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A NEW TECHNIQUE FOR DETERMINING THE SHOCK INITIATION SENSITIVITY OF EXPLOSIVES*

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DISCLAIMER

Abstract

A new technique for determining the shock initiation sensitivity of explosives is described. It involves a flyer plate impinging upon the test explosive to induce initiation of detonation. An electrically exploded foil propels the flyer plate, which is a thin disk of polyimide (Kapton) 1 mm in diameter; the charging voltage applied to the capacitor discharge fireset is used to preselect the desired velocity of the flyer plate. Its impact on the explosive introduces a rectangular pressure pulse, P, whose amplitude depends on the velocity of the flyer at impact and the shock properties of the flyer and the explosive. The duration of the pulse, τ, depends upon flyer thickness. The test objective is to establish the critical pressure at a given duration which results in a 50% probability of detonating the explosive. The data, presented in a log P-log τ plot, generate a demarcation line between detonation and nondetonation regions.

In our experiments the impact pressure was in the range of 1 to 10 GPa and the duration from 0.039 to 0.070 μs. We evaluated pentaerythritol tetranitrate (PETN) and three forms of hexanitrostilbene (HNS). For both materials the variation of the threshold stimulus with initial compaction density was measured. Since a single flyer thickness was used in all but one of the experiments, the data for each explosive give only a single value (P, τ) on the demarcation line which separates detonation from nondetonation. Additional tests with other flyer thicknesses are needed to define this line over a broad range of τ.

This new technique employs conventional laboratory equipment and a simple, inexpensive test device. The initiation stimulus may be expressed in a clearly defined form which is directly applicable to safety or performance computations.

Introduction

The initiation sensitivity of explosives has been measured by many methods. Some of the more common ones are included in Table I. These and similar tests provide useful information to the experimenter and permit the ranking of explosives according to their relative sensitivity values. One serious limitation of these tests is that the input stimulus delivered to the explosive has not been quantified. Rank-order lists generated by one method are often different from rank-order lists generated by another method. A more complete characterization of the input stimulus might explain some of these anomalies or sensitivity reversals. Two such cases have been analyzed (1) which confirm this need for an accurate definition of the input stimulus.

The impact of a thin flyer plate on an explosive provides a reproducible means for applying a pressure whose intensity, P, and duration, τ, are independently controlled. Walker and Wasley (2) have shown that an independent assessment of P and τ is essential to define the threshold initiation sensitivity based on the critical energy concept for explosives such as PBX-9404 and TNT. DeLongueville showed that some explosives do not follow the cirtical energy concept but can be characterized by a critical curve in the pressure-time plane (1).

It is the intent of this report to describe a test method which utilizes a simple, flyer-plate impact system to provide a fully characterized input stimulus for initiation sensitivity testing. This device can be used to map out the critical lines or curves which describe sensitivity to shock for explosive materials.

Experimental Technique

Test Device

A small test device, identified as the TC-817, was used to provide the input shock stimulus. This device, which was originally conceived by Stroud (3), is shown in Fig. 1 along with the acceptor pellet. The firing set was a capacitor discharge unit which, when discharged, applied a current pulse through the metal bridge-foil; this vaporized the foil, propelling the Kapton flyer to the desired impact velocity. The velocity determined the impact pressure intensity and the flyer thickness determined the pressure duration. Since the shock impedance of the flyer was less than that of the explosive, a well-controlled, single-step, rectangular pulse was introduced into the test explosive.

Two methods were used to calibrate the flyer velocity as a function of electrical input. The streak camera method is illustrated in Fig. 2. The camera was a Beckman and Whitely Model 189 which provided a timing accuracy of ± 1/4% and a total measurement accuracy over short flight distances of approximately ± 5%.

During a test on the TC-817, light is produced when the copper foil bursts. Since Kapton is transparent, light can travel through the flyer during the free-flight period. Hence, light is transmitted through the lucite window and is observed with the camera. When the flyer impacts the lucite, the stress produces changes in the optical properties of the lucite indicating the time of impact of the flyer on the window. Using onset of light from the foil as the start time, total flight time can be determined over a preselected interval. Therefore, average flyer velocity can be computed. The streak camera records showed that the center of the flyer impacted the target first (by as much as 0.05 μs).

A second and more precise method, VISAR,* was used to measure the entire velocity history. Different histories were measured as a function of charging voltage. From these data velocity versus displacement was computed, and it was determined that a flight distance of 0.38 mm was an appropriate standoff distance for the flyer to reach 90% or more of terminal velocity.

Figure 3 shows the flyer velocity for this standoff distance versus charging voltage. The streak camera data are also given for comparison but were not used in subsequent calculations. The data in Fig. 3 apply only to a specific firing set whose lumped circuit characteristics match those given (C = 5.32 μF, L = 180 nH, R = 88 mΩ). The circuit impedance plays a significant role in establishing flyer velocity.

A more fundamental plot (5) of the data, flyer velocity versus burst-current density (burst current/cross section of foil), is given in Fig. 4. This presentation is independent of the circuit characteristics. Note that the fit is linear when the burst-current density is greater than 400 GA/m^2. The nonlinearity below 400 GA/m^2 probably results from

*Acronym for Velocity Interferometer System for Any Reflector; operational details in Ref. 4.

the influence of flyer shear properties and other edge effects. Since velocity measurements by VISAR are accurate within ± 1% and burst-current density measurements within ± 2%, system accuracy within ± 2.5% is reasonable for the data in Fig. 4.

A charging voltage of about 600 V (corresponding to a burst-current density of 180 GA/m^2) represented the minimum electrical input for which any flyer velocity was achieved; at less than 600 V the flyer was perturbed by the electrical discharge and showed some bulging, but did not shear out and achieve free flight.

Test Procedure

The following step-by-step procedure was used to conduct an initiation sensitivity test on a typical explosive.

1. The group of test devices were assembled per Fig. 5.

2. The charging voltage was preselected to provide the desired flyer velocity (e.g., 2000 volts for 2.40 mm/μs).

3. For each shot the current through the bridge-foil and the voltage across the foil were recorded on oscilloscope traces (see Fig. 6). Burst current was that value in time at which the voltage peak occurred. Explosive response, i.e., detonation or nondetonation, was noted by measuring the time from flyer impact to shock output and comparing this value with that calculated for steady detonation. Rough equivalency of timing indicated detonation. Dent block response was also noted. Lack of an audible "bang" supported by lack of powder consumption were obvious indications of nondetonation.

4. An "up-down" method, in which the charging voltage was adjusted upward after a nondetonation and downward after a detonation, was used to determine the threshold voltage. Threshold voltage is that value of charging voltage on the firing set which, when discharged, results in a flyer velocity sufficient to induce a 50% probability of initiation to detonation. In these early experiments, only five to nine samples were expended per test; a more rigorous application of the Bruceton technique (6) with a larger sample size would improve the statistical accuracy of the data.

5. The burst current density was determined at the threshold voltage and the corresponding flyer velocity, v_f, was taken from Fig. 4.

6. Shock pressure, P, at the explosive surface was determined graphically per Fig. 7 using v_f and the Hugoniot data on the unreacted explosives and Kapton (Appendix A); pressure duration, τ, was computed as illustrated.

Test Results

Shock sensitivity data for several explosive types are contained in Table II; these include three different forms of HNS and one form of PETN along with initial density variations for each of the two kinds of explosives. The data are also presented graphically in the log P-log τ plots of Figs. 8 and 9.

The demarcation line separating detonation from nondetonation for PETN is shown in Fig. 8. The slope of the line was shown as -1/2 based on some unpublished data. A sharp dependence on initial density is clearly shown. Low density PETN is relatively shock sensitive and is not much different from the single crystals of β-lead azide reported on by Chaudhri (7). That datum is included for comparison in Fig. 8. This does not imply that the present usage of PETN is hazardous, but it should encourage caution in applications where shock environments might provide sufficient stimuli. Of course shock is only one of several hazard environments, including electrostatic fields, which affect the selection of an explosive.

HNS data are given in Fig. 9. HNS-II has the largest particle size (150 μm, mean length); HNS-I and HNS-SF are fine-particle-size materials (35 and 7 μm, respectively) and HNS-SF is supposed to be purer than HNS-I. The data show that HNS-II is less sensitive than either of the other two forms; no investigation was instituted to correlate different performance with specific chemical or physical properties, although particle size probably has some effect.

The role of original density upon sensitivity is illustrated for HNS-SF; the trend toward increased sensitivity, as density was decreased, duplicated the results obtained for PETN.

An additional datum for HNS-SF at density of 1.50 Mg/m^3 was obtained with a flyer whose thickness was 0.127 mm, providing a τ of 0.070 microseconds. The demarcation line separating detonation from nondetonation was assumed to be a straight line connecting the two points; these data indicate the slope of the line to be approximately -1/4, considerably different from that for PETN. The slope of the demarcation line is believed to be a significant sensitivity parameter, but experimental verification is needed.

The "excess transit time" data of Table II indicate that all samples initiated promptly.

On each experiment where the flyer velocity was just below the threshold for initiation, post-mortem examination revealed a cavity in the explosive sample. Generally there was evidence of melting based on the glassy appearance of the HE surface.

A measure of the precision or repeatability, of this test technique is illustrated by the plot of Fig. 10. The constancy of performance is shown for a 2-year time span for HNS-SF when gaged both by burst-current density at initiation threshold and by impact pressure at initiation threshold. It is of interest that the mean pressure at threshold for the 2-year period was 6.8 ± 0.1 GPa.

Conclusions and Recommendations

A new technique, employing conventional laboratory equipment and a simple test device, has been used to provide shock initiation sensitivity data. The initiation stimulus may be quantified. The stimulus is regulated by firing-set charging voltage, on a finely adjustable basis.

It was shown that the test is capable of providing initiation sensitivity data which distinguishes differences between explosive types (PETN, HNS).

It was shown that the test is able to distinguish changes in sensitivity due to differences in initial density (PETN, HNS) and to differences in morphology (HNS).

It was shown that the test has the potential for good precision. Planned future work includes the following:

- Obtain P-τ sensitivity data for a range of pulse durations so that an accurate demarcation line may be established for each sample formulation.

- Improve the one-dimensional character of the test. This includes providing better flyer planarity at impact and assuring adequate flyer diameter, especially for explosives that exhibit long growth-to-detonation distances or large "critical" diameters.

- Extend the flyer velocity achievable in both directions.

- Expand the data bank of Hugoniot data for unreacted explosives (or other energetic materials).

References

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TABLE I

Some Common Initiation Sensitivity Tests

Test Method	Reference (No.)
• Small Scale Gap Test	Ayres (8)
• Rifle Bullet Impact	USAMC (9)
• Susan Test	Dobratz (10)
• Drop Hammer Impact Test	USAMC (9)
• Skid Test	Dobratz (10)

TABLE II

Summary of Initiation Sensitivity Data for PETN and HNS

Explosive	Density (Mg/m^3)	Current Density at Threshold (GA/m^2)	Flyer Velocity at Threshold (mm/μs)	Initiation Conditions: P (GPa)	Initiation Conditions: τ (μs)	Initiation Conditions: Excess Transit Time* (μs)
PETN	1.60	405	1.70	4.5	.043	-0.08
	1.40	345	1.45	3.2	.045	-0.04
	1.20	220	.75**	1.0	.047	+0.01
HNS I	1.60	755	2.42	7.2	.040	-0.01
HNS II	1.60	910	2.73	8.3	.039	+0.04
HNS-SF	1.60	710	2.37	6.9	.040	0.00
	1.50	660	2.26	6.5	.041	-
	1.50	760	2.05	5.8	.070	-
	1.30	640	2.22	6.4	.041	+0.01

*Difference in elapsed time between: (1) flyer impact on the acceptor until shock output and (2) time for steady detonation to have occurred over the same distance. Estimated accuracy ± 0.01 μs.

**Taken from Fig. 3

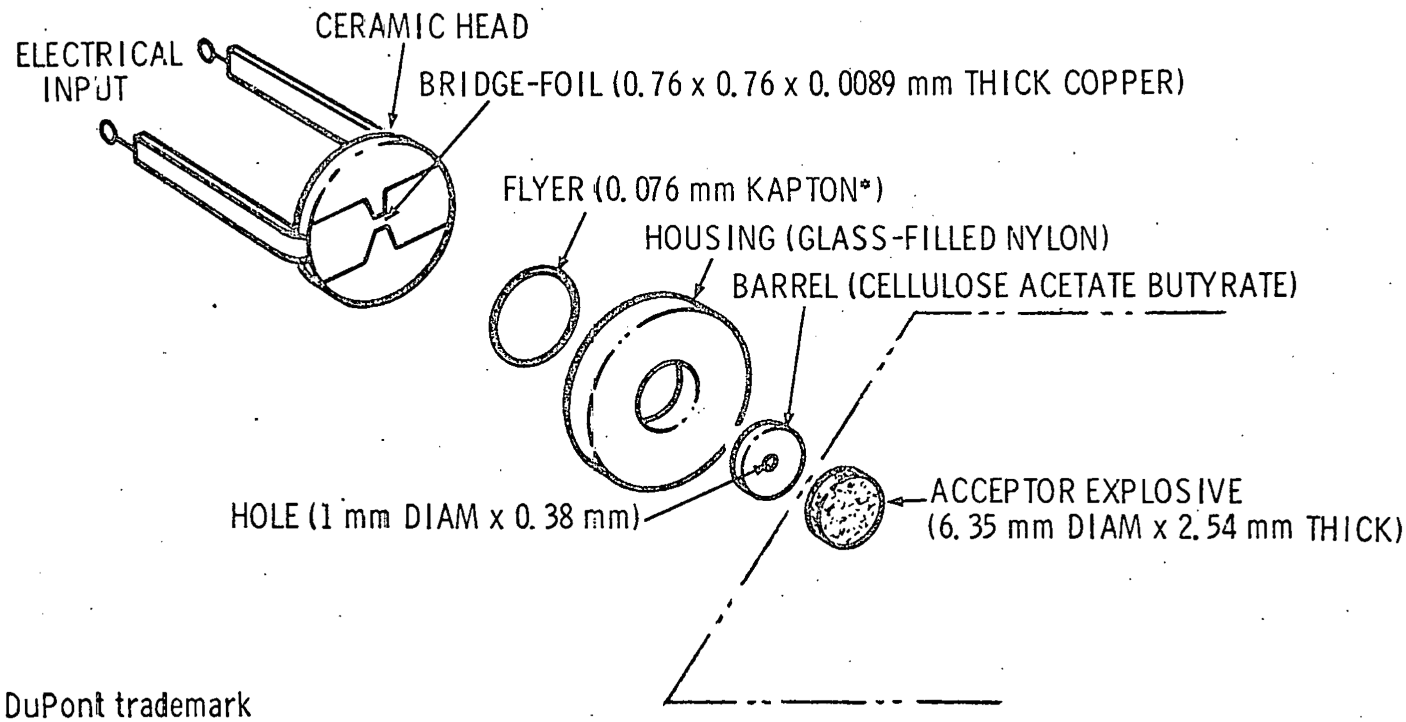
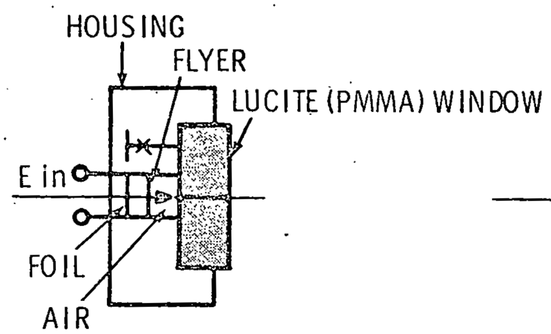
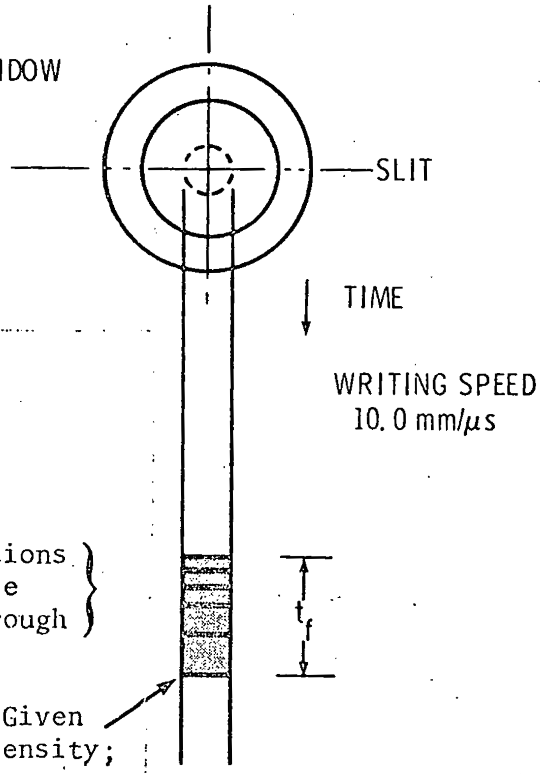


Fig. 1. Exploded View of the TC-817 with Acceptor Explosive





- Barrel Length, x
- Light is Generated by Bursting Foil
- Light Intensity Fluctuations are Related to the Double Transit of the Shock through the Kapton
- Impact of Flyer/PMMA is Given by a Sharp Change in Intensity; t_f is the Flight Time.
- $v_f = \dfrac{x_2 - x_1}{t_{f_2} - t_{f_1}}$

Fig. 2. Schematic Drawing for Streak Camera Measurement of Flyer Velocity

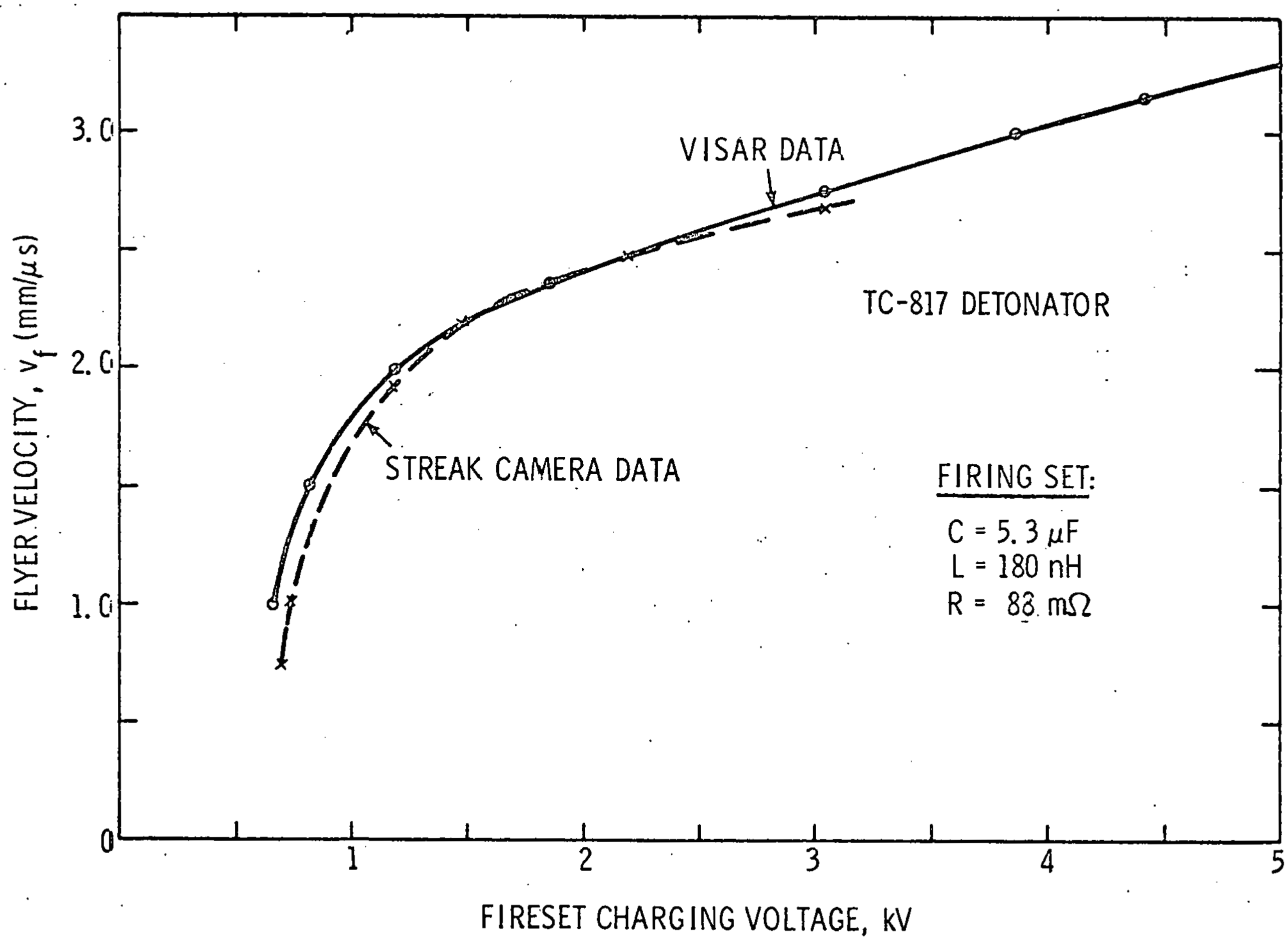


Fig. 3. Flyer Velocity vs Charging Voltage

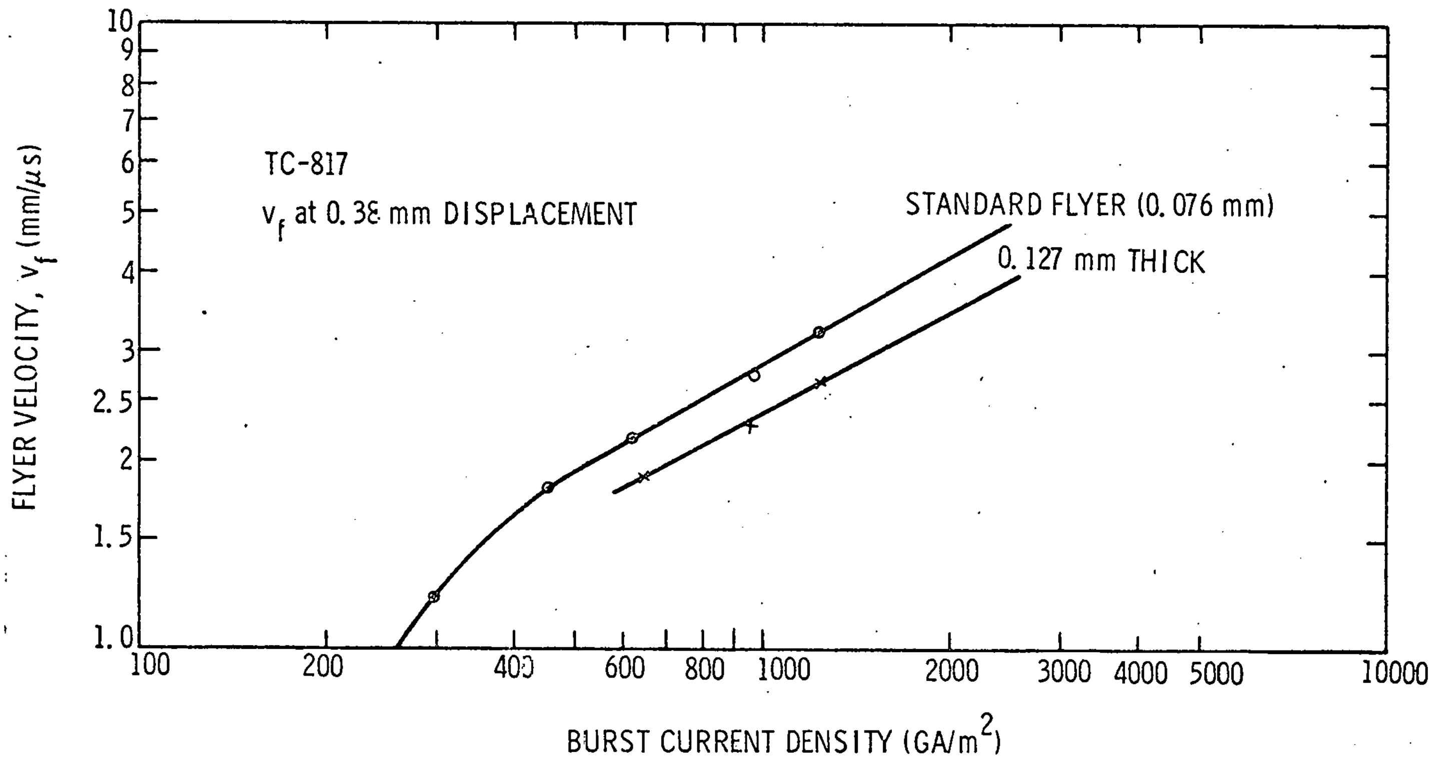


Fig. 4. Flyer Velocity vs Burst Current Density

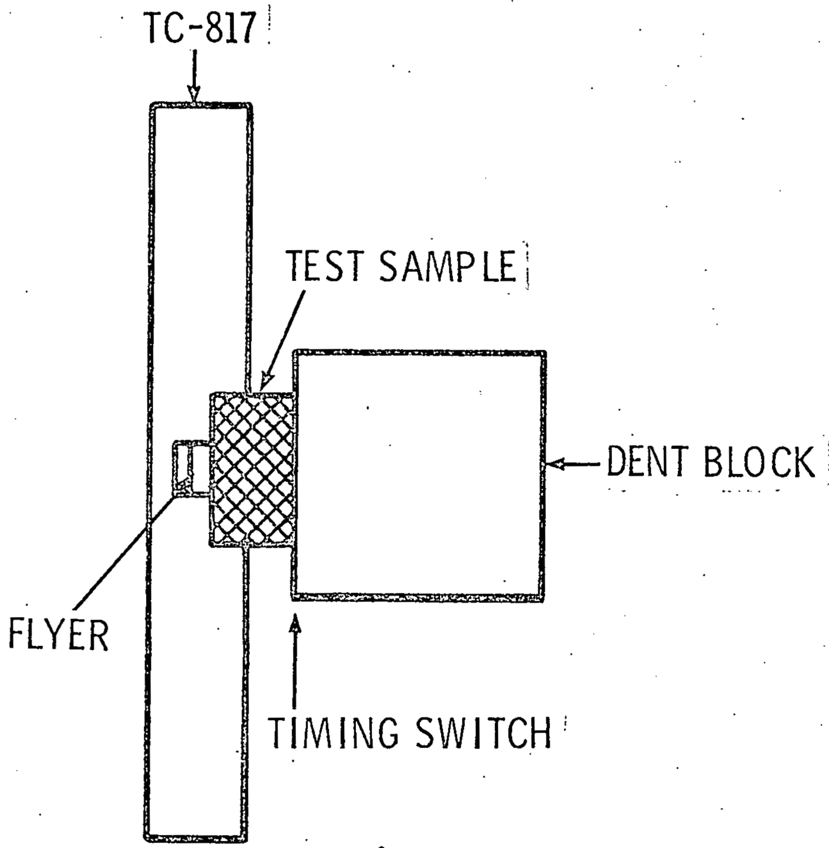


Fig. 5. Schematic Drawing (Cross-Section) of Test Assembly

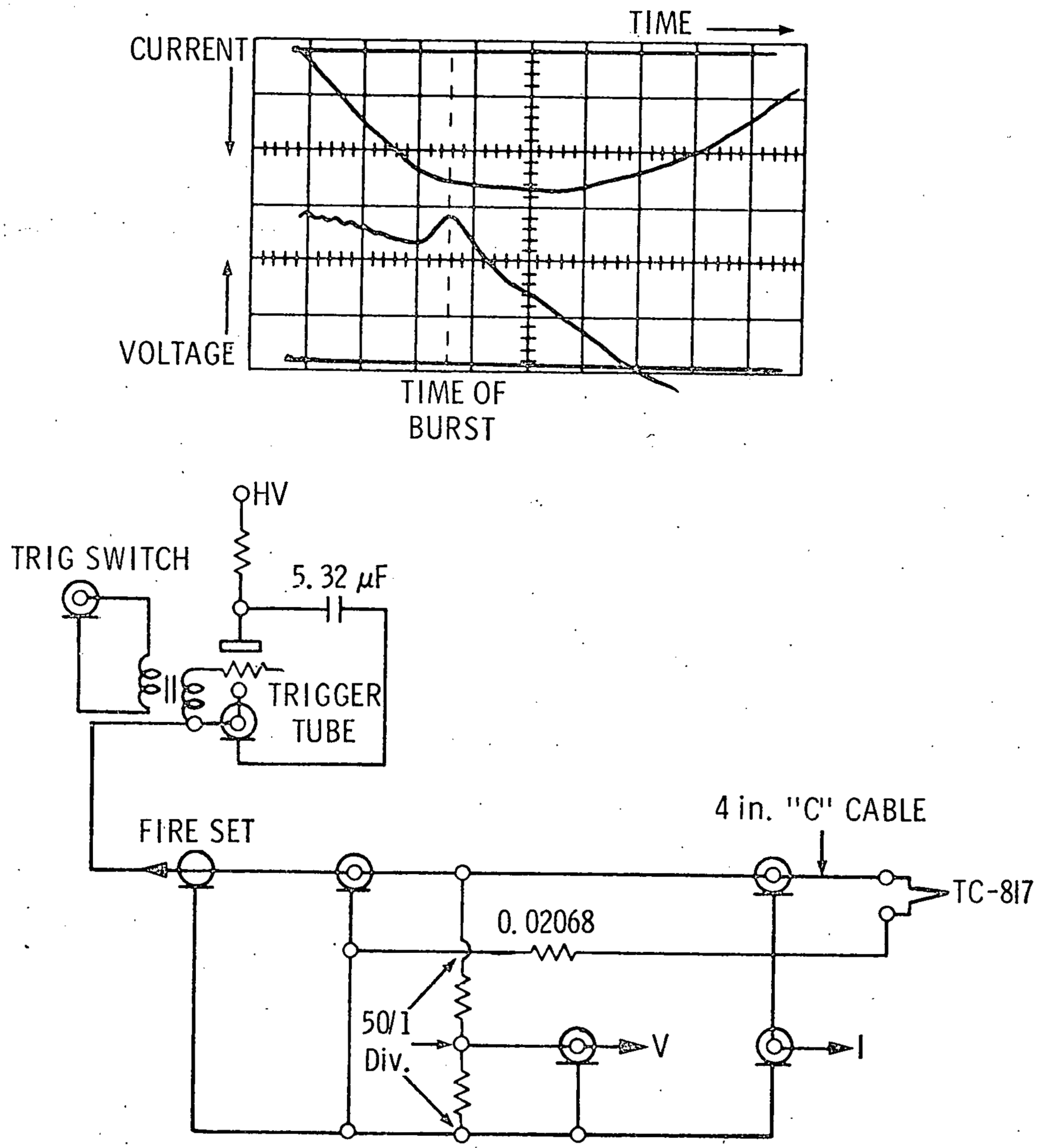
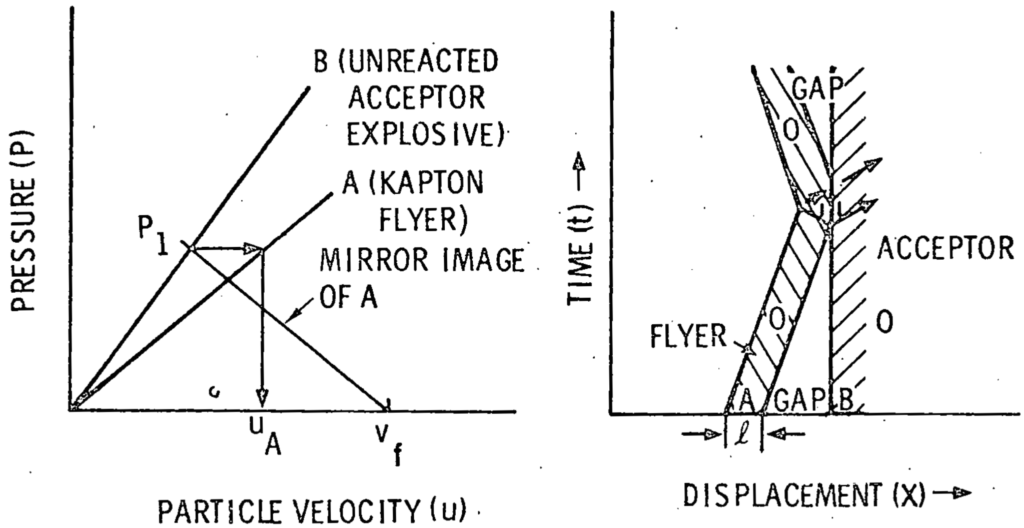


Fig. 6. Typical Oscilloscope Record and Measurement Circuit



P_1 = Pressure Imparted to Acceptor When Kapton Impacts at Velocity, v_f

$$\tau = \frac{2\ell u_A \rho_A}{P_1}$$

where

τ = Pulse Duration of P_1

ℓ = Thickness of Flyer

u_A = Particle Velocity in Flyer

ρ_A = Original Density of Flyer

Fig. 7. Graphical Solution to Determine P_1 and τ from P-u and x-t Diagrams

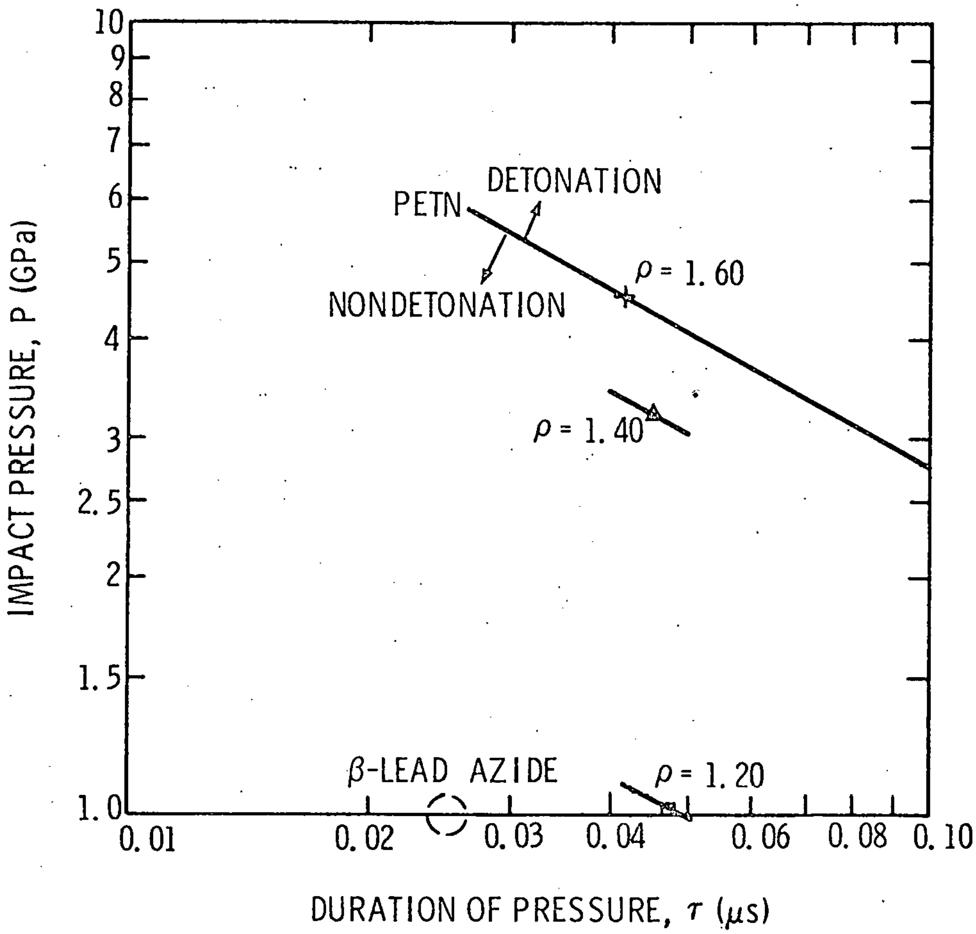


Fig. 8. Initiation Sensitivity of PETN

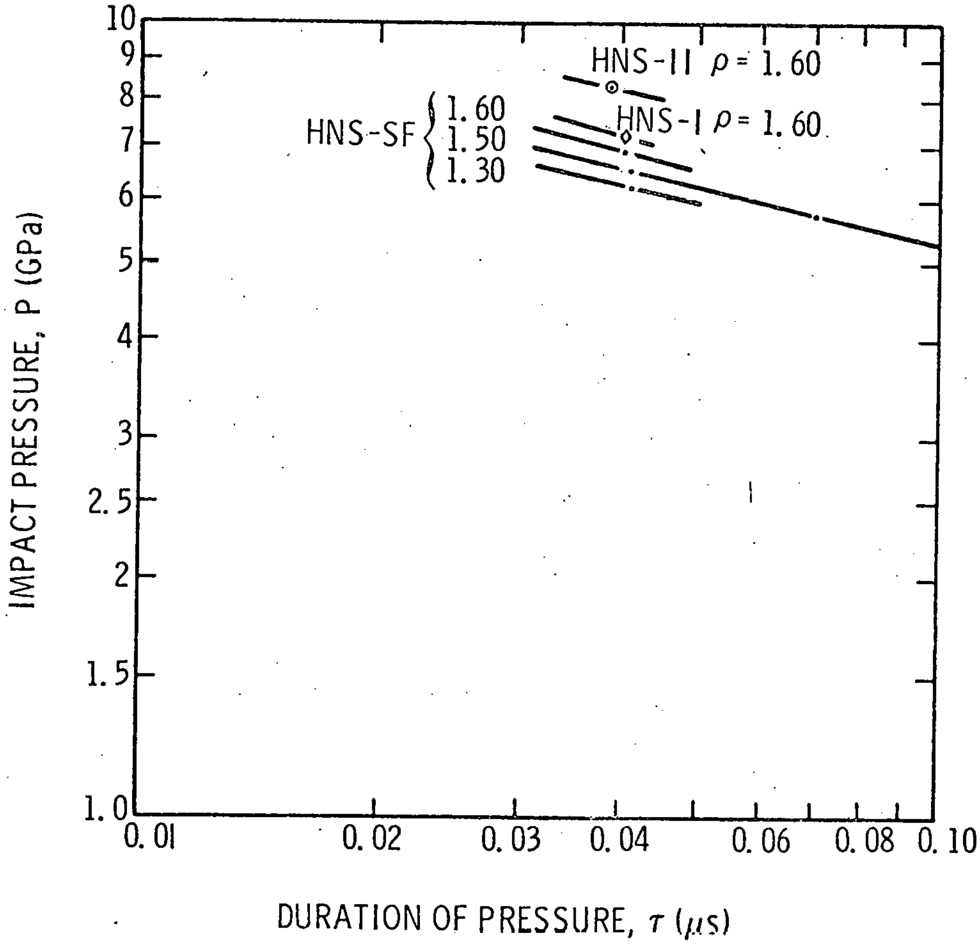


Fig. 9. Initiation Sensitivity of HNS

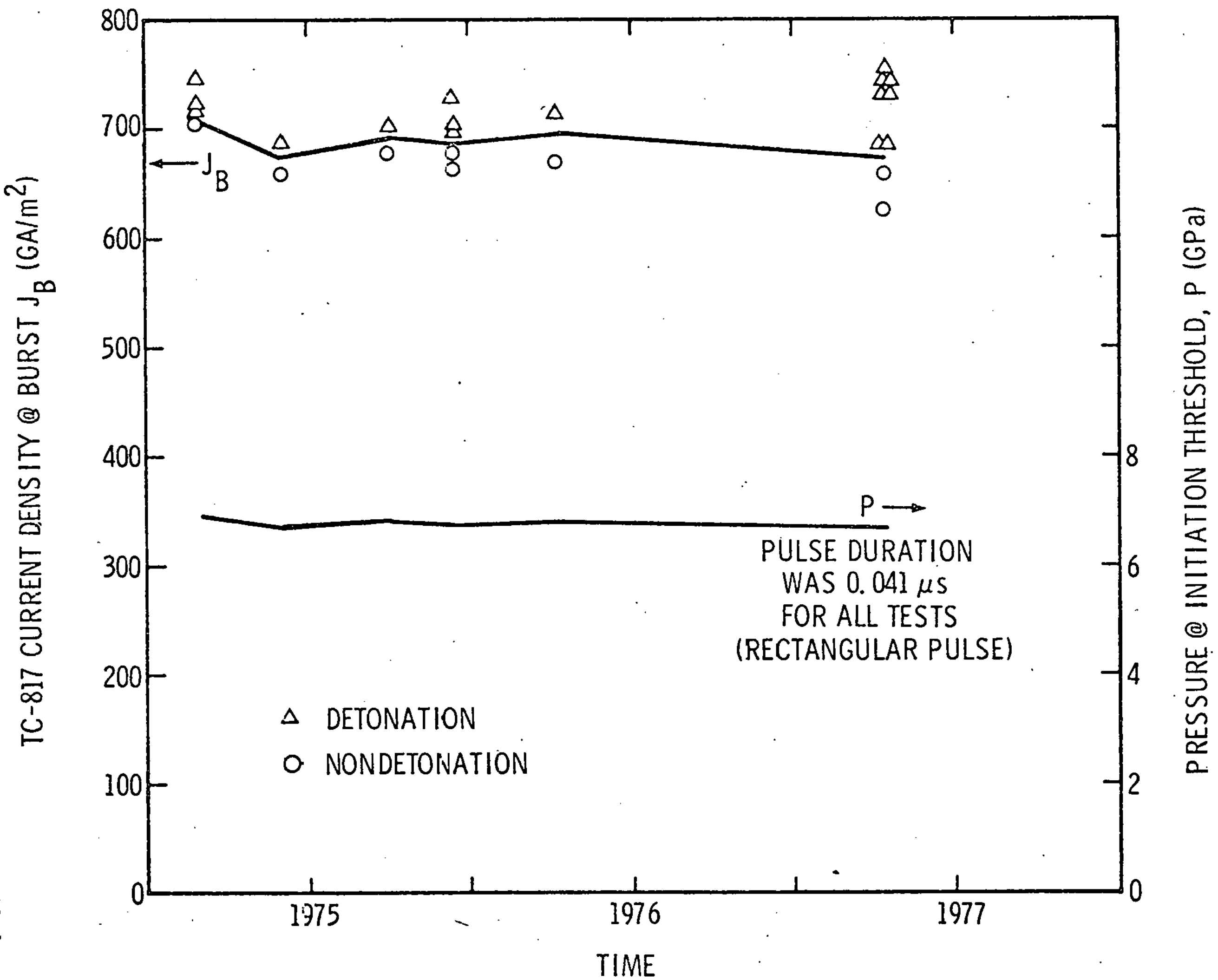
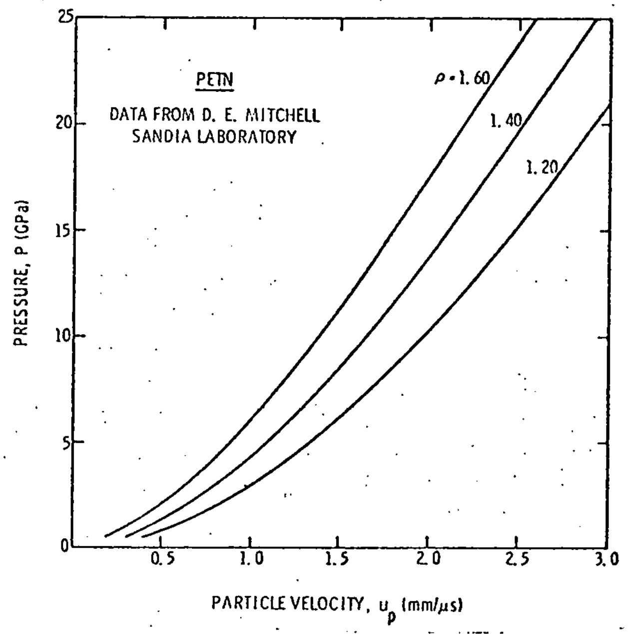
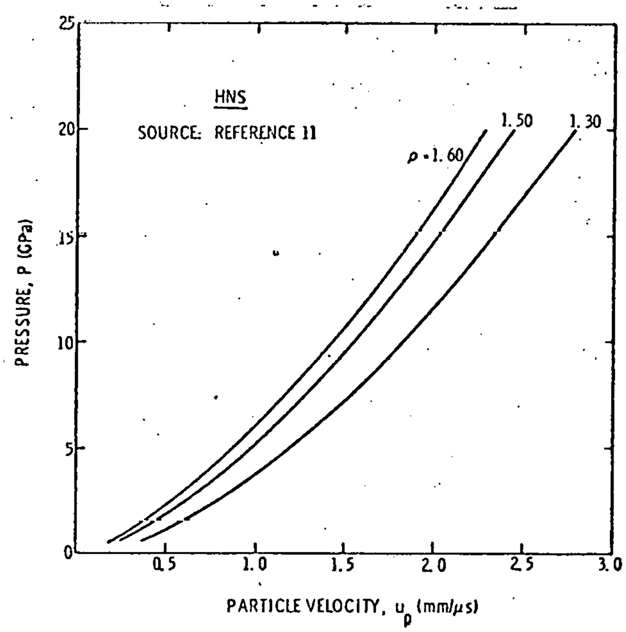


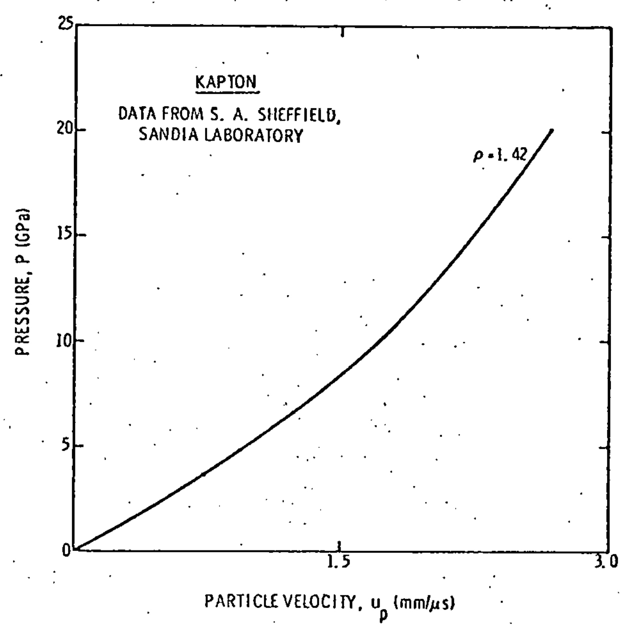
Fig. 10. TC-817 Performance with HNS-SF Explosive over a 2 Year Period

APPENDIX

P-u Hugoniots






KAPTON
DATA FROM S. A. SHEFFIELD,
SANDIA LABORATORY
ρ = 1.42
PRESSURE, P (GPa)
PARTICLE VELOCITY, u_p (mm/μs)
25
20
15
10
5
0
1.5
3.0