New Army XM1002 TPMP-T Cartridge Design Performance Assessment and Selection Process *

John F. Kostka
TACOM-ARDEC

Roger Peterson
Alliant Techsystems Inc.

* The Development of the XM1002 (MPAT) Trainer is Managed by Project Manager – Maneuver Ammunition Systems (PM-MAS, Picatinny Arsenal, NJ)
26 March 2003
Acknowledgements

• Dick McDanolds (OPM-MAS) Program Manager
• Jim Persoon (Alliant Techsystems) Program Manager
• Jim Newill (Army Research Laboratory) Computational Structure Dynamics, Team Leader
Contents

• XM1002 Projectile
• Key Requirements
• Development Strategy
• Gun/Projectile Dynamic Simulations
• Dynamics of Launch
• Example of Gun/Projectile Dynamic Simulations
  ▪ Sensitivity to Tube Shape and Tube Defects
• Success Criteria Evaluation
• Current Project Status
XM1002 - Training for M830A1

- XM1002 External Geometry Identical to M830A1
- Weight & CG Location Similar to M830A1
- Conical Flare to Stabilize and Drag Down
- M14 Propellant to Achieve Cost Objective
- Consistent Flight Characteristics (Low TID)
XM1002 – M830A1 Trainer ORD

Key Requirements (JUL 98)

- Max Range 8 KM (10° Gun Elevation)
- Dispersion ~ at 3 km
- Visual Appearance ~ M830A1
- Ballistics Similar to 3000m (Requires FC Solution)
- Checking / Setting Capability of Dummy Air / Ground Switch
- Tracer Different Color than M865 & Visible To 3000m
- Cost Comparable to Current Training Cartridges
- Weight(+0/-6 Pounds) Compared to M830A1
- Center Of Gravity (+/-3 Inches) Compared to M830A1
### XM1002 Key Requirements

**Status Date:** 8/16/00

**Key:**
- High Risk
- Med Risk
- Low Risk

<table>
<thead>
<tr>
<th>System</th>
<th>Propulsion</th>
<th>Cartridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>TID</td>
<td>Muzzle Velocity</td>
<td>Appearance</td>
</tr>
<tr>
<td>Max Range</td>
<td>Pressure</td>
<td>Air Ground Switch</td>
</tr>
<tr>
<td>Strength of Design</td>
<td>T4 Time</td>
<td>Weight and CG</td>
</tr>
<tr>
<td>Tracer Color/Visibility</td>
<td>Negative DP</td>
<td>Robustness</td>
</tr>
<tr>
<td>Crew Survivability</td>
<td>Misfire</td>
<td>UPC</td>
</tr>
<tr>
<td>Tube Service Life</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hangfire</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

034_T105235.ppt
Development Strategy

- Low Cost Development
  - Fewer Full Scale Rounds Available for Ballistic Testing
- Required Integrated Approach With More Up Front Experiments and Simulations To Insure Success
  - Subscale Ballistic and Wind Tunnel Experiment
  - Bench Laboratory Experiments
  - Extensive Use of Simulation
ATK XM1002 Design
Modified TACOM ARDEC Enhances Structural Margin

Iteration #1: Develop Database for Analysis and Design Selection

- Wind Tunnel Test
  - Evaluate Effect of:
    - Flare Configurations (Diameter, Slots, Range)
    - Body Geometries (Diameter, Groove/Thread)
    - New Configurations (Symmetry)

- Sub-Scale Spark Range Test
  - 3 Configurations Incorporating Wind Tunnel Data
  - Free Flight Aerodynamic Coefficients for Modeling

- Propellant Charge Establishment
  - Establish Propulsion System
  - Charge Weight
  - Pressures, Etc.

- Target Impact Dispersion (TID-1)
  - Evaluate Performance of Design Options
  - Flight
  - Population
  - Launch

Analysis & Laboratory Testing

ATK XM1002 Shoot-Off Design
ATK Delivers 210 Cartridges for Shoot-Off Testing & Analysis Confirms Performance & Producibility Requirements Achieved

Iteration #2: Incorporate Design Enhancements using Iteration #1 Database

- Target Impact Dispersion (TID-2)
  - Evaluate Performance Enhancements of Design Options
  - Flight
  - Population
  - Launch

- Transportation Handling & Drops
  - Verify Candidate Designs meet Robustness Requirements

- Analysis & Laboratory Testing
  - Verify Performance Requirements Not Directly Tested

- Iteration #3: Finalize Design and Confirm Key Requirements

- Target Impact Dispersion (TID-3)
  - Confirm Final Design Performance
  - Flight
  - Population
  - Launch

- Strength of Design, Maximum Range & Tracer Visibility
  - Verify Candidate Designs meet Safety Requirements

- Analysis & Laboratory Testing
  - Producibility Investigations, Requirements, Verifications

- ATK XM1002 Shoot-Off Design
  - ATK Delivers 210 Cartridges for Shoot-Off Testing & Analysis Confirms Performance & Producibility Requirements Achieved
XM1002 Approach to Reduce TID

Gravity Drop:
- Reduce Propellant Variability
- Reduce Time of Flight

Aerodynamic Jump:
- Increase Stability (Cp Back, CG Forward)
- Reduce Jump Factor, Decrease Transverse MOI
- Reduce Asymmetries

Sabot Discard:
- Move Pivot Near Cp, Reduce Sabot Weight Ratio
- Center of Gravity/Crossing Velocity/Muzzle Pointing Angle
- ARL In-Bore Analysis and Transonic Range Testing
Jump Variability

- Gravity Drop
- Aerodynamic Jump
- Sabot Discard
- Center of Gravity
- Crossing Velocity
- Muzzle Pointing Angle

\[ \sigma^2 = \sigma_{mp}^2 + \sigma_{cv}^2 + \sigma_{cg}^2 + \sigma_{sd}^2 + \sigma_{aj}^2 + \sigma_{gd}^2 + 2\sigma_{cjaj} \]

\[ \text{TID} = \text{Variability in Jump} \]
Major Influences on Jump

- Gun Motion
- Gun Tube Centerline Shape
- Projectile Structure (Mass Properties, Bourrelet Configuration, Tolerances, etc.)
- Projectile Flight Characteristics
- Propellant (Consistency, Temperature, etc.)
XM1002 Enhancements

Three Tail Cone Concepts all have “short” 5mm boom.

Aerodynamic:
- Heavy Nose – CG Moves Forward Improving Stability
- Thicker Body & Increased Grooves – Reduces Plastic Deformations
- Stabilizer – Optimize Stability & Jump Factor

Sabot Discard:
- Sabot Pivot Near Cp – Reduces Impulse From Sabot Discard
- Truncated Sabot – Reduced Sabot Weight Ration Reduces Impulse
- M829E3 Obturator – Proven Obturation

Threaded Grooves Reduces Cost

Threaded Grooves Reduces Cost
XM1002 Cartridge
Training projectile for the M1A1/M1A2 Abrams M256 120-mm Cannon

Plan A
Preliminary Design Concept Utilizes ARDEC Design Modifications to Improve Structural Margin & Jump Sensitivity

Plan B
Plan A - “Modified Boat Tail”

Slot Angle Reduced to 5° from 30°. Plan B slot angle is 10°.

Boat Tail Angle
6° changed from original
20° Boat Tail
Plan B

Eliminate Trapped Propellant by Pushing the Tail Cone Forward

Minimal Volume for Propellant Entrapment
Use of Gun/Projectile Dynamic Simulations

• Overview of Techniques
• Data Obtained from the Simulations
• Projectile Dynamics
• Gun Tube Shape Effects
• Ideal Tube Shape Results
• Tortuous Path Results
How Is It Done?

- Models “Numerically Manufactured” in Components
- Components Are Assembled
- Interfaces Between Parts Are Defined
- The M256 Gun System
  - System Is Modeled Back to the Trunions
  - System Includes Recoil
  - Gun Tube Shapes Are Taken From Measurements Made of Tubes in the Inventory
    - Every Tube Is Different
- Typical Simulation takes ~ 10-12 Hours
  - Over 4000 simulations have been done
  - ~ 5 CPU Years of Computer Time Utilized
Data Obtained from the Simulation

5 Cocking Angles are Used as Initial Conditions to induce Variability into the Dynamic Path

GUN/PROJECTILE DYNAMIC SIMULATIONS

The 5 Jump Resultant Vectors Determine the Performance

Variability

Average

Area Swept Out Represents the Variability
Lower Variability Translates into Lower Dispersion

JUMP RESULTANT VARIABILITY AND AVERAGE

PROJECTILE JUMP AERODYNAMICS AND PROJECTILE PHYSICALS

\[ C_{\text{total}} = \frac{V_{\text{transverse}}}{V_{\text{muzzle}}} \]

\[ AJ = -k \frac{C_{\text{na}}}{C_{\text{na}} V_{\text{muzzle}}} \]

Exit State Conditions Converted to Jump Components Then Combined into Performance Data

Aerodynamic Jump (~Angular Rate at the Muzzle)

Jump Resultant Vector (Total Jump)

Total CG\(_{\text{jmp}}\) = MP + CV + CG

JUMP MODEL AT THE MUZZLE
Launch Simulations

max: 1.77e+03, brick 15709
min: 0.00e+00, brick 32641
Total Jump for the Tubes Based on SN2658

Areas: Plan A -> 4.2x3.4=14.3
Plan B -> 6.1x3.6=22.0
Plan A’s area ~ 35 % smaller
Dynamic Loading of the Projectile During Launch

XM1002 MPAT Training Projectile
t = 3.05000e-05
Launch Dynamics Conclusions

- Projectiles showed different launched behavior
- In realistic gun systems the Plan A Projectile launch with lower disturbance
- Difference in launch disturbance attributed to differences in projectile’s transverse moment of inertia
- $I_{\text{tranverse}}$ expected to affect discard in a similar manner

<table>
<thead>
<tr>
<th>Stabilizer Dia. (mm)</th>
<th>Plan A</th>
<th>Plan B</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG (mm)</td>
<td>247.080</td>
<td>219.610</td>
</tr>
<tr>
<td>CG (Cal)</td>
<td>3.089</td>
<td>2.745</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>8.053</td>
<td>7.596</td>
</tr>
<tr>
<td>$I_{xx}$ (kg mm$^2$)</td>
<td>6091</td>
<td>5616</td>
</tr>
<tr>
<td>$I_{yy}$ (kg mm$^2$)</td>
<td>138500</td>
<td>88740</td>
</tr>
</tbody>
</table>
Success Criteria Evaluation

Producibility Criteria (DTUPC)

Risk Criteria

8 Design Threshold Requirements
- 3 Km TID
- Maximum Range
- Peak Pressure
- Negative Delta Pressure
- Maximum Range
- Cartridge Mass
- Center of Gravity
- T4 (Action Time)
- 3 Km Tracer Visibility
- 4 Km Tracer Visibility

Weighted Comparative Performance Evaluations

- 6 Primary Performance Criteria
  - 3 Km Horizontal TID @ 3 Temperatures
  - 3 Km Horizontal TID Pooled
  - 3 Km Vertical TID @ 3 Temperatures
  - 3 Km Vertical TID Pooled
  - Accuracy (Predicted)
  - Aerodynamic Static Margin

- 4 Secondary Performance Criteria
  - Muzzle Velocity Standard Deviation
  - Crosswind Sensitivity (Calculated)
  - 4 Km Gravity Drop Standard Deviation
  - Negative Delta Pressure
Today's Program Status and Plans

- Have Down-Selected to Plan A Design
- Have Modified Propellant Grain Design
  - Produced new pilot lot
  - Completed characterization tests at 5 temperatures
- Verified TID Performance at 3 Temperatures
- Increased Adapter-Obturator Joint Strength
- Performing SCV Pre-look Testing
- Nearing Completion of EMD-1 (PPQT) Hardware Manufacture
- EMD-2 (PQT) Hardware Manufacturing Completion Scheduled for June 2003
- TC/LRIP Release Planned for November 2003