HYDROBALLISTICS

Development, Theory &
Some Test Results

Thomas K. Harkins

April 12, 2001

Sponsor: PMS-210 Through NSWCCD CSS
### Report Documentation Page

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<td>Proceedings from the 36th Annual Gun &amp; Ammunition Symposium &amp; Exhibition 9-12 April 2001 Sponsored by NDIA</td>
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MH-60S With RAMICS Installed

Target Reacquisition Using LIDAR
MK 44 Bushmaster II Chain Gun
MK 258 Hydroballistic Ammo
What Is Hydroballistics?

• The Study Or Design Of Objects That Have Momentum Underwater
  – Fully Wetted, Cavitating, & Supercavitating
• Key Parameters Are Drag, Stability & Control, & Structural Integrity
• Water Entry Of Projectile Considerations:
  – Air Entrainment (Not A Great Factor In Supercavitating Bodies)
  – Water Impact Loads
Hydroballistics Of Supercavitating Water Entry Projectiles

• Spin-Stabilized (In-Air) Projectiles Are Not Good Performers
  – Conventional Bullets Tumble Quickly After Water Entry
• Mass Stabilized Projectiles Are Successful
• High L/D Projectiles Have Consistently Proven Superior Hydroballistic Performance
  – Stabilizing Empennage Shared For Both Air And Water
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)
Kopfring Device
25mm WHITE OAK DEVELOPMENT (1995-1996) ONR Sponsor

Series I: Adapt Finned Long-Rods (U. S. Army 25mm M919 APFSDS-T); 9 Shots – Blunt Nose Proved Successful With Fins

Series II: Optimize Design (Reduce Nose Flat, Lengthen Nose & Increase Material Strength); 15 Shots

Series III: Introduced Carbide Nose Insert; Last Shot Established Record For Water Vehicles At 4300 ft/sec; 21 Shots
Hydroballistic Nose Shapes
Tested At White Oak – Series I

- Blunt Nose
- Conical Nose
- Power Law Nose
Refinement Of The Blunt Nose At White Oak – Series II & III

Generation I

Generation II

Generation III (Carbide Insert)
Generation IV: MK 258 Mod?

- Velocity: 1430m/sec
- Pen. Mass: 150 g
- Pen. Length: 188mm
- Pen. Dia: 9mm
- Nose Dia: 2.3mm
Cavity Equation: \[ y = \frac{d}{2} \sqrt{(kx/d)} + 1 \]
Water Impact Loads

• Theoretical Formula:
  \[ C_d^* = 0.79 + 0.93 \tan(\alpha) \]

• Stress At Preferred Impact Angle (60°) Can Climb To Over 300,000 psi

• Carbide Tips Successfully Tested (420,000 psi Strength)

• Successful Tests At 45° Exceeded Material Strength
  – Bow Shock May Mitigate Impact Load

Shot #8494: 3800 ft/sec; Mat. Limit – 3700 ft/sec 90x Magnification
Theoretical Water Entry Loads
HYDRO) DRAG COEFFICIENT

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

\[
\begin{align*}
\beta &= \frac{W}{C_d A} \\
T &= \frac{2 \beta}{\rho V_0} e^{\frac{\rho S}{2\beta}} - 1 \\
V &= V_0 e^{-\frac{\rho S}{2\beta}}
\end{align*}
\]

- **Known**
  - $W$: Weight
  - $A$: Reference Area
  - $S$: Length
HYDROBALLISTIC TEST SERIES I & II
ABERDEEN TEST CENTER
BRIAR POINT TEST POND
APRIL & AUGUST to OCTOBER 2000

OBJECTIVES

VERIFY PERFORMANCE OF 25MM

EVALUATE PERFORMANCE OF 30MM

DEMONSTRATE UNDERWATER LETHALITY
Hydroballistic Test Peculiarities

• Target “Sighting”
  – Land Based Surveying + Diligent Positioning

• Test Limitations
  – Limited Air Flight; Limited Water Depth
  – Underwater Cameras & Clarity Changes
  – Difficult To Measure Velocity

• Compounded Safety Considerations
  – Gun On Tower & Target In Water
Briar Point Test Site

Target
- (1) Break Screen Box (2 Screens)
- or (2) 50# Surrogate
- or (3) Mk 6

GUN
- 1. 25mm Mann
- 2. 30mm Mann

Doppler Radar

Video Cameras (6)

PVDF Sensors (6)
30mm MK 258 Hydro Performance

![Graph showing the relationship between Water Travel (meters) and Velocity (m/sec). The graph indicates a linear decrease in velocity as water travel increases.]
30mm MK 258 Hydro Performance

![Graph showing the relationship between water travel (feet) and velocity (ft/sec). The graph indicates a downward trend, suggesting that as water travel increases, velocity decreases.]
30mm Hit Pattern
75 ft slant range

high yaw

shots 131-136
shots 139-141
Entrance hole

30mm
1330 m/sec Water Entry
TARGET: Surrogate Mine
NEW: 45 lbs. TNT
Mooring Depth: 25 feet
Water Entry: 4628 Ft/Sec

30mm 20 Feet Deep

Recovered Pieces

Bottom

Inner Bulkhead
Other Aberdeen Test Results & Observations

• Seventy 30mm Rounds Fired
  – Very Consistent Drag

• Underwater Dispersion
  – 0.70 To 1.4 Milliradians (1σ Radius)

• Demonstrated 5-Round Bursts Into Water

• Long-Rods Are Robust Hydroballistic Designs
  – Nose Material
  – Spin/Yaw

• Established Lethal Depth Capability
Summary

Water Entry
> 4600 Ft/sec

Improved Projectile Designs

Accurate Target Hits from 75’ Slant Range

Destruction of Surrogate Target
Shot 130

September 28, 2000
Aberdeen Test Center