GENERAL DYNAMICS
Armament and Technical Products

PHALANX

ARROW TECH

If you Can't Get a Bigger Target...

Optimized Gun Barrel Targeting Investigation

Jeff Siewert
Arrow Tech Associates
Systems Engineer

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Outline

- Requirements & Problem
- Diagnostic Tests
- Targeting Background & MPI Shift Sources
- Analyses & Measurements
- Firing Results
- Conclusions

- Thanks to Ms. JoAnn Kramer, GDATP Phalanx PM

OGB Targeting Requirements

Burst Dispersion – One Sigma

- Req'mt < 1.0 milr

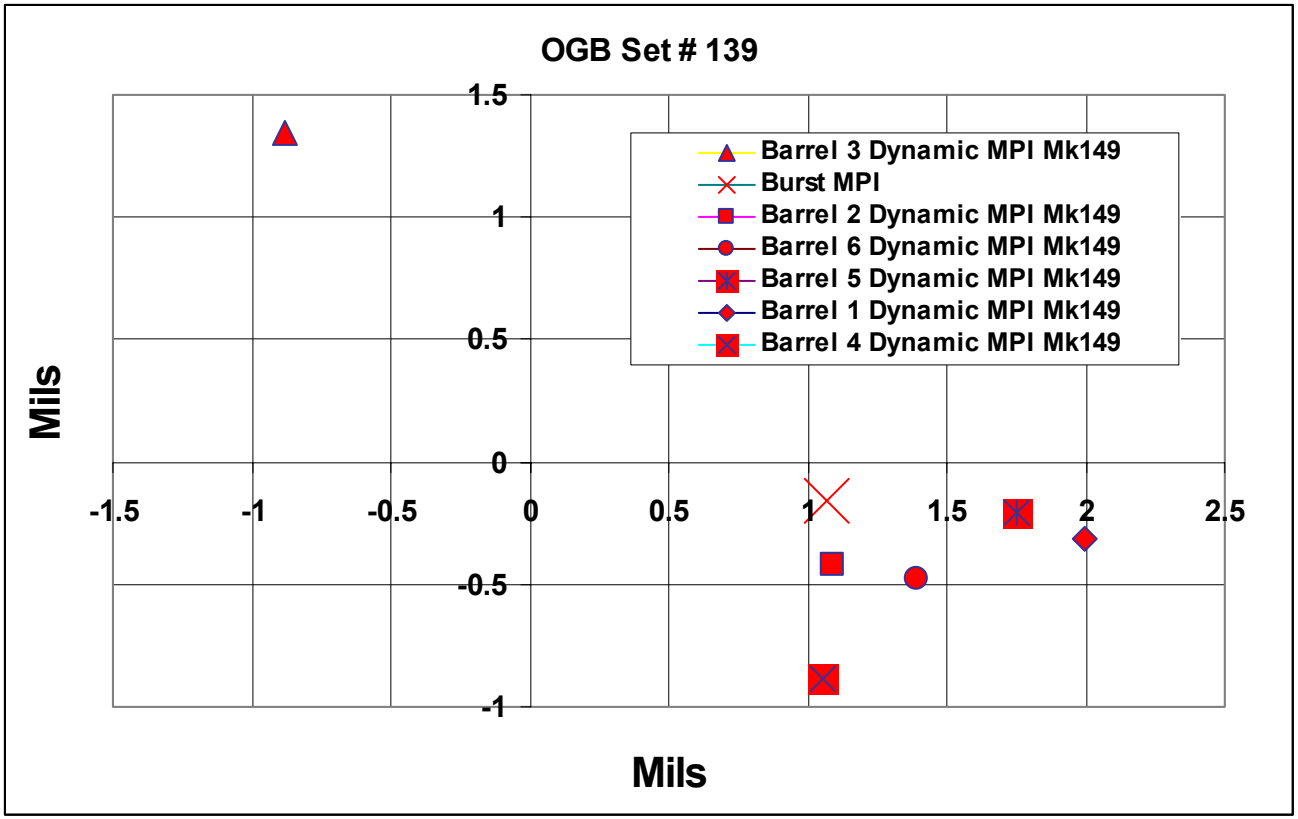
Max Individual Bbl MPI wrt Burst MPI

- Req'mt < 1.5 milr

Average Bbl MPI wrt Burst MPI

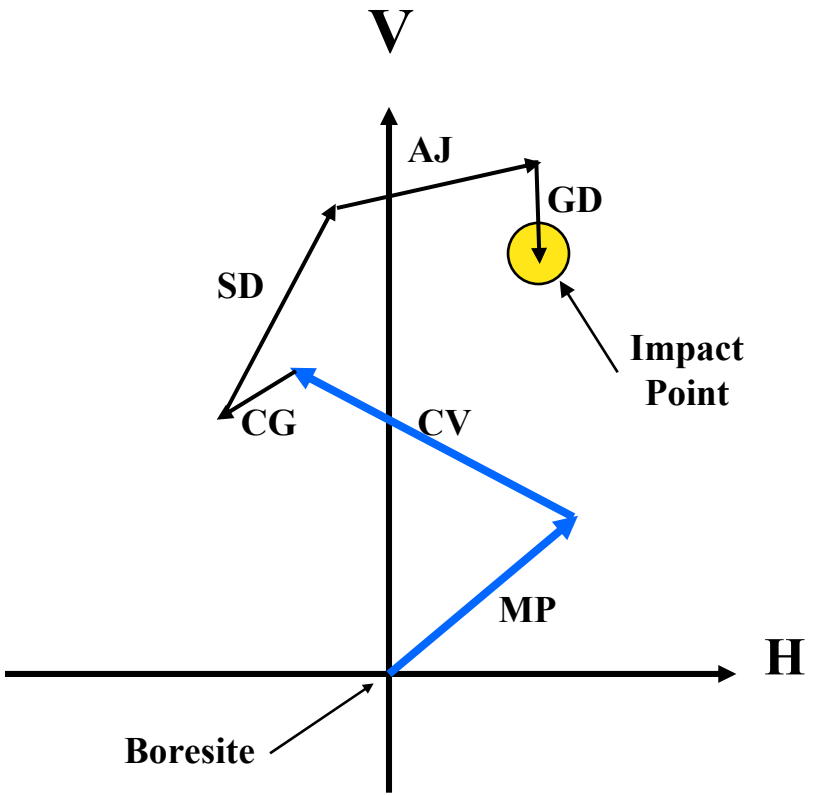
- Req'mt < 1.0 milr

Typical "Problem" Target



- MPI of one or more barrels fails to fall within 1.5 milr of average burst MPI
- Barrels meet TDP established during system qualification

Background: Jump Budget



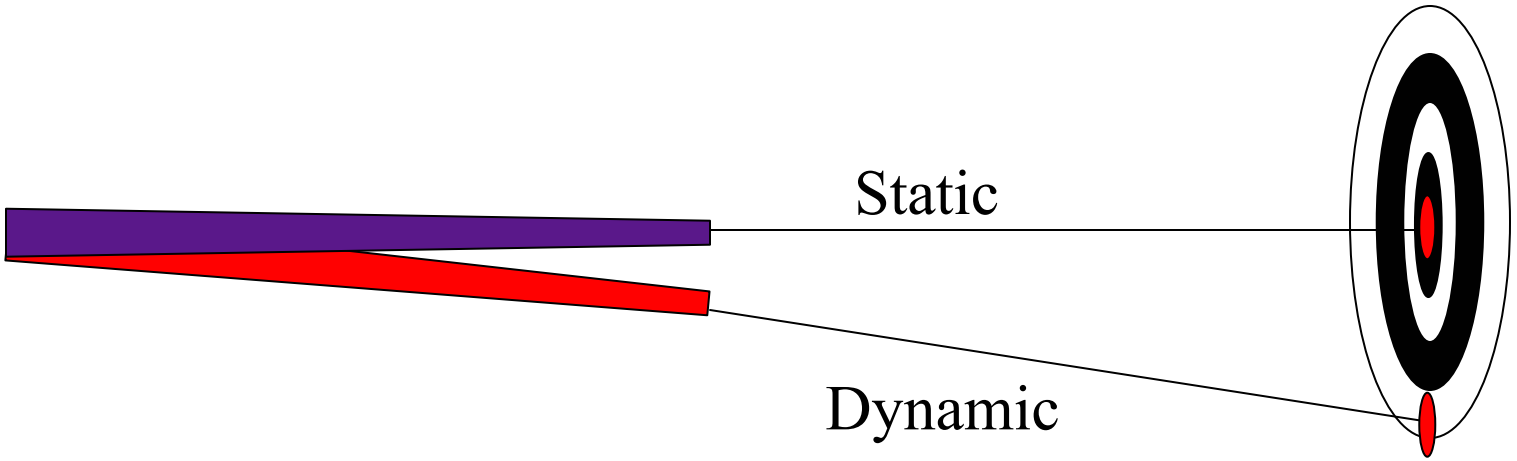
MP = Muzzle Pointing
CV = Barrel Cross Velocity
CG = Projectile CG Cross Velocity
SD = Sabot Discard
AJ = Aero Jump
GD = Gravity Drop

- Objective: Make MP & CV small, repeatable on a barrel-barrel basis

MPI Shift Sources

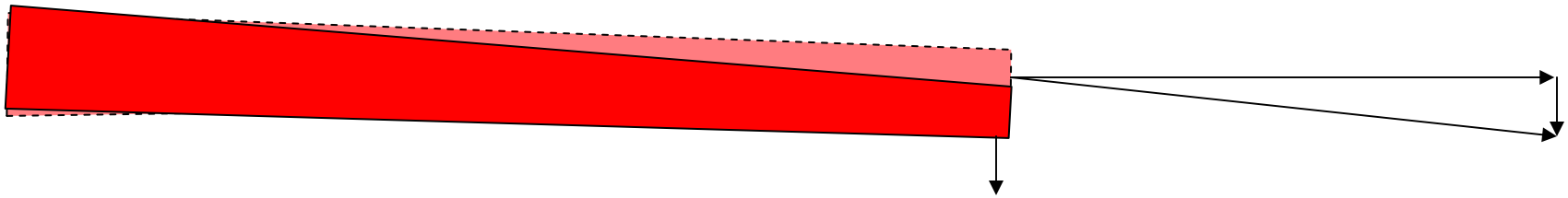
- Bore Straightness (pointing, x velocity, angular rate)
- Barrel Ring Length (pointing, bending stiffness)
- Chamber Run Out (initial condition bias)
- Gun Dynamics (pointing, x velocity, angular rate)
- External sources (e.g. Blast, Sabot Discard)

Barrel Pointing



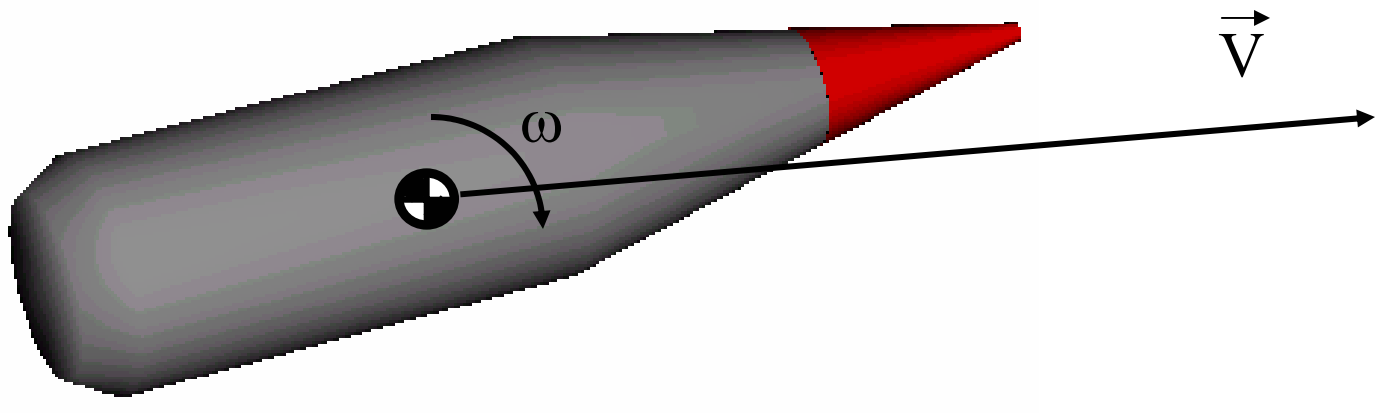
- At muzzle exit, tube is not aligned with static boresite point
  - ↗ Symptoms: Impact not at boresite point, no yaw visible, tube motion during in bore travel
- Caused by: bore curvature, projectile-barrel interactions

Barrel Cross Velocity



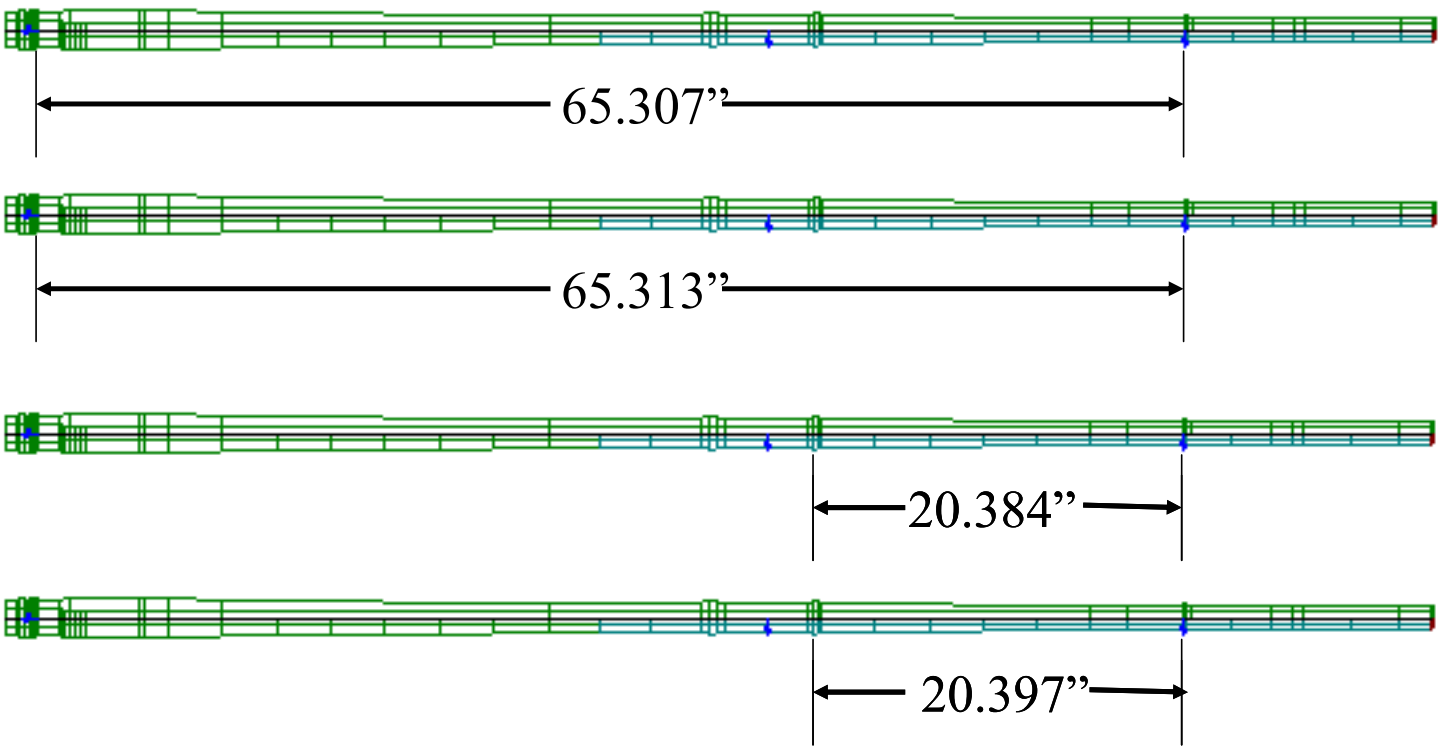
- At projectile release, velocity vector is imparted to the projectile perpendicular to muzzle velocity
  - ↗ Symptoms: Impact not at boresite point, no yaw visible, tube motion during in bore travel
- Caused by: Barrel run-out, bore curvature, L-G Run out, projectile CG offset, projectile-barrel interactions

Preferred Angular Rate



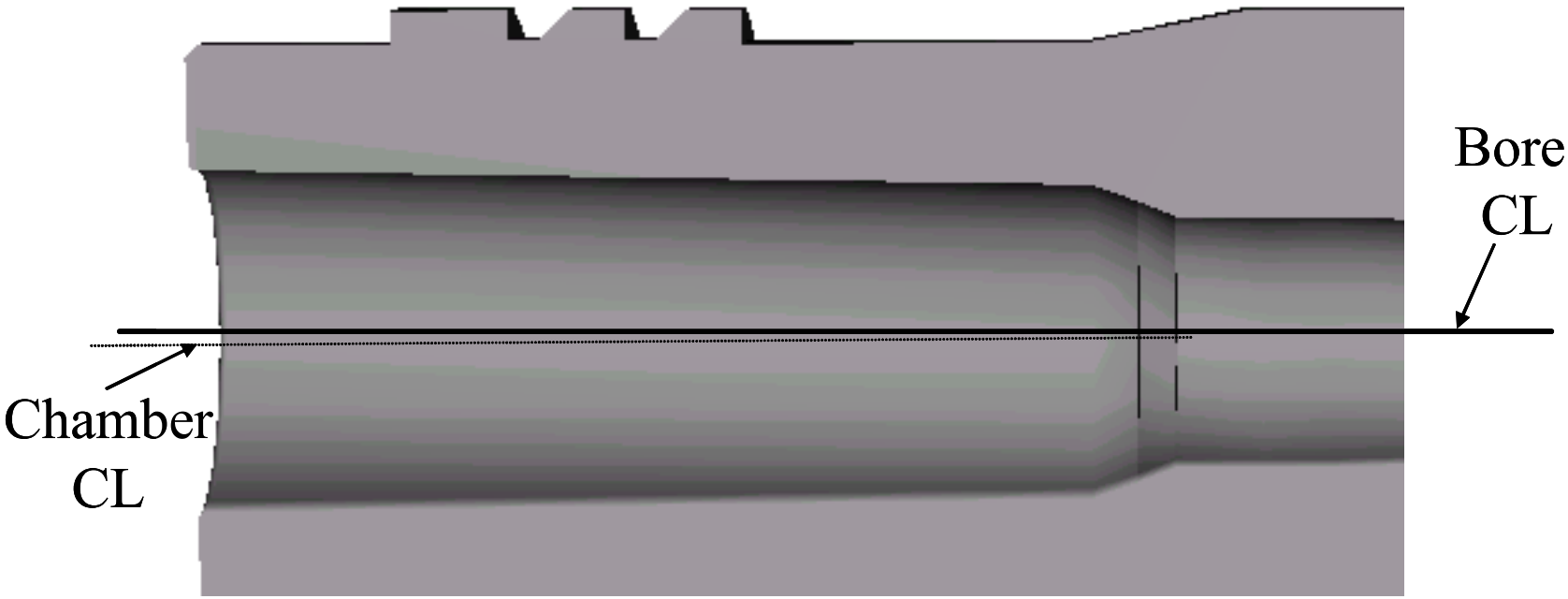
- Moment applied to projectile at muzzle release
  - ↗ Symptoms: Yaw Visible, Preferred Orientation = MPI Shift; Random Orientation = dispersion
- Sources: In bore clearance x spin, projectile–barrel interactions, bore curvature, change in bbl cross velocity between fwd & aft bourrelet release, etc.

Barrel "Ring" Length



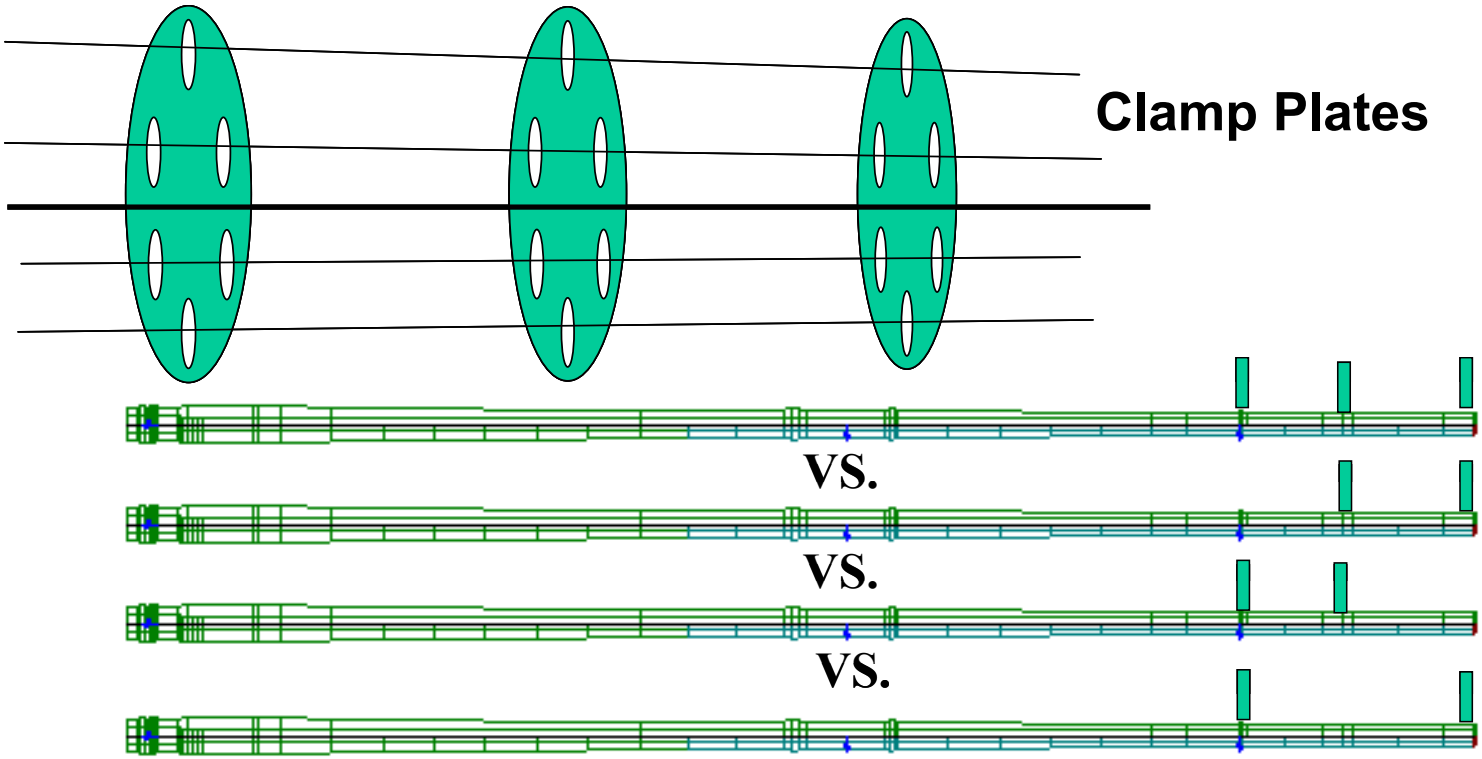
- Minor Effect on Pointing
- Potentially Large Effect on cluster bending stiffness
- Effect of mid bbl clamp & muzzle clamp axial gaps

Chamber Run Out



- Easily visible if present in forcing cone
- Not observed on “problem” barrels

Gun Dynamics: Clamping Variability



- Small changes barrel-barrel cause variations in boundary conditions (location of applied mass) for each barrel
- Interactions occur w/ bore straightness, projectile & barrel stiffness
- Can cause large changes in Mean Point of Impact

Gun Dynamics: Balloting Simulation

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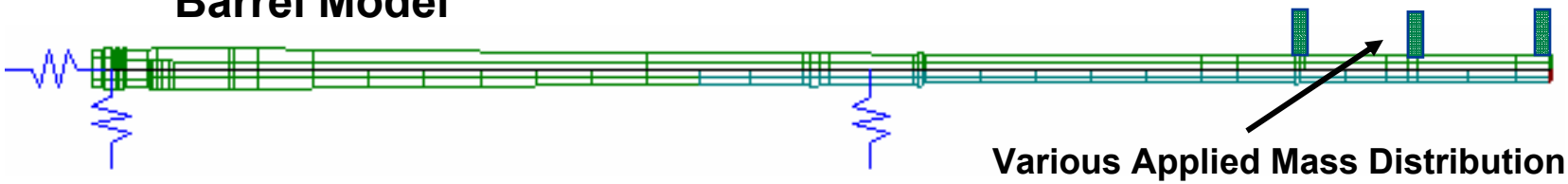
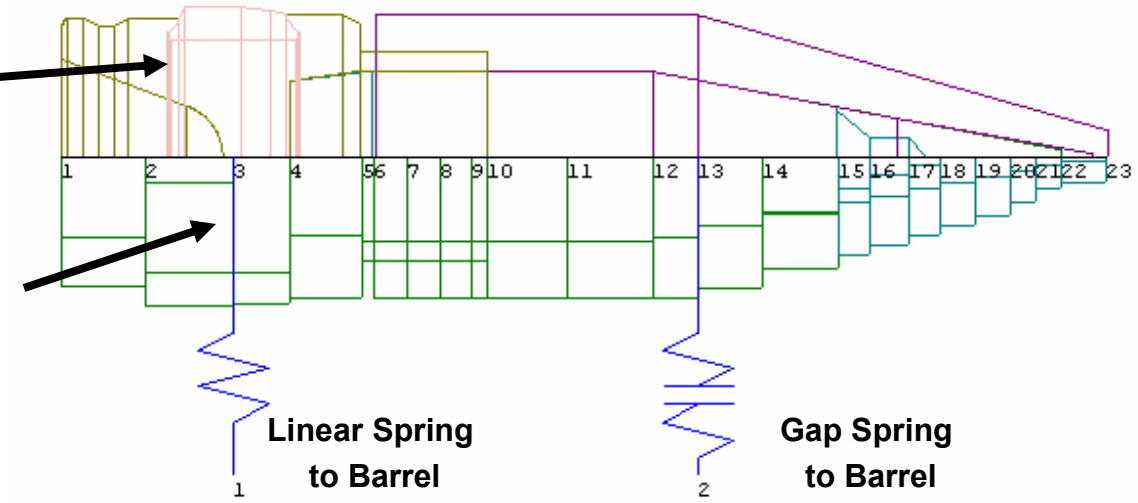
Barrel Model



Various Applied Mass Distribution

Projectile Geometry

Lumped Mass & Beam Element Projectile Model



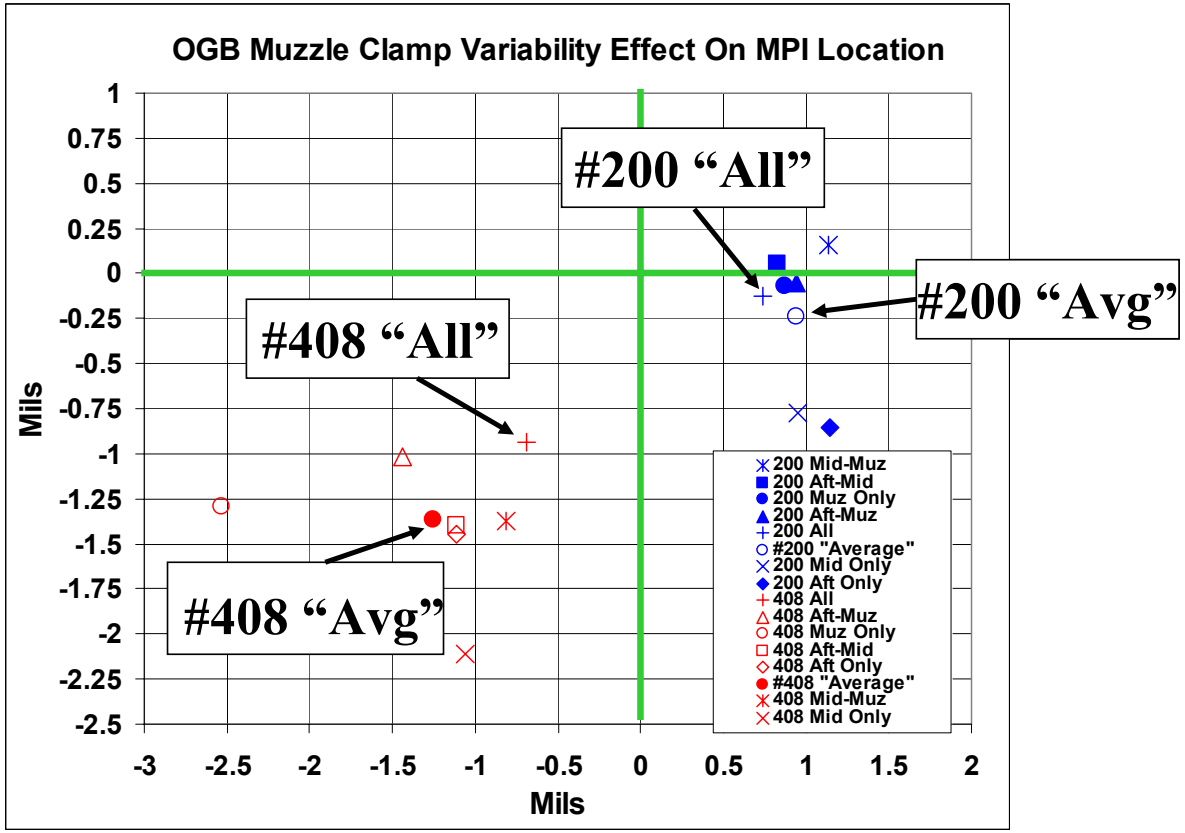
Linear Spring to Barrel

Gap Spring to Barrel

- Balloting Analysis Model of Barrel & Projectile
- 500 Runs in Monte Carlo Mode to Obtain MPI

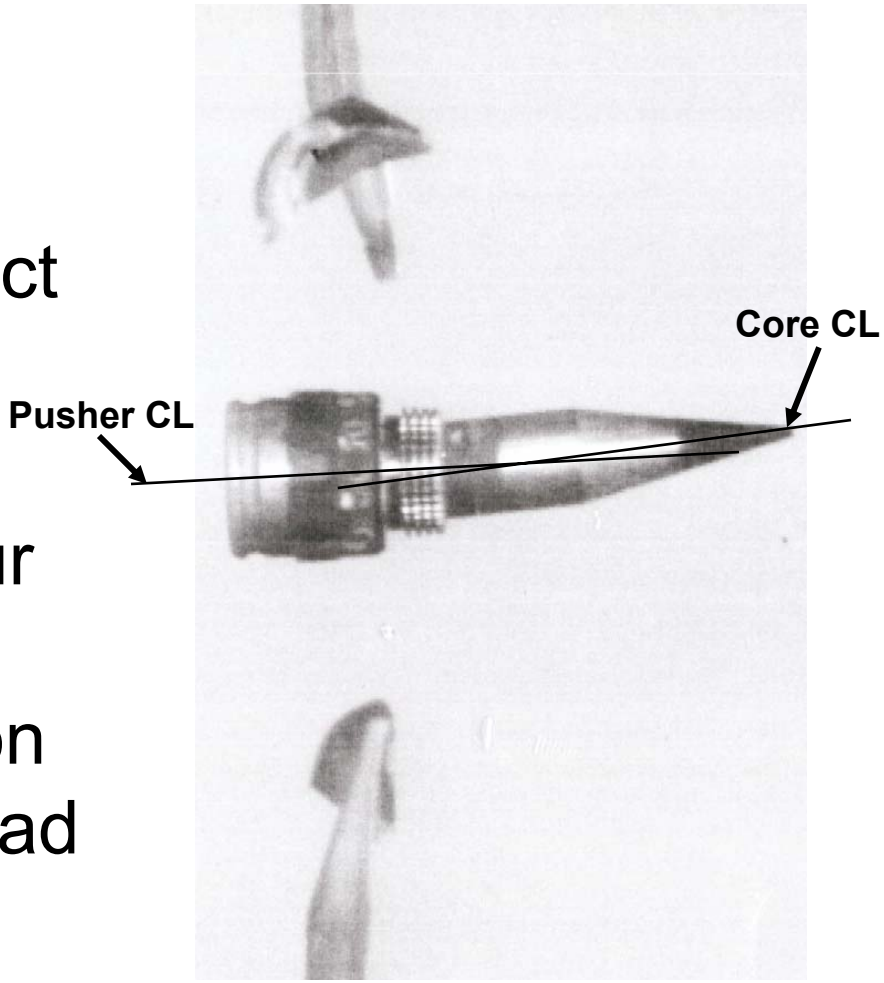
Clamping Variability Targeting Results

- Results of analytical treatment of balloting interaction between flexible barrel & projectile
- 500 simulations per predicted impact point
- #200 is “straight”, #408 has ~ 0.009” TIR change over last 3” of travel
- Illustrates need to make bore straight
- Illustrates need to make clamping consistent



Sabot Discard

- Mismatched yaw period of pusher & core guarantee impact w/ hi angular rates
- Large jump can occur for very small lateral impulse depending on location of applied load



Investigation Plan

Nov 2003

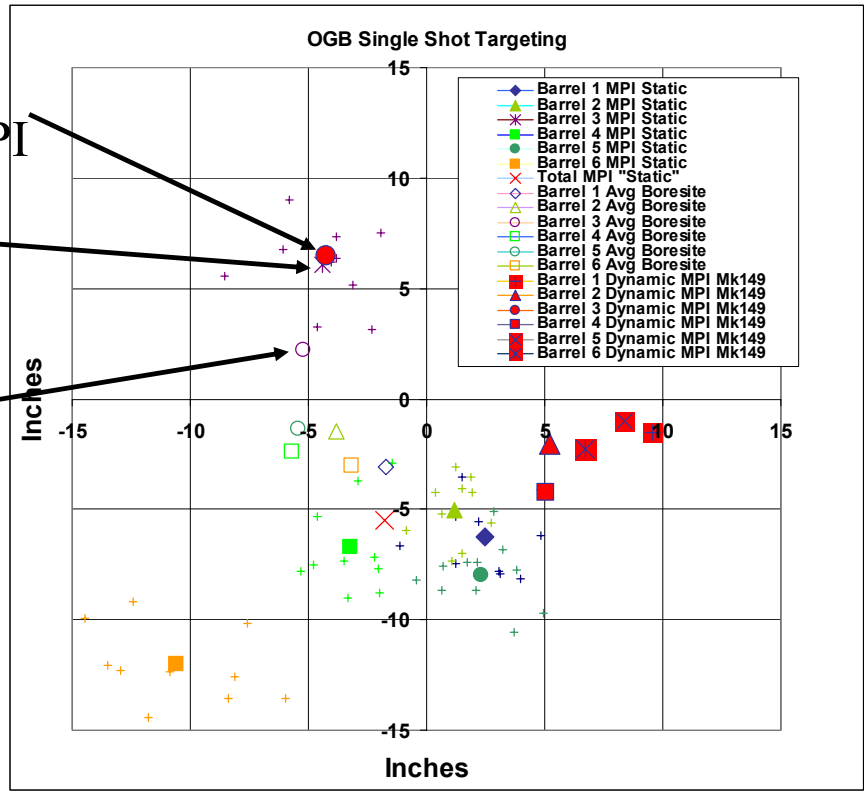
- Single Shot Firing of Barrels & Clamps comprising Kit # 139 w/ Mk-244 Ctgs.
- Purpose: Determine which barrel parameter affects targeting
- Compare static results w/ dynamic firing to isolate gun dynamic effects
- Trends visible useful for “screening”?

Diagnostic Test Target

BBL 408
Dynamic MPI

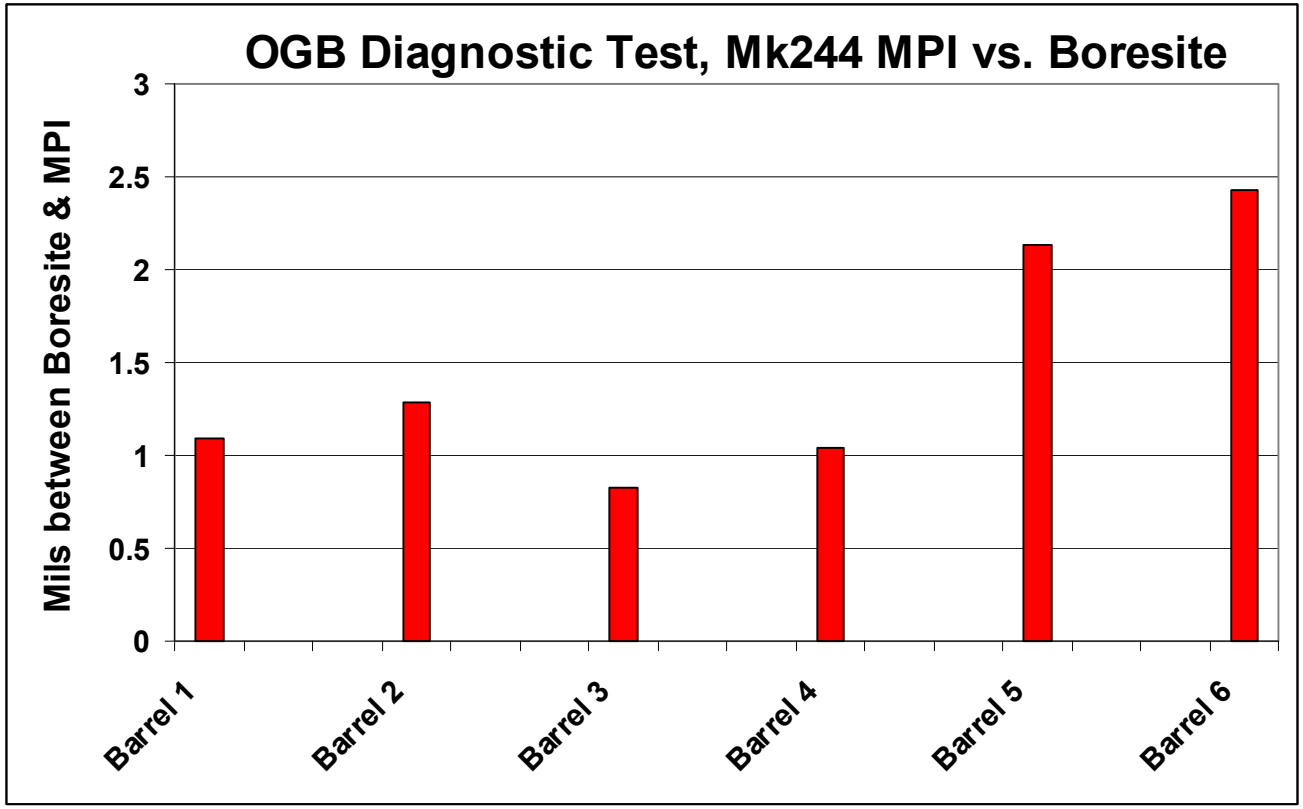
BBL 408
Static MPI

BBL 408
Boresite



- Kit 139, Autogun Fired in single shot mode
- Projectiles from bbl 3 (#408) & bbl 6 (#465) have yaw

MPI vs. Boresite



- Barrel 3 (#408, problem barrel) hits closest to boresite!!
- Why is Barrel 3 MPI so far from other barrels??

Single Shot Test Results

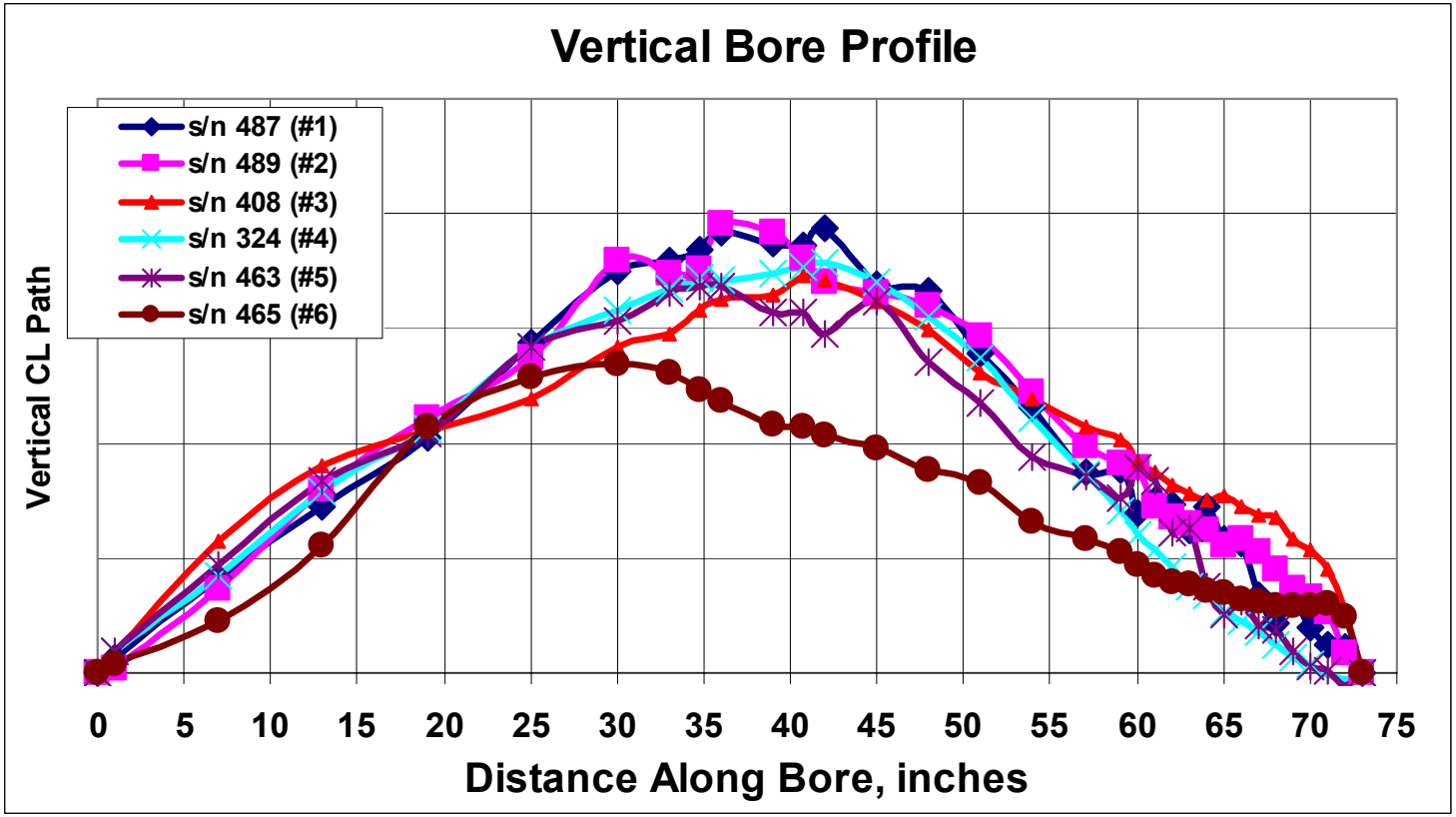
	Yaw Angle @ 400 ft Deg.	$\alpha^{\cdot}$ @ muzzle rad/sec.	Expected Jump Mils	Implied Clearance inches
Barrel #6	9.5	~200	~2.13	~0.026
	7.5	~160	~1.70	~0.021
	7.5	~160	~1.70	~0.021
	5.0	~105	~1.12	~0.014
	5.0	~105	~1.12	~0.014
	2.0	~ 42	~0.45	~0.005
Barrel #3	7.5	~160	~1.70	~0.021
	7.5	~160	~1.70	~0.021
	5.5	~116	~1.23	~0.015
	3.0	~ 63	~0.67	~0.008

- **Large yaw levels imply in bore disturbance**
- **Examine bore straightness**

Bore Straightness Investigation

- Laser (optical) measurement of bore
  - Map entire bore profile
- Wiggler (mechanical) measurements of bore
  - Map muzzle end of bore

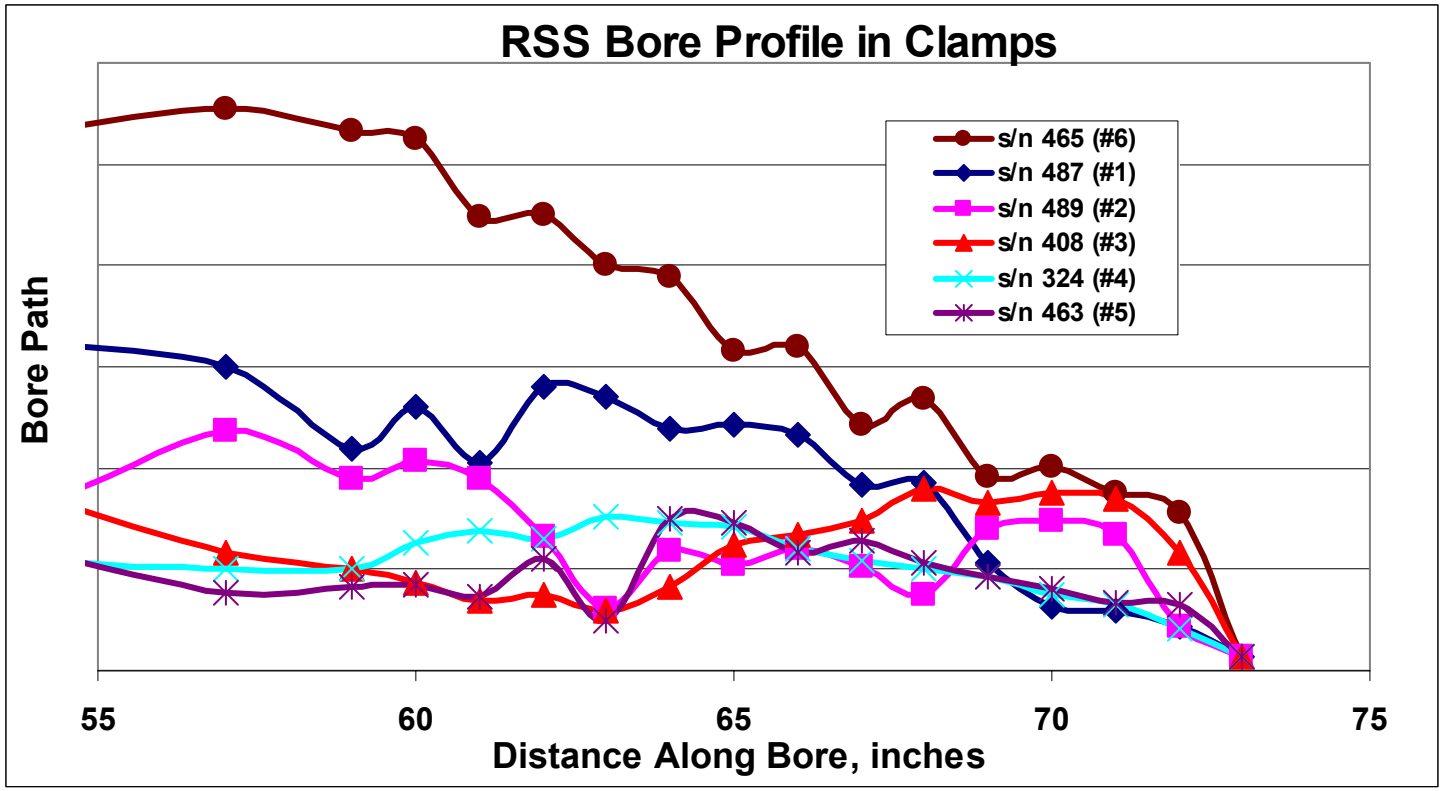
Bore Straightness in Clamps



Barrels supported at aft & mid barrel (~ 39”)

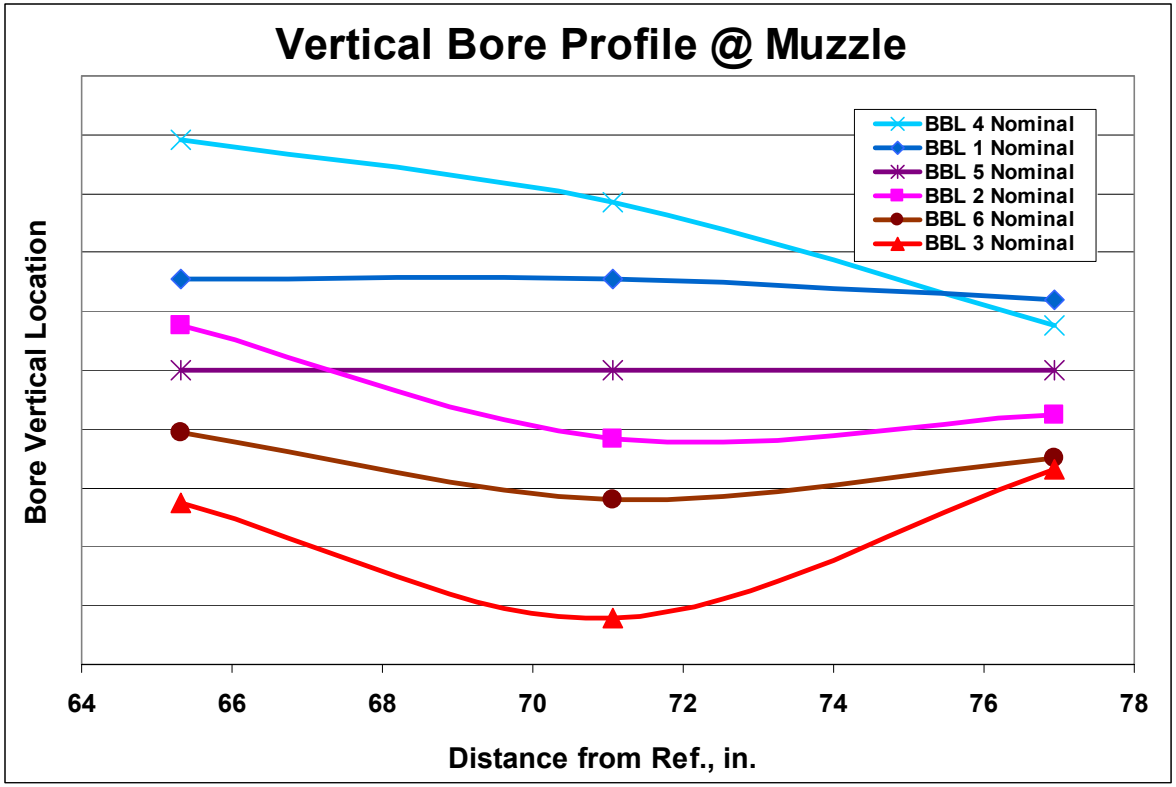
Mathematically zeroed at breech & muzzle

Kit 139 Muzzle Close-up



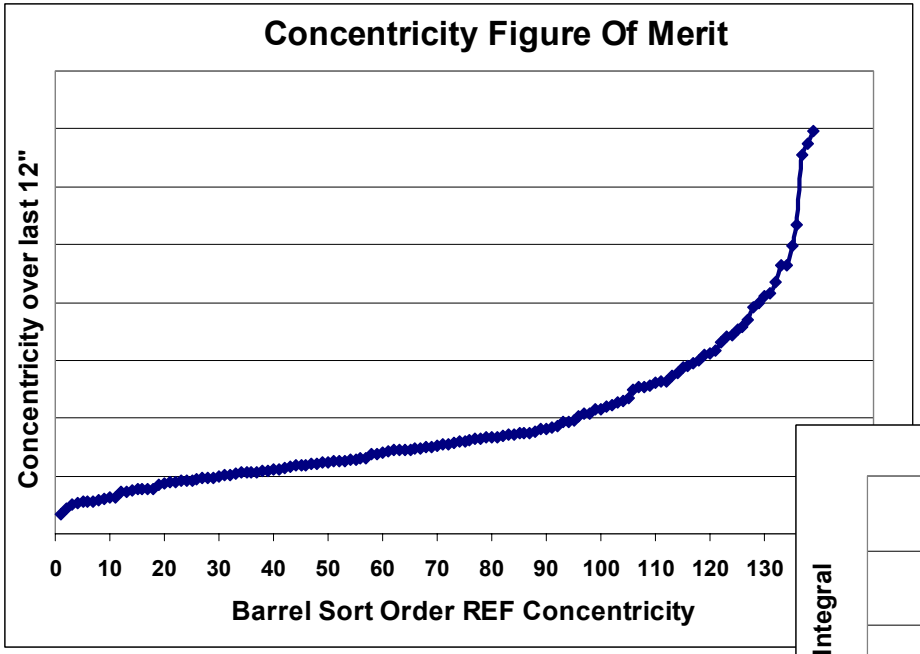
- Barrels w/ yawed projectiles also have straightness problem near muzzle!

Kit 139 Wiggler Measurement

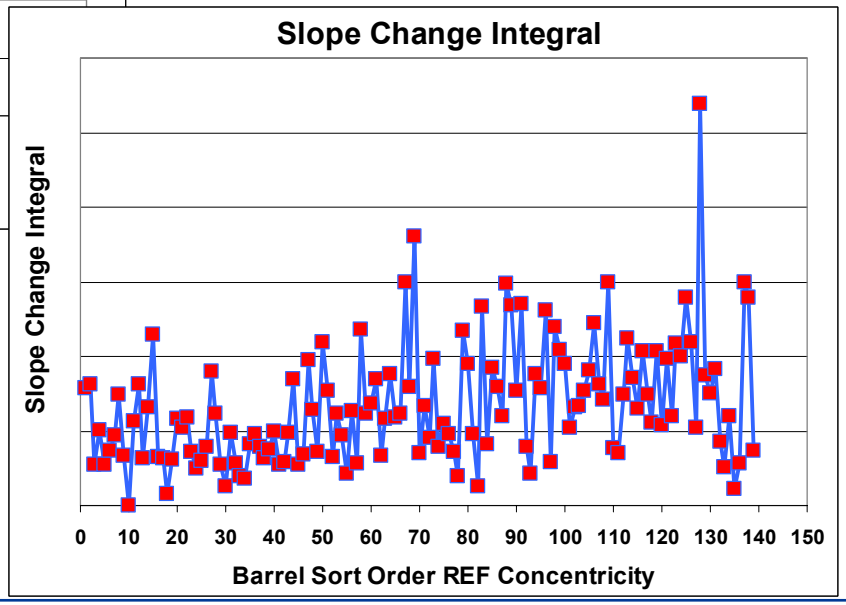


- Problem readily identified w/ either wiggler or laser

Bore Concentricity & Straightness



- Inspect 167 bbls on hand
- Sort by concentricity & straightness
- Group & Fire Test to find straightness limits



Firing Results

- Passed 45 of 46 acceptance tests
  - "Avg." Max Barrel MPI ~ 1.05 mils, σ ~ 0.28 mils
  - Avg. Cluster Dispersion ~ 0.72 mils, σ ~ 0.12 mils
  - Avg. Barrel MPI ~ 0.65 mils, σ ~0.17 mils

- Slave Performance:
  - "Avg." Max Barrel MPI ~ 0.77 mils, σ ~ 0.21 mils
  - Avg. Cluster Dispersion ~ 0.59 mils, σ ~ 0.11 mils
  - Avg. Barrel MPI ~ 0.50 mils, σ ~ 0.14 mils

- Pass probability for Max Barrel MPI ~ 94% (Gaussian)

Straightness Limits

- Empirical TIR change limit determined of 0.0015”/1 inch and 0.0025”/2 inch over last 6” of barrel travel.

Conclusions

- Monitoring bore straightness critical to targeting success.
- Process improvements underway to reduce straightness variability.

Translating Lessons Learned into Systems Requirements

- Bore straightness can be critical for low dispersion, multi-barrel systems.
- Bore straightness has implications for single barrel weapons with MPI vs. aim point requirements when barrels are changed.
- Bore straightness of single barrel guns will influence MPI difference for projectiles w/ significantly different action times
  (e.g. APFSDS-T vs. HE)