DEFENCE R&D DÉFENSE

System Modeling of a 40mm Automatic Grenade Launcher

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Canada

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


GDATP Mk47 *Striker* 40 AGL

- CASW (Company Area Suppression Weapon) is a high priority procurement project for the CF

- 40 mm grenade launcher for various rounds:
  - HEDP
  - Airbursting


Santa Barbara LAG-40 SB-M1 40mm AGL

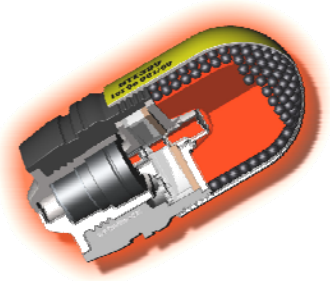
- DRDC tasked to compare the various contenders:
  - FCS
  - Aero and flight dynamics of rounds
  - P_{hit} and lethality
  - Direct and indirect fire capability


Denel (Vektor) Y3 40mm AGL

Background

Weapon system modeling

Ammo: mass, CP, CG, shape, aero



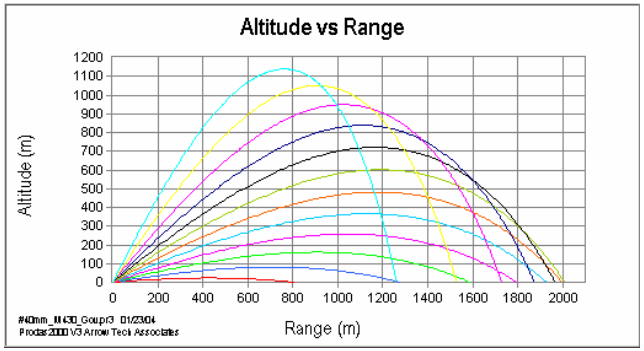
Weapon System representation

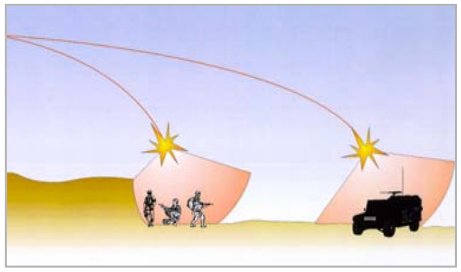
MET data

PRODAS

Round Characteristics at time of burst or detonation:

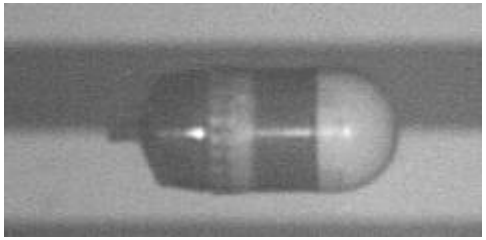
- Dispersion
- Probability of hit
- Remaining Speed
- Remaining Spin
- Angle of descent (AOD)
- Time of Flight

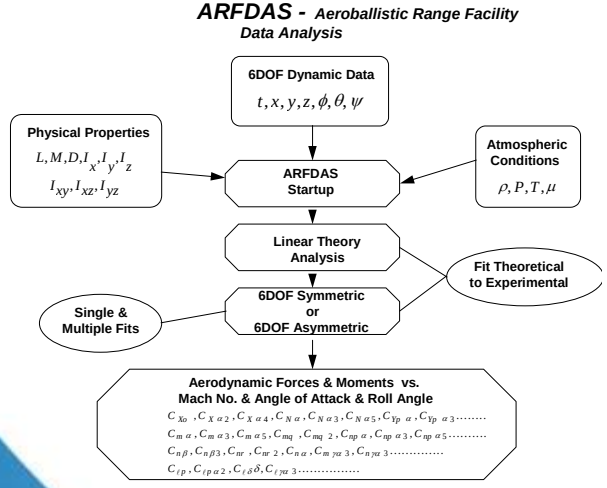




Ammo model development

A/B range trial



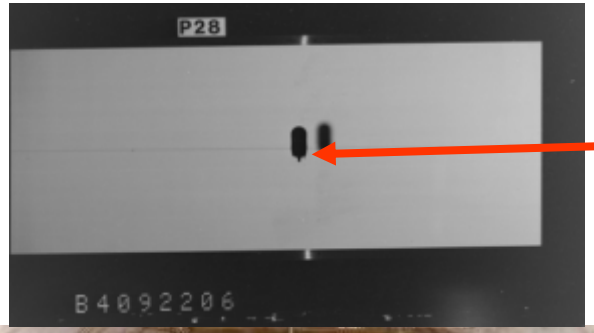


- Complete ammo aero model

Ammo model development

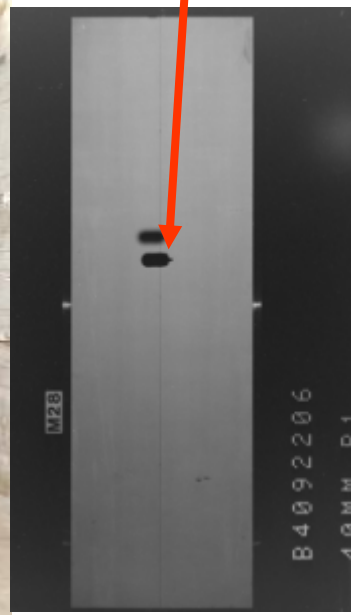
Shadowgraphs

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



Pit View

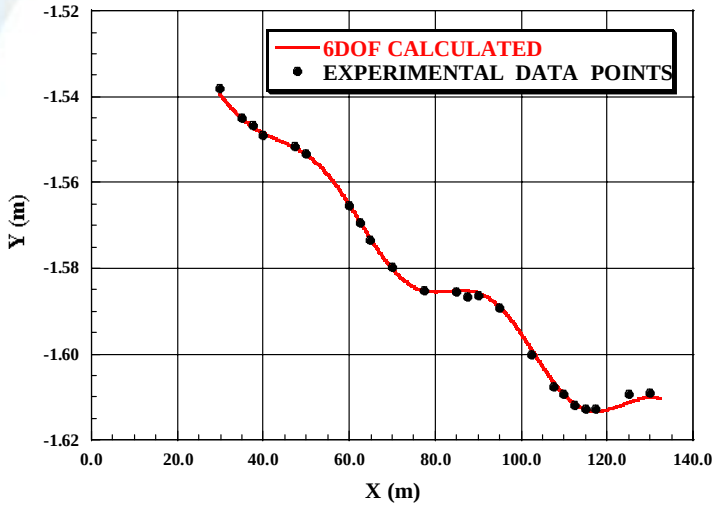
Shadow

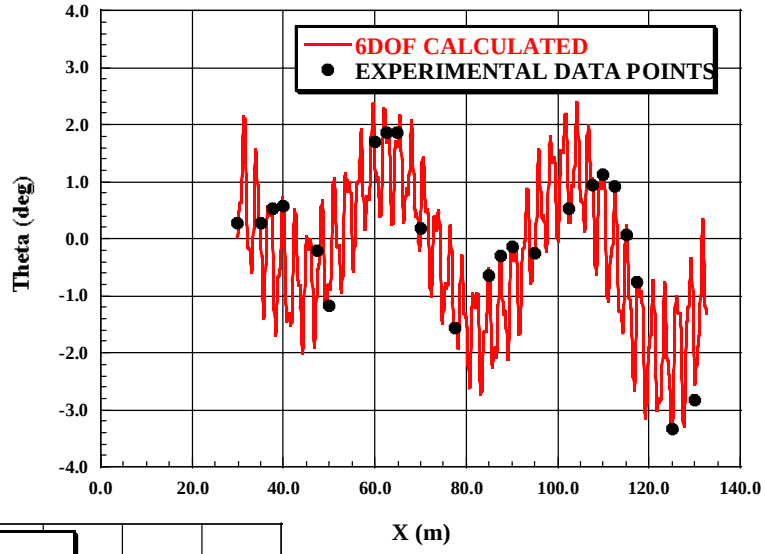


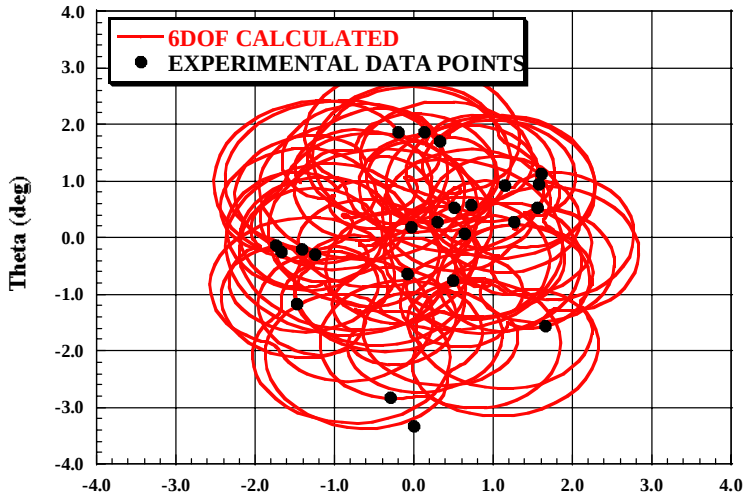
Wall View

Ammo model development

Projectile motion

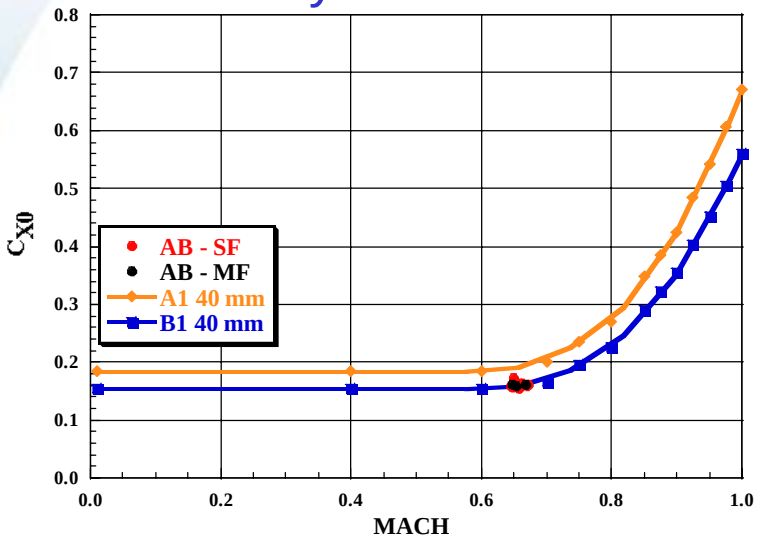


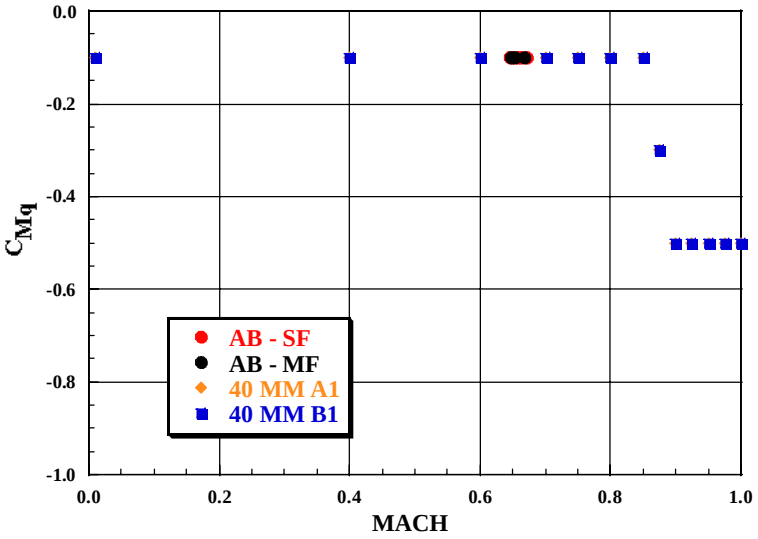


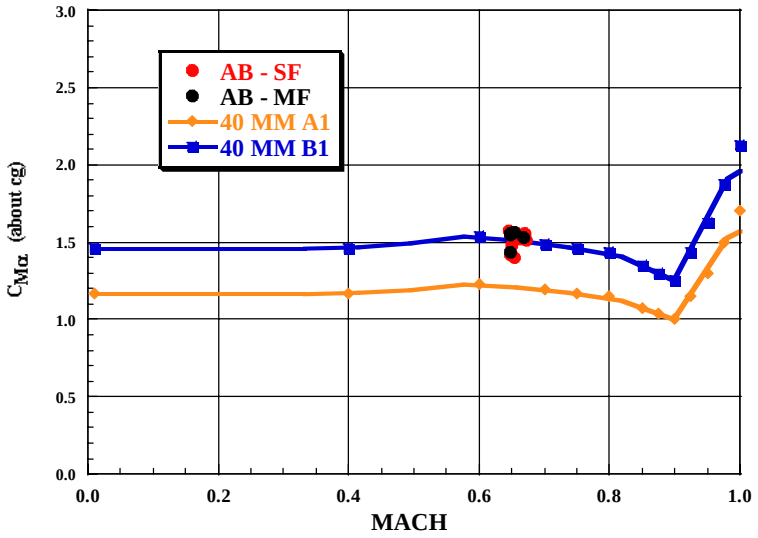


Ammo model development

Aerodynamic model



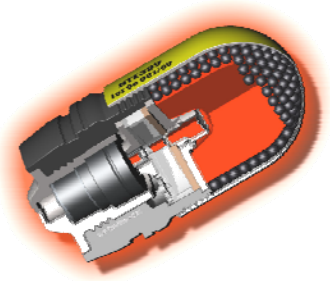




Background

Weapon system modeling

Ammo: mass, CP, CG, shape, aero



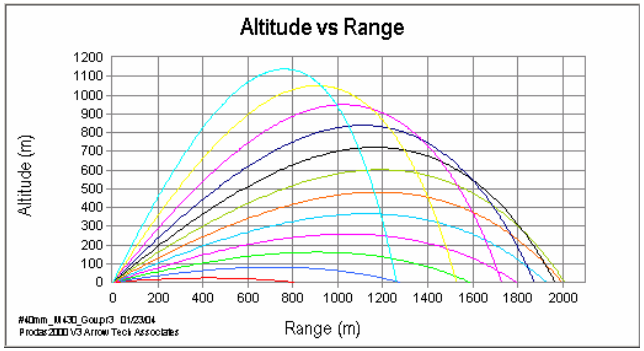
Weapon System representation

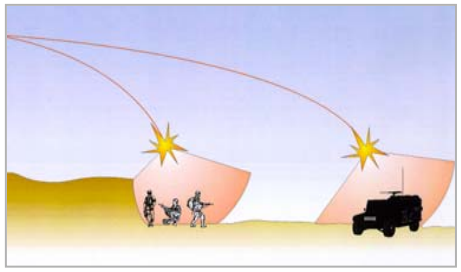
MET data

PRODAS

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

$$S^2_{DX_{TOTAL}} = S^2_{DVx} + S^2_{GDx} + S^2_{ADx}$$

$$S^2_{DY_{TOTAL}} = S^2_{DVy} + S^2_{GDy} + S^2_{ADy}$$

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)

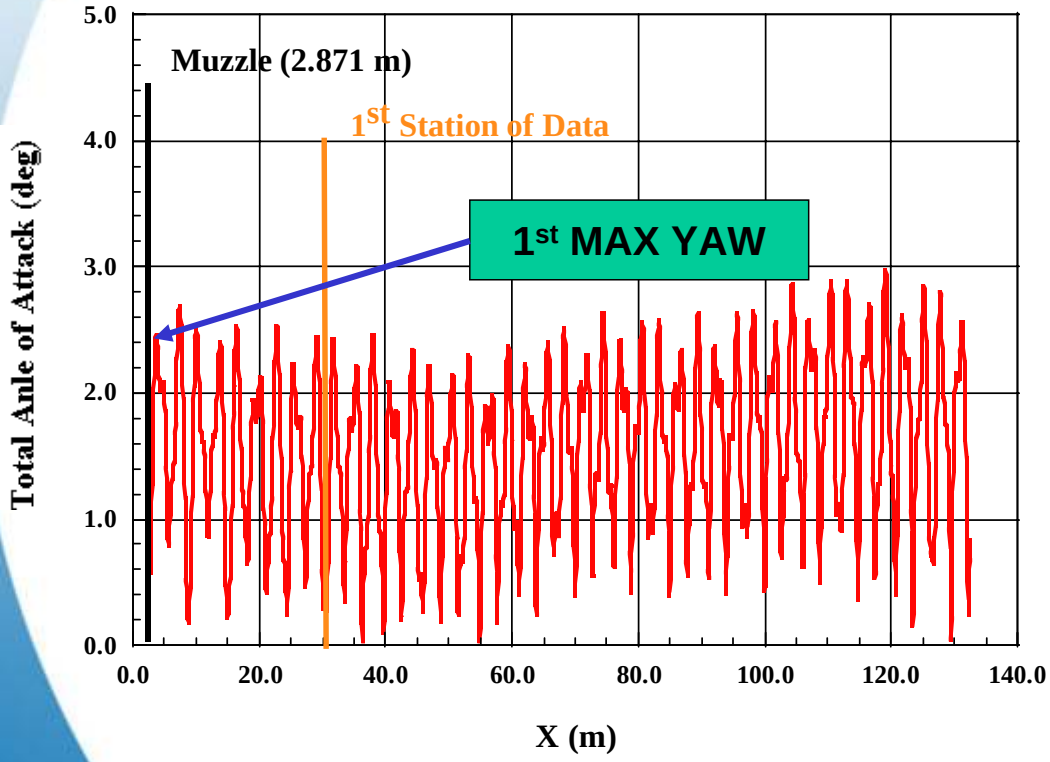
- **Due Mainly to Initial Yaw Rate**
  - **In bore Balloting**
  - **CG Offset**

- **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)

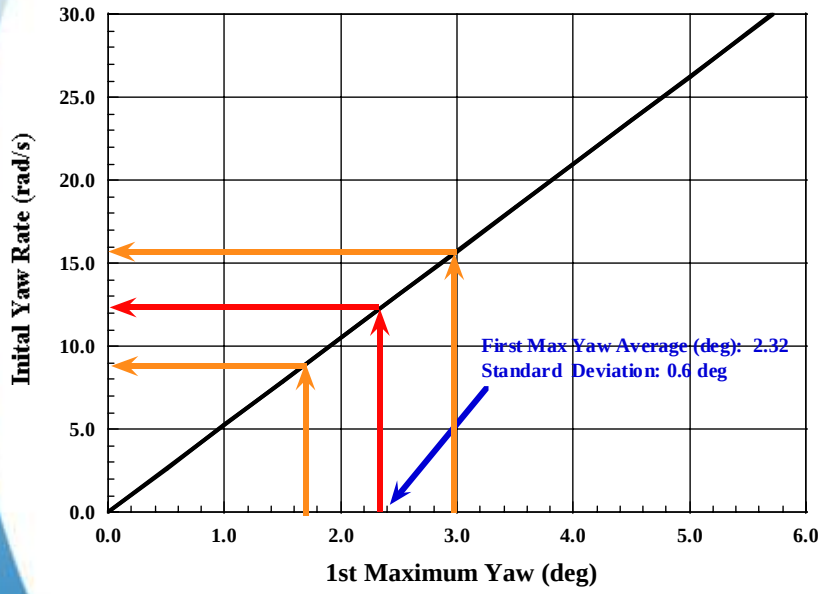
Angle of Attack – Extrapolated to Muzzle with A/B Range Data

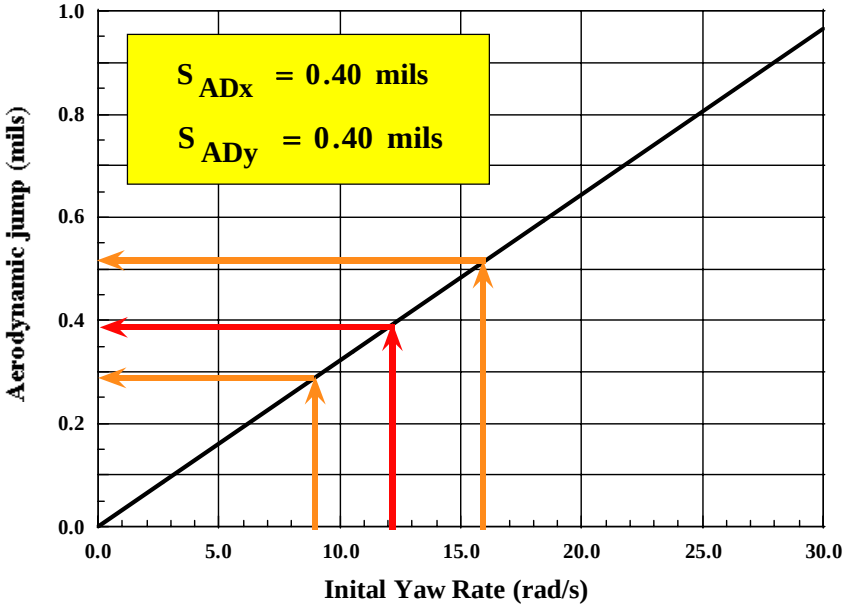


SHOT NUMBER	1st Max Yaw (deg)
B01	2.87
B02	1.55
B03	2.85
B04	2.90
B05	1.74
B06	2.71
B07	2.46
B08	2.10
B09	2.73
B10	1.31
Mean	2.323
STD. DEV.	0.601

Error budget development

Ammunition dispersion (aerodynamic jump)





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

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

Error budget development

Gun dispersion: drop and lateral analyses

$$S^2_{DY\,TOTAL} = S^2_{D\,Vy} + S^2_{GDy} + S^2_{ADy}$$

$$S^2_{DX\,TOTAL} = S^2_{D\,Vx} + S^2_{GDx} + S^2_{ADx}$$

Total Observed

Due to Gravity drop (V_{MUZ}, mass, C_{X0})

Gun Dispersion

Ammunition Dispersion

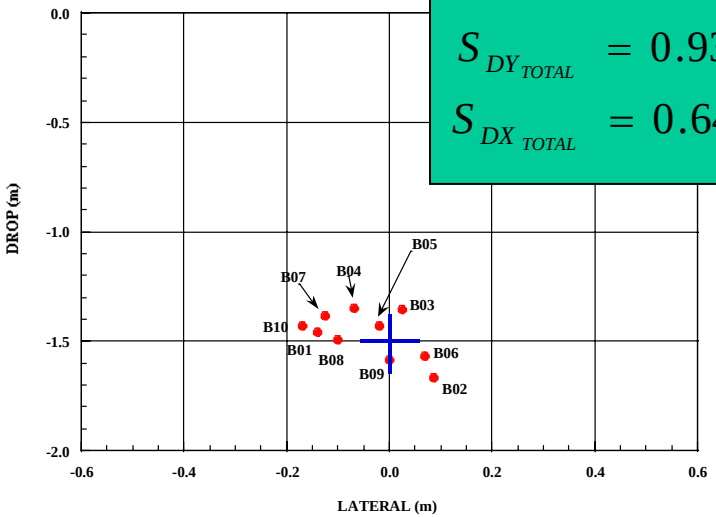
Error budget development

Gun dispersion: total dispersion

Measured

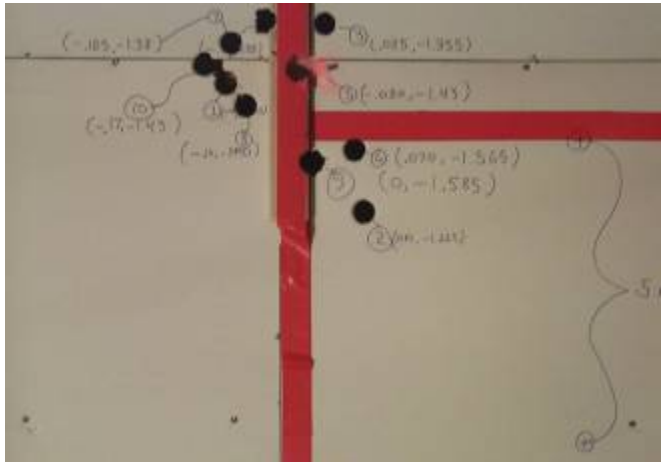
$S_{DY_{TOTAL}} = 0.93 \ mils$

$S_{DX_{TOTAL}} = 0.64 \ mils$



Accuracy trial:

- NATO StanAg procedure



Error budget development

Gun dispersion: drop analysis

$$S^2_{DX_{TOTAL}} = S^2_{D_{Vx}} + S^2_{GDx} + S^2_{ADx}$$

Total Observed

$S_{DX_{TOTAL}}$

0.640 mil

Due to Gravity drop (V_{MUZ}, mass, C_{X0})

$S_{D_{Vx}}$

0.353 mil

Gun Dispersion

=

Ammunition Dispersion

S_{ADx}

mil

0.400 mil

Error budget development

Gun dispersion: lateral analysis

$$S^2_{DY_{TOTAL}} = S^2_{D_{Vy}} + S^2_{GDy} + S^2_{ADy}$$

Total Observed

$S_{DY_{TOTAL}}$

0.930 m

Due to Gravity drop (V_{MUZ}, mass, C_{X0})

$S_{D_{Vy}}$

0.00 m

Gun Dispersion

$S_{GDy} = 0.84$ m

Ammunition Dispersion

S_{ADy}

0.400 m

Error budget development

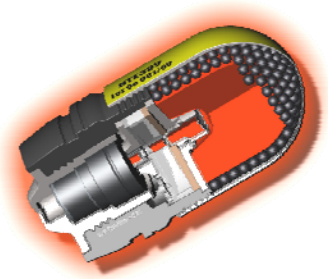
Error budget model

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 V: 0.35 A: 0.60	H: 0.42 V: 0.18 A: 0.50	H: 0.42 V: 0.18 A: 0.50	H: 1.05 V: 0.44 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



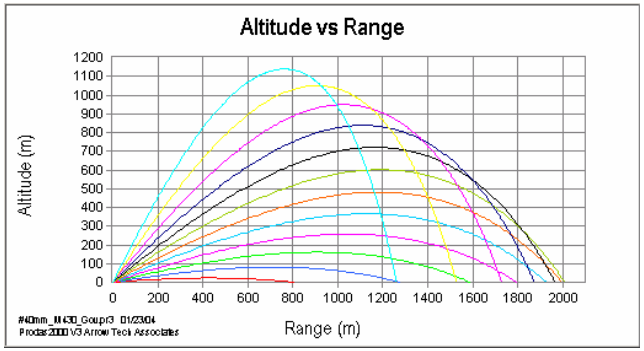
Weapon System representation

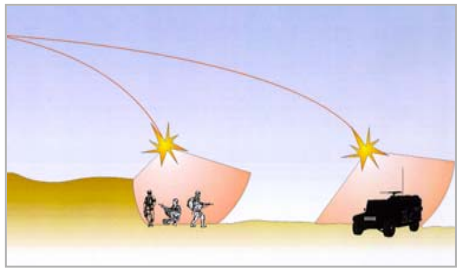
MET data

PRODAS

Round Characteristics at time of burst or detonation:

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

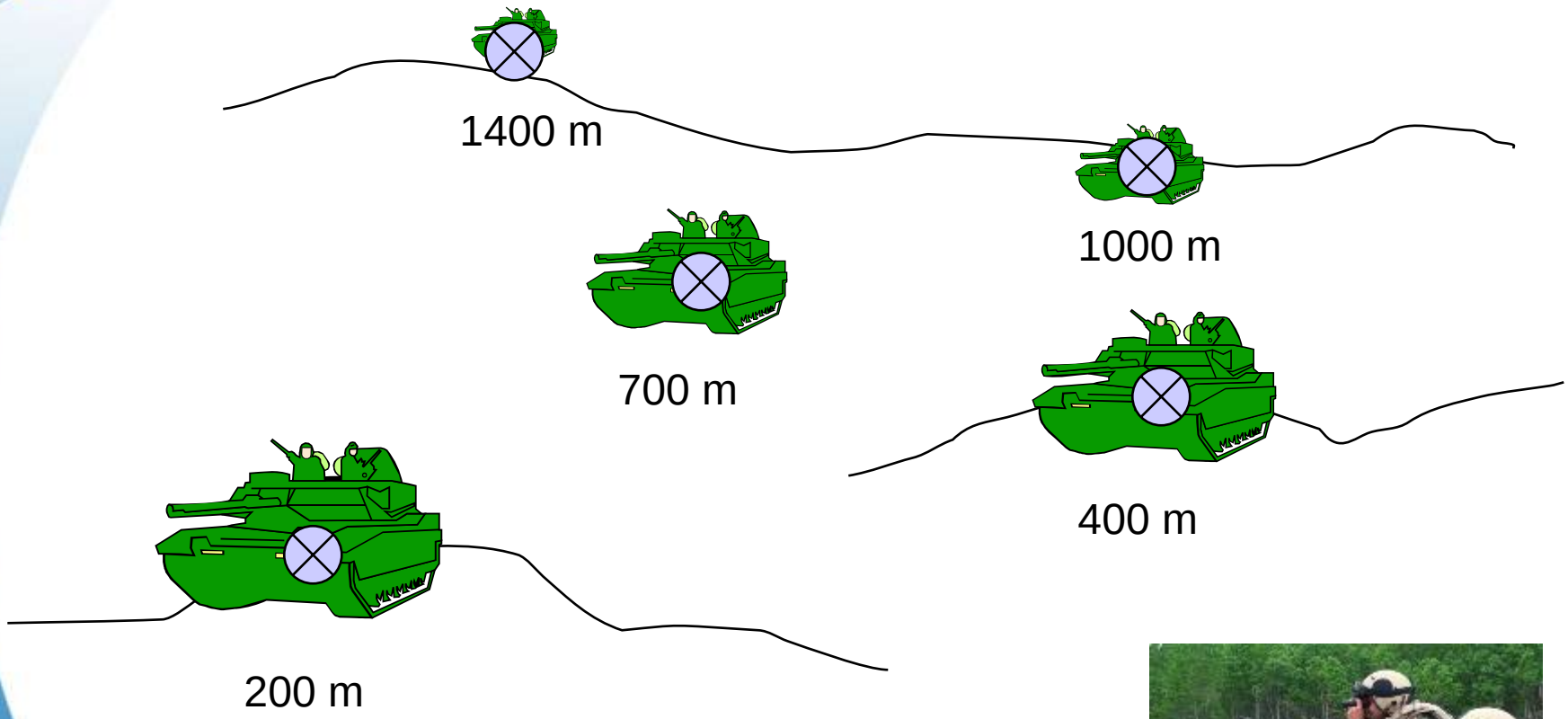




Monte-Carlo Based Weapon System Simulations

- 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:

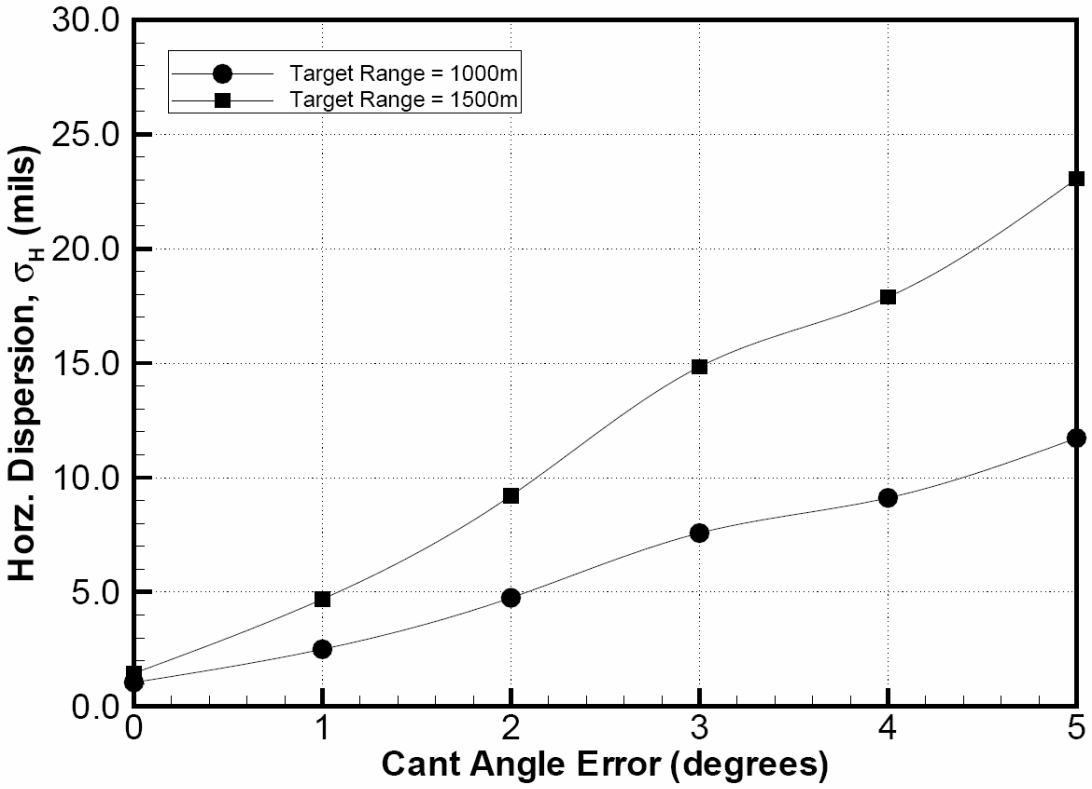
RANGE	P^{1S}_{HIT}	N	Number of individual shots required obtain 90% mission success	Cummulative number of individual shots required obtain 90% mission success
200	1.000	0.00	1	1
400	1.000	0.00	1	2
700	0.876	1.10	2	4
1000	0.532	3.03	4	8
1400	0.142	15.03	16	24
Mission success:			100%	

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

Weapon System Specifications: FCS

Cant angle error

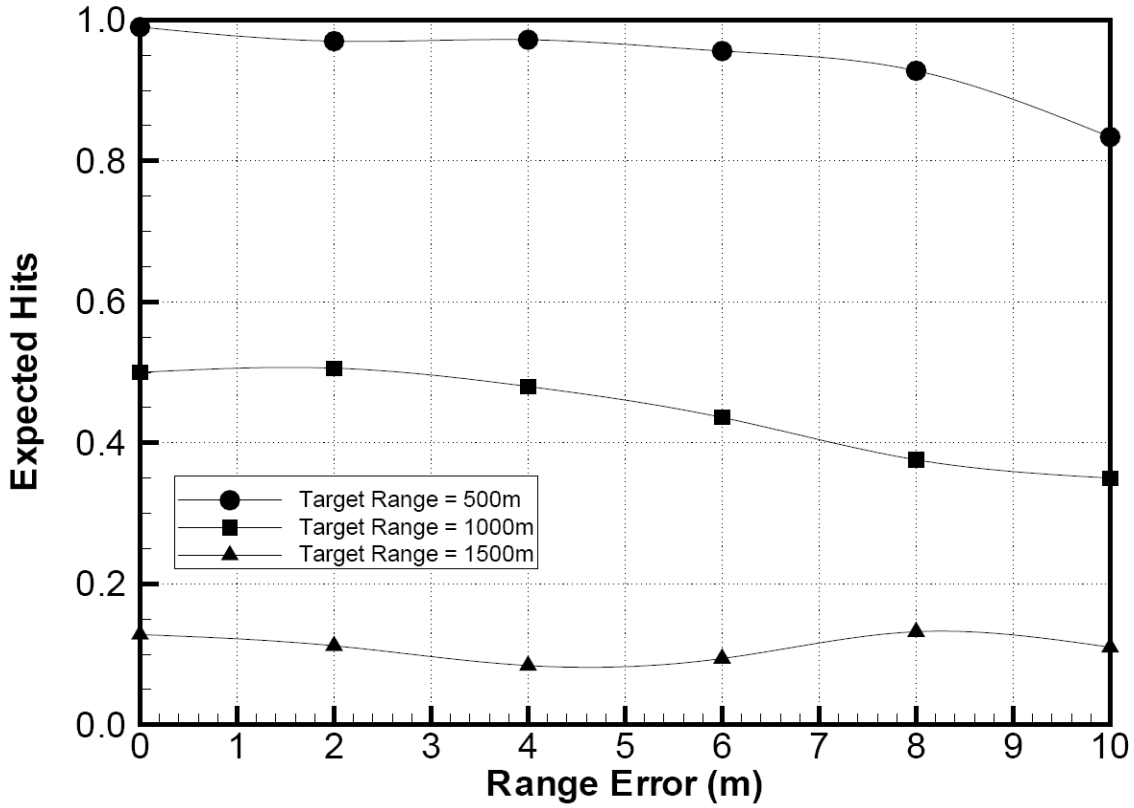
- Standard vertical NATO targets: 2.3m high X 4.6m wide



Weapon System Specifications: FCS

Range error

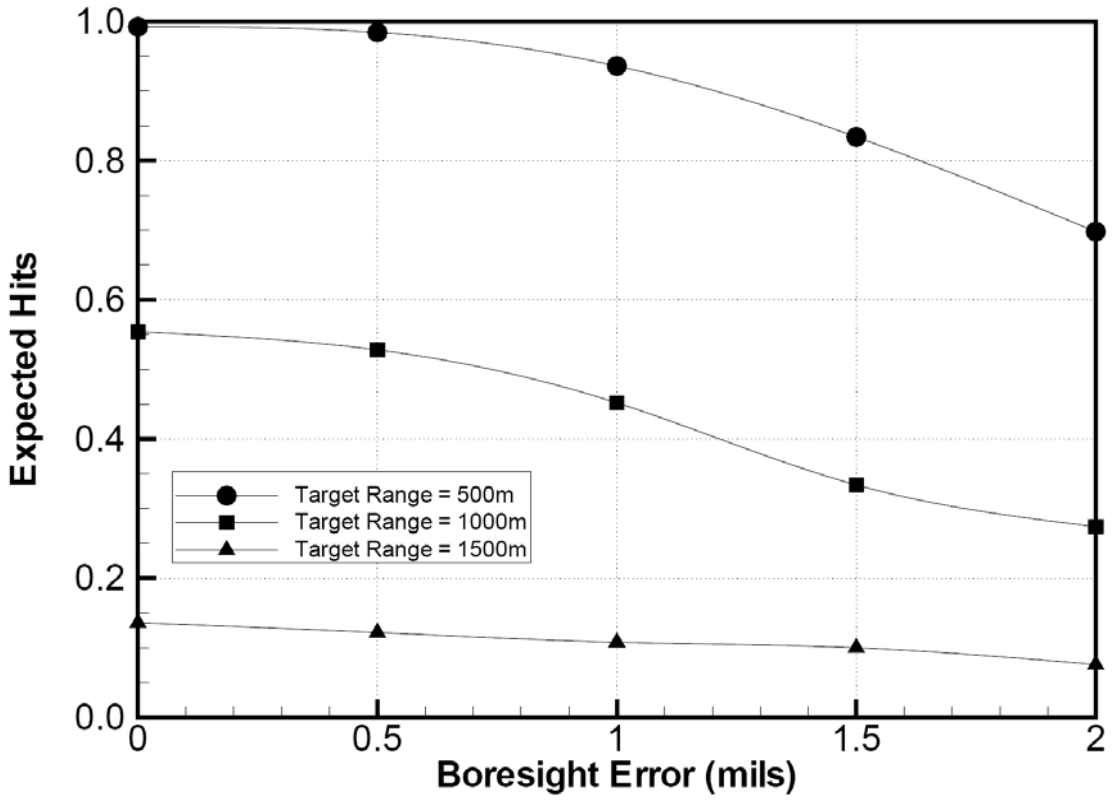
- Standard vertical NATO targets: 2.3m high X 4.6m wide



Weapon System Specifications: FCS

Boresight error

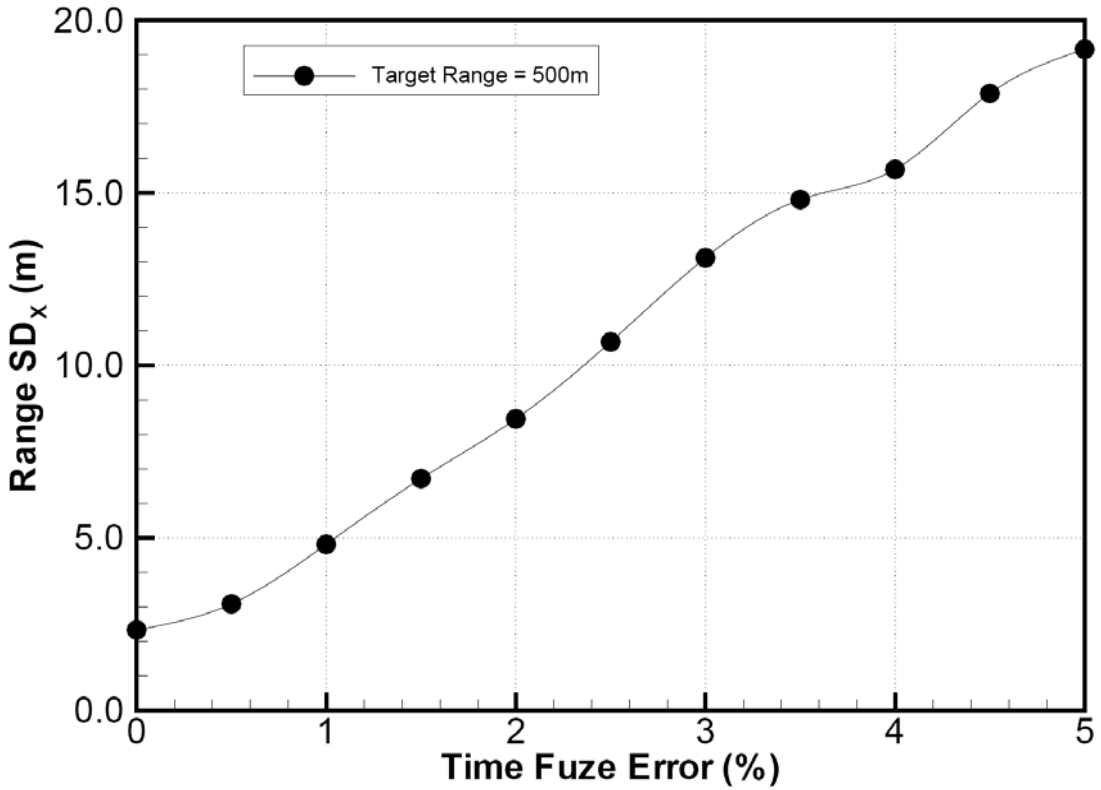
- Standard vertical NATO targets: 2.3m high X 4.6m wide



Weapon System Specifications: Ammo

Time fuze error

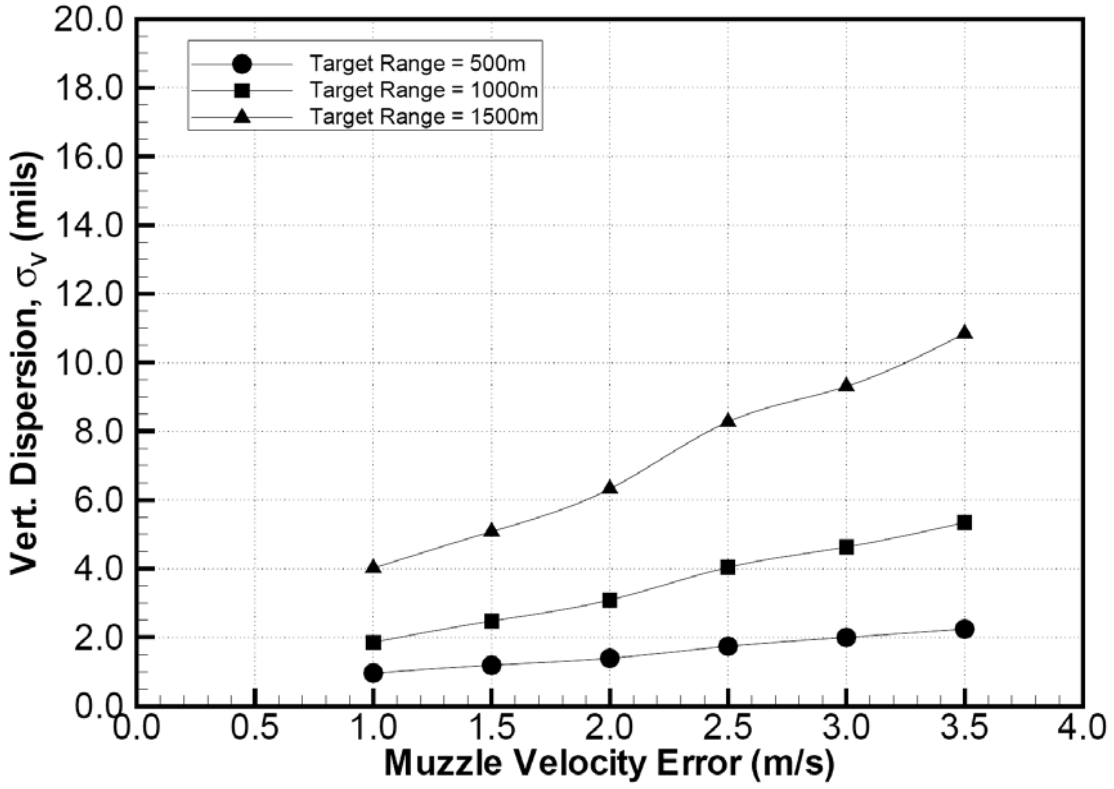
- Ground target



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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