Inclusion of Rifling and Variable Centerline for Enhanced Modeling of Launch Dynamics

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Outline

- Introduction
- Rifled barrel meshing
- Modeling barrel centerlines
- Measuring rigid body dynamics
- Effects/examples

Introduction

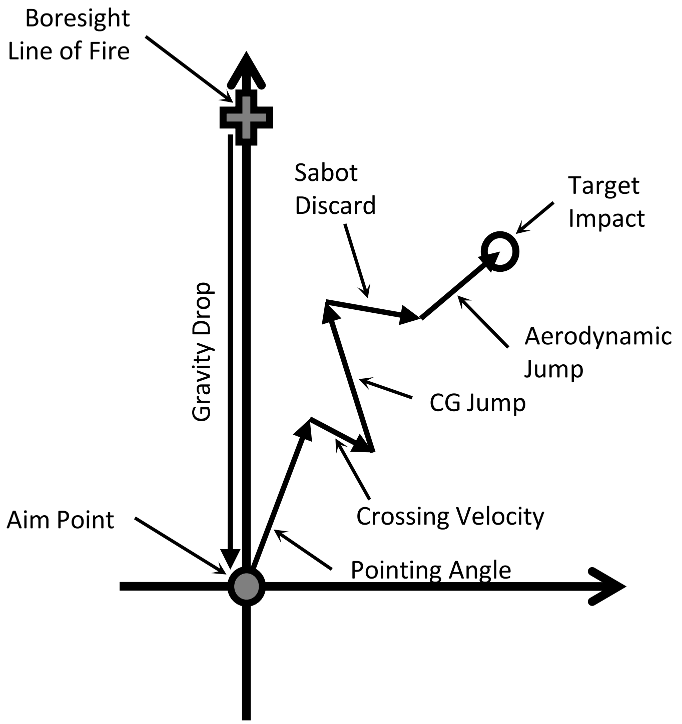
- Objective: Improve modeling of gun barrel and projectile interactions and dynamics
  - – Streamline the process of adding twisted rifling and barrel centerline data
  - – Extract projectile motion data from results
    - Allows rational determination of transverse and spin-up loading
  - – Allows for more accurate predictions of projectile motion at muzzle exit
    - Can be used to reduce target impact dispersion

Introduction

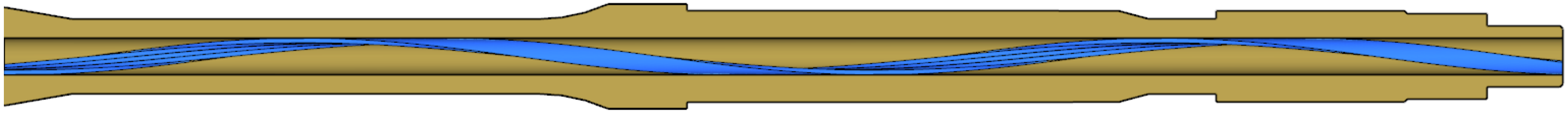
- Defining the bore/barrel geometry correctly in FE models can be laborious and prone to user error
  - Automating this process through scripting can greatly reduce these problems
- High-fidelity FE models require a large number of nodes
  - Rigid-body projectile motion found by processing node data from results files

Jump Theory

- Methods described can be used to predict muzzle exit conditions related to jump
- Post-processing can provide projectile angles, angular rates, and velocities
  - Used in jump predictions
- Jump testing can be simulated when combined with exterior ballistics modeling



Rifled Barrel Meshing



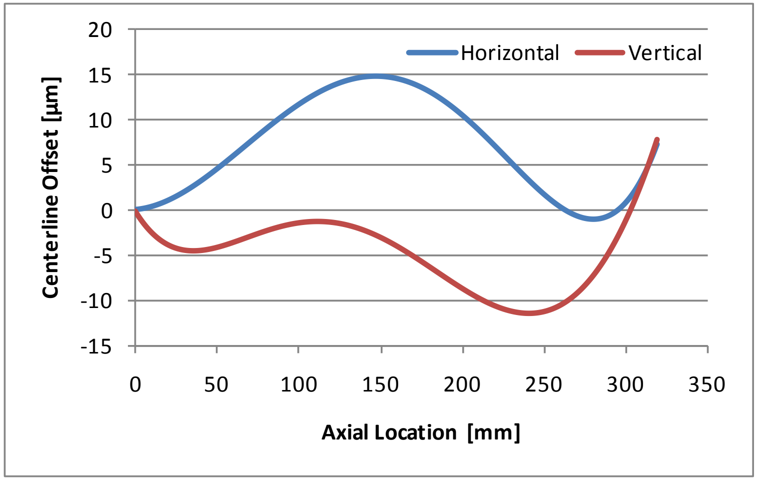
- Rifling is needed for accurate modeling of projectile engraving and spin-up
- CAD geometry often very complex for automated meshing algorithms
  - Many additional steps required to create a high quality hexahedral mesh from a CAD model

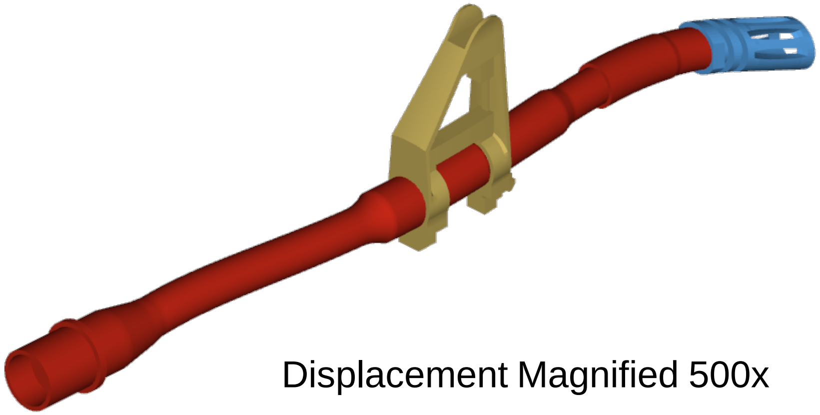
Rifled Barrel Meshing

- Base 2D mesh extruded and rotated following a specified twist rate
  - Can be easily automated in pre-processing tools
- Variable twist rates and mesh densities can be specified
- Does not depend on rifled CAD model
  - Allows for easy generation and comparison of different rifling twist rates

Barrel Centerlines

- Barrel centerlines needed for accurate modeling of transverse loads
- Centerline profile controls the CG jump of the projectile





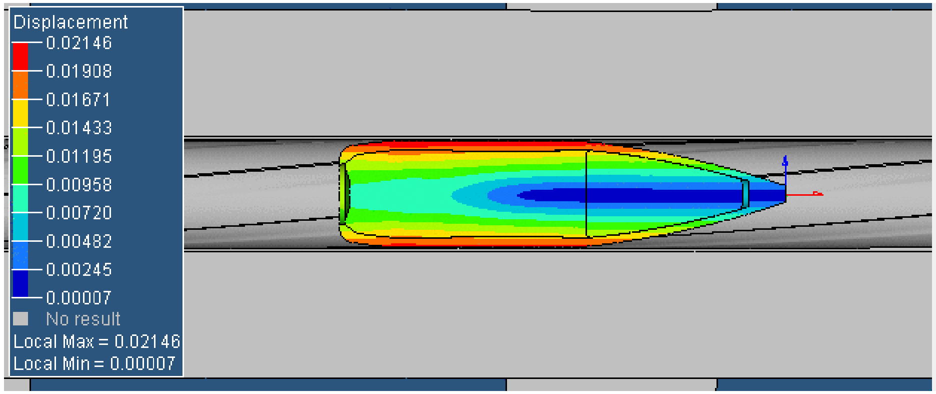
Displacement Magnified 500x

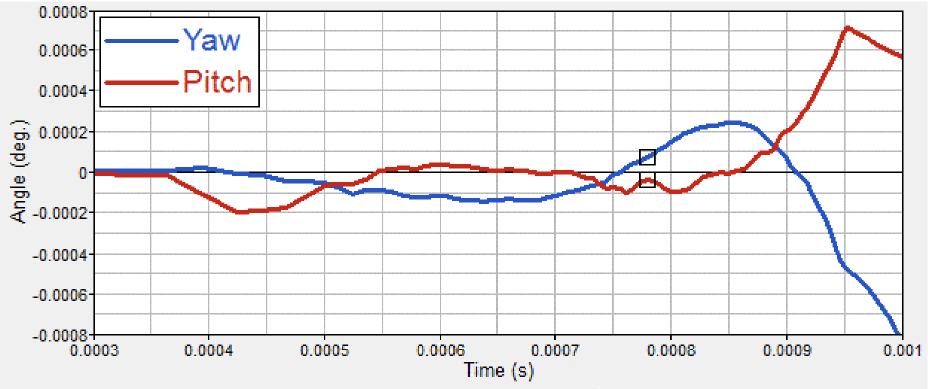
Barrel Centerlines

- Centerline shape can be measured using bore-riding optical sensors
  - This will generate a list of offset coordinates along the barrel’s axis
- Pre-processing tools can be scripted to apply these offsets to the barrel’s mesh
  - Allows for parametric studies comparing different centerlines

Measuring Projectile Rigid Body Dynamics

- Projectile rigid body motion extracted from results
  - Provides an accurate representation of projectile motion





Measuring Projectile Rigid Body Dynamics

$$\mathbf{u}_{CG} = \sum_i \frac{m_i \mathbf{u}_i}{m} \qquad \mathbf{v}_{CG} = \sum_i \frac{m_i \mathbf{v}_i}{m} \qquad \mathbf{a}_{CG} = \sum_i \frac{m_i \mathbf{a}_i}{m}$$

$$\mathbf{u}_i^* = \mathbf{u}_i - \mathbf{u}_{CG} \qquad \mathbf{v}_i^* = \mathbf{v}_i - \mathbf{v}_{CG}$$

$$\mathbf{L} = \sum_i \mathbf{u}_i^* \times m_i \mathbf{v}_i^*$$

$$\mathbf{I} = \sum_i m_i \begin{bmatrix} u_{i,2}^{*\,2} + u_{i,3}^{*\,2} & -u_{i,1}^* u_{i,2}^* & -u_{i,1}^* u_{i,3}^* \\ -u_{i,1}^* u_{i,2}^* & u_{i,1}^{*\,2} + u_{i,3}^{*\,2} & -u_{i,2}^* u_{i,3}^* \\ -u_{i,1}^* u_{i,3}^* & -u_{i,2}^* u_{i,3}^* & u_{i,1}^{*\,2} + u_{i,2}^{*\,2} \end{bmatrix}$$

$$\mathbf{L} = \mathbf{I}\boldsymbol{\omega}$$

- CG motion
  - Mass-weighted average of node motion
- Angular rates
  - Moment of inertia and angular momentum calculated for all nodes
  - Angular momentum of a rigid body solved for angular velocity

Measuring Projectile Rigid Body Dynamics

$$\mathbf{U}^* = \mathbf{A}\mathbf{U}_0^*$$

$$\overline{\mathbf{A}}(\phi,\theta,\psi) = \mathbf{B}_1(\phi)\mathbf{B}_2(\theta)\mathbf{B}_3(\psi)$$

$$\mathbf{R}(\phi,\theta,\psi) = \mathbf{A} - \overline{\mathbf{A}}(\phi,\theta,\psi)$$

$$\mathbf{B}_1(\phi) = \begin{bmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{B}_2(\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}$$

$$\mathbf{B}_3(\psi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\psi & -\sin\psi \\ 0 & \sin\psi & \cos\psi \end{bmatrix}$$

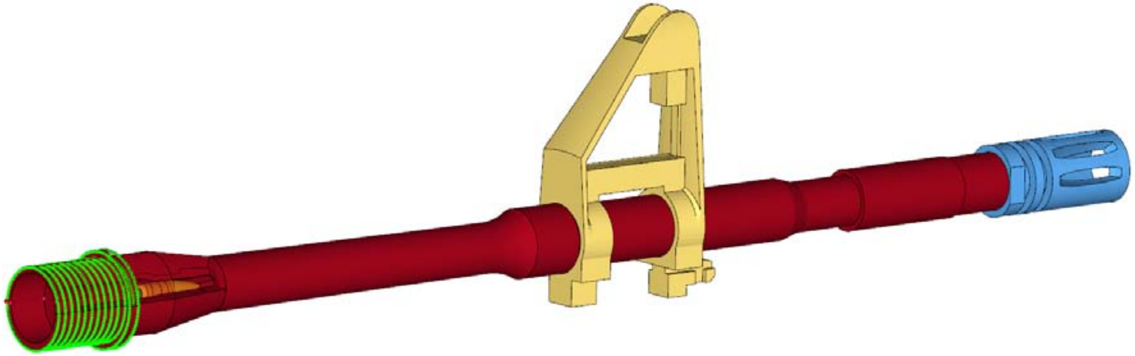
- Rotation matrix $\mathbf{A}$ computed from initial ($\mathbf{U}_0^*$) and current ($\mathbf{U}^*$) nodal coordinate matrices
  - Deformation of the material means there is not a direct rotation
  - Iterative method used to find the best fit
- Function $\overline{\mathbf{A}}$ defined as a product of Euler rotations $\mathbf{B}_i$
- Yaw, pitch, and roll found using nonlinear least-squares fitting techniques

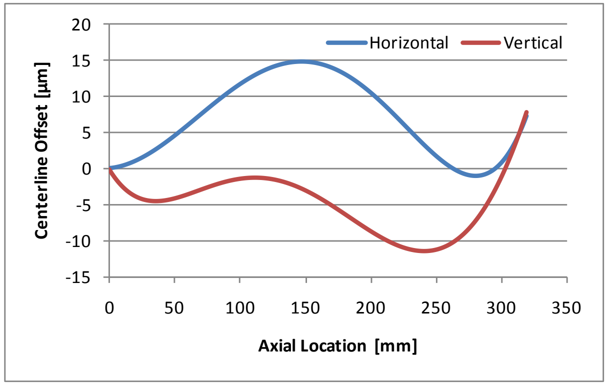
Effect of Rifling and Centerline

- Simplified 5.56mm barrel model is used to demonstrate the effects of including rifling and centerlines on the projectile’s:
  - Transverse displacements
  - Transverse velocities
  - Yaw and pitch angles
  - Angular rates

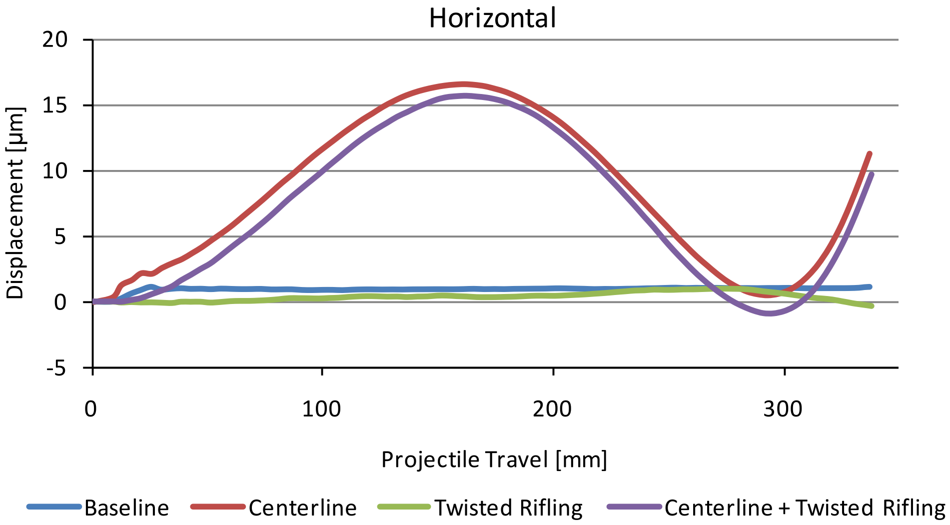
Effect of Rifling and Centerline

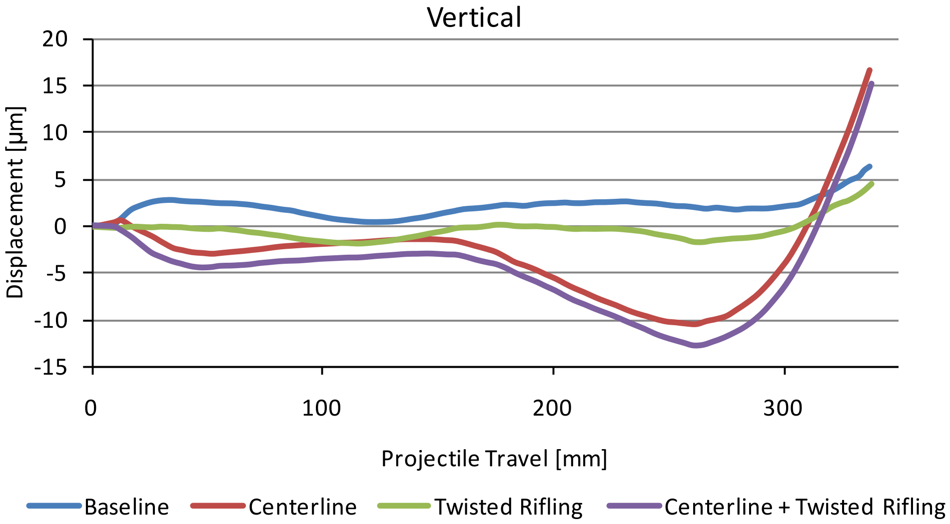
- Model is of a 5.56mm barrel (with sight and muzzle brake) and projectile
  - Cantilevered support on the barrel
  - Pressure loads determined using IBHVG2 software
  - Simple polynomial centerline





Effect of Rifling and Centerline

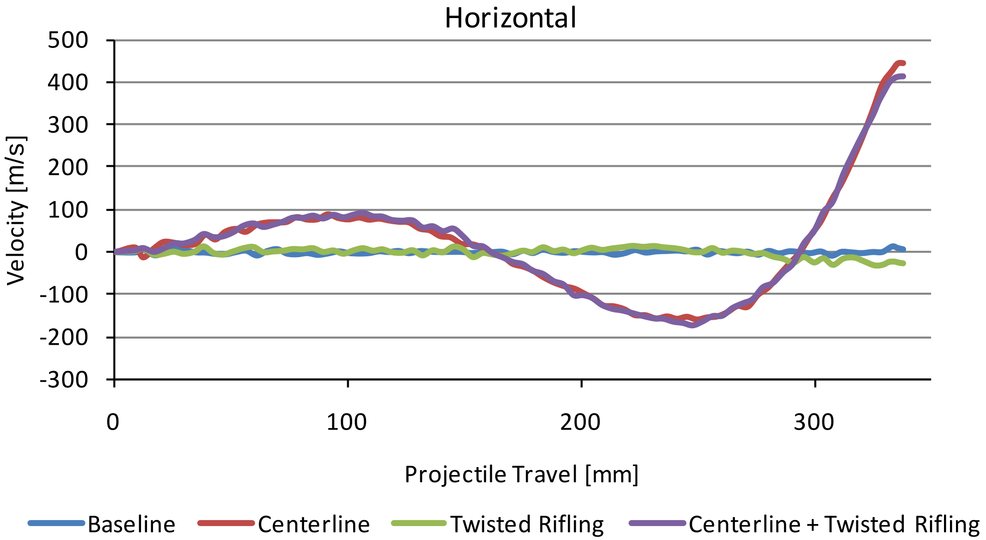


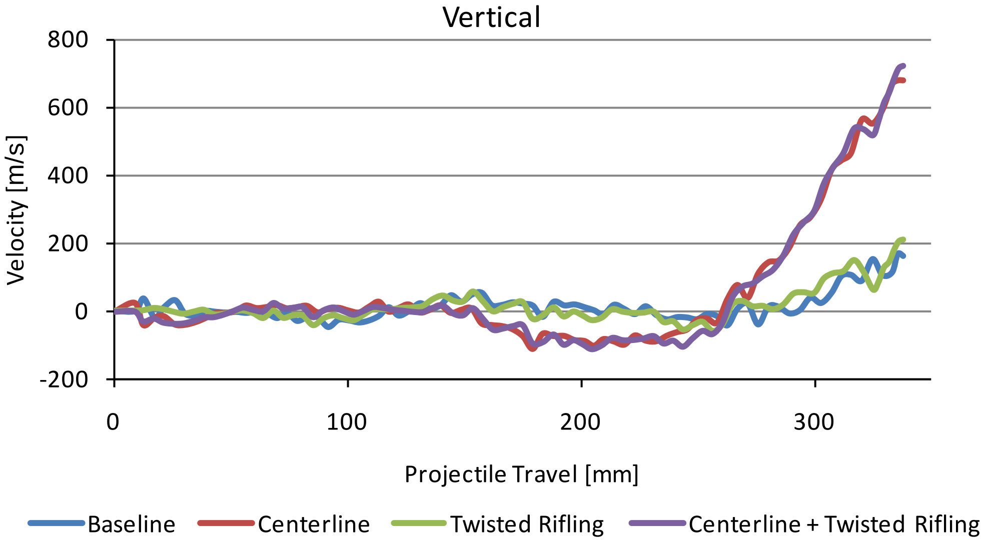


Displacement

- Transverse displacements primarily driven by the centerline profile
  - Only a small difference is created by rifling
  - Sight and muzzle brake also create vertical displacements

Effect of Rifling and Centerline

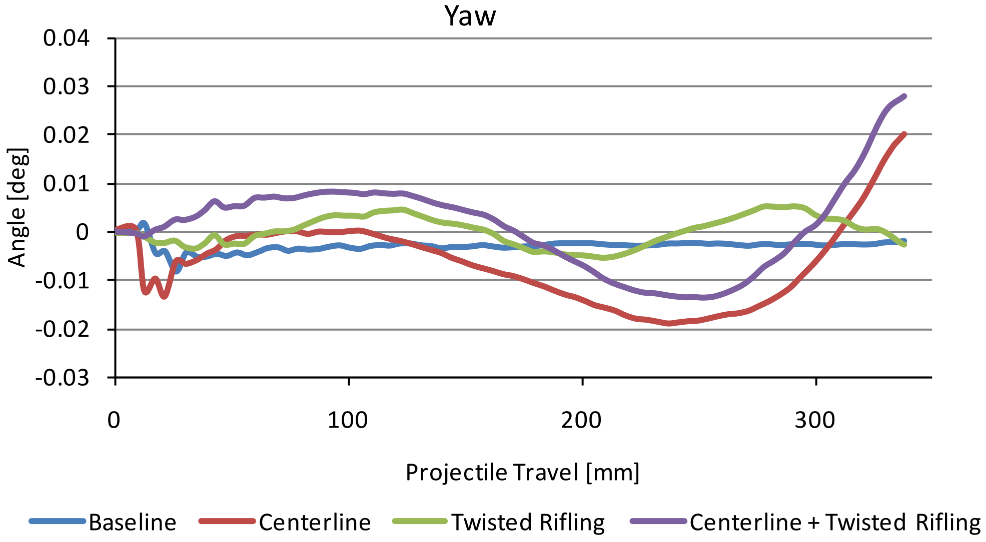


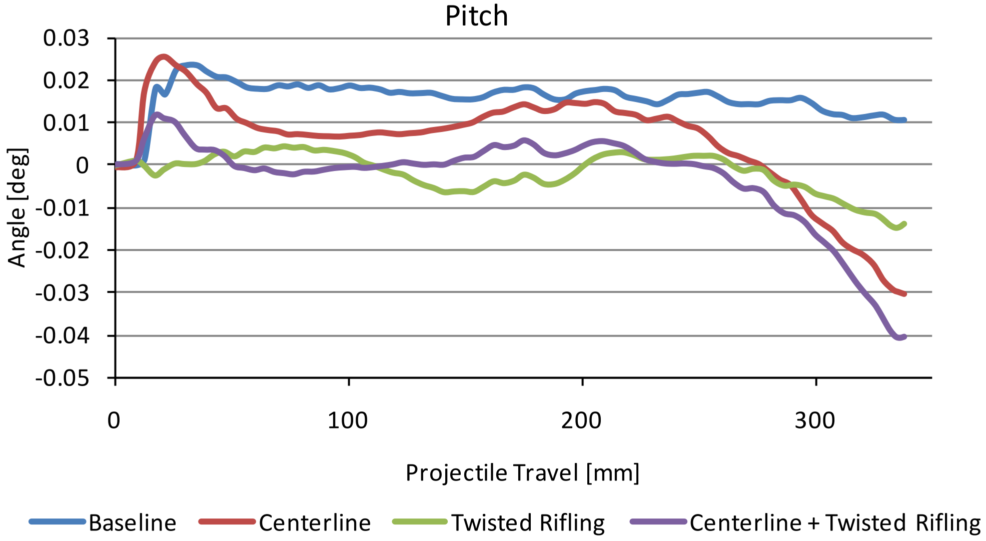


Velocity

- Transverse velocities also show effect of centerline profile

Effect of Rifling and Centerline

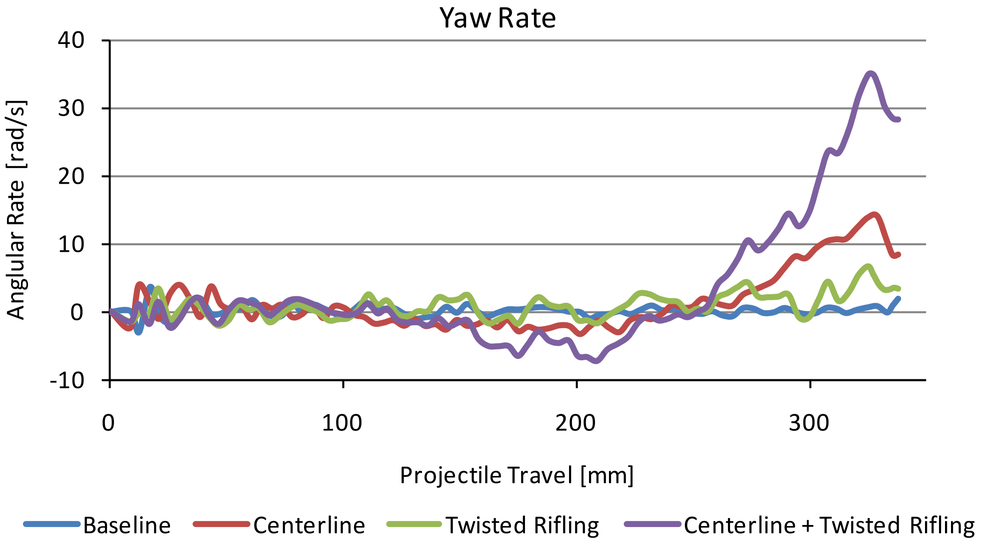


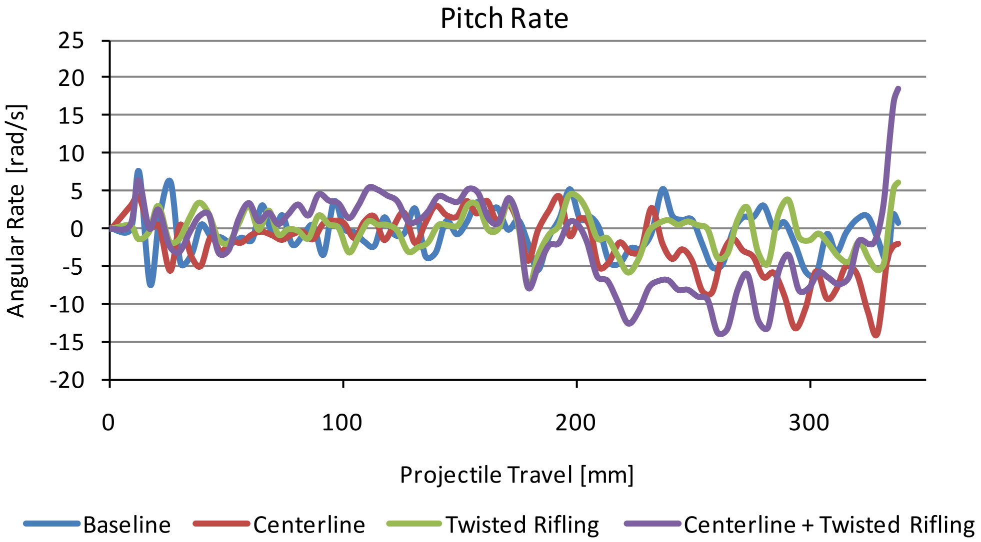


Yaw and Pitch Angle

- Projectile angular results show a clear difference between all test cases

Effect of Rifling and Centerline





Angular Rate

- Angular rates, although noisy, also show large differences between all test cases, especially at muzzle exit
- Angular rates at muzzle exit have a significant effect on aerodynamic jump

Conclusions

- Rifling and barrel centerlines have a significant effect on in-bore dynamics
- Inclusion of these techniques is important for a high-fidelity finite element analysis
  - Necessary for predicting transverse and spin-up loads
  - Allows for study of muzzle exit conditions and jump
- Scripting and external tools allow these methods to be included in an analysis quickly and reliably

Contact Information

Questions?

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