High Performance Propellant
Fragment Impact Testing: Small-scale
and Full-scale

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Background

• Full-scale rocket motor assets are expensive to test. The development of predictive tools to help predict/understand the response of propellants (non-ideal explosives) would lower overall cost and provide useful IM tools.

• Goal: Predictive capabilities for IM threats on energetics in representative systems
ABVR (Army Burn to Violent Reaction)- Sub scale fragment impact tests representing full scale; data provided for M&S; component tests performed for material characterization and model calibration

M&S- Modeling and simulation iterations to design a full scale fragment impact prediction tool; Integrated analog T&E Demo pre-test predictions

Test and Evaluation (T&E) Analog Demo– Full scale fragment impact test with analog rocket motor; Integrated analog T&E Demo test materials & test article fabricated, test range configured and test executed

Sub Scale ABVR → Sub Scale ABVR → T&E Demo

M&S → M&S Prediction
High Performance Propellant (HPP)-Ammonium Perchlorate (AP) and aluminum powder bonded by hydroxyl-terminated butadiene
ABVR Results

Fragment Velocity

- 6000 ft/sec
- 5000 ft/sec
- 4000 ft/sec
- 3000 ft/sec

Time After Impact

- 87 μsec
- 217 μsec
- 434 μsec

Time After Impact Images:

- 3000 ft/sec @ 174us
- 5000 ft/sec @ 174us
- 4000 ft/sec @ 261us
- 3000 ft/sec @ 348us
ABVR Results

Velocities 5600-6100 ft/sec

Peak Pressure (psi)

Case/Propellant to Propellant/Case (CPPC)

Case/Propellant to Inert/Case (CPIC)

Case/inert to Propellant/Case (CIPC)

No Case/Propellant to Propellant/No Case (NPPN)

Case/inert to Inert/Case (CIIC)

Web / Gap (in)
• Test articles represent the dimensions and materials used for T&E Demonstration.

-4 ABVR Tests
  • Composite panels
  • 3.65” thick HPP propellant slabs
  • 1.5” Air Gap
  • Fragment Impact Velocity (4000 to 6000ft/sec)

-4 Inert Impact Tests
  • Composite Panel (Bare)
  • Composite Panel with Insulation
  • Canister and Composite Panel (Bare) Canister
  • Fragment Impact Velocity 6000ft/sec

• Supply data to modelers for T&E demonstration predictions
- Reduction in velocity due to canister, case, and insulation material was significantly more than anticipated (see chart, 5-15% reduction).
- Increasing impact velocity increased pressure reading; with the exception of the added canister

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Canister</th>
<th>Composite Panel</th>
<th>Insulation</th>
<th>Test Article</th>
<th>Initial Impact Velocity, ft/sec</th>
<th>Velocity Reduction, %</th>
<th>Reaction Type</th>
<th>Peak Pressure, psi</th>
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<td>Burn</td>
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Test 5

Test 6
• ALE3D multi-physics code with the PERMS reaction/burn model
  – Arbitrary Lagrangian Eulerian Three Dimensional (ALE3D) code
  – Propellant Energetic Response to Mechanical Stimuli (PERMS) material model with Equivalent Plastic Strain (EPS)-enhanced burning parameters to explore reactivity
  – Used ABVR test results to calibrate the models for Demo tests
  – Performed sensitivity studies on model parameters due to uncertainties in the HPP fragmentation response and its central role in capturing reaction violence
• CTH shock hydro-code with two propellant models
  – Initial model was Coupled Damage and Reaction with Kinetics (CDAR-K) but was not well suited to HPP material
  – Propellant Model (PMOD) was used effectively starting in 2012
  – PMOD parameters calibrated from ABVR results for Demo tests
• Material models for reactive & inert constituents were used extensively in both codes
  – ABVR-related experiments helped team to better understand physics
## IM Analog Demo Rocket Motor Test Plan

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Planned Impact Velocity, ft/sec</th>
<th>Bore Dimension, in</th>
<th>Configuration</th>
<th>Test Description</th>
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<tr>
<td>1</td>
<td>8300</td>
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<td>No Canister</td>
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<td>8300</td>
<td>4</td>
<td>No Canister</td>
<td>Bore Variation</td>
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<td>3</td>
<td>8300</td>
<td>2</td>
<td>Canister</td>
<td>Canister Influence</td>
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</table>
• In-Bore Pressure Transducer
• Open Air Over-Pressure (OP) Gauges
• Breakscreens (6) near and on Test Article
  – Measure Fragment Velocity, $V_o$
  – Time, $T_o$, for Fragment Impact on Test Article
  – Time, $T_f$, for (potential) Fragment Exit
• Standard Video (3 views)
• High Speed Video (3 views)
• Still Photography
• Photodiode
• Photonic Doppler Velocimetry (PDV)
HPP IM T&E Demonstration
Test Setup

The diagram illustrates a test setup for HPP IM T&E demonstration. The central test article is surrounded by various components and measurement points at different distances: 5ft, 10ft, 15ft, and 20ft. Video cameras and pressure gauges are positioned at specific locations, and there are labeled sections for 'Raised Earth' and 'Shelter/Gun Shelter'. The layout includes clear distances and positioning to facilitate the demonstration.
IM Analog Motor Demo Video
## IM Analog Demo Rocket Motor Test Data

### Test Results

<table>
<thead>
<tr>
<th>Test</th>
<th>Velocity (ft/s)</th>
<th>Max.@5ft OP, (psi)</th>
<th>In-Bore Pressure, psi</th>
<th>Reaction Type</th>
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<td>7989</td>
<td>12</td>
<td>&gt;10K</td>
<td>IV</td>
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### Test Number Description

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<th>Distance, ft</th>
<th>Location, degree</th>
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<td>220</td>
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<td>1</td>
<td>Dome and Case Material</td>
<td>35</td>
<td>60</td>
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<tr>
<td>1</td>
<td>Propellant and Case Material</td>
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<td>1</td>
<td>Firebrand</td>
<td>249</td>
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<tr>
<td>1</td>
<td>Forward Closure</td>
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<td>Aft End of Motor</td>
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<td>Firebrand</td>
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<td>2</td>
<td>Case Material</td>
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<tr>
<td>3</td>
<td>Motor and Canister (minus Forward End Cap)</td>
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<tr>
<td>Test</td>
<td>Case Velocity (PDV 90° probe) (ft/s)</td>
<td>Photodiode (time to 1st light) (µsec)</td>
<td>Max. OP, Stem 4 (psi)</td>
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Conclusions

– ABVR tests provided useful velocity, pressure, and visual data to make pre-test prediction simulations for the analog demonstration rocket motor IM tests

– ABVR tests provided velocity reduction information
  • Canister reduced fragment speed by approx. 7% (from ABVR)
  • Composite with insulation reduced fragment speed by approx. 8% (from ABVR)

– Pre-test predictive simulations of the analog demonstration rocket motor tests suggested bore size would influence the violence of the reaction
  – Bore size did influence violence of the reaction
  – As anticipated, data confirmed a more violent reaction for the larger bore diameter

– Pre-test prediction modeling was important to the analog demo RM design and the test matrix
– Canister appeared to mitigate the reaction of the motor to fragment impact

– Placement of over pressure gauges closer to target was important to provide meaningful data as suggested by simulations

– 10K in-bore pressure gauge was not rated high enough for actual pressures

– Placement and type of break screens is critical to accurate time and velocity measurements

– Refined post-test ALE3D and CTH model simulations provided values that were improvements compared to the original predictions
  - Gaps in the test data and needed improvements in the M&S technology
  - Further experimental work and modeling enhancements are needed to continue to evolve predictive capabilities
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