Presented By: Thomas K. Harkins

To National Defense Industry Association

March 27, 2003

RAMICS Ammunition

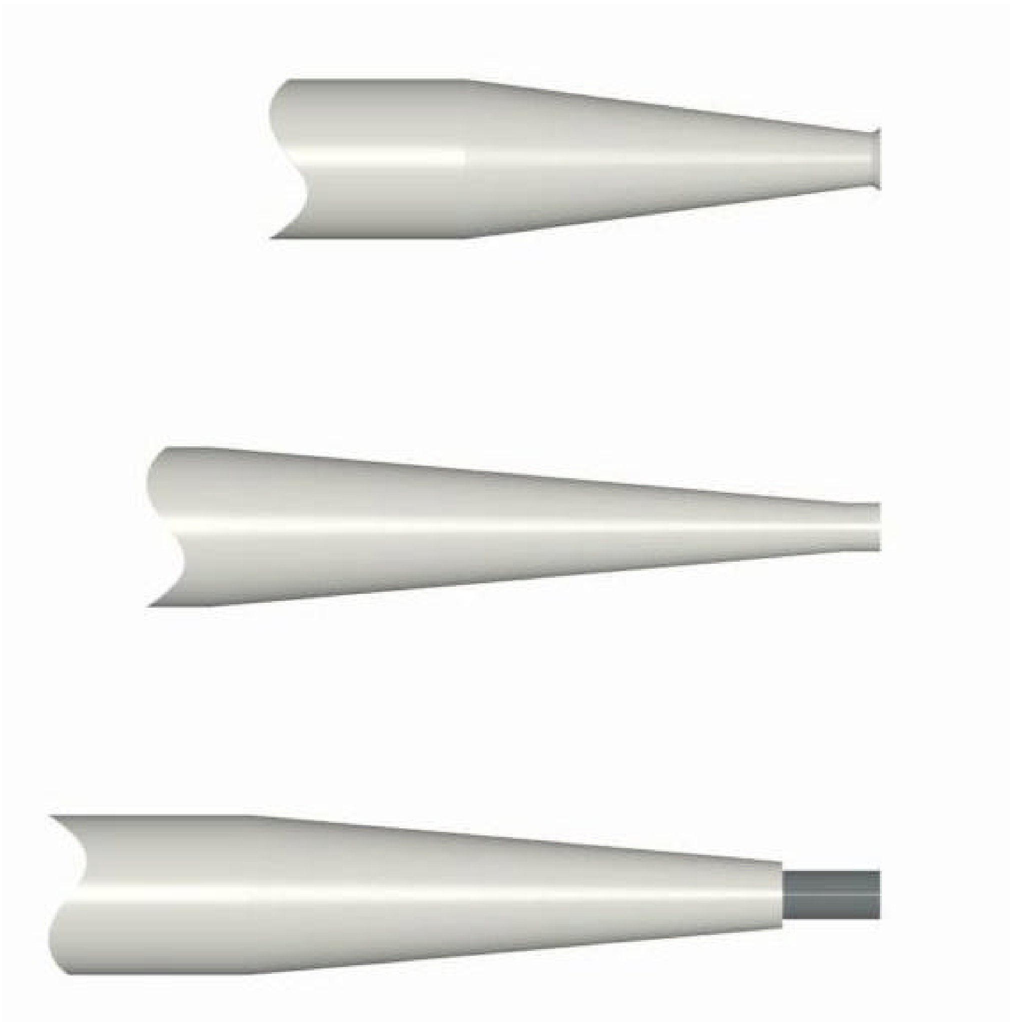
- Flat Nose Creates Pressure Field That Supercavitates Fluid
  - Significant Drag Reduction
  - Term Supercavitation Given To Objects That Generate Vapor Cavities That Exist Well Beyond The Size Of The Vehicle
  - Cavity Shape Is Elliptical (Approximated By Parabolic Formula)
- Term Hydroballistic Given 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: $y = \frac{d}{2} \cdot \sqrt{(kx/d) + 1}$

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



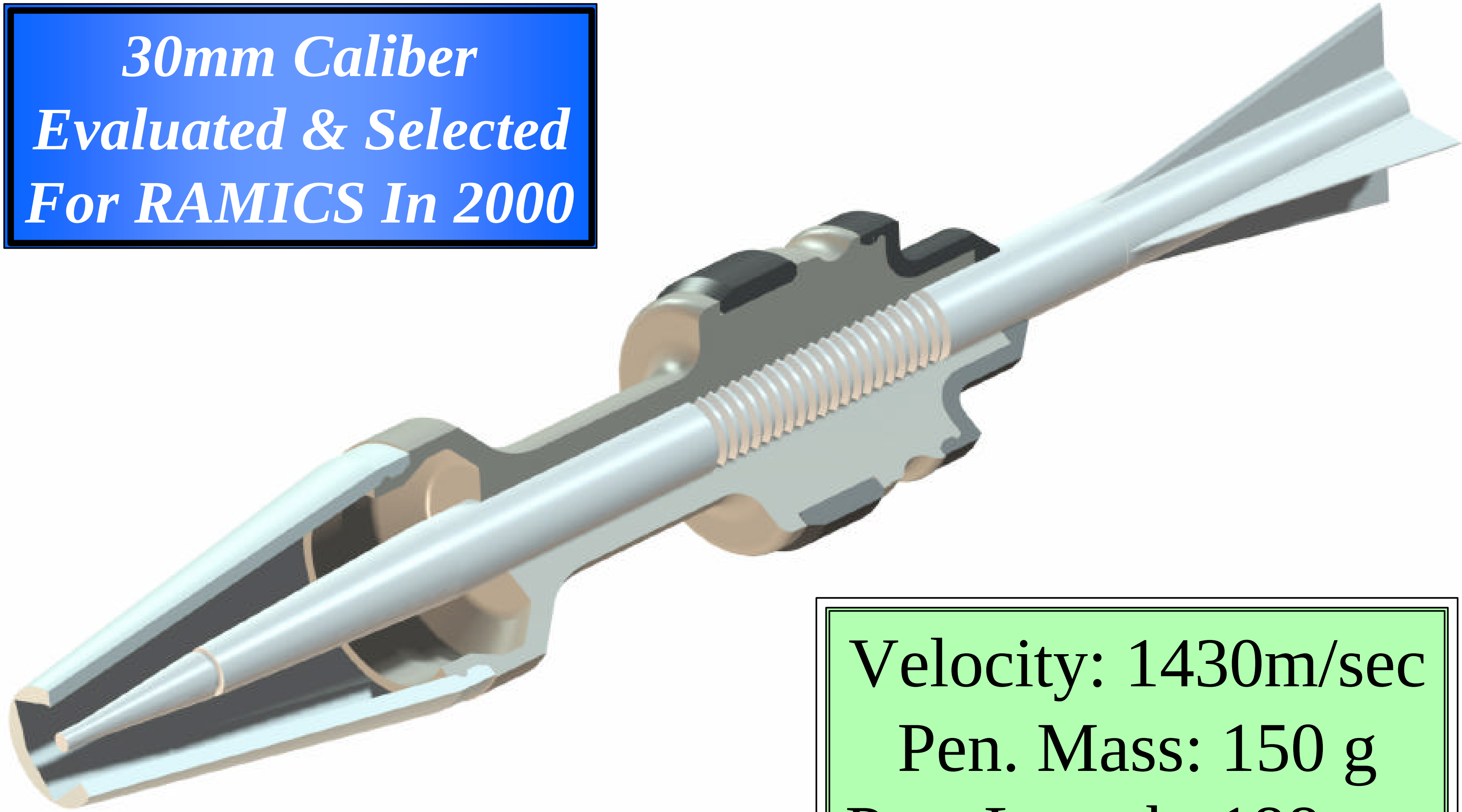
Generation I

Generation II

Generation III (Carbide Insert)

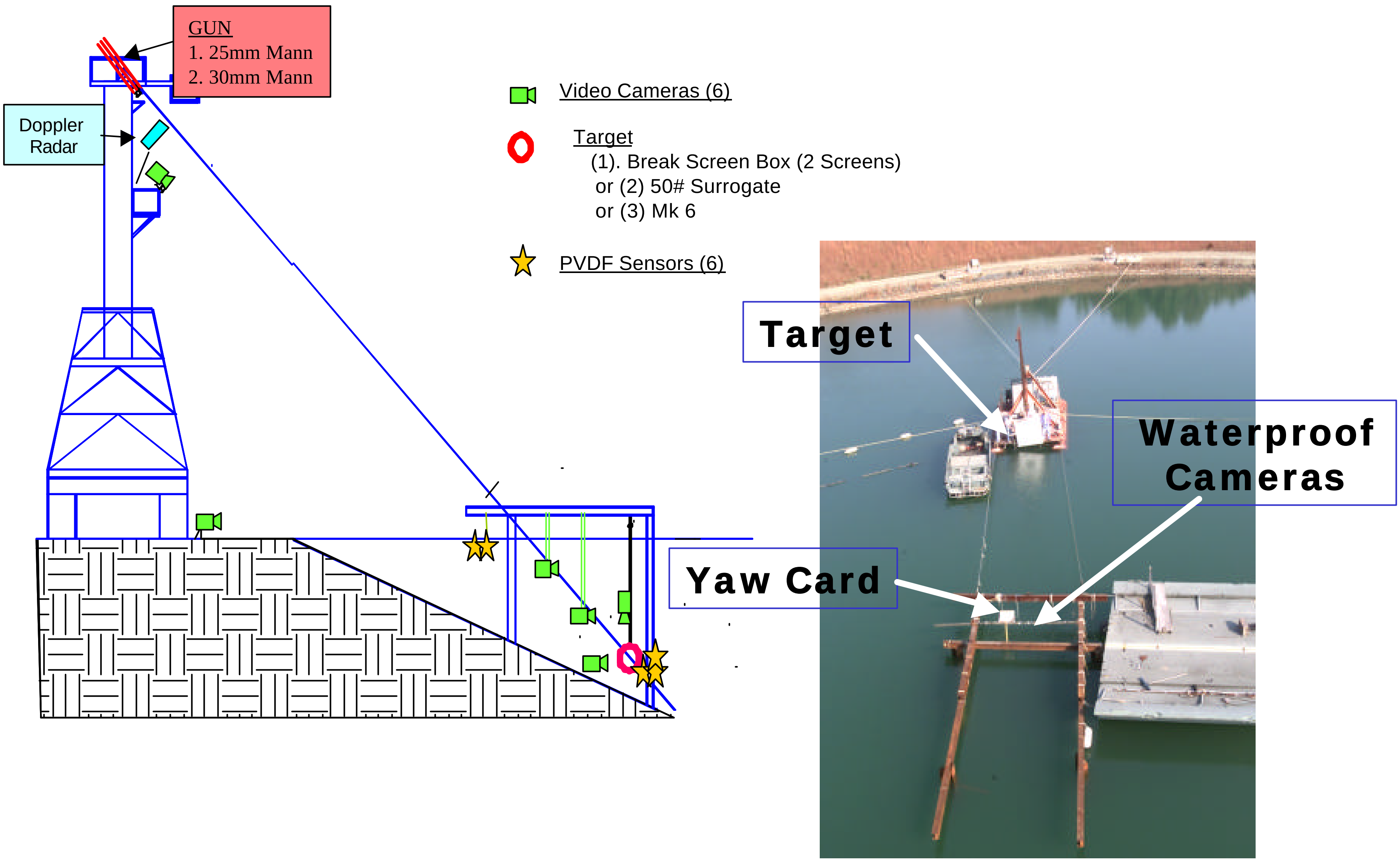
LRAMP II
11/21/96

30mm Caliber Evaluated & Selected For RAMICS In 2000



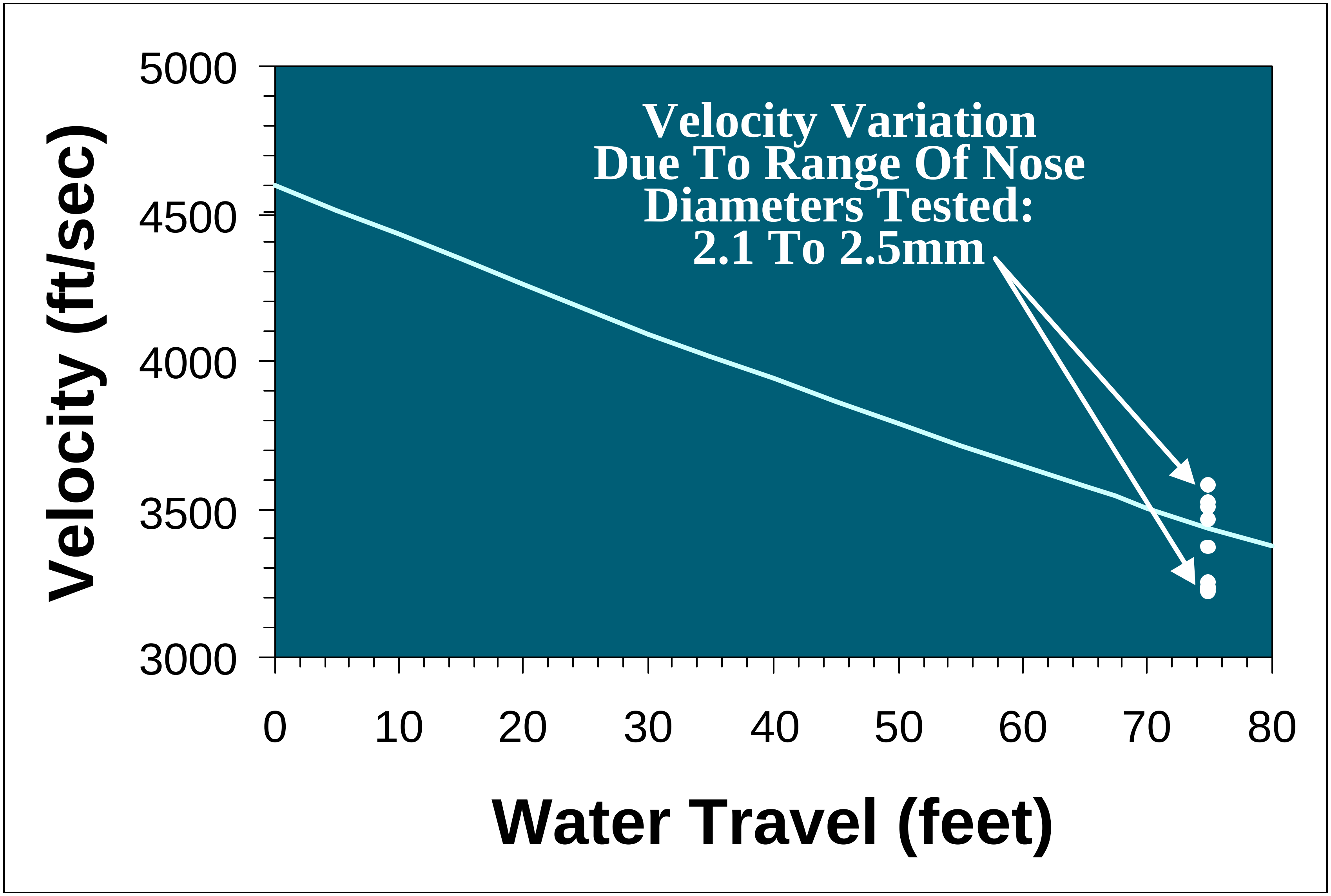
Generation IV: 30mmMK 258 Mod 1

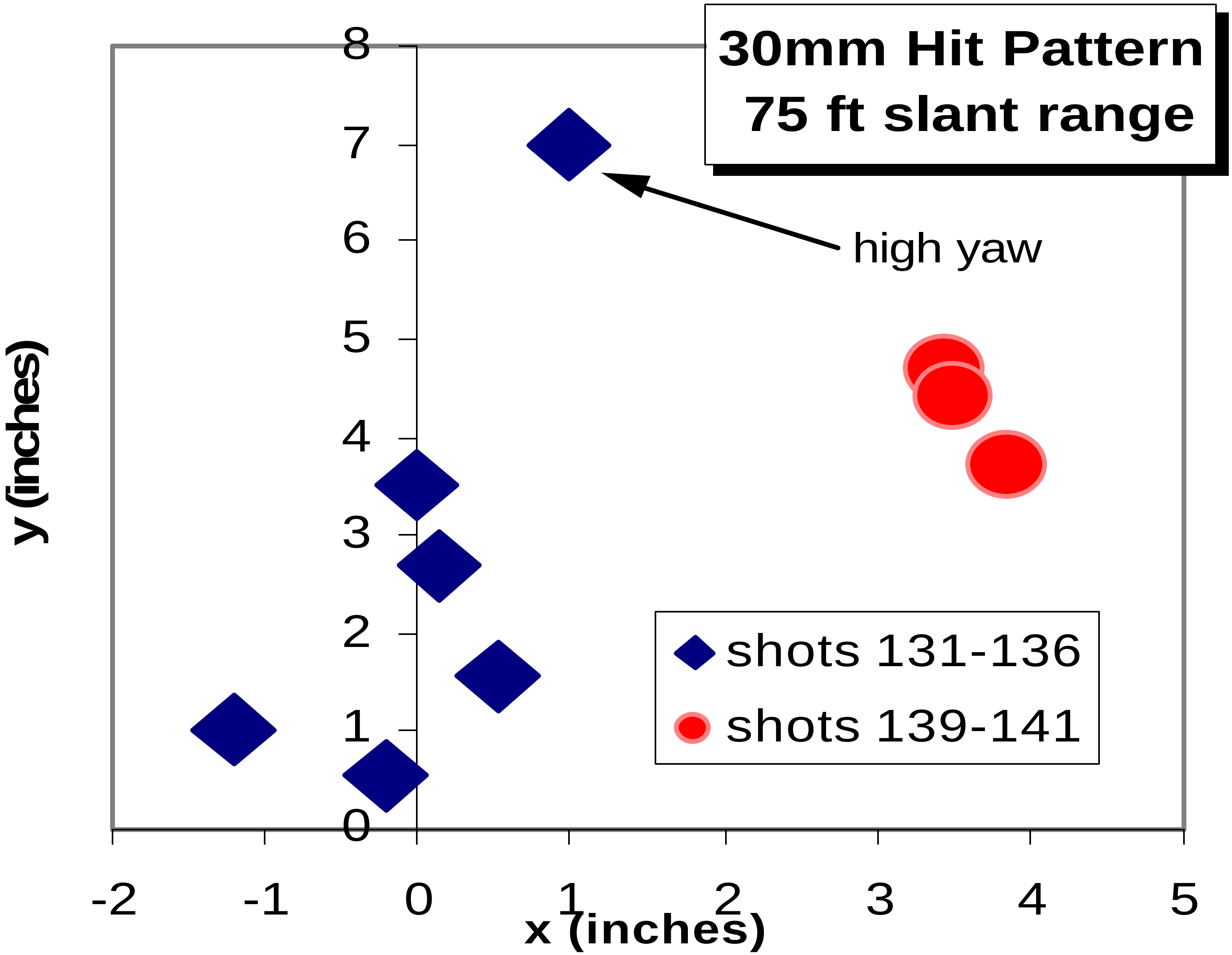
Velocity: 1430m/sec
Pen. Mass: 150 g
Pen. Length: 188mm
Pen. Dia: 9mm
Nose Dia: 2.3mm



Briar Point Test Site

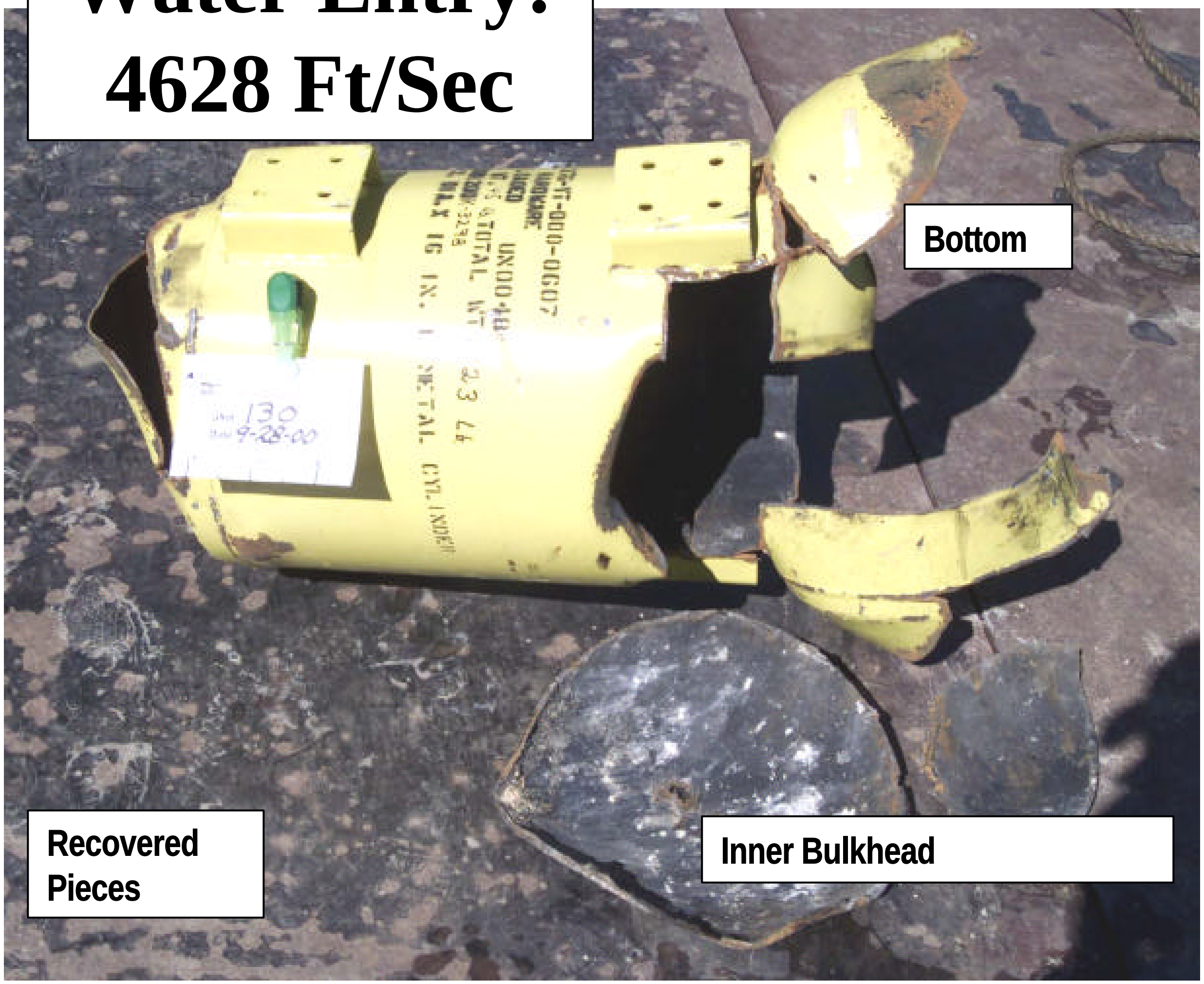
30mm MK 258 Hydro Performance




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

30mm
20 Feet Deep

Water Entry:
4628 Ft/Sec



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 (1σ 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

LETHATITY TEST
DERA (NOW QINITEQ)
BAY LUCE   SCOTLAND
AUGUST 2001

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

DISPERSION/PENETRATION TEST
NAMMO RAUFOSS (AND OTHERS)
SNILLFJORD, NORWAY
OCTOBER 2002

OBJECTIVES

VERIFY DEEP HYDROBALLISTIC PERFORMANCE

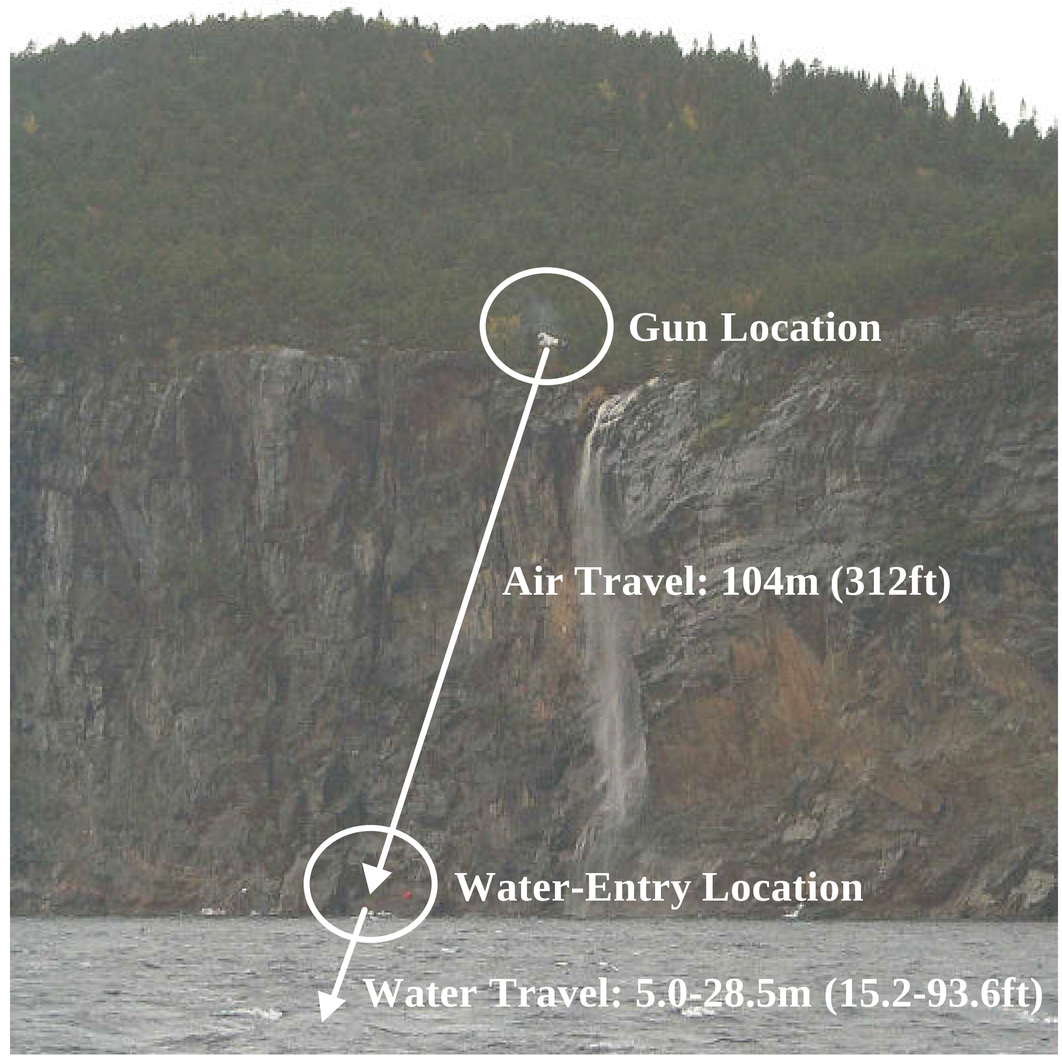
EVALUATE LONG RANGE DISPERSION

DEMONSTRATE AMMUNITION DESIGN IS SATISFACTORY

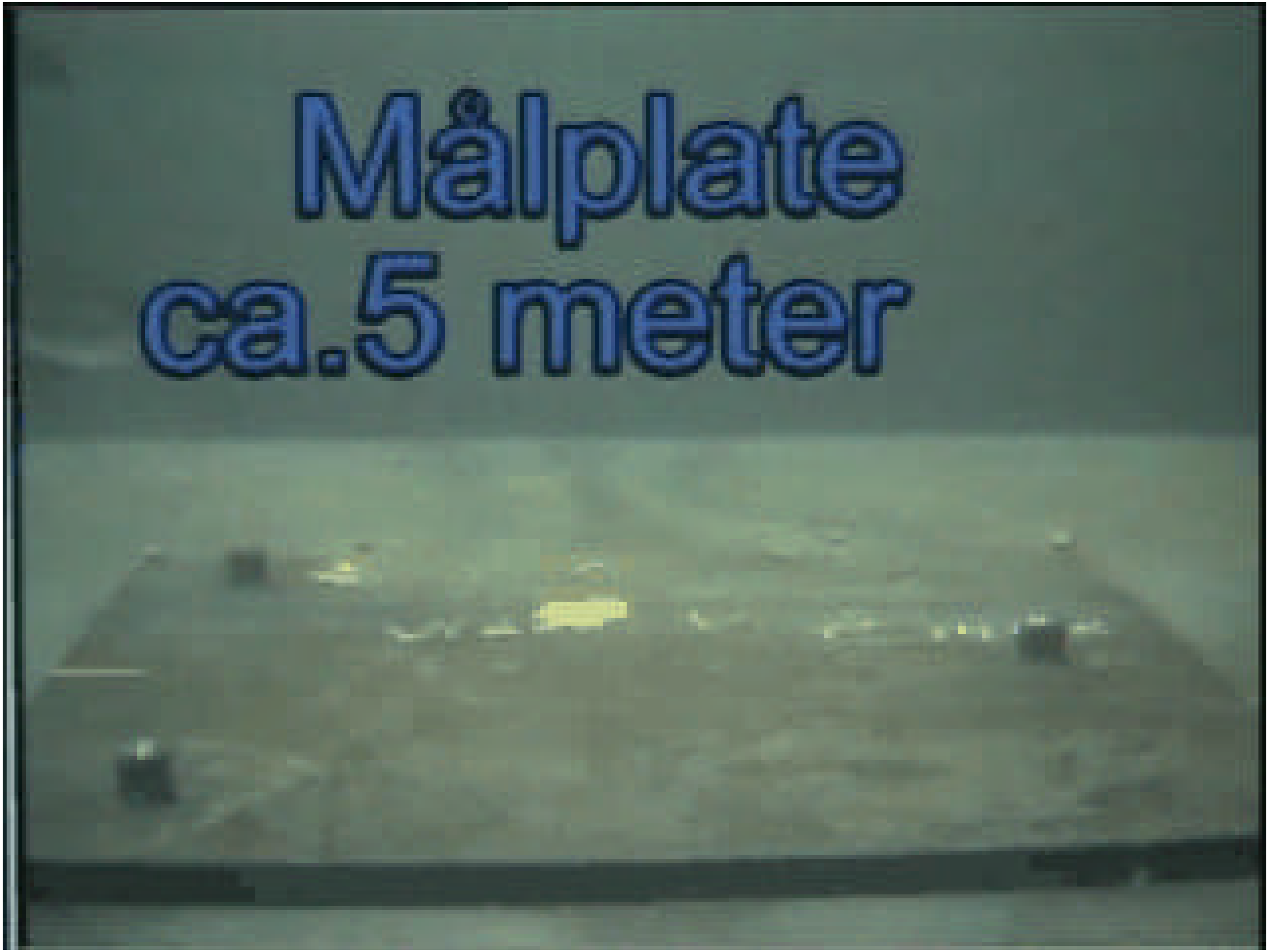
Snillfjord, Norway Testing

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.



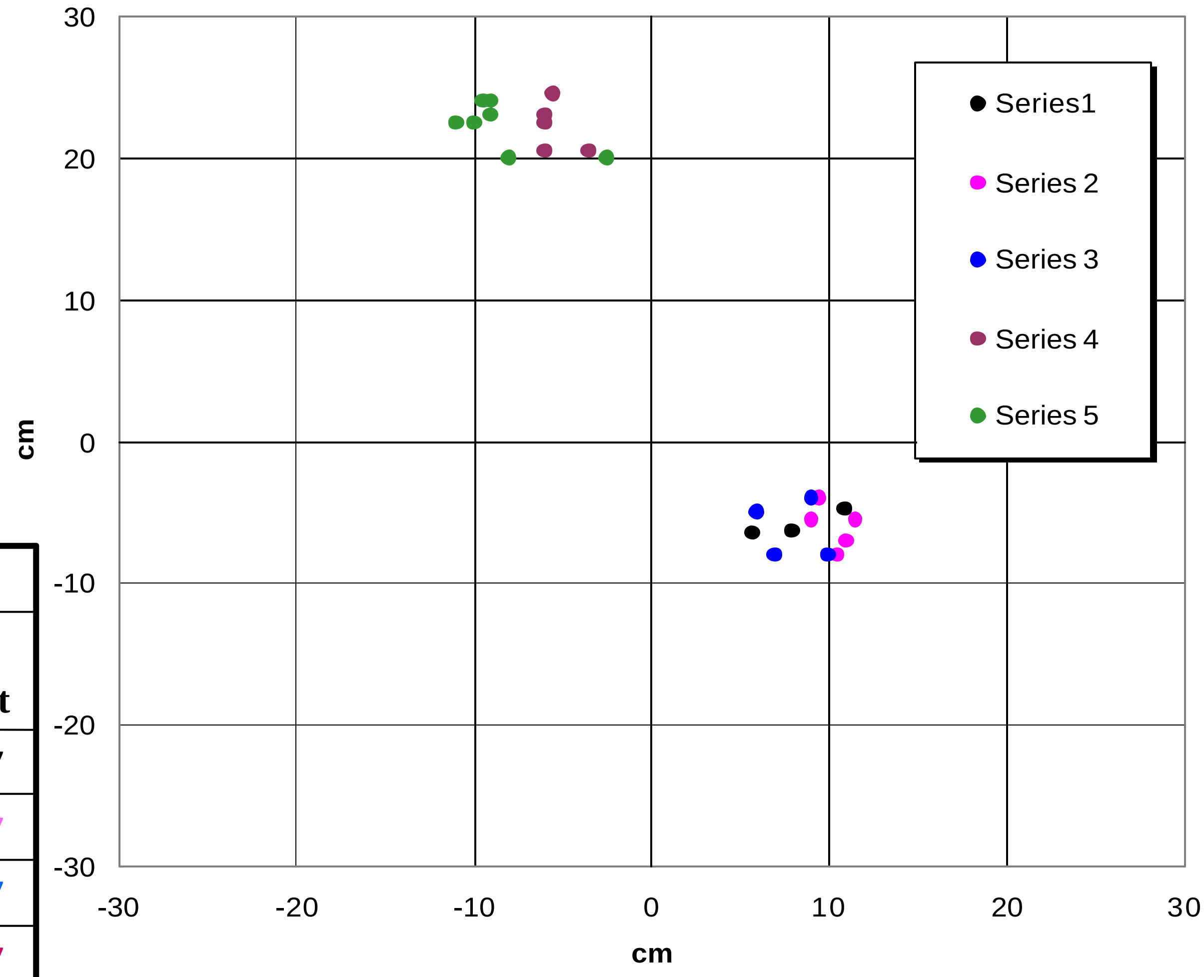
GUN BARREL VIEW OF TEST PLATE


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

1 sigma Dispersion (mrad)			
Group	**x**	**y**	**# shots On Target**
Series 1	**0.21**	**0.07**	**3 out of 7**
Series 2	**0.08**	**0.12**	**5 out of 7**
Series 3	**0.15**	**0.16**	**4 out of 7**
Series 4	**0.09**	**0.14**	**5 out of 7**
Series 5	**0.22**	**0.13**	**7 out of 7**



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**

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

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

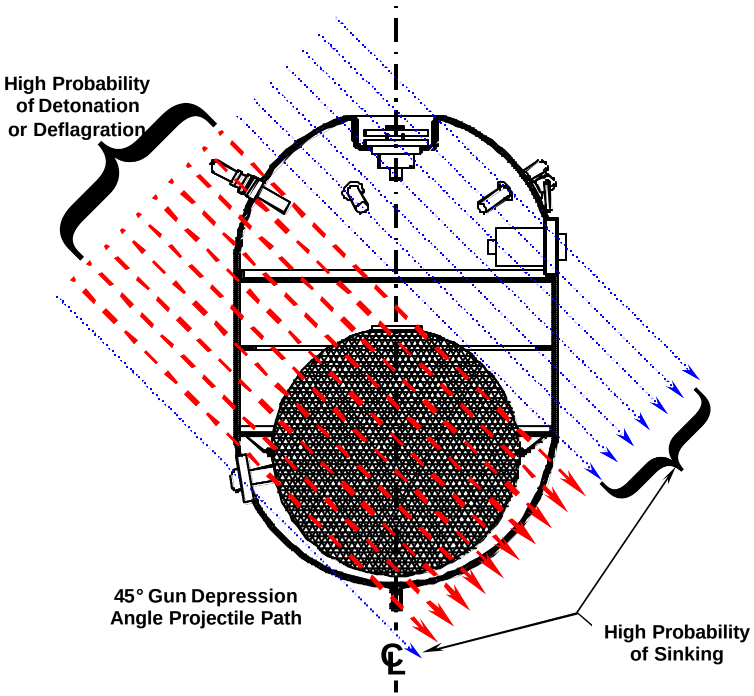
$$V = V_0 e^{-\frac{rS}{2b}}$$

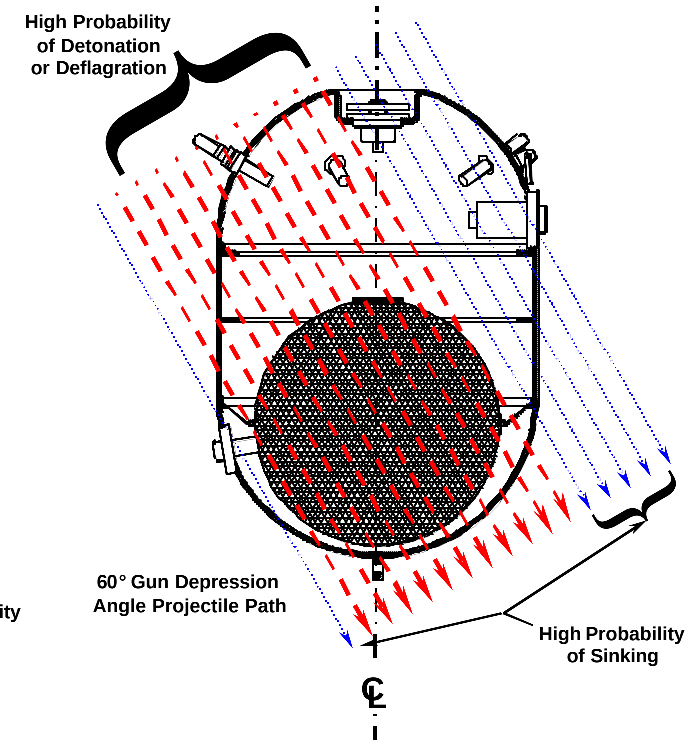
Known

W: Weight

A: Reference Area

S: Length





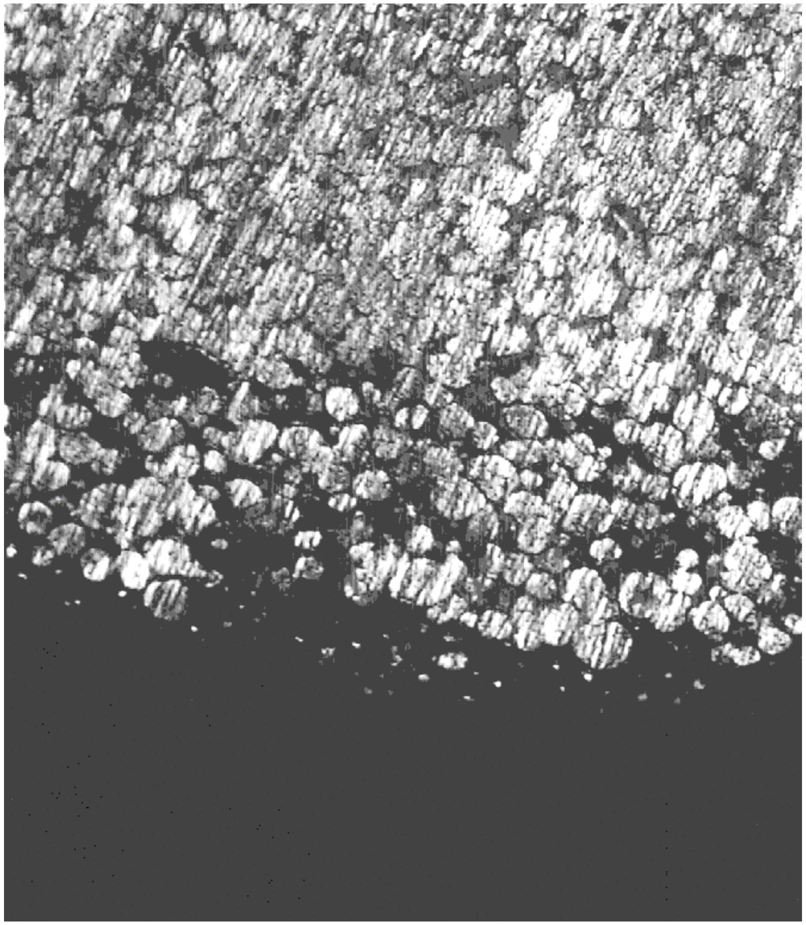
Sinking As Well As Explosive Reaction Acceptable For RAMICS

Water Impact Loads

- Theoretical Formula:

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

- Nose Material Stress Can Climb To Over 300,000 psi
- Carbide Tips Successfully Tested (420,000 psi Strength)
- Successful Tests At 45^o & 60^o Exceeded Theoretical Material Strength Predictions
  - Bow Shock May Mitigate Impact Load

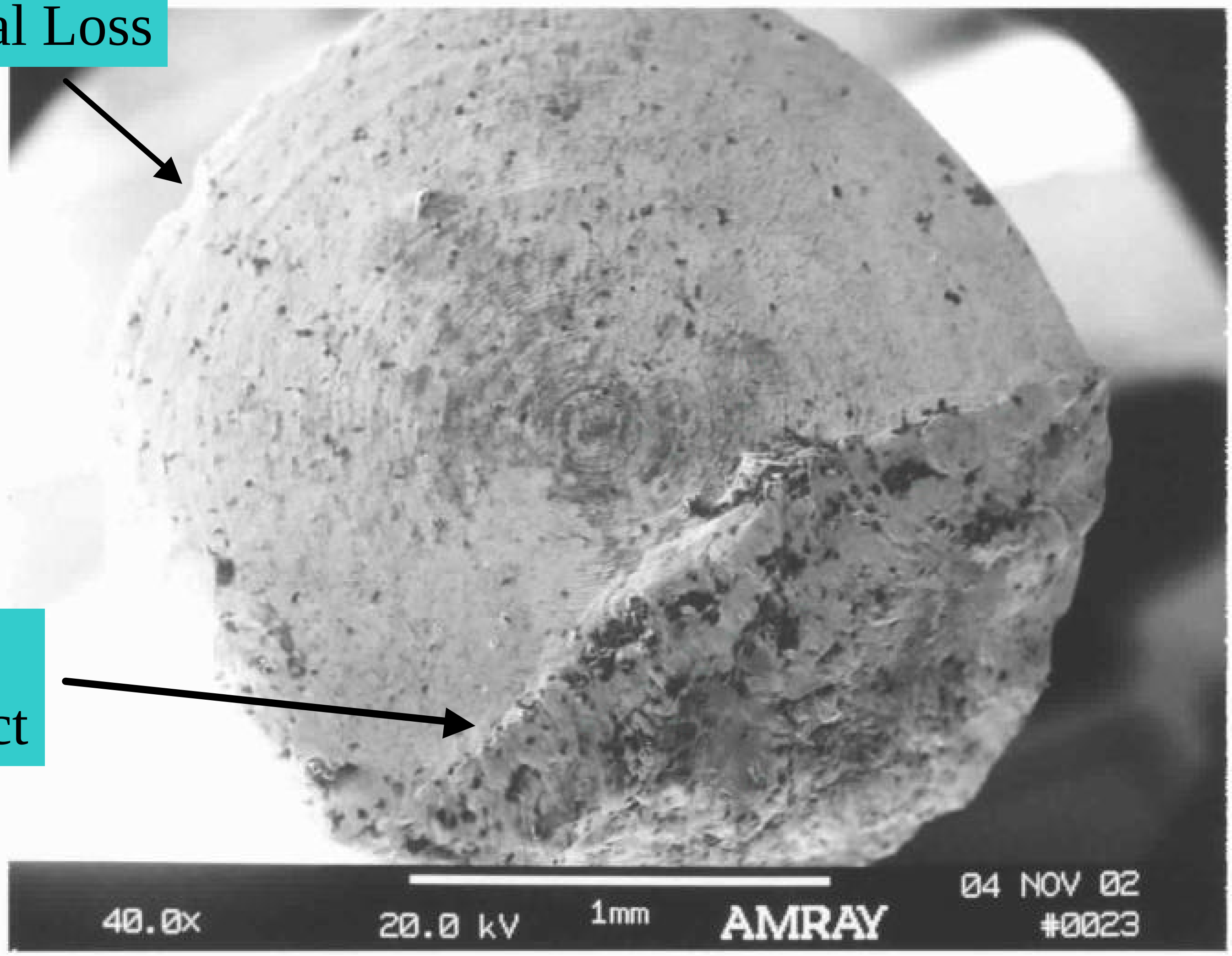


Shot #8494: 3800 ft/sec; Mat. Limit – 3700 ft/sec 90x Magnification

Recovered Nose Tip (*Snillfjord Test*)

Slight Material Loss

Deformation Due To Impact

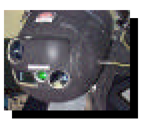


RAMICS Evolution

ATD Configuration (FY98-00)

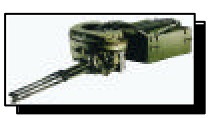
AH-1W SUPERCOBRA

LIDAR

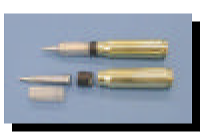


Gimbal

Fire Control Computer

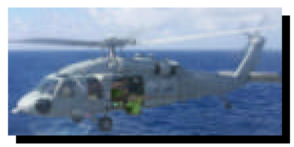


M 197
20mm Gattling Gun

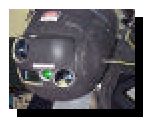


20mm Super Cavitating Projectile

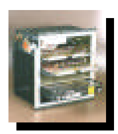
CTD Configuration(FY00-02)



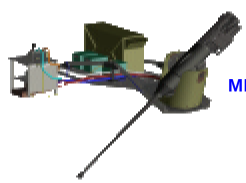
MH-60S KNIGHTHAWK



TBD Targeting Sensor Subsystem (TSS)

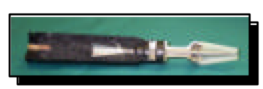


TBD Fire Control Subsystem (FCS)

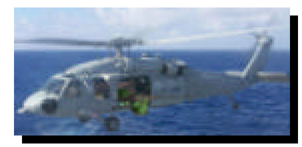


Gun Subsystem –
MK 44 30 mm Bushmaster II
Modified Apache Turret
Gun Control Unit

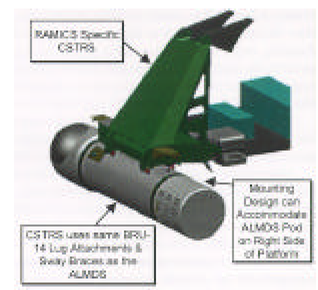
Munitions Subsystem –
MK 258 Mod 1
30mm APFSDS-T

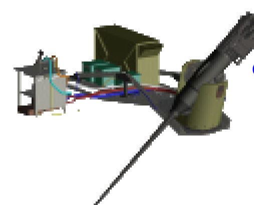


SDD Configuration (FY02-06)



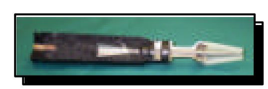
MH-60S KNIGHTHAWK





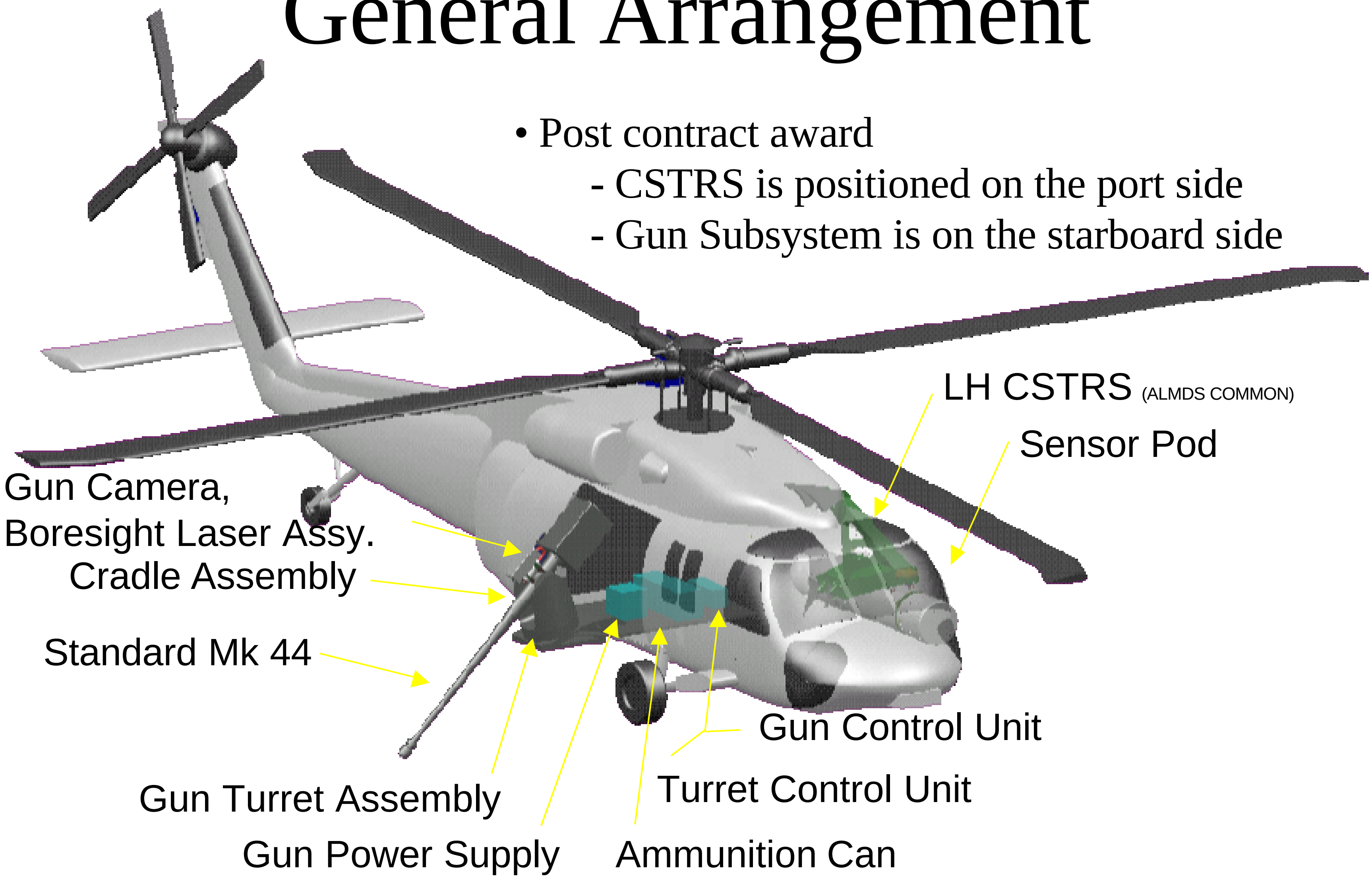
Gun Subsystem – MK 44 30 mm Bushmaster II
Modified Apache Turret Gun Control Unit

Munitions Subsystem –
MK 258 Mod 1
30mm APFSDS-T

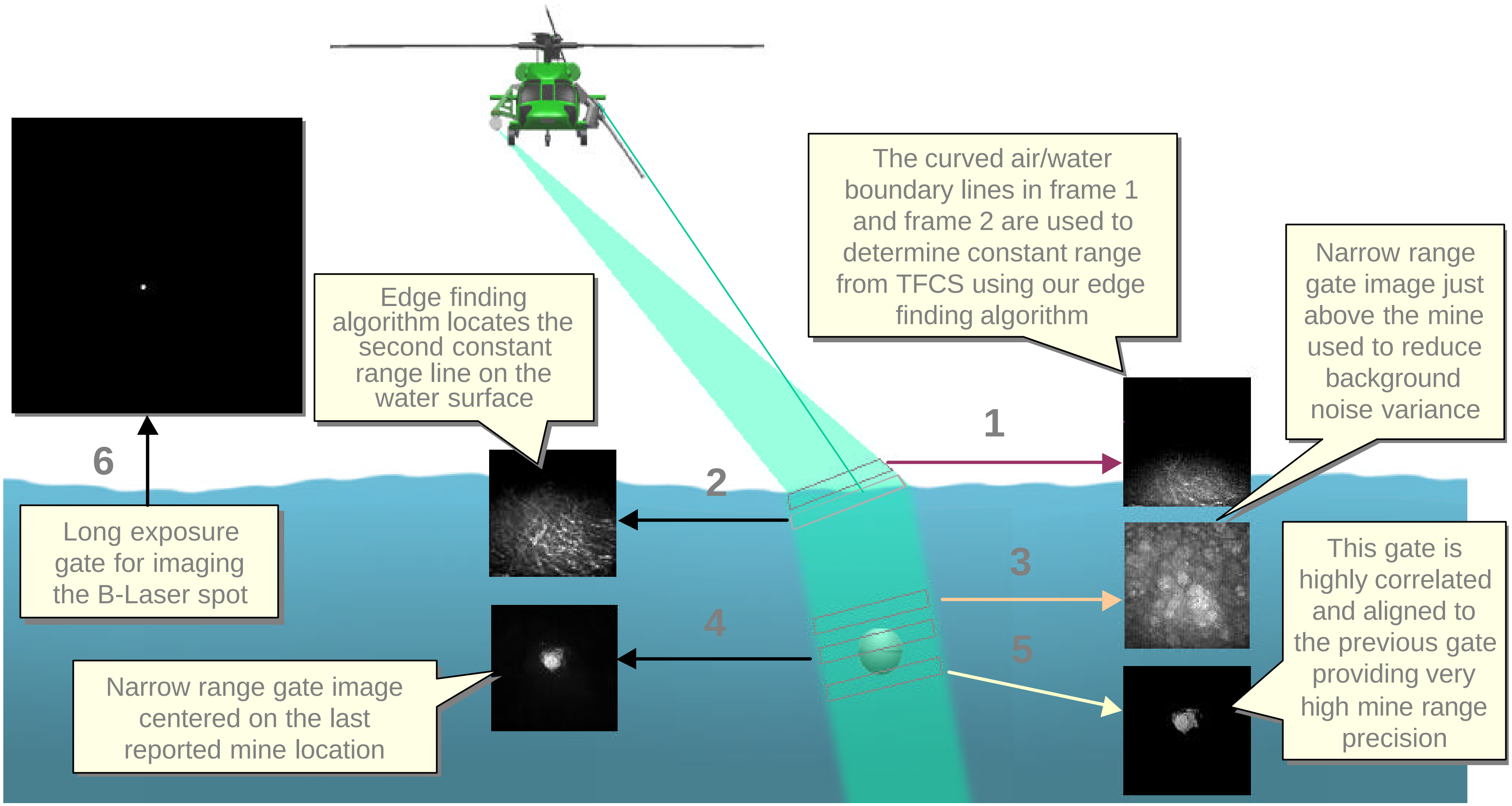


RAMICS Kit
General Arrangement

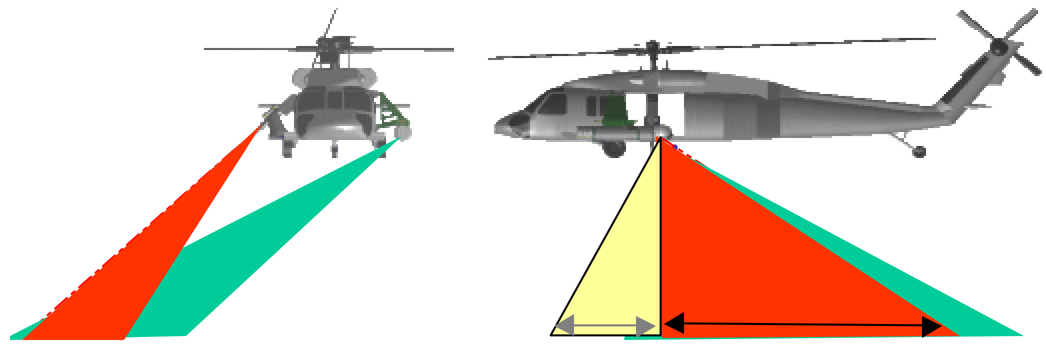
- Post contract award
  - CSTRS is positioned on the port side
  - Gun Subsystem is on the starboard side



Target Find/Lock Imagery



The RAMICS Mission



Install RAMICS Kit On Helicopter

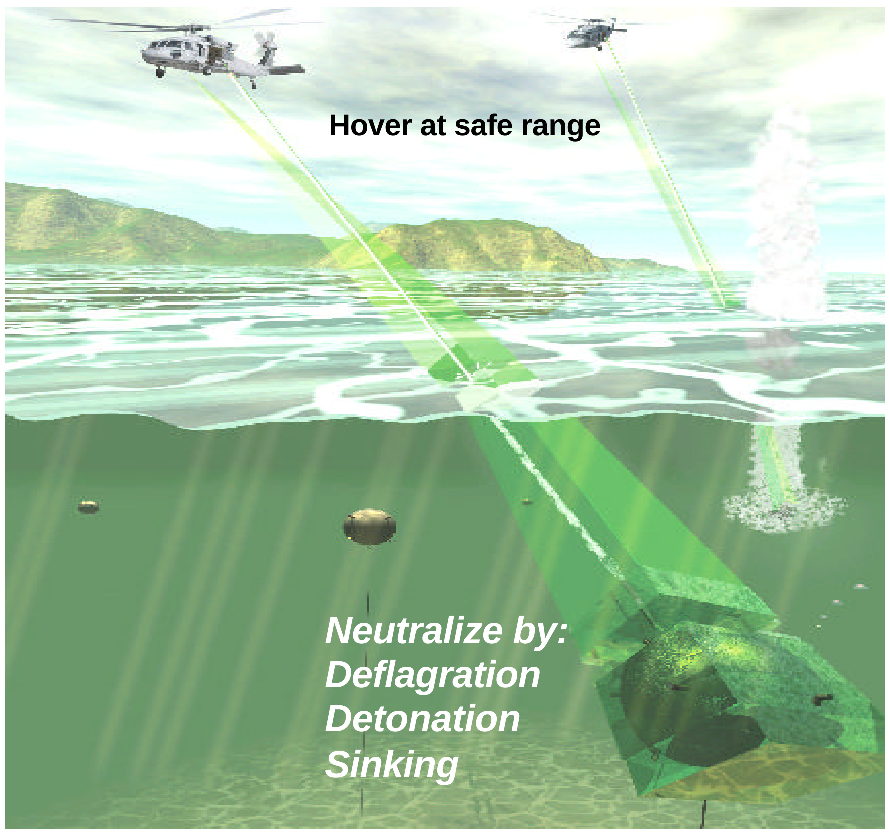
Launch w/Pre-Flight Target List

Mission Phases

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

<u>MH-60S Endurance</u>

-2 hour max sortie time.
-75 minute total hover mission endurance.



Field Of Fire

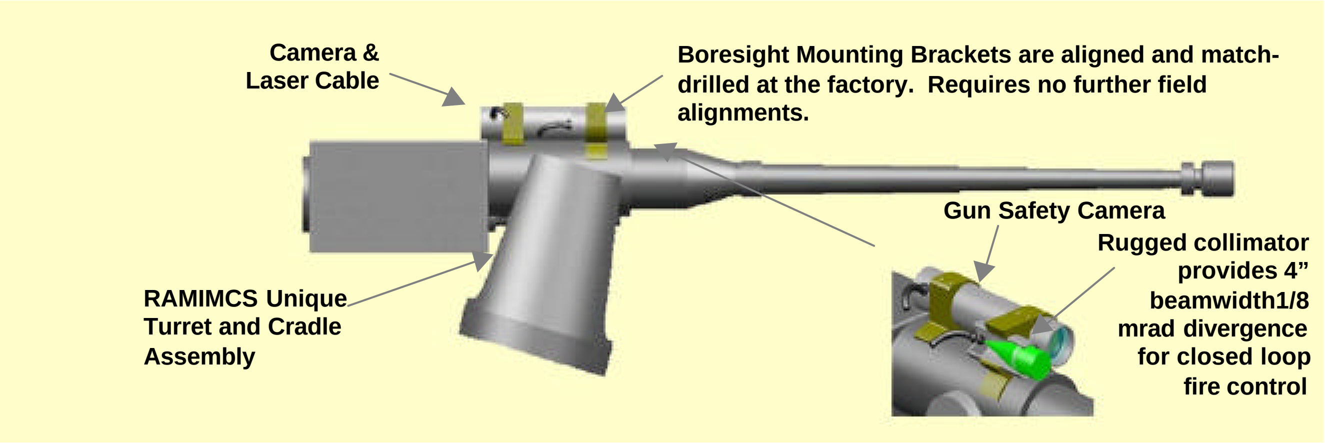
45 Thru 60 Deg. Depression

0 Thru 60 Deg. Trailing Azimuth (DT-IIA Approved) Forward 30 Thru 60 Trailing Recommended

LIDAR FOV Consistent w/Field Of Fire

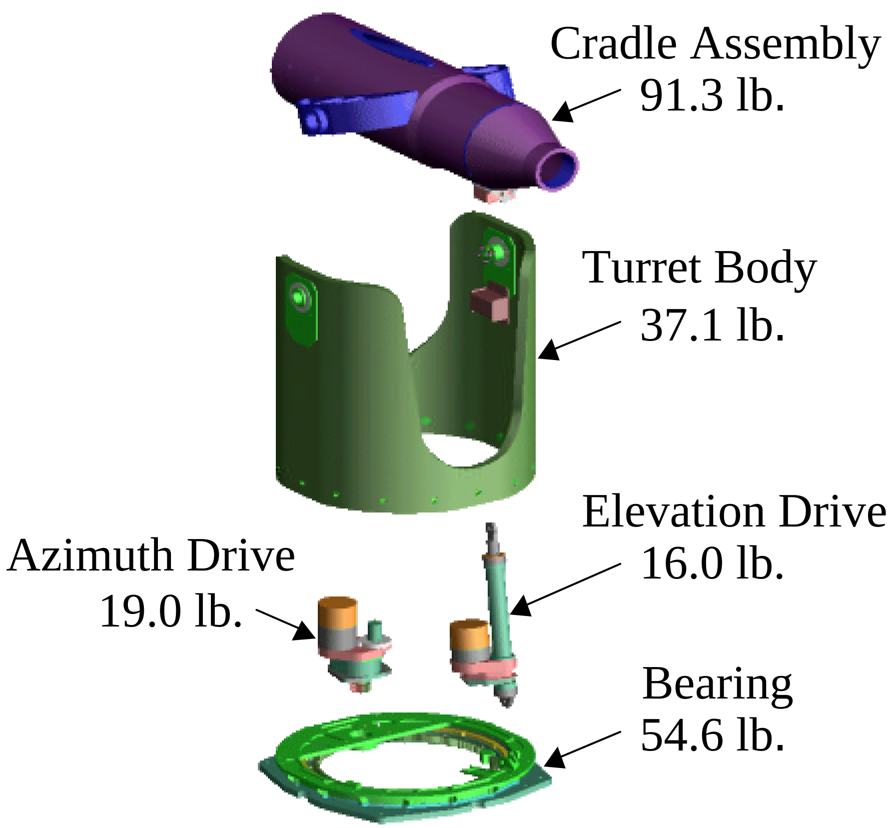
RAMICS Gun System

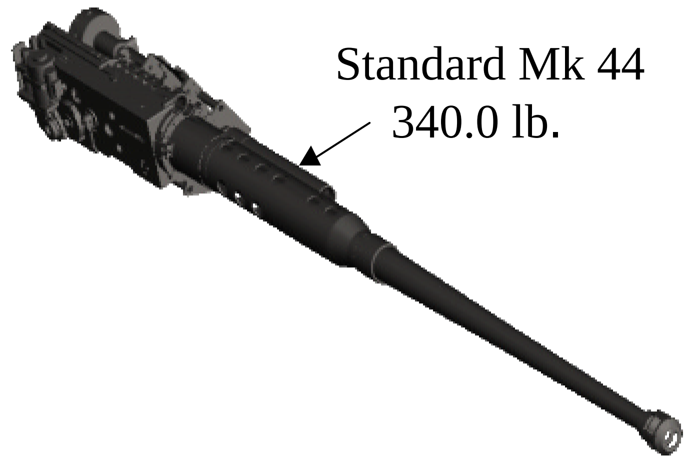
Based on MK 44 30mm Bushmaster II Cannon



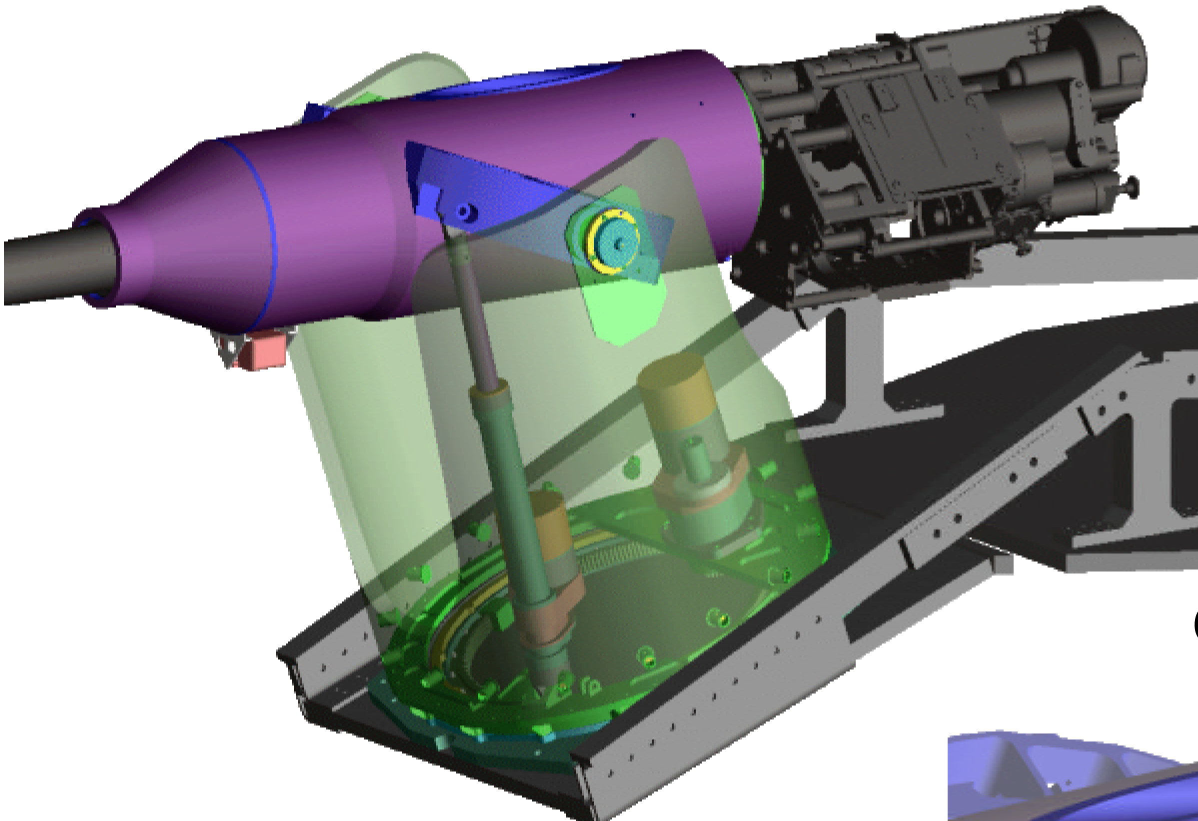
- Mounting of a boresight collimator on the gun barrel allows a closed loop gun pointing solution
- Fiber Optic Laser light fed into the boresight collimator provides shock isolation of boresight laser
- Cradle recoil mechanism reduces recoil to less than 4000 lb.
- Gun mounted camera allow viewing of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

Turret Component Breakout

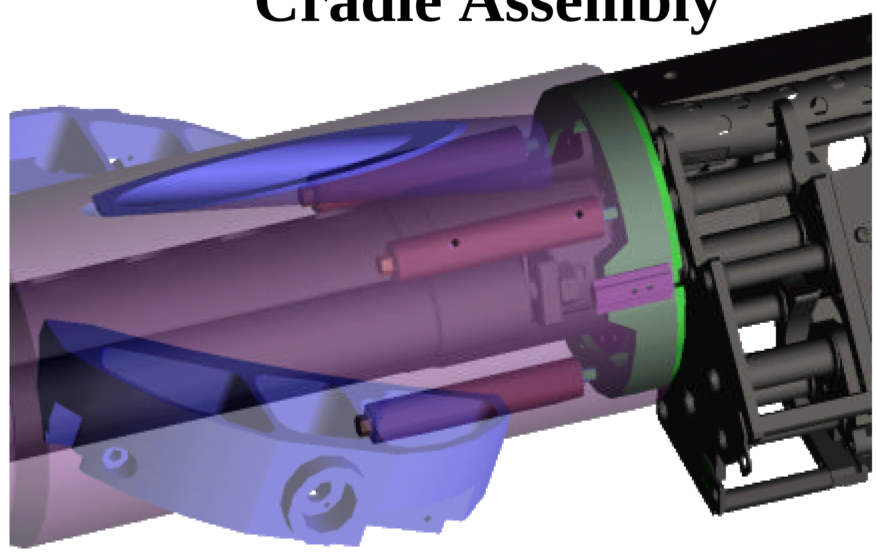


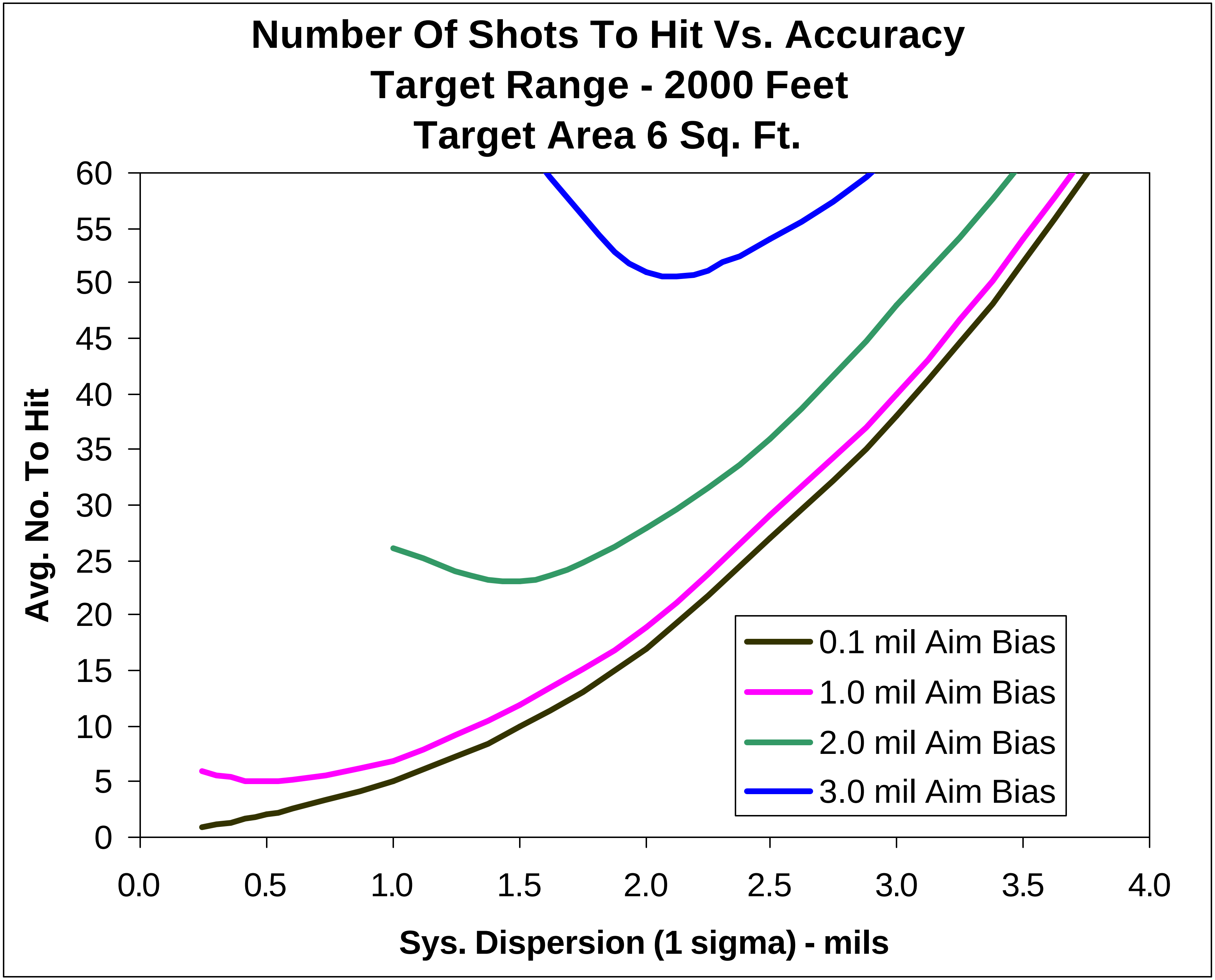


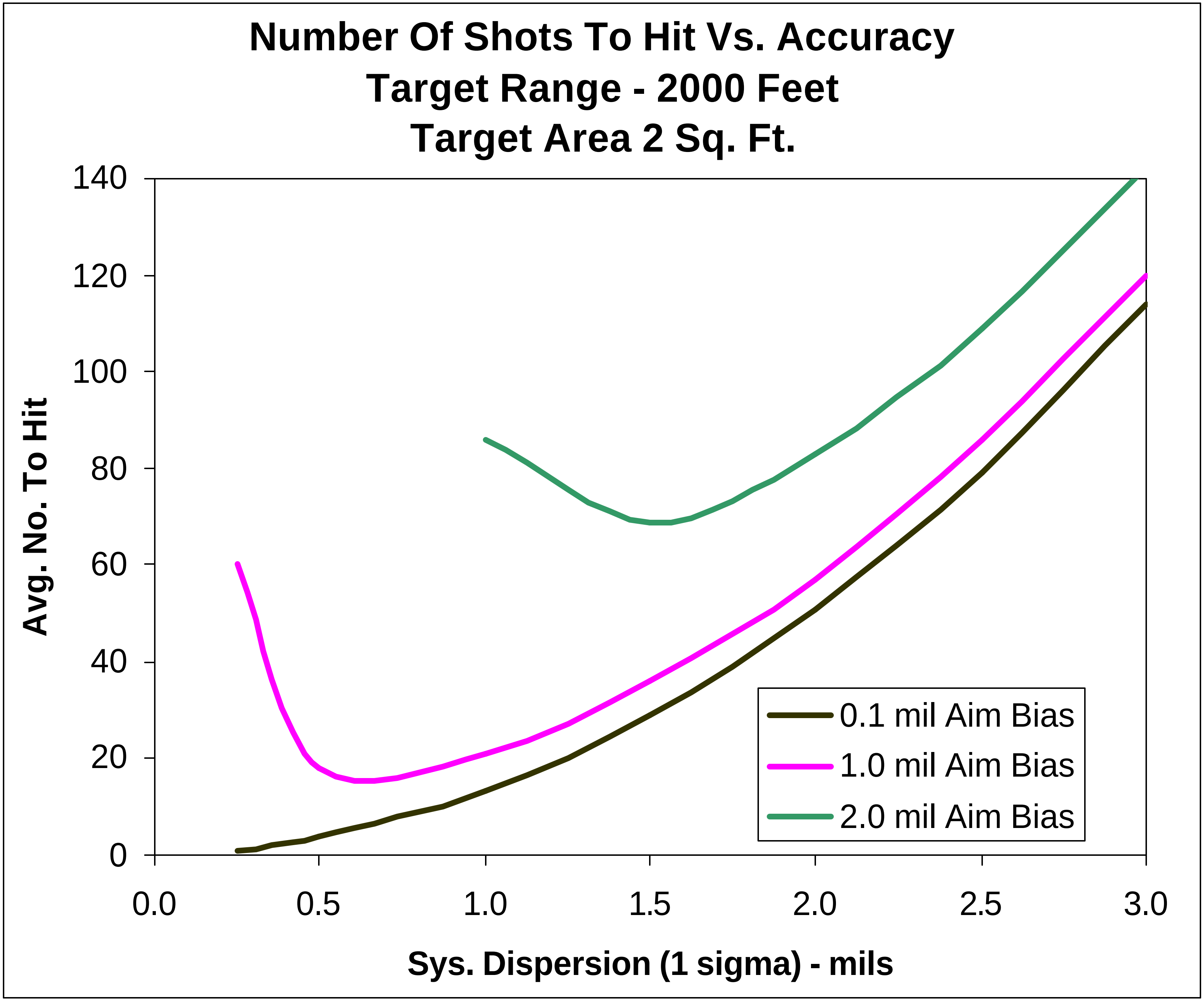
GUN SUBSYSTEM ASSEMBLY



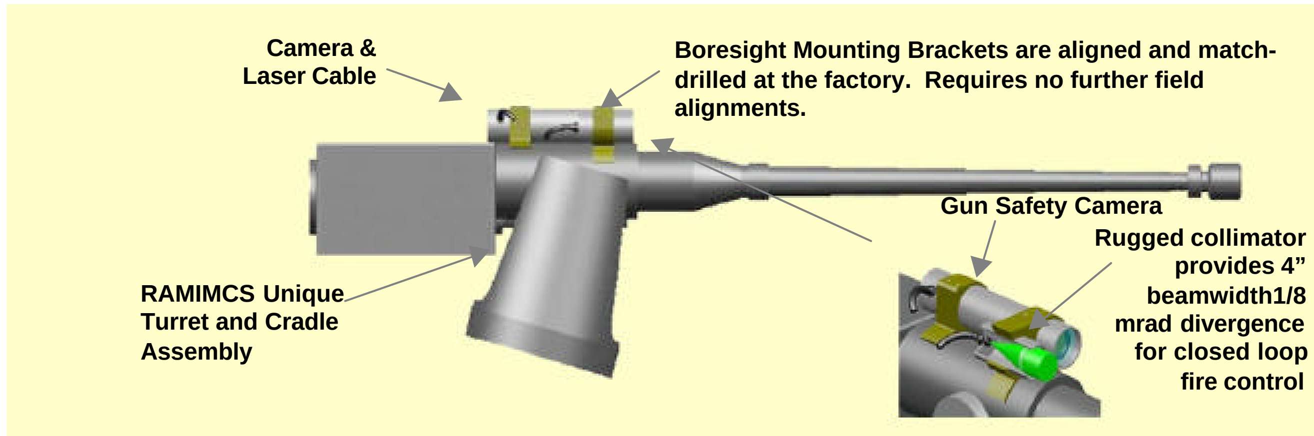
Cradle Assembly




Number Of Shots To Hit Vs. Accuracy
Target Range - 2000 Feet
Target Area 6 Sq. Ft.
Avg. No. To Hit
0
5
10
15
20
25
30
35
40
45
50
55
60
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Sys. Dispersion (1 sigma) - mils
0.1 mil Aim Bias
1.0 mil Aim Bias
2.0 mil Aim Bias
3.0 mil Aim Bias

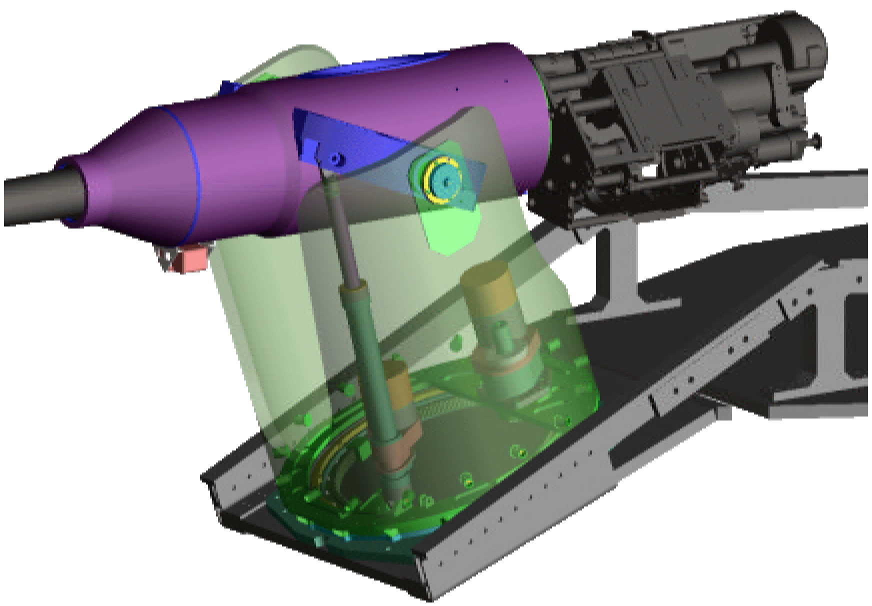

Number Of Shots To Hit Vs. Accuracy
Target Range - 2000 Feet
Target Area 2 Sq. Ft.
Avg. No. To Hit
140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Sys. Dispersion (1 sigma) - mils
0.1 mil Aim Bias
1.0 mil Aim Bias
2.0 mil Aim Bias

RAMICS Gun System Based on MK 44 30mm Bushmaster II Cannon

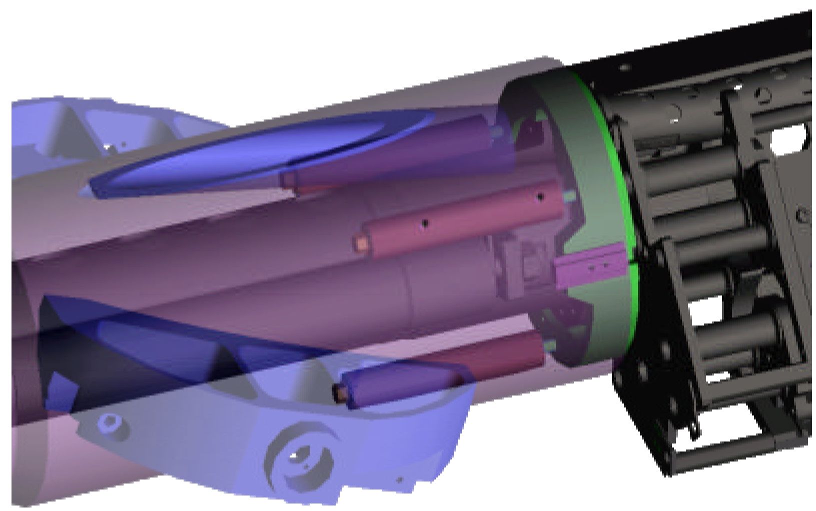


Characteristics

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)



Cradle Assembly



RAMICS Risk Assessment

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:

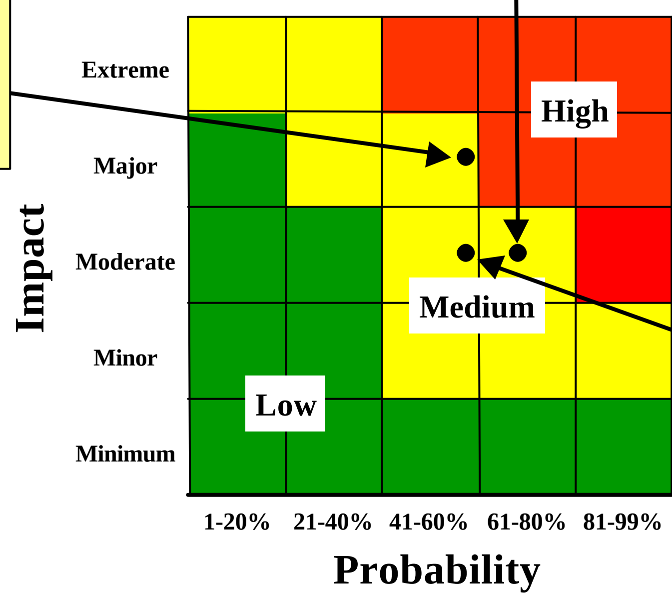
- Collimator mounted on a like-gun system; Done on a packaging options trade; Laser on turret can survive shock-Trade study performed by HR Textron
- Move Laser source into the RAMICS targeting POD to lesson shock

Technical Issue (#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 (#3)

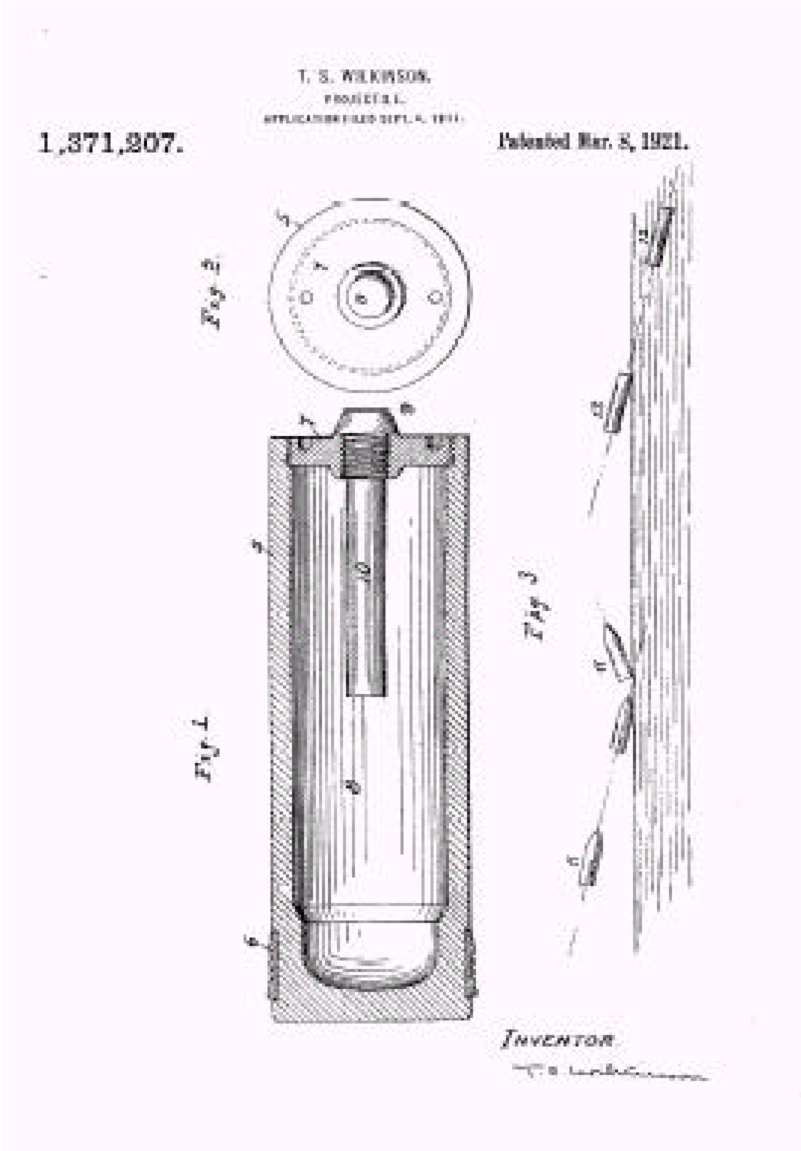
- Reacquisition Search Area (RSA) Timeline – Specified gimbal performance capability, laser power, IFOV of 19 mrad, number of gates used and standoff position for performing complete reacquisition over the whole RSA for all depths may not be performed within the Reacquisition Neutralization timeline.

Mitigation efforts:

- Design algorithms that minimize helicopter repositioning during the reacquisition phase and use SMART POSITIONING, SMART POINTING and SMART FIRING alorithms 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