

PROTON RADIOGRAPHY EXPERIMENTS ON SHOCKED HIGH EXPLOSIVE PRODUCTS

Eric N. Ferm¹, Steve Dennison¹, Robert Lopez¹, Kathy Prestridge¹,
John P. Quintana¹, Camilo Espinoza¹, Gary Hogan¹, Nick King¹, Julian D. Lopez¹,
Frank Merrill¹, Kevin Morley¹, Christopher L. Morris¹, Peter Pazuchanics¹,
Andy Saunders¹, Stuart A. Baker², Rodger Liljestrand² and Richard T. Thompson²

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

²*Bechtel Nevada, Los Alamos, NM 87544*

Abstract. We studied the propagation of detonation waves and reflections of normal incident detonation waves in explosive products using the 800 MeV proton radiography facility at LANSCE. Using this system, we obtain seven to twenty-one radiographic images of each experiment. We have examined the experimental wave velocity and density of the materials ahead and behind of the shocks as inferred from radiographs and compare them to standard explosive equations of state. Finally we compare the experiments with calculations of the experiments using the MESA hydrodynamics code.

INTRODUCTION

The grand challenge of radiography in dynamic explosive experiments is to understand the radiographic system well enough that the object can be compared quantitatively to fluid mechanics calculations of the dynamic event. Here we examine two simple explosive experiments and compare them to their MESA calculations. We have performed several detonation-wave-propagation experiments on two configurations each one relying on a different region of the explosive's equation of state. The first configuration is a rate-stick experiment, resulting in the steady propagation of a detonation wave through a cylindrical charge. The calculation of this experiment is determined primarily from the principal release isentrope of the explosive products. The second configuration, the wave-collider experiment, involves the head-on collision of two detonation waves in which strong shock waves waves in which strong shock waves are reflected back into the explosive products. The

models of these experiments require information not only on release isentrope but also good models of released and shocked explosive products.

The radiographs of these experiments were made using the Proton Radiography Facility^{1,2} at the Los Alamos Neutron Science Center. Up to twenty-one proton-radiograph images of the same explosive experiment have been taken on many explosive drive experiments.

EXPERIMENTAL PROCEDURE

Rate-stick charges are used for the measurement of the steady detonation velocity in cylindrical charges and its variation with charge radius and initial conditions. We have used 0.5" and 0.375" diameter PBX9501 and 12 mm diameter PBX9502 rate-stick charges³ in the PRad 0079, 0080, and 0116 experiments. The detonation wave was allowed to travel more than 100 mm before the radiographs were taken over the subsequent 100 mm. The detonation wave shown in Fig. 1 has already reached steady propagation,

having traveled more than 100 mm before the wave had entered the field of view. By measuring the positions of the initial wave front at different times, we verified that the detonation wave was propagating at a constant velocity of 8.83 mm/ μ s for PBX 9501 and 7.50 mm/ μ s for PBX 9502.

We can make better density estimates¹ of the explosive products by averaging translated images and subsequently reducing the radiographic noise

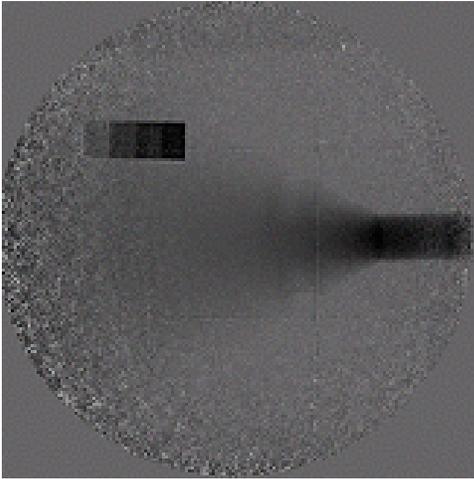


Figure 1. This transmission radiograph is of detonation wave in PBX 9502 rate stick, PRad 0080.

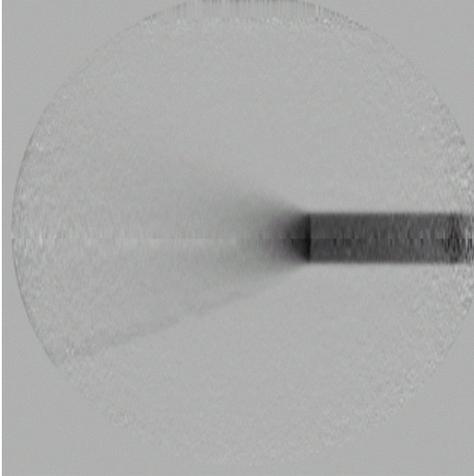


Figure 2. PRad 0116 density estimation of a PBX 9501 rate stick using the average of seven transmission radiographs all taken at the same time of detonation wave in PBX 9501.

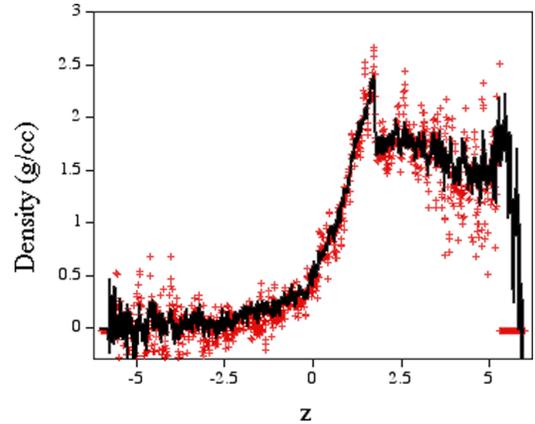


Figure 3. Comparison of the average density measurement in black to the density estimated from a single frame in PRad 0116 red points.

in the images as is shown in Fig 2. These averaging techniques are important in order to reduce the noise in the density estimations.

The release isentrope revealed in rate stick experiments is only part of the story. We used a second experiment, the wave-collider to examine other areas of the explosive's equation of state. The wave-collider experiment radiographed in Fig. 4 shows four images of the experiment. Like the rate-stick experiments, these results are also cylindrically symmetric; however, in this experiment, the speed or flow field of the steady detonation wave is not achieved. Furthermore, because the reflected shock waves do not propagate into a uniform state, their subsequent propagation into the reflected products is not steady state. Assuming axial symmetry, our analysis resulted in a measurement of the material density. Four of the analyzed radiographs are shown in Fig. 4. The waves approach the center at about 7.3 mm/ μ s. The shock waves then reflect outward initially at almost 7 mm/ μ s but then quickly slow down to 5 mm/ μ s after 2 μ s. By the end of the observation, the shock velocity is down to 2 mm/ μ s. These wave velocities are measurements made in the experimental frame of reference, so the shock waves that have material movement ahead are stronger than the velocity might indicate.

Estimates on shock-wave compressions would indicate about 15% volume compression in the incoming detonation wave, which takes unreacted explosives from an initial density of 1.9 g/cc (state O) to about 2.2 g/cc (state A) of reaction products. As the wave travels away from the center where

the products have been allowed to expand for a longer period of time, the density ahead of the shock is reduced to 0.8 g/cc, and the density behind the shock is reduced to about 1.1 g/cc, or 30% compression at the end of the experiment.

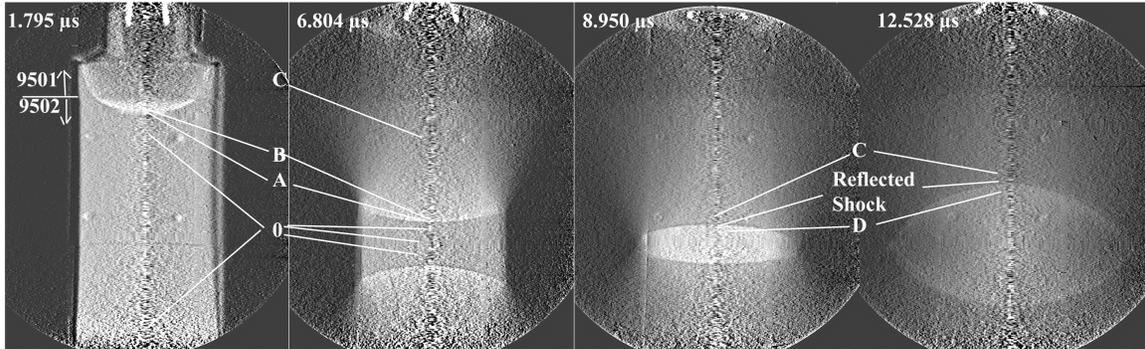


Figure 4. Volume-density images determined from the radiographs of PRad 0110 experiment. State A is ahead of the detonation wave, B and C behind the detonation front. State D is material that has been detonated, released to state C, and then reshocked.

RESULTS AND DISCUSSION

These radiographic density estimates can be compared to computer-calculations of the experiment. MESA³ has been used to model these experiments. Standard material constants⁴ for the JWL explosive equations of state have been used to model the explosive materials. Shown in Fig. 5 is a comparison of calculated and experimental measurements of a PBX 9502 rate stick. The axial comparison is good in the center of the image where the the experimental data is less noisy. Using averaging techniques as shown in Fig. 3 makes even more favorable comparisons, although the comparison at the ends of the image are still poorer than in the center. This would indicate the principle release isentrope is well represented by the JWL equation of state, not totally surprising since this type of information, from copper cylinder tests, is what this equation of state is based on.

In Fig. 6 we show the comparison of the wave-collider experiment and its calculation. The released products in front of the reflected shock make a reasonable comparison, although

the experimental data for $z < 0$ has significant noise. Even with the noise in the experiment results, it can be seen that the experimental wave is propagating through the released products faster than in the calculated wave. The density behind the shock is higher in the experiment than in the calculation. These are consistent with each other and may indicate that the Grüneisen parameter needs adjustment.

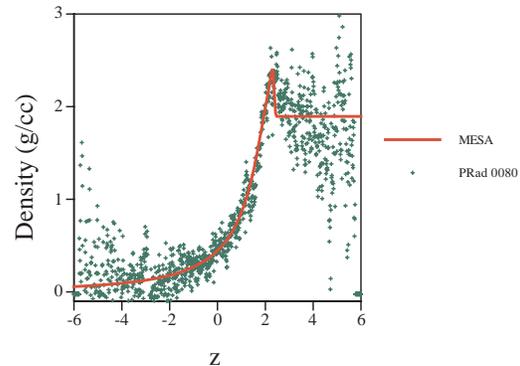


Figure 5. Comparison of the density on axis from the MESA calculation of the rate stick experiment density estimated from a single frame in PRad 080.

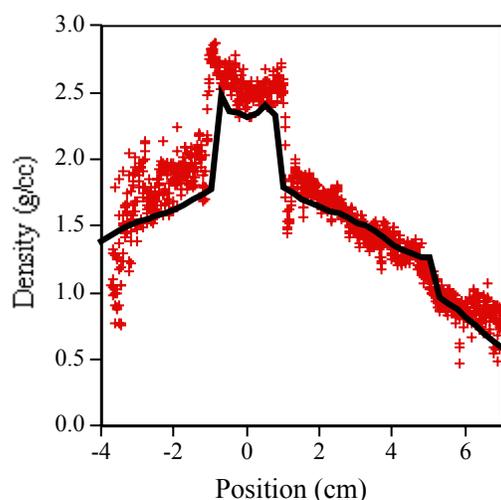


Figure 6. Comparison of the density on axis from the MESA calculation (line) of the wave-collider experiment density estimated from a single frame in PRad 110 indicated with points.

CONCLUSIONS

Proton Radiography results in valuable information on shock and particle kinematics of explosives experiments. Obtaining quantitative density measurements is more challenging. Density measurements were inferred from proton radiographs of the explosive experiments. Although comparisons can be made with each image, to get density measurement with low noise requires a significant amount of averaging. There are three different ways which we have used to make these averages: reducing the resolution of the image (averaging over pixels), taking multiple camera images of the same radiographic image, or by experimenting on a steady process and averaging the translated images. These methods of reducing the noise result in temporal or spatial sacrifices, which must be weighed with other experimental objectives.

We have used the density measurements to make comparisons to MESA simulations of these experiments. The comparisons were favorable, although showed some areas whether further investigations are warranted. These experiments

are being examined by Mathews, Brand, and Buescher to develop a technique, which uses the experimental information to help guide the choice of calculational parameters.

ACKNOWLEDGEMENTS

Racci Deluca, John Gomez, and Howard Stacy provided addition technical expertise to the experiments. Tariq Aslam, Holmann Brand, John Bdzil, Charles Mader, Allen Mathews, John Zumbro have contributed with technical discussions on the problems. Larry Hill provided much of the PBX 9502 explosive as well as providing experimental advice.

This work was supported by the Department of Energy under contract W-7405-ENG-36 to the University of California.

REFERENCES

1. N.S.P. King *et al.*, "An 800-MeV Proton Radiographic Facility for Dynamic Experiments," *Nuclear Instruments and Methods* **424**, 84-91 (1999).
2. J. D. Zumbro, K. R. Alrick, R. A. Gallegos *et al.*, Technical Report No. LA-UR-98-1015, presented at the Eleventh Symposium on Detonation, Breckenridge, 1998.
3. L.G. Hill, J.B. Bdzil, and T.D. Aslam, "Front Curvature Rate Stick Measurements and Detonation Shock Dynamics Calibration for PBX 9502 over a Wide Temperature Range," in *Proceedings of the 11th Symposium on Detonation* (1998).
4. B. M. Dobratz, LLNL Explosives Handbook, Properties of Chemical Explosives and Explosive Stimulants. LLNL Technical Report, UCRL-52997, (1981).