transition occurring at about 70% of the distance for a shot fired at 24°C with the same initial pressure. The one point at 131°C is indistinguishable from the ambient data in the  $U_s$ - $u$  plane (Fig. 6) and may indicate a slight increase in sensitivity as shown in Fig. 7. However, during the experiment this sample was heated to above 140°C, cooled to ambient, and reheated. This cycling might have affected the performance.

#### B. Cast TNT

An upper temperature of 73°C was selected for TNT to avoid possible melting of impurities. The data obtained are presented in Table II. Figure 8 shows the relationship between shock velocity and particle velocity obtained for this study plus data previously obtained by Craig.<sup>14</sup> The earlier data are "creamed" TNT of the same nominal density; however, because of different lots of starting material and minor variations in casting procedures, the sets may not be directly comparable. They are included to show the type and size of variations expected to occur in normal production. The break in the  $U_s$ - $u$  curve has been reported previously.<sup>15</sup> The initial-pressure/distance-to-detonation data are summarized in Fig. 9. Considering the new data on a booster-by-booster basis, all three experiments show an increase in sensitivity with temperature. However, by including the earlier data, the temperature effect is masked by the spread.

TABLE I

SHOCK INITIATION DATA FOR PBX-9501 AT 24, 100, AND 150°C

Shot No.	Temp (°C)	Density (g/cm <sup>3</sup> )	$U_s$ (mm/ $\mu$ s)	$u$ (mm/ $\mu$ s)	P (GPa)	$x^*$ (mm)	$t^*$ ( $\mu$ s)	Booster	$U_{fs}$ (mm/ $\mu$ s)
E4366	23	1.833	3.15	0.37	2.16	17.8	4.98	A	0.936
E4370	131	1.80	3.24	0.36	2.08	16.0	4.60	A	0.903
E4380	150	1.79	2.86	0.40	2.03	12.8	4.02	A	0.933
E4417	150	1.79	2.91	0.41	2.13	12.9	3.87	A	0.965
E4372	23	1.833	3.54	0.50	3.26	9.06	2.26	B	1.271
E4411	100	1.81	3.95	0.50	3.57	9.70	2.39	B	1.324
E4410	150	1.79	2.99	0.57	3.03	8.47	2.20	B	1.295
E4391	24	1.833	4.56	0.81	6.73	3.52	0.72	C	2.097
E4416	100	1.81	4.45	0.80	6.44	3.13	0.67	C	2.052
E4415	150	1.79	3.91	0.88	6.17	2.48	0.59	C	2.098
E4457	150	1.79	4.24	0.85	6.42	3.04	0.61	C	2.097

## BOOSTER SYSTEMS

- A. P-081; 25 mm Baratol; 18 mm foam; 11 mm stainless steel; 51 mm polycarbonate; 6.3 mm air; 6.3 mm polycarbonate.
- B. P-081; 25 mm Baratol; 38 mm polycarbonate; 6.3 mm air; 6.3 mm polycarbonate.
- C. P-081; 25 mm Baratol; 24 mm stainless steel; 8.9 mm polycarbonate; 6.3 mm air; 6.3 mm polycarbonate.

- - -

$U_s$  = acceptor shock velocity (experimentally measured).

$u$  = acceptor particle velocity (calculated from  $U_s$ ,  $U_{fs}$ , and density).

P = acceptor pressure (calculated from  $U_s$ ,  $U_{fs}$ , and density).

$x^*$  = distance-to-detonation (experimentally measured).

$t^*$  = time-to-detonation (experimentally measured).

$U_{fs}$  = booster free-surface velocity (experimentally measured).

C. Liquid TNT

Four shots were fired to measure the shock sensitivity of liquid TNT at 150°C. A characteristic of liquid explosives is the narrow range of shock

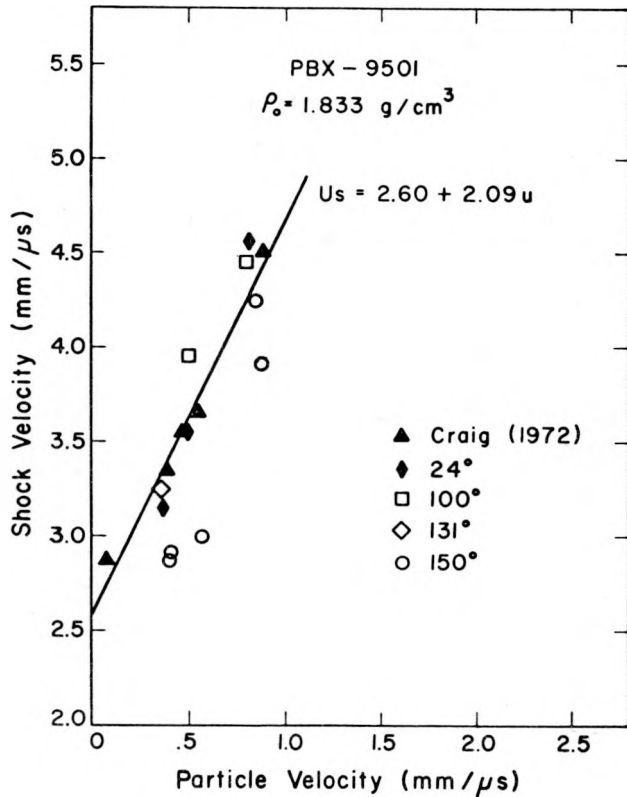


Fig. 6.  
Shock Hugoniot for PBX-9501 at three  
temperatures.

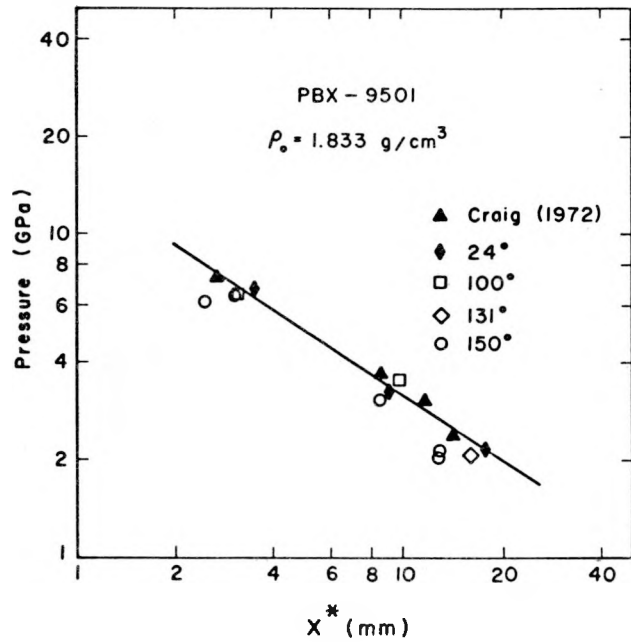


Fig 7.  
Relationship between initial pressure  
and distance-to-detonation for  
PBX-9501 at three temperatures.

pressures over which the transition-to-detonation can be observed. In one of the four shots, we observed that detonation in the compressed liquid overtook the shock front  $0.23 \mu\text{s}$  after the shock entered the liquid. The pressure generated by the driver was estimated by firing a duplicate shot and measuring the free-surface velocity of the polycarbonate plate. From the pressure in the driver and the reported equation of state for liquid TNT<sup>16</sup> at  $85^\circ\text{C}$ , the pressure in the liquid TNT was estimated as 13.5 GPa. The distance before the shock front was overtaken by the detonation from the rear was estimated as 1.2 mm. Decreasing the pressure to 12 GPa in another shot, no transition was observed in a 50-mm run. Campbell et al.<sup>1</sup> report an induction time of  $0.7 \mu\text{s}$  for liquid TNT shocked to 12.5 GPa at an initial temperature of  $85^\circ\text{C}$ . The estimated distance for this result is 3.4 mm. These data are included in Fig. 9 showing the relationship between initial pressure and distance-to-detonation for cast TNT. These data show that for pressures of about 12.5 GPa or above

TABLE II  
SHOCK INITIATION DATA FOR CAST TNT AT 25 AND 73°C

Shot No.	Temp (°C)	Density (g/cm <sup>3</sup> )	$U_s$ (mm/μs)	$u_p$ (mm/μs)	P (GPa)	$x^*$ (mm)	$t^*$ (μs)	Booster	$U_{fs}$ (mm/μs)
E4451	25	1.634	4.43	1.03	7.43	>25.4	>5.22	A	2.407
E4373	25	1.634	4.85	1.16	9.17	22.2	4.30	B	2.746
E4377	73	1.62	4.69	1.16	8.80	18.9	3.80	B	2.705
E4393	25	1.634	5.05	1.26	10.4	20.3	3.84	C	2.992
E4399	73	1.62	4.80	1.34	10.4	14.3	2.77	C	3.069
E4412	25	1.634	5.49	1.69	15.1	6.96	1.24	D	3.877
E4414	73	1.62	5.44	1.69	14.9	4.42	0.76	D	3.867

#### BOOSTER SYSTEMS

- A. P-081; 25 mm TNT; 32 mm polycarbonate; 6.3 mm air; 6.3 mm polycarbonate.
- B. P-081; 25 mm PBX-9404; 32 mm polycarbonate; 6.3 mm air; 6.3 mm polycarbonate.
- C. P-081; 25 mm PBX-9404; 19 mm polycarbonate; 6.3 mm air; 6.3 mm polycarbonate.
- D. P-081; 51 mm PBX-9404; 19 mm polycarbonate; 6.3 mm air; 6.3 mm Lexan®.

- - -

$U_s$  = acceptor shock velocity (experimentally measured).  
 $u$  = acceptor particle velocity (calculated from  $U_s$ ,  $U_{fs}$ , and density).  
 $P$  = acceptor pressure (calculated from  $U_s$ ,  $U_{fs}$ , and density).  
 $x^*$  = distance-to-detonation (experimentally measured).  
 $t^*$  = time-to-detonation (experimentally measured).  
 $U_{fs}$  = booster free-surface velocity (experimentally measured).

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liquid TNT is "more shock sensitive" than the cast material, whereas below 12 GPa, it is less "sensitive."

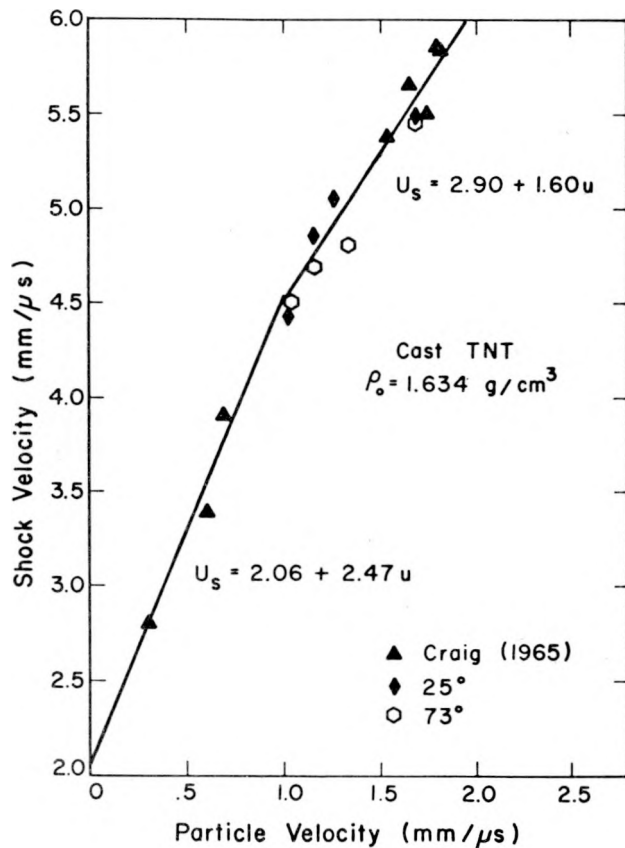


Fig. 8.  
Shock Hugoniot for cast TNT at two  
temperatures.

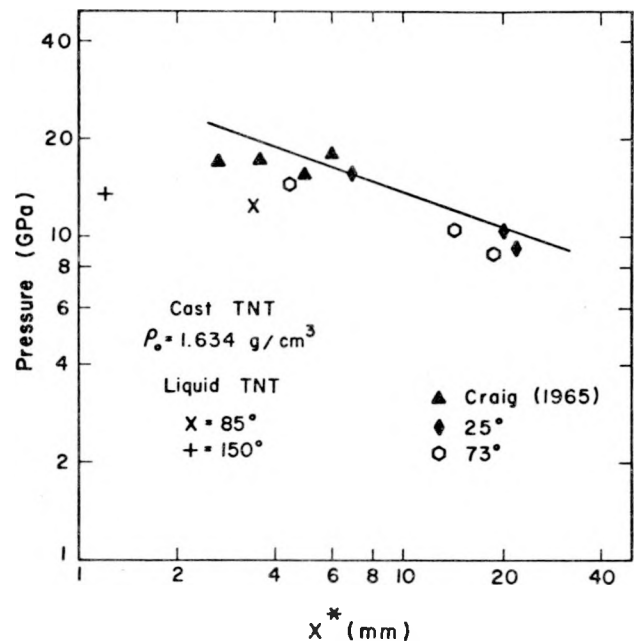


Fig. 9.  
Relationship between initial pres-  
sure and distance-to-detonation for  
cast TNT at 25 and 73°C and liquid  
TNT at 85 and 150°C.

#### D. DATB (95 wt% DATB/5 wt% Viton A)

This material was elected for test as an example of a reasonably insensitive, thermally stable explosive. A discussion on the preparation of the DATB is presented in the Appendix. The nominal density obtained was about  $1.64 \text{ g/cm}^3$ , which is about 90% of the theoretical density. This is lower than we had hoped to prepare, but because of the need to complete the experimental work on the shock sensitivity, we decided to use the material without further formulation development. The formulation was identified locally as X-0299. The data obtained for X-0299 are presented in Table III. The shock sensitivity at  $25^\circ\text{C}$  proved to be about the same as that for the PBX-9501 formulation and is presented graphically in Fig. 10. With this increased sensitivity, we did

TABLE III  
SHOCK INITIATION DATA FOR DATB AT 25, 100, AND 150°C

Shot No.	Temp (°C)	Density (g/cm <sup>3</sup> )	$U_s$ (mm/ $\mu$ s)	$u$ (mm/ $\mu$ s)	P (GPa)	$x^*$ (mm)	$t^*$ ( $\mu$ s)	Booster	$U_{fs}$ (mm/ $\mu$ s)
E4475	26	1.641	2.49	0.47	1.92	> 23.2	> 11.3	A	0.982
E4495	150	1.61	2.16	0.46	1.59	> 16.0	> 8.0	A	0.895
E4476	30	1.642	3.12	0.68	3.48	9.59	2.75	B	1.487
E4492	25	1.641	2.91	0.70	3.35	10.4	3.14	C	1.488
E4460	25	1.636	3.03	0.71	3.51	9.32	2.83	C	1.521
E4493	100	1.62	3.33	0.58	3.12	10.9	3.28	C	1.324
E4479	150	1.61	2.71	0.65	2.82	6.82	2.17	C	1.335
E4498	22	1.636	3.15	0.75	3.88	8.65	2.42	D	1.628
E4499	100	1.62	3.19	0.65	3.34	8.15	2.32	D	1.429
E4500	150	1.61	2.95	0.69	3.28	5.46	1.69	D	1.466

#### BOOSTER SYSTEMS

- A. P-081; 25 mm Baratol; 18 mm foam; 19 mm stainless steel;  
5.1 mm polycarbonate; 6.3 mm air; 6.3 mm polycarbonate.
- B. P-081; 25 mm PBX-9404; 24 mm stainless steel; 26 mm polycarbonate;  
6.3 mm air; 6.3 mm polycarbonate.
- C. P-081; 25 mm PBX-9404; 24 mm stainless steel; 19 mm polycarbonate;  
6.3 mm air; 6.3 mm polycarbonate.
- D. P-081; 51 mm Composition B; 24 mm stainless steel; 19 mm poly-  
carbonate; 6.3 mm air; 6.3 mm polycarbonate.

- - -

$U_s$  = acceptor shock velocity (experimentally measured).  
 $u$  = acceptor particle velocity (calculated from  $U_s$ ,  $U_{fs}$ , and density).  
 $P$  = acceptor pressure (calculated from  $U_s$ ,  $U_{fs}$ , and density).  
 $x^*$  = distance-to-detonation (experimentally measured).  
 $t^*$  = time-to-detonation (experimentally measured).  
 $U_{fs}$  = booster free-surface velocity (experimentally measured).

not succeed in obtaining as broad a spread in the pressure range as we hoped, which limits the precision of the sensitivity curve. Again, as with PBX-9501,



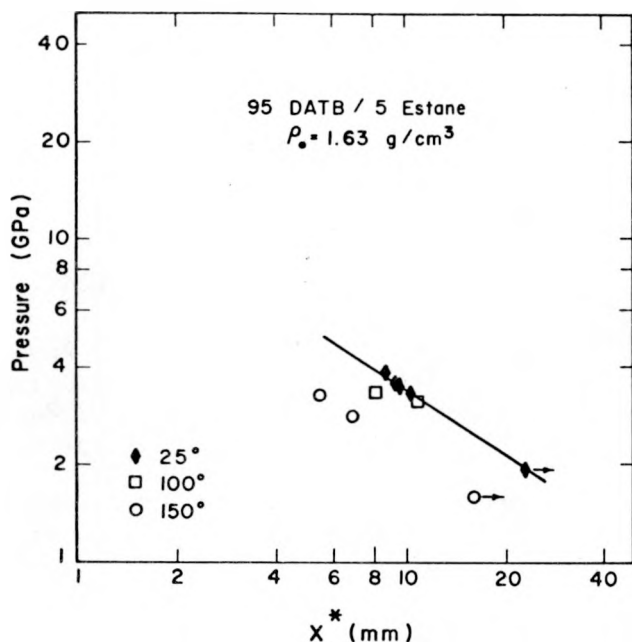


Fig. 10.  
 Relationship between initial pressure and distance-to-detonation for DATB at three temperatures. The arrows indicate that the transition was not observed up to the distance where the point is plotted.

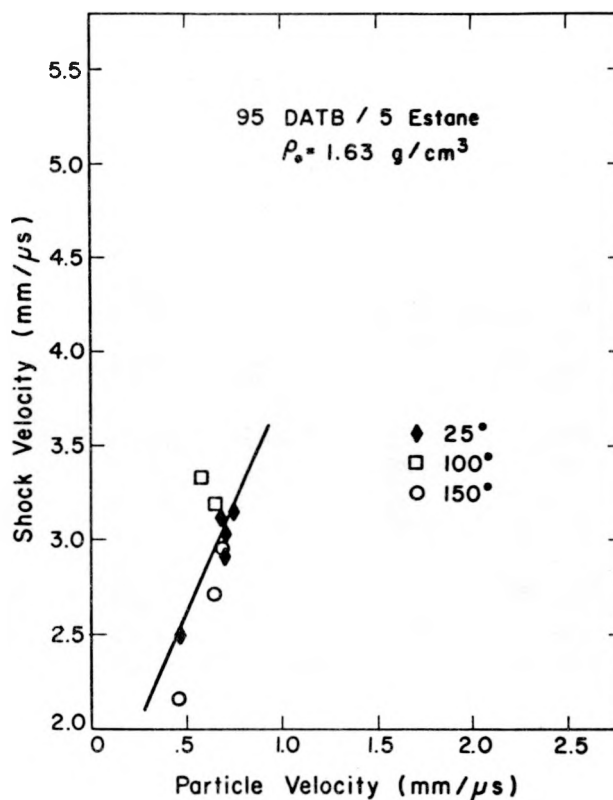


Fig 11.  
 Shock Hugoniot for 95 DATB/5 Estane at three temperatures.

the data for charges at 100°C show no significant change in shock sensitivity. Those fired at 150°C do appear to be somewhat more sensitive, with the transition occurring at approximately 70% of the distance of the equivalent 25°C experiment. The shock-velocity/particle-velocity data show considerable scatter relative to the range of the data as shown in Fig. 11. Again, as with the PBX-9501, the data obtained at 150°C lie below the 25°C line (that is, the material is somewhat more compressible), whereas data obtained at 100°C lie above the line.

## VI. DISCUSSION

The data for the polycrystalline explosives lie in the direction expected, but do not suggest a model for the effect of temperature. The data do permit bounds to be placed on temperature effects within the range studied. Also,

the data provide the necessary input to calculate two-dimensional geometric, divergent, and confinement effects by using the computer programs Forest Fire<sup>17</sup> and 2DL.<sup>18</sup> Basically, for temperatures well below melting or decomposition of any component, plastic bonded explosives (exemplified by PBX-9501, PBX-9404, and DATB/Viton A) do not exhibit a significant change in shock sensitivity. However, as a higher temperature is reached, particularly as it approaches some physical or chemical change in the material (that is, the melting point of TNT, or the softening or melting of the binder in PBX-9501 and DATB/Viton A), an increase in the shock sensitivity can be expected. The effect of thermal cycling on the sensitivity of these solid explosives has not been examined adequately. It is known that cycling will introduce flaws into the material, and it is expected that the flaws would increase the shock sensitivity. With respect to handling safety, the failure diameter of explosives decreases with increasing temperature; that is, a smaller stimuli could initiate accidental detonation.<sup>19</sup>

Within the accuracy of the pressure estimates from the two data points for liquid TNT, the decrease in induction time is about what would be expected. That is, for homogeneous explosive, a simple thermal initiation model<sup>1,20</sup> can be used to predict, at least roughly, the induction time expected for a given temperature and input pressure. Generally, liquid explosives are not of concern to munition designers. However, should partial melting occur in a munition containing a TNT-based explosive and the liquid TNT phase be in contact with the initiator, then significant changes in firing efficacy could be expected. Cavitation in liquid explosives will reduce the shock pressure required for initiation by several orders of magnitude.<sup>19,21</sup> Agitation of a molten explosive from aircraft vibration could easily create an extremely sensitive system.

#### ACKNOWLEDGMENTS

The interest and care shown by John E. La Berge and his assistants at the firing site ensured the veracity of the results. W. C. Chiles designed, executed, and assisted in firing the shots above ambient conditions. His skill and knowledge made this project possible.

This work was supported by contract from the Air Force Armaments Testing Laboratory at Eglin Air Force Base, Florida (Authorization No. ATL-7-33).

Capt. H. R. Lewis and later T. Floyd of EAFB supervised the contract for the Air Force. Their support is gratefully acknowledged.

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APPENDIX  
PREPARATION OF DATB/VITON-A CHARGES

by  
T. Rivera

The DATB used was supplied by Chemtronics and had a particle size distribution as shown in Table A-I.

We found that preparing a satisfactory PBX is very difficult because very fine agglomerates tend to form. The procedure for preparing a 23-kg batch of X-0299 follows.

A lacquer containing 1.1 kg of Viton A dissolved in 5.0 kg of ethyl acetate is prepared. The DATB (21.6 kg) is slurried in 45.4 kg of water at 60°C. The slurry is agitated for about 1 h. The lacquer is added to the slurry with continued agitation. Sufficient ethyl acetate (about 11 kg) is added to form an organosol. With continued agitation and while temperature

is maintained at 60°C, 51 kg of quench water is added to induce agglomeration. At this point, it is necessary to add a small amount of n-butyl acetate ( $\approx 0.5$  kg) to gather the "fines."

The temperature is raised to  $\approx 68^\circ\text{C}$  to distill the azeotrope. The resulting material presses to a density of 1.636 to 1.641 g/cm<sup>3</sup>, compared with the theoretical maximum density of 1.835, even though maximum pressing conditions within the limitation of the apparatus are used [138 MPa (20,000 psi)] with three 5-min cycles at 110°C.

Because of the physical characteristics of the DATB and the Viton A, the material presses to a low density. The DATB particle-size distribution is not optimum for high pressed density, and the Viton A exhibits poor coating properties at the low concentration in X-0299.

TABLE A-I  
DATB PARTICLE-SIZE DISTRIBUTION

<u>Particle Size (<math>\mu\text{m}</math>)</u>	<u>Wt% Retained</u>
125	0.3
90	0.3
60	1.7
45	1.9
30	16.0
20	29.4
20	50.4