Title: Burn Front and Reflected Shock Wave Visualization in an Inertially Confined Detonation of High Explosive

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Intended for: 2011 APS Shock Compression of Condensed Matter Conference
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Abstract

Proton radiography was used to investigate the spatiotemporal evolution of the burn front and associated reflected shocks on a PBX-9502 charge confined between an outer cylindrical steel liner and an inner elliptical tin liner. The charge was initiated with a line wave generator at 30 degrees from the major axis of the ellipse. This configuration provides a large region where the high explosive (HE) is not within the line of sight of the detonation line and thus offers a suitable experimental platform to test various burn models and EOS formulations. In addition, the off axis initiation allows for the burn fronts to travel around the charge through different confining paths. Simulations were performed to assess the accuracy of several HE burn methodologies. Experimental data from initiation through HE shock collision will be presented and simulation comparison results will be discussed.
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Acknowledgments

• M. E. Briggs
• L. M. Hull
• R. T. Olson
• P. M. Rightley
• R. F. Shea
• M. A. Shinas
• E. F. Shores
• J. D. Zumbro
Objective

• Use pRad data to determine the accuracy of current burn models for the computation of the burn front and associated reflected shocks beyond the shadow region in an insensitive high explosive.
Cylindrical Assembly

Conceptual Design

Shadow Region

Booster

Detonation Point
Cylinder Cross Section

Steel 304L
(3 mm thick)

RTV
(300 mm thick)

PBX-9502

PBX-9501

Tin

30°

LWG

0.9 cm

1 cm

5.33 cm

5.03 cm

5 cm
3D Model

- Tin Elliptical Shell (3 mm thick)
- PBX-9502

- LWG

- Steel 304L Cylindrical Shell (3 mm thick)
- PBX-9501

10 cm
No Field of View Obstructions

All HE Has burned

t = 17 μs
Field Assembly

- PDV Probes
- Steel 304L Cylindrical Shell
- Tin Elliptical Shell
- PBX-9502
- LWG
Velocimetry Data
Synthetic P-Rad

pRad Image at 14.8 \( \mu s \)

Synthetic pRad Image at 15 \( \mu s \)
computed with MCNP by John Zumbro
Digitized pRad Shock Data

Burn Fronts

HE Reflected Shocks

Reflected Shocks
Artificial Viscosity (Q) Map

\[ t = 8.75 \mu s \]
Shock Fronts from Processing Q

Tracer 155

- Burn Front
- Pit Reflected Shock
- Case Reflected Shock

$r(\theta,s)$

$s = 1$

$y (cm)$

$x (cm)$

$Q^{0.15}$

$t (\mu s)$
Quantitative Comparisons

• Metric: The time \( \Delta \tau \) (in shakes) it would have taken the computed front to reach the experimental one (\( \Delta \tau > 0 \Rightarrow \text{data leads} \)).

• Calculate the average for every point on the isochrone \( \langle \Delta t \rangle \) (in shakes).
Shadow Fraction = 0.95

Dots = pRad Data
Lines = Simulation

\[ t = 16.8 \mu s \]
\[ t = 10.8 \mu s \]
\[ t = 3.8 \mu s \]
0.95 Shadow Fraction (Upper Fronts)
0.95 Shadow Fraction (Lower Fronts)
Shadow Fraction = 0.95
Dots = pRad Data
Lines = Simulation

$t = 3.8 \, \mu s$
$t = 10.8 \, \mu s$
$t = 16.8 \, \mu s$
DSD (Upper Fronts)

- $t = 3.8\ \mu s$
- $t = 4.8\ \mu s$
- $t = 5.8\ \mu s$
- $t = 6.8\ \mu s$
- $t = 7.8\ \mu s$
- $t = 8.8\ \mu s$
- $t = 9.8\ \mu s$
- $t = 10.8\ \mu s$
- $t = 11.8\ \mu s$
- $t = 12.8\ \mu s$
- $t = 13.8\ \mu s$
- $t = 14.8\ \mu s$
- $t = 15.8\ \mu s$
- $t = 16.8\ \mu s$
DSD (Lower Fronts)

\[ t = 3.8 \mu s \] \[ t = 4.8 \mu s \] \[ t = 5.8 \mu s \] \[ t = 6.8 \mu s \]

\[ \Delta t \]

20

-20

0.2 0.6 1.\text{s}

\[ t = 7.8 \mu s \] \[ t = 8.8 \mu s \] \[ t = 9.8 \mu s \] \[ t = 10.8 \mu s \]

\[ \Delta t \]

20

-20

0.2 0.6 1.\text{s}

\[ t = 11.8 \mu s \] \[ t = 12.8 \mu s \] \[ t = 13.8 \mu s \] \[ t = 14.8 \mu s \]

\[ \Delta t \]

20

-20

0.2 0.6 1.\text{s}

\[ t = 15.8 \mu s \] \[ t = 16.8 \mu s \]

\[ \Delta t \]

20

-20

0.2 0.6 1.\text{s}
DSD

Upper Burn Fronts

Lower Burn Fronts

$\langle \Delta \tau \rangle$: Mean $\Delta \tau$ along isochrones

- Upper
- Lower
Forest Fire

Dots = pRad Data
Lines = Simulation

$t = 16.8 \, \mu s$

$t = 10.8 \, \mu s$

$t = 3.8 \, \mu s$
Forest Fire (Upper Fronts)

t = 3.8 µs

t = 4.8 µs

t = 5.8 µs

t = 6.8 µs

t = 7.8 µs

t = 8.8 µs

t = 9.8 µs

t = 10.8 µs

t = 11.8 µs

t = 12.8 µs

t = 13.8 µs

t = 14.8 µs

t = 15.8 µs

t = 16.8 µs
Forest Fire (Lower Fronts)

- $t = 3.8 \mu s$
- $t = 4.8 \mu s$
- $t = 5.8 \mu s$
- $t = 6.8 \mu s$
- $t = 7.8 \mu s$
- $t = 8.8 \mu s$
- $t = 9.8 \mu s$
- $t = 10.8 \mu s$
- $t = 11.8 \mu s$
- $t = 12.8 \mu s$
- $t = 13.8 \mu s$
- $t = 14.8 \mu s$
- $t = 15.8 \mu s$
- $t = 16.8 \mu s$
Forest Fire

Upper Burn Fronts

Lower Burn Fronts

$\langle \Delta \tau \rangle$: Mean $\Delta \tau$ along isochrones

- Upper
- Lower
Spatiotemporal Global Averages in Shakes

- No Shadow Fraction
  - Up 21.6
  - Down 26.1
- Shadow Fraction 0.95
  - Up 8.4
  - Down 10.6
- Two Regions No Shadow Fraction
  - Up 6.3
  - Down 9.6
- DSD
  - Up 3.8
  - Down 8.4
- Forest Fire
  - Up 6.6
  - Down 5.7
Reflected Shocks

Dots = pRad Data
Lines = Simulation
Reflected Shocks

At 12.8 μs $\langle \Delta T \rangle = 14.8$ shakes

At 16.8 μs $\langle \Delta T \rangle = 11$ shakes
Concluding Remarks

- The Forest Fire reactive burn model and DSD have provided the best agreement with the data. However, FF is mesh dependent and in this problem it required a mesh resolution of 150 µm.

- Two more burn algorithms (CJ Volume and Dynamic Burn) will be compared with data.

- While the agreement with reflected shocks loci is acceptable, on average is twice as large as that for the burn fronts.