



System Modeling of a 40mm Automatic Grenade Launcher

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Defence Research and
Development Canada

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pour la défense Canada

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Presentation Overview

- Objectives
- Background
- Aerodynamics of a 40 mm HV grenade
- Error budget development
- Weapon system simulation results
- Conclusions



Objectives



- Develop an aerodynamics model for a generic 40 mm HV grenade
- Develop an error budget model for the MK19 AGL
 - Drag/Mass error (%)
 - Round-to-round muzzle velocity error (m/s)
 - Gun dispersion (mils)
 - Ammunition dispersion (mils)
- Establish the specification requirements for a new AGL gun system



Background

- CASW (Company Area Suppression Weapon) is a high priority procurement project for the CF
- 40 mm grenade launcher for various rounds:
 - HEDP
 - Airbursting
- DRDC tasked to compare the various contenders:
 - FCS
 - Aero and flight dynamics of rounds
 - P_{hit} and lethality
 - Direct and indirect fire capability



GDATP Mk47 *Striker*40 AGL



Santa Barbara
LAG-40
SB-M1
40mm
AGL



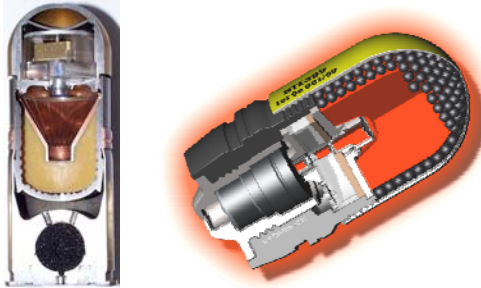
Denel (Vektor) Y3 40mm AGL



Background

Weapon system modeling

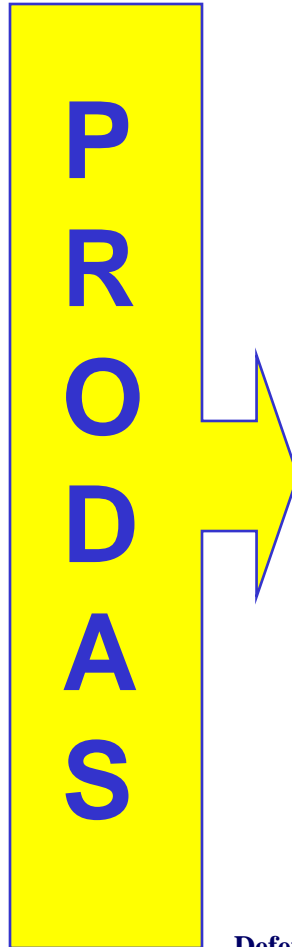
Ammo: mass, CP, CG, shape, aero



Weapon System representation

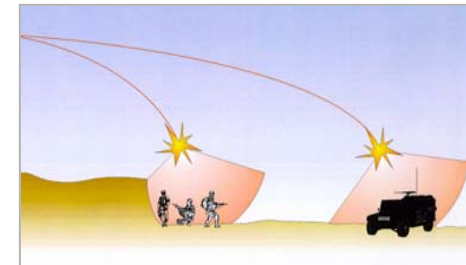
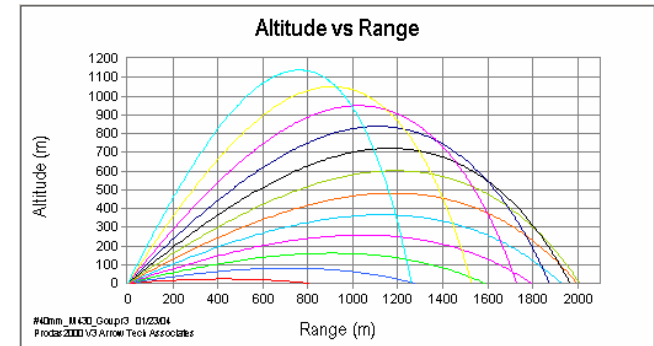


MET data



Round Characteristics at time of burst or detonation:

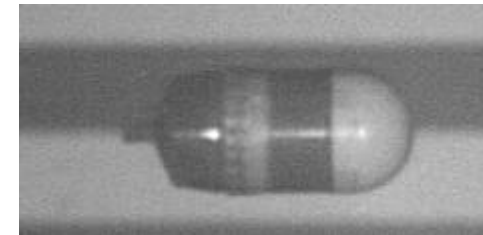
- Dispersion
- Probability of hit
- Remaining Speed
- Remaining Spin
- Angle of descent (AOD)
- Time of Flight



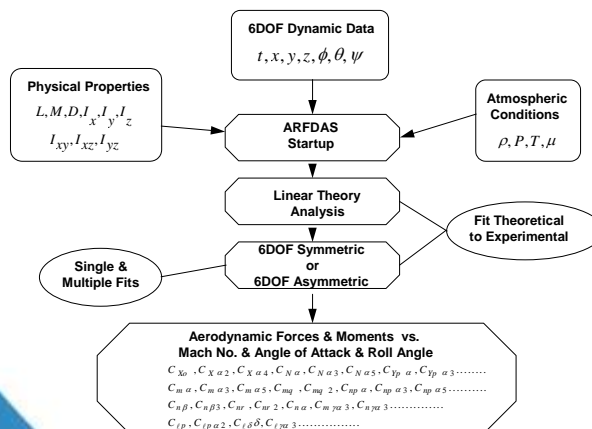


Ammo model development

A/B range trial



ARFDAS - Aeroballistic Range Facility
Data Analysis



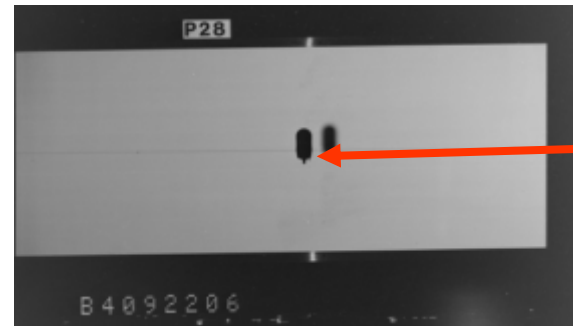
• Complete ammo aero model



Ammo model development

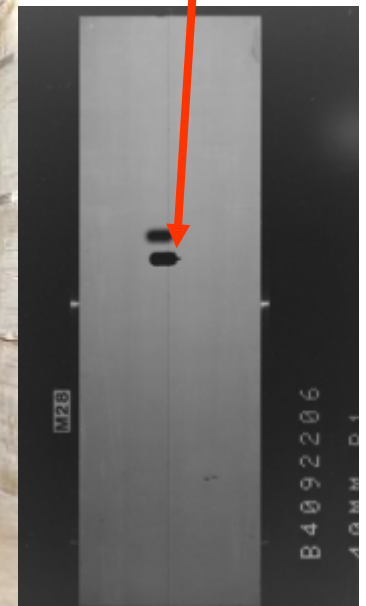
Shadowgraphs

Pit View



Shadow

- Instrumented length: 220 m
- Section: 6 m x 6 m
- 54 Stations:
Indirect orthogonal
shadowgraphs
- 4 Schlieren stations

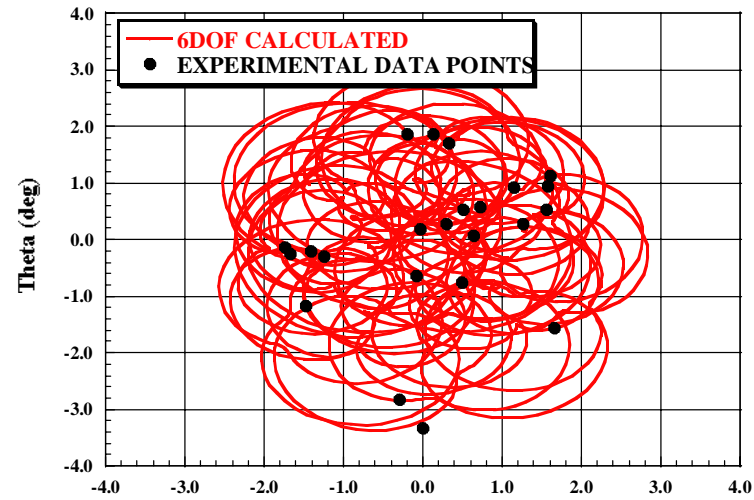
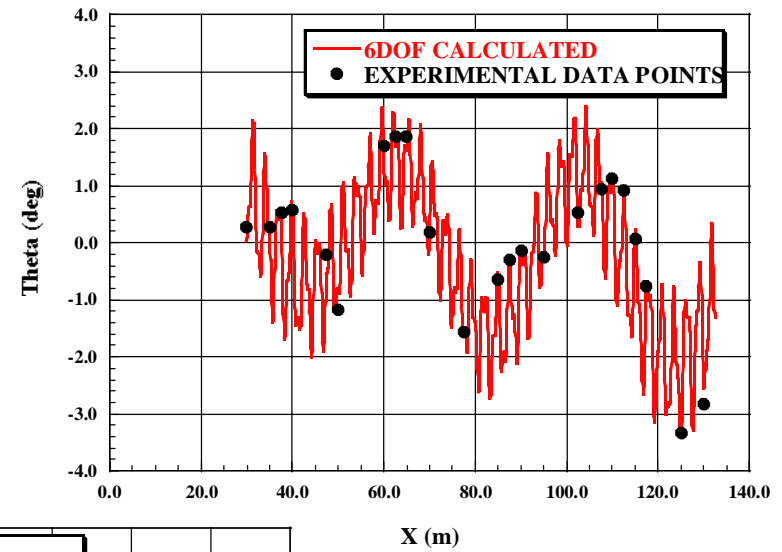
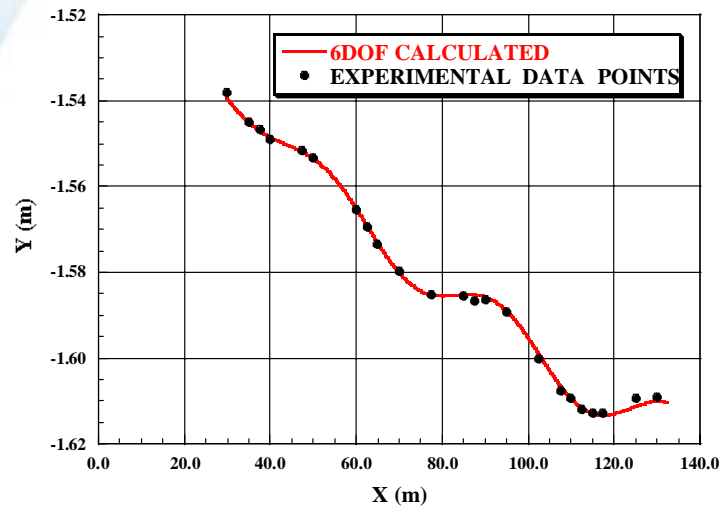


Wall View



Ammo model development

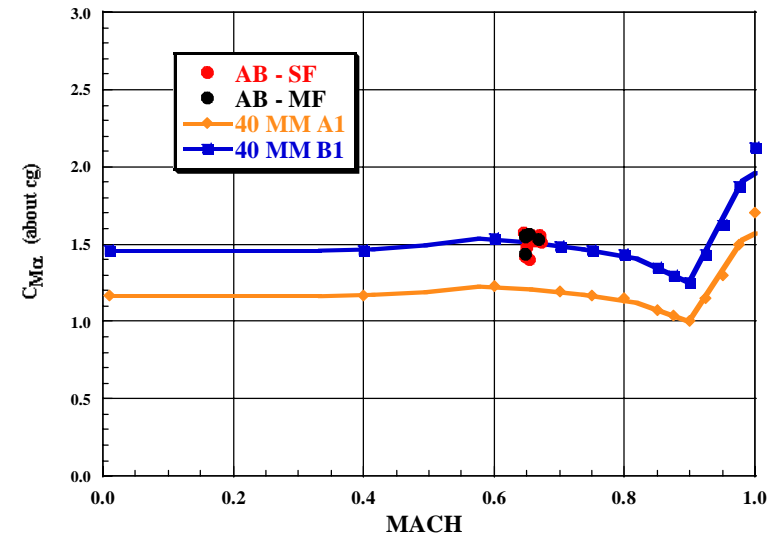
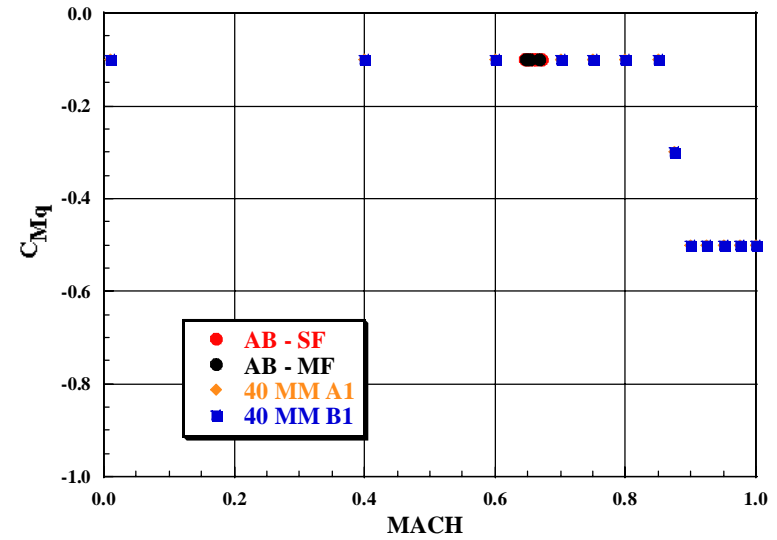
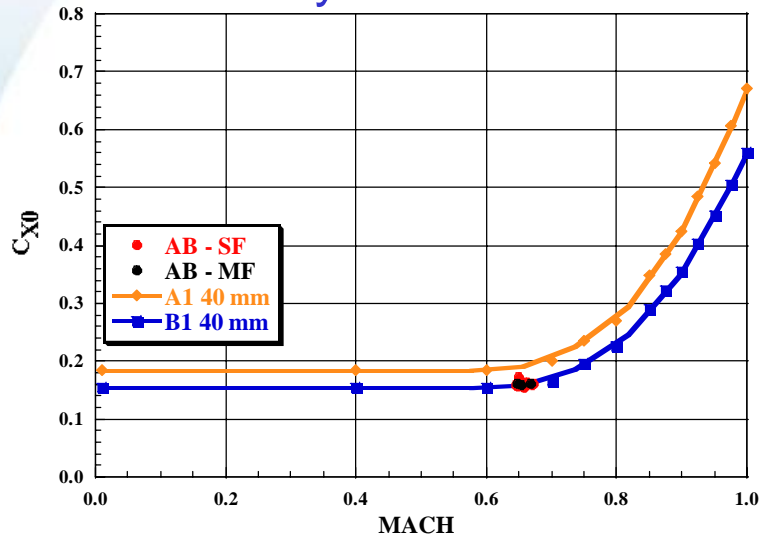
Projectile motion





Ammo model development

Aerodynamic model

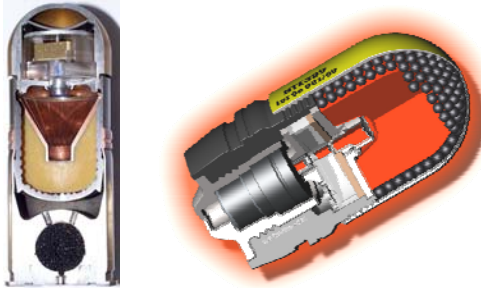




Background

Weapon system modeling

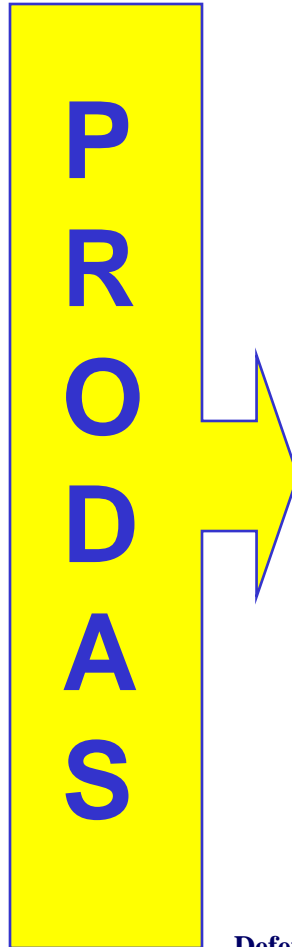
Ammo: mass, CP, CG, shape, aero



Weapon System representation

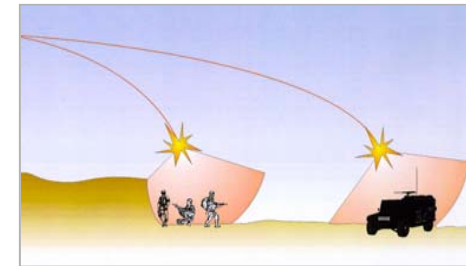
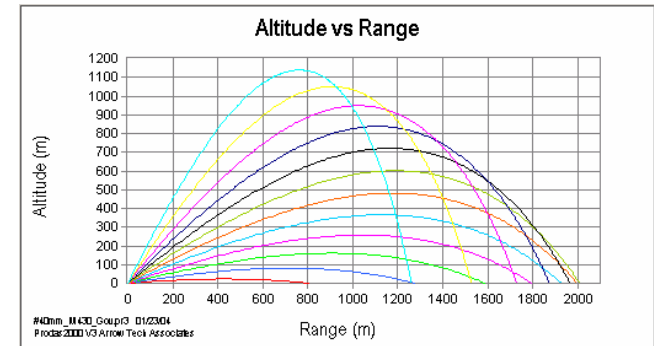


MET data



Round Characteristics at time of burst or detonation:

- Dispersion
- Probability of hit
- Remaining Speed
- Remaining Spin
- Angle of descent (AOD)
- Time of Flight





Weapon system model development

- Weapon system representation:
 - Error budget model
 - Dispersion analysis

$$S_{DX_{TOTAL}}^2 = S_{DV_x}^2 + S_{GD_x}^2 + S_{AD_x}^2$$

$$S_{DY_{TOTAL}}^2 = S_{DV_y}^2 + S_{GD_y}^2 + S_{AD_y}^2$$





Error budget development

| MODEL | B1 | A1 | | |
|---------------------------------------|----------|-----------|--------------|------------|
| Errors | Measured | LOW LEVEL | MEDIUM LEVEL | HIGH LEVEL |
| Drag/Mass (%) | | 1.0 | 3.0 | 5.0 |
| V _M – round to round (m/s) | | 0.5 | 1.5 | 4.0 |
| V _M – lot to lot (m/s) | | 0.5 | 1.5 | 4.0 |
| Wind Std(m/s) | | 1.0 | 3.0 | 5.0 |
| Pressure Std (mbars) | | 1.0 | 2.0 | 4.0 |
| Air Temp (C) Std Dev | | 1.0 | 3.0 | 5.0 |
| Vert. Bore sight alignment (mils) | | 1.0 | 2.0 | 3.0 |
| Horz. Bore sight alignment (mils) | | 1.0 | 2.0 | 3.0 |
| Target range Error (m) | | 1.0 | 2.0 | 4.0 |
| Gun dispersion (mils) | | 0.6 | 1.2 | 4.0 |
| Ammunition Dispersion (mils) | | 0.5 | 1.5 | 3.0 |
| Fuze Error (% of time) | | 1.0 | 3.0 | 4.0 |

- Required as input to Prodas:
 - Estimated based on literature and user experience
 - Determined accurately through an accuracy trial



Error budget development

Muzzle velocity error

- Determined using Radar measurements
- Data processed using Radar2000



| SHOT NUMBER | V_{MUZ} (m/s) |
|-------------------|--------------------|
| B01 | 240.91 |
| B02 | 242.73 |
| B03 | 238.67 |
| B04 | 242.81 |
| B05 | 243.31 |
| B06 | 242.33 |
| B07 | 243.63 |
| B08 | 243.66 |
| B09 | 240.14 |
| B10 | 242.12 |
| Mean | 242.03 |
| Std Deviation | 1.55 |
| Std Deviation (%) | 0.64 |



Error budget development

Drag/Mass error

| SHOT NUMBER | Mass (gm) | C _{x0} |
|-------------------|-----------|-----------------|
| B01 | 239.64 | 0.16120 |
| B02 | 240.56 | 0.16028 |
| B03 | 240.03 | 0.16167 |
| B04 | 242.10 | 0.17356 |
| B05 | 240.75 | 0.16238 |
| B06 | 241.54 | 0.16434 |
| B07 | 240.36 | 0.15635 |
| B08 | 242.16 | 0.15558 |
| B09 | 241.11 | 0.15850 |
| B10 | 240.82 | 0.15936 |
| Mean | 241.26 | 0.154 |
| Std Deviation | 0.7336 | 0.002 |
| Std Deviation (%) | 0.30 | 1.30 |

- Variation in C_{x0} due to non-uniform band engraving
- Variation in mass due to quality control

$$\sigma\left(\frac{\overline{C_{X0}}}{\overline{M}}\right) = \frac{\sigma_{\overline{C_{X0}}}}{\overline{M}} - \frac{\overline{C_{X0}}}{\overline{M}^2} \sigma_{\overline{M}} = 1.0$$



Error budget development

Ammunition dispersion (aerodynamic jump)

- **Due Mainly to Initial Yaw Rate**

- In bore Balloting
- CG Offset

- **Theory States**



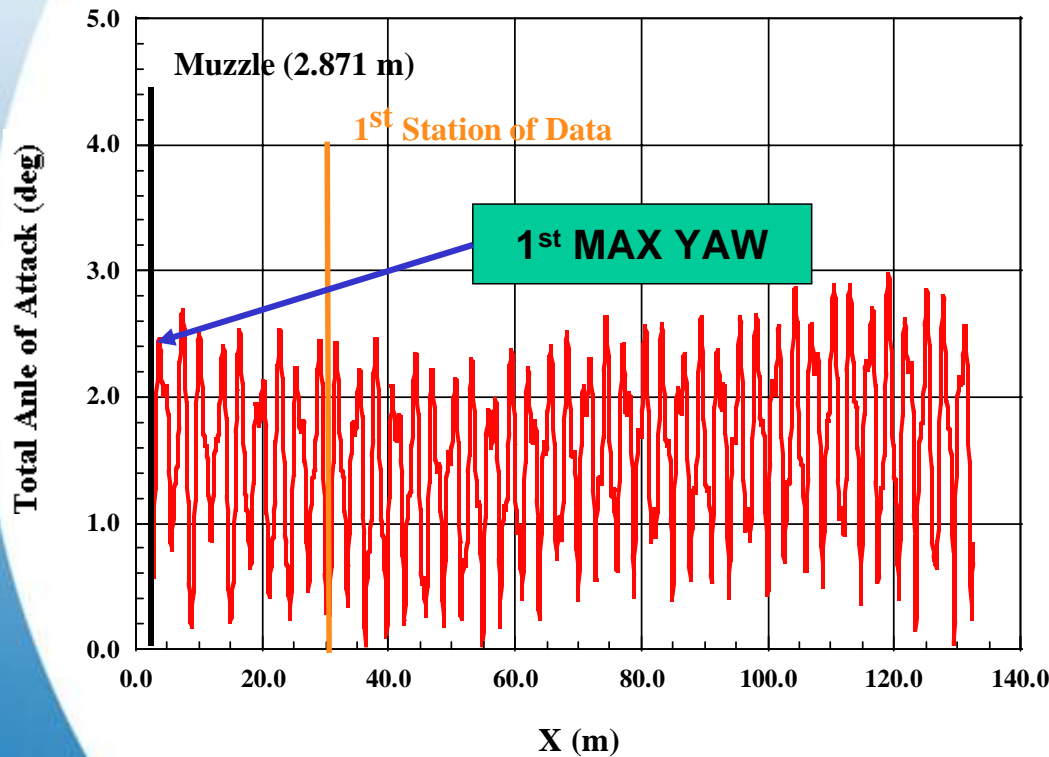
- If initial yaw rate, q_0 , is known
- with aerodynamic package and physical properties
- can calculate ammunition disp.



Error budget development

Ammunition dispersion (aerodynamic jump)

Angle of Attack – Extrapolated to Muzzle with A/B Range Data

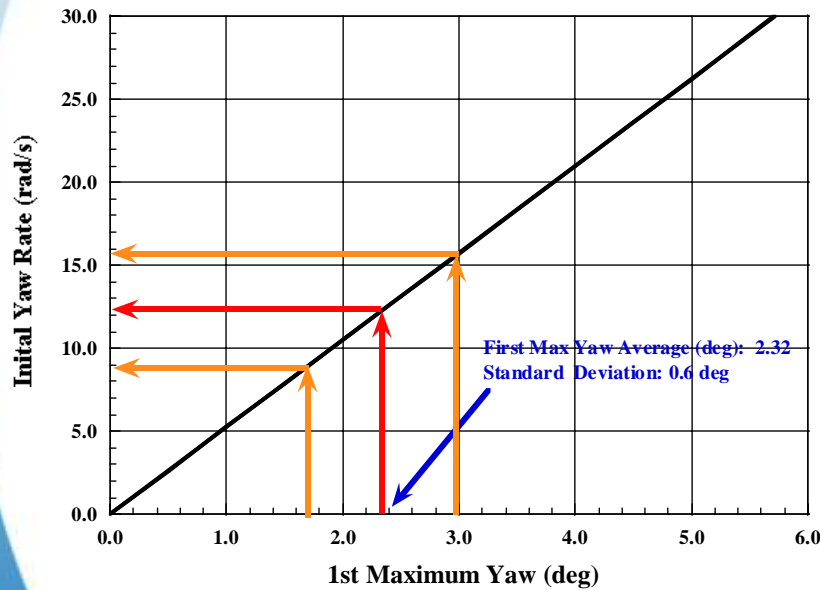


| SHOT NUMBER | 1 st Max Yaw (deg) |
|-------------|-------------------------------|
| B01 | 2.87 |
| B02 | 1.55 |
| B03 | 2.85 |
| B04 | 2.90 |
| B05 | 1.74 |
| B06 | 2.71 |
| B07 | 2.46 |
| B08 | 2.10 |
| B09 | 2.73 |
| B10 | 1.31 |
| Mean | 2.323 |
| STD. DEV. | 0.601 |

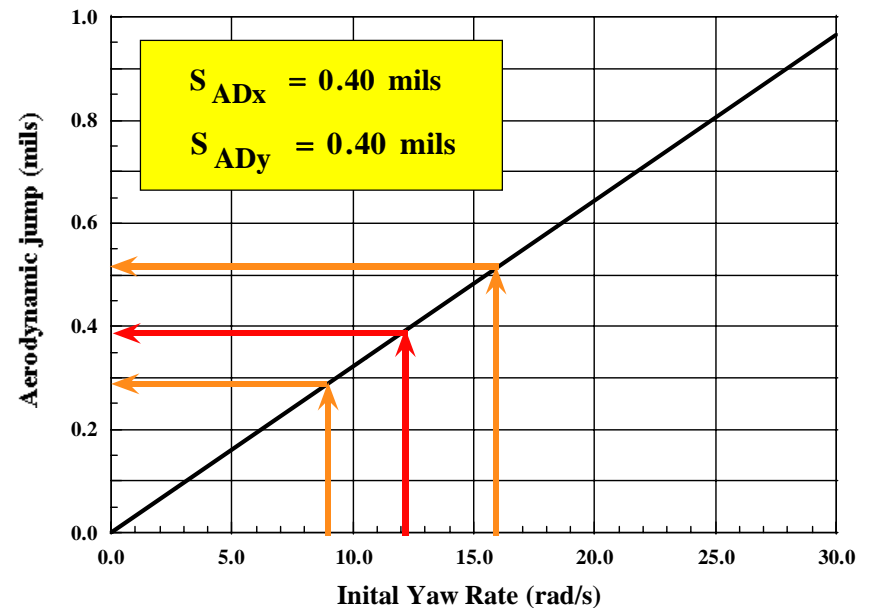


Error budget development

Ammunition dispersion (aerodynamic jump)



$$q_0 = \frac{(\dot{\phi}_F - \dot{\phi}_S)}{2} \bar{\alpha}_{\max}$$



$$\theta_{aero} = \frac{(C_{N\alpha} - C_X)d}{C_{m\alpha} V_0} \left(\frac{I_y q_0}{md^2} \right)$$



Error budget development

Gun dispersion: drop and lateral analyses

$$S_{DY\text{ TOTAL}}^2 = S_{D V_y}^2 + S_{GD_y}^2 + S_{AD_y}^2$$

$$S_{DX\text{ TOTAL}}^2 = S_{D V_x}^2 + S_{GD_x}^2 + S_{AD_x}^2$$

↑
Total
Observed

↑
Due to
Gravity drop
(V_{MUZ} , mass, C_{x0})

↑
Gun
Dispersion

↑
Ammunition
Dispersion



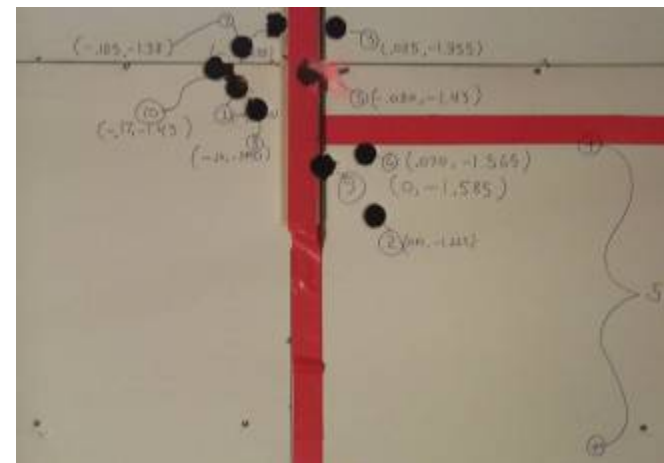
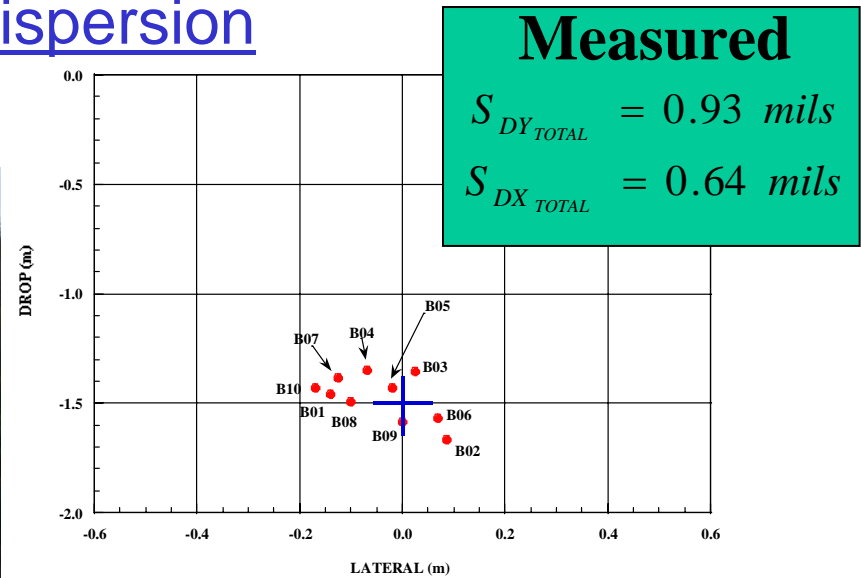
Error budget development

Gun dispersion: total dispersion



Accuracy trial:

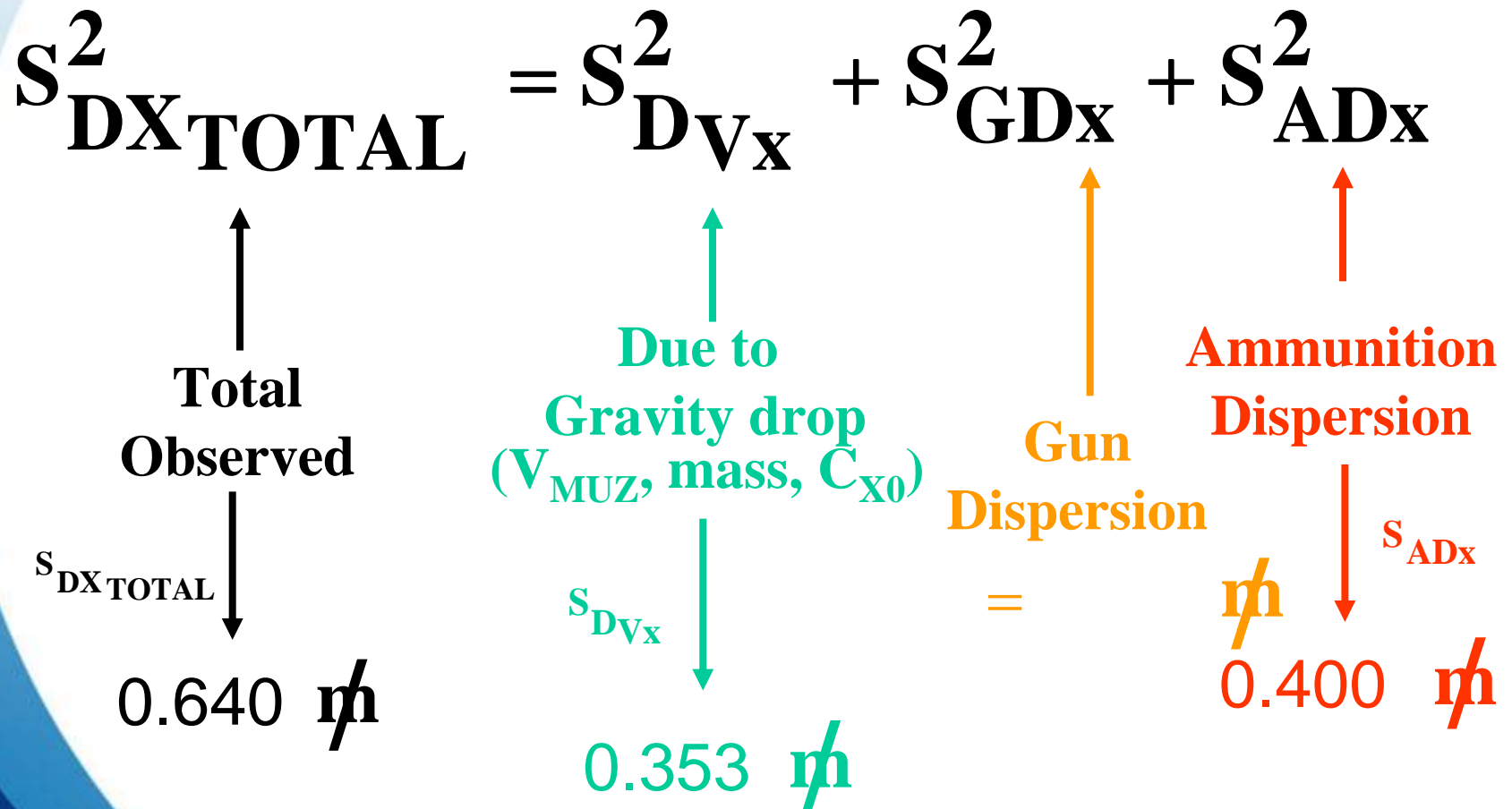
- NATO StanAg procedure





Error budget development

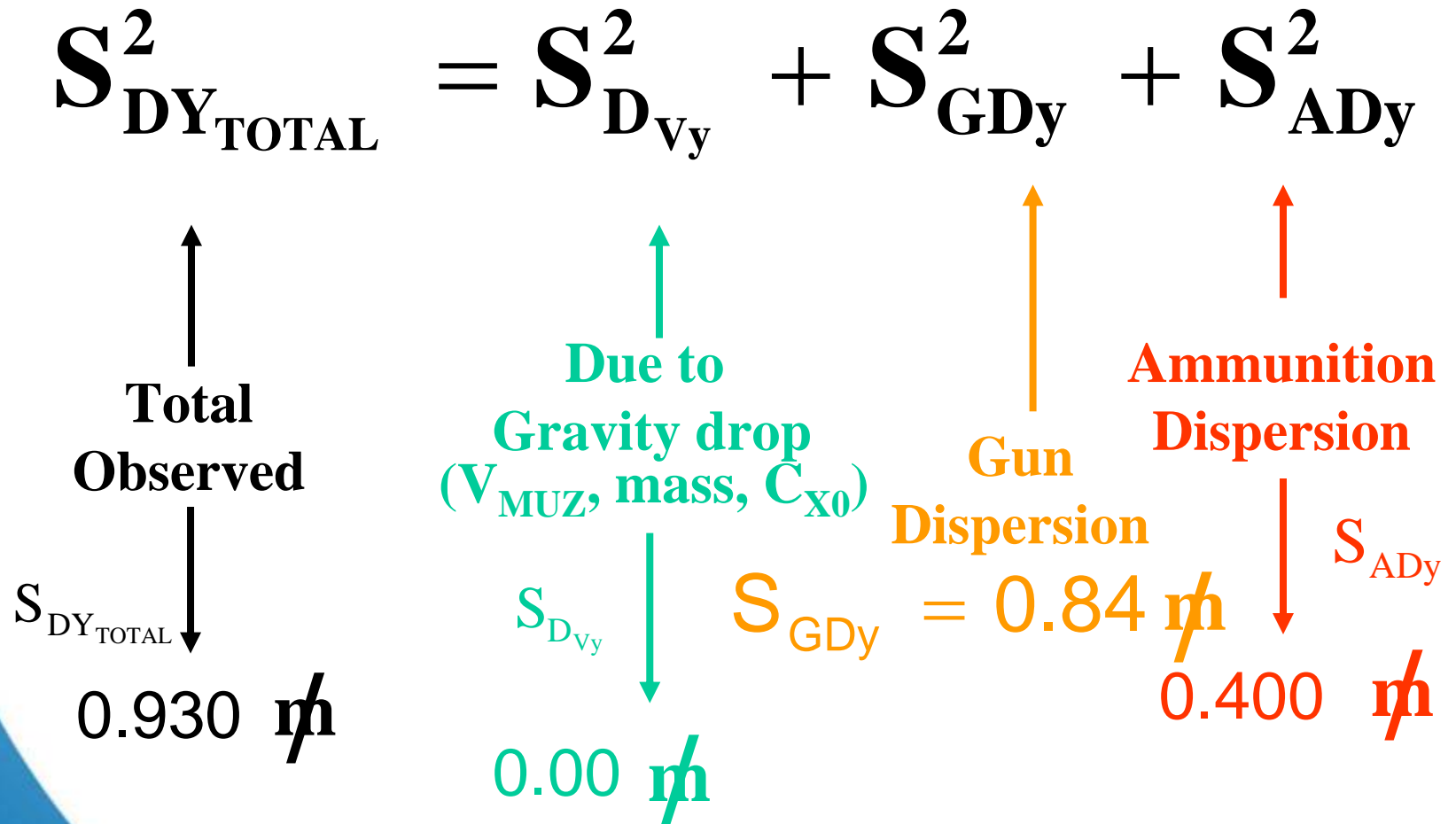
Gun dispersion: drop analysis





Error budget development

Gun dispersion: lateral analysis





Error budget development

Error budget model

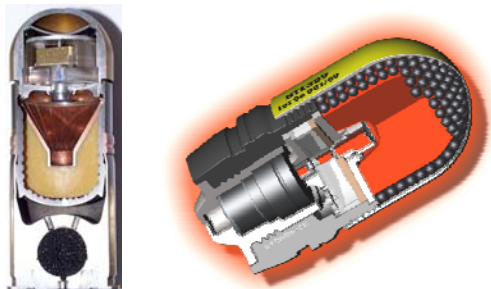
| Errors | SERIES D | PROPOSED ERROR BUDGET For LETHALITY Study | | |
|---------------------------------------|-------------------------------------|---|-----------|---------|
| | Tripod w/o sand bag, natural ground | LOW | LOW IDEAL | HIGH |
| Drag/Mass (%) | 1.00 | 1.0 | 1.0 | 1.5 |
| V _M – round to round (m/s) | 1.6 | 0.8 | 0.8 | 2.0 |
| V _M – lot to lot (m/s) | | 0.8 | | 2.0 |
| Wind Std(m/s) | | 0.5 | | 1.0 |
| Pressure Std (mbars) | | 1.0 | | 2.0 |
| Air Temp (C) Std Dev | | 0.5 | | 1.5 |
| Bore sight alignment (mils) | | 0.5 | | 1.25 |
| Target range Error (m) | | 1.0 | | 2.0 |
| Gun dispersion (mils) | H: 0.84 | H: 0.42 | H: 0.42 | H: 1.05 |
| | V: 0.35 | V: 0.18 | V: 0.18 | V: 0.44 |
| | A: 0.60 | A: 0.50 | A: 0.50 | A: 1.0 |
| Ammunition Dispersion (mils) | 0.40 | 0.30 | 0.30 | 0.50 |
| Fuze Error (% of time) | | 0.5 | | 3.0 |



Background

Weapon system modeling

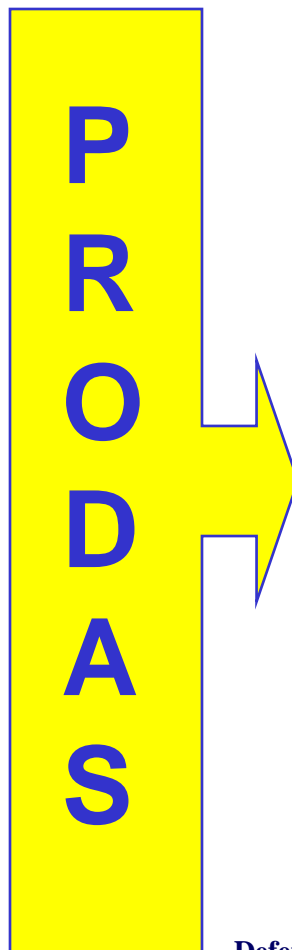
Ammo: mass, CP, CG, shape, aero



Weapon System representation

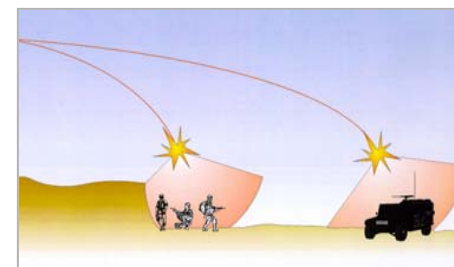
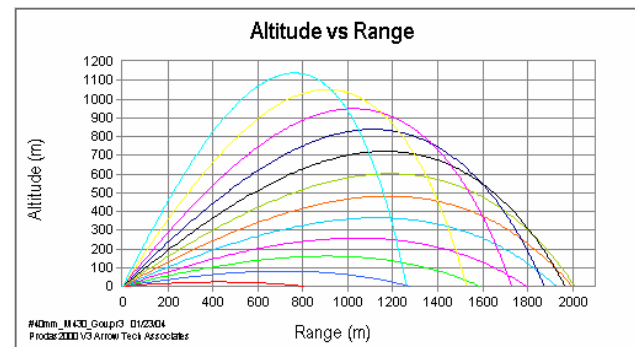


MET data



Round Characteristics at time of burst or detonation:

- Dispersion
- Probability of hit
- Remaining Speed
- Remaining Spin
- Angle of descent (AOD)
- Time of Flight



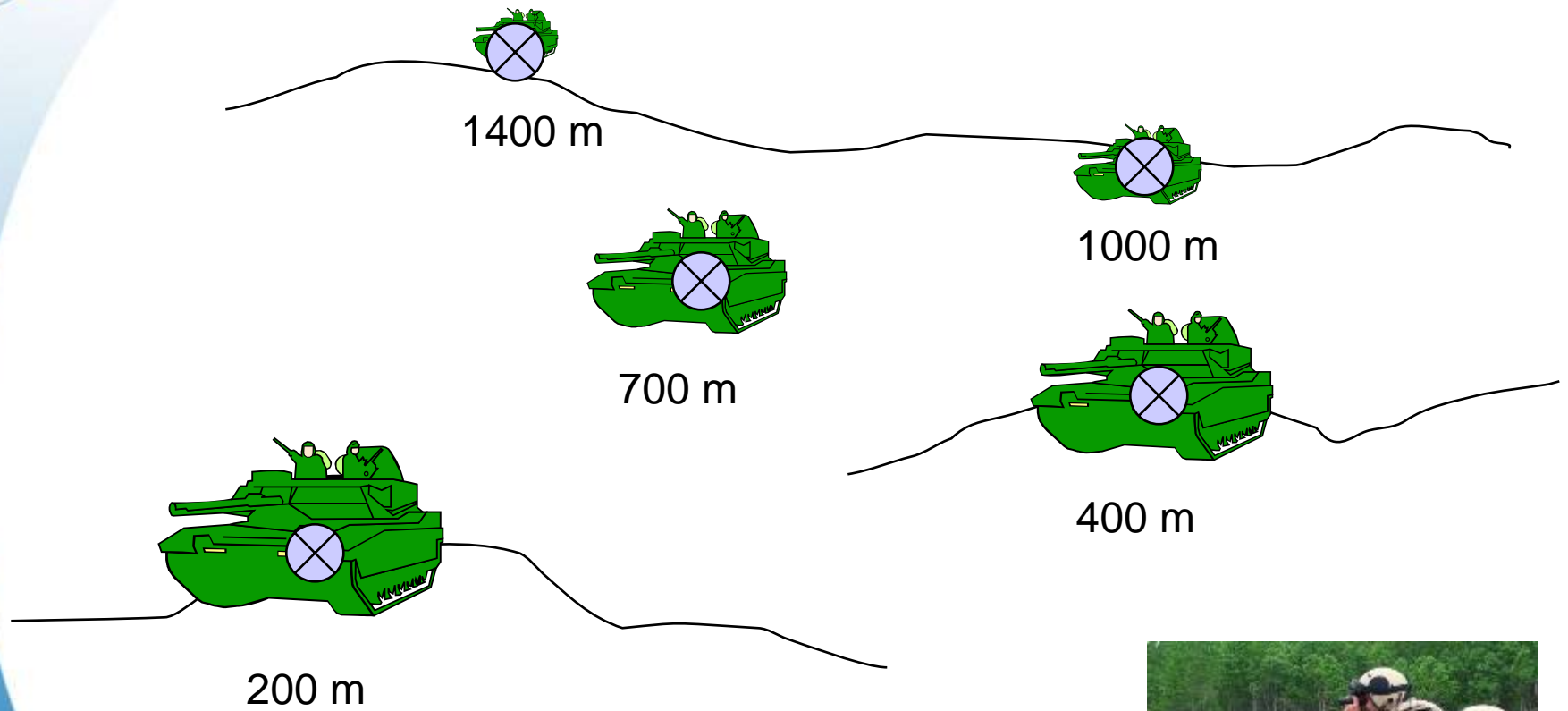


Monte-Carlo Based Weapon System Simulations

- Performed using the Ground-to-Ground module of PRODAS
- 2 DOF fly-out routine
- Hundreds of fly-out simulation with randomly varied system errors
- Yield dispersion at target and probability of hit
- Enables one to perform or determine:
 - Scenario/Mission simulations
 - Weapon system specifications
 - Weapon system weaknesses



Scenario/Mission Simulations



➔ 5 standard NATO targets: 2.3m high X 4.6m wide

1 box of ammo: 32x





Scenario/Mission Simulations

Assuming a $P_{HIT}^* = 90\%$ to be considered a good hit by the gunner then:

| RANGE | P_{HIT}^{1S} | N | Number of individual shots required obtain 90% mission success | Cummulative number of individual shots required obtain 90% mission success |
|------------------|----------------|-------|--|--|
| 200 | 1.000 | 0.00 | 1 | 1 |
| 400 | 1.000 | 0.00 | 1 | 2 |
| 700 | 0.876 | 1.10 | 2 | 4 |
| 1000 | 0.532 | 3.03 | 4 | 8 |
| 1400 | 0.142 | 15.03 | 16 | 24 |
| Mission success: | | | 100% | |

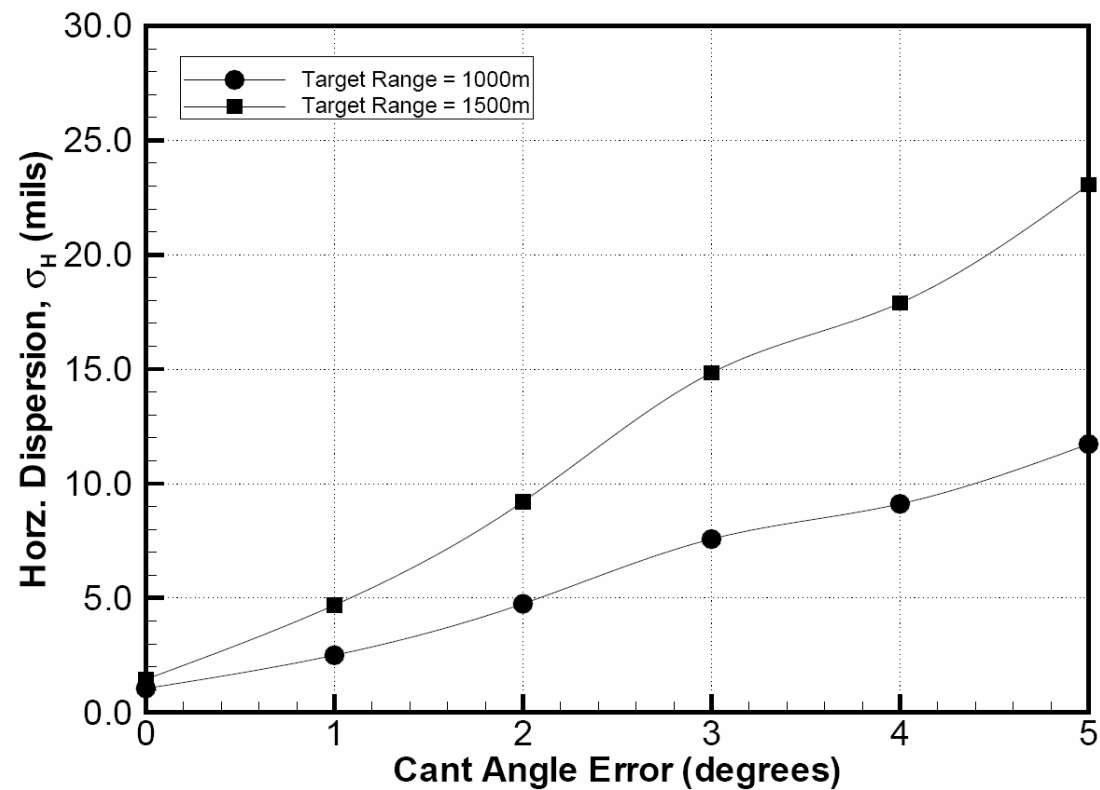
$$\text{where } N = \frac{\ln(1 - P_{HIT}^*)}{\ln(1 - P_{HIT}^{1S})}$$



Weapon System Specifications: FCS

Cant angle error

- Standard vertical NATO targets: 2.3m high X 4.6m wide

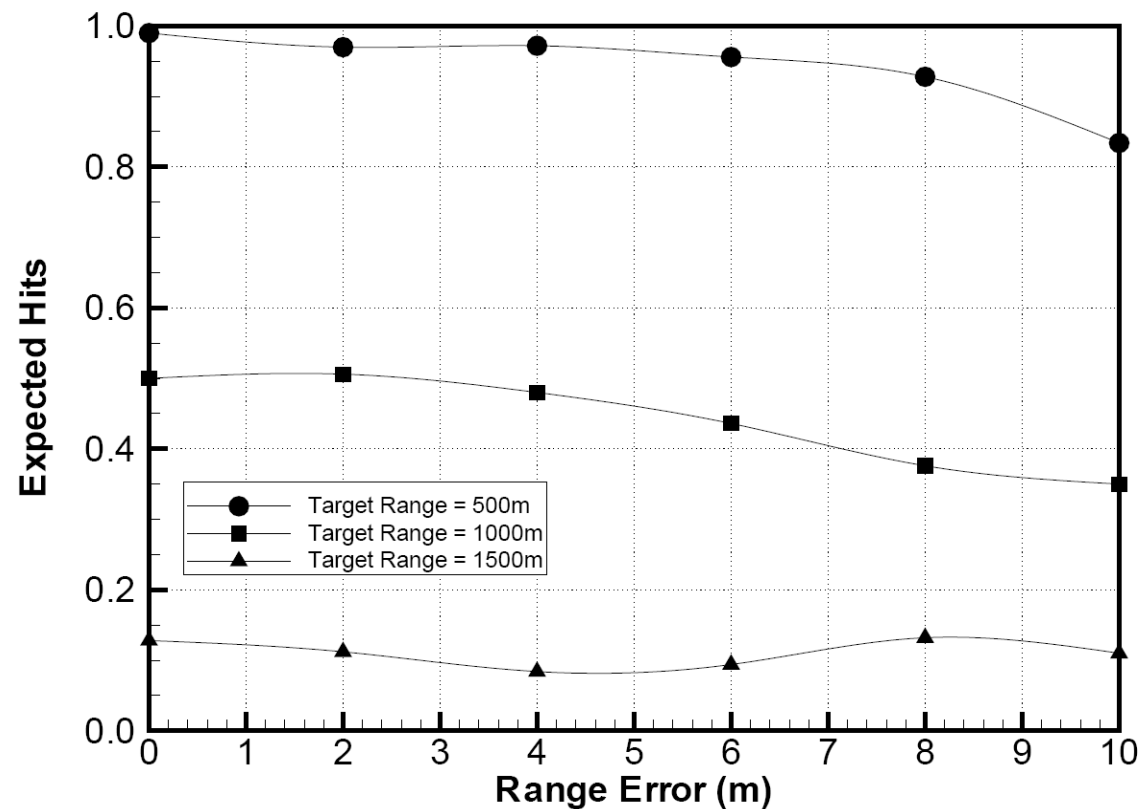




Weapon System Specifications: FCS

Range error

- Standard vertical NATO targets: 2.3m high X 4.6m wide

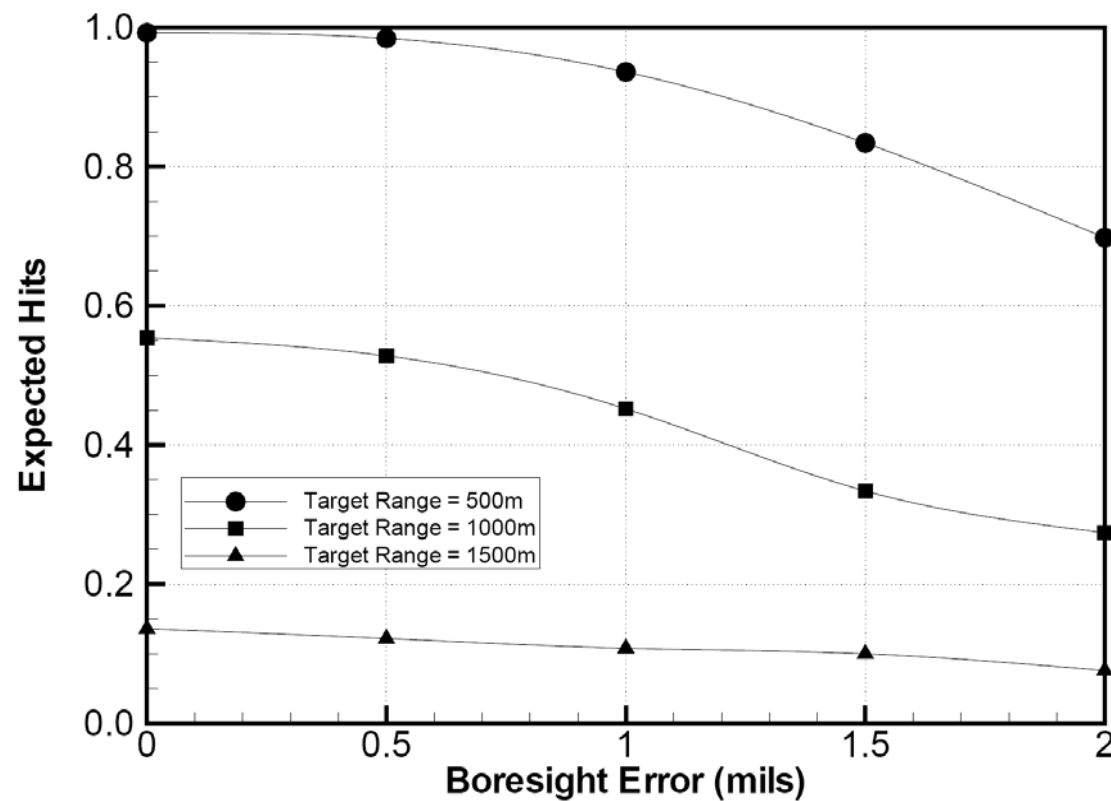




Weapon System Specifications: FCS

Boresight error

- Standard vertical NATO targets: 2.3m high X 4.6m wide

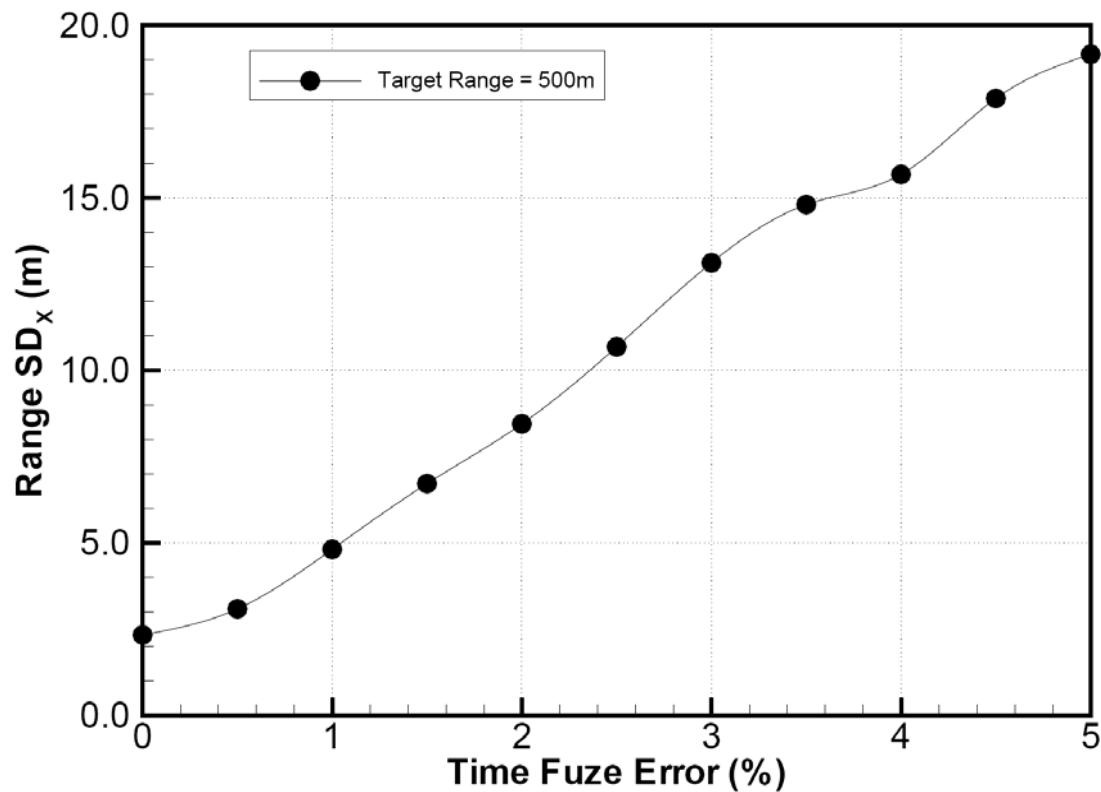




Weapon System Specifications: Ammo

Time fuze error

- Ground target

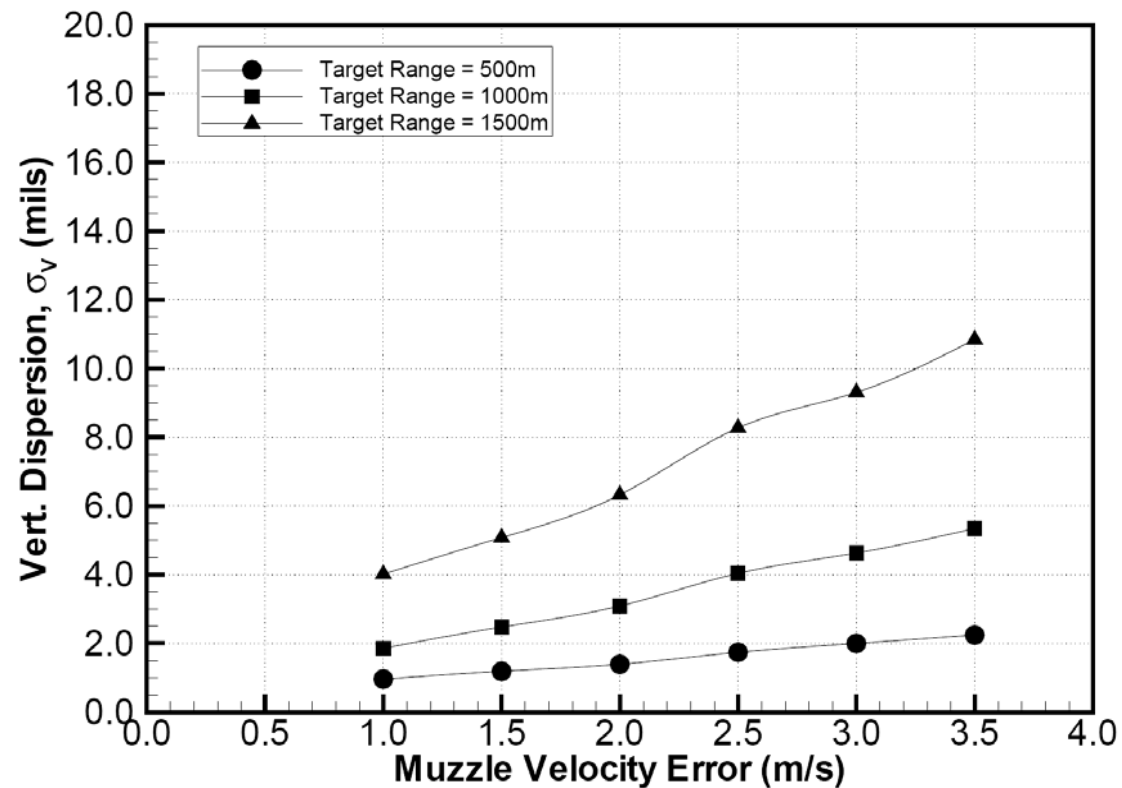




Weapon System Specifications: Ammo

Muzzle velocity error

- Standard vertical NATO targets: 2.3m high X 4.6m wide





Conclusion

- An aerodynamic model was developed for a 40 mm HV grenade
- An error budget model was developed for the MK19 AGL
- These models were used successfully to perform system simulations of 40mm AGL

DEFENCE



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