Guided Projectiles Theory of Operation
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Abstract

Subject Terms

Report Classification	Classification of this page
unclassified	unclassified

Classification of Abstract	Limitation of Abstract
unclassified	UU

Number of Pages
16

Improved Terminal Effects

Altitude (k ft) vs Kilometers

- Crusader
- Paladin

0   8.5   37   50 Kilometers

Wide Attack Footprint

Kilometers (vertical) 0–50, Kilometers (horizontal) -40 to 40

X — Maximum Target

Baseline XM982 can hit any target in this area from one tube position!

Crusader Location

Enhanced Range - Artillery Range Overmatch

- XM982 Crusader
- XM982 Paladin & LWH
- Current US Capability
- International Capability

Kilometers: 0   10   20   30   40   50

Improved Effectiveness / Lethality

Rounds (Weight) Transported	No. of DPICM Rounds Required
11,340 lbs M864 FAPP	M864
4,392 lbs XM982 U-PAC	XM982
25km Range at 10% EFD	35km Range, Normalized, at 10% EFD
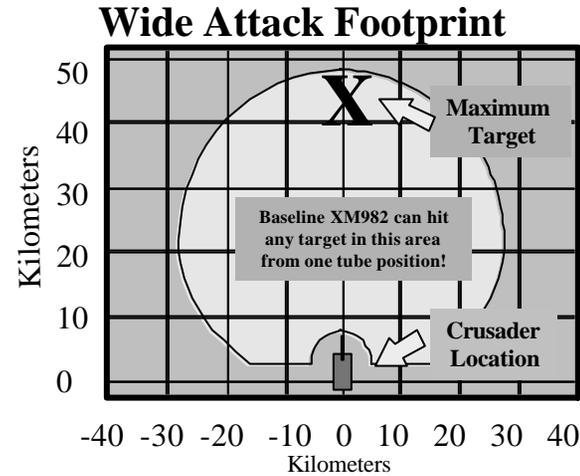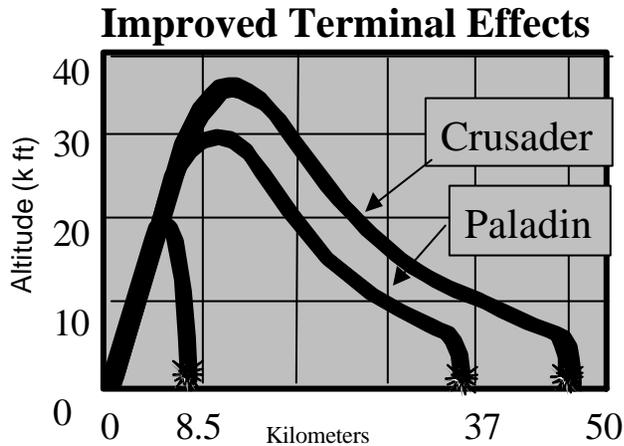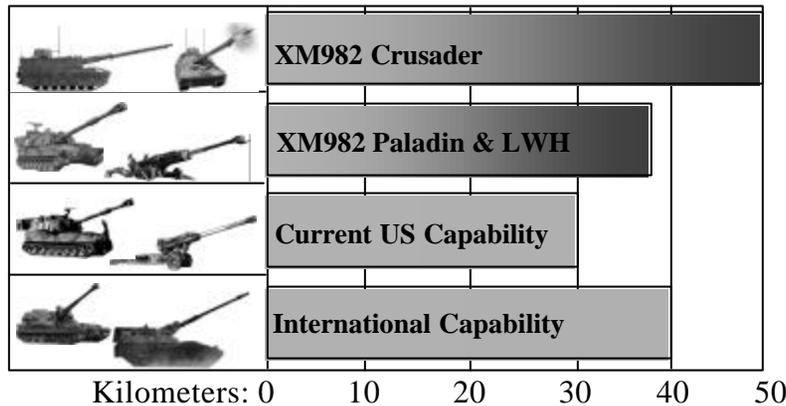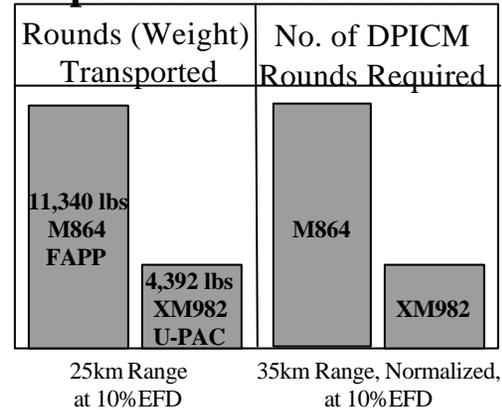
Data from Public Released presentation

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Potential Solutions for Projectile Guidance

	Configuration	**Range**	**Accuracy**

Unguided

~ 100 M

~ 300 M

1-DOF Correction
Controls X

2-DOF Correction
Controls X, Y

7-DOF Correction
Controls time, X, Y, Z, pitch, yaw, roll
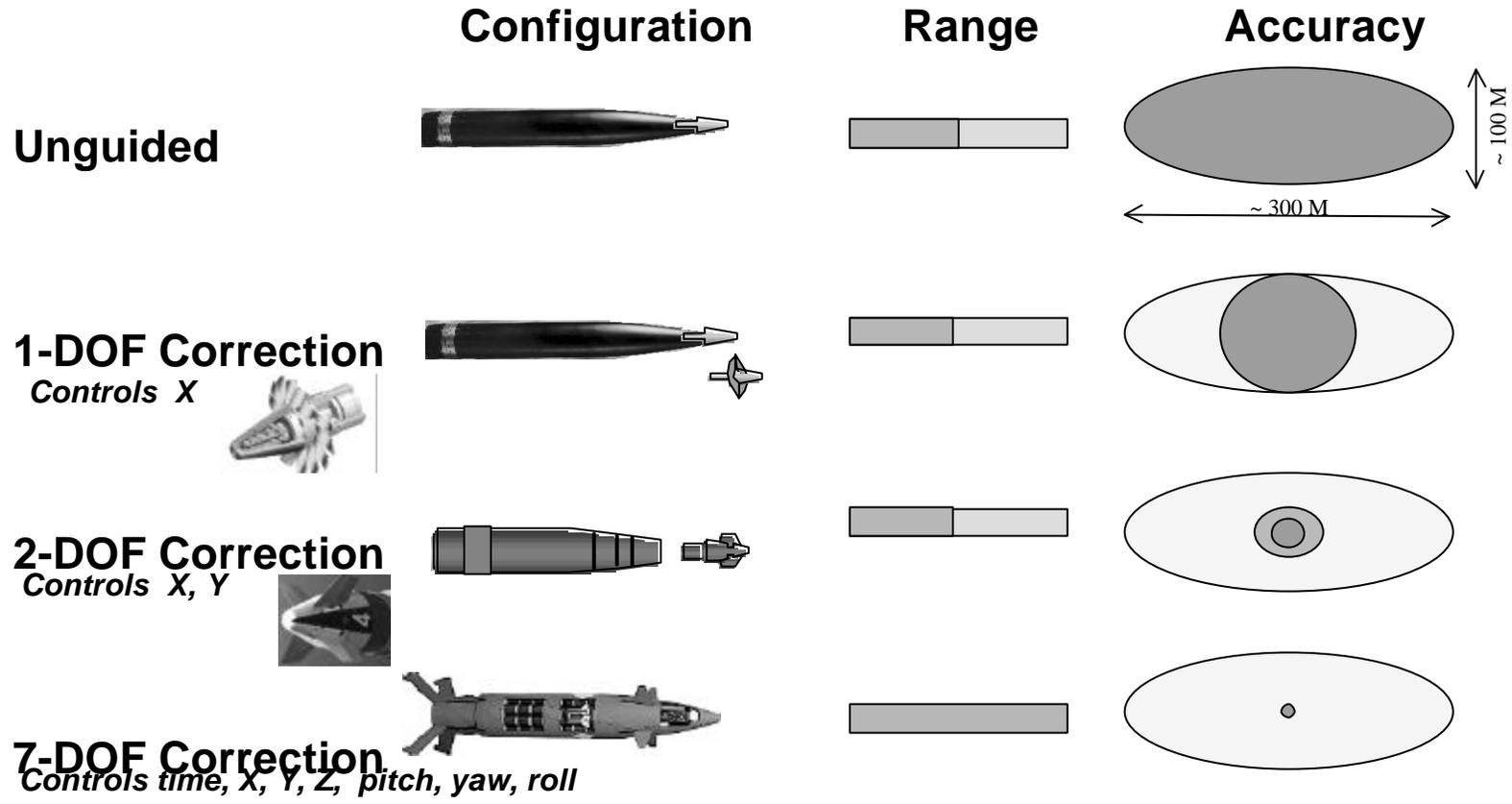
Data expanded from NDIA Web site

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Various Guidance Options

Ballistic

Mid-Course Phase

CONTROL	GUIDANCE
Aerodynamic	IMU
Thruster	GPS
None	Beacon
	None

STABILIZATION	DATA LINK
Spin	Radio
Fin	None
Spin/Despin/Fin	

PROPULSION	SEEKER
None	IR
Rocket	mmW
Ram Jet	TV
	None

CALIBER	PAYLOAD
Full Calibre	Lethal
Sub-Calibre	Non-Lethal

Launch Phase   *Terminal Phase*
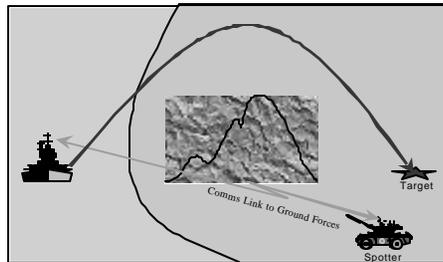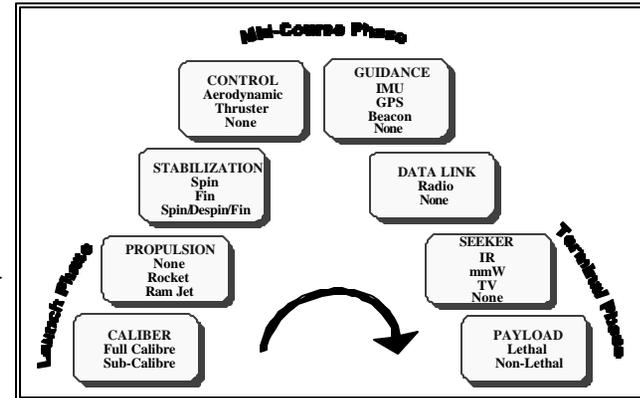
Self Guided
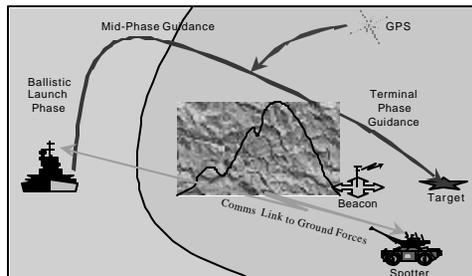
Follow Me
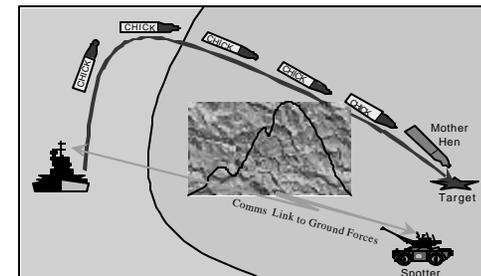
Command Guided
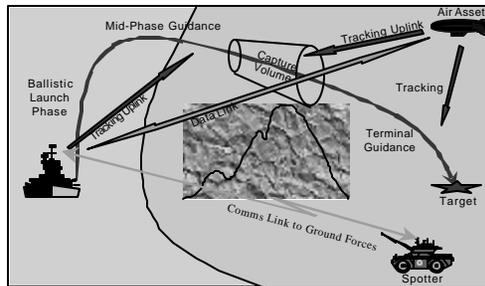
Laser Guided
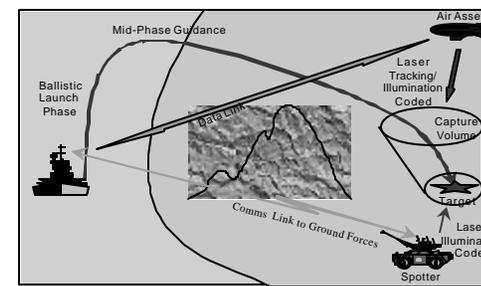
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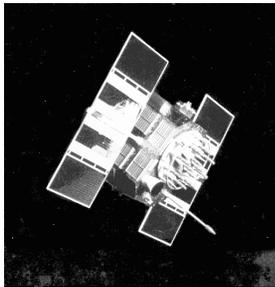
IMU provides very accurate body based rate and acceleration data

GPS / IMS provides very accurate projectile inertial data
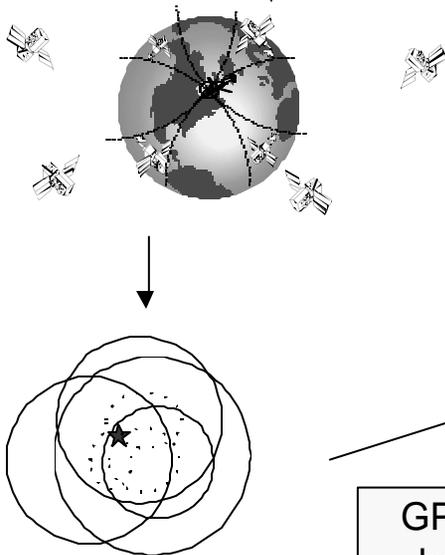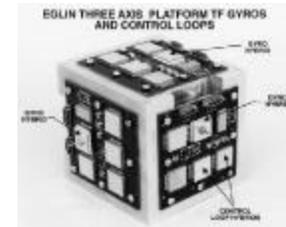
GPS provides very accurate Earth based position and velocity data

Data from GPS web site

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Example - Rocket Assisted Design

The Gun Envionment

XM 234 Submunition
Self-Destruct Fuze
(Arming)

EX 18 Payload
Safe/Arm

- Payload Base Eject
- Gas-Expanded Metal Bladder
  Submunition Dispense

TC5 - Pyrotechnic
Delay Igniter

Selectable Home-
on-GPS-Jam
Guidance

TC6 - Inertial
Measuring
Unit

Flight Thermal
Battery
(Not Shown)

TC4 - Four-Fin
Tail Assembly

Tightly Coupled,
Fast Acquisition, High
Anti-Jam GPS

TC3 - Ram Brake
(Not Shown)

Low-Drag
Boat Tail Taper

Breech Pressure
Equalizing Rocket
Motor

Low-Drag
Fineness
Ratio

TC1 - System
Software

Canard Control
Electro
Mechanical
Actuators

72 EX-1
Submunitions
(Lethality)

TC2 - Forward
Located Slip
Obturator

~ 12 KG's

~ 18 msec

Projectile In Bore Acceleration vs Time

Projectile Attributes

CHALLENGE - Build a projectile with all the functionality
of a missile but robust enough to gun fired

Data from Surface Warfare Web site

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General Concept of Operations

Baseline Capabilities

- On and off axis target attack (large downrange/ cross-range envelope)
- Trajectory optimized for aerodynamic efficiency
- Wind estimator to offset dispense for target area winds
- Moderate GPS jamming immunity / moderate effectiveness after jamout
- Adjustable dispense diameter, altitude and angle

Payload Dispense

Midcourse Guidance

Inertial Guidance

GPS Acquisition Window

Motor Burn

*Canards Deploy
Battery On
Fins Deploy

DCI

Data redrawn from Surface Warfare Web site

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Projectile Initialization requires very aggressive timelines to meet firing rates comparable to "dumb" projectiles

Primary

Power

Secondary

Shield

Data / Timing

Primary

Power
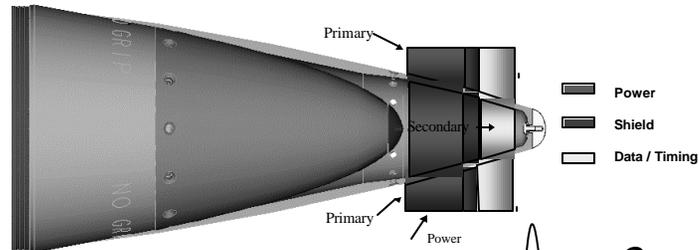
~ 3 seconds

~ 10 minutes
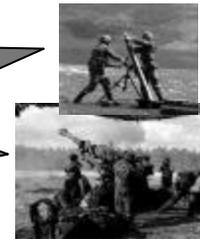
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Navigation/Midcourse Timeline

GPS Refinement of Attitude
and IMU Error Calibration Continue

Maximum GPS Acquisition Time
Accurate Maneuvering Possible

Terminal Jamming Provisioned

Initial Roll Finder Results Available

Battery Start, Software Elaboration,
Round Despin
Roll Finder Algorithm Starts

Dispense
or
Impact

FIRE!

Altitude

Down Range

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Terminal Time Line

$T_t = T_a - 3.0$
**Declare
Terminal**

$T_a = T_c - 1.0$
**Select Pattern
Arm Payload,
Zeroize**

T= T_{tof}

**Monitor
Estimated
Range to
Target**

$T_c = T_e - .02$
**Command
Sequence**

$T_e = T_d - .05$
**Submunition
Eject**

$T_d = T_0 - (2 \text{ to } 4)$
**Submunition
Dispense**

T_0
**Submunition
Impact**

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Multiple Rounds Simultaneous Impact

Closed form TOA solutions from Fire Control do not work

To supply MRSI, each projectile must both:
• accurate estimate time to target
• control it continuously

T$_n$

Trajectory flown

Possible trajectories to target

T$_{n+x}$

Trajectory flown

Possible trajectories to target
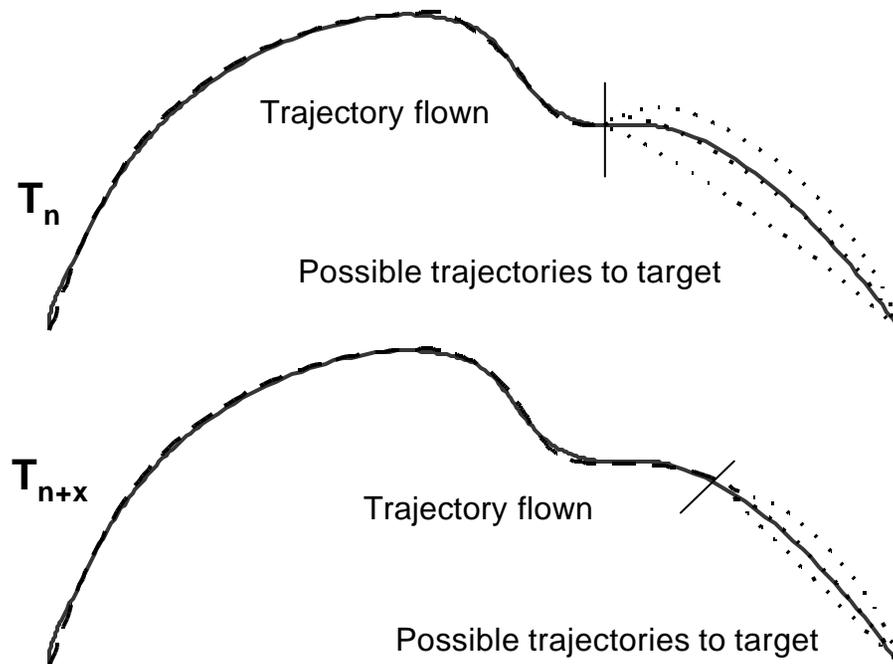
Biases error sources
(errors which dominate the time of flight)
> **Propellant performance**
> **Firing time errors**
> **Non standard Atmosphere**
> **Dominant wind direction**
> **Aerodynamic variations**

Colored noise sources
*(errors which confuse active time of arrival control)*
> **Wind shears**
> **GPS error shifts**

White noise sources
(errors which just "stimulate" any control)
> **Wind gusts**

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HOJ Operational Timeline

No Target Acquisition
* Inertial Guide to Pre-Brief
* Will not return to GPS

Dispense Command
* Range Estimation for Timing
  - *Algorithm based on Intensity*
* Angle Limited by Antenna FOV

Establish Target Acquisition
* Switch antennas to HOJ
* Develop AOA estimate
* Within DF limits of Pre-Brief Target
  - *Jammer close to target*

Loss of Track
* Will not return to GPS
* Guide to Last Est. Target Location

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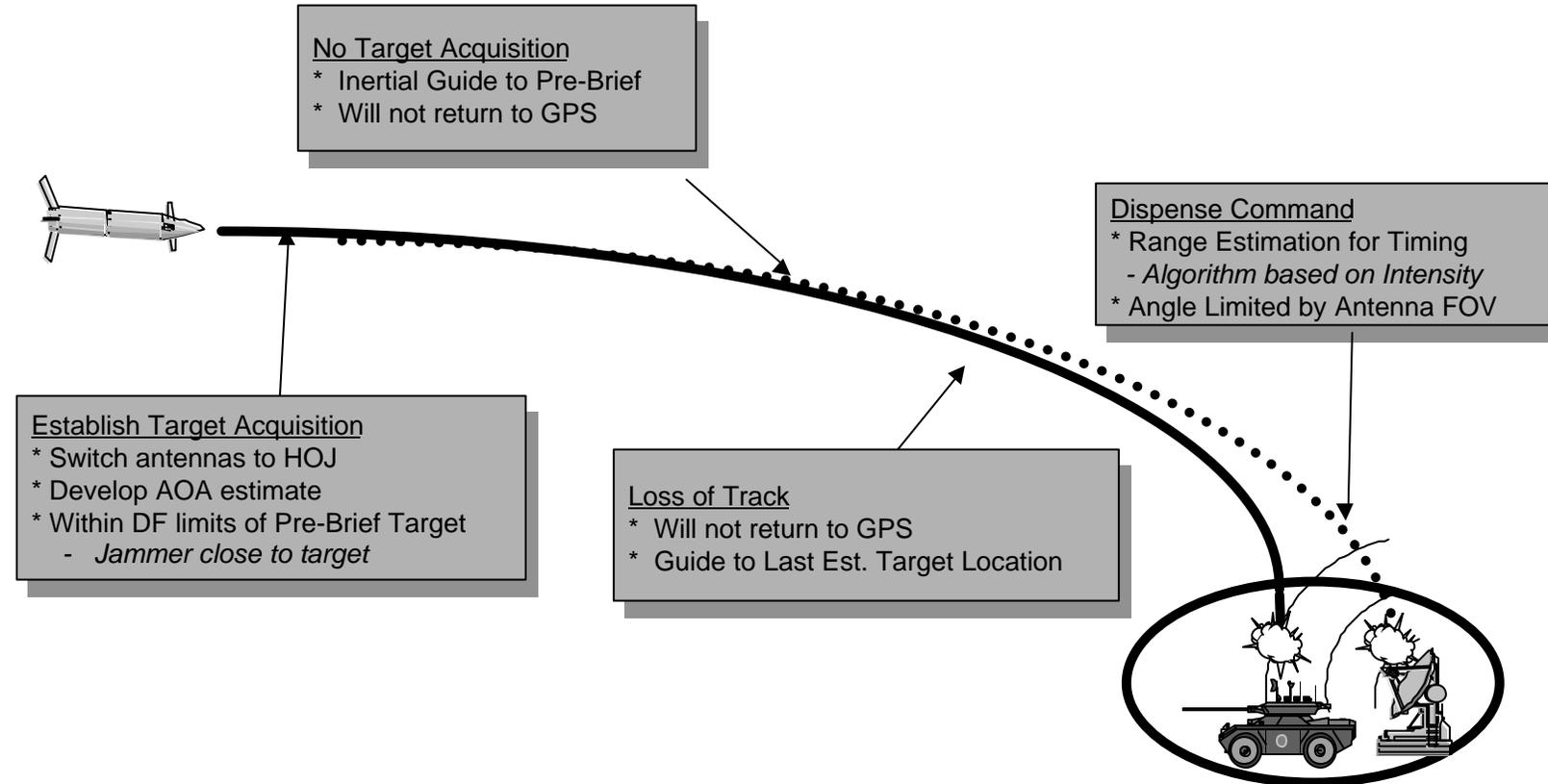
Off Axis Attack Capability provided

The ability to "fly" (example assumes 7-DOF guidance solution) means a gun can execute many firings missions from a single surveyed site without repositioning barrel


Conventional Unguided Projectile Footprint

Potential Footprint of a "constrained" Guided Projectile

Potential Attack Footprint of a Guided Projectile

Cross range (KM)

Downrange (KM)
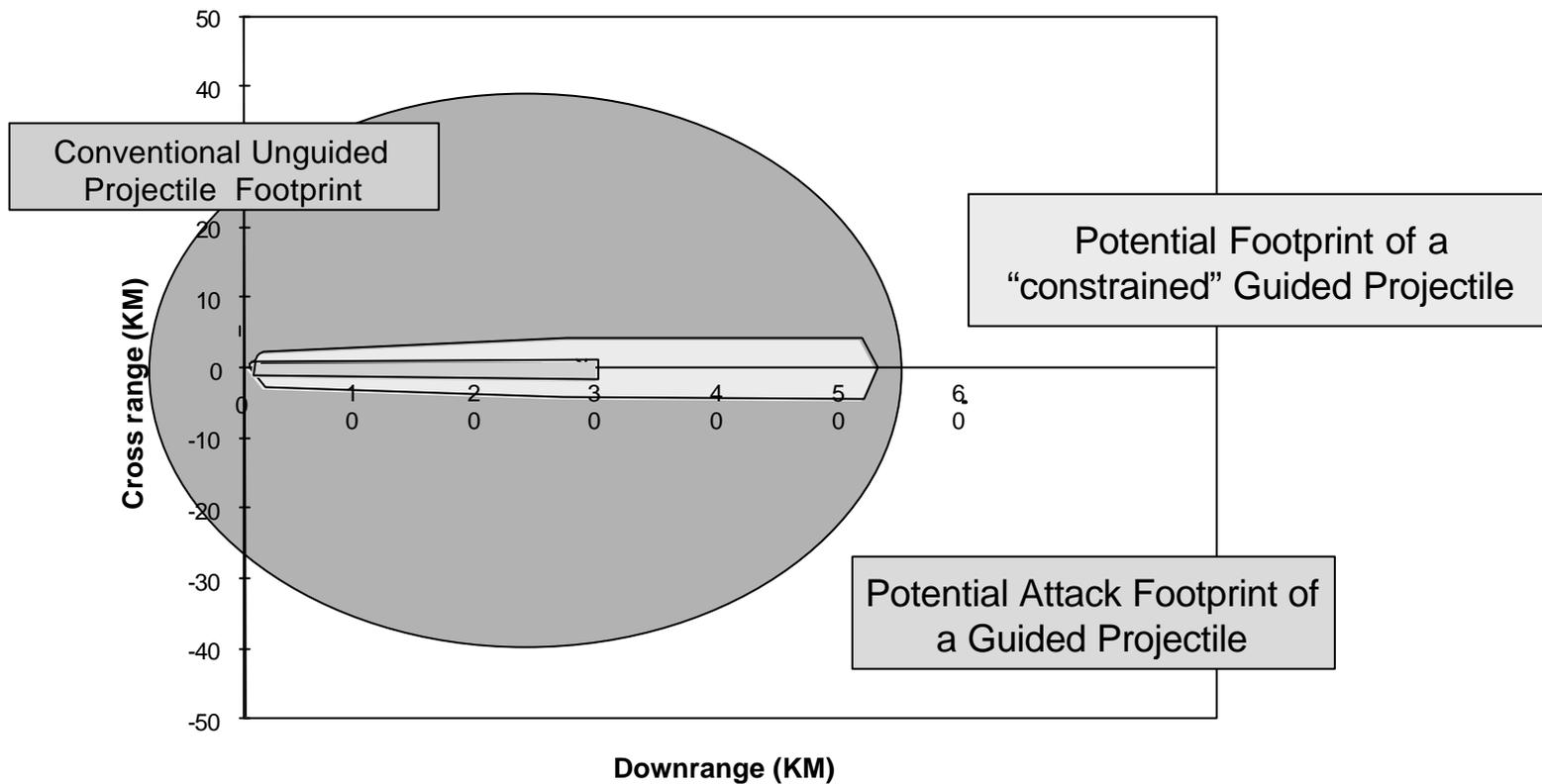
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- **Most guided weapons were not designed to be fired over friendly forces**(so provisions for operation as a failed weapons was not really considered in the design)

- **BLUE trajectories** represents the fact most guided weapons have been designed to be employed at or in advance of the battle front (called Forward Line Of Engagement or FLOE).

- **Red trajectory** represents the fact guided projectiles will operationally be employed such that they will be behind FLOE and will overfly all forces up to FLOE.

AAMs

AGMs

Guided Projectiles

ATMs
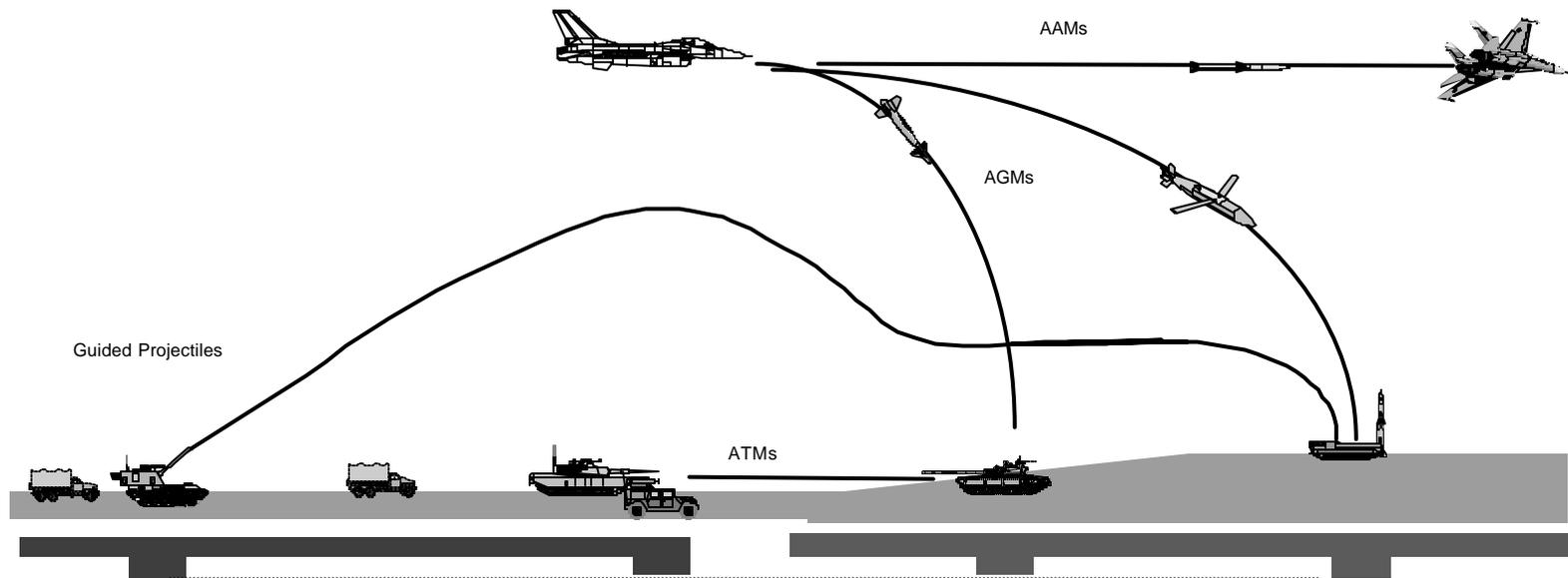
For the first time, overhead safety for EXTENDED ranges must be considered

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Example - Safety Features Over a Mission

Push-over (apogee) must be achieved to enable second arming environment

S&A is not fully armed until projectile enters "terminal" phase of guidance

Integrity checks confirm good guidance and Mission Computer operability

Guided trajectory thwarts counter-battery fire

Reverse Slope

S&A Provides Safe Separation Distance

No Rocket Motor Noise or Plume

Extended Range

Firing initiates battery and represents first arming environment

Off Boresight

Shoot & Scoot!

◆ Dispense based upon GPS/INS solution
◆ Submunitions equipped with Self-Destruct Feature
◆ Reduced Hazardous Dud Rate

Data from Public Released Presentation

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Improved Terminal Effects

Crusader

Paladin

Altitude (k ft)

40
30
20
10
0

0   8.5   Kilometers   37   50

Wide Attack Footprint

X

Maximum Target

Baseline XM982 can hit any target in this area from one tube position!

Crusader Location

Kilometers

50
40
30
20
10
0

-40 -30 -20 -10 0 10 20 30 40
Kilometers

Enhanced Range - Artillery Range Overmatch

XM982 Crusader

XM982 Paladin & LWH

Current US Capability

International Capability

Kilometers: 0   10   20   30   40   50

Improved Effectiveness / Lethality

Rounds (Weight) Transported	No. of DPICM Rounds Required

11,340 lbs M864 FAPP

4,392 lbs XM982 U-PAC

M864

XM982

25km Range at 10% EFD   35km Range, Normalized, at 10% EFD