Title:
Proton Radiography of Shape Charge Jets Penetrating Teflon and Explosive

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2. WX-4: Weapons Experiments, DARHT Experiments & Diagnostics
3. Currently at Sandia National Laboratory
4. P-25: Subatomic Physics
5. XTD-1: Theoretical Design, Safety and Surety
6. WX-5: Weapons Experiments, DARHT Physics & Pulsed Power

This document deemed Unclassified by Eric N. Ferm

(ADC)
Abstract

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Los Alamos National Laboratory —

We have used proton radiography at the Los Alamos Neutron Science Center to observe viper shaped charge jets penetrating inert and explosive materials. A viper jet was observed penetrating both Teflon and PBX 9501. Radiographs captured the penetration events at several times and are analyzed to determine the density of the materials imaged at each time. The interfaces and shock waves in the flow are clearly evident in the images. Multiple time images allow the determination of the velocities of the interfaces and shock waves. Comparisons are made in the Teflon case with estimates of penetration rates and densities using the quasi-steady approximation analysis used in many terminal ballistics models. The PBX 9501 clearly detonated from the impact of the shape charge jet tip traveling at 9.1 mm/μs. The detonation wave is examined to see what support it obtains from the pursing jet and the jet is examined to find the influence of the explosive products on penetration velocity. This experiment gives us experimental results of in-situ penetration process that can be used to verify common modeling techniques and fluid mechanic calculations of the penetration process.

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LA-UR-11-xxxxx (Talk)

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Proton Radiography Experiment of Shaped Charge Jet Penetrating Teflon and PBX 9501

Very good models of the penetration process have been created using:

- Bernoulli’s Law in the stagnation point coordinate system
- Assuming the flow is quasi-steady
- Perfect stretching rods of constant diameter
- Both incompressible and compressible models have been examined along with various methods of modeling strength
- Modeling of HE penetration has been examined by Chapyak et al. and Poulsen

Proton Radiography’s high number of multiple images allows us to look experimentally at the modeling of the penetration process inside the target and examine the assumptions use in the models
Viper Shape Charge Characterization

Vipers have been well characterized as stretching rods and used in numerous penetration and initiation Experiments.

Viper at 35.00 μs

Viper at 65.12 μs

↑ 75.08 μs

↓ 85.17 μs

Optical Shadowgraph recorded by Synchro-ballistic Technique on Streak Camera at 303 mm from face of charge

Average Jet Diameter at 300 mm SO
pRad 0422 and pRad 0423 Results

9501:
Detonation wave promptly initiates
Jet becomes diffuse and tip seems to “disappear at times”
Jet tip position is not markedly different than in PTFE. Tip may be more deformed in HE.

PTFE (Teflon ®):
Bow wave is well developed at end.
Both seem to have difficulty moving the large tip out of the way.

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pRad423 Viper into Teflon Cylinder.

After the large tip was finished a hesitation in the penetration occurred.

The steady penetration did not establish until nearly 6-10 μs after impact.
pRad 422: Jet into PBX 9501 - More Challenging

- Asymmetries in tip – 3-d disturbances
- Sections of disrupted jet material
- Hints of overdriven detonation in early velocities.

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Conclusions

- The tip particle gives is a significant perturbation in the penetration and must be cleared away before a quasi-steady process is established in the inert case.

- In the penetration of the explosive, much more 3 dimensional behavior is observed, the HE products disrupt the jet well away from the detonation wave, and disperse through out the product (Similar to Chapyak et al. and Poulsen work).

- The densities both on axis and off axis a being examined in the PTFE case to examine penetration models and states in the steady bow wave.

- Material ID radiography would be valuable in these experiments.

Proton Radiography Collaboration

Acknowledgements

Jeremy J. Fait's RadLab radiographic analysis tool was used to analyze the images for this work, and Jeremy's assistance in it's use is acknowledged and appreciated.

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Further Analysis

Densities on axis at locations before and after each feature have been measured.

Axial Density Profile - PTFE

- Density Ahead Shock
- Density Behind Shock
- Density Ahead Stagnation Pt.
- Density Behind Stagnation Pt.
Chris Morris's Bow Wave Density Analysis

Densities ratios across the bow shock plotted against normal velocity through an assumed steady shock.

Comparison of bow waves at 66.64 and 67.64 μs
Previous modeling of jet penetration of HEs

pRad 0422 Viper into HE Areal Density Proton Radiographs
pRad 0422 Viper into HE Areal Density Proton Radiographs

8.5 μs 9.5 μs 10.5 μs 11.5 μs 12.5 μs 13.5 μs

14.5 μs 15.5 μs 16.5 μs 17.5 μs 18.5 μs
pRad 0422 Viper into HE Volume Density Proton Radiographs

0.0 μs 0.5 μs 1.0 μs 1.5 μs 2.0 μs 2.5 μs

3.0 μs 3.5 μs 4.5 μs 5.5 μs 6.5 μs 7.5 μs

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### pRad 0422 Viper into HE Volume Density Proton Radiographs

<table>
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<th>Time (µs)</th>
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<th>9.5µs</th>
<th>10.5µs</th>
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pRad 0223 Viper into PTFE Areal Density Proton Radiographs

1.5 µs  2.5 µs  3.5 µs  4.5 µs  5.5 µs  6.5 µs

7.5 µs  8.5 µs  9.5 µs  10.5 µs  11.5 µs  12.5 µs
pRad 0223 Viper into PTFE Areal Density Proton Radiographs

13.5 μs  14.5 μs  15.5 μs  16.5 μs  17.5 μs  18.5 μs
pRad 0423 Viper into PTFE Volume Density Proton Radiographs

1.5 μs  2.5 μs  3.5 μs  4.5 μs  5.5 μs  6.5 μs
7.5 μs  8.5 μs  9.5 μs  10.5 μs  11.5 μs  12.5 μs
pRad 0423 Viper into PTFE Volume Density Proton Radiographs

13.5 µs  14.5 µs  15.5 µs  16.5 µs  17.5 µs  18.5 µs
pRad 0223 Viper into PTFE Ratio Volume Density to Initial Density Proton Radiographs

1.5 µs  2.5 µs  3.5 µs  4.5 µs  5.5 µs  6.5 µs

7.5 µs  8.5 µs  9.5 µs  10.5 µs  11.5 µs  12.5 µs
pRad 0223 Viper into PTFE Ratio Volume Density to Initial Density Proton Radiographs

13.5 μs  14.5 μs  15.5 μs  16.5 μs  17.5 μs  18.5 μs
Tip Trajectory very similar in Teflon and PBX 9501
Steady or Quasi-Steady Supersonic Penetration of an Inert Material

Penetration velocities can be estimated by application of Bernoulli’s law.

Mesa calculation of 6 and 9 mm/μs rod penetrating nonreactive NM at 4.25 and 6.4 mm/μs. Calculation is done in the frame of reference of the stagnation point (penetrator/NM interface note the accuracy of the penetration rate estimates.

The supersonic bow wave structure is similar to that of a detonation, but the energy supplied to the shock is provided by the jet rather than reaction.

![Diagram showing penetration velocities and Mach 1 surface](image-url)
Curved Shock Waves in Steady Flow

Shock Polar: Locus of Shock states attainable from one steady flow velocity with variable shock attack angle (θ).

Estimates of time for the reaction to overtake the initiating shock wave have been measured in initiation experiments.
Shock Polar Analysis of Bow Shock from Penetration Process

Bow wave states lie on the shock polar

The point on the bow wave where the flow exits at sonic velocity can be identified on the shock polar.

The calculations show the sonic surface is nearly planar and perpendicular to penetration axis.

\[ U_{\text{rod}} = 6 - 4.25 = 1.75 \]
\[ U_{\text{target}} = -4.25 \]
Application of Bernoulli’s Law to the Steady Flow of a Supersonic Penetrator

\[
(U(\theta, \rho))^2 = (U_s(\theta))^2 + 2\left(\frac{P_s(\theta)}{\rho_s(\theta)} - \frac{P_l(\theta, \rho)}{\rho} + \int_{1/\rho_s(\theta)}^{1/\rho} P_l(\theta, 1/\nu) d\nu\right)
\]

\[
(U(\theta, \rho_{c\theta}))^2 = (C(P_l(\theta, \rho_{c\theta}), \rho_{c\theta}))^2
\]
Results of Bernoulli Analysis

From Bernoulli analysis and EOS information the thermodynamic state and exit speed at the sonic surface is determined for each streamline. With a few assumptions of scale one can associate points on the sonic surface with points on the bow shock.
What Do We Know About Quasi Steady Supersonic Penetration of a Nonreactive Material?

- Mesa calculation of 9 mm/μs rod penetrating nitromethane at 6.4 mm/μs. Calculation is done in the frame of reference of the stagnation point.

- The supersonic bow wave structure of the penetrating jet is similar to that of a detonation, but the energy supplied to the shock is provided by the jet rather than reaction.
Viper

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### Viper Virtual Origin Description

<table>
<thead>
<tr>
<th>Tip Velocity (mm/µs)</th>
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<th>$t_{vo}$ (µs)</th>
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</table>
Impact Initiation of Explosives Studies

Radiograph of an attenuated Viper Shape Charge. 1-2 mm dia. rods with velocities 2-9 mm/μs

Nitromethane (NM)
- Density 1.125
- Sound Speed 1.65 mm/μs
- Det Velocity 6.2 mm/μs
- Failure diameter 25 mm

Experimental Results of 6.5 mm/μs penetration

4 mm/μs - Failure
6 mm/μs - Failure
7 mm/μs - Detonation.

At 6.5 mm/μs we obtained multiple initiations and failures.