Experimental Support of a Slow Cookoff Model Validation Effort

Weapons Division
Research Department

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15-17 November 2004
Technical Challenge

• To generate a set of experimental data that can be used to validate cookoff models currently under development

Prediction capability for not only time to reaction but reaction violence
Why Bother?

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Date</th>
<th>Casualties</th>
<th>Aircraft Information</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>USS Oriskany</td>
<td>1966</td>
<td>44 killed, 156 injured</td>
<td>3 aircraft destroyed, $63.6M</td>
<td></td>
</tr>
<tr>
<td>USS Forestal</td>
<td>1967</td>
<td>134 killed, 162 injured</td>
<td>21 aircraft destroyed, 43 aircraft damaged, $758M</td>
<td></td>
</tr>
<tr>
<td>USS Enterprise</td>
<td>1969</td>
<td>28 killed, 343 injured</td>
<td>15 aircraft destroyed, 17 aircraft damaged, $554M</td>
<td></td>
</tr>
<tr>
<td>USS NIMITZ</td>
<td>1981</td>
<td>14 killed, 48 injured</td>
<td>3 aircraft destroyed, $150M</td>
<td></td>
</tr>
</tbody>
</table>

220 killed, $1525.6M - None under attack
Needs

• Ship Commanders need information
  – How long sailors have to fight fire?
  – What are the most vulnerable munitions?
  – Can munitions load-out reduce vulnerability?
  – What are the consequences of cookoff reaction?
Leveraged Program

- Joint effort between Navy and DOE
  - Navy working under ONR
    - NAWCWD-CL
    - NSWC - IH
  - DOE working under MOU
    - LLNL
    - SNL
    - LANL (partial)
Approach

- Three year project initiated by DOD Office of Munitions based on meeting success criteria
  - Time to reaction ± 10%
  - Temperature at reaction ± 10%
  - Degree of reaction violence
  - Location of reaction
  - Extent of reaction
- Phase I (FY00)
  - Simple geometry
  - Single sample
- Phase II (FY01/02)
  - Increased geometric complexity
  - Different materials
- Phase III (FY02/03)
  - Predict ordnance item in cookoff
Phase I

- Simple geometry
- Single sample
Phase I Test Fixture

Type 4130 Steel
Tube Length ~ 229 mm
Explosive Length ~ 102 mm

Experimental Variables
Confinement
Ullage
Heating profile
FORMULATION OF PBXN-109
COMPOSITION ANALYSIS

• Mix 991206

<table>
<thead>
<tr>
<th>INGREDIENT</th>
<th>WEIGHT PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td>64.94</td>
</tr>
<tr>
<td>BINDER</td>
<td>14.09</td>
</tr>
<tr>
<td>ALUMINUM</td>
<td>20.97</td>
</tr>
</tbody>
</table>

Only mild reactions observed in all conditions tested
Phase II

– Increased geometric complexity
– Different materials
# Phase II Energetic Materials

<table>
<thead>
<tr>
<th>Energetic Material</th>
<th>Composition – Wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBXN-109</td>
<td>65% RDX, 15% HTPB, 20% Al</td>
</tr>
<tr>
<td>LX-10</td>
<td>95% HMX, 5% VitonA</td>
</tr>
<tr>
<td>PBX9501</td>
<td>95% HMX, 2.5% BDNPF/A, 2.5% Estane</td>
</tr>
<tr>
<td>PS-1</td>
<td>70% AP, 10% HTPB, 20% Al</td>
</tr>
</tbody>
</table>
Type 1018 Steel Test Fixture

- Torq n-seal Plug
- Torq n-seal Anchor
- Steel Cover
- Thermal Barrier
- Energetic Material
- 1018 Steel Tube

ID ~ 22 mm
Tube Length = 250 mm
Center wall = 2.54 mm
Explosive Length ~ 102 mm
65-95 grams energetic
Thermocouple Placement

- TC10
- TC9
- TC8
- TC1
- TC5
- TC6
- TC7

2.54 mm wall

32 mm

41 mm
Thermocouple Data

Temperature - deg. C

Time - Ksec.

030923
PBX-9501
No ullage

tc1
 tc2
 tc3
 tc4
 tc5
 tc6
 tc7
 tc8
 tc9
tc10
Strain Gage Placement

SG1, SG3, SG5
45 degrees

SG2, SG4, SG6
225 degrees

3.8 cm

UNCLASSIFIED
Strain Gage Data

030923
PBX-9501
No ullage

Microstrain X 1000

Time - microseconds

sg1
sg2
sg3
sg4
sg5
sg6
# Phase II Results

<table>
<thead>
<tr>
<th>Material</th>
<th>Free Volume - CC</th>
<th>Reaction Temperature, C</th>
<th>Fragments</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBXN-109</td>
<td>4</td>
<td>169.0</td>
<td>1</td>
</tr>
<tr>
<td>LX-10</td>
<td>6</td>
<td>205.0</td>
<td>9</td>
</tr>
<tr>
<td>LX-10</td>
<td>1</td>
<td>197.1</td>
<td>7</td>
</tr>
<tr>
<td>PBX9501</td>
<td>4</td>
<td>185.0</td>
<td>15</td>
</tr>
<tr>
<td>PBX9501</td>
<td>1</td>
<td>185.6</td>
<td>108</td>
</tr>
<tr>
<td>PS-1</td>
<td>4</td>
<td>238.0</td>
<td>3</td>
</tr>
</tbody>
</table>
Fragmentation

PBXN-109

PBX9501
## Phase II Porosity Study
### LX-10

<table>
<thead>
<tr>
<th>Percent TMD</th>
<th>Free Volume - CC</th>
<th>Reaction Temperature, C</th>
<th>Fragments</th>
</tr>
</thead>
<tbody>
<tr>
<td>98</td>
<td>1</td>
<td>197</td>
<td>7</td>
</tr>
<tr>
<td>99</td>
<td>6</td>
<td>205</td>
<td>9</td>
</tr>
<tr>
<td>85</td>
<td>10</td>
<td>204</td>
<td>15</td>
</tr>
<tr>
<td>85</td>
<td>15</td>
<td>202</td>
<td>5</td>
</tr>
<tr>
<td>75</td>
<td>20</td>
<td>202</td>
<td>208</td>
</tr>
<tr>
<td>75</td>
<td>25</td>
<td>203</td>
<td>15</td>
</tr>
</tbody>
</table>
LX-10 Porosity Study

98 % TMD, 1 cc free volume

75% TMD, 20 cc free volume
LX-10 Strain Rate Comparison

Comparison of Strain rate

- LX-10(1023)
- LX-10(1102)
- LX-10(85% TMD, nU)
- LX-10(85% TMD, 10% U)
- LX-10(75% TMD, 10% U)
- LX-10(75% TMD, nU)

Time (usec)

Strain rate

0 2000 4000 6000 8000 10000 12000
Phase III

–Predict ordnance item in cookoff
Phase III
Heavywall Penetrator (HWP)

• **Dimensions**
  - Total Length: 17.8"
  - Outer Diameter: 8.0"
  - Wall: 0.5"
  - Aft Plate: 0.5"
  - Nose Plate: 1.5"
  - Liner: 0.06"
  - Interior Volume: 573.6 in³

• **Weights**
  - Empty: 81.2 lb
  - Typical Load: 33.8 lb
  - Total: 115.0 lb

• **Material**
  - 4130 steel
Modified HWP Aft Closure
HWP - Two heating configurations

Configuration 1
End heating

Configuration 2
Side heating

Configurations 1 and 2
Quick ramp to 150 deg C
side = 3.3 deg C/min
end = 2.6 deg C/min
Soak 5 hours
Slow ramp at 0.05 deg C/min

Mica

Silicon Rubber
Sample

• Inert Explosive – one HWP cast

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Weight percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass beads</td>
<td>71.3</td>
</tr>
<tr>
<td>Binder</td>
<td>28.69</td>
</tr>
<tr>
<td>Blue dye</td>
<td>0.01</td>
</tr>
</tbody>
</table>

• PBXN-109 – two HWP cast

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Weight percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td>64.87</td>
</tr>
<tr>
<td>Binder</td>
<td>15.62</td>
</tr>
<tr>
<td>Aluminum</td>
<td>19.51</td>
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</table>
HWP Results

• End heated
  – Cookoff at 1015.0 min (16.9 hr)
  – Maximum temperature of 181.4 °C at control TC (184.8 °C predicted)
    • Externally mounted on down facing forward end
    • Ignition at center of forward end (as predicted)

• Side heated
  – Cookoff at 654.4 min (10.9 hr)
  – Maximum temperature of 176.6 °C at internal TC in center about one inch from wall
    • External control TC at 163.8 °C (165.5 °C predicted)
    • Ignition off center near wall (as predicted)
End Heated HWP
End Heated HWP

Mica Heater
HWP End Heated PBXN-109

HWP at test site

Note
Strain Gage Data

HWP Live End Heat Strain Data

Time (kSec)

Microstrain

sg1
sg2
sg3
sg4
sg5
sg6
sg7
sg8
sg9
sg10
HWP End Heated PBXN-109

Post test
HWP End Heated PBXN-109

Recovered cylinder

Exterior of aft end fragment
End plate in place - bolts sheared

30.56 lbs explosive recovered
Side Heated HWP
Side Heated HWP

Silicon rubber heater
HWP Side Heated PBXN-109

HWP at test site

Note
Side Heated HWP

021213 SIDE HEAT
- P90-6 internal thermocouple
- Control thermocouple

Temperature - deg. C

Time - ksec.
HWP Side Heated PBXN-109

Cylinder located 550 feet from test pad
Aft end fragment located 415 feet from test pad
9.44 lbs explosive recovered
HWP: Simulation vs. Experiment

Simulations were real predictions (Inert tests were used to estimate heat loss BC's for live tests)

Data fell within range of predictions

Improvements can be made with more thorough knowledge of boundary conditions

Comparison with Simulation Results

Experiment: ~1015 min ~654 min

Note: Cases 1-9 were a priori simulations, case A (end heated) was done afterwards.
Accomplishments

• Slow cookoff model validation effort contributed to development of protocol for slow cookoff

• Platform for collaboration
  – Small scale experimental design
  – Placement of thermocouples and strain gages

• Range of reaction violence was demonstrated in small scale experiment
  – HMX containing explosives were most violent
  – Porosity contributes to reaction violence

• Full scale experiments demonstrated importance of geometry and boundary conditions
  – Initial ambient air conditions
Where do we go from here?

• Apply experimental and analytical tools to real problems and realistic heating profiles
  – Ordnance design
  – Fire fighting tactics
  – Magazine design
  – Captive carry
  – Development of a sub-scale bonfire test - TB700-2