Presented By: Thomas K. Harkins
To National Defense Industry Association
March 27, 2003
RAMICS Ammunition

- Flat Nose Creates Pressure Field That Supercavitates Fluid
  - Significant Drag Reduction
  - Term Supercavitation Given To Objects That Generate Vapor Cavities That Exist Well Beyond The Size Of The Vehicle
  - Cavity Shape Is Elliptical (Approximated By Parabolic Formula)

- Term Hydroballistic Given To Ammunition Designs That Exhibit Supercavitation
  - Projectiles That Are Launched Underwater
  - Projectiles That Are Launched In Air And Achieve Water Entry

- Design Of RAMICS Ammo Was A Combination Of Experience And An Iterative Method Of Experimentation
  - APFSDS-T Cartridge Adapted To Hydroballistic Use

- Significant Savings In Time & Money

Cavity Equation: \( y = \frac{d}{2} \sqrt{(kx/d)} + 1 \)
RAMICS Ammunition Development

- **NSWC White Oak (ONR ATD 1995-96)**
  - Explore Feasibility Of Adapting Existing APFSDS-T Cartridge
  - Refine Design Of Flat Supercavitating Nose (3 Test Series; 45 Shots of Modified 25mm M919 APFSDS-T Cartridges)

- **Aberdeen Proving Ground (Briar Point Test Pond 2000)**
  - Develop & Prove 30mm Hydroballistic Design (Raufoss)
  - Demonstrate Lethality & 5 Round Burst Firings (25mm)
  - 2 Test Series; 81 25mm Shots & 70 30mm Shots

- **West Freugh, Scotland (Luce Bay Bombing Range 2001)**
  - Demonstrate Performance In At-Sea Environment
  - Lethality Against Large Mine Target
  - 23 30mm Cartridges (Single Shot & 5 Round Bursts)

- **Snillfjord, Norway (Nammo Raufoss 2002)**
  - Test Design To The Operational Limit (Steep & Deep)
  - 63 30mm Cartridges Fired
Refinement Of The Blunt Nose

Generation I

Generation II

Generation III (Carbide Insert)
Generation IV: 30mmMK 258 Mod 1

- Velocity: 1430m/sec
- Pen. Mass: 150 g
- Pen. Length: 188mm
- Pen. Dia: 9mm
- Nose Dia: 2.3mm

30mm Caliber Evaluated & Selected For RAMICS In 2000
Target
(1). Break Screen Box (2 Screens)
or (2) 50# Surrogate
or (3) Mk 6

PVDF Sensors (6)

Video Cameras (6)

Briar Point Test Site
30mm MK 258 Hydro Performance

Velocity Variation Due To Range Of Nose Diameters Tested: 2.1 To 2.5mm
30mm Hit Pattern
75 ft slant range

high yaw

shots 131-136
shots 139-141
Water Entry: 4628 Ft/Sec

Recovered Pieces

Inner Bulkhead

Bottom

30mm

20 Feet Deep
Shot #126
25 Sept. 2000
Shot 130
September 28, 2000
Aberdeen Test Center
Aberdeen Test Results & Observations

- Seventy 30mm Rounds Fired
  - Very Consistent Drag
- Underwater Dispersion
  - 0.70 To 1.4 Milliradians ($1\sigma$ Radius)
- Demonstrated 5-Round Bursts Into Water
- Long-Rods Are Robust Hydroballistic Designs
  - Tungsten Alloy Nose Material Works
  - Yaw Limitations Observed Due To Short Air Flight
    - Abbreviated Hydroballistic Trajectory Associated With Yawed Penetrators (Limit Observed To Be Three Degrees)
- Established Lethal Depth Capability
OBJECTIVES

VERIFY AT SEA PERFORMANCE

EVALUATE PRODUCTION QUALITY AMMO

DEMONSTRATE LETHALITY OF TACTICAL MINE UNDER TACTICAL CONDITIONS
Test Outline

• 5 British MK 17 Mine Targets Available
  – Two Mines Inert (Tests 2 & 3)
    • Fuze Horns Instrumented To Evaluate Effect Of Penetrator Impact
    • Measure Time To Sink
  – Three Mines Explosively Loaded (Tests 4, 5 & 6)
    • Booster Charge Only (Approx. 4 pounds of PETN)
    • Main Charge Only (500 pounds of TNT)
    • Booster & Main Charge

• Gun Positioned Approximately 60 Feet Above Water

• 45 Degree Water-Entry Angle

• Multiple Shots Performed On Tests 3 & 4
British MK XVII Mine
500 Pound Explosive Weight
5 meter Mooring Depth

Test Platform: Existing Structure
60 To 75 Feet Above Water
Target/Instrumentation Rig
Fabricated For Test

Gun Fired Remotely During Explosive Tests
Bay Luce Scotland Test Results & Observations

• Continue To Prove Single-Hit Lethality Capability
• Large Mines Can Take Several Minutes To Sink When Explosive Load Is Not Hit
• Fuze Horns Did Not Function During Penetrator Impact
• Explosive Load Hit Only On Test 5 (TNT Load Only)
• Experienced Abbreviated Hydroballistic Trajectories On 1 Out Of 4 Shots
  – Yaw At Water Entry Due To Short Air Flight The Probable Cause
• Sea State & Marine Environment Does Not Seem To Affect Ammunition Performance
OBJECTIVES

VERIFY DEEP HYDROBALLISTIC PERFORMANCE

EVALUATE LONG RANGE DISPERSION

DEMONSTRATE AMMUNITION DESIGN IS SATISFACTORY
Objectives:

- Demonstrate and Evaluate Performance and Precision of the MK 258 Mod 1 Projectile At Steep Water-Entry Angle (60 Degrees)
- Determine Projectile Dispersion At 80 Foot Depth
- Maximize Air Flight To Establish Low Projectile Yaw at Water Entry.

Snillfjord, Norway Testing

Air Travel: 104m (312ft)

Water Travel: 5.0-28.5m (15.2-93.6ft)
GUN BARREL VIEW OF TEST PLATE
Målplate ca. 5 meter
Snillfjord Dispersion Results

- Nominal Target Depth: 24 meters
- Nominal Air Travel: 97 meters
- Nominal Entry Angle: 60 Degrees
- Five 7-Shot Series

<table>
<thead>
<tr>
<th>Group</th>
<th>x</th>
<th>y</th>
<th># shots On Target</th>
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<tr>
<td>Series 1</td>
<td>0.21</td>
<td>0.07</td>
<td>3 out of 7</td>
</tr>
<tr>
<td>Series 2</td>
<td>0.08</td>
<td>0.12</td>
<td>5 out of 7</td>
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<tr>
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<td>0.15</td>
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</tr>
<tr>
<td>Series 4</td>
<td>0.09</td>
<td>0.14</td>
<td>5 out of 7</td>
</tr>
<tr>
<td>Series 5</td>
<td>0.22</td>
<td>0.13</td>
<td>7 out of 7</td>
</tr>
</tbody>
</table>
**Conclusion!**

- Long-Rod Penetrators Can Be Adapted To Hydroballistic Use
  - Larger Calibers Give Better Performance
- For RAMICS, In-Water Dispersion Insignificant In Comparison To Dispersion In Air
  - Water Trajectory Is Slight Fraction Of Total Penetrator Trajectory
- Ammunition Proven Lethal; Targeting Is The Key To Overall Success
- Ammunition Qualification Leverage Off Of Baseline APFSDS-T Design Qualification Tests
  - WSERB Required Just Two Additional Tests
    - 300 kVolt Electostatic Discharge
    - Aircraft Vibration
BACKUP SLIDES
(HYDRO) DRAG COEFFICIENT

• Same Principle As Aerodynamic Drag
• Instrumentation provides:
  - Water Impact Velocity, $V_0$
  - Trajectory Time, $T$

\[
\beta = \frac{W}{C_d A}
\]

\[
T = \frac{2 \beta}{\rho V_0} e^{\frac{\rho S}{2 \beta}} - 1
\]

\[
V = V_0 e^{-\frac{\rho S}{2 \beta}}
\]

Known

$W$: Weight

$A$: Reference Area

$S$: Length
Sinking As Well As Explosive Reaction Acceptable For RAMICS
Water Impact Loads

- Theoretical Formula:
  \[ C_d^* = 0.79 + 0.93 \tan(\alpha) \]
- Nose Material Stress Can Climb To Over 300,000 psi
- Carbide Tips Successfully Tested (420,000 psi Strength)
- Successful Tests At 45° & 60° Exceeded Theoretical Material Strength Predictions
  - Bow Shock May Mitigate Impact Load

Shot #8494: 3800 ft/sec; Mat. Limit – 3700 ft/sec 90x Magnification
Recovered Nose Tip (*Snillfjord Test*)

- Slight Material Loss
- Deformation Due To Impact
RAMICS Evolution

ATD Configuration (FY98-00)
- AH-1W SUPERCOBRA
- LIDAR
- Gimbal
- Fire Control Computer
- M 197 20mm Gatling Gun
- 20mm Super Cavitating Projectile

CTD Configuration (FY00-02)
- MH-60S KNIGHTHAWK
- TBD Targeting Sensor Subsystem (TSS)
- TBD Fire Control Subsystem (FCS)
- Gun Subsystem – MK 44 30 mm Bushmaster II Modified Apache Turret Gun Control Unit
- Munitions Subsystem – MK 258 Mod 1 30mm APFSDS-T

SDD Configuration (FY02-06)
- MH-60S KNIGHTHAWK
- Gun Subsystem – MK 44 30 mm Bushmaster II Modified Apache Turret Gun Control Unit
- Munitions Subsystem – MK 258 Mod 1 30mm APFSDS-T
RAMICS Kit
General Arrangement

- Post contract award
  - CSTRS is positioned on the port side
  - Gun Subsystem is on the starboard side
Target Find/Lock Imagery

Long exposure gate for imaging the B-Laser spot

Edge finding algorithm locates the second constant range line on the water surface

The curved air/water boundary lines in frame 1 and frame 2 are used to determine constant range from TFCS using our edge finding algorithm

Narrow range gate image just above the mine used to reduce background noise variance

This gate is highly correlated and aligned to the previous gate providing very high mine range precision

Narrow range gate image centered on the last reported mine location
The RAMICS Mission

Install RAMICS Kit On Helicopter
Launch w/Pre-Flight Target List

Mission Phases
- Reacquire & Reclassify Target
- Neutralize
- Perform Battle Damage Assessment
- Re-engage as required

MH-60S Endurance
- 2 hour max sortie time.
- 75 minute total hover mission endurance.

Field Of Fire
45 Thru 60 Deg. Depression
0 Thru 60 Deg. Trailing Azimuth (DT-IIA Approved)
Forward 30 Thru 60
Trailing Recommended
LIDAR FOV Consistent w/Field Of Fire

Neutralize by:
Deflagration
Detonation
Sinking

Hover at safe range
RAMICS Gun System

Based on MK 44 30mm Bushmaster II Cannon

- Mounting of a boresight collimator on the gun barrel allows a closed loop gun pointing solution
- Fiber Optic Laser light fed into the boresight collimator provides shock isolation of boresight laser
- Cradle recoil mechanism reduces recoil to less than 4000 lb.
- Gun mounted camera allow viewing of field of fire region for safety
Turret Component Breakout

- Cradle Assembly: 91.3 lb.
- Turret Body: 37.1 lb.
- Elevation Drive: 16.0 lb.
- Azimuth Drive: 19.0 lb.
- Bearing: 54.6 lb.
- Standard Mk 44: 340.0 lb.

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GUN SUBSYSTEM ASSEMBLY

Cradle Assembly
Number Of Shots To Hit Vs. Accuracy
Target Range - 2000 Feet
Target Area 6 Sq. Ft.

<table>
<thead>
<tr>
<th>Sys. Dispersion (1 sigma) - mils</th>
<th>Avg. No. To Hit</th>
</tr>
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<tbody>
<tr>
<td>0.0</td>
<td>0.5</td>
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<td>0.5</td>
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<td>3.5</td>
</tr>
<tr>
<td>3.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

- 0.1 mil Aim Bias
- 1.0 mil Aim Bias
- 2.0 mil Aim Bias
- 3.0 mil Aim Bias
Number Of Shots To Hit Vs. Accuracy
Target Range - 2000 Feet
Target Area 2 Sq. Ft.

Sys. Dispersion (1 sigma) - mils

Avg. No. To Hit

0.1 mil Aim Bias
1.0 mil Aim Bias
2.0 mil Aim Bias
RAMICS Gun System Based on MK 44 30mm Bushmaster II Cannon

Characteristics
Gun Weight: 340 lbs
Turret Weight: 232 lbs
Gun Length: 11 feet
Rate Of Fire: 200 spm
Power: 28 Volts DC
Recoil Force: < 4000 lbs
Ammunition Capacity: 200 to 250 rnds
Assembled Pallet Weight: 1430 lbs (w/out ammo)
RAMICS Risk Assessment

Technical Issue (#1)
• AMCM Mission Kit weight may impact mission performance

Mitigation efforts:
• Weight Control Board established
• Carry less ammunition
• Carry less fuel
• Reduce time on station

Technical Issue (#2)
• Collimator Survivability – The 4” collimator housing must be hardened to survive the ~4000 lb. Gun recoil shock or the collimator product life could be compromised

Mitigation efforts:
• Collimator mounted on a like-gun system; Done on a packaging options trade; Laser on turret can survive shock; Trade study performed by HR Textron
• Move Laser source into the RAMICS targeting POD to lesson shock

Technical Issue (#3)
• Reacquisition Search Area (RSA) Timeline – Specified gimbal performance capability, laser power, IFOV of 19 mrad, number of gates used and standoff position for performing complete reacquisition over the whole RSA for all depths may not be performed within the Reacquisition Neutralization timeline.

Mitigation efforts:
• Design algorithms that minimize helicopter repositioning during the reacquisition phase and use SMART POSITIONING, SMART POINTING and SMART FIRING algorithms to meet the timeline requirement
History Of Water-Entry & Supercavitation Work

• 1870: Franco-Prussian War - Kopfring Developed
• 1908: “Study Of Splashes” - First Water-Entry Photos (Worthington)
• WW I: Edison Proposed Pagoda Head For Water-Entry Device
• WW II: Torpedoes, Mines, and Water-Entry Bombs
• Post WW II: Numerous Water-Entry/Cavitation Studies Of Rockets & Gun-Launched Projectiles
• 1970’s To Present: Exploit Supercavitation (Drag Reduction)
MK 258 Pitch Damping

Average Pitch vs. Range
Pitch Rate = 0°/sec