DEFENCE R&D DÉFENSE

Using a 40mm Automatic Grenade Launcher as a Precision Weapon at Long Ranges

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Presentation Overview

- Objective
- Background
- Aerodynamics of a 40 mm HV grenade
- Error budget development
- Long range firing trial and simulation dispersions
- Weapon system simulation results
- Conclusions

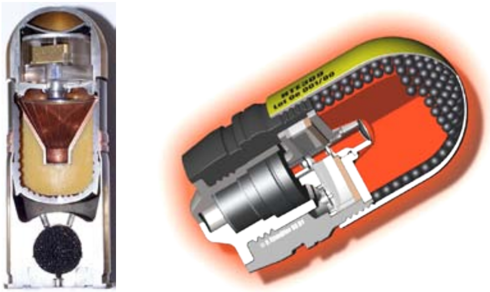
Objective

- Demonstrate the feasibility of using a 40mm AGL at long range for precision effects
  - 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)
  - Validate results with long range firings

Background

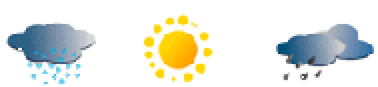
Weapon system modeling

Ammo: mass, CP, CG, shape, aero



Weapon System representation

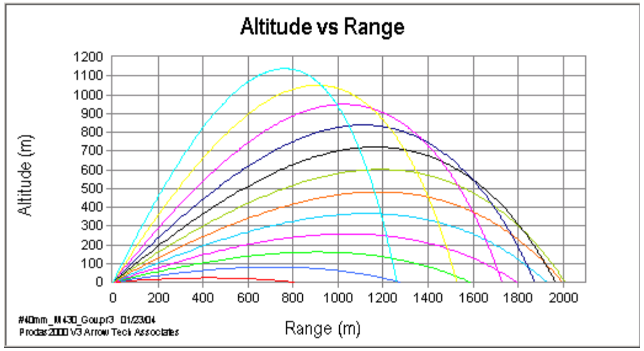
MET data

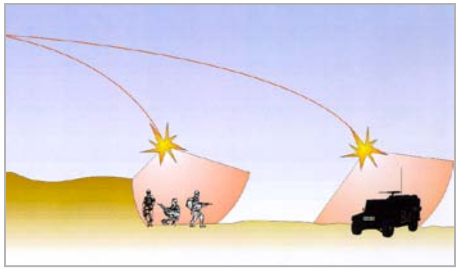


P R O D A S

Round Characteristics at time of burst or detonation:

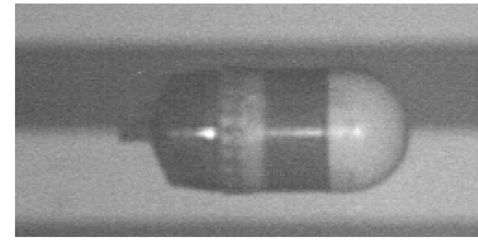
- Dispersion
- Probability of hit
- Remaining Speed
- Remaining Spin
- Angle of descent (AOD)
- Time of Flight

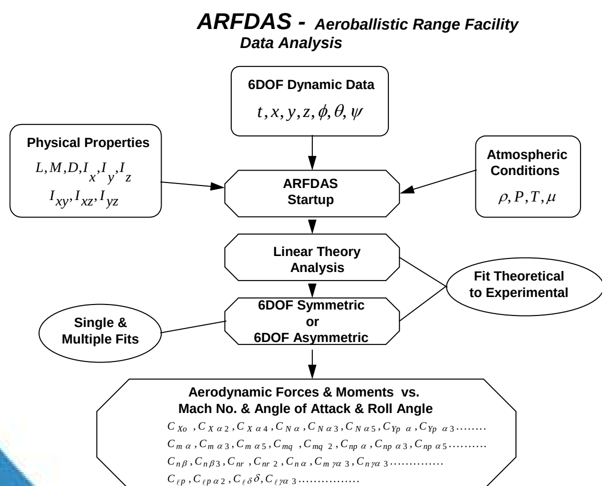




Ammo model development

Aeroballistic range trial



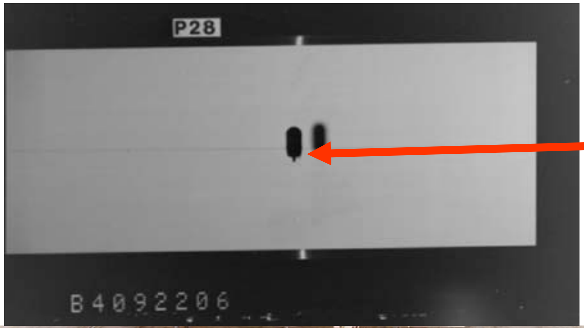


- Complete ammo aero model

Ammo model development

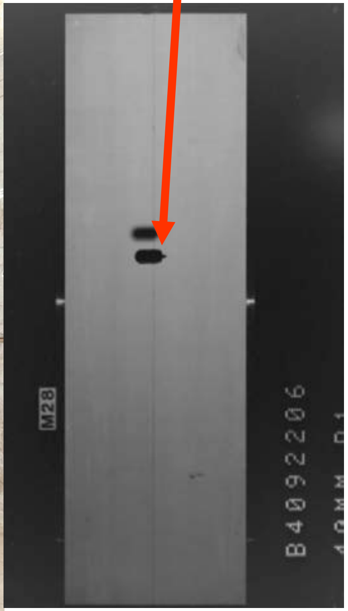
Shadowgraphs

Pit View



Shadow

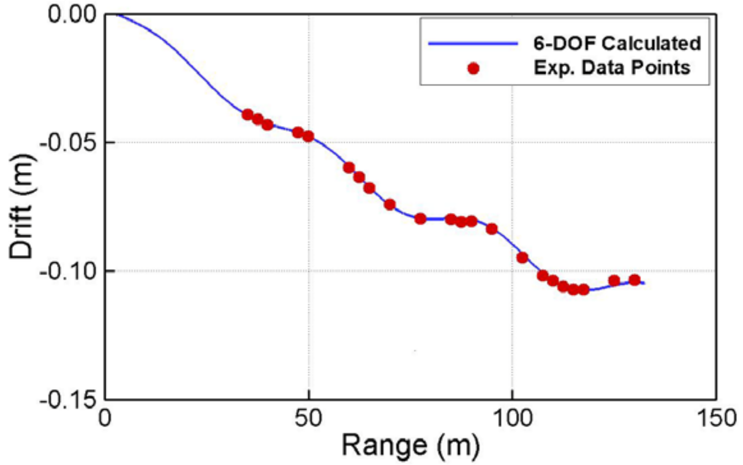
- Instrumented length: 220 m
- Section: 6 m x 6 m
- 54 Stations:
  Indirect orthogonal shadowgraphs
- 4 Schlieren stations

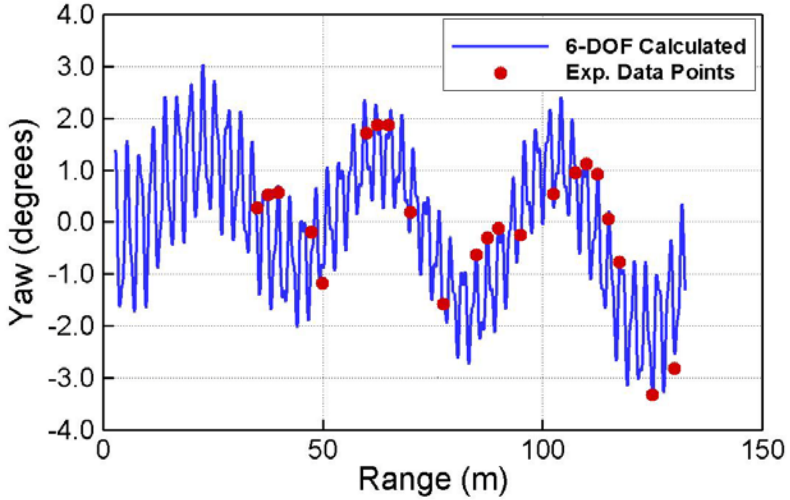


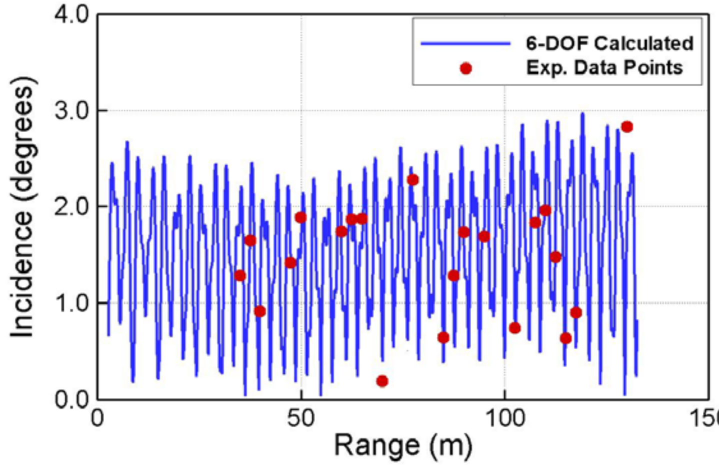
Wall View

Ammo model development

Projectile motion

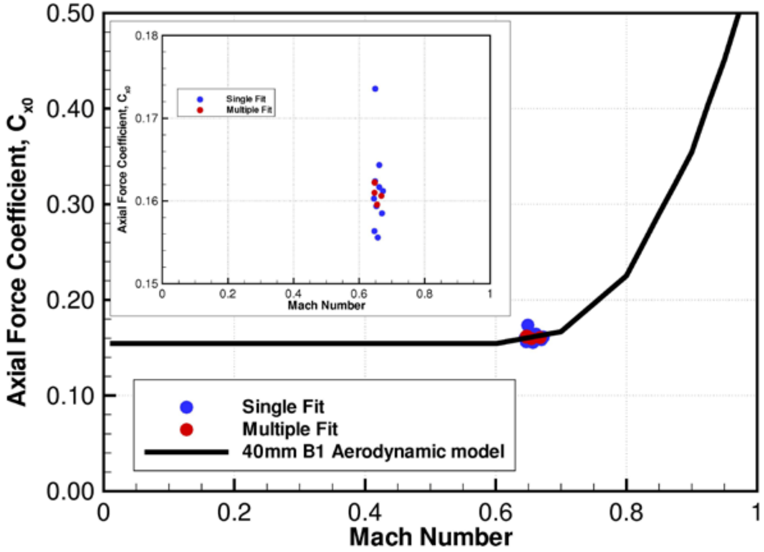


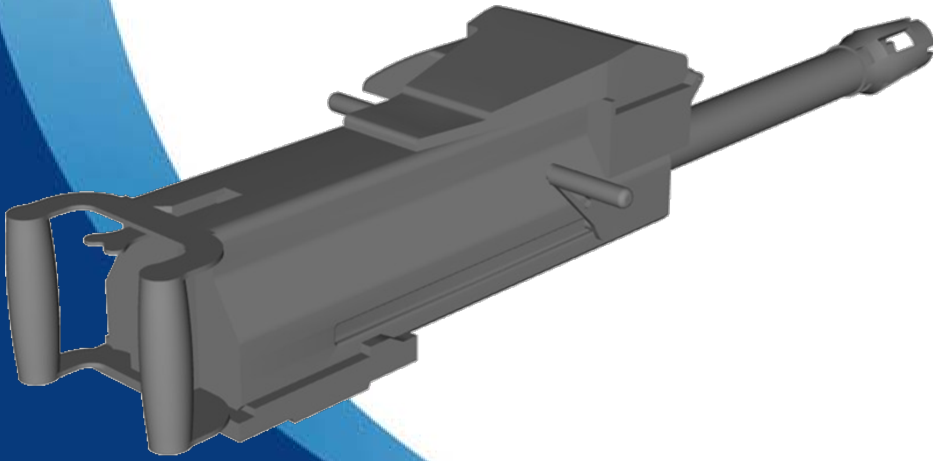




Ammo model development

Aerodynamic model

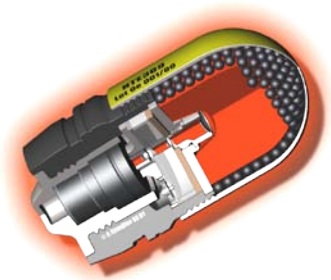




Background

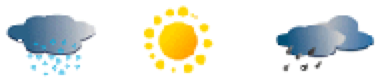
Weapon system modeling

Ammo: mass, CP, CG, shape, aero



Weapon System representation

MET data



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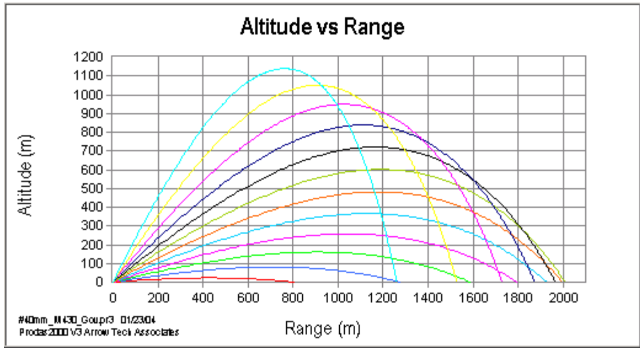
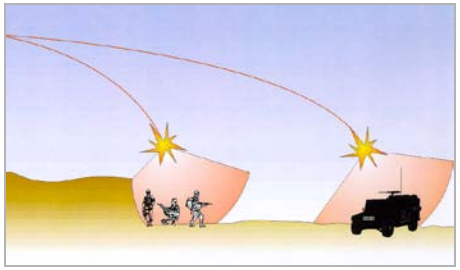
Round Characteristics at time of burst or detonation:

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





Error budget development

MODEL	40mm HV
Errors	Measured
Drag/Mass (%)	
V_M – round to round (m/s)	
V_M – lot to lot (m/s)	
Wind Std(m/s)	
Pressure Std (mbars)	
Air Temp (C) Std Dev	
Vert. Aiming Error (mils)	
Horz. Aiming Error (mils)	
Vert. Boresight alignment (mils)	
Horz. Boresight alignment (mils)	
Target range Error (m)	
Horz. Gun dispersion (mils)	
Vert. Gun dispersion (mils)	
Ammunition Dispersion (mils)	
Fuze Error (% of time)	

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

Error budget development

Total dispersion breakdown

$$S^2_{D_{X\,TOTAL}} = S^2_{D_{Vx}} + S^2_{GDx} + S^2_{ADx}$$

$$S^2_{D_{Y\,TOTAL}} = S^2_{D_{Vy}} + S^2_{GDy} + S^2_{ADy}$$

Total Observed Dispersion

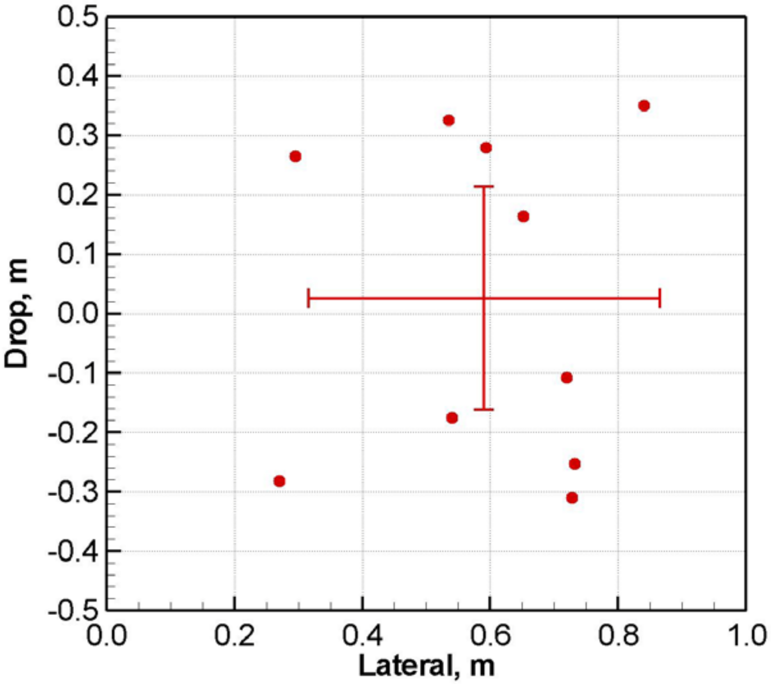
Gravity Drop (V_{MUZ}, mass, C_{X0})

Gun Dispersion

Ammunition Dispersion

Error budget development

Total dispersion



Precision trial:

- NATO StanAg procedure
- Firing at 300m
- Tripod mounted MK19 on natural ground
- T&E mechanism
- Single-shot firing
- Elevation and azimuth adjusted manually prior to firing

$$S_{DX_{TOTAL}} = 0.93 mils$$

$$S_{DY_{TOTAL}} = 0.64 mils$$

Error budget development

Ammunition dispersion (aerodynamic jump)

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

- **Theory States** ⇒

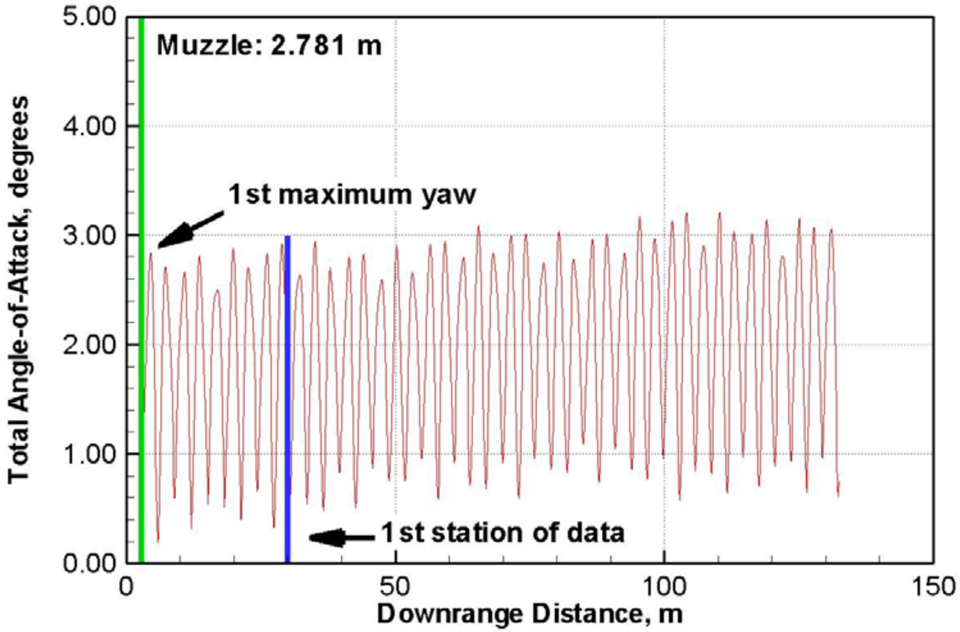
- If initial yaw rate, q_0 , is known
- with aerodynamic package and physical properties

- 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

$$q_0 = \frac{\left(\dot{\phi}_F - \dot{\phi}_S\right)}{2}\overline{\alpha}_{\max} \longrightarrow \theta_{aero} = \frac{\left(C_{N\alpha} - C_X\right)d}{C_{m\alpha}V_0}\left(\frac{I_y q_0}{md^2}\right)$$

$$\boxed{S_{ADx} = S_{ADy} = 0.4 mils}$$

Error budget development

Muzzle velocity error

- Measured for each individual round in precision trial at 300m
- Determined using Radar measurements
- Data processed using Radar2000

SHOT NUMBER	V_{MUZ} (m/s)
D01	243.5
D02	242.6
D03	245.1
D04	243.2
D05	243.8
D06	242.9
D07	242.6
D08	242.1
D09	243.4
D10	241.0
Mean	243.0
Std Deviation	**1.1**

Error budget development

Drag/Mass error

- Measured for each individual round in precision trial at 300m

SHOT NUMBER	Mass (gm)	C_{X0}
D01	239.64	0.16120
D02	240.56	0.16028
D03	240.03	0.16167
D04	242.10	0.17356
D05	240.75	0.16238
D06	241.54	0.16434
D07	240.36	0.15635
D08	242.16	0.15558
D09	241.11	0.15850
D10	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

Gun dispersion: lateral analysis

$$S^2_{D_{X\,TOTAL}} = S^2_{D_{Vx}} + S^2_{GDx} + S^2_{ADx}$$

Total Observed
0.93mils

Gravity drop (V_{MUZ}, mass, C_{X0})
0.00mils

Gun Dispersion
0.84mils

Ammunition Dispersion
0.40mils

Error budget development

Gun dispersion: drop analysis

$$S^2_{D_{Y\,TOTAL}} = S^2_{D_{Vy}} + S^2_{GDy} + S^2_{ADy}$$

Total Observed
0.64mils

Gravity drop (V_{MUZ}, mass, C_{X0})
0.35mils

Gun Dispersion
0.35mils

Ammunition Dispersion
0.40mils

Error budget development

Error budget model

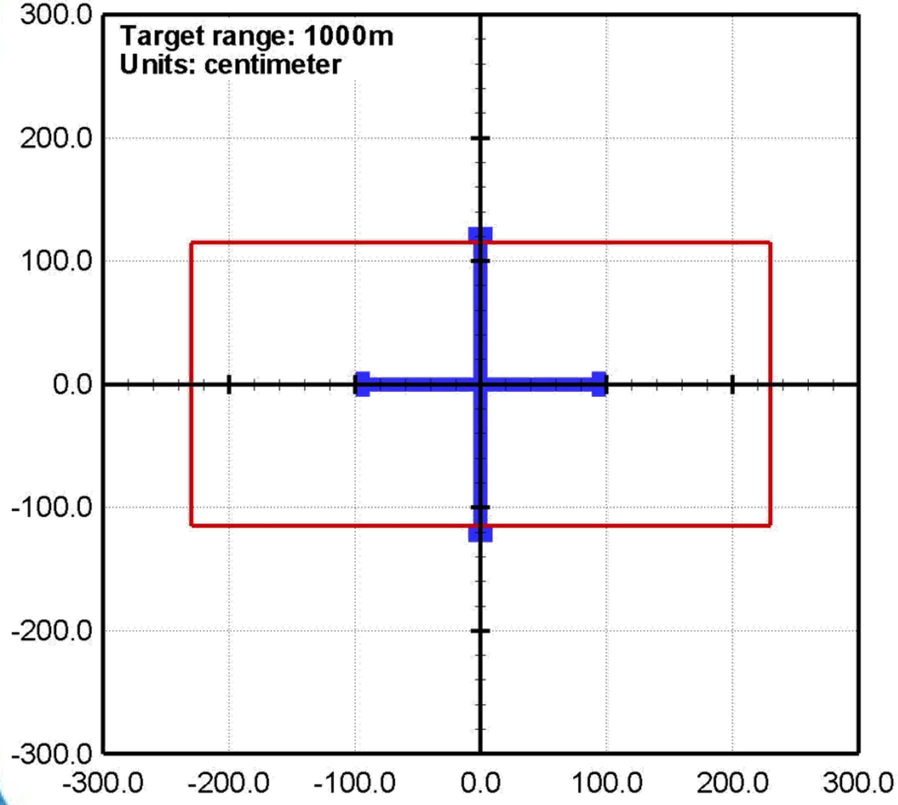
MODEL	40mm HV
Errors	Measured
Drag/Mass (%)	1.0
V_M – round to round (m/s)	1.1
V_M – lot to lot (m/s)	
Wind Std(m/s)	
Pressure Std (mbars)	
Air Temp (C) Std Dev	
Vert. Aiming Error (mils)	
Horz. Aiming Error (mils)	
Vert. Boresight alignment (mils)	
Horz. Boresight alignment (mils)	
Target range Error (m)	
Horz. Gun dispersion (mils)	0.84
Vert. Gun dispersion (mils)	0.35
Ammunition Dispersion (mils)	0.40
Fuze Error (% of time)	

Valid for:

- Tripod mounted MK19 on natural ground
- T&E mechanism
- Single-shot firing

Scenario/Mission Simulations

Firing simulations at 1000m




NATO side profile: 2.3m x 4.6m

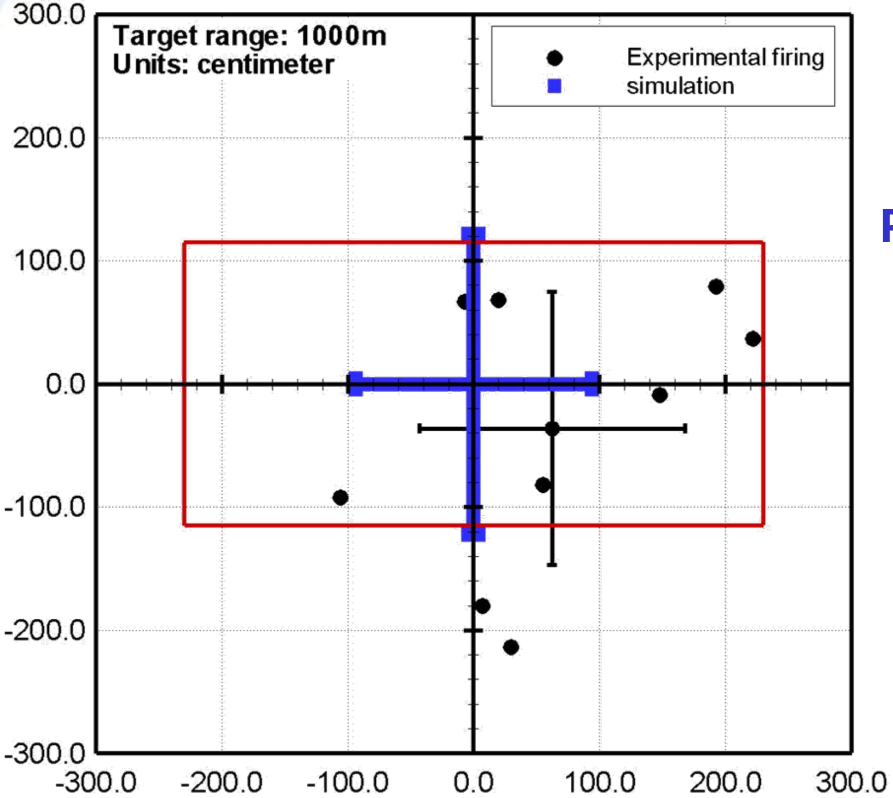
Horz. Disp.: 0.94mils

Vert. Disp.: 1.22mils

Single shot P_{hit}: 0.66

Scenario/Mission Simulations

Firing simulations at 1000m



NATO side profile:
2.3m x 4.6m

Precision trial:

- NATO StanAg procedure
- Firing at 1000m
- Tripod mounted MK19 on natural ground
- T&E mechanism
- Single-shot firing
- Weapon zeroed on target
- Elevation and azimuth adjusted manually prior to firing

Simulation:

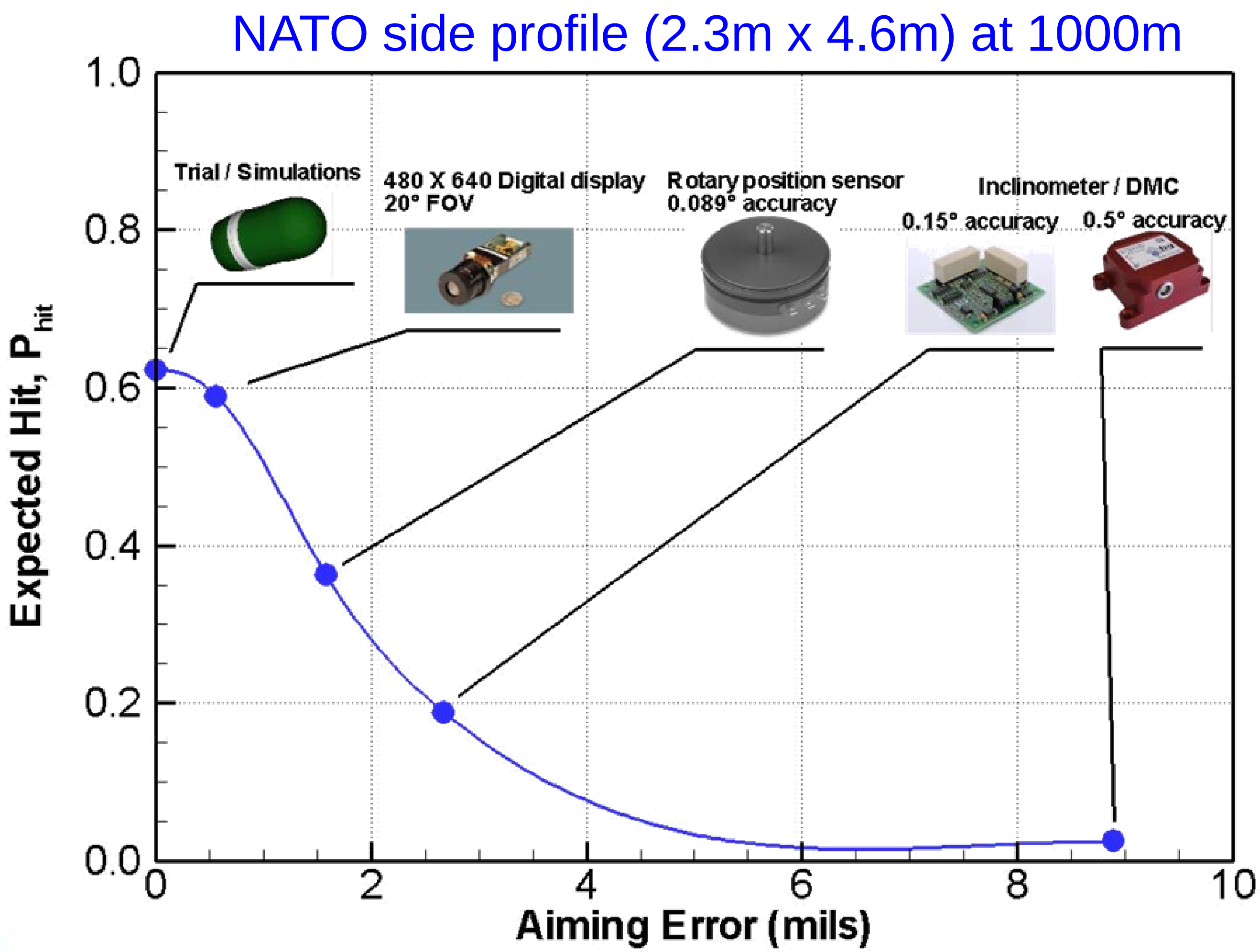
Horz. Disp.: 0.94mils
Vert. Disp.: 1.22mils

Experimental firing:

Horz. Disp.: 1.05mils
Vert. Disp.: 1.11mils

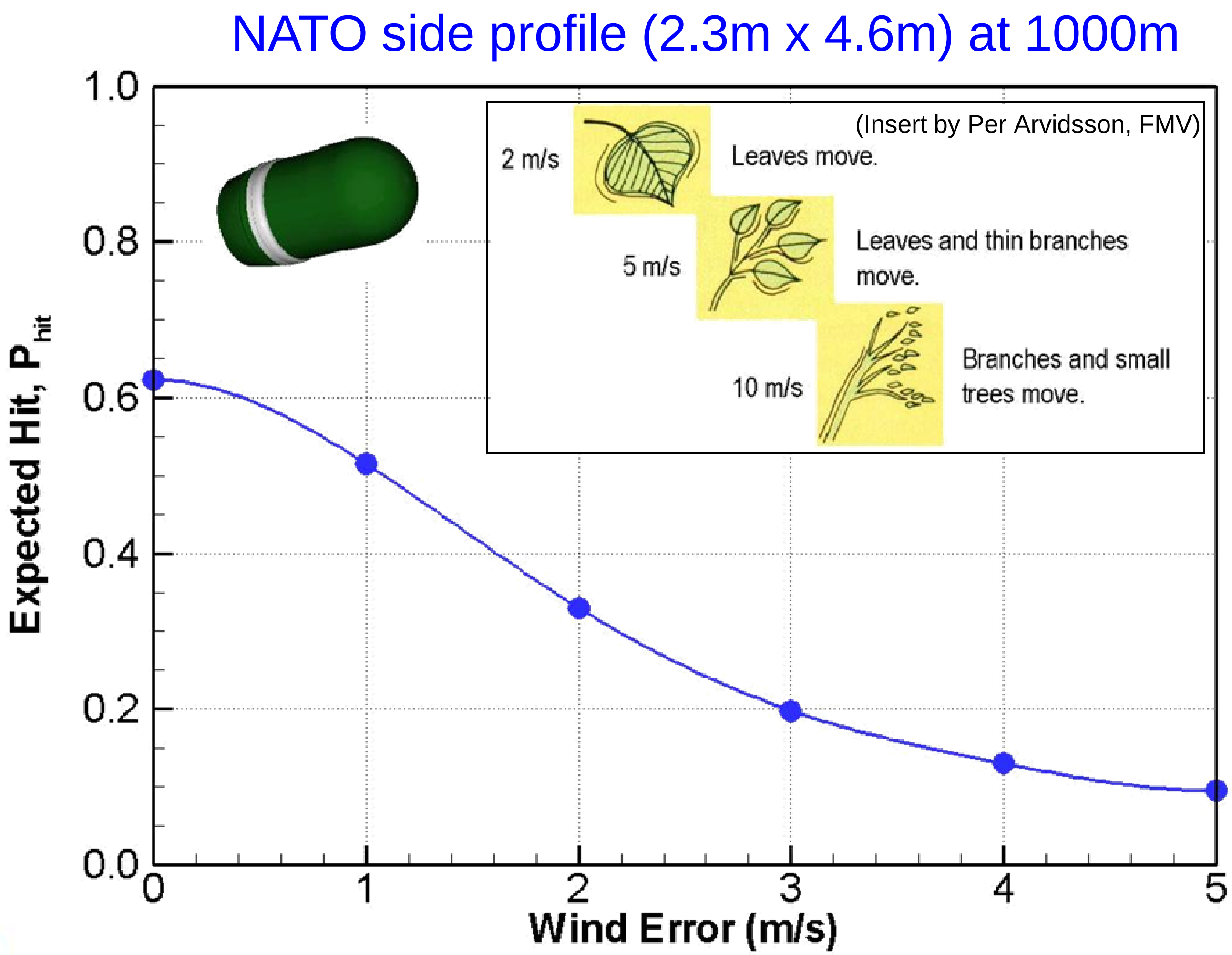
FCS Performance Estimations

Effect of error on elevation (aiming error)



FCS Performance Estimations

Effect of error on wind (std. dev.)



FCS Performance Estimations

Adding the aiming error and the wind error...

NATO side profile (2.3m x 4.6m) at 1000m

- Baseline single-shot model prediction (no aiming or wind errors): $P_{hit} = 0.66$

- Single-shot model prediction with aiming and wind errors: $P_{hit} = 0.12$
  - Std. Dev. on wind: 2m/s
  - Elevation set using DMC with an accuracy of 0.15^{o}

Extrapolating...

- 5 rounds burst model prediction with aiming and wind errors: $P_{hit} = 0.66$
  - Std. Dev. on wind: 2m/s
  - Elevation set using DMC with and accuracy of 0.15^{o}

(!!!Caution: model not developed for burst firing!!!)

Conclusions

- An experimentally developed error budget model was used to demonstrate the precision of a properly zeroed 40mm AGL at long ranges (~1000m)
- The simulation results at 1000m were validated with live firings
- Without a state-of-the-art FCS, the precision of the 40mm AGL would be limited in a real engagement scenario
  - » Aiming error
  - » Wind error
  - » Ballistic solution error

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