Proton Radiographic and Numerical Modeling of Colliding, Diverging PBX-9502 Detonations

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The Proton radiographic shot PRAD0077 was designed to study the interaction of colliding, diverging PBX-9502 detonations. The shot consisted of a 50-mm by 50-mm cylinder of PBX-9502 initiated on the top and bottom at the axis by a SE-1 detonator and a 12.7-mm by 12.7-mm cylinder of 9407. Seven radiographs were taken at times before and after the detonation collision.

The system was modeled using the one-dimensional SIN code with C-J Burn in plane and spherically diverging geometry and using the two-dimensional TDL code with C-J Burn and Forest Fire. The system was also modeled with the recently developed AMR Eulerian reactive hydrodynamic code called NOBEL using Forest Fire.

The system results in a large dead or nonreactive zone as the detonation attempts to turn the corner which is described by the model using Forest Fire. The peak detonation pressure achieved by the colliding diverging detonation is 50 gpa and density of 3.125 mg/ml which is about the same as that achieved by one-dimensional spherically diverging 9502 detonations but less than the one-dimensional plane 9502 peak colliding detonation pressure of 65 gpa and density of 3.4 mg/ml.

The detonation wave travels for over 10-mm before it starts to expand and turn the corner leaving more than half of the explosive unreacted. The resulting diverging detonation is more curved than a one-dimensional spherical diverging detonation and has a steeper slope behind the detonation front. This results in the colliding pressure decaying faster than one-dimensional colliding spherical diverging pressures decay. The calculations using Forest Fire reproduce the major features of the radiograph and can be used to infer the colliding detonation characteristics.

INTRODUCTION

TATB (Triamino-trinitro benzene) explosives became important by the 1960's because of their shock insensitivity to accidental initiation.

Such explosives required large and powerful initiating systems which often resulted in large amounts of the explosive failing to detonate. These undetonated regions are often called "dead-zones". The dead-zones were first qualitatively measured using the PHERMEX radiographic facility in planar experiments where the detonation propagation of shock insensitive TATB based explosives X-0219 (90/10 TATB/Kel-F at 1.914 mg/ml) and PBX-9502 (95/5 TATB/Kel-F at 1.894 mg/ml) into a larger block of the explosive left large regions of partially undecomposed explosive (the dead-zone) as the detonation wave tried to turn the corner. The corner turning radiographs for X-0219 are Shots 1795, 1796 and 1797 and for PBX-9502 are Shots 1705, 1937, 1941 and 1943. The radiographs are available as part of the Los Alamos Series of Dynamic Material Properties in reference 1. The observed dead-zone formation for X-0219 was reproduced using the two-dimensional Lagrangian reactive hydrodynamic code, TDL, with the Forest Fire heterogeneous shock initiation rate model (2). The experimental results were also described using the two-dimensional Eulerian reactive hydrodynamic code, 2DE (2).

PHERMEX radiographs are available for colliding planar detonations of Composition B-3 (Shots 86, 87, 91, 92, 139, 140, 195, 196, and 273-277) of Cyclotol (Shots 203-206 and 291), of Octol (Shots 294-297) and of PBX-9404 (Shots 207-210, 292 and 1151). These shots were used to evaluate the equation of state of detonation products at pressures up to twice the C-J pressure of the explosives such as the BKW equation of state (2) which was used to reproduce the radiographic results.

Travis (2) used the image intensifier camera to examine the nature of the diverging detonation waves formed in PBX-9404, PBX-9502, and X0219 by hemispherical initiators. The geometries of the initiators were (A) a 0.635-cm-radius hemisphere of PBX-9407 at 1.61 mg/ml surrounded by a 0.635-cm-radius hemisphere of PBX-9404, (B) a 0.635-cm-radius hemisphere of 1.7 mg/ml TATB surrounded by a 1.905-cm-thick hemisphere of 1.8 mg/ml TATB or (C) a 1.6-cm- radius hemisphere of X0351 at 1.89 mg/ml. The dead-zones for PBX-9404 were too small to observe experimentally for initiator system (A) while about 1/5 of the explosive PBX-9502 remained unreacted. The initiator system (A) developed a dead-zone for X-0219 so large that the detonation failed in the geometry studied. The larger detonator (B) resulted in smaller dead-zones for PBX-9502 as did the higher pressure detonator (C).

The observed dead-zone formations and failure was reproduced using the two-dimensional reactive Lagrangian hydrodynamic code, TDL, with the Multiple-Shock Forest Fire heterogeneous shock initiation rate model as described in reference 2.

PROTON RADIOGRAPHY

The Proton Radiography Program at LANL has developed a radiographic facility at the Los Alamos Neutron Science Center (LANSCE). Multiple proton radiographic images of the same explosive experiment can be taken (3, 4, 5). The facility provides a method of making multi-axis, multi-frame radiographs using the 800-MeV protons at LANSCE. It is analogous to taking an X-ray picture of an object, but using protons instead of photons. A magnetic lens focuses the protons onto a detector to take a shadow radiograph.

Proton radiographic studies have been performed by Ferm, et. al (5) of the formation of dead-zones by cylindrical PBX-9502 detonations as they propagated into large cylindrical blocks of PBX-9502. The regions persisted for more than 6 microseconds at densities slightly higher than initial density. Parts of the dead-zones show indication of a slow reaction occurring. Attempts at modeling the cylinder edge break-out using Detonation Shock Dynamics (DSD), implanted in the MESA code, were unsuccessful. It was concluded that the DSD model needs explicit dead-zone capability to get accurate wave speeds around dead-zones (5).

COLLIDING DIVERGING PBX-9502 DETONATIONS

Experimental and numerical studies of colliding planar detonations are available as are studies of the formation of dead-zones in corner turning experiments and hemispherical initiator experiments for shock insensitive explosives such as PBX-9502. What remained to be determined was the interaction of colliding diverging detonations that also exhibit large regions of partially undecomposed explosives as the colliding detonation is formed.

The Proton radiographic shot PRAD0077 was designed to study the interaction of colliding diverging PBX-9502 detonations which exhibit dead-zone formation. The shot consisted of a 50-mm by 50-mm cylinder of PBX-9502 initiated on the top and bottom at the axis by an SE-1 detonator and a 12.7-mm by 12.7-mm cylinder of 9407. The PBX-9502 was Lot #HOL88H891-008, 95.00 wt.% TATB/ 5.00 wt.% Kel-F 800 at 1.890 mg/ml. Seven radiographs were taken at times before and after the detonation collision.

The geometry of the system studied is shown in Figure 1. The seven radiographs are shown in Figure 2 as dynamic to static ratios at intervals of 0.358 microseconds.

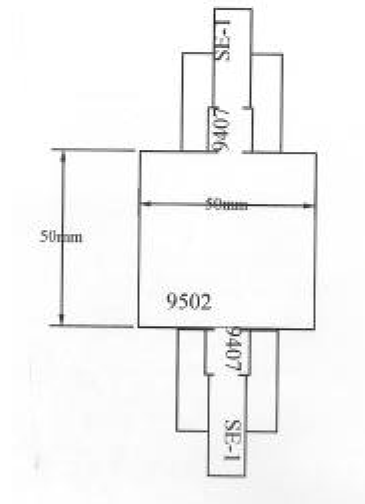

FIGURE 1. The geometry of the Prad077 Shot.

FIGURE 2. The seven Prad0077 Proton Radiographs at intervals of 0.357 microseconds.

The system results in a large dead or nonreactive zone as the detonation attempts to turn the corner. The detonation wave travels for over 10-mm before it starts to expand and turn the corner leaving more than half of the explosive unreacted.

The diverging detonations collide first along the center axis. The density of the resulting shocked detonation products decays as the reflected shock travels back into the lower density products. As the diverging detonation waves continue to collide, detonation regular reflections and then Mach stems develop at the interaction interfaces.

MODELING

The system was modeled using the one-dimensional SIN code (2) with C-J Burn in plane and spherically diverging geometry and using the two-dimensional TDL code (2) with C-J Burn and Multiple-Shock Forest Fire. The HOM equation of state and Forest Fire rate constants used were identical to those used to model the PHERMEX corner turning experiments in the mid 1970's and listed in reference 2.

The calculated pressure at the axis as a function of time is shown in Figure 3 for the SIN and TDL calculations.

The TDL calculated density and mass fraction of undecomposed explosive contours are shown in Figure 4 for the TDL calculation with the Multiple-Shock Forest Fire heterogeneous shock initiation burn. The calculated radiographic profile of the diverging detonation wave just before collision is shown in Figure 5. The computer animation shown at The Detonation Symposium is available at http://t14web.lanl.gov/Staff/clm/prad77/prad77.htm.

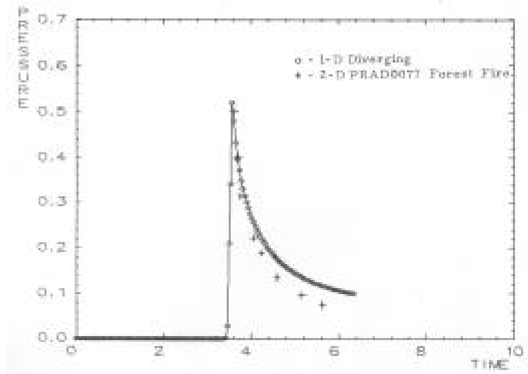

FIGURE 3. The calculated pressure at the axis as a function of time for the one-dimensional (SIN) diverging detonation and the two-dimensional (TDL) calculation with Multiple-Shock Forest Fire shown in Figure 4.

The system was also modeled with the recently developed AMR Eulerian reactive hydrodynamic code called NOBEL (6, 7, 8) using Forest Fire. The calculated density contours and mass fraction of undecomposed explosive at the same times as PRAD0077 are shown in Figure 6 for the NOBEL calculation with multiple-shock Forest Fire. The calculated density profiles at the same times as PRAD0077 are shown in Figure 7. The calculated and experimental radiographic profile of the diverging detonation wave just before collision is shown in Figure 8. The NOBEL computer animation shown. at the Detonation Symposium is available at http://t14web.lanl.gov/Staff/clm/prad77/prad77.htm

The calculated peak detonation pressure achieved by the colliding diverging detonation is 50 gpa and density of 3.125 mg/ml which is about the same as that achieved by one-dimensional spherically diverging 9502

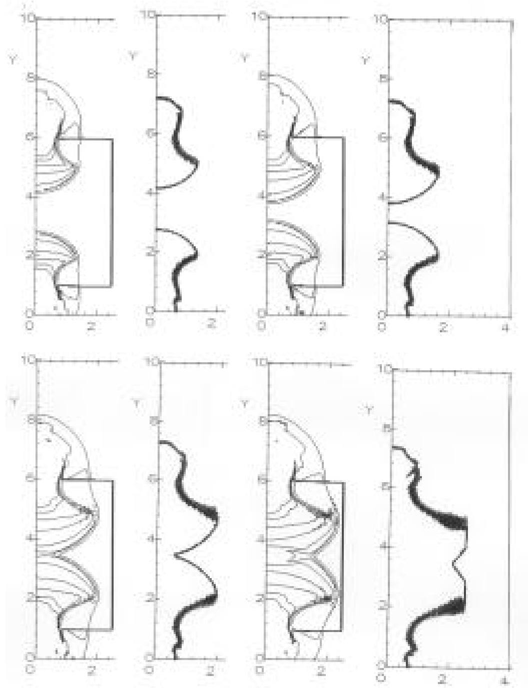

FIGURE 4. The two-dimensional density contours and mass fraction of undecomposed explosive at 0.5 microsecond intervals for the two-dimensional Lagrangian TDL calculation with Multiple-Shock Forest fire.

detonations but less than the calculated one-dimensional plane 9502 peak colliding detonation pressure of 65 gpa and density of 3.4 mg/ml.

The calculated detonation wave travels for over 10-mm before it starts to expand and turn the corner leaving more than half of the explosive unreacted. The resulting diverging detonation is more curved than a one-dimensional spherical diverging detonation and has a steeper slope behind the detonation front. This results in the colliding pressure decaying faster than one-dimensional colliding spherical diverging pressures decay.

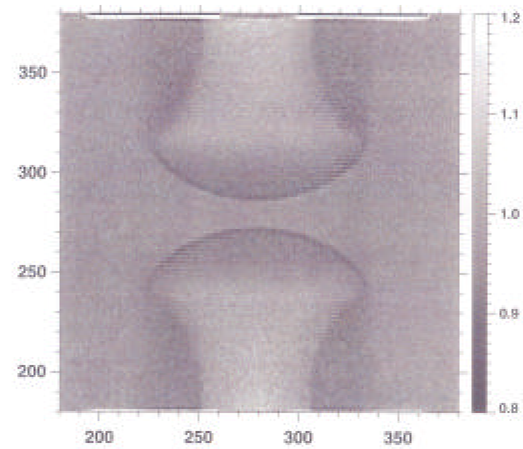

FIGURE 5. The calculated radiograph for the TDL densities just before the collision of the PBX-9502 diverging detonation waves.

CONCLUSIONS

Experimental and numerical studies of colliding planar detonations are available as are studies of the formation of dead-zones in corner turning experiments and hemispherical initiator experiments for shock insensitive explosives such as PBX-9502. The interaction of colliding diverging detonations that also exhibit large regions of partially undecomposed explosives as the colliding detonation is formed has been experimentally radiographed using the Proton Radiographic facility at Los Alamos. Numerical modeling using Lagrangian and Eulerian reactive hydrodynamic codes and the Forest Fire heterogeneous shock initiation rate model gave results that reproduced the radiographs.

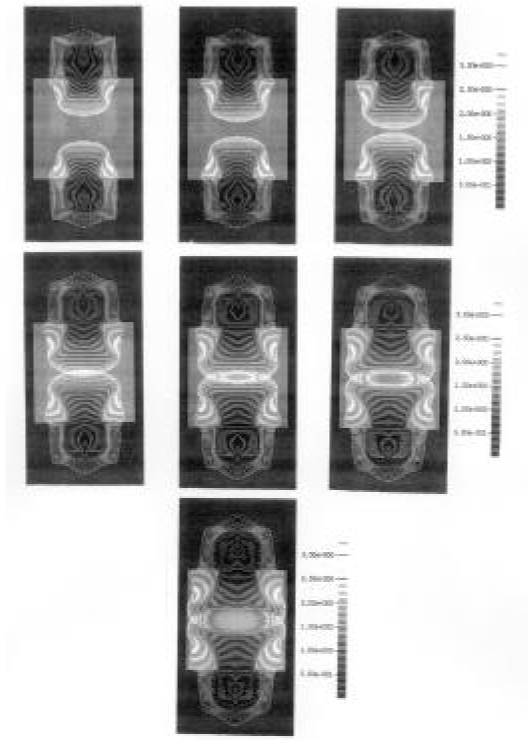

FIGURE 6A. The two-dimensional density contours and mass fraction of undecomposed explosive plots for the Eulerian NOBEL calculation with Multiple-Shock Forest Fire heterogeneous shock initiation burn at the same times as PRAD0077.

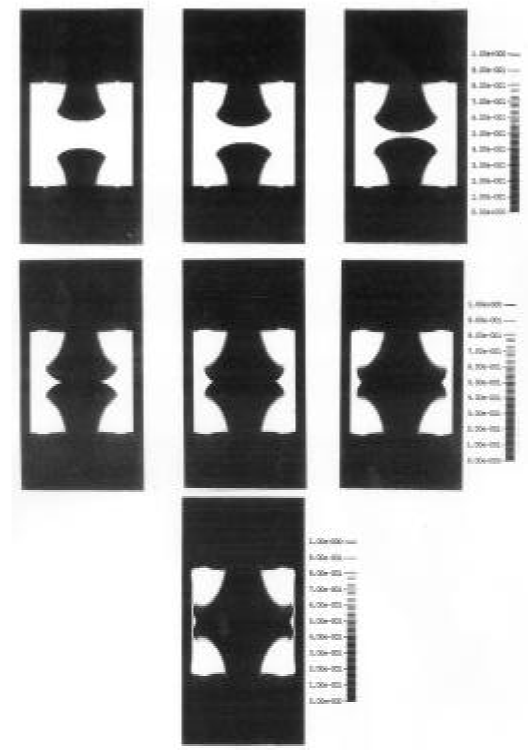

FIGURE 6B.

Many important features of detonation physics are exhibited by this study of diverging, colliding PBX-9502 detonations which exhibit significant additional curvature as they fail to turn corners promptly. New detonation models must be able to reproduce the complicated physics illustrated by proton radiograph PRAD0077.

ACKNOWLEDGEMENTS

This work was supported by the U. S. Department of Energy and is Los Alamos publication LA-UR-02-1644.

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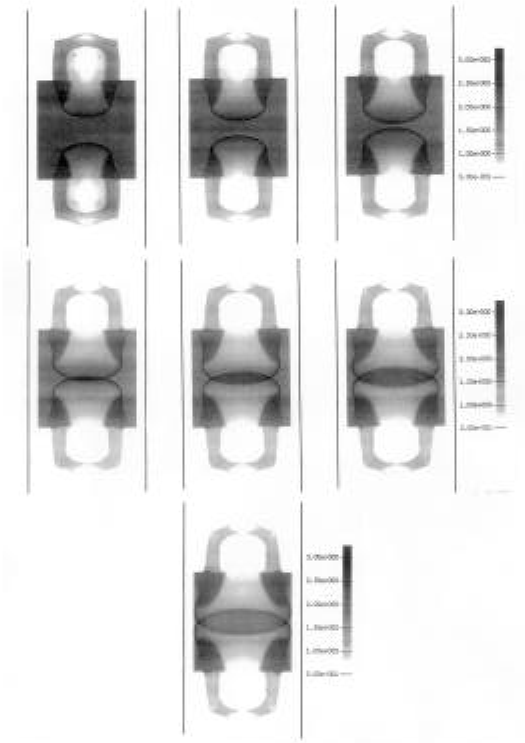

FIGURE 7. The density profiles for the Eulerian NOBEL calculation with Multiple-Shock Forest Fire heterogeneous shock initiation burn at the same times as PRAD0077.

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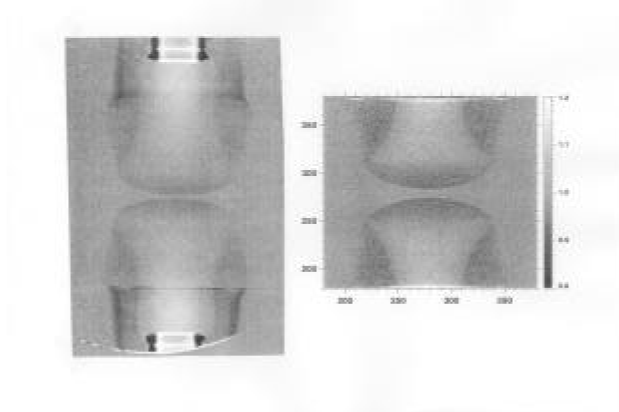

FIGURE 8. The calculated radiograph for the NOBEL densities and the experimental radiograph just before the collision of the PBX-9502 diverging detonation waves.

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