Title:

TRANSIENT DETONATION PROCESSES IN A PLASTIC BONDED EXPLOSIVE

Author(s):

Keith A. Thomas, Eric S. Martin, James E. Kennedy,
Ismael A. Garcia, and Joseph C. Foster Jr

Submitted to:

<http://lib-www.lanl.gov/la-pubs/00818494.pdf>

TRANSIENT DETONATION PROCESSES IN A PLASTIC BONDED EXPLOSIVE

Keith A. Thomas¹, Eric S. Martin¹, James E. Kennedy¹, Ismael A. Garcia¹, and
Joseph C. Foster Jr²

¹*Los Alamos National Laboratory, Los Alamos, NM 87545*

²*Air Force Research Laboratory, Eglin AFB, FL 32542*

Abstract. Experiments involving the transfer of detonation from small booster charges of PBXN-5 (95% HMX and 5% Viton A) into larger charges of various plastic-bonded explosives (PBXs) have produced some surprising results and have stimulated investigation into the factors governing observed responses. To understand these results, we conducted a series of tests with different miniature detonator-booster configurations using laser velocimetry to quantify the pressure pulse that is transmitted from the PBXN-5 booster. Models were used to determine the ideal explosive behavior for comparison with the measured results. The differences are interpreted as being due to transient behavior and late-time energy release from the booster charge. We characterize these behaviors as evidence of microdetonics, where we define microdetonics as the study of less-than-CJ detonation performance due to curvature and/or transient behavior. This provides useful insights into the fundamentals of the detonation process that can feed into advanced modeling approaches such as Detonation Shock Dynamics (DSD).^{1,2}

INTRODUCTION

Research on the detonation of condensed phase explosives spans many decades in both length and time scales. Early work was limited primarily by the instrumentation response. Improvements in the instrumentation have revealed many aspects of the detonation process that are best studied during the shock-to-detonation transition phase under conditions which represent high geometrical divergence. An asymptotic solution to the classical Zel'dovich, Von Neuman, Doering (ZND) theory of detonation, called Detonation Shock Dynamics (DSD), has emerged in recent years.^{1,2} Continuum variables emerge out of DSD for the influence of curvature of the detonation front and the reaction-zone chemistry on the detonation wave propagation. It has been expanded to include transient effects of

accelerating detonation waves.^{3,4} Experimental calibrations of DSD to date have addressed only the curvature effects, through measurements of the curved front in steady-detonation experiments in cylindrical columns only slightly larger than the failure diameter⁵ and with high convergence.⁶ Those efforts have focused on explosives that are used for the large-volume, main charge of an explosive assembly. However, an essential element of the detonation process is initiation, which is usually triggered by a detonator and booster system that occupies a small volume in comparison to the main charge.

Historically, very little attention has been paid to the performance of real initiation systems. It is generally assumed that the initiation-system explosives operate at steady-state C-J detonation conditions as they are used to transfer detonation

into the main explosive of interest. However, depending on the experimental configuration, the miniature detonator-booster system's small size implies a highly divergent, transient region of detonation physics, which we call *microdetonics*. Microdetonics refers to the combination of behaviors dominated by transient effects in detonation, such as detonation acceleration and spreading, or curvature effects associated with initiation by small sources. This paper is an attempt to determine whether these dynamics manifest themselves in miniature detonation systems with highly localized, short-duration, shock pulse outputs. Thus we will focus our efforts on the behavior of the second element in the explosive train commonly referred to as the booster.

EXPERIMENTS

To determine the presence of transient effects in the output of charges typically used in detonators or boosters, we consider a few different experimental configurations. For most of our experiments we use a typical detonator arrangement with an electrically driven exploding foil initiator (EFI) detonating a pellet of pentaerythritol tetranitrate (PETN). The PETN output drives detonation into a booster pellet of PBXN-5, which is a commonly used pressed explosive booster composed of 95% HMX with 5% Viton A binder. The PBXN-5 in all of our tests was pressed to a density of 1.77 g/cm³. Since most real initiation systems are sealed in cups, we observe the outputs through a barrier material. Although interaction of this barrier with the detonation front complicates the shock waveform, we feel that it represents a real-world constraint in designing or analyzing explosive initiation systems.

To quantify the performance of these miniature detonator-booster systems, we used a VISAR system to measure the particle velocity history of an experiment driven into a coated lithium fluoride (LiF) window. The impedance of the Al barrier and the LiF crystal are closely match to minimize any reflections at this interface. The VISAR system for the experiments had a dual-leg arrangement utilizing two interferometer cavities with different fringe constants. This arrangement enables unambiguous recognition of and correction for

missed fringes in the data trace, and thus provides more accurate data.

In order to determine deviations from ideal behavior, we simulated the experimental arrangements with the CTH hydrocode.⁷ The one-dimensional model we used applies a constant energy release rate across the detonation front traveling at full detonation velocity to achieve proper C-J pressure. Thus, it represents an ideal steady-state explosive behavior and serves as a basis for comparison for the measured VISAR records. Any observed deviations from the predicted CTH models should indicate the presence of transient or nonideal behavior.

Case 1: Aluminum Barrier

The first experimental setup consisted of an exploding foil initiator detonating a 4-mm-diameter x 2-mm-long PETN pellet in contact with a 5-mm-diameter PBXN-5 booster pellet. A 0.254-mm-thick aluminum barrier plate between the PBXN-5 and the LiF crystal simulated the booster cup. VISAR measurements were then made of the particle velocity at the aluminum-LiF interface.

Figure 1 shows the measured particle velocities in the LiF for two lengths of PBXN-5 pellets, 6mm and 2.2 mm, as well as the CTH simulations for both lengths. There is a large discrepancy between the calculated and measured velocity histories for the 2.2-mm-long pellet. The lower peak amplitude

FIGURE 1. Particle velocity for the 6-mm and 2.2-mm long PBXN-5 pellets with an aluminum barrier. CTH calculations representing an ideal explosive behavior are shown for comparison.

in the measured waveform is approximately half of the C-J pressure. The shapes of the waveforms behind the front are also considerably different. The measured waveform displays a relatively flat segment just behind the front, and its subsequent decline in velocity is slower than that in the calculation. We interpret this to indicate the presence of an extended reaction zone that extends through the supersonic and the subsonic portions of the flow behind the front.

The measured velocity history for the 6-mm pellet is higher than that for the 2.2-mm pellet, but it is still lower than the calculated curve for 6 mm. Also, the slope of the wave immediately behind the front more closely resembles the CTH model. This indicates a buildup of detonation has occurred in the interval between the 2.2 and 6 mm lengths, but the detonation front has still not completely attained a full C-J detonation.

Case 2: Initiation Methods

In case 1 the initiation of the booster was accomplished by placing the output of a detonator pellet in contact with the PBXN-5 booster. To determine what effect the form of initiation has on the booster performance, we conducted tests with a configuration designed to initiate the booster via a flying plate that is believed to overdrive detonation. A PETN pellet, initiated using an EFI, propelled a 0.127-mm-thick, 2-mm diameter stainless-steel flyer across a 0.91-mm gap. The booster pellet for this case was a 2.2-mm PBXN-5 similar to that used in case 1. The output of the PBXN-5 is in direct contact with the LiF crystal, i.e. there is no barrier for this case.

Figure 2 shows the output from this experiment along with the CTH estimate, and the experimental results are also shown again for the 2.2-mm-long pellet initiated by direct contact with a similar PETN detonator pellet. The particle velocity data from the flyer-initiated PBXN-5 pellet is more representative of a C-J detonation. The first peak jumps to a velocity of 1810 m/s corresponding to a measured pressure of 36 GPa, which agrees with the accepted C-J value for PBXN-5.⁸ The steep velocity drop behind the front resembles a Taylor decay following a more ideal detonation. The differences between these two experimental

measurements have been seen in repeated tests and must be the result of the difference in initiation in the two cases.

FIGURE 2. Particle velocity for a 2.2-mm long N-5 pellets at the LIF interface. A CTH calculation without the aluminum plate is shown for comparison.

DISCUSSION

The experimental results from the 6-mm and 2.2-mm boosters shown in Figure 1 reveal very different performances for the two different column lengths of explosive. The fact that the peak of the longer booster pellet more closely approaches the CTH estimate is not surprising since the longer column of explosive may be expected to produce a more “ideal” detonation. At first glance one might conclude that the 2.2-mm pellet is still running up to detonation as is observed in a wedge test. While the VISAR data is not particularly clean, it appears the energy is being released over a period of at least 50 ns; implying a very extended reaction region that is much longer than the 6-mm PBXN-5 pellet.

The presence of this extended reaction region indicates that DSD theory may not be well suited to describe these waves since it may violate one of the fundamental assumptions of the DSD approach, i.e. the reaction zone length is smaller than the radius of curvature.^{1,2} Perhaps these miniature systems will

have to be modeled using direct numerical simulation explicitly addressing the chemical reactions and their associated energy release. This may provide insight to clarify whether this type of waveform represents a feeble detonation or a re-initiation of detonation following detonation failure.

The 6-mm PBXN-5 pellet has a more classical wave shape with a negative slope immediately behind the initial peak indicative of a detonating explosive. However, the peak amplitude is well below the C-J level implying that even at this longer column length the PBXN-5 may be undergoing a buildup *of* detonation. This behavior is evidence for the presence of a transient (dD_n/dt) term.^{3,4} Further experiments with PBXN-5 columns of even longer lengths leading up to a full C-J particle velocity are needed to confirm this observation.

Comparing the 2.2-mm-long booster performance in Figures 2, we again see dramatically different behaviors. The peak pressure of the experimental arrangement for case 1 is 40% lower than that of case 2. Given the slopes behind the shock fronts, this disparity cannot be attributed to differences in attenuation losses in the barrier. We attribute the disparity to the difference in initiation methods. Late energy release from the case 1 initiation scheme does not appear to be present in the data from case 2. This not only indicates that the initiation mechanism matters, but appears to be evidence of a transient state in the detonation of case 1, i.e. a dD_n/dt behavior as described in the DSD theory.^{3,4}

CONCLUSIONS

While the results shown here are preliminary, they indicate a few trends that are significant considerations for explosive train designers. For

short explosive booster columns, the initiation method affects the explosive output, as does the length of the booster column. We have presented evidence indicating that there is delayed energy release in short columns of PBXN-5 that corresponds to nonideal detonation. The data implies a transient detonation behavior building toward C-J pressure with increased column length. While further experiments are needed in this area, we believe that these results indicate that microdetonics, i.e. transient effects, occurs in detonator-booster systems.

ACKNOWLEDGEMENTS

The authors wish to thank Willard Hemsing and Michael Shinas for their assistance with the VISAR system and data reduction.

REFERENCES

1. J.B. Bdzil, W. Fickett, & D.S. Stewart, Ninth Symposium (Intl.) on Detonation, pages 730-742, OCNR 113291-7 (1989).
2. J.B. Bdzil & D.S. Stewart, Phys. Fluids A **1**, 1261 (1989).
3. J. Yao & D.S. Stewart, J. Fluid Mech. **309**, 225 (1996).
4. T.D. Aslam & D.S. Stewart, Combust. Theory Modeling **3**, 77 (1999).
5. L.G. Hill, J.B. Bdzil, & T.D. Aslam, Eleventh Symposium (Int.) on Detonation, pages 1029-1037, Office of Naval Research, ONR 33300-5 (1998).
6. L.M. Hull, Tenth Symposium (Intl.) on Detonation, pages 11-18, ONR 33395-12 (1993).
7. J.M. McGlaun, S.L. Thompson, L.N. Kmetyk, & M.G. Elrick, Intl. J. Impact Eng. **10**, 351, (1990).
8. T.N. Hall & J.R. Holden, Navy Explosives Handbook, NSWC MP 88-116, Naval Surface Warfare Center, Dahlgren, VA.