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Factors Affecting Small Caliber Dispersion

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Purpose

- **Enhance Warfighter Lethal Capability via Reduced Small Caliber Ammunition Dispersion**
- **Product Capability Achieved Thru:**
  - **Design**
  - **Performance**
  - **Manufacturing**
  - **Ensure Reduced Dispersion thru changes in:**
  - **High Volume Production**
  - **Specialized Weapons and Ammunition**
    - **Precision Products**
    - **Low Volume**

Why is small cal dispersion so hard to estimate?

- **Small caliber bullets in hi pressure systems operate at stress levels above projectile material yield stress**
  - **Deformed projectile shape may not be symmetric**
  - **Orientation of in-bore angle & CG offset varies shot-to-shot**
  - **"Linearity" assumptions valid for med. & large cal are not valid for small caliber**

- **Average dispersion (in mils) is small, factors not a significant influence for dispersion of medium & large cal rounds can be a large fraction of total error budget in small caliber…**

"Internal" Dispersion Factors

- **Projectile**
  - Geometry / Mass Prop. (Quality?)
  - Exterior Grooves
- **Cartridge**
  - Projectile run out
  - Seating depth / free run
- **Gun / Fixture**
  - Barrel Flexural Properties (bending & hoop stiffness)

- **Cartridge / Fixture Interactions**
  - Action Time variation / Bore Straightness / Barrel Pointing
  - Engraving Variations
    - In Bore Angle / Exit Angular Rate / Effect on IB
  - Projectile radial stiffness / barrel bending
  - Bore Parameters
    - Groove-Land width ratio
    - Free run / Forcing Cone
  - Muzzle Blast / Base Pressure at Muzzle Exit

"External" Dispersion Factors

- **Muz. Vel. / Action Time Variations**
- **Projectile mass / Drag Variation**
- **Winds / Wind Variation**
- **Aiming/Boresite Variation**
- **Muzzle Blast**
- **Cant Error**
- **Range Measurement Error**

Spinner Dispersion

$$\Theta_j = \left[\left[\underbrace{\left(\frac{C_{N\alpha} - C_D}{C_{m\alpha}} \right)}_{\text{Aero's}} \underbrace{\left(\frac{I_y - I_x}{md^2} \right)}_{\text{Mass Prop.}} \underbrace{\left(\frac{d}{V_m} \right)}_{\text{"Scale"}} \underbrace{\left(\alpha_g \bullet p_m \right)}_{\text{Angular Rate}} \right]^2 + \left[\underbrace{\Delta_{CG} \bullet \frac{p_m}{V_m}}_{\text{Cross Vel.}} \right]^2 \right]^{\frac{1}{2}}$$

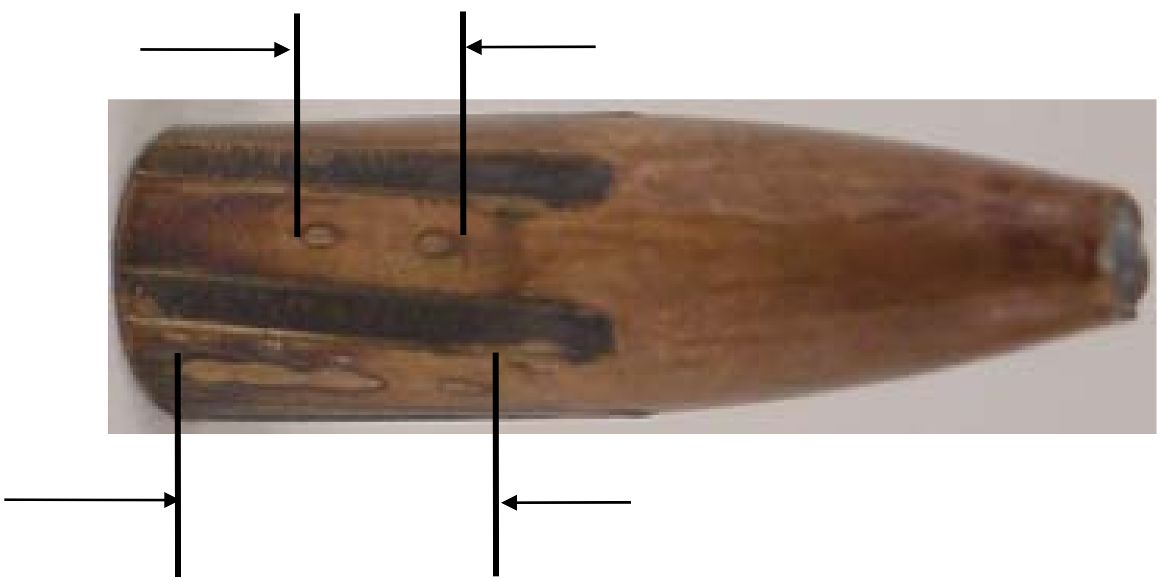
- **Transverse Moment of Inertia**
- **Separation between CG & CP**
- **Run out of inner cavities or core relative to the bourrelet**
- **In-Bore Clearance**
- **Bourrelet Length**
  - **The last 3 above factors combine to produce CG offset and tilt of the principal axis**

-----Factors which are not very important

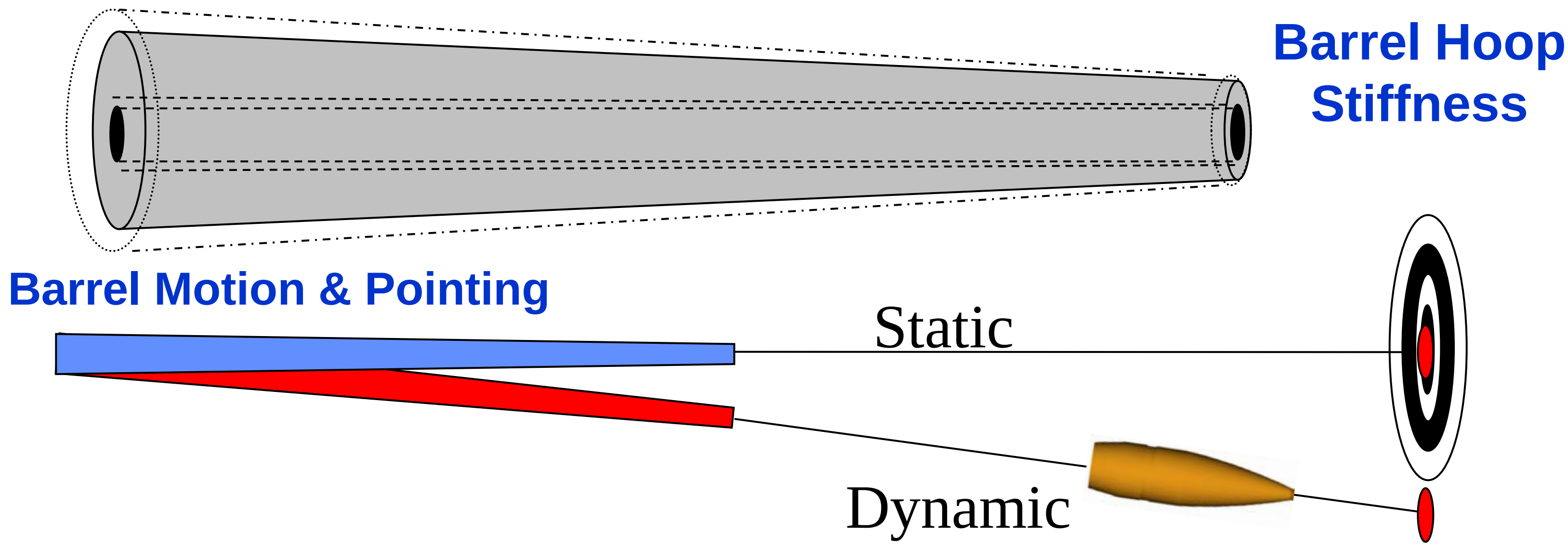
- **Gyroscopic Stability (must be above 1)**
- **Dynamic Stability**
- **Aerodynamic asymmetries (provided Axis Tilt & CG offset not affected)**

Why is there Small Cal Dispersion?

- **Projectile body is nominal interference fit w/ lands, but…**
- **Elastic deflection of bore due to internal pressurization allows the projectile to tip in-bore relative to bore centerline**
- **Random orientation of projectile in-bore angle and random magnitude of in-bore angle applies loads to the barrel which affect barrel pointing and cross velocity @ muzzle exit.**

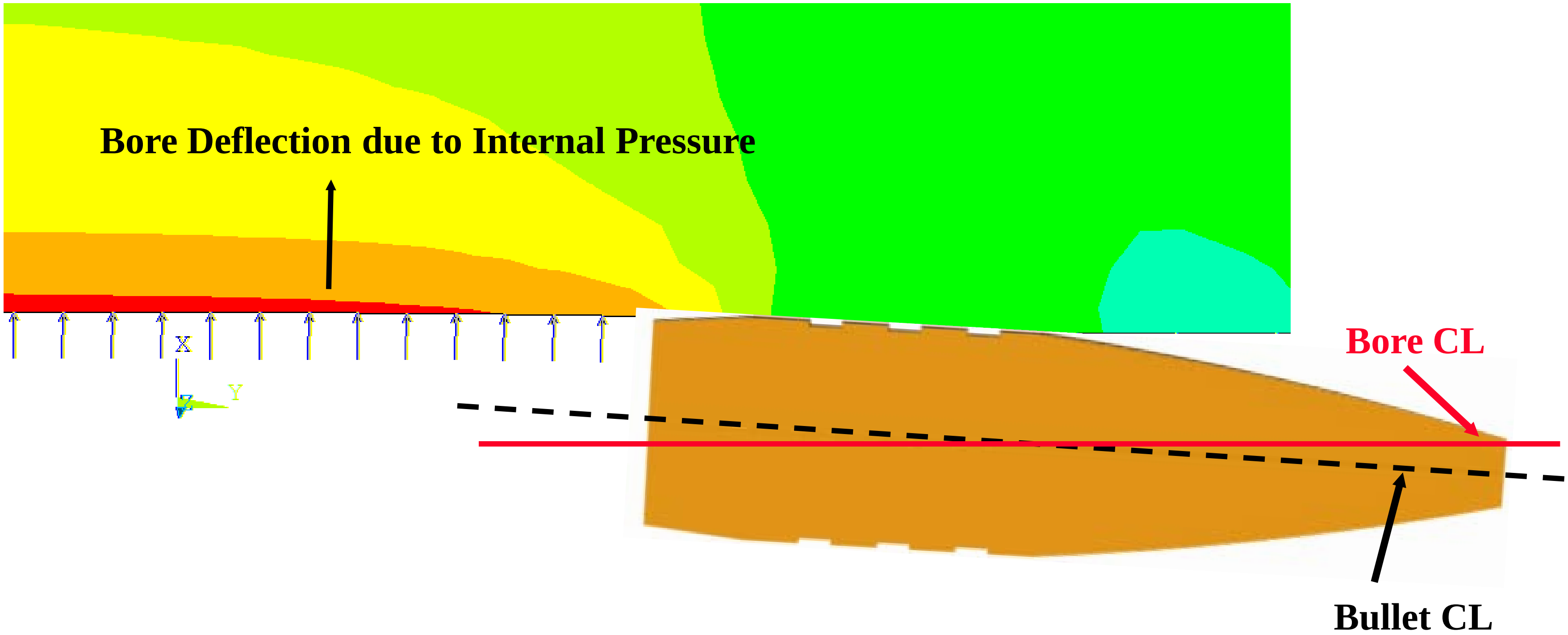


Barrel Hoop & Bending Stiffness



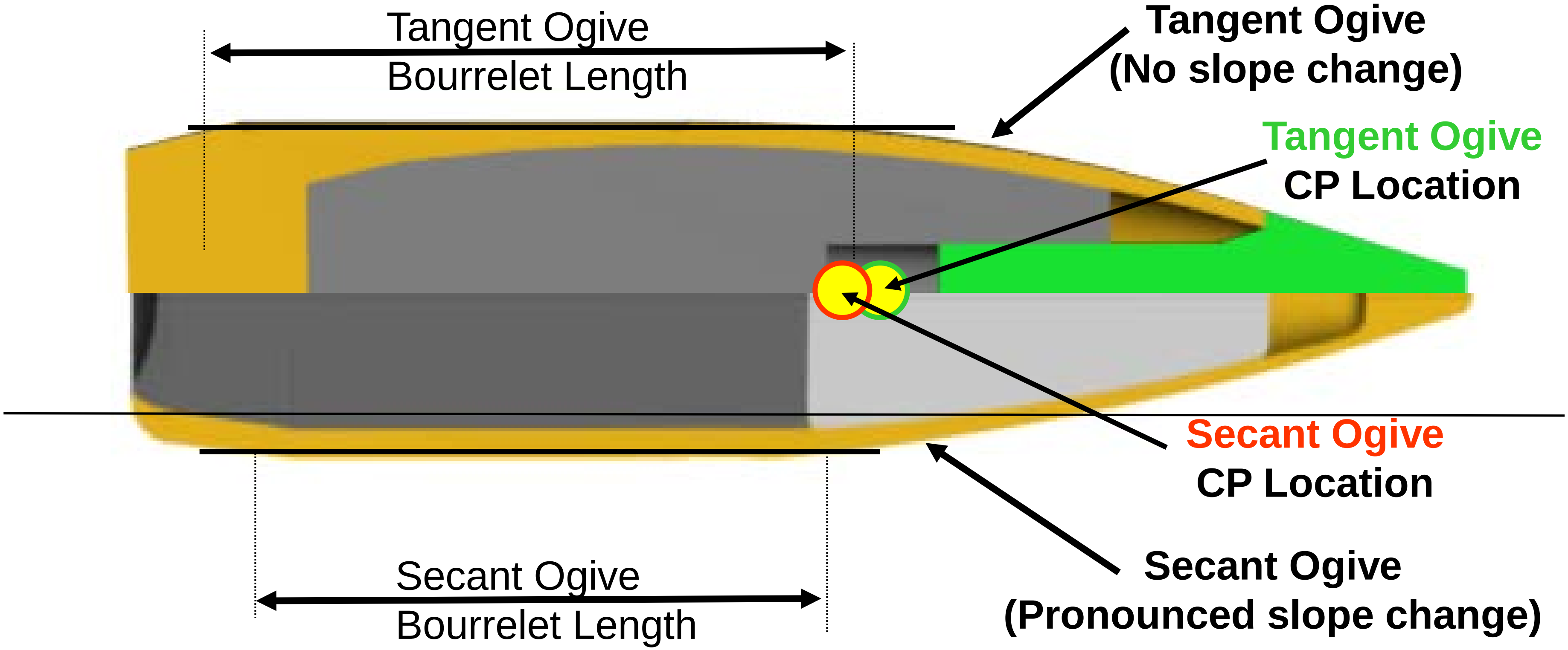
- **Gun barrel diameter grows elastically in response to internal pressurization**
  - **OD influences ID growth**
- **Projectile Tips in Bore due to ID Growth**
- **Projectile tilt / CG offset / spin during early in-bore travel drives barrel transverse motion**

Projectile/Barrel Interaction



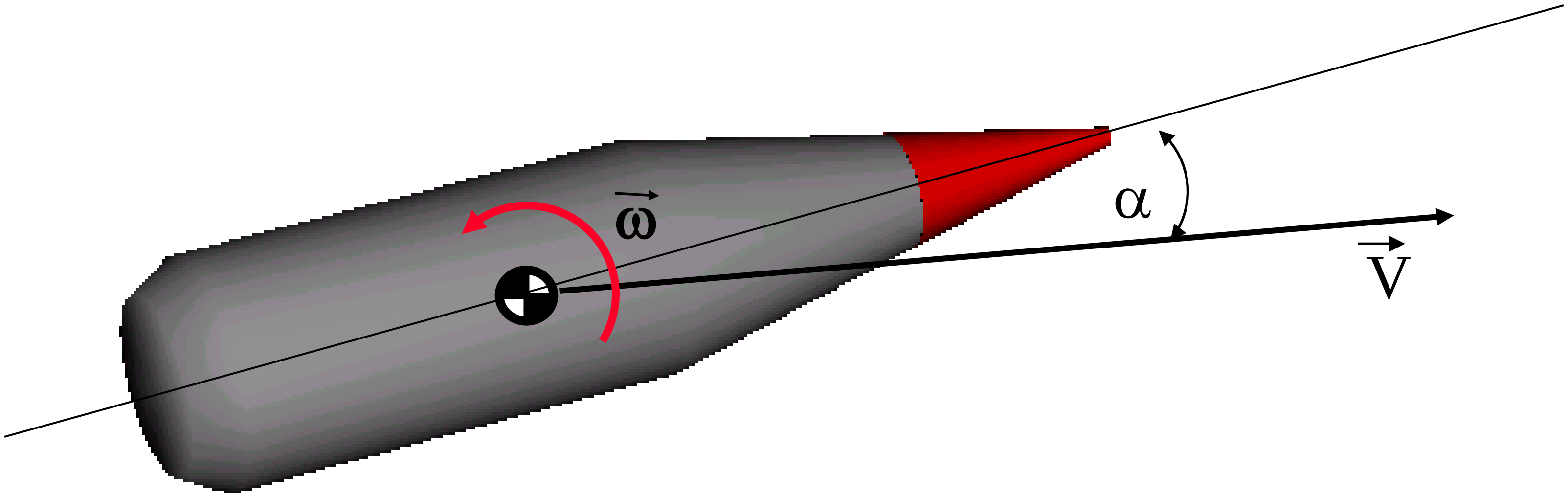
- **Forward bourrelet controlled by (undeflected) barrel lands**
- **Aft bourrelet has clearance caused by bore deflection due to internal pressure**
- **Bullet CG Offset & Tilt, combined w/ spin forces barrel vibration…**

Land Interface & Ogive Geometry



- **Tangent Ogive Moves CP Fwd ~ 0.2 Caliber, ~ 20% dec. in Jump Sens.**
- **Ogive Geometry Has Effect on Bourrelet Length**
    - **Tangent ogives have longer contact length = lower in-bore angle**

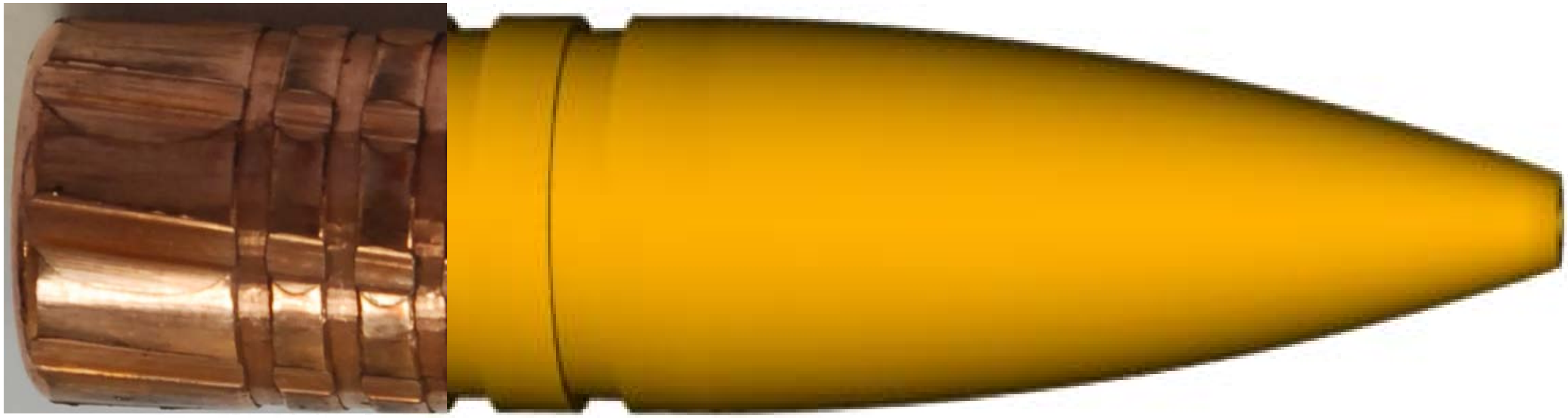
Initial Angle of Attack & Initial Angular Rate



- **<u>Initial angle of attack</u> (α) with respect to initial velocity vector at muzzle release**
  - **Bad news: difficult to measure**
  - **Good news: usually small, and effect on dispersion (~10%) is small even for large angles**

- **Initial Angular Rate (ω):**
  - **<u>THE</u> major dispersion source (~ 75% +)**

External Grooves



- **External Grooves provide clearance for body material displaced during engraving**
  - **Prevents tipping of projectile in bore during engraving**
- **Reduces radial stiffness relative to same bullet w/o Grooves (see next slide)**
- **Empirical evidence: no benefit if grooves are > Land diameter**

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Bourrelet Stiffness vs. Dispersion

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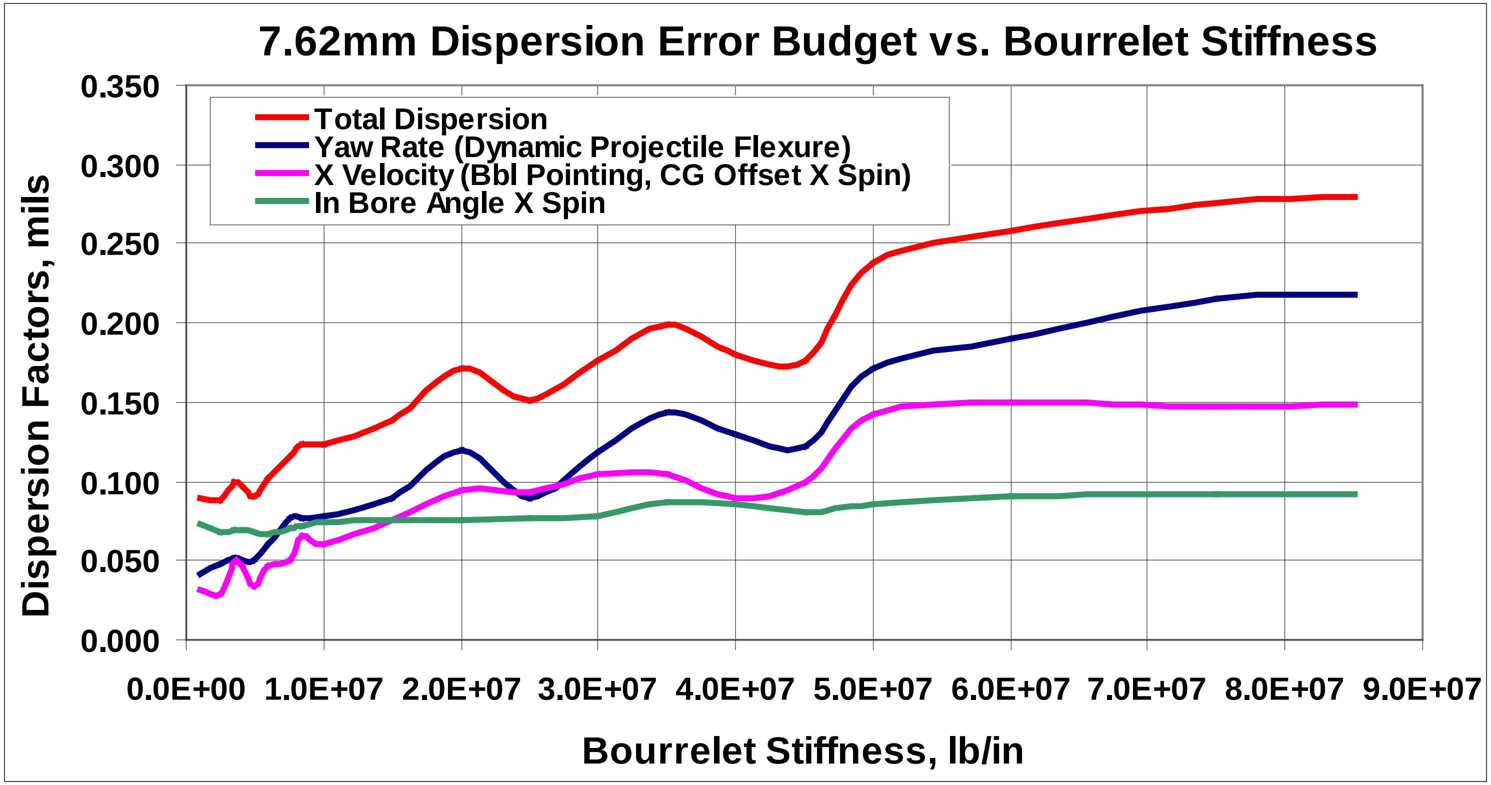
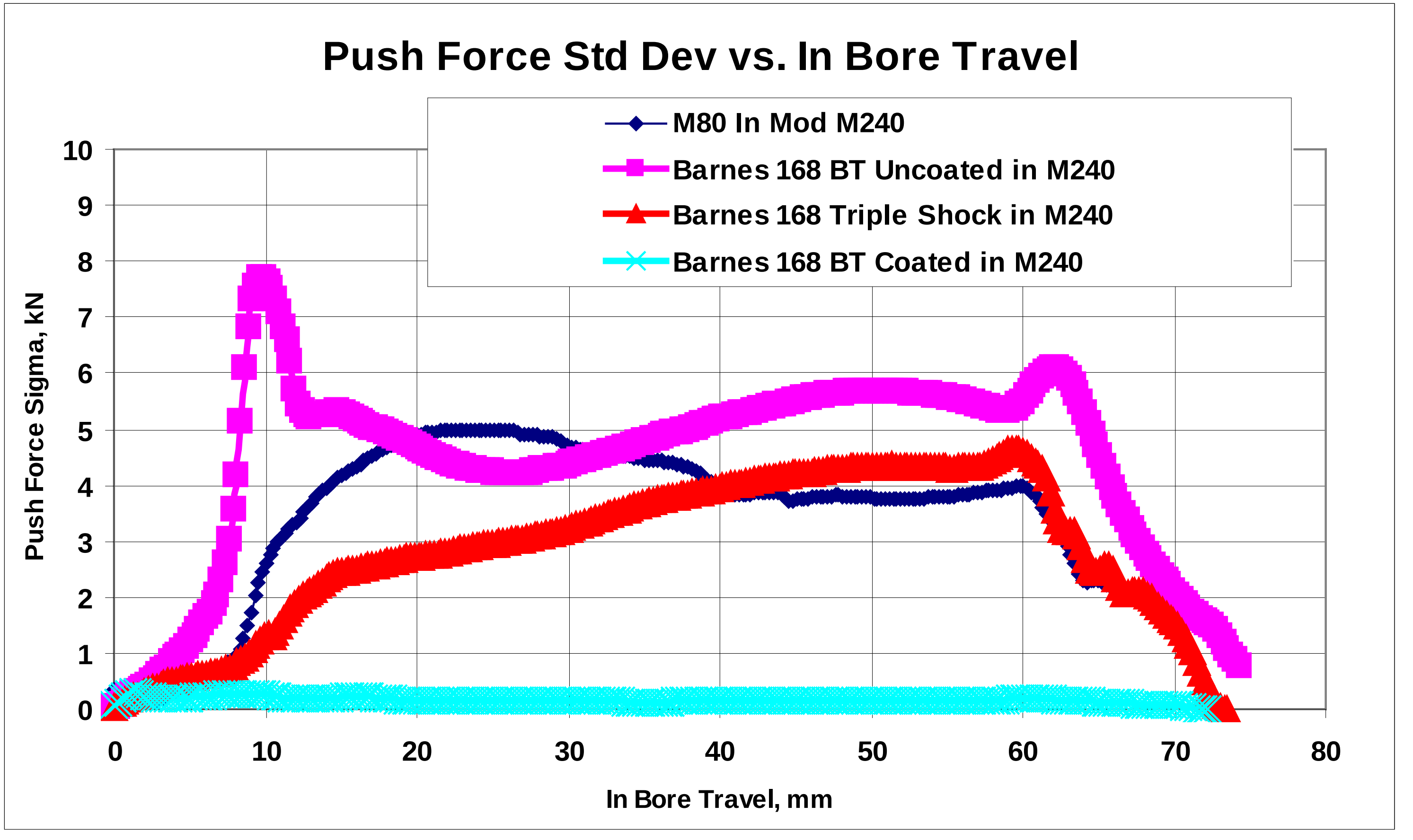


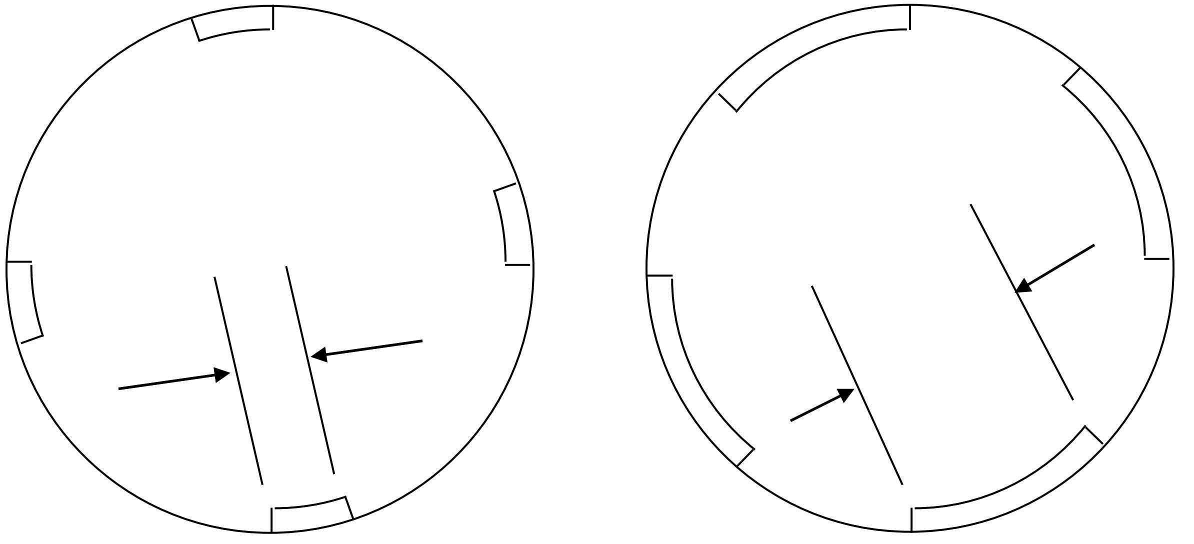
- **Disp. @ 5m lb/in is <40% of Disp. @ 50 m lb/in.**
- **Analysis assumes solid copper projectile….**
- **Unique response map for each bullet/fixture combination**

Engraving Variation



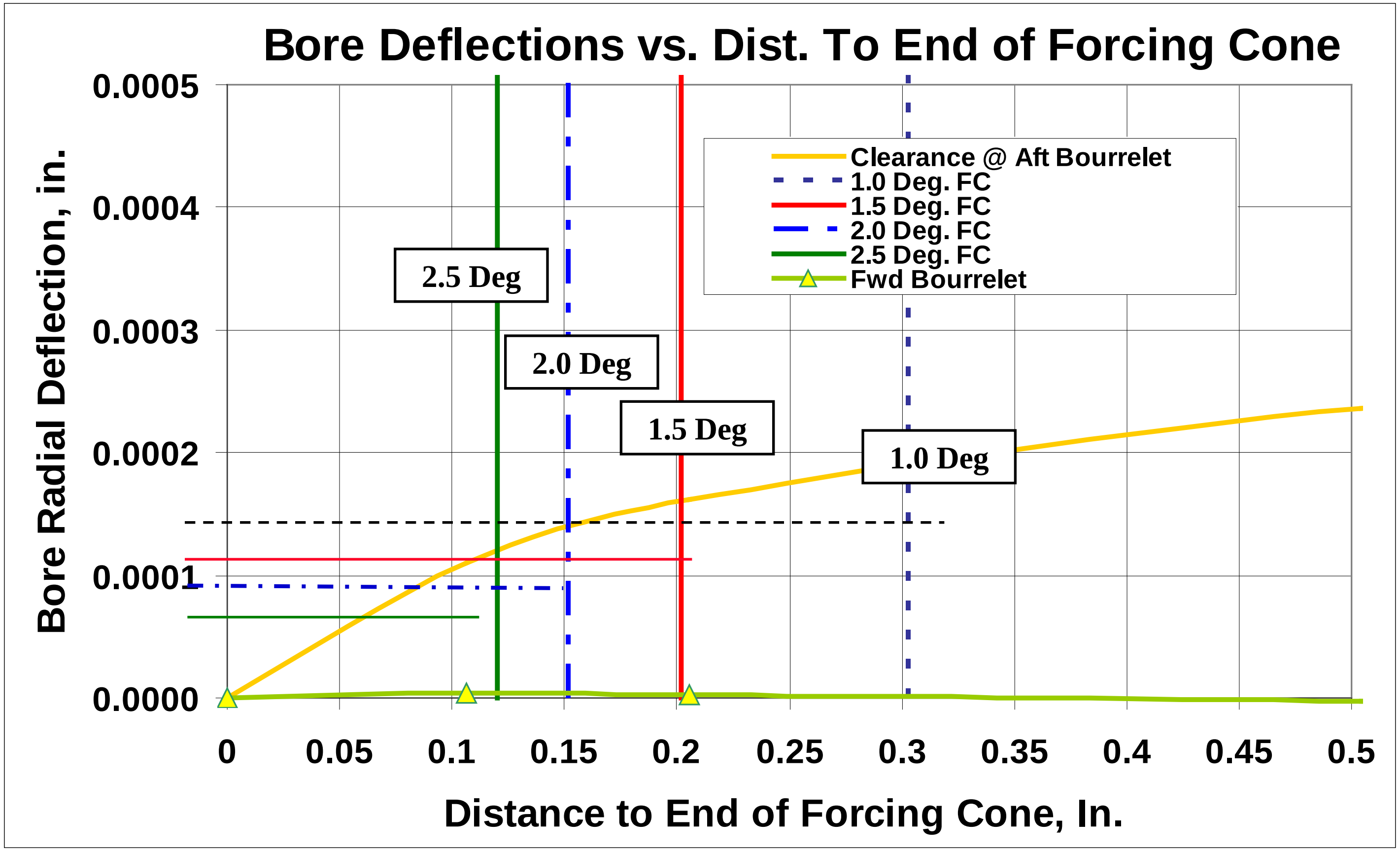
- **Increased Engraving Std. Dev = Inc. MV & Action time Variability**
- **Both can have an effect on barrel dynamics & dispersion**

Barrel G/L Width Ratio



- **Low G/L Width Ratio = Wider Lands**
- **Provides Inc. In Bore Control = Dec. Dispersion**

Bore Growth vs. Forcing Cone Angle



- **Shallower Angles = Inc. press. & inc. bore defl. @ all engraved**
- **Inc. projectile material remains @ end of engraving, reducing in-bore angle down bore**

Free Run & Bullet Construction

- **Solid Bullets shoot smallest dispersion w/ 0.050”-0.080” Free run**
- **“Conventional” Drawn Copper Jacket / Lead Core bullets shoot smallest dispersion w/ 0.015-0.030” free run**
- **Details dependent on:**
  - **Case volume & propellant rise rate**
  - **Yielding/deformation of jacket and / or core resulting from accel.**
  - **Travel until projectile side wall is fully supported**
  - **Details of bore elastic deflection during engraving**

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30 Cal Von Mises Stress @ 60 KPSI

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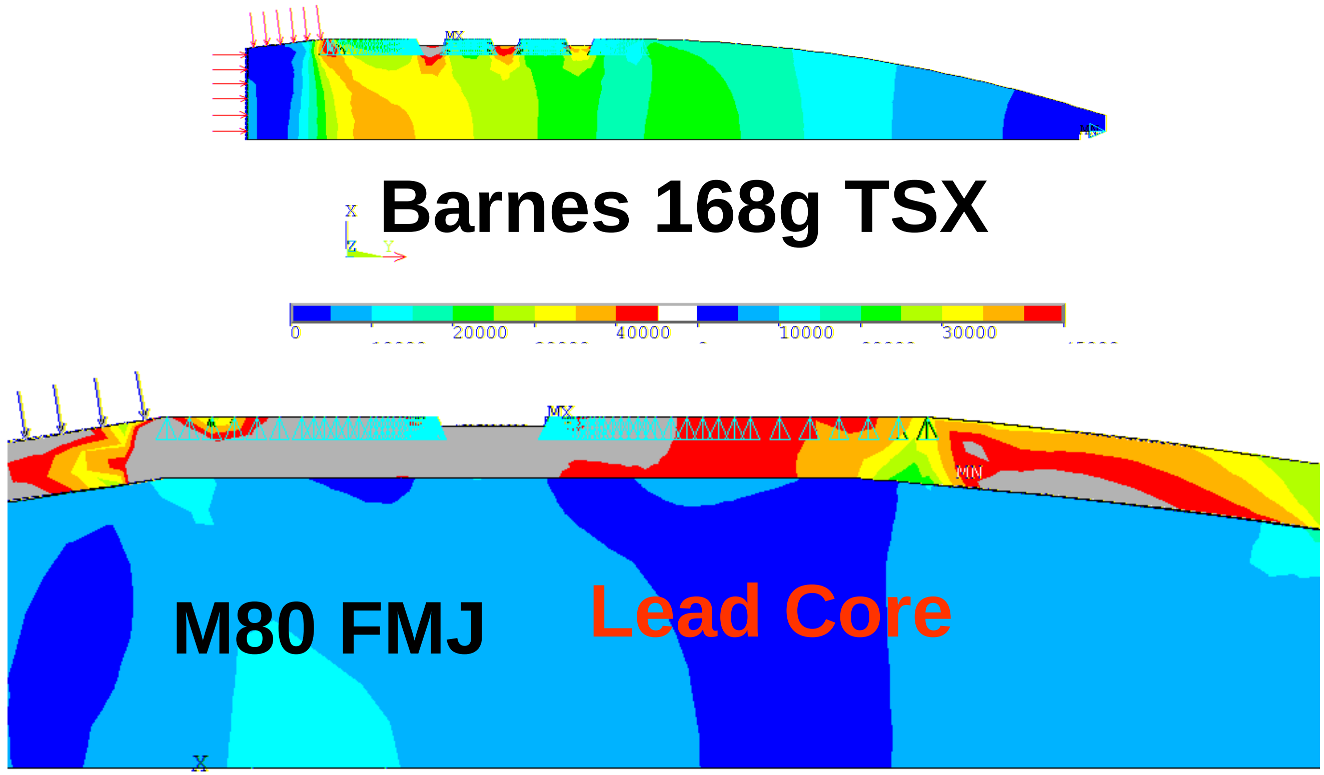

- **Jacketed Bullet has higher stresses @ rifling interface**
- **What is Yield Strength of body/jacket/core?**
- **Earlier support (e.g. less free run) required for lead bullet to limit asymmetric deformation due to low mat'l Y.S.**

Jacket Deposits on Lands

Bore Photos From:
www.gradientlens.com

Relatively Uniform Deposition

Non-Uniform Deposition

- **Non-uniform deposition causes local, asymmetric variations in bore straightness, varies shot-to-shot**
- **Generates lateral loads on projectile & barrel**
- **Creates increased variations in projectile angular rate & bore pointing vector at muzzle release**
- **Exit Conditions vary shot-to-shot, causing dispersion**

Summary
Design Factors

- **Ammunition Parameters:**
  - **High Quality Projectile & Cartridge**
  - **Projectile Material Properties Selected for Mission**
  - **Radial Stiffness Appropriate for Weapon**
  - **Reduce Engraving variability**
  - **Reduce Jacket Melting / Deposition**
  - **Appropriate Projectile "Free Run"**

- **Barrel Parameters:**
  - **Shallow Forcing Cone**
  - **Increased Land Width**
  - **Appropriate Hoop & Bending Stiffness**

Wrap-Up Conclusions

- **Established and Quantified Ammunition and Weapon Interaction Parameters Which Drive Dispersion**
  - **Dispersion Capability**
  - **Repeatability**
- **Priorities Established for Ammunition and Weapons**
  - **Design**
  - **Performance Guidelines**
  - **Production**
  - **Maintenance**
- **Parameter Impact confirmed by Analysis and Test**
  - **Expanded Test Approach Established**

Factors Identified are Compatible with Volume Manufacturing and Applications

Warfighter Benefits

- **Reduced Dispersion**
- **Uniformity of Performance Across Lots**
- **Establish Design & Manufacturing Criteria for:**
  - **Weapon**
  - **Ammunition**

Enhance Small Arms Effectiveness in Current and Future Operations