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TITLE. CHARACTERIZATION OF HIGH-EXPLOSIVE INITIATION AND SAFETY AT LOS ALAMOS

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CHARACTERIZATION OF HIGH-EXPLOSIVE INITIATION AND SAFETY AT LOS ALAMOS

John M. McAfee

Abstract

The Chapman-Jouget and ZND models of steady detonation have proved most useful for engineering estimation of the propagation of near-planar. steady detonation in short-reaction-zone explosives. However. even in well characterized systems. the purposeful initiation of detonation is not described by these models. The highly divergent and microscopic nature of point initiation require discerning experiments, modeling, and theoretical analysis.

Recently, safety considerations in complex or damaged systems. possibly containing long-reaction-zone (insensitive) high explosives, have dominated our thinking. These situations are rarely planar or steady, the physical state of the explosive may not be easily characterized, and there is a wide range of potential stimuli. The high-explosive reaction may range from none, to deflagration, to partial detonation, or to full detonation. Techniques and data applicable to estimating the level of response are needed.

The design and prediction of explosive systems have mostly been accomplished using the simple C-J model. In most cases considerable testing and incremental modification are necessary to produce the desired function for even moderately complex geometries. However, the precise and reproducible initiation of detonation has relied even more on the empirical approach.

The build-up to detonation from an initial stimulus is a transient phenomenon (Fig. 1). It involves an interplay of chemical kinetics. mechanics, hydrodynamics. and material properties. Historically. the first predictive correlation between stimulus and transition-to-detonation was discovered by Ramsay and Popolato[1]. They showed. for a one-dimensional promptly initiating system. that the logarithm of the shock input pressure was linearly proportional to the logarithm of either the distance- or time-from-impact to full detonation (Fig. 2). These relationships, named "Pop Plots". are a function of the density, temperature, phase. particle size, particle-size distribution. and almost any other physical variable. The Pop plot is widely used for the estimation of where and when a detonation will occur, given a specific shock strength.

The first successful continuum model to extract "microscopic" rate information from these measurements is the Forest Fire model[2]. Although based on the incorrect assumption of "single-curve build up," this model has had considerable use and success in calculations of resolved 1-, 2-, and 3-dimensional initiation problems. Because this and similar approaches do not account for the heterogeneous nature of solid explosives, the rates derived from this and similar models are only averaged properties that represent only the heat release. The details of the microscopic mechanics and chemistry are not predicted or accounted for.

The design of precision detonators and detonation systems is primarily based on comprehensive experience and testing. *A priori* prediction of the quantitative interactions of exploding bridge wires (EBWs, Fig. 3) with fine-grained initiating explosives has not been possible because of the strong coupling of divergence, kinetics, mechanics, and other phenomena. Only in the past few years has an empirically calibrated model of the slapper detonator (Fig. 4) proved useful. R. J. Yactor[3] has correlated hundreds of experimental measurements by fitting a multi-parameter model based on simple physical concepts. The SLAPPER model can predict values and trends for firing-set voltage thresholds for single and multi-point detonators.

We at Los Alamos are very interested in safety considerations for complex or damaged systems. Understanding and predicting the response of explosives to abnormal environments and accidents are important components of our program. Probable scenarios are rarely planar or steady, the physical state of the explosive is not easily characterized, and there are a wide range of potential stimuli and responses. An insult that will not normally produce a violent response in undisturbed explosive may produce high-explosive reaction ranging from none, to combustion, to deflagration, to partial detonation, to full detonation in a damaged system. Our goal is to develop experimental and computational tools that qualitatively and quantitatively predict the level of energy release.

Explosive systems, even when used as designed, have many space and time scales. The introductory papers by Fauquinon and Davis have described the wide range and interdependence of these scales for steady detonation. Accidents and abnormal environments introduce the additional factors of system size, configuration, confinement, altered material properties, and lengthened time scales. At Los Alamos, we have approached this complex and ill-defined problem by performing experiments on simplified systems. As examples, I will describe two projects: The initiation of a liquid explosive by hypervelocity metal jets, and our studies of the deflagration-to-detonation transition (DDT) in metal-confined granular explosive.

The planar shock initiation of nitromethane (NM) was first described by Los Alamos workers in the 1960s[4] (Fig. 5), and has been continued and refined more recently[5]. The behavior of this system is perhaps the simplest and best explained for common condensed explosives. However, when we initiate NM with an explosively-formed hypervelocity metal jet[6], some results are very complex. High-speed photographs (Fig. 6) show the formation of periodic three-dimensional structures. Analysis of the velocity of the leading wave shows cycles of detonation and failure (Fig. 7). Such complex behavior is not accounted for by the simplest theories.

The build-up to detonation from relatively weak thermal or mechanical insults involves a complex interaction of combustion, deflagration, and mechanics[7,8]. Our experimental system to simulate a damaged explosive system is a strong steel pipe filled with granular HMX (Fig. 8). Initial combustion in the HMX can be started by mechanical or thermal input. In either case, the initial energy and power are far below that necessary to initiate detonation. Figure 9 describes the Los Alamos model of the DDT in this system. Undoubtedly, the very early stages of combustion in ignited experiments are convective. The pressures, Reynolds numbers, and gas-evolution rates are small enough that gas can flow through the initial bed (60-70% of the Theoretical Maximum Density, TMD). However, the gas permeation velocity into the nascent bed is limited (10s of m/s). The HMX burning rate is high enough that gas is produced faster than it can flow away. Therefore, the gas pressure in the combustion region builds rapidly. The rising pressure eventually becomes greater than the strength of the granular bed, and a combustion-supported compaction wave is started.

The compaction wave velocity is significantly faster (100s of m/s) than the combustion. Behind the wave, the bed is compacted to approximately 90% TMD. Throughout this dynamic compaction, shear of and friction between the granules provide energy to start decomposition of the compacted material. After an induction time determined by the chemical kinetics, deflagration in the compacted HMX begins and proceeds at a velocity approximately equal to the compaction-wave velocity. The onset and propagation of this deflagration does not depend on the permeation of hot gasses, but rather on the length of time since the passage of the compaction wave. This "ignition wave" is merely the locus of a specified level of reaction or reaction rate. It defines the boundary between the slowly decomposing compact and the quickly deflagrating compact.

After the deflagration is established, a competition between gas pressure and mechanical stress in the region above the ignition locus and behind the compaction wave determines the next stage. The region below the ignition locus pressurizes rapidly because of the fast burning. The forces generated by this pressure are carried above the ignition locus as mechanical stress in the matrix of solid particles. At the same time, the gas pressure between these solid particles is rising because of the slow decomposition started by the compaction wave. The mechanical stresses are trying to further compact the bed while the gas pressure is resisting. There is a point where the mechanical stress becomes much larger than the inter particle pressure, and the granular bed further compacts to near 100% TMD. We call this region of complete compaction the "plug" because on the time scale of interest (10s of μs) it behaves as inert material.

In the plug, the gas-phase and gas-producing reactions stop because there is essentially no free volume and the increase in thermal conduction rapidly cools the residual gas. Therefore, the ignition locus terminates when it intersects the plug.

If the mechanical confinement of the burning region is sufficient, the high gas pressures accelerate the plug into the compact. Mass balance arguments show that the top of the plug has a velocity approximately ten times faster than the bottom. At these high velocities, the top of the plug is a shock traveling in the compact. This shock will transit to detonation if the velocity is high enough and duration long enough. Failure of the mechanical confinement can slow the shock such that detonation does not occur. The combustion-deflagration process can begin again when the shock overtakes the compaction wave. We have strong evidence for such interrupted processes eventually leading to detonation (Fig. 10).

Computational modeling of this process is formidable. The space scales range from detonation reaction zone thickness to the full system size. The time scales range from fractions of nanoseconds to seconds. In the past two years J. Bdzil, B. Asay, and S. Son at Los Alamos and D. S. Stewart and A. Kapila from universities have developed a computational model that reproduces the observed phenomena starting with the compaction wave. However, accurate and physically-based chemical kinetic information is still needed.

Additional projects at Los Alamos are attempting to characterize the mechanical and chemical states of damaged explosives. We have a great need for appropriate diagnostics, well designed experiments, and convincing analysis.

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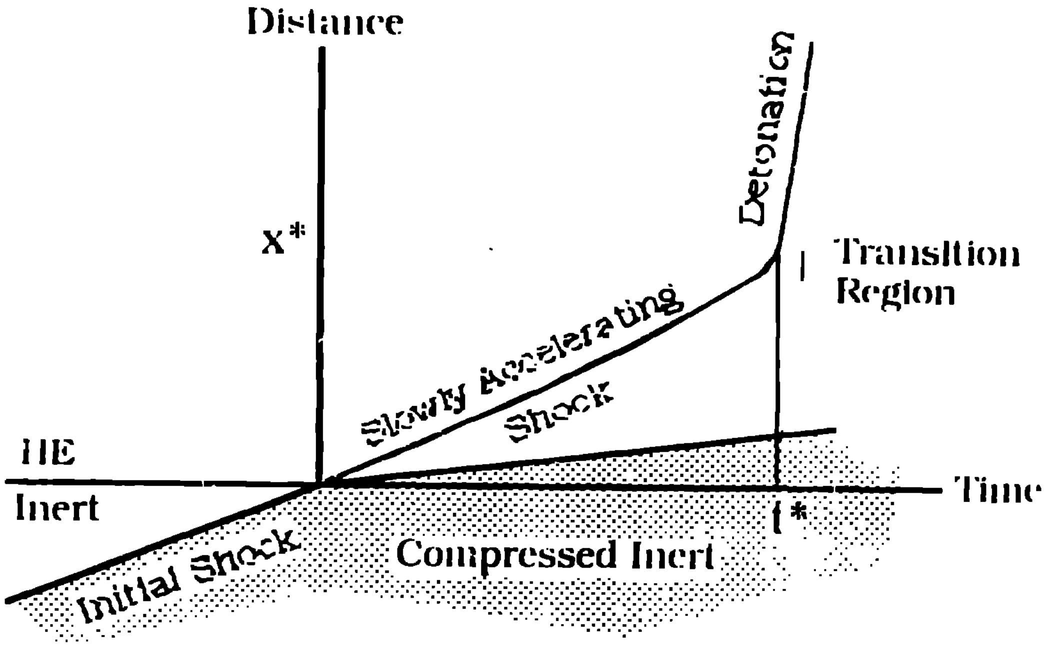
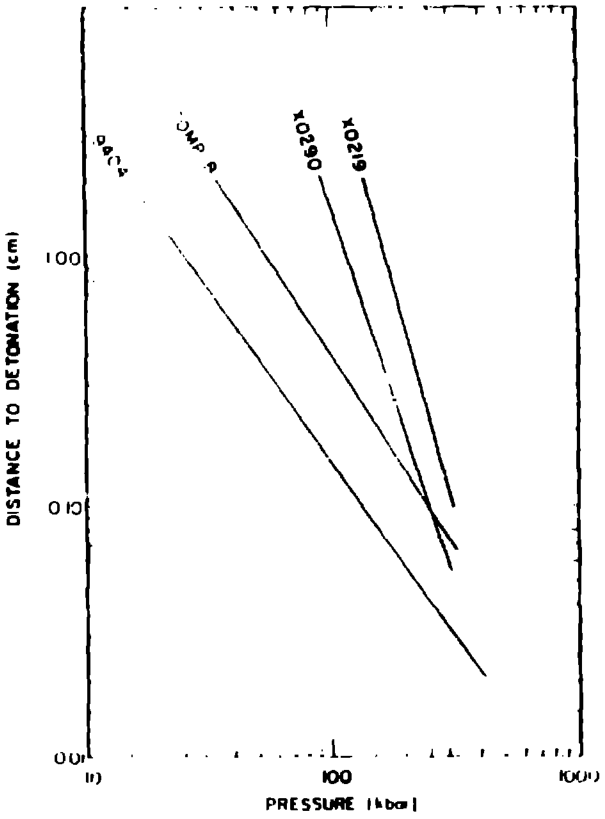
Shock Initiation of Heterogeneous Explosive

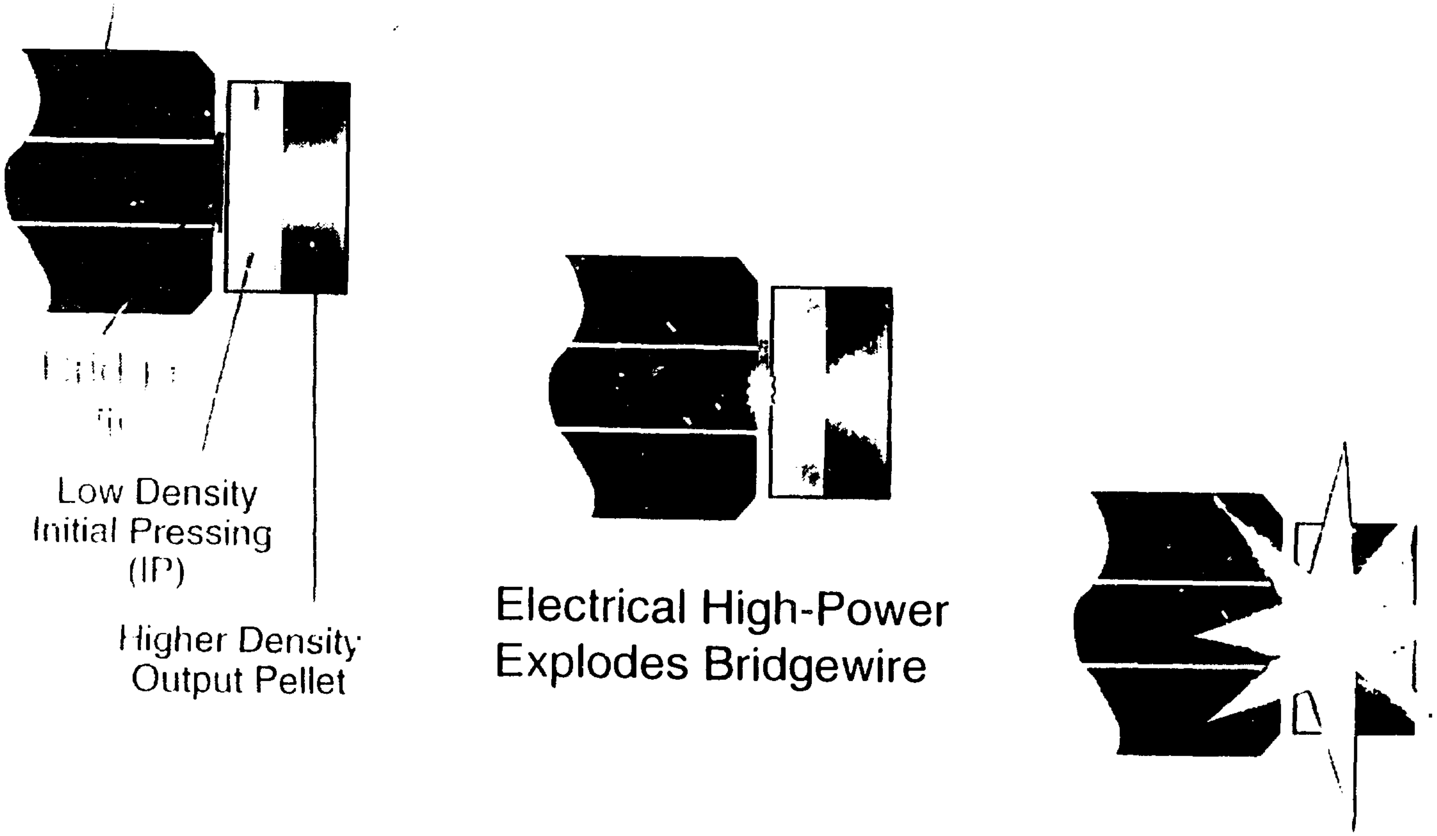


- Induction distance (x*) and time (t*) are a function of Shock Pressure: x*= x*(P), and t* = t*(P)

The “Pop Plot” for Some High Explosives



Exploding BridgeWire (EBW)



Plastic Header

Explosive

Bridge Pin

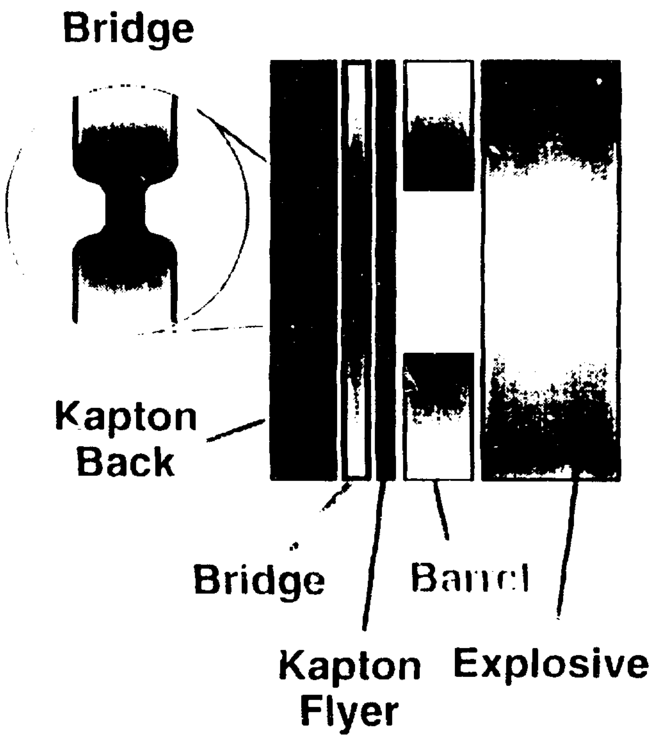
Low Density Initial Pressing (IP)

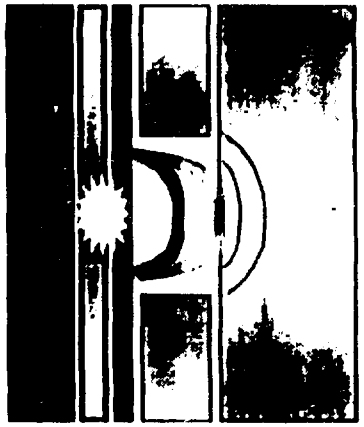
Higher Density Output Pellet

Electrical High-Power Explodes Bridgewire

Shocked Explosive Detonates

Slapper Detonator

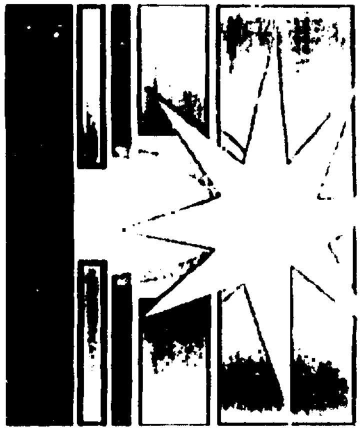




High Power Explodes Bridge

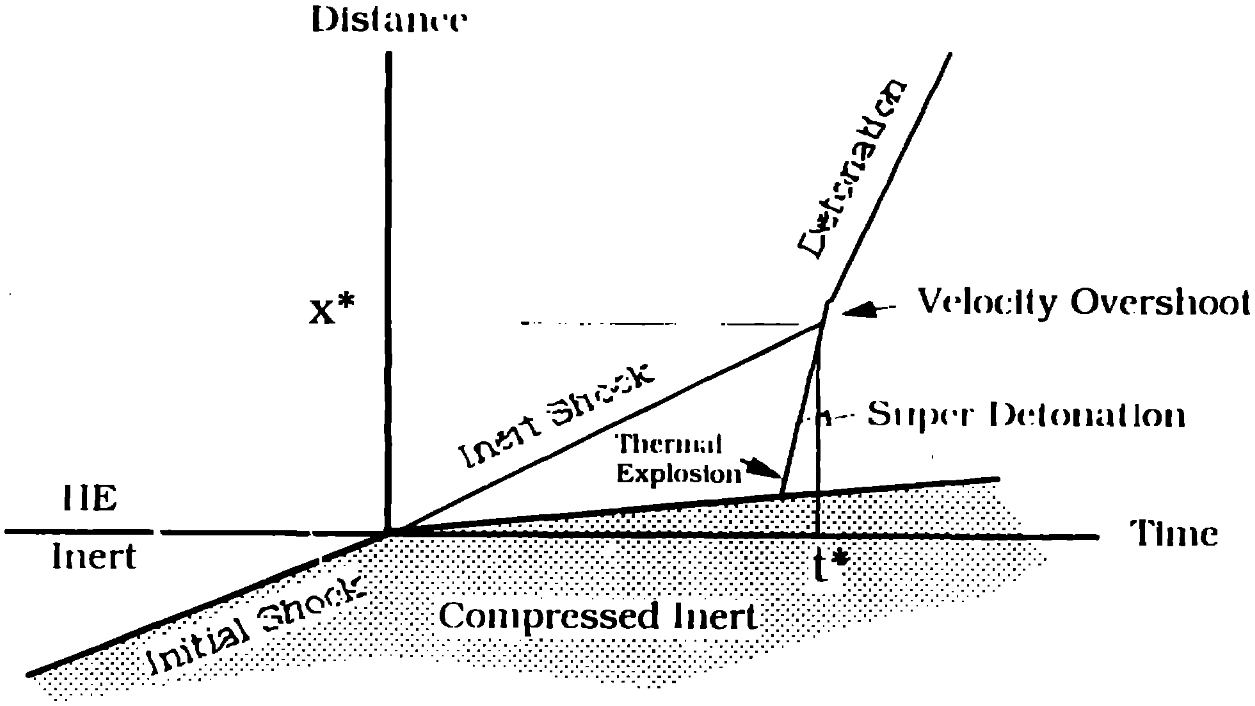
Flyer Accelerated Across Barrel

Flyer Shocks Explosive



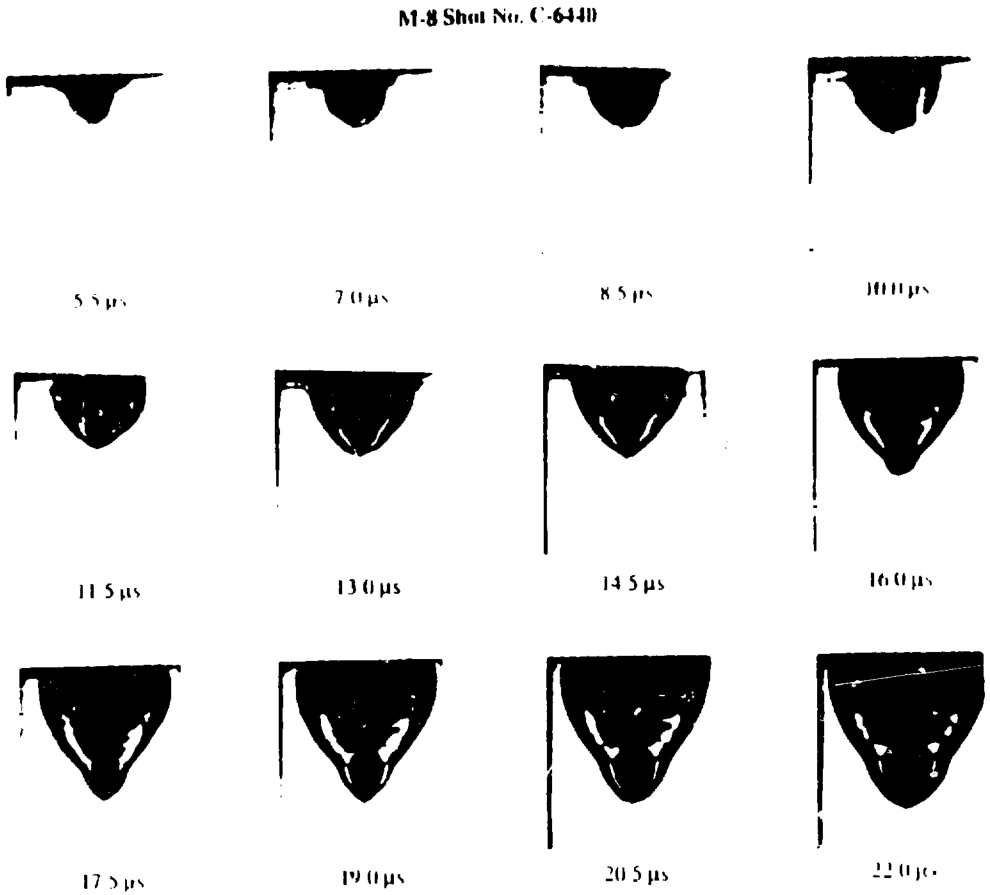
Explosive Detonates

Shock Initiation of Homogeneous Explosives

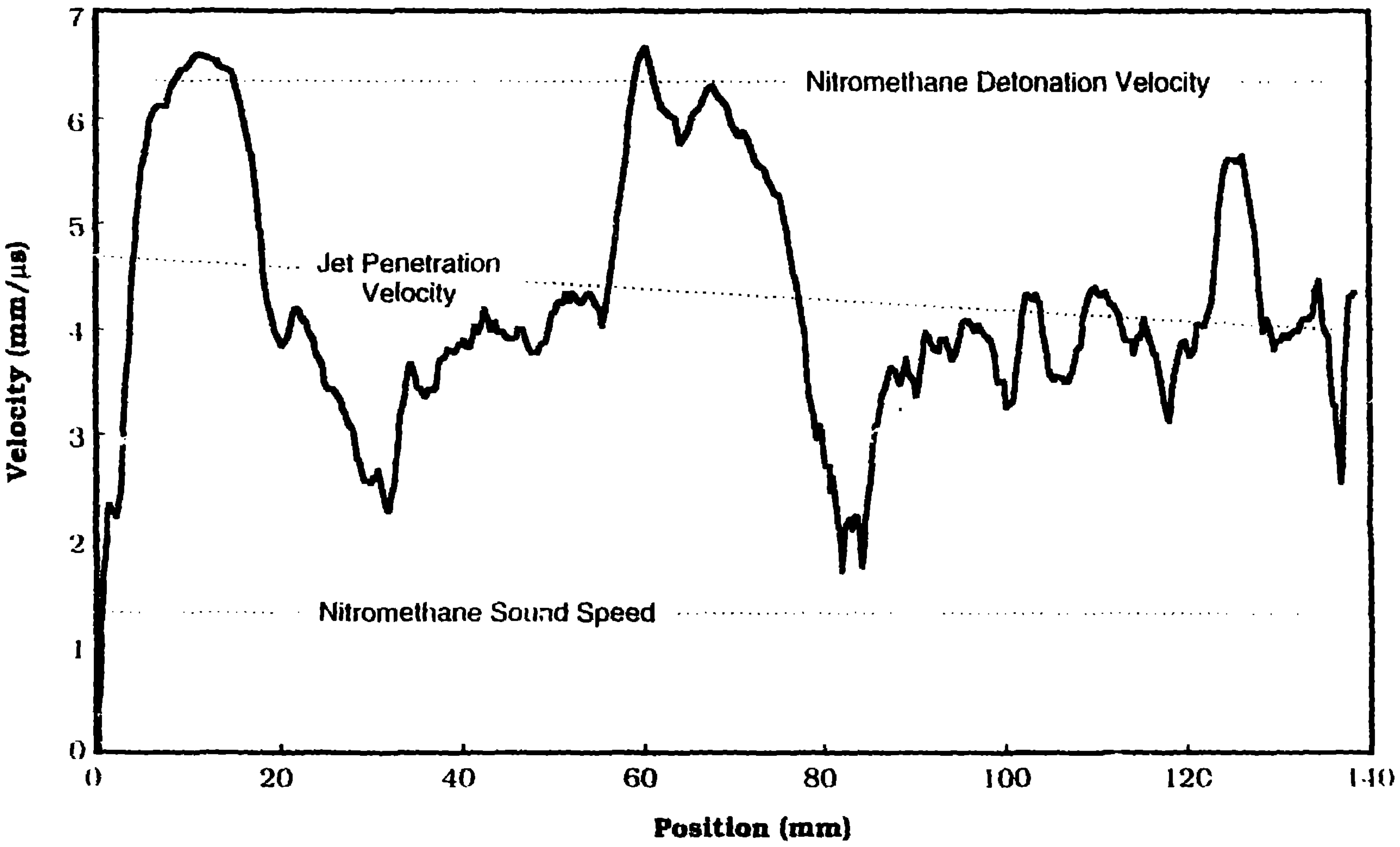


- Induction distance (x^*) and time (t^*) are a function of Shock Pressure: $x^* = x^*(P)$, $t^* = t^*(P)$

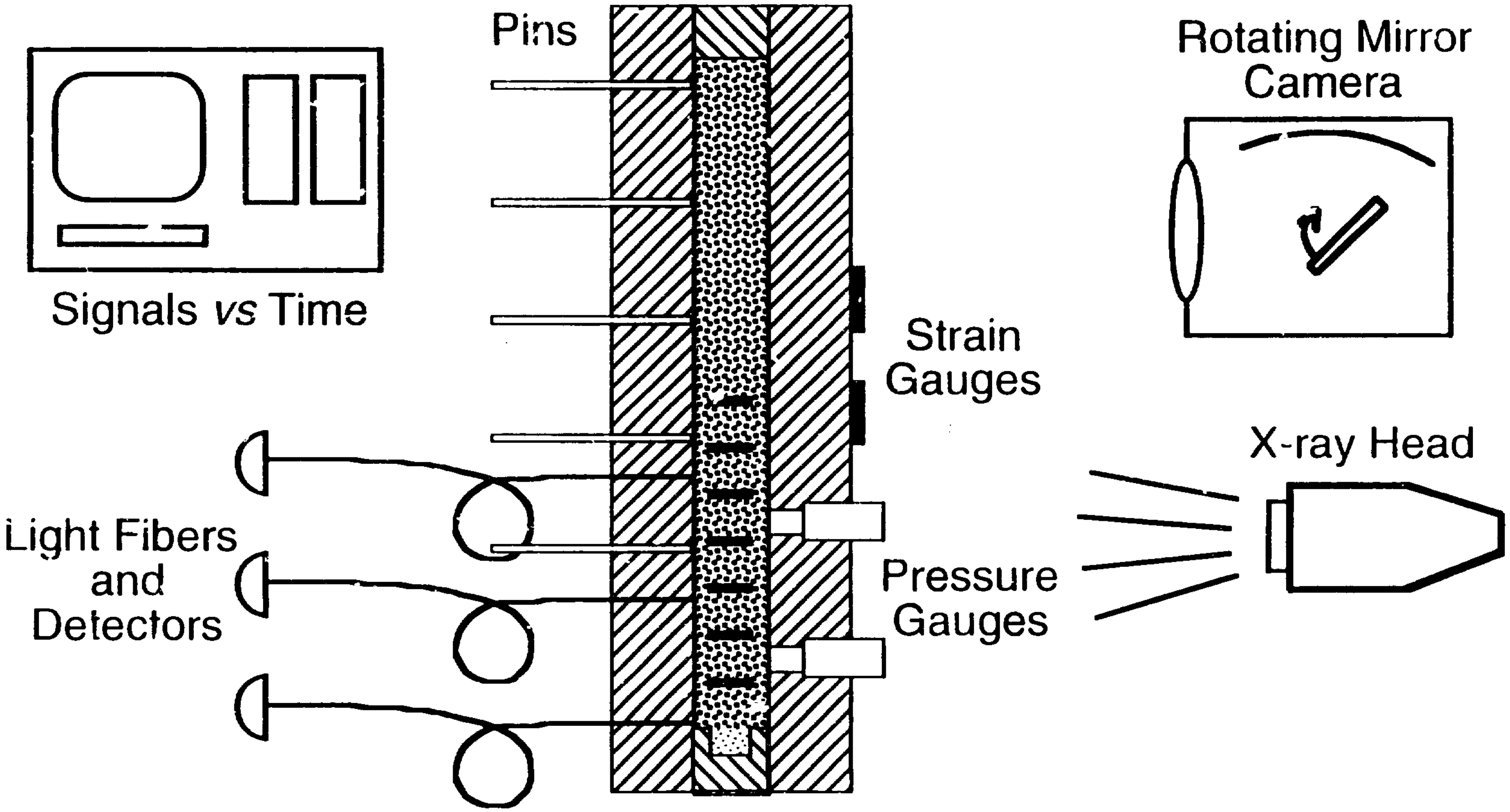
Photographs of a 6.5-mm/µs Jet in Nitromethane



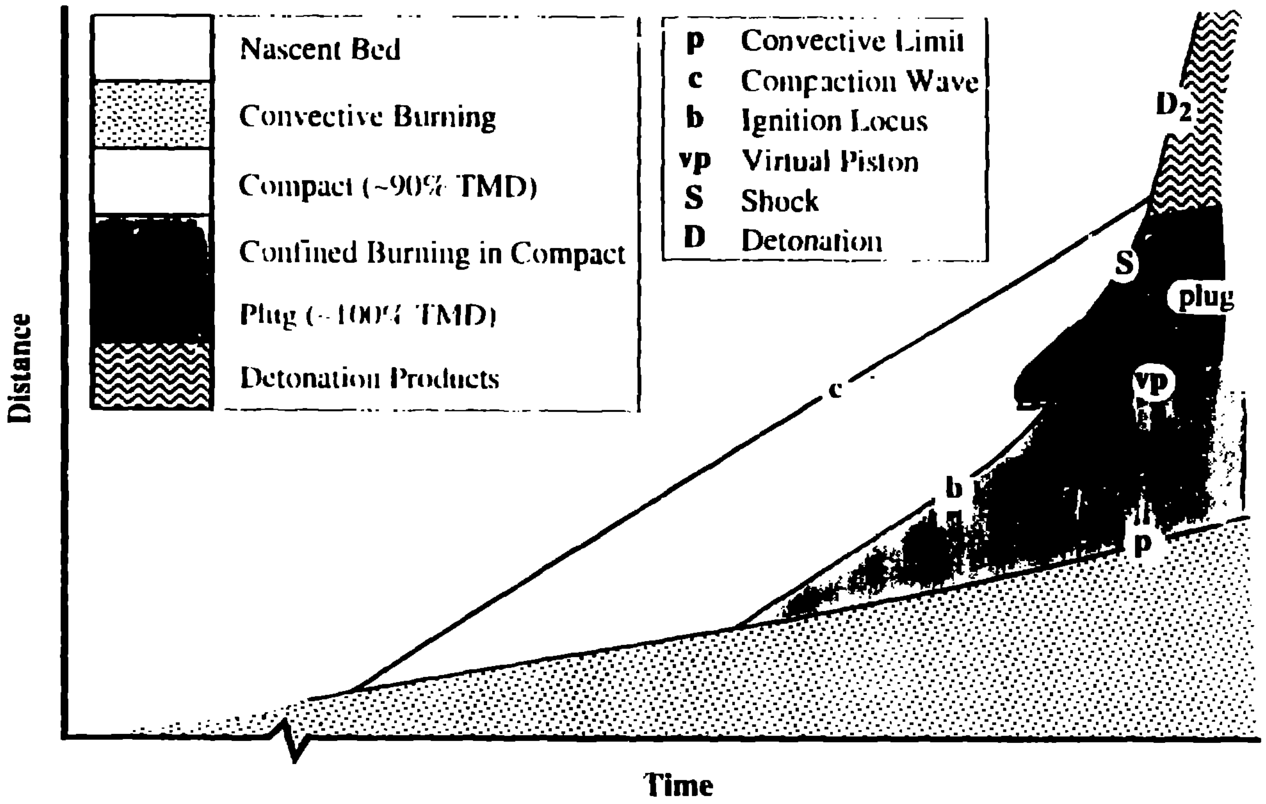
Tip Velocity of 6.5-mm/μs Jet in Nitromethane



Los Alamos DDT Experiment and Diagnostics



Time -Distance Discription of DDT in HMX



Typical Data - Radiography