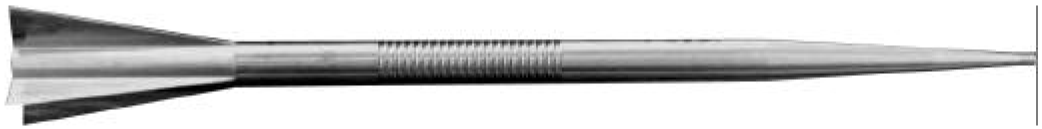

HYDROBALLISTICS

Development, Theory & Some Test Results

Thomas K. Harkins

April 12, 2001

Sponsor: PMS-210 Through NSWCDD CSS

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Number of Pages 27	

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

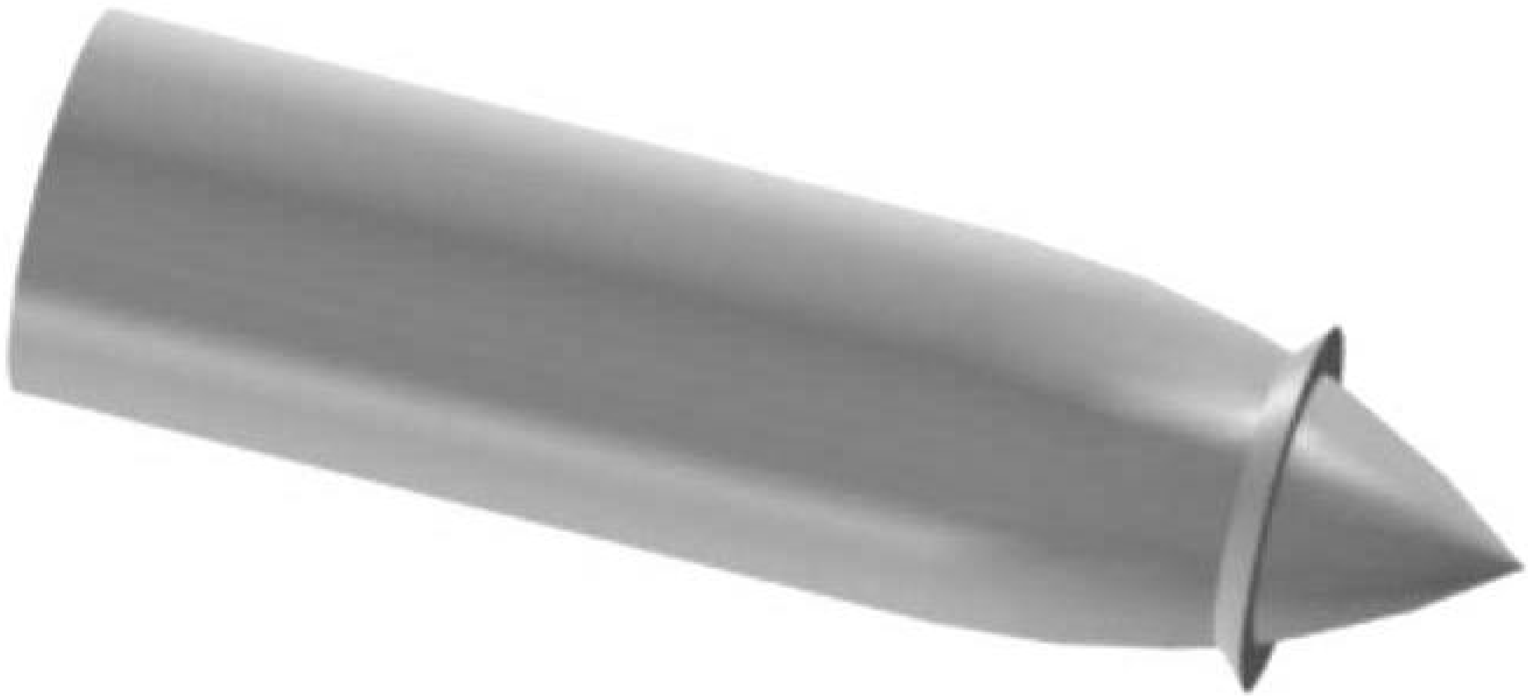
Hydroballistics Of Supercavitating Water Entry Projectiles

- 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



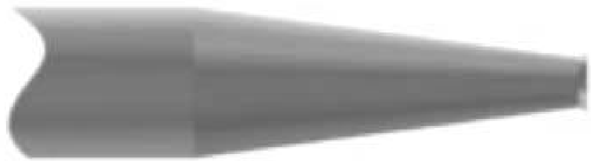
25mm WHITE OAK DEVELOPMENT (1995-1996) ONR Sponsor

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

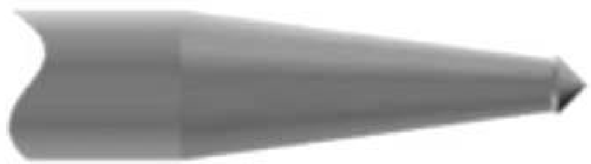
Series II: Optimize Design (Reduce Nose Flat, Lengthen Nose & Increase Material Strength); 15 Shots

Series III: Introduced Carbide Nose Insert; Last Shot Established Record For Water Vehicles At 4300 ft/sec; 21 Shots

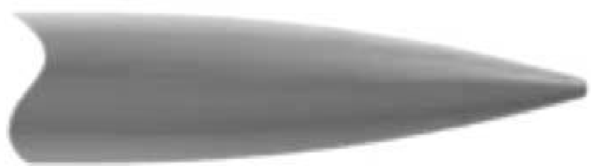
Hydroballistic Nose Shapes Tested At White Oak – Series I



Blunt Nose

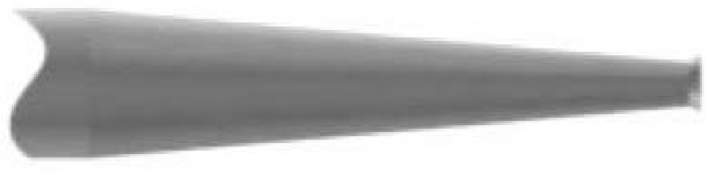


Conical Nose

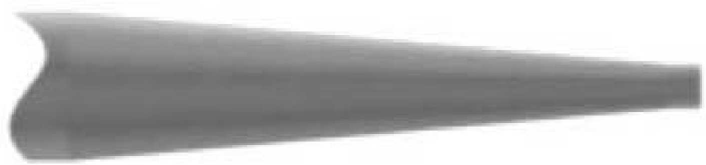


Power Law Nose

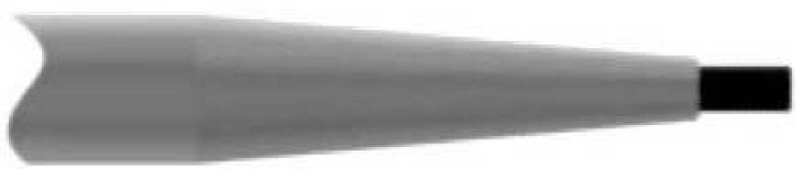
Refinement Of The Blunt Nose At White Oak – Series II & III



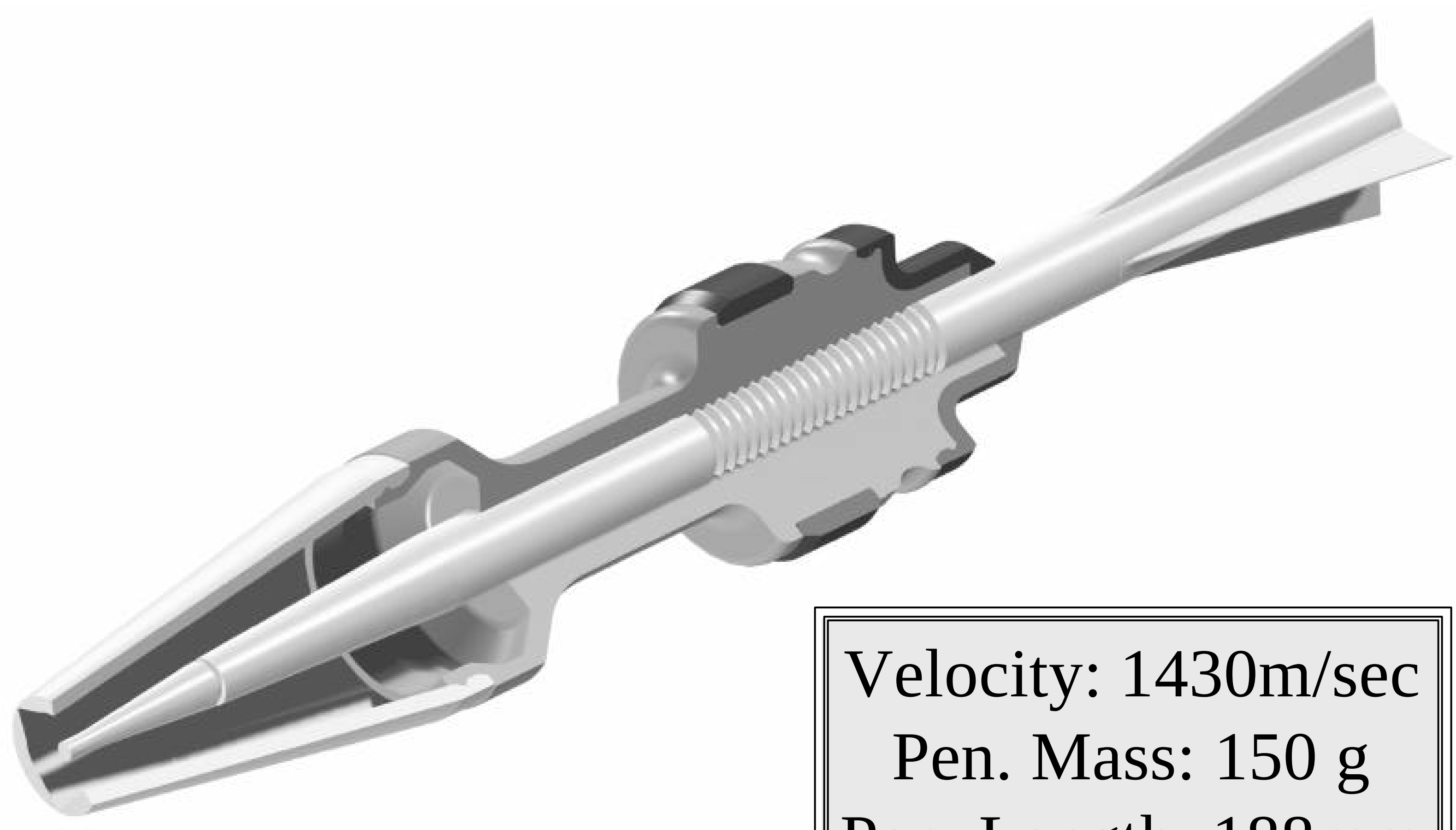
Generation I



Generation II

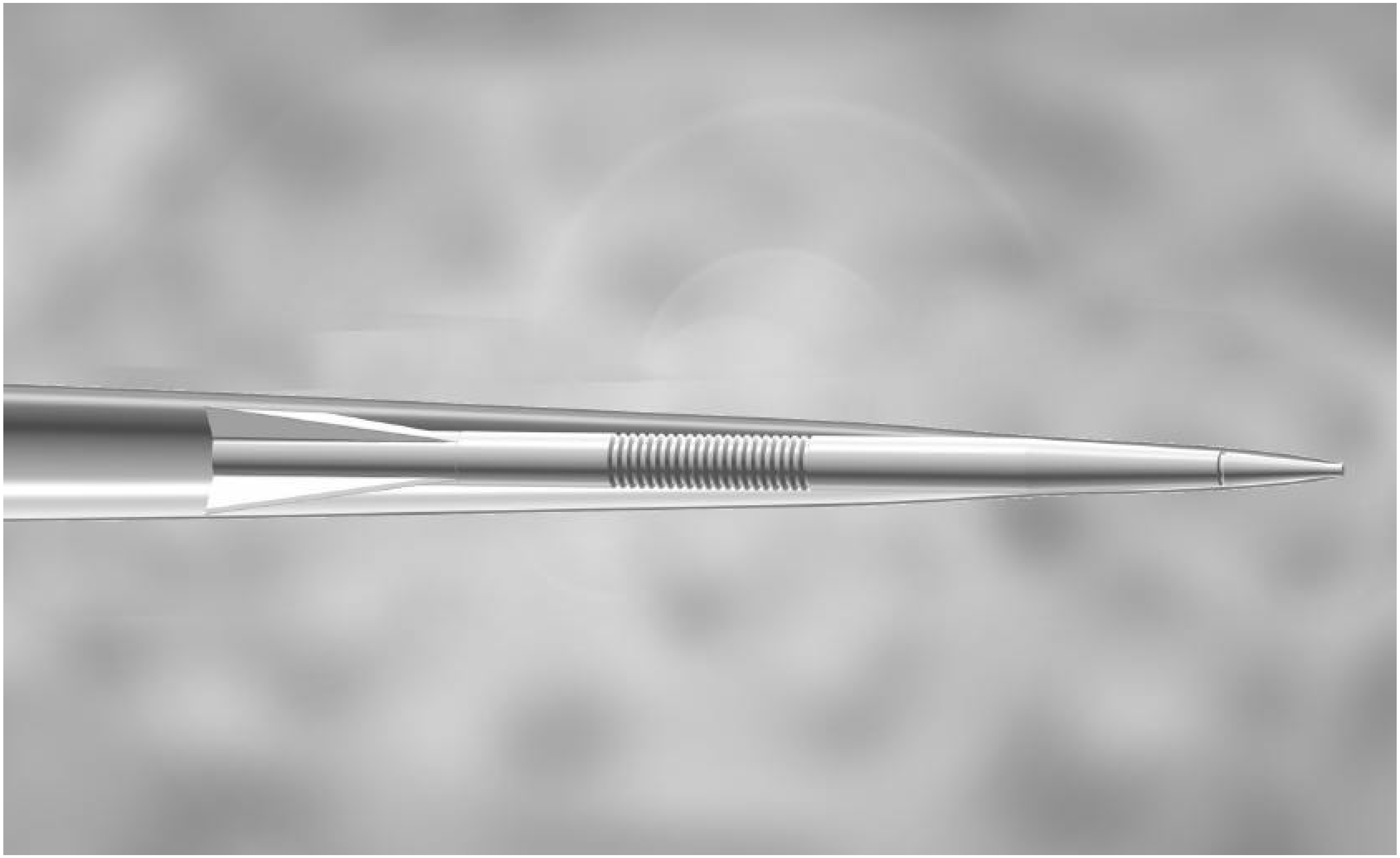


Generation III
(Carbide Insert)



Generation IV:
MK 258 Mod ?

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



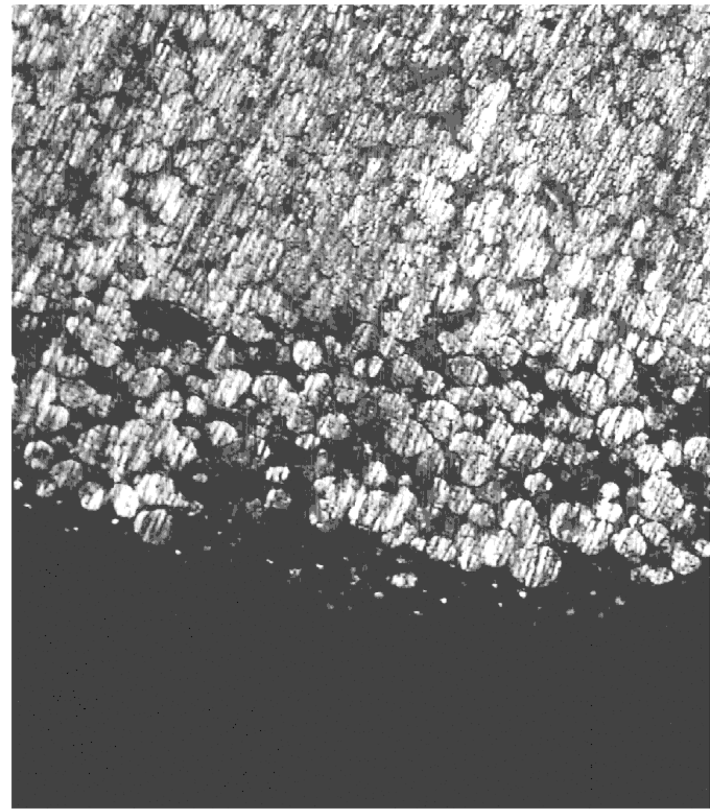
Cavity Equation: $y = \frac{d}{2}\sqrt{(kx/d)+1}$

Water Impact Loads

- Theoretical Formula:

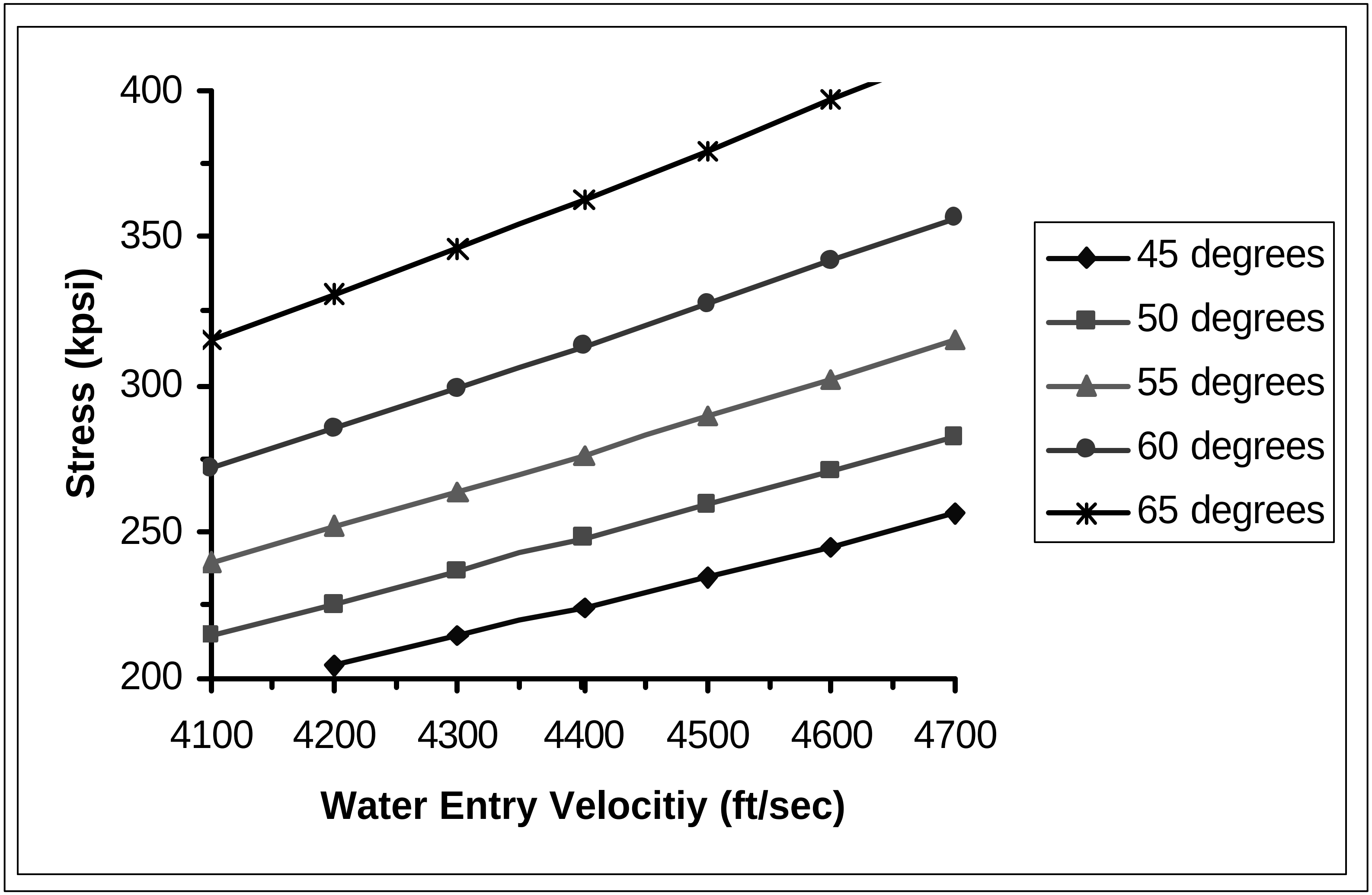
  $$C_d^* = 0.79 + 0.93\text{Tan}(\alpha)$$

- Stress At *Preferred* Impact Angle (60^o) Can Climb To Over 300,000 psi
- Carbide Tips Successfully Tested (420,000 psi Strength)
- Successful Tests At 45^o 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**

$$b = \frac{W}{C_d A}$$

$$T = \frac{2b}{rV_0} e^{\frac{rS}{2b}} - 1$$

$$V = V_0 e^{-\frac{rS}{2b}}$$

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

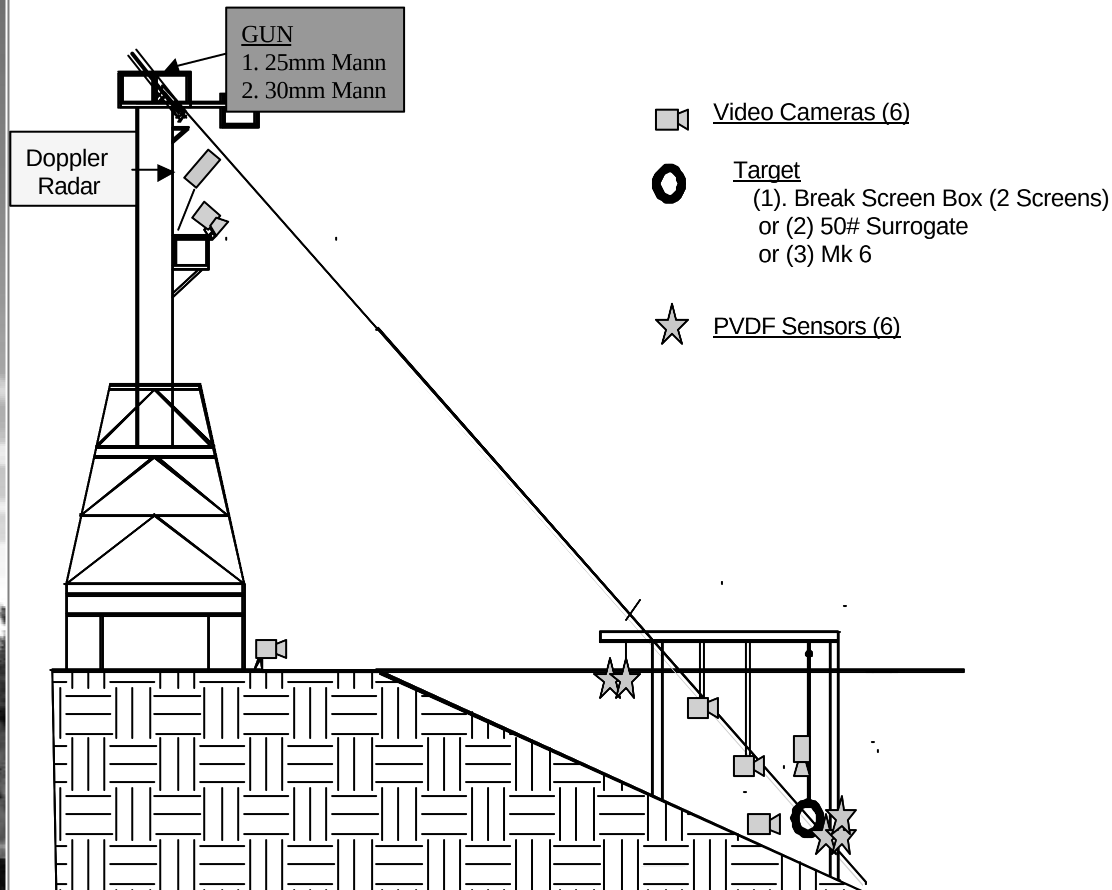
VERIFY PERFORMANCE OF 25MM

EVALUATE PERFORMANCE OF 30MM

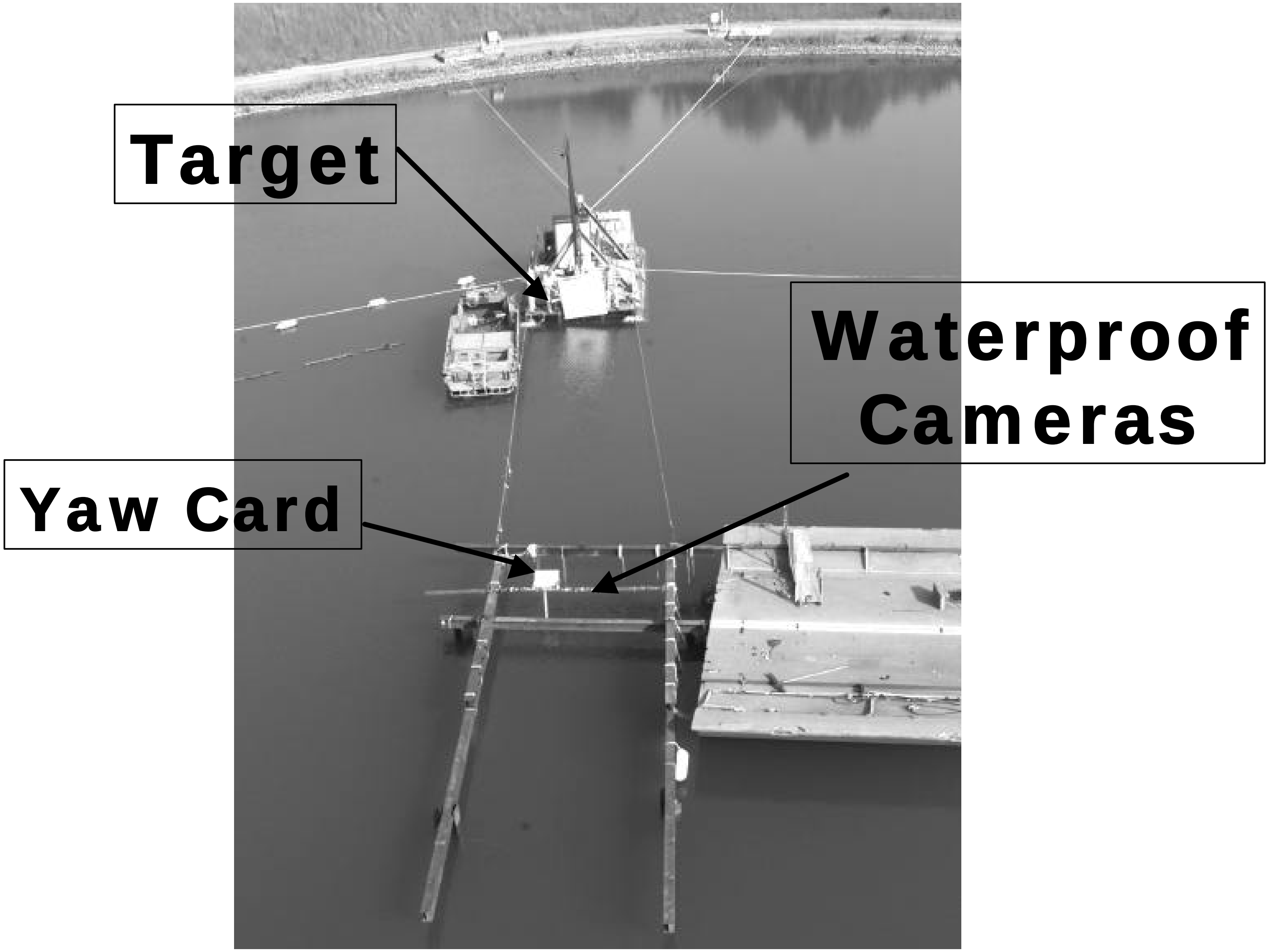
DEMONSTRATE UNDERWATER LETHALITY

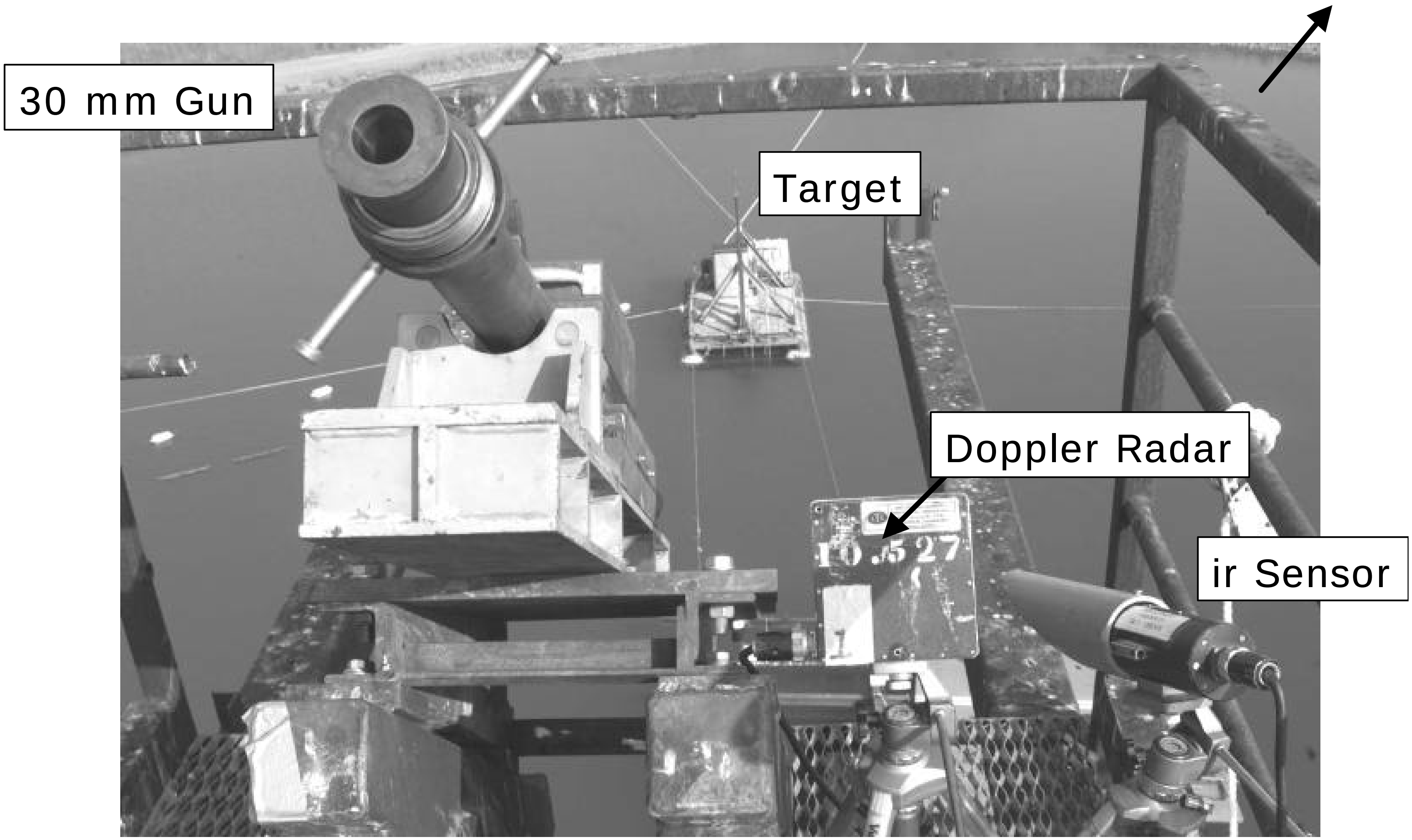
Hydroballistic Test Peculiarities

- 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

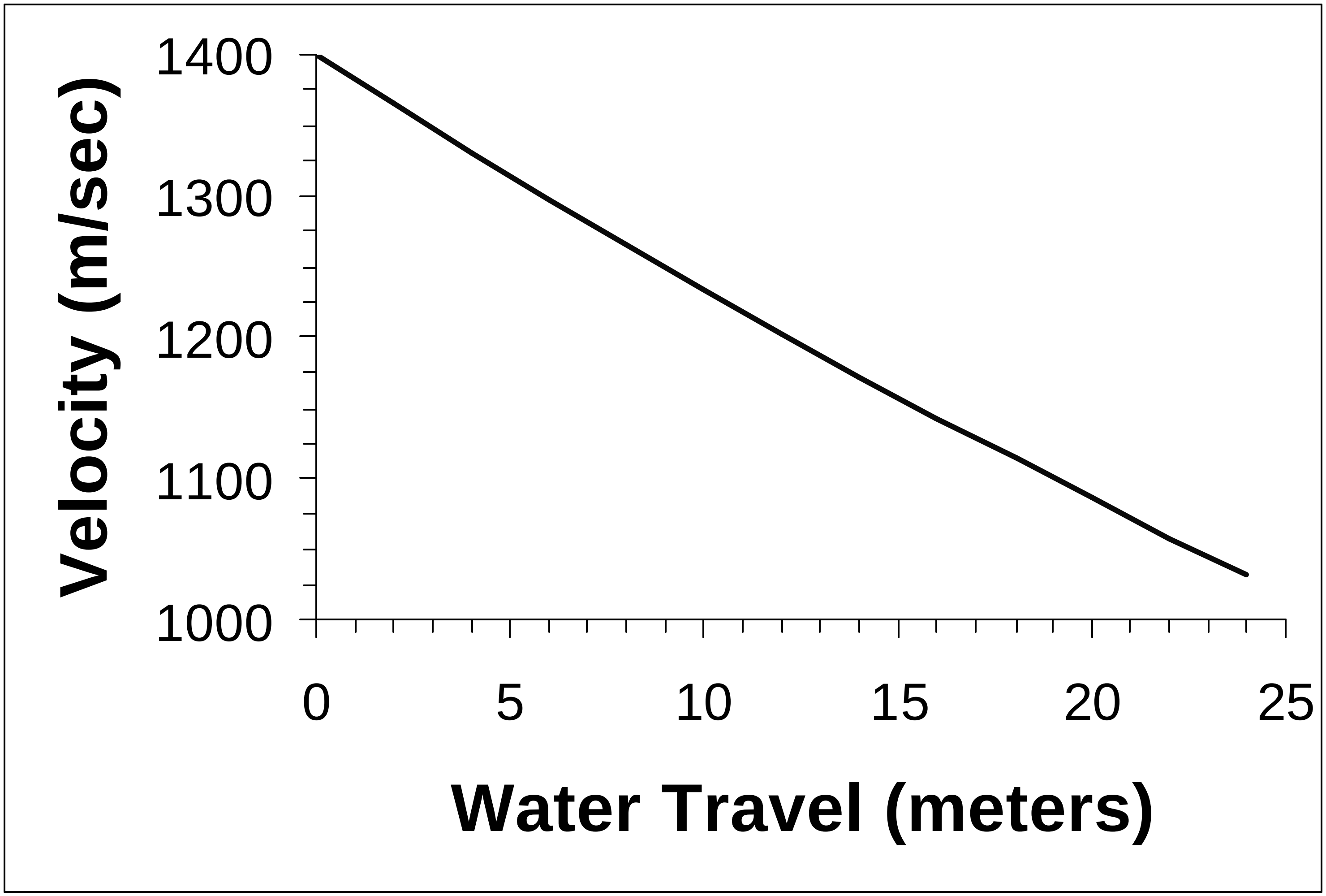


Briar Point Test Site

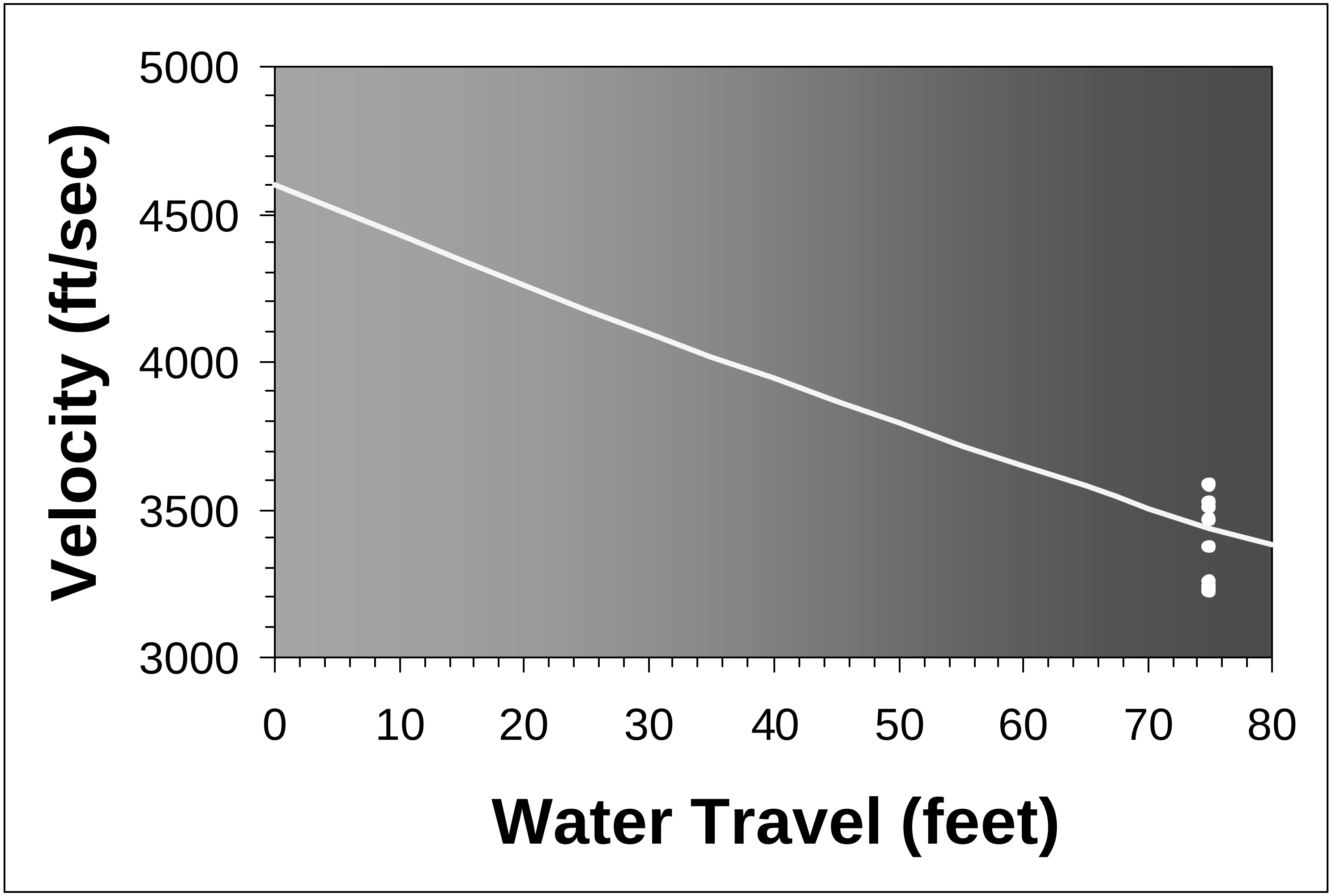

Target
Waterproof Cameras
Yaw Card

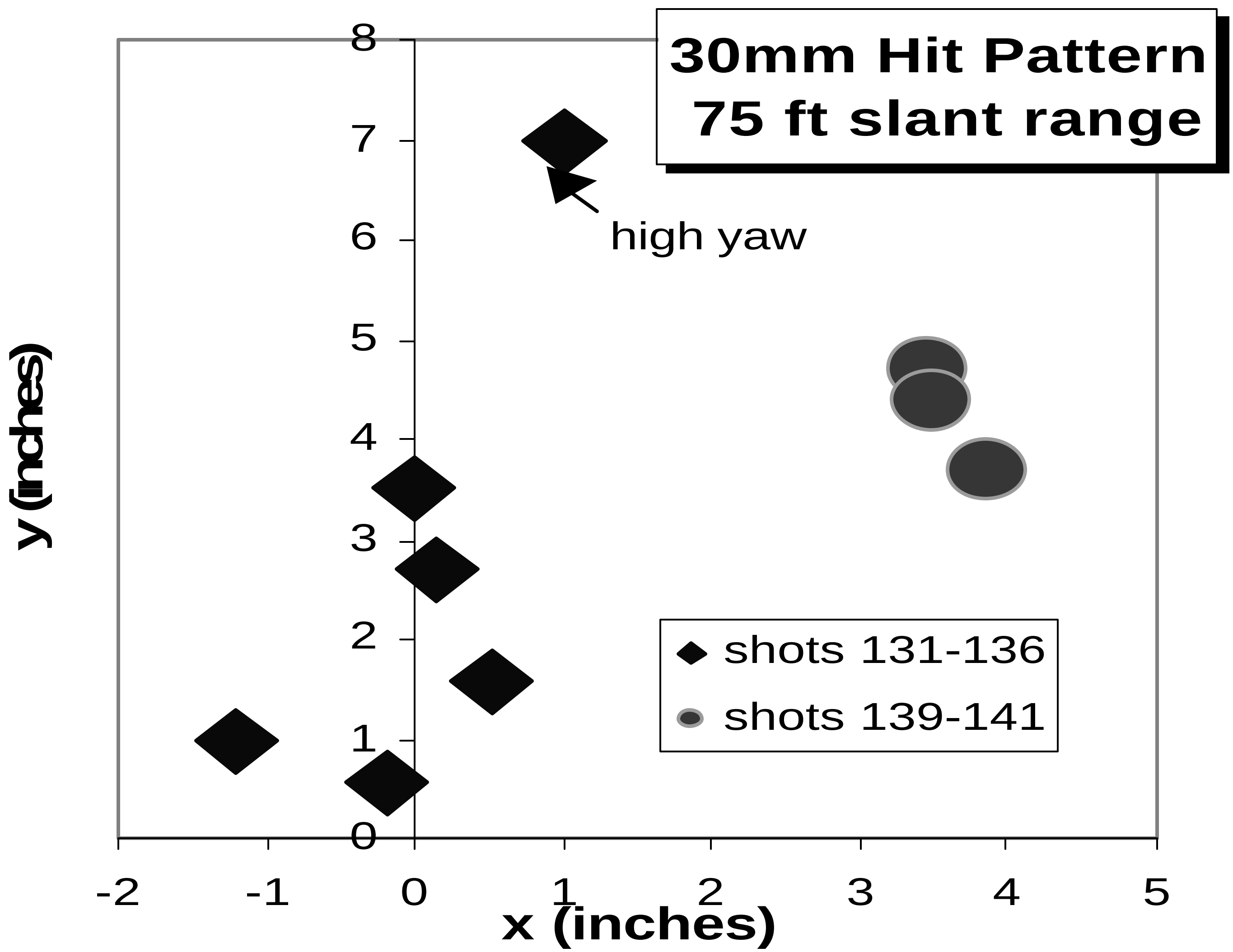

30 mm Gun
Target
Doppler Radar
ir Sensor

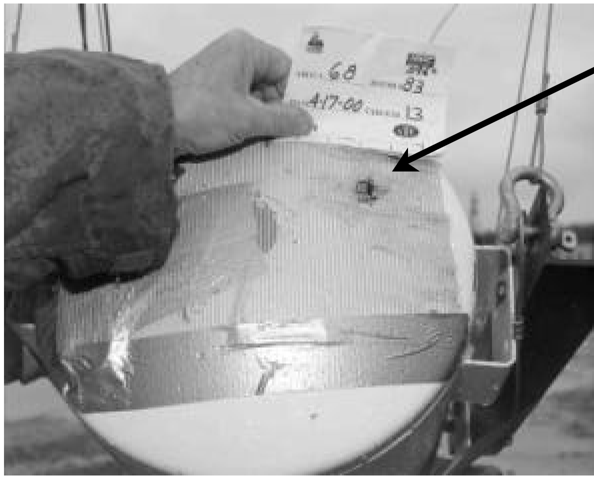
30mm MK 258 Hydro Performance



30mm MK 258 Hydro Performance




30mm Hit Pattern
75 ft slant range
high yaw
shots 131-136
shots 139-141
y (inches)
x (inches)
0
1
2
3
4
5
6
7
8
-2
-1
0
1
2
3
4
5



Entrance hole

30mm

1330 m/sec Water Entry

TARGET: Surrogate Mine

NEW: 45 lbs. TNT

Mooring Depth: 25 feet

30mm
20 Feet Deep

Water Entry:
4628 Ft/Sec

Other Aberdeen Test Results & Observations

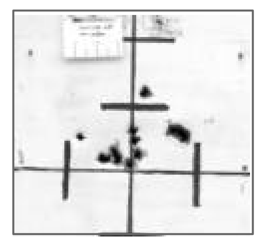
- Seventy 30mm Rounds Fired
  - Very Consistent Drag
- Underwater Dispersion
  - 0.70 To 1.4 Milliradians (1σ Radius)
- Demonstrated 5-Round Bursts Into Water
- Long-Rods Are Robust Hydroballistic Designs
  - Nose Material
  - Spin/Yaw
- Established Lethal Depth Capability

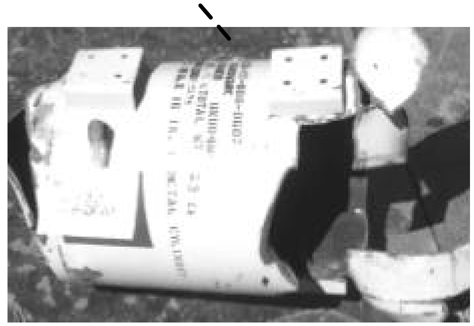
Summary

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