U.S. Army Research, Development and Engineering Command

5.56 mm M855 Accuracy and Jump Measurements

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Ilmars Celmins

U.S. Army Research Laboratory, Flight Sciences Branch

26th International Symposium on Ballistics – September 2011

Approved for public release; distribution unlimited.

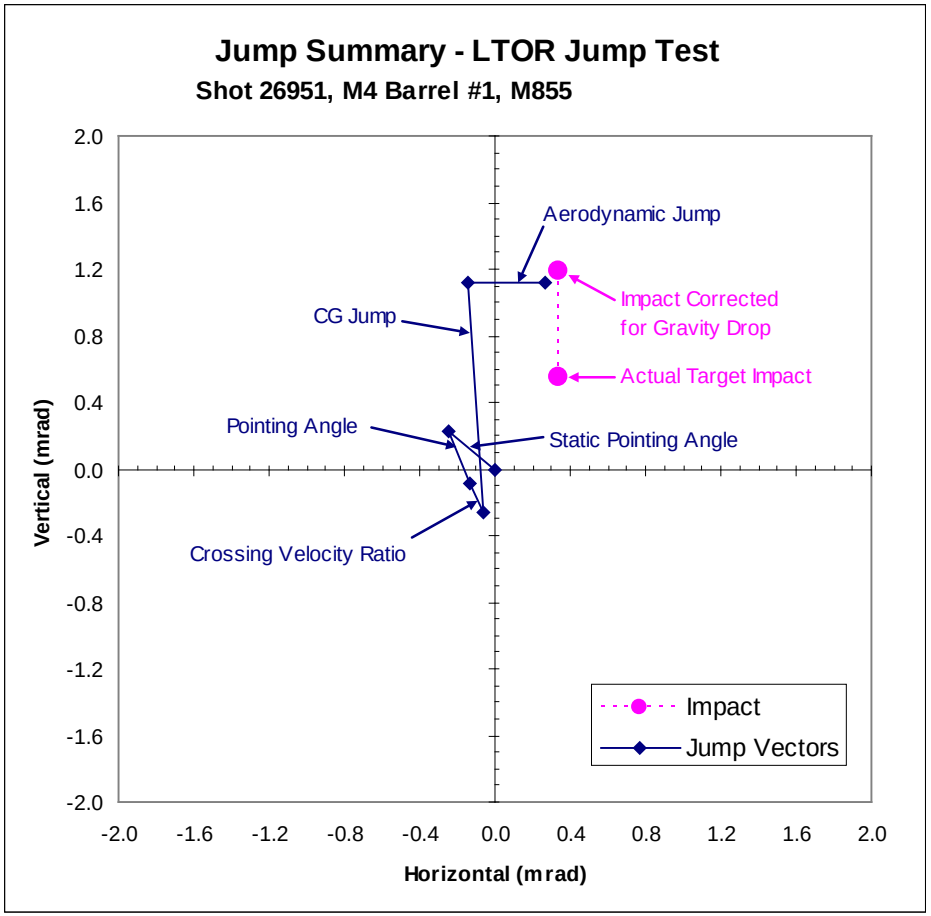
Outline

- Description of jump components
- M855 reference ammunition test results
- Summary and conclusions
- Backup slides: description of test setup, instrumentation, and measurement techniques

Approved for public release; distribution unlimited.

Jump testing measures individual trajectory components

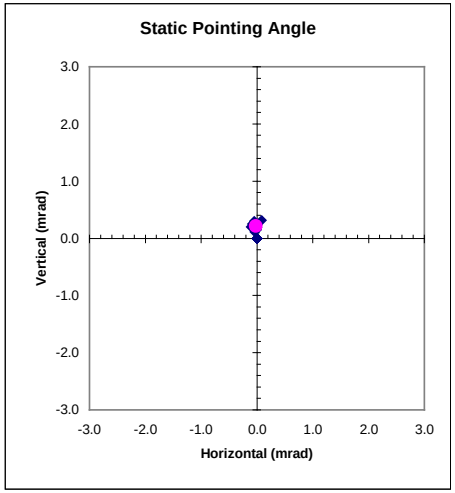
- Three gun motion parameters
  - Static pointing angle
  - Dynamic pointing angle
  - Crossing velocity ratio
- Three projectile motion parameters
  - CG jump
  - Aerodynamic jump
  - Gravity drop (added to impact location)



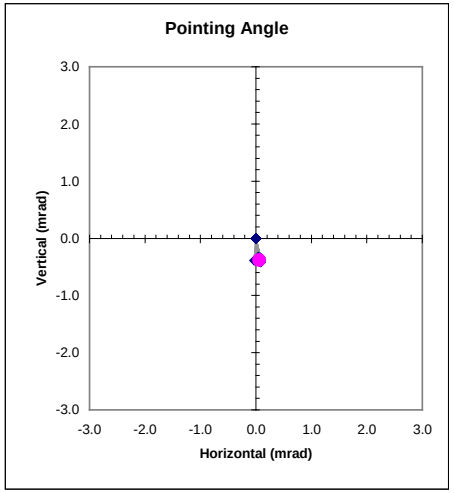
Approved for public release; distribution unlimited.

Jump Components, M4 Barrel #2, M855

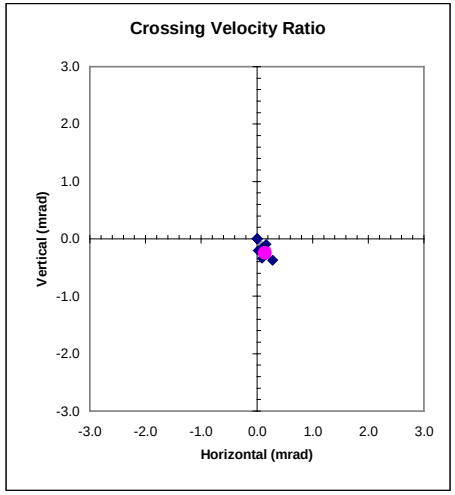
Jump Summary - LTOR Jump Test
M4 Barrel #2, M855



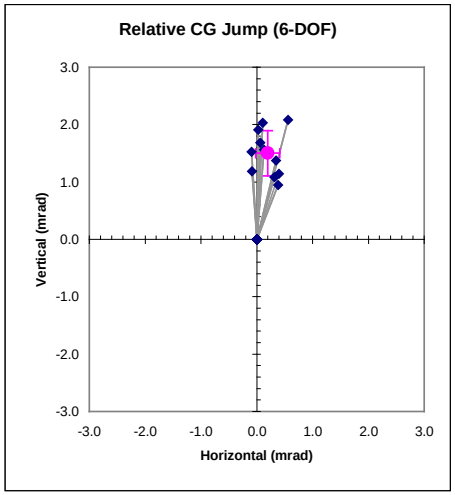
Avg.=(-0.02, 0.21) SD=(0.05, 0.06)



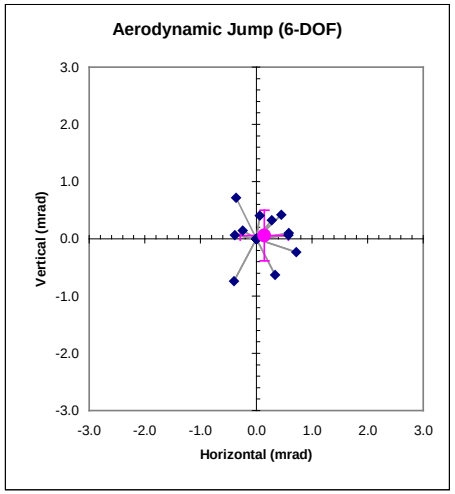
Avg.=(0.06, -0.38) SD=(0.04, 0.03)



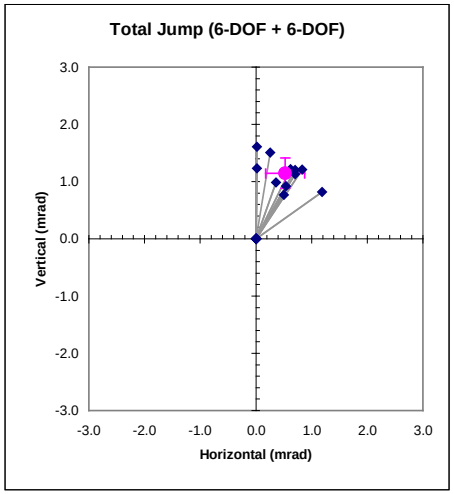
Avg.=(0.15, -0.25) SD=(0.08, 0.09)



Avg.=(0.20, 1.50) SD=(0.22, 0.39)



Avg.=(0.15, 0.06) SD=(0.43, 0.44)



Avg.=(0.52, 1.15) SD=(0.35, 0.26)

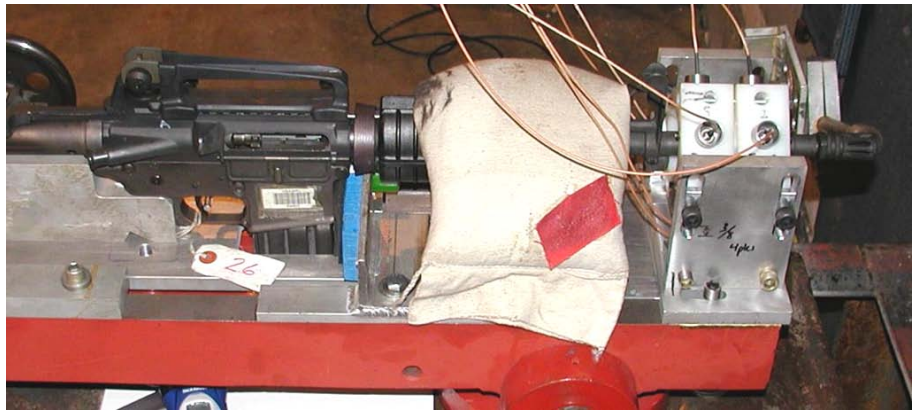
Approved for public release; distribution unlimited.

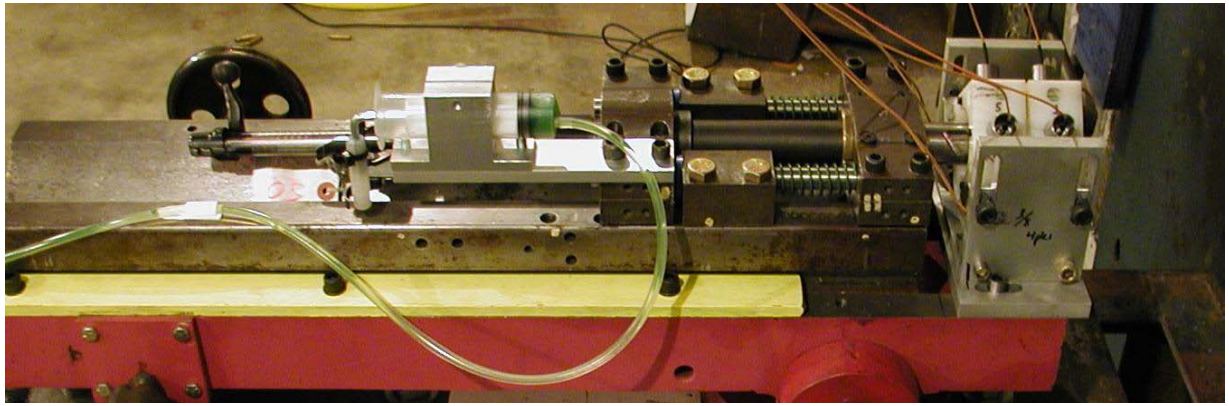
M855 reference ammunition tests

Ammunition Lot No. LC-87F000R011

Four different barrel configurations were tested

- M4, Barrel #1
- M4, Barrel #2
- M4, Barrel #2, bare muzzle
- Mann Barrel



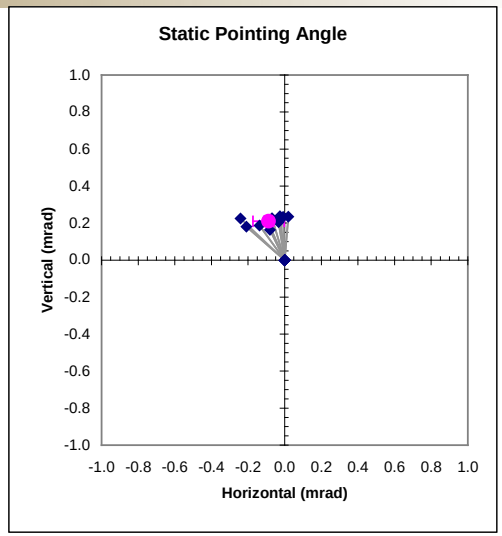


Approved for public release; distribution unlimited.

Comparison of Static Pointing Angle Jump Component

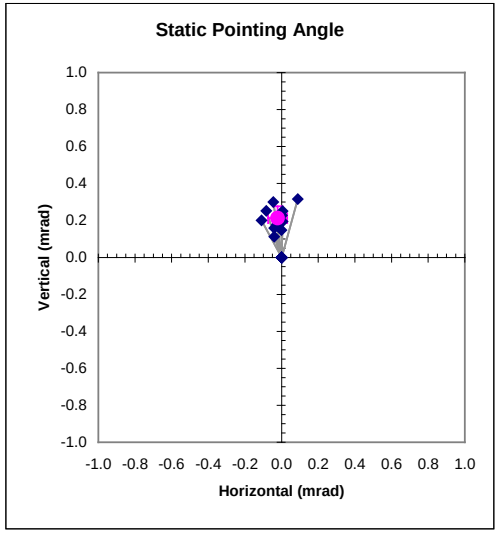
Expanded Scale (3X)

M4 Barrel #1, M855



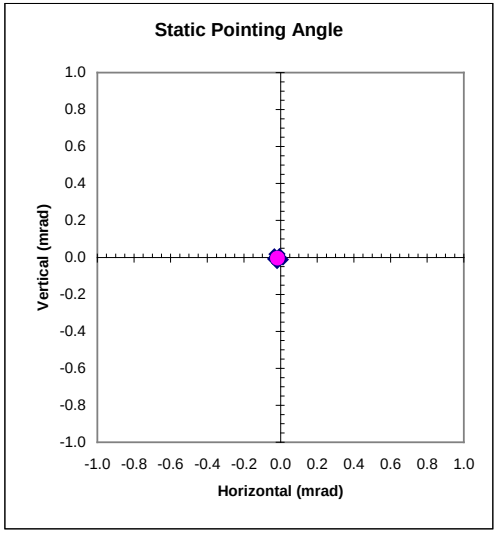
Avg.=(-0.09, 0.21) SD=(0.09, 0.03)

M4 Barrel #2, M855



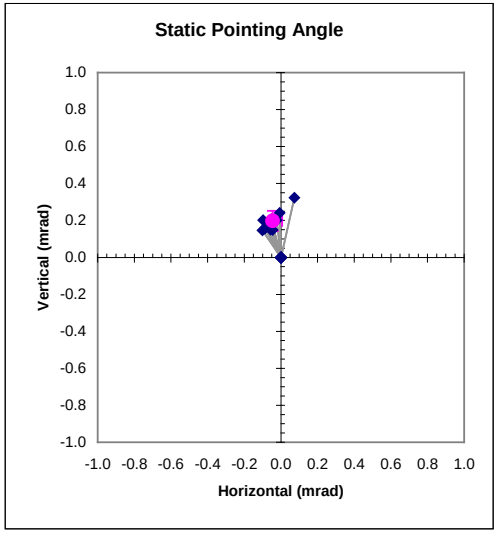
Avg.=(-0.02, 0.21) SD=(0.05, 0.06)

Mann Barrel, M855



Avg.=(-0.02, 0.00) SD=(0.02, 0.02)

M4 Barrel #2, Bare Muzzle M855



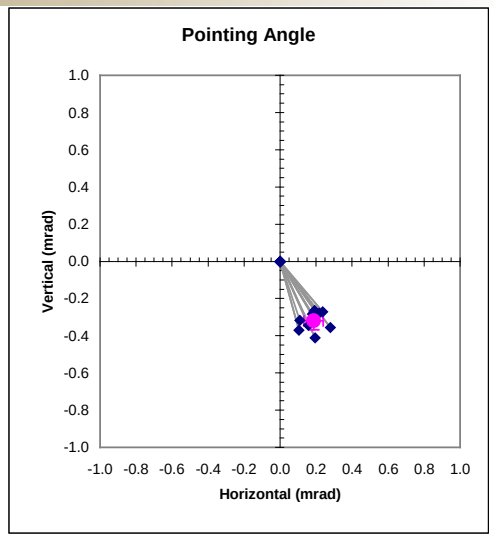
Avg.=(-0.04, 0.20) SD=(0.05, 0.05)

Approved for public release; distribution unlimited.

Comparison of Muzzle Pointing Angle Jump Component

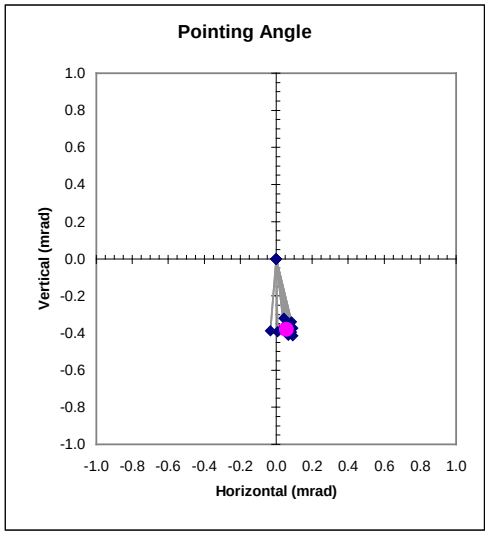
Expanded Scale (3X)

M4 Barrel #1, M855



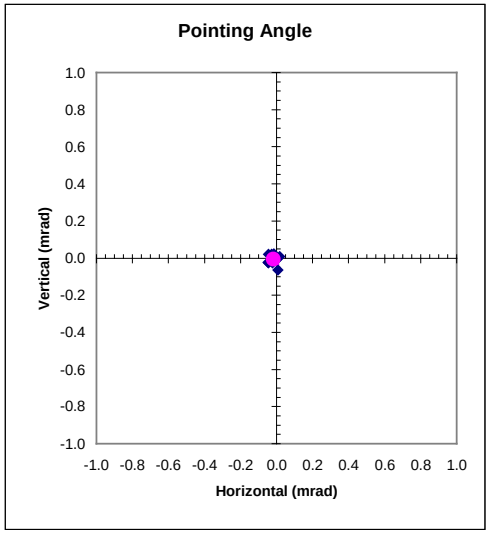
Avg.=(0.19, -0.32) SD=(0.05, 0.05)

M4 Barrel #2, M855



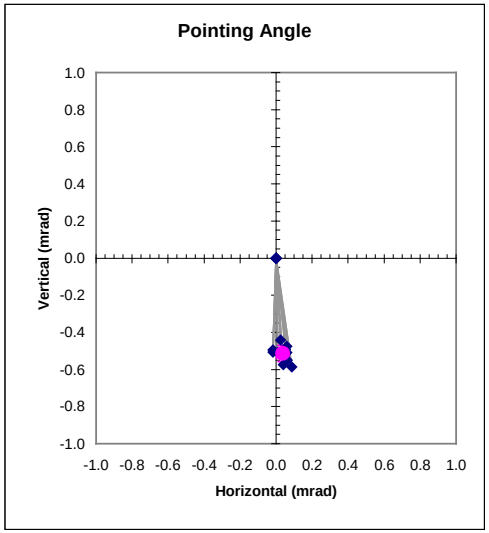
Avg.=(0.06, -0.38) SD=(0.04, 0.03)

Mann Barrel, M855



Avg.=(-0.02, -0.01) SD=(0.02, 0.03)

M4 Barrel #2, Bare Muzzle M855



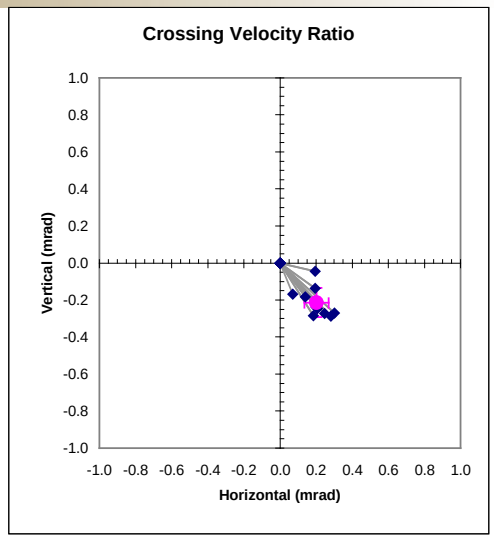
Avg.=(0.04, -0.51) SD=(0.04, 0.04)

Approved for public release; distribution unlimited.

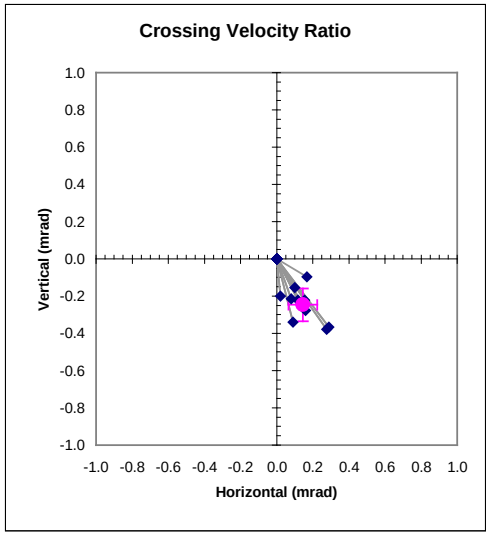
Comparison of Muzzle Crossing Velocity Jump Component

Expanded Scale (3X)

M4 Barrel #1, M855



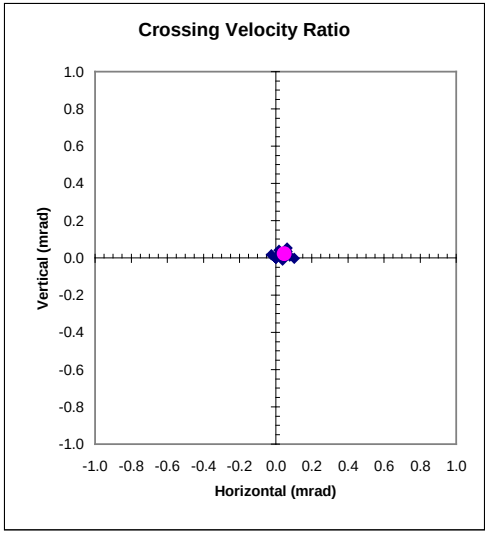
Avg.=(0.20, -0.21) SD=(0.07, 0.08)



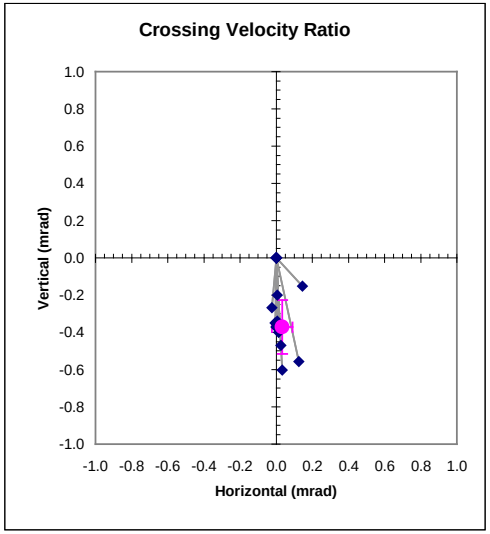
Avg.=(0.15, -0.25) SD=(0.08, 0.09)

M4 Barrel #2, M855

Mann Barrel, M855



Avg.=(0.05, 0.02) SD=(0.03, 0.02)



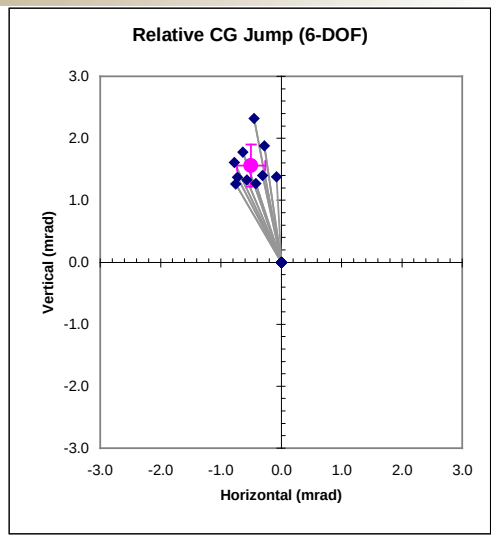
Avg.=(0.03, -0.37) SD=(0.06, 0.14)

M4 Barrel #2, Bare Muzzle M855

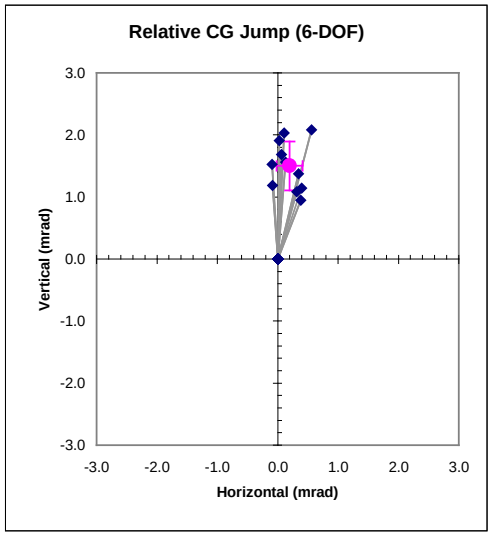
Approved for public release; distribution unlimited.

Comparison of Relative CG Jump Component

M4 Barrel #1, M855



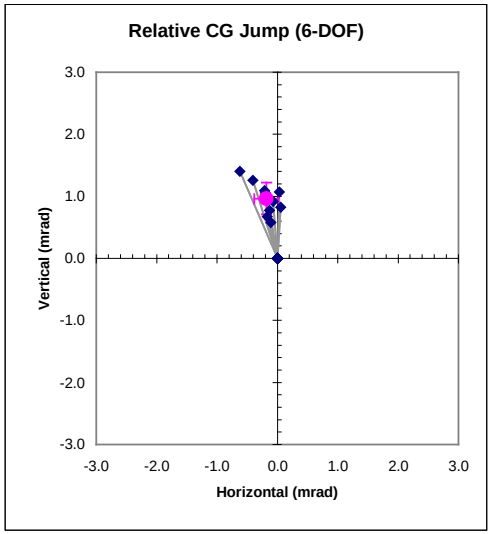
Avg.=(-0.50, 1.56) SD=(0.23, 0.34)



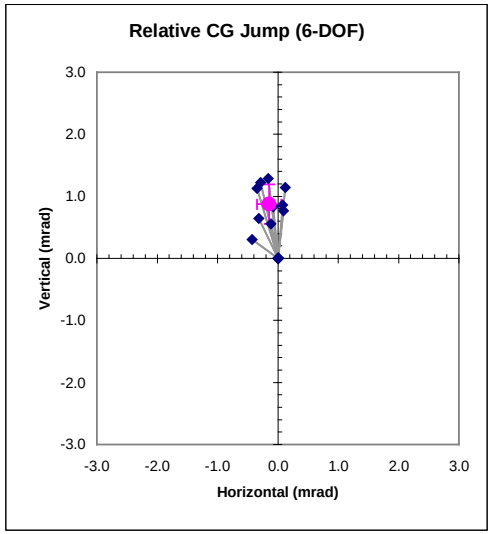
Avg.=(0.20, 1.50) SD=(0.22, 0.39)

M4 Barrel #2, M855

Mann Barrel, M855



Avg.=(-0.18, 0.96) SD=(0.20, 0.26)



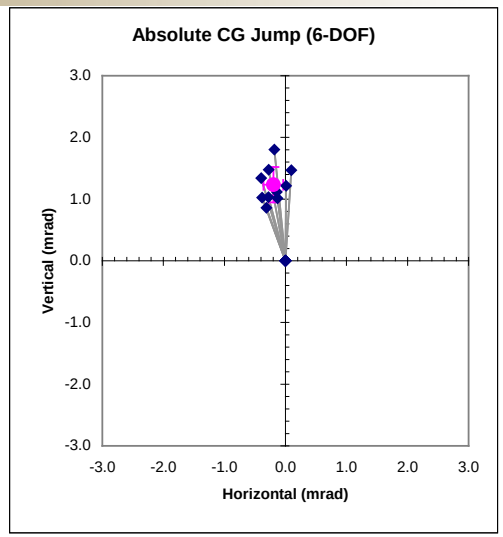
Avg.=(-0.14, 0.87) SD=(0.20, 0.32)

M4 Barrel #2, Bare Muzzle M855

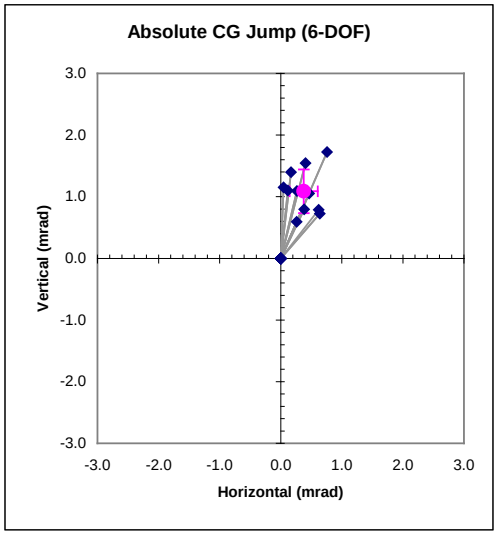
Approved for public release; distribution unlimited.

Comparison of Absolute CG Jump Component

M4 Barrel #1, M855



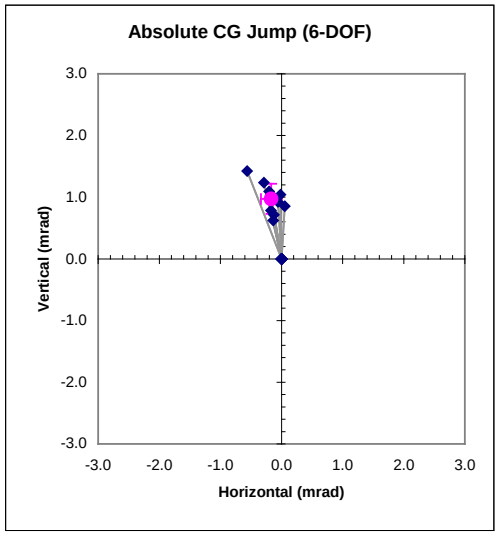
Avg.=(-0.20, 1.23) SD=(0.16, 0.29)



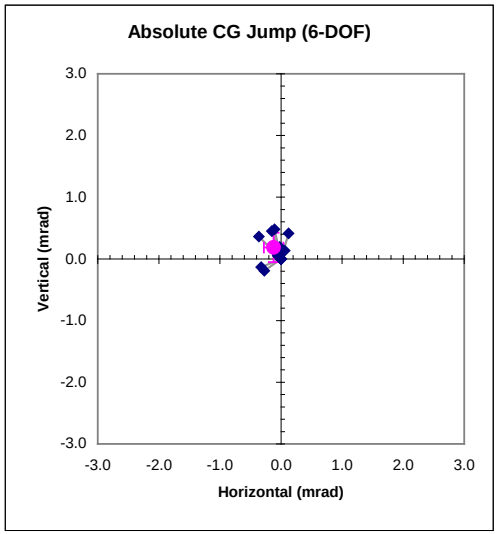
Avg.=(0.38, 1.09) SD=(0.23, 0.36)

M4 Barrel #2, M855

Mann Barrel, M855



Avg.=(-0.17, 0.97) SD=(0.17, 0.24)



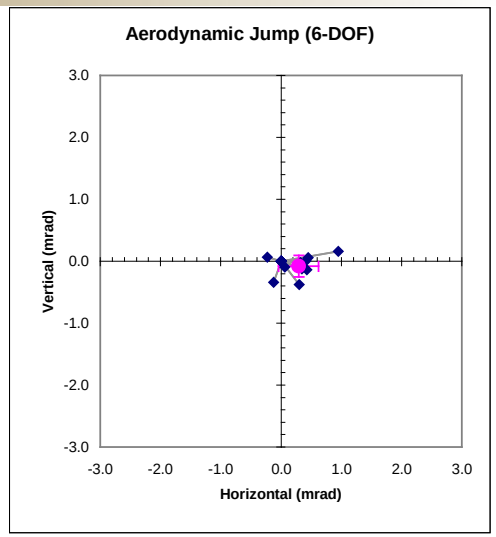
Avg.=(-0.12, 0.19) SD=(0.16, 0.24)

M4 Barrel #2, Bare Muzzle M855

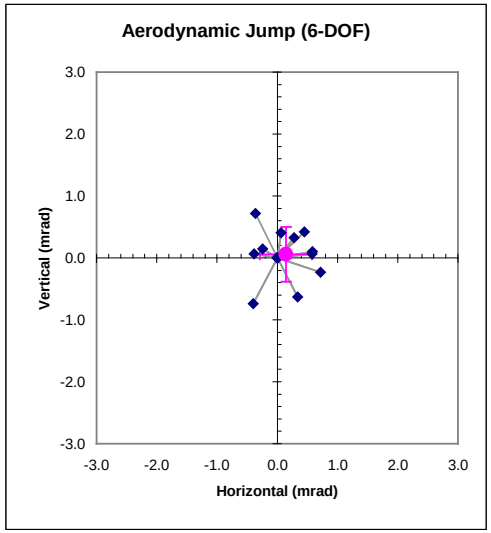
Approved for public release; distribution unlimited.

Comparison of Aerodynamic Jump Component

M4 Barrel #1, M855



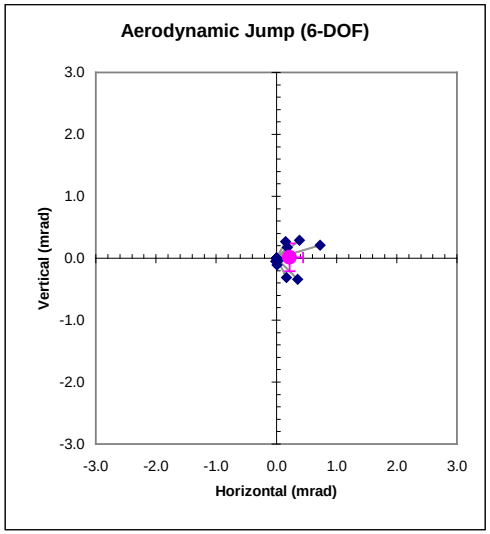
Avg.=(0.29, -0.08) SD=(0.33, 0.17)



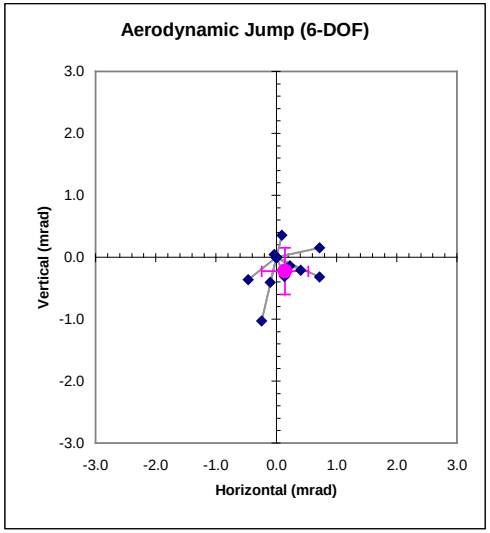
Avg.=(0.15, 0.06) SD=(0.43, 0.44)

M4 Barrel #2, M855

Mann Barrel, M855



Avg.=(0.22, 0.01) SD=(0.22, 0.23)



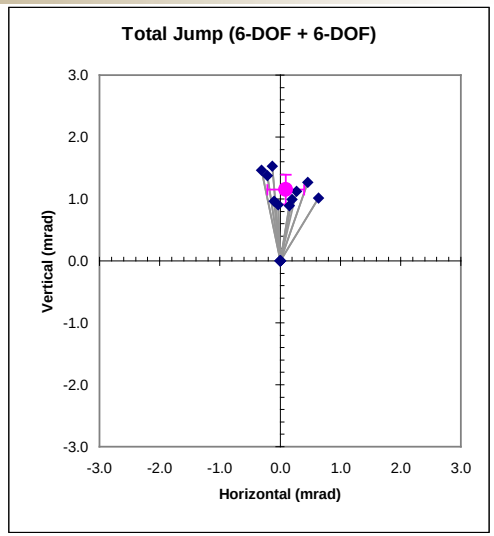
Avg.=(0.15, -0.22) SD=(0.39, 0.38)

M4 Barrel #2, Bare Muzzle M855

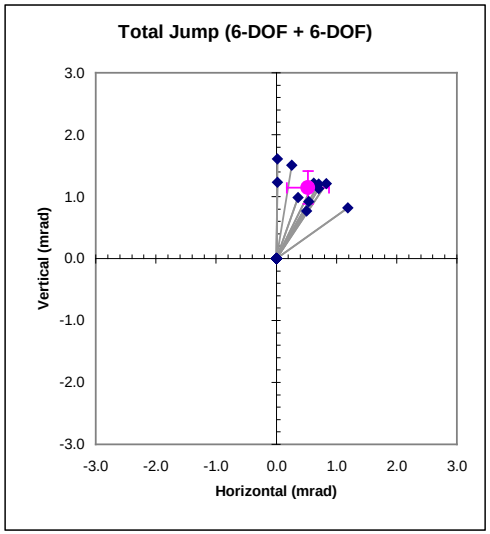
Approved for public release; distribution unlimited.

Comparison of Total Jump

M4 Barrel #1, M855



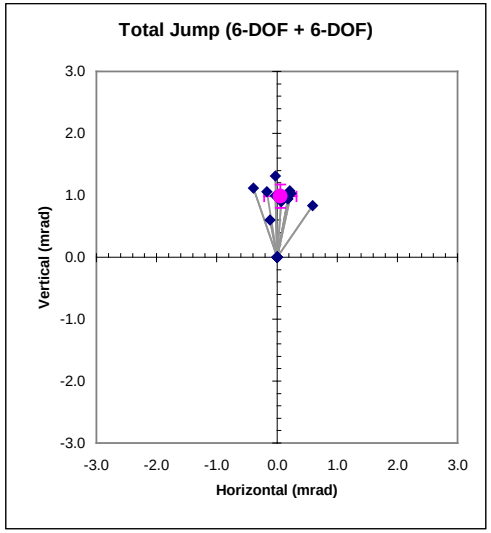
Avg.=(0.09, 1.15) SD=(0.30, 0.24)



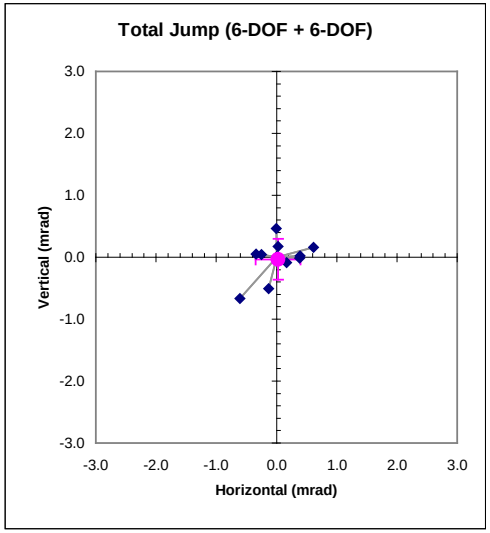
Avg.=(0.52, 1.15) SD=(0.35, 0.26)

M4 Barrel #2, M855

Mann Barrel, M855



Avg.=(0.06, 0.99) SD=(0.27, 0.19)



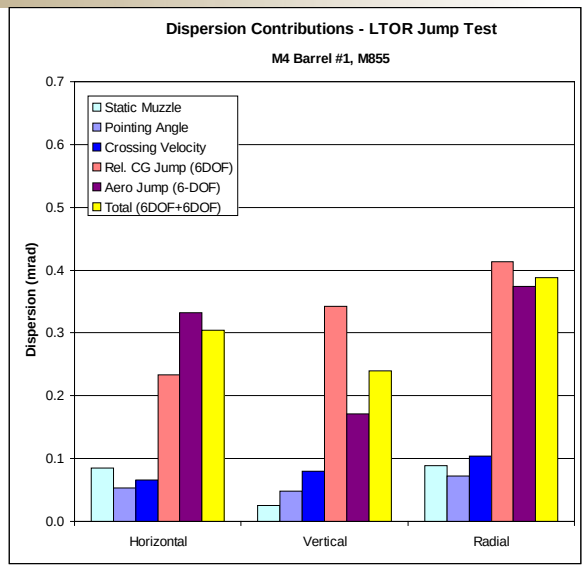
Avg.=(0.03, -0.04) SD=(0.38, 0.33)

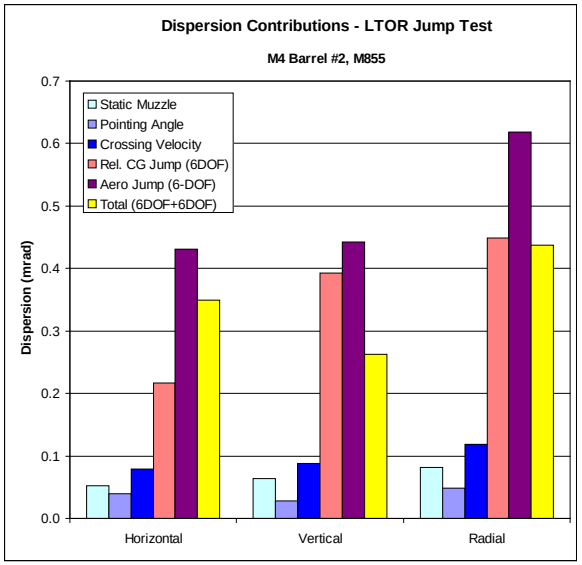
M4 Barrel #2, Bare Muzzle M855

Approved for public release; distribution unlimited.

Comparison of Dispersion Contributors

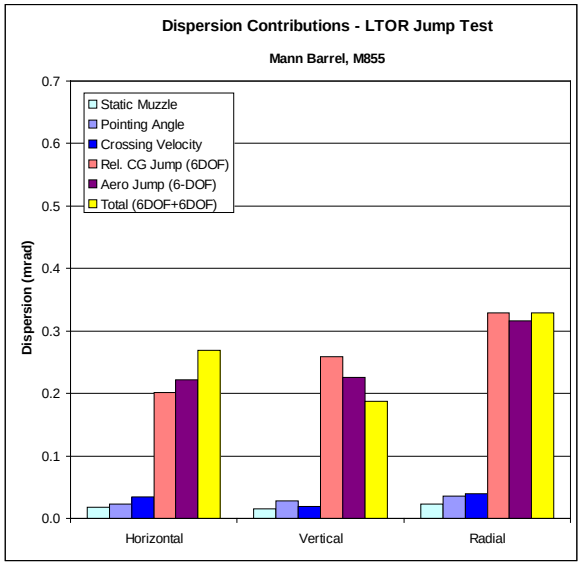
M4 Barrel #1, M855

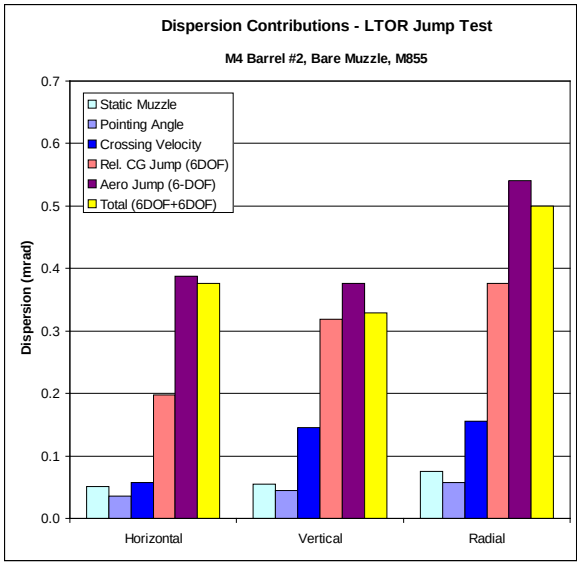




M4 Barrel #2, M855

Mann Barrel, M855

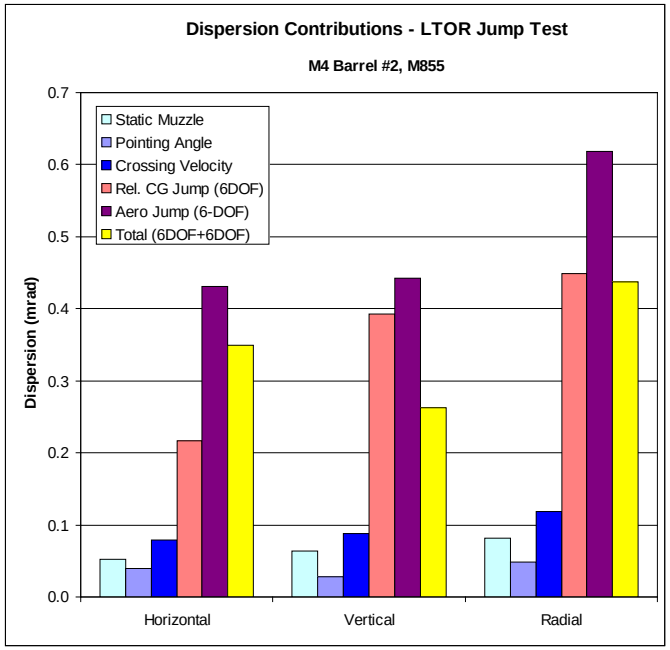


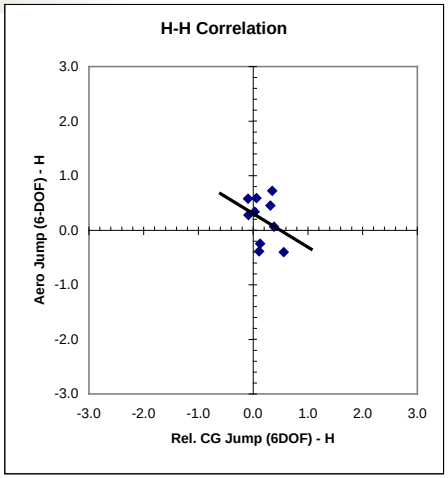


M4 Barrel #2, Bare Muzzle M855

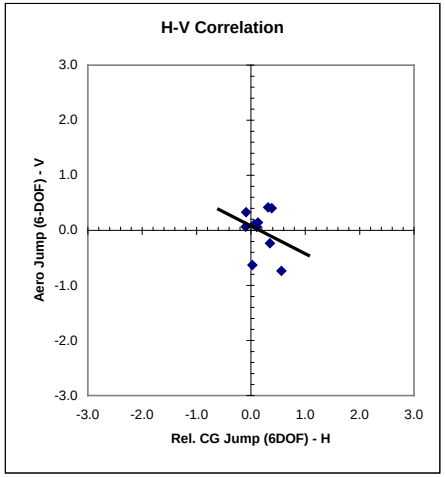
Approved for public release; distribution unlimited.

Correlations – Barrel #2, M855

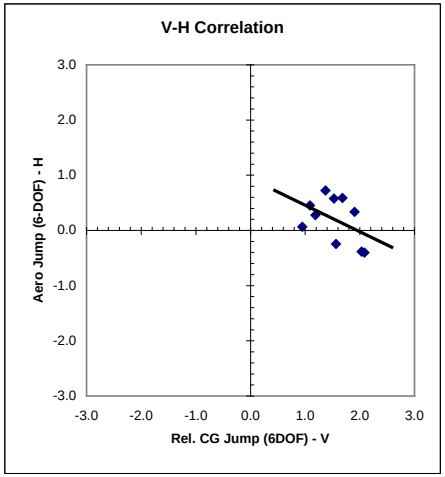




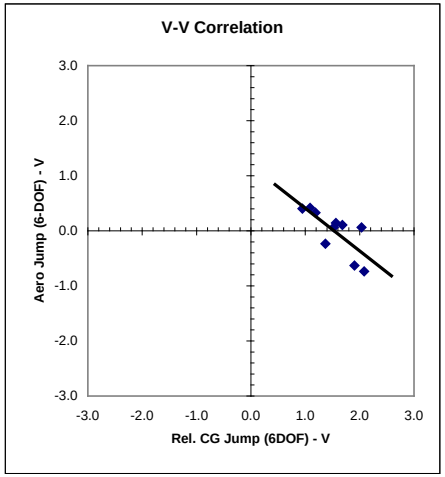
Correlation : -0.319
P value : 0.369
Confidence (%) : 63.1
Slope : -0.615



Correlation : -0.271
P value : 0.448
Confidence (%) : 55.2
Slope : -0.506



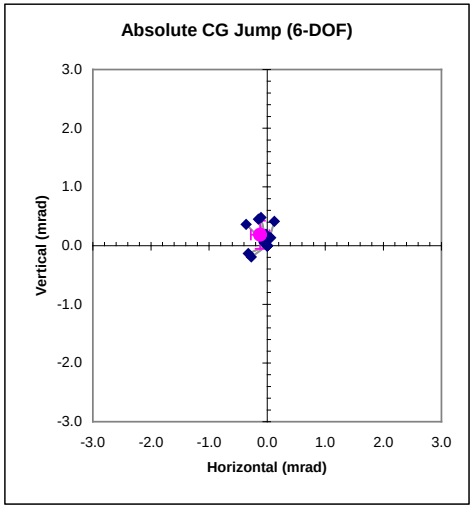
Correlation : -0.455
P value : 0.187
Confidence (%) : 81.3
Slope : -0.481



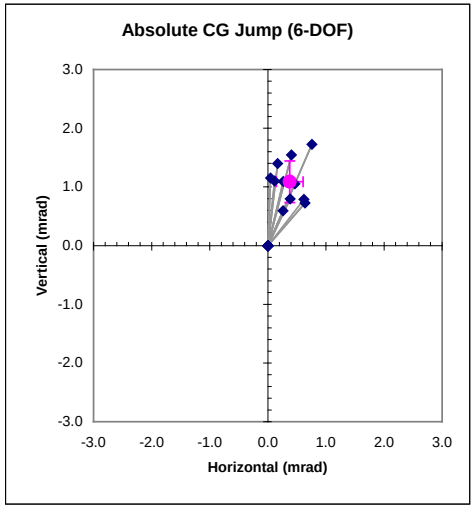
Correlation : -0.754
P value : 0.012
Confidence (%) : 98.8
Slope : -0.774

Muzzle compensator effect

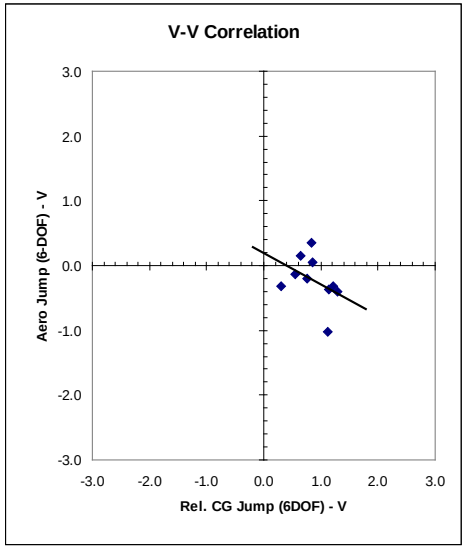
- Muzzle compensator is vertically asymmetrical
- Induces vertical CG jump and negative correlation

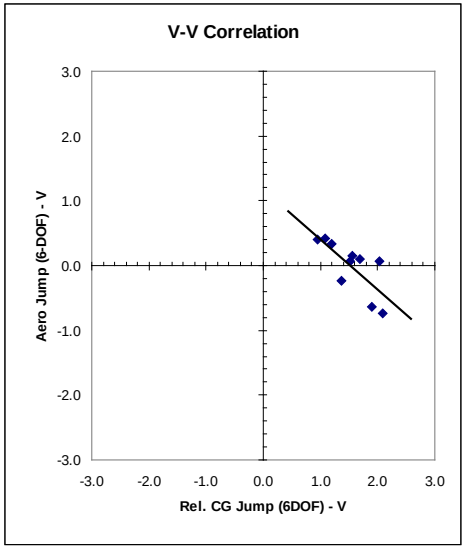


M4, Barrel #2, Bare Muzzle



M4, Barrel #2, With Compensator



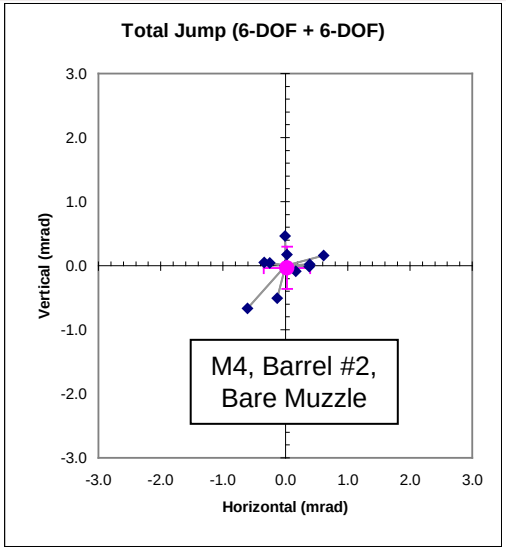


Approved for public release; distribution unlimited.

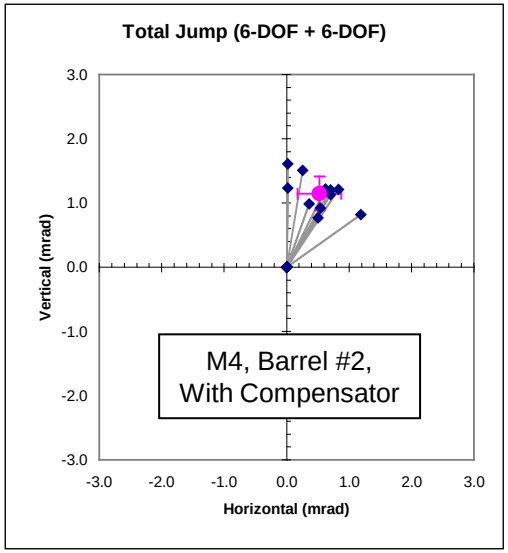
Muzzle compensator effect (continued)

- Magnitude of total jump increases dramatically
  - Total radial jump increase: 0.05 → 1.26 mrad
- Small decrease in dispersion of gun dynamics
  - Pointing angle RSD decrease: 0.06 → 0.05 mrad
  - Crossing velocity RSD decrease: 0.16 → 0.12 mrad
- Slight decrease in total dispersion
  - Total dispersion (RSD) decrease: 0.50 → 0.44 mrad
  - Dispersion decrease is mostly in vertical plane

Net effect of muzzle compensator seems to be positive (total dispersion is reduced).



Avg.=(0.03, -0.04) SD=(0.38, 0.33)



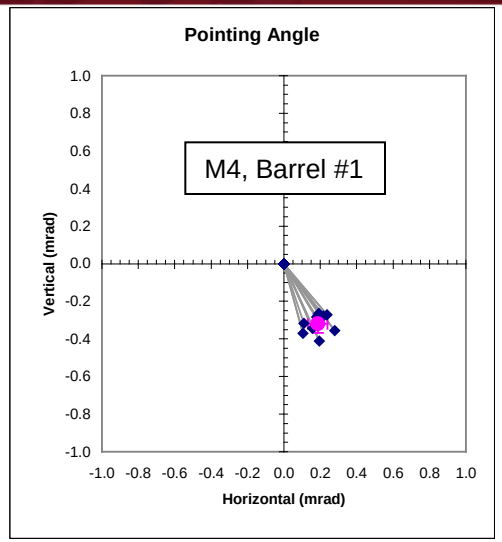
Avg.=(0.52, 1.15) SD=(0.35, 0.26)

Approved for public release; distribution unlimited.

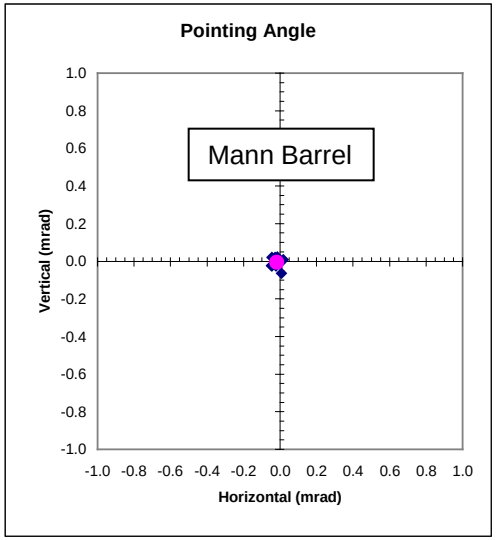
Mann Barrel Results

When compared to standard M4 (average of Barrels #1 and #2)

- Magnitude of gun dynamics is reduced dramatically
  - Pointing angle (radial): 0.38 → 0.02 mrad
  - Crossing velocity (radial): 0.29 → 0.05 mrad
- Smaller decrease in dispersion of gun dynamics
  - Pointing angle RSD: 0.06 → 0.04 mrad
  - Crossing velocity RSD: 0.11 → 0.04 mrad
- Slight reduction in total dispersion
  - Total dispersion (RSD): 0.42 → 0.33 mrad



Avg.=(0.19, -0.32) SD=(0.05, 0.05)



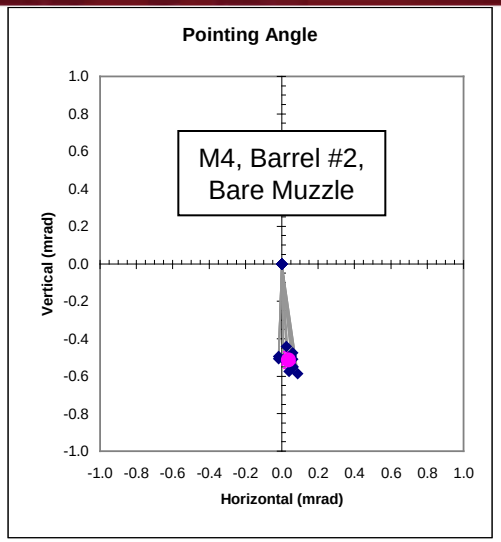
Avg.=(-0.02, -0.01) SD=(0.02, 0.03)

Approved for public release; distribution unlimited.

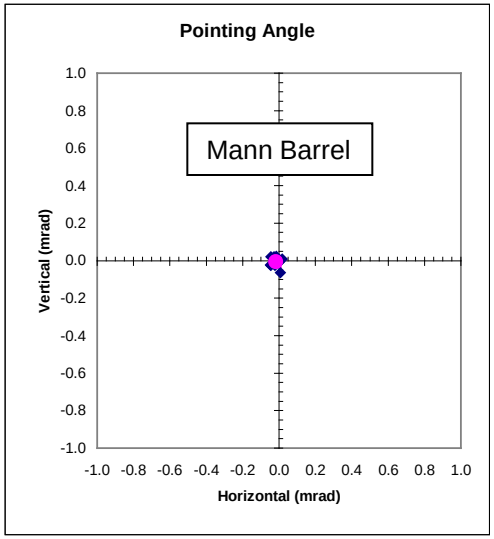
Mann Barrel Results

When compared to bare muzzle M4

- Magnitude of gun dynamics is reduced dramatically
  - Pointing angle (radial): 0.51 → 0.02 mrad
  - Crossing velocity (radial): 0.37 → 0.05 mrad
- Smaller decrease in dispersion of gun dynamics
  - Pointing angle RSD: 0.06 → 0.04 mrad
  - Crossing velocity RSD: 0.16 → 0.04 mrad
- Total dispersion is reduced
  - Total dispersion (RSD): 0.50 → 0.33 mrad



Avg.=(0.04, -0.51) SD=(0.04, 0.04)



Avg.=(-0.02, -0.01) SD=(0.02, 0.03)

Approved for public release; distribution unlimited.

Summary/Conclusions

- Jump test methodology has been developed and validated for small caliber weapon systems
- Gun dynamics account for approx. 25% of dispersion of M4, M855 system
- Negative correlations between CG and Aerodynamic jump reduce total dispersion
- Reducing component dispersions will not always reduce overall target impact dispersion
- Muzzle compensator seems to enhance negative correlations
- Mann barrel launch environment is significantly different from M4
  - Mann barrel testing seems to reduce contribution of gun dynamics to dispersion
  - Some benefit for ammunition comparisons (with caveats)
  - Not valid for assessing system performance

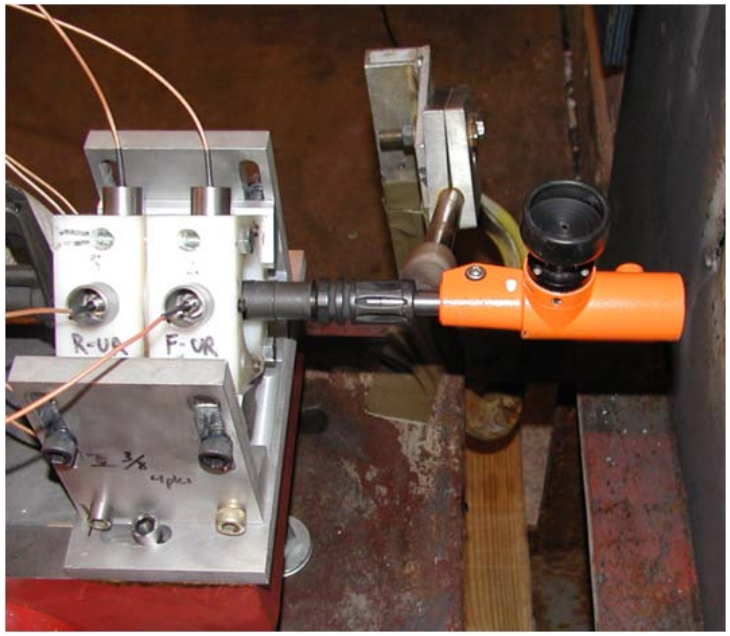
Approved for public release; distribution unlimited.

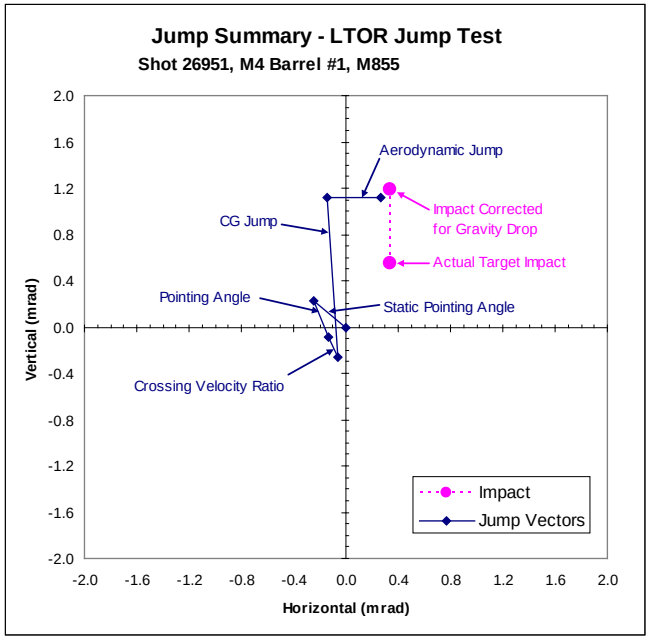
Backup Slides

Description of test setup, instrumentation, and measurement techniques

Jump Test Description

- Description of test setup, instrumentation, and measurement techniques
- Description of jump components

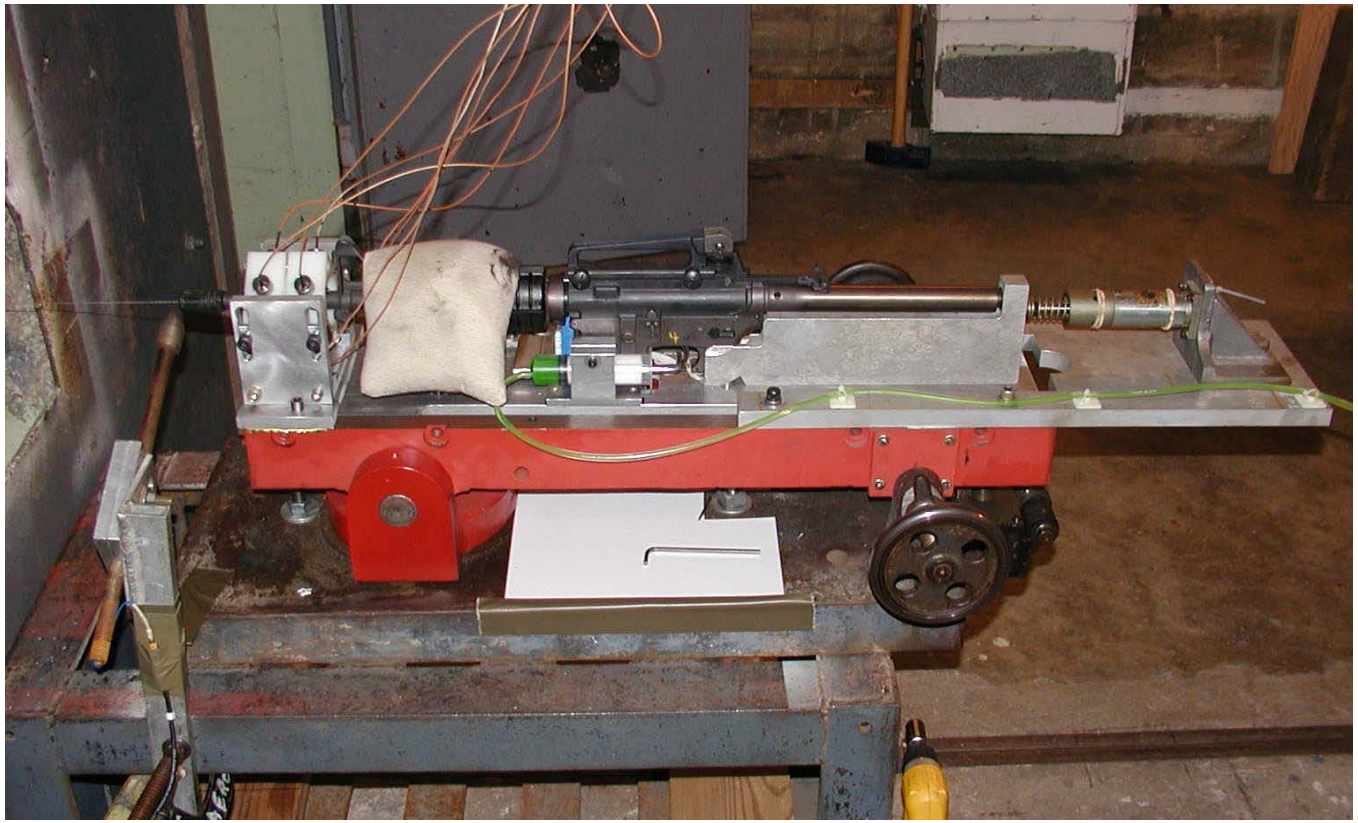




Approved for public release; distribution unlimited.

Gun mount

- Efforts were made to simulate a soldier holding the weapon by mounting the gun in a semi-rigid support
- The gun was allowed to recoil, the hand rest was supported underneath, and a shotbag was used to simulate grip



Approved for public release; distribution unlimited.

Testing was conducted in the ARL Aerodynamic Experimental Facility

39 direct image orthogonal shadowgraph stations in 5 groups

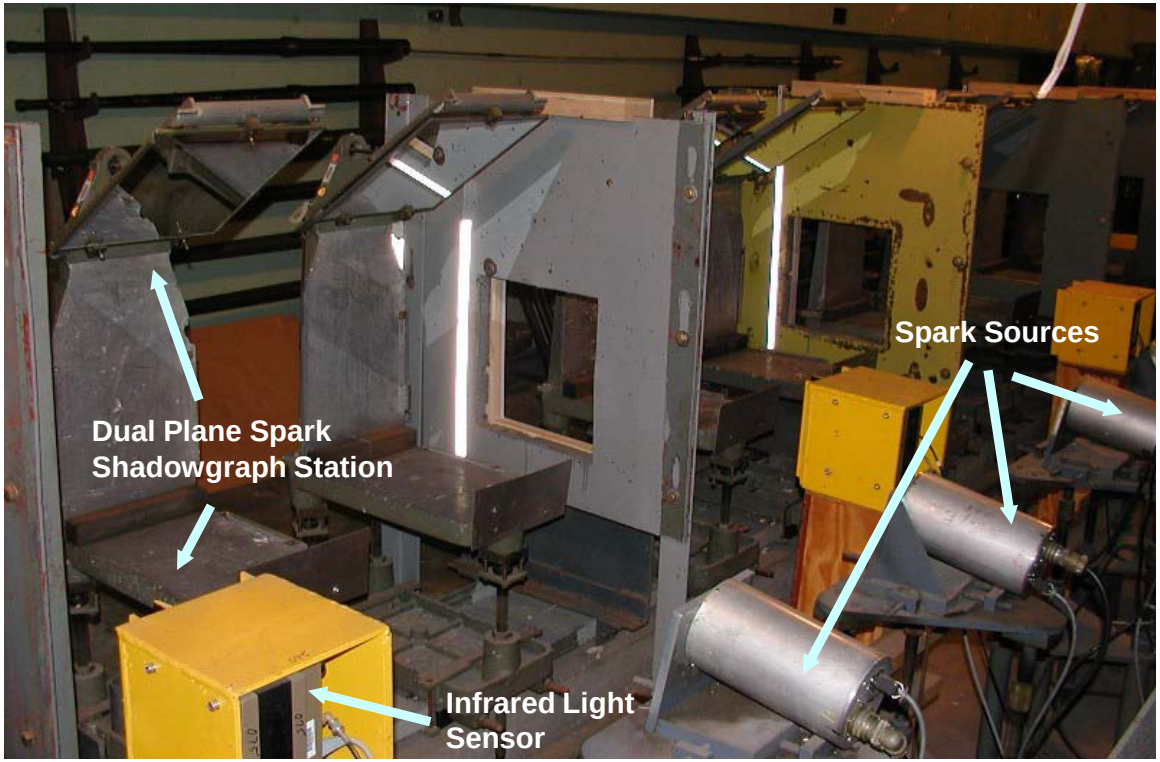


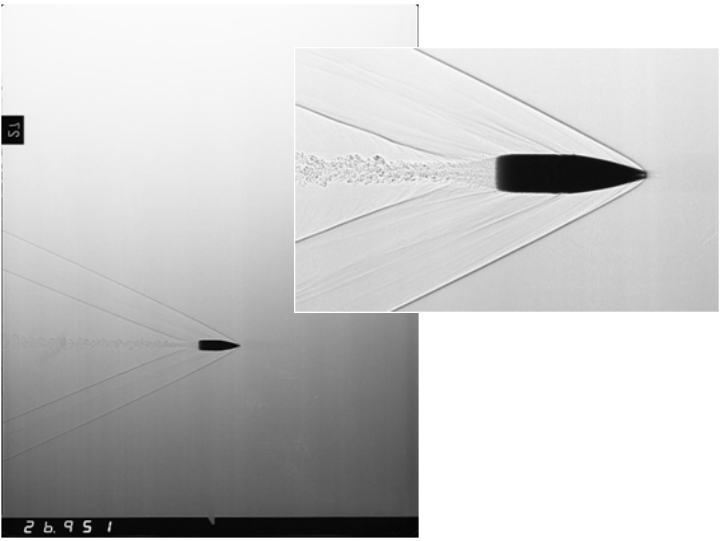
Image window is less than 14 inches across

Spark source triggered at a recorded time after infrared sensor detects passing projectile

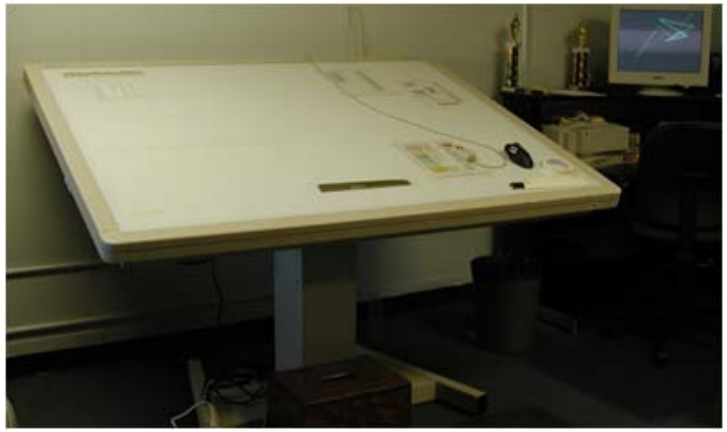
Each station surveyed into a fiducial system that is simultaneously imaged on the film with the projectile

Approved for public release; distribution unlimited.

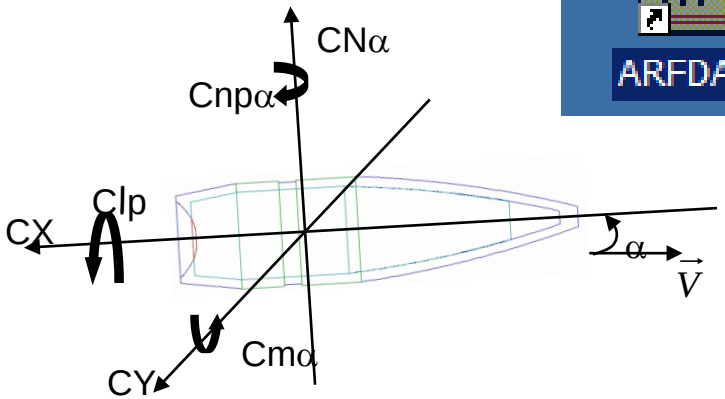
The spark shadowgraphs are used to obtain the projectile position and angle



Film is read using a precision light table to determine spatial coordinates and angular orientation of the projectile



Aero Range Facility Data Analysis Software – ArrowTech Associates



Data is reduced for a 6-DOF fit in order to obtain an aerodynamic model and motion fit

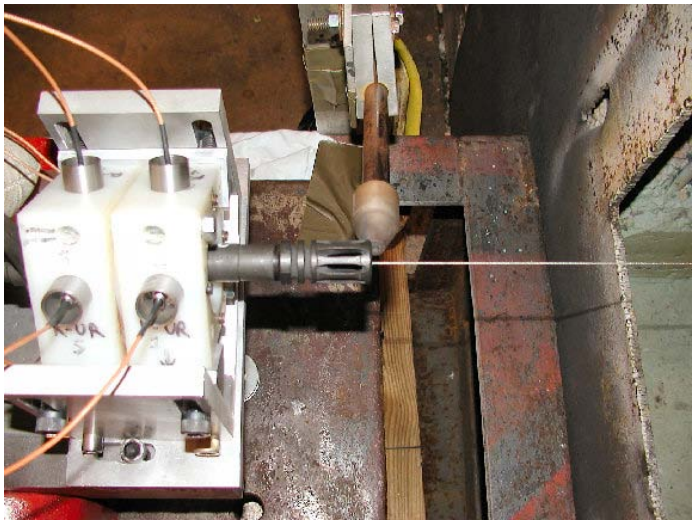
Approved for public release; distribution unlimited.

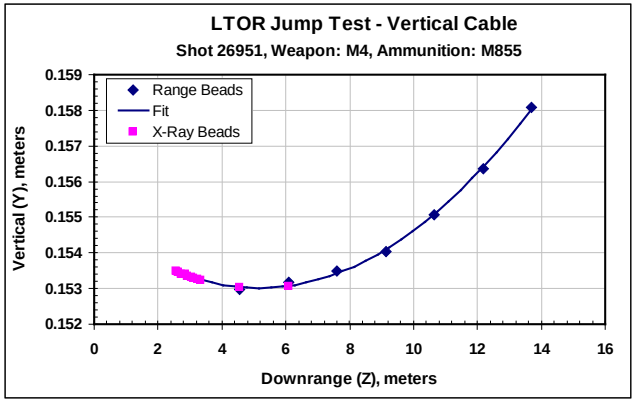
The initial line of fire (LOF) must be established in range coordinates

- LOF is defined by muzzle location and boresighted aimpoint
- Muzzle is located using fiducial cable hung through first group of range stations
- Aimpoint is measured in range coordinates

Approved for public release; distribution unlimited.

The muzzle location is determined by hanging a fiducial cable



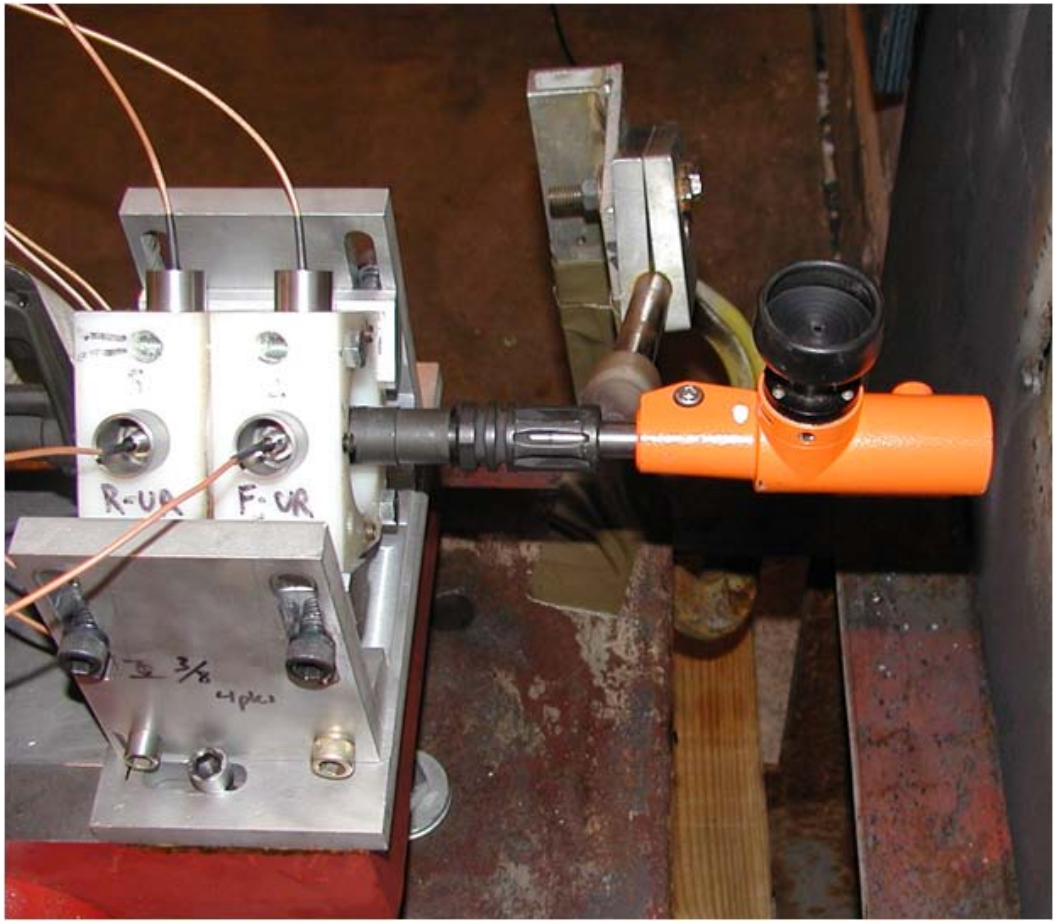


- Cable extends from muzzle through first group of range stations
- Calibrated bead locations are measured in range coordinates
- Extrapolated fit defines muzzle position (and x-ray beads)

Approved for public release; distribution unlimited.

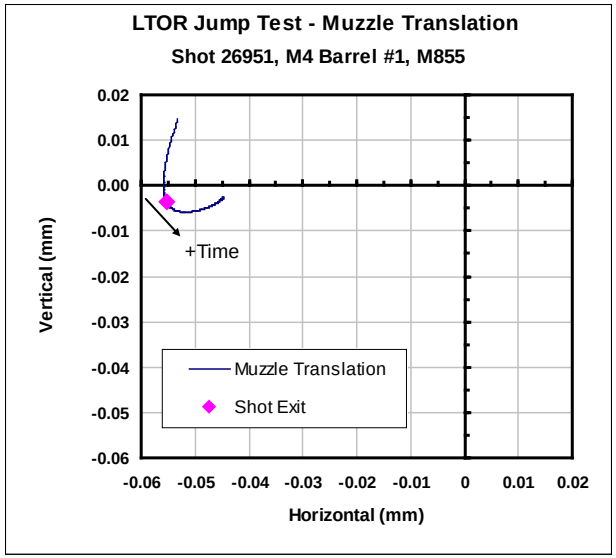
Gun motion is measured using proximity (eddy current) probes

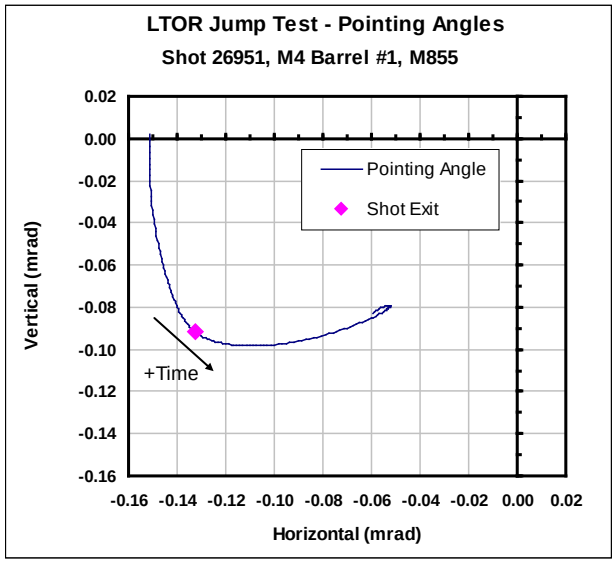
- Initial (boresighted) angle
- Dynamic angle and motion at shot exit

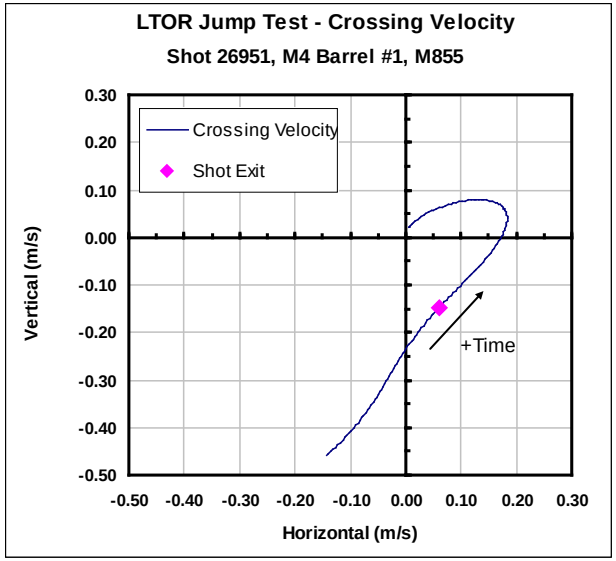


Approved for public release; distribution unlimited.

The eddy probe data is processed to determine the muzzle condition at shot exit





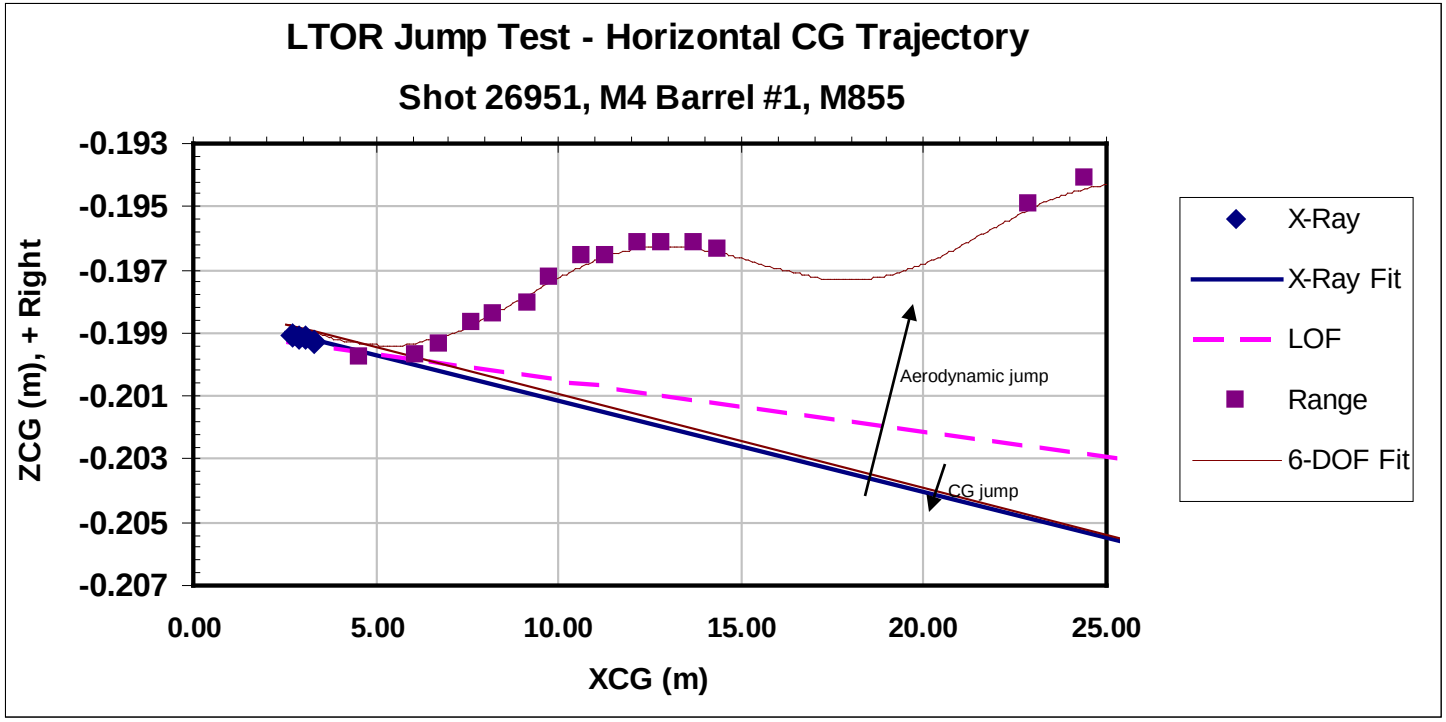


- Muzzle Pointing Angle – where the gun muzzle is pointed at instant of shot exit
- Muzzle Crossing Velocity – which way the gun muzzle is moving at shot exit

Approved for public release; distribution unlimited.

Initial CG trajectory is determined from the spark range data

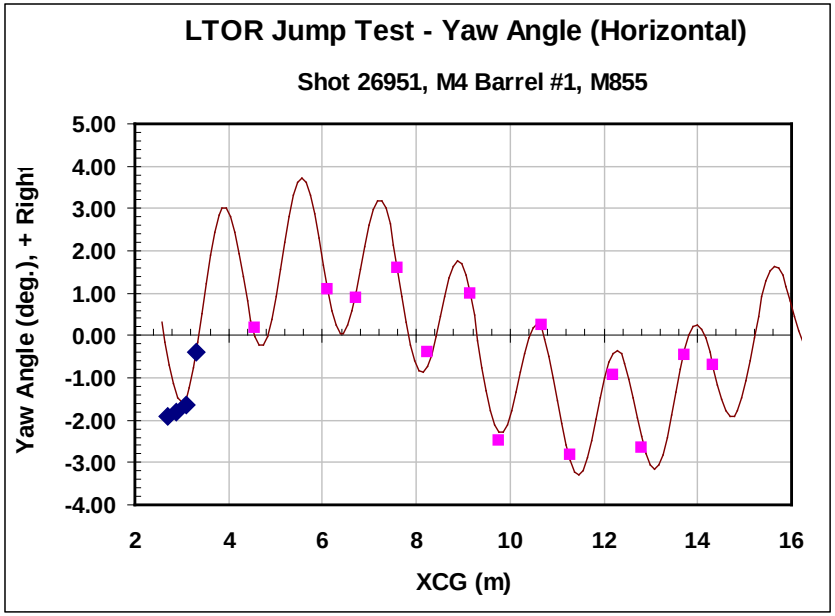
- Initial tests showed x-rays were not needed
- 6-DOF fit to range data is extrapolated back to muzzle to get initial trajectory

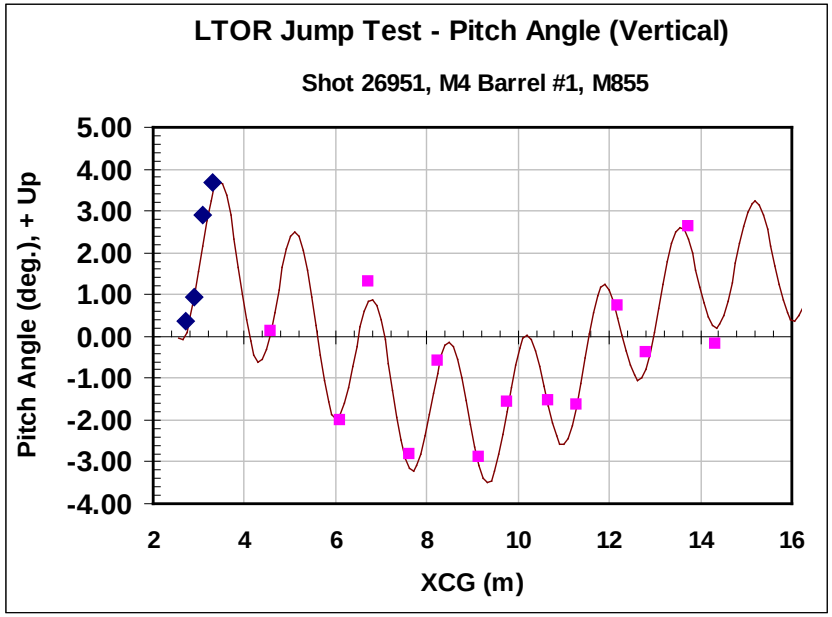


Approved for public release; distribution unlimited.

Aerodynamic jump is calculated from initial angles, angular rates, and aerodynamic coefficients

$$A_J = \left(\frac{I_y}{md^2}\right)\left(\frac{C_{L_\alpha}}{C_{M_\alpha}}\right)\left[i\left(\frac{I_x}{I_y}\right)\left(\frac{pd}{V}\right)\xi_0 - \xi_0'\right]$$



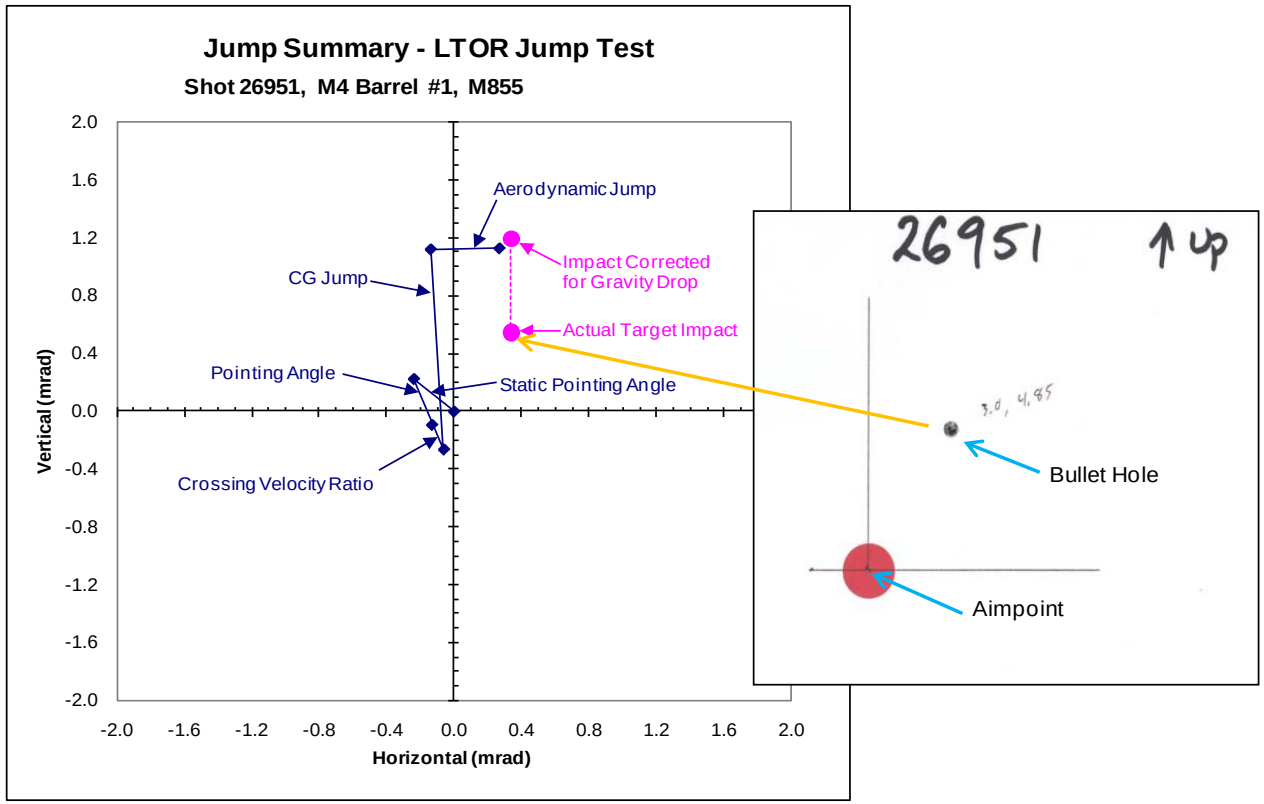


- Initial tests showed x-ray angular measurements were unreliable
- Initial angles and rates are obtained by extrapolating 6-DOF fit of range data back to the gun muzzle
- Aerodynamic coefficients obtained from 6-DOF fit of range data and augmented with results from previous testing

Approved for public release; distribution unlimited.

Impact location is measured on the target

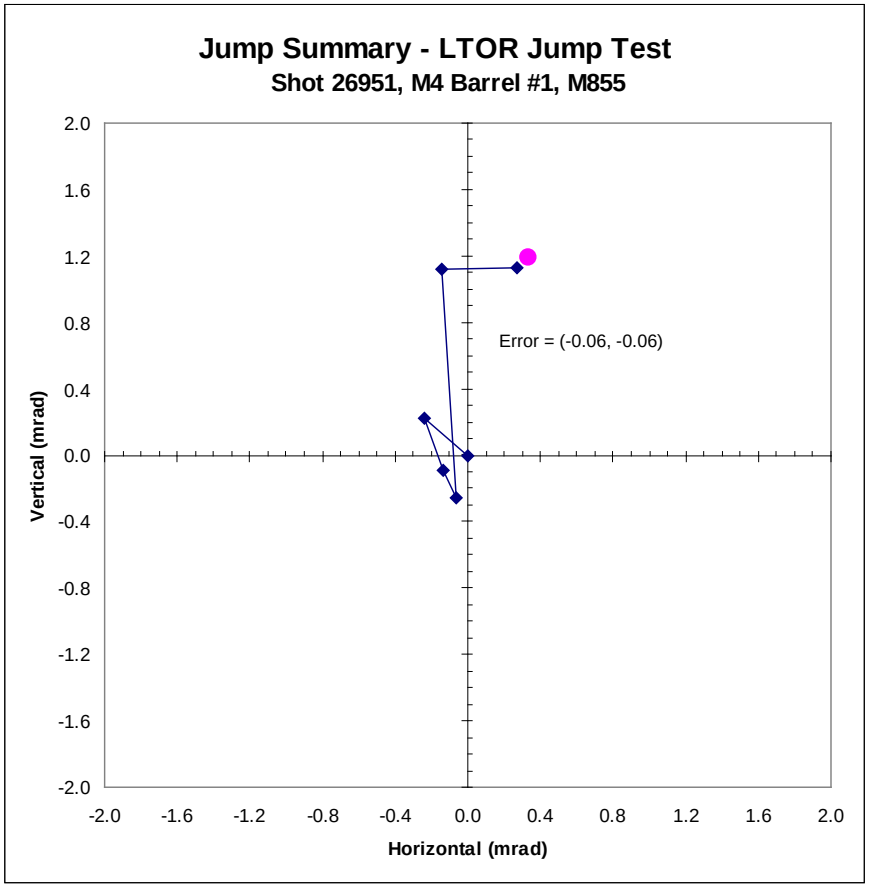
- Impact is measured relative to aimpoint
- Impact is adjusted for gravity drop



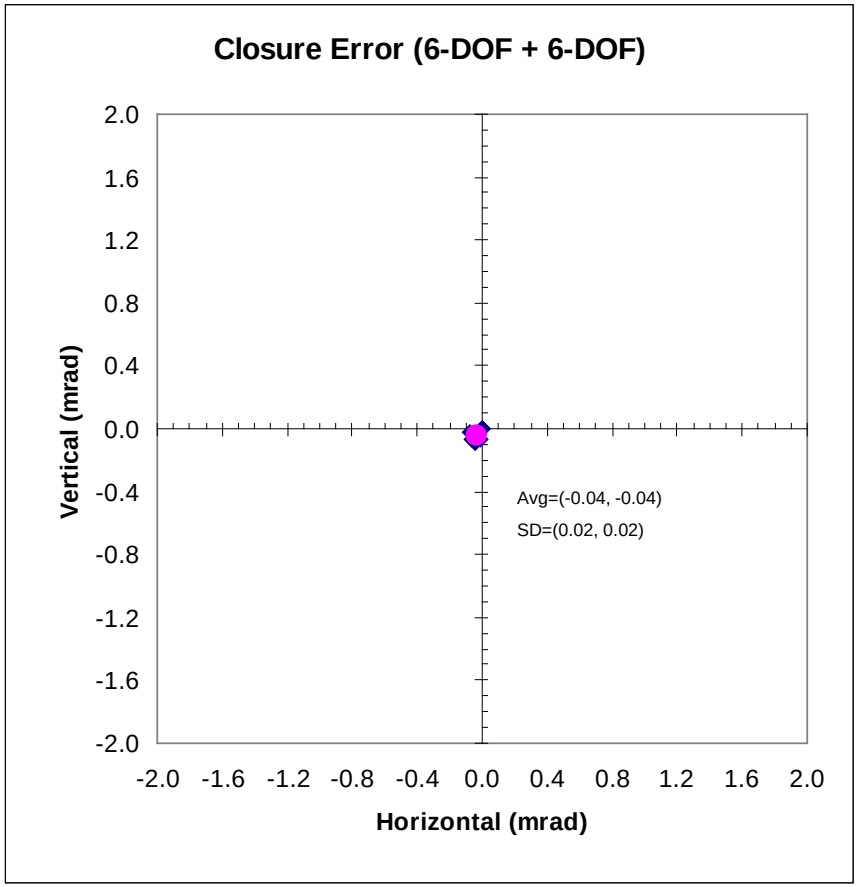
Approved for public release; distribution unlimited.

Closure is determined by comparing vector sum of jump components with adjusted impact

Closure diagram for single shot



10-shot group, M4 Barrel #1, M855



Traditionally, closure is declared when error < 0.2 mrad
For this test setup, 1 bullet diameter = 0.06 mrad.

Approved for public release; distribution unlimited.

Contact Info

Ilmars Celmins
U.S. Army Research Laboratory
ATTN: RDRL-WML-E
Aberdeen Proving Ground, MD 21005-5066
410-306-0781 Fax: 410-306-0666
Email: ilmars.celmins.civ@mail.mil