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*Customer Success Is Our Mission*

# Presentation to 42nd Annual Gun and Missiles Conference

## Trade Space on Appropriate Caliber Ammunition for Terminal Defense Guided Projectile

Advanced Programs

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April 23, 2007



*NOTE – All equations, weapon descriptions, and equipment specific materials are from open sources, usually the internet to avoid ITARS or classification issues*

# Traditional Threats

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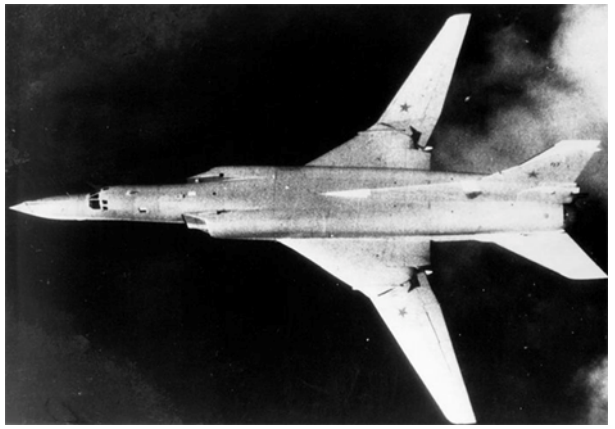
- Large capital platforms
- Large, highly capable weapons
- Low engagement rates
- Relatively long reaction times
- Usually engaged by a large, high performance missile
- Gunfire  used only as last ditch defense against “leakers”
- “Cost Effectiveness” equation based on cost to kill ~ cost of threat



**Main Defensive weapons designed against these threats**

# New Asymmetric Platform Threats

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- With loss of “active” peer threats, lower capability countries dominant threat
- Weapons used by these countries are usually militarized commercial products
- GPS or GPS/INS permits easy weaponization of UAV or USV platforms
- Terrorists can also use same technology as effectively as the U.S.
- Threats likely to employ multiple units and surprise to ensure mission success with low reaction times
- Guns are appropriate as primary engagement weapon
- “Cost Effectiveness” equation requires cost to kill ~ “political” cost of failure

Cigar Boat Threat (BOGHAMMER)

Jet Ski

RPG threat

Micro UAV

Large UAV

Mini UAV

**Newer threats, secondary weapons being designed to handle**

# New Non-Traditional Threats

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- New generation of low volume, GPS or SAL guidance applied to unguided munitions
- These weapons will result in simultaneous attacks in large numbers
- Low reaction times due to short ranges and large numbers
- Gunfire only practical means to respond to these threats in high engagement rates
- Target “hardness” ranges from hard to very hard, a major technical challenge


- Equally available to terrorists and even the smallest of nation states
- “Cost Effectiveness” equation should be cost per kill ~ “political” cost of failure

**A new problem, requiring new solutions**

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# Not All Functions Drive Trade Space

| Function | Projectile Caliber Influence | Comments |
|---|---|---|
| Detection | Weak | Primarily a function of the search sensor |
| Classification | Weak | Determines if signal represents a threat |
| Engagement Planning | Strong | Determines order of engagement, how many projectiles per target to fire (projectile lethality used in calculations) |
| Fire Control System (FCS) | Weak | Coordinates target state, sensor pointing and gun pointing to begin engagement |
| Weapon Initialization | Medium | Smaller calibers cannot be guided but would have smart-fuzing larger calibers that may require additional states to support guidance |
| Weapon Deployment | Strong | Gun carriage and auto-loader characteristics strongly determined by caliber of projectile fired |
| Weapon Control System (WCS) | Medium | Smaller caliber may have fuze aiding and larger caliber may require additional transmitted states for guidance (lethal radius influences accuracy required) |
| Terminal Effects | Strong | Caliber size determines both lethal radius and per-shot-lethality of projectile |

**Projectile, gun, and fire control must be solved holistically**

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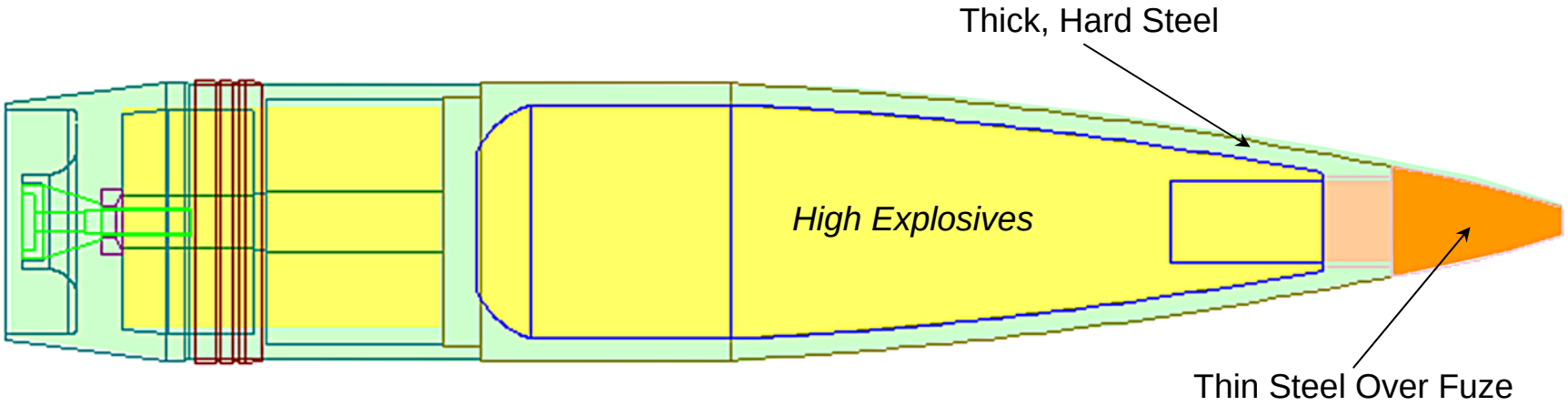
# Newest Threats are Hardest to Defeat




- Small radar cross section
- Very hard shell body
- Small vulnerable area
- Small reaction times
- Likely to have large number of simultaneous threats
- Requires K-kill to not revisit (soft kill is a dud but not known until impact)

**These threats drive the requirements for a self defense projectile**

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# Side by Side Analysis

| Caliber | US DoD | Other | In Production |
|---|---|---|---|
| **20 mm** | USAF | Aircraft Guns<br>Vulcan ADU | Yes |
| **25 mm** | M2A1 Bushmaster | | Yes |
| **30 mm** | USAF, USM | FRG-ABM | Yes |
| **35 mm** | N/A | Skyguard | Yes |
| **40 mm** | USAF | BOFORS | Yes |
| **57 mm** | USN LCS, DDX | BOFORS | Yes |
| **60 mm** | N/A | X-WP | No |
| **76 mm** | USN FFG, USCG | NATO FFG | Yes |
| **90 mm** | N/A | Unknown | Yes |

**Selection is available from a large range of operational calibers**

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# Combat Proven Answer to New and Non-Traditional Threats

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- Exists and fielded
- Proven lethality
- Low per engagement cost
- RF primary sensor
  IIR capability
- Engages low elevation targets
- Engages high elevation targets
- Multiple projectiles
  - HE
  - Incendiary
  - Tracer
  - Self destruct
- Support leveraged by large installed base

*http://www.raytheon.com/products*

Test and combat video available at
*http://www.videotiger.com/vids/amazingmilitarydefensiveweapon.wmv*

Scale UAV

Personal Watercraft

Small Boat Threat

Surface Mine

**Proven highly effective in ship-board and static-land scenarios**

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# 30 mm/35 mm Operational

- AHEAD technology, developed by Oerlikon Contraves, improves the capability of air defense guns to engage and destroy aerial targets from large aircraft to small targets like missiles or PGMs
- The gun fires short, 24 round burst of high velocity AHEAD rounds aimed at the target's intercept point to activate and separate the projectile into 152 heavy tungsten metal spin-stabilized sub-projectiles (3.3 grams each), forming a lethal cone shaped metal cloud, placed ahead of the target in its flight path
- 35 mm AHEAD is designed to fit existing Skyguard air defense systems
- The 30 mm AirBurst Munition (ABM) is currently being qualified for the German Army for deployment with the MK 30-2 ABM cannon mounted on the Puma AIFV
- A 35 mm version optimized for ground-to-ground effect is being qualified for the Bushmaster III chain gun mounted on the new CV9035 IFV of the Royal Dutch Army. Denmark has also selected the ABM capability for its CV9035
- The ABM concept is also highly suitable as a Counter-Rockets, Mortars and Artillery (C-RAM)

*http://www.defense-update.com/products/a/ahead.htm*

**“Cargo-based” KE rounds exist for point defense**

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# 40 mm/57 mm Cannons Operational

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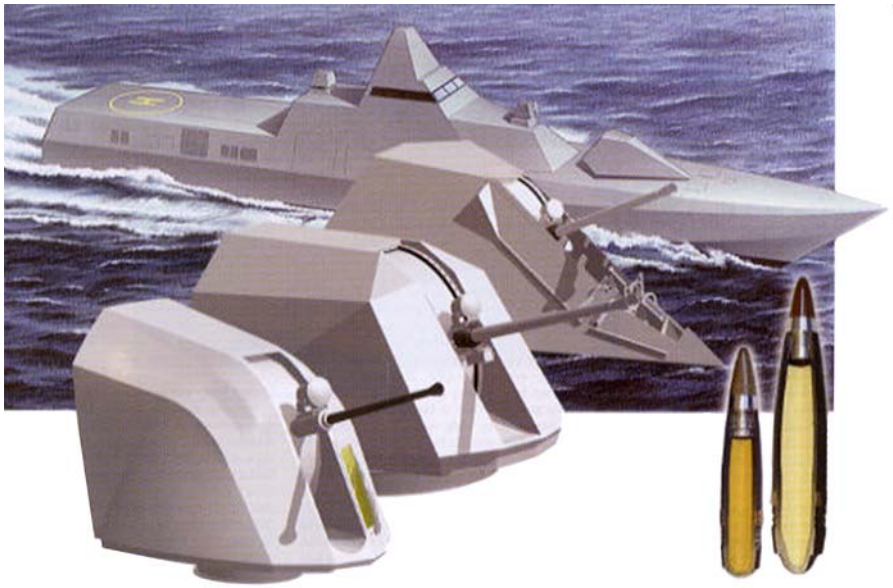
- The 57 mm MK 3 provides unmatched lethality with multiple 57 mm ammunition options available from the weapon's twin compartment magazine that can shift between round types instantly. Bofors 57 mm 3P all-target programmable ammunition allows three proximity fuzing options as well as settings for time, impact and armor-piercing functions. With a range of 17 kilometers, Bofors 57 mm HCER surface target ammunition provides reach and explosive effect comparable to larger caliber guns



| Cartridge Weight | | Velocity | Energy |
|---|---|---|---|
| Gun | G | Meters per Second | Joules |
| 40mm L/60 40x311R | 955 | 850 – 900 | 345,000 – 387,000 |
| 40mm L/70 40x364R | 870 | 1,030 | 461,000 |
| 57mm m/47 57x230R | 2,230 | 744 | 617,000 |
| 57mm L60-70 57x438R | 2,400 | 1,020 | 1,250,000 |

*http://www.uniteddefense.com/prod/ngun_mk3.htm*

**Littoral combat ship using the larger rounds as primary batteries**

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# 76 mm Cannons Operational and New Solutions are in Work

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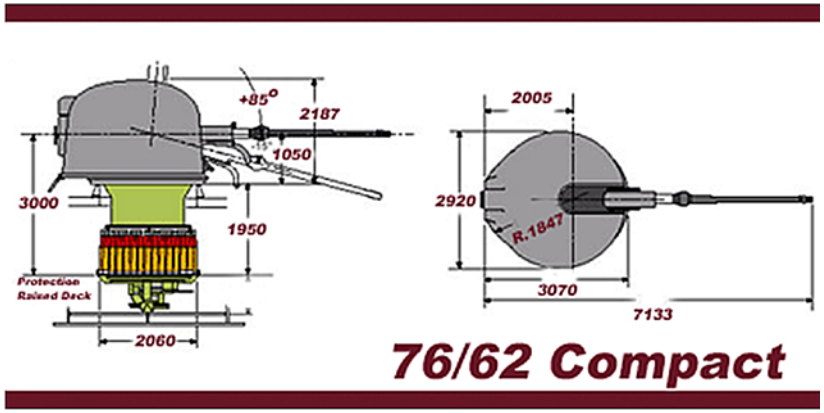
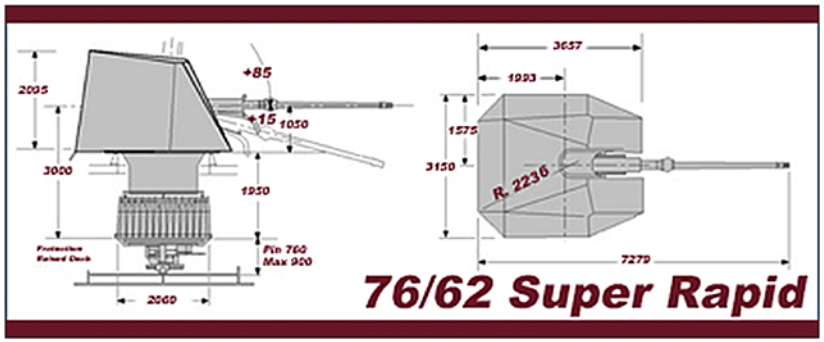
## Naval Applications

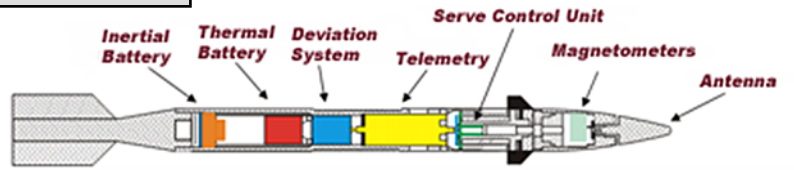


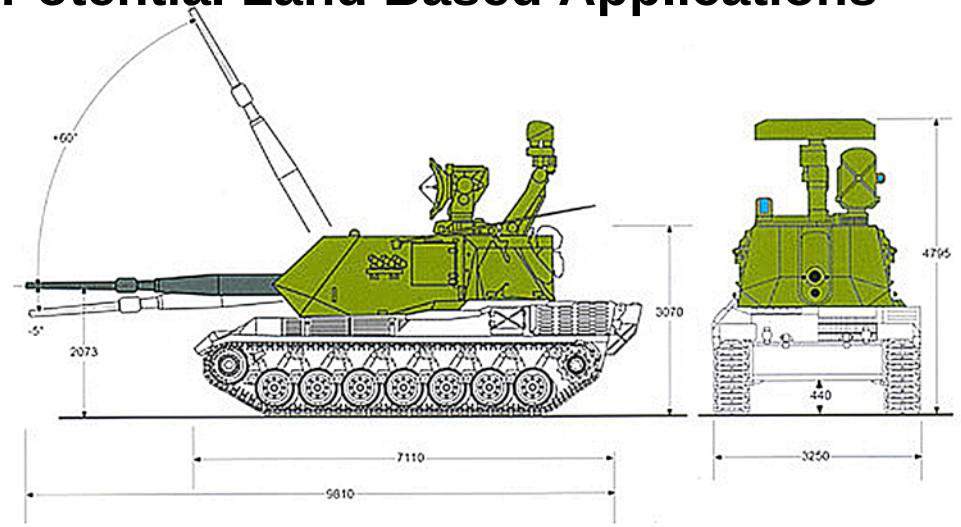

*http://www.finmec.com*

## Advanced Projectiles

**Dart**




## Potential Land Based Applications




**High speed 76 mm compatible for naval and land combat employment**

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# Caliber Trade – Army Application

## Moderate Engagement Rate

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## DOES NOT INCLUDE 2 + 1 Firing Protocol

| Calibre cm | Weight kg | Volume cm^3 | number per ton | load per 5T truck | fired per kill & | intercepts per truck | trucks per K intercept | gun firing rate | Firing Vehicle WT | Time to engage @ | Time to engage # | Max Eff Range | 1st Engage Range |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.3 | 1 | 105 | 889 | 4267 | *20* | 213 | 5 | 600 | 20 | 48 | 16 | 5,000 | 16,800 |
| 4 | 2.1 | 574 | 423 | 2032 | *10* | 203 | 5 | 300 | 20 | 48 | 16 | 11,000 | 16,800 |
| 5.7 | 4 | 1,749 | 222 | 1067 | *3* | 356 | 3 | 150 | 20 | 29 | 10 | 14,000 | 10,080 |
| 7.6 | 10 | 3,455 | 89 | 427 | *2* | 213 | 5 | 120 | 40 | 24 | 8 | 18,000 | 8,400 |
| 9 | 15 | 5,814 | 59 | 284 | *1* | 284 | 4 | 20 | 40 | 72 | 24 | 18,000 | 25,200 |
| 10.5 | 17.8 | 8,573 | 50 | 240 | *1* | 240 | 5 | 10 | 40 | 144 | 48 | 18,000 | 50,400 |
| 12 | 27.6 | 11,198 | 32 | 155 | *1* | 155 | 7 | 6 | 60 | 240 | 80 | 20,000 | 84,000 |
| 15.5 | 52 | 26,630 | 17 | 82 | *1* | 82 | 13 | 4 | 60 | 360 | 120 | 30,000 | 126,000 |
| | | | | | | | | rpm | ton | sec | sec | meter | meter |

@ Assume one AD vehicle - ignoring azimuth training time
# Assume 3 AD vehicles with overlapping azimuths - ignoring azimuth training time
& Assumed to be required to effect a K kill

## INCLUDES 2 + 1 Firing Protocol

| Calibre cm | Weight kg | Volume cm^3 | number per ton | load per 5T truck | fired per kill & | intercepts per truck | trucks per K intercept | gun firing rate | Firing Vehicle WT | Time to engage @ | Time to engage # | Max Eff Range | 1st Engage Range |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.3 | 1 | 105 | 889 | 4267 | *20* | 213 | 5 | 600 | 20 | 48 | 16 | 5,000 | 16,800 |
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| 5.7 | 4 | 1,749 | 222 | 1067 | *4* | 267 | 4 | 150 | 20 | 38 | 13 | 14,000 | 13,440 |
| 7.6 | 10 | 3,455 | 89 | 427 | *3* | 142 | 8 | 120 | 40 | 36 | 12 | 18,000 | 12,600 |
| 9 | 15 | 5,814 | 59 | 284 | *2* | 142 | 8 | 20 | 40 | 144 | 48 | 18,000 | 50,400 |
| 10.5 | 17.8 | 8,573 | 50 | 240 | *2* | 120 | 9 | 10 | 40 | 288 | 96 | 18,000 | 100,800 |
| 12 | 27.6 | 11,198 | 32 | 155 | *2* | 77 | 13 | 6 | 60 | 480 | 160 | 20,000 | 168,000 |
| 15.5 | 52 | 26,630 | 17 | 82 | *2* | 41 | 25 | 4 | 60 | 720 | 240 | 30,000 | 252,000 |
| | | | | | | | | rpm | ton | sec | sec | meter | meter |

@ Assume one AD vehicle - ignoring azimuth training time
# Assume 3 AD vehicles with overlapping azimuths - ignoring azimuth training time
& Assumed to be required to effect a K kill

**57 mm and 76 mm appear best for intermediate range intercept**

# Payload Lethality Inputs
## (All Data from Open Sources)

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### Joules required to Damage Target

| Target | Light Damage | Moderate Damage | Heavy Damage |
|---|---|---|---|
| **Personnel** | 0.1 | 1 | 4 |
| **Aircraft** | 4 | 10 | 20 |
| **Armor** | 10 | 500 | 1000 |

$J = Kg*(m/s)^2$

### Probability of Kill

$N_{hits} = A(N_o/4\pi R^2)$

where:

$N_{hits}$ is the expected number of fragments hitting;
$N_o$ is the initial number of fragments from the warhead;
A is the frontal area of the target presented to the warhead; R is the range of the target to the warhead.

For multiple hits the overall $P_k$ is found from

$P_k = 1 - (1-P_K|_{hit})^{Nhits}$, if $N_{hits} > 1$, or

### Initial Fragment Velocity

The theoretical result for fragment velocity using the Gurney constant ($2\Delta E$) for TNT is 2328 m/s:

$$v = \sqrt{2\Delta E}\sqrt{\frac{C/M}{1+K(C/M)}}$$

where:

C/M is the charge-to-metal ratio
K depends on the configuration:
Flat plate: K = 1/3
Cylinder: K = 1/2
Sphere: K = 3/5

### Fragment Velocity at Range

$V(s) = V_o * e^{-\rho C_d A s/2M}$

$\rho$ = The density of air. Normally 1.2 Kg/m3

$V_o$ = The fragment velocity

$C_d$ = The coefficient of drag. Depends on the shape of the fragment and to some extent, the velocity

A = The cross-sectional area of the fragment

M = Mass of fragment

s = Distance traveled

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# Projectile Must Match Warhead Size to Miss Distance Performance

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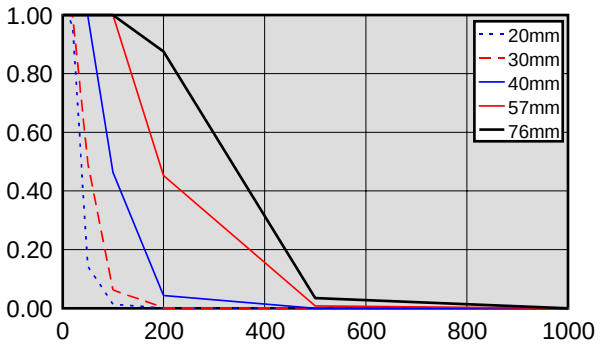
## Projectile Data Derived from Jane's Ammunition Handbook

| Dia | Length | C/M | No | Vo | Jo |
|---|---|---|---|---|---|
| 20 | 110 | 0.1 | 600 | 600 | 12 |
| 30 | 110 | 0.15 | 900 | 1100 | 20 |
| 40 | 210 | 0.13 | 2300 | 1000 | 30 |
| 57 | 340 | 0.19 | 5400 | 1200 | 68 |
| 76 | 375 | 0.10 | 7900 | 900 | 51 |

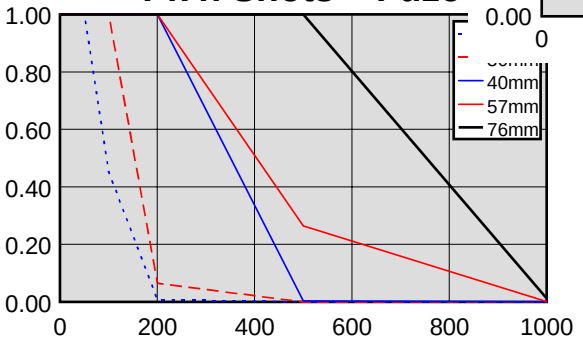
Blast

Fragment

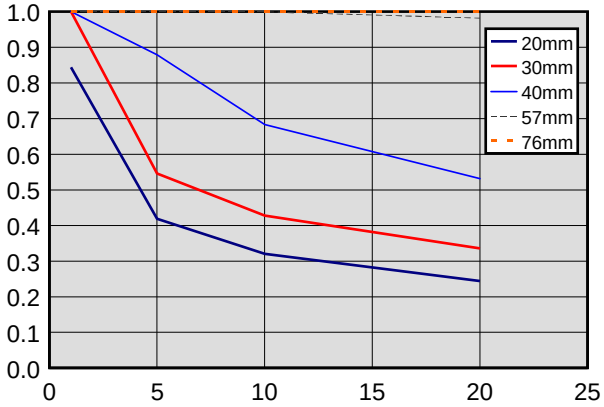
### Pk n Shots – Shell



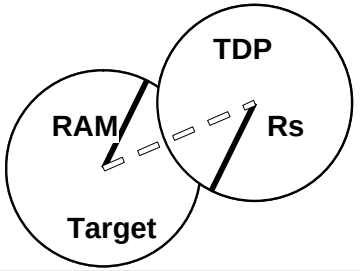

### Pk n Shots – Fuze




### KE Submunitions (HTK)




### Projectile Hit to Kill (HTK)




| RAM Target Type | Required Miss (mm) |
|---|---|
| 280 mm Rocket | 220 |
| 155mm Artillery | 122 |
| 81 mm Mortar | 92.4 |

***A hit is when the miss is less than 80% of the sum of the weapon diameters***

**All payloads require hit to kill or very high precision guidance**

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# Gun Accuracy Implies Different Solution for Different Engagement Ranges

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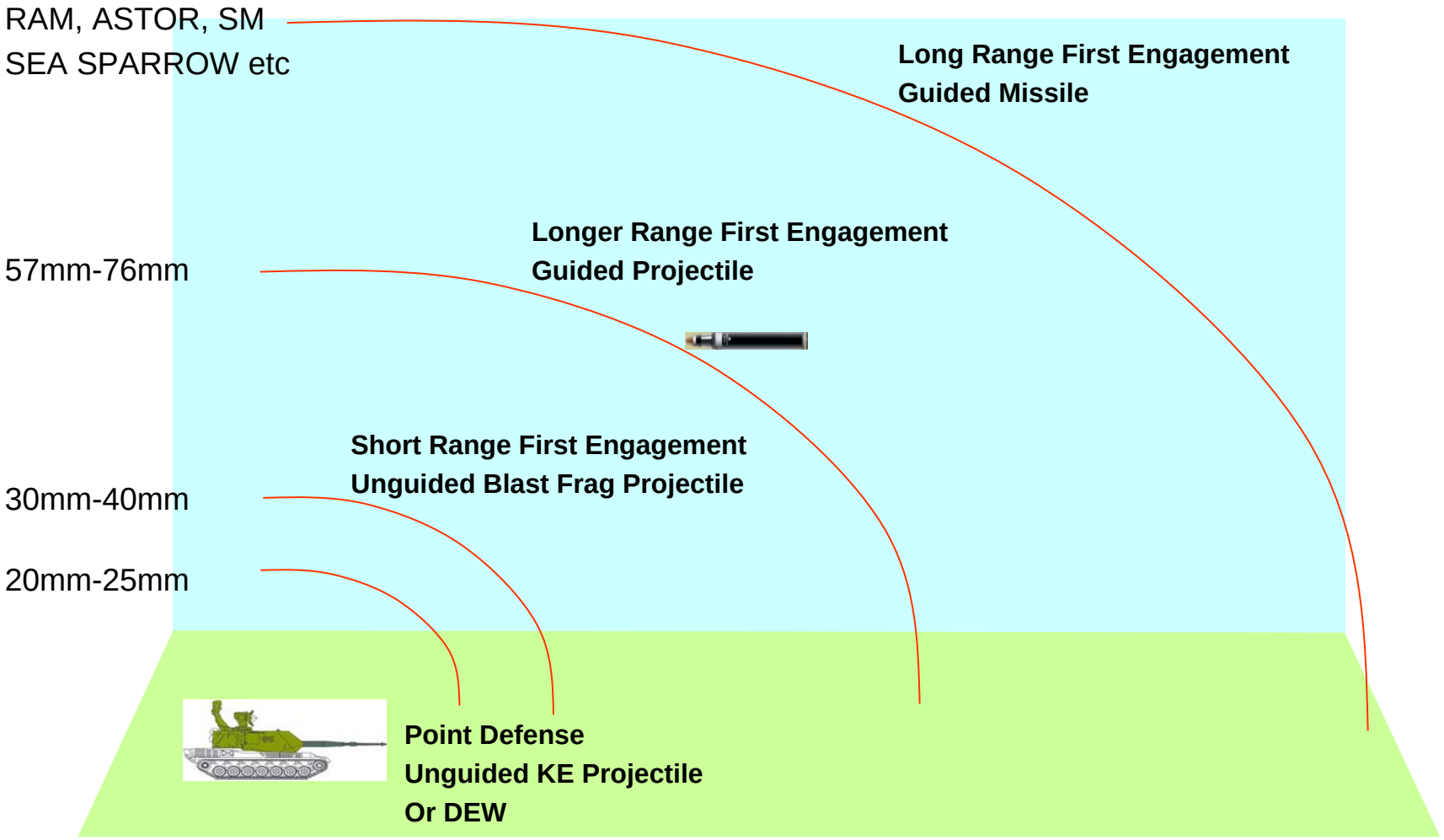


**All solutions require hit to kill or very high precision**

# Conceptual Volume Allocation

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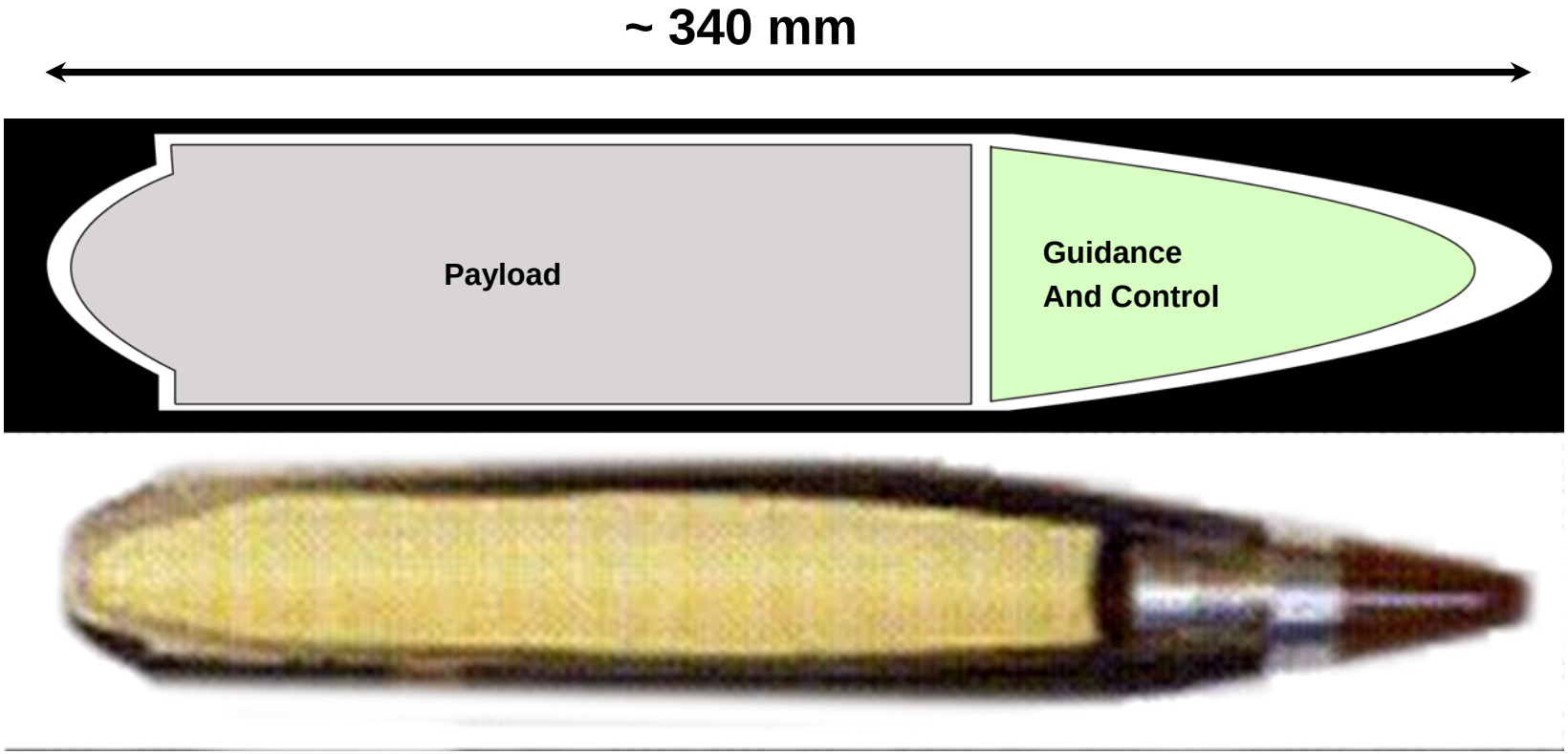


**Volume Allocation Based on 57 mm Projectile**

**Recent miniaturization allows guidance in 76 mm and 57 mm projectiles and moving towards 40 mm**

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# Summary

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- Depending on desired operational flexibility and cost sensitivity, there are a number of potential solutions
  - Targets come in radical size differences
  - Targets come in radical differences in “hardness”
- Cost/performance standard set by trailer mounted PHALANX system
- For higher mobility, the candidate calibers are between 20 mm – 155 mm
- Projectiles calibers of 20 mm, 30 mm, 40 mm would likely be unguided
  - Insufficient volume for payload/guidance/power
- Guidance can be realistically considered for 57 mm and 76 mm projectiles
  - Both gun sizes can be mounted in AFV chassis
  - Guided 76 mm projectiles in advanced development
  - Projectile volumes sufficient for GNC/power considerations
- Implementation of actuation and power source are the technical challenges in smaller calibers
- For any caliber, due to wide variations in target size/hardness, it may take different warhead families to best cover threats