Enhanced Fragmentation Studies for a 40mm Dual Purpose Grenade

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  - Warhead designs and analyses
- Systems Dynamics Corporation
  - Warhead initiation electronic circuit designs

The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the U.S. Government.
Program Overview

- **Objective**
  - Increase warfighter effectiveness through the use of small fragmenting munitions that provide an increase in Pi/Lethal Area of at least 25% against a specified array of threats in specified scenarios

- **Contract**
  - NBCH3090001-0003
  - Phase I Design Study

- **Quantitative Metrics**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Current</th>
<th>RPP Requirement</th>
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<tbody>
<tr>
<td>Small Fragmenting Munitions- P(I)</td>
<td>Pi/Lethal Area</td>
<td>Threshold (T): 25% over current systems</td>
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<td>Objective (O): &gt;25% over current systems</td>
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<td>TRL Level: Start TRL 2, End TRL 4</td>
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Program Approach

- Improve 40mm M433 dual purpose grenade
- Improve both kill mechanisms
  - Fragmentation- primary emphasis
  - Armor Penetration (shaped charge)- secondary emphasis
  - Combined optimization tradeoffs
M433 40mm HEDP Cartridge
Requirements Analysis- Key Req’ts

- Maintain dual-purpose projectile design
  - Anti-armor & Anti-personnel
  - Maintain shoulder fire capability (same max impulse)
  - Minimal max range degradation
- Anti-Personnel (Fragmentation)
  - Increase Pi/Lethal Area footprint by 25%
  - Consider full 360 degree lethality effects
  - Consider impact geometry
- Anti-Armor (Shaped Charge)
  - Penetrate RHA- same or better than current
  - Increase behind armor effects
Shaped Charge Tradeoff Analysis
Shaped Charge Modeling Approach (CTH)

2D non-spinning, standoff against RHA

Add spin effects of (2D geometry, 3D CTH)

Add spit-back initiation effects

Add 3D fuze component effects with spit-back and spin

2D equivalent geometry of full up 3D run. Utilized for baseline and tradeoffs.
Tradeoff Studies and Performance Measures

- Shaped Charge Trade Studies
  - Detonation Location(s)/ Wave Shaper
  - Liner Geometry
  - Liner Material
  - Explosive Material
  - Confinement

- Performance evaluation measures
  - Spall ring area
  - Spall $\frac{1}{2}$ cone angle
  - Average through hole diameter
Detonation Location Configurations

- Midpoint Detonation
- Base Detonation
- Base Detonation With Waveshaper
- Spit-Back Base Detonation With Hollow Waveshaper
Detonation Location Effect
Target Perforation Characteristics

Mid Point Detonation
Base Detonation
Base Det With Wave Shaper
Spit-Back Base Det With Hollow Wave Shaper
Detonation Location Effect

Configuration
- No other changes to M433 baseline

Conclusions
- Base detonation with wave shaper offers significant benefit
- Spitback initiation with hollow wave shaper enhances performance and allows current fuze arrangement
Liner Apex Angle Effect

Liner Included Angle
- Baseline
- + 35%
- + 75%

Configuration
- Liner thickness increased 50% with angle increase
- No other changes to M433 baseline

Conclusions
- Moderate increase in apex angle beneficial

<table>
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<tr>
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<th>+150%</th>
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Liner Material Effect

Materials
- Copper (baseline)
- Molybdenum
- Tantalum
- Both materials more dense

Configuration
- Liner thickness scaled to obtain equal mass for all materials
- No other changes to M433 baseline

Conclusions
- Significant gain with increased density

Spall Ring Area
- Copper: 100%
- Molybdenum: +160%
- Tantalum: +260%

Spall Ring 1/2 Cone Angle
- Copper: 100%
- Molybdenum: +200%
- Tantalum: +300%

Avg Thru Hole Dia
- Cu: 100%
- Mo: +5%
- Ta: -10%
Explosive Material Effect

Explosive
- Baseline-Comp-A5 (modeled A3)
- LX-14
- PAX-2A (IM Compliant)

Configuration
- No other changes to M433 baseline

Conclusions
- Both replacement explosives offer significant benefit
- PAX-2A gives best performance
Casing Confinement Material Effect

**Explosive**
- Baseline-Aluminum
- Substitute steel

**Configuration**
- No other changes to M433 baseline

**Conclusions**
- Offers significant benefit
- Weight increase a consideration

<table>
<thead>
<tr>
<th>Spall Ring Area</th>
<th>Spall Ring 1/2 Cone Angle</th>
<th>Avg Thru Hole Dia</th>
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<tbody>
<tr>
<td>Alum 100%</td>
<td>Alum 100%</td>
<td>Alum 100%</td>
</tr>
<tr>
<td>Steel +300%</td>
<td>Steel +230%</td>
<td>Steel +10%</td>
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</tbody>
</table>
Combined Improvement Effects

**Representative Improvements**

- Molybdenum liner
- PAX-2A explosive
- Base initiation with wave shaper
- No other changes to M433 baseline

**Conclusions**

- Significantly exceeds program goals

![Graph showing combined improvement effects]

- Spall Ring Area
- Spall Ring 1/2 Cone Angle
- Avg Thru Hole Dia
Conclusions- Shaped Charge

• All options improved performance
  – Detonation Location(s)/ Wave Shaper ....+600%
  – Liner Design...................................................... +210%
  – Liner Material..................................................... +260%
  – Explosive Material............................................... +200%
  – Confinement....................................................... +300%
  – Implementation complexity varies

• Combining options provides significant improvements

• Performance potential significantly exceeds program goals

• Provides trade space for fragmentation improvements
Fragmentation Tradeoff Analyses
Baseline Fragmentation Distribution

- Cross range- Fragmentation primarily from sidewall of steel cup
- Up range- Primarily steel fragments from cup base
- Down range- Primarily aluminum sidewall fragments
Fragmentation Lethality Analysis Approach

1. Generate CAD model of grenade concept
2. Translate CAD model to CTH input, simulate detonation
3. Employ JMEM standard methodology: Pi for single fragment
4. Total Pi calculated for all ranges and azimuths
5. Fragment distribution and target presented area determine hits, Pi
6. Calculate fragment density, velocity f(range, impact angle) via CTH
Baseline Fragmentation
Lethality Directionality

Pi Directionality

Pi ≥ 0.5 Contour

Probability of Incapacitation vs Range:
- Cross Range
- Up Range
- Down Range

Range vs Cross Range:
- Down Range
- Impact Point
- Up Range
# Fragmentation Performance Evaluation Parameters

<table>
<thead>
<tr>
<th>Items From Shaped Charge Study</th>
<th>Additional Fragmentation Specific Items</th>
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<tbody>
<tr>
<td>Detonation Location</td>
<td>Fragment Shape</td>
</tr>
<tr>
<td>Detonation Wave Shaper</td>
<td>Fragment Material</td>
</tr>
<tr>
<td>Explosive Material</td>
<td>Number of Fragments</td>
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<tr>
<td>Liner Material</td>
<td>Total Fragment Mass</td>
</tr>
<tr>
<td>Liner Shape</td>
<td>Warhead Shape</td>
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<tr>
<td>Fwd Sidewall Material</td>
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### Fragmentation Performance Enhancements

*Items with ≤ 10% Improvement*

<table>
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<tr>
<th>Design Parameter</th>
<th>Evaluation Approach</th>
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<tbody>
<tr>
<td>Detonation Location</td>
<td>Base Detonation</td>
</tr>
<tr>
<td>Detonation Wave Shaper</td>
<td>Wave Shaper With Base Detonation</td>
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<tr>
<td>Explosive Material</td>
<td>LX-14, PAX-2A, CL-20</td>
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<tr>
<td>Liner Material</td>
<td>Molybdenum</td>
</tr>
<tr>
<td>Liner Shape</td>
<td>Shallower Apex Angle</td>
</tr>
<tr>
<td>Fragment Shape</td>
<td>Cubes, Spheres, Rods</td>
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</table>

- Designs that benefited shaped charge have negligible benefit to fragmentation.
- Indicates potential to separate variables for independent optimization.
Fragmentation Performance Enhancements
Lethal Area Improvement

Program Goal - 25%

Steel Forward Casing
Proj Wt +40%
+12%
+Downrange +Crossrange

2x # Frags
+20%

Tungsten Fragments
Proj Wt +40%
+Uprange +Crossrange

+50% Fragment Mass
Proj Wt +15%
+Uprange

Rounded Warhead Base
+Uprange +Crossrange

+14%
Fragmentation Performance Enhancements
Lethal Area - Combined Improvements

<table>
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<tr>
<th>Pgm</th>
<th>Goal</th>
<th>25%</th>
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<tbody>
<tr>
<td>Rounded Whd Base, Steel Fwd Case</td>
<td>+40%</td>
<td></td>
</tr>
<tr>
<td>Rounded Whd Base, +50% Frag Mass</td>
<td>+40%</td>
<td>+50%</td>
</tr>
<tr>
<td>Rounded Whd Base, Steel Fwd Case, +50% Frag Mass</td>
<td>+75%</td>
<td>+50%</td>
</tr>
<tr>
<td>Rounded Whd Base, Steel Fwd Case, Titanium Fwd Case, +50% Frag Mass</td>
<td>+30%</td>
<td>+60%</td>
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</table>

Proj Wt
+40%
+15%
+55%
+30%
Improved Fragmentation Lethality

**M433 vs. Rounded Warhead Base and Steel Fwd Sidewall**

**Directional Pi Improvements**

- Baseline
- Improved

**Pi ≥ 0.5 Improvements**

- 40% Increase in Coverage Area

**Impact Point**

- Down Range
- Up Range
- Cross Range

**Range**

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Conclusions- Fragmentation Improvements

- Individual design improvements offer lower magnitude gains than for shaped charge
- Incremental combination of best designs enable program requirements to be met
- Greatest benefits derive from improving up/down range effectiveness via fragment distribution pattern.
- Can achieve 40-75% improvement in lethal area, exceeds program goals
- Challenge- Most increase projectile weight
Conclusions-
System Improvement Options

- Shaped charge and fragmentation improvement approaches exhibit significant independence of variables
- Improvement potential disproportionately skewed in favor of armor penetration versus fragmentation, not reflective of program goals
- **Most efficient use of trade space is to reduce shaped charge size/weight allocation to increase fragmentation performance.**
Conclusions - Proposed Grenade Concept

Baseline M433

Improved Design

• Shaped charge improvements allow smaller diameter liner to maintain armor penetration/behind armor effectiveness
• Truncated elliptical warhead body significantly increases up and downrange fragmentation coverage

Baseline M433

Improved Design

Increased Whd Mass

Elliptical Base

PAX-2A Explosive

Reduced Liner Diameter

Warhead Extended Forward
Conclusions - Proposed Grenade Concept

- Meets program goal of > 25% Pi/Lethality increase
  - Armor Penetration (shaped charge)
  - Fragmentation
- Applies current warhead and explosive technologies
- Conceptual feasibility established via analysis, additional detailed design required to support hardware implementation