Correlation of Analysis and Firing Test Results for a Turreted Gatling Gun System

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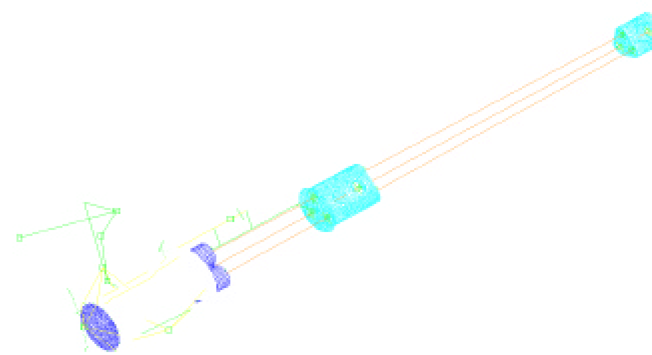
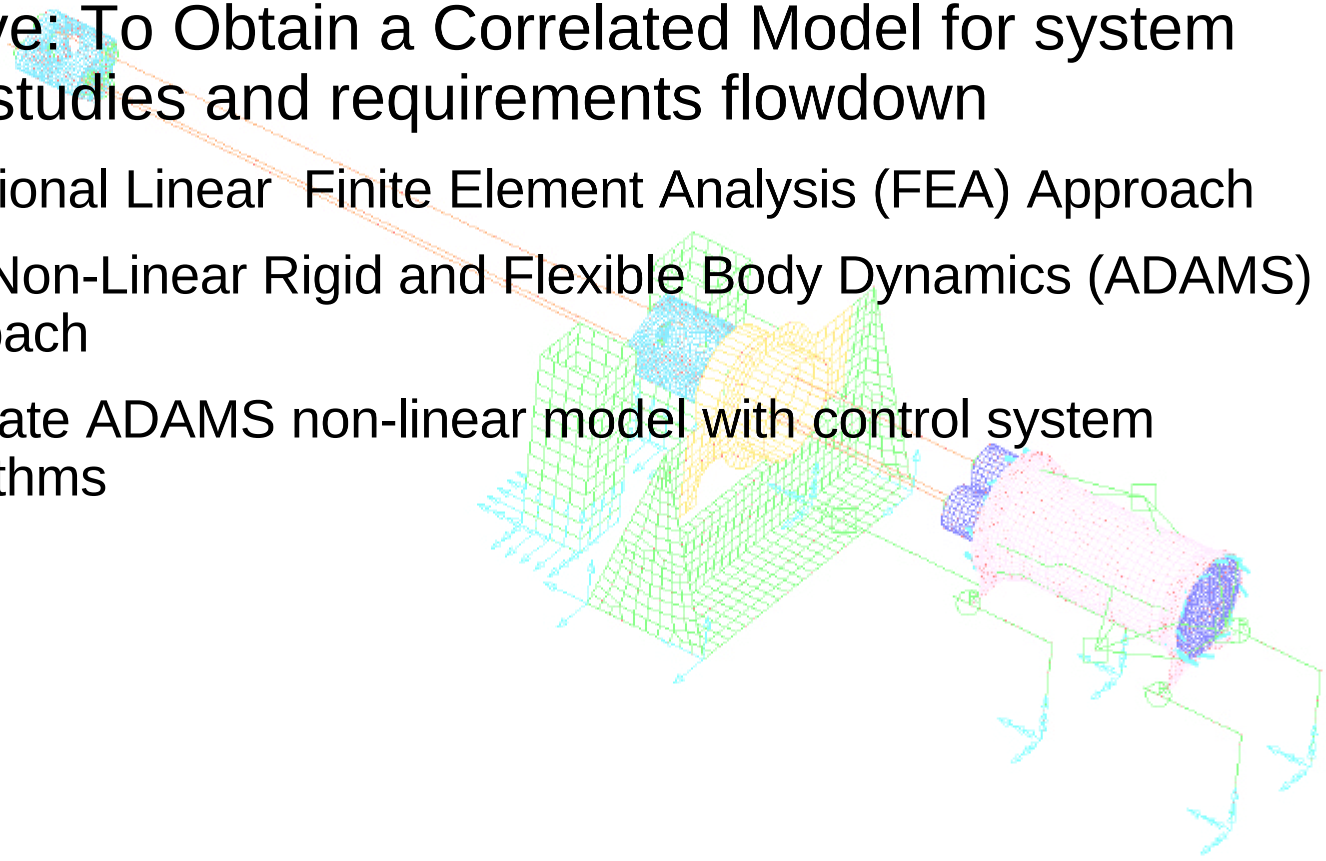
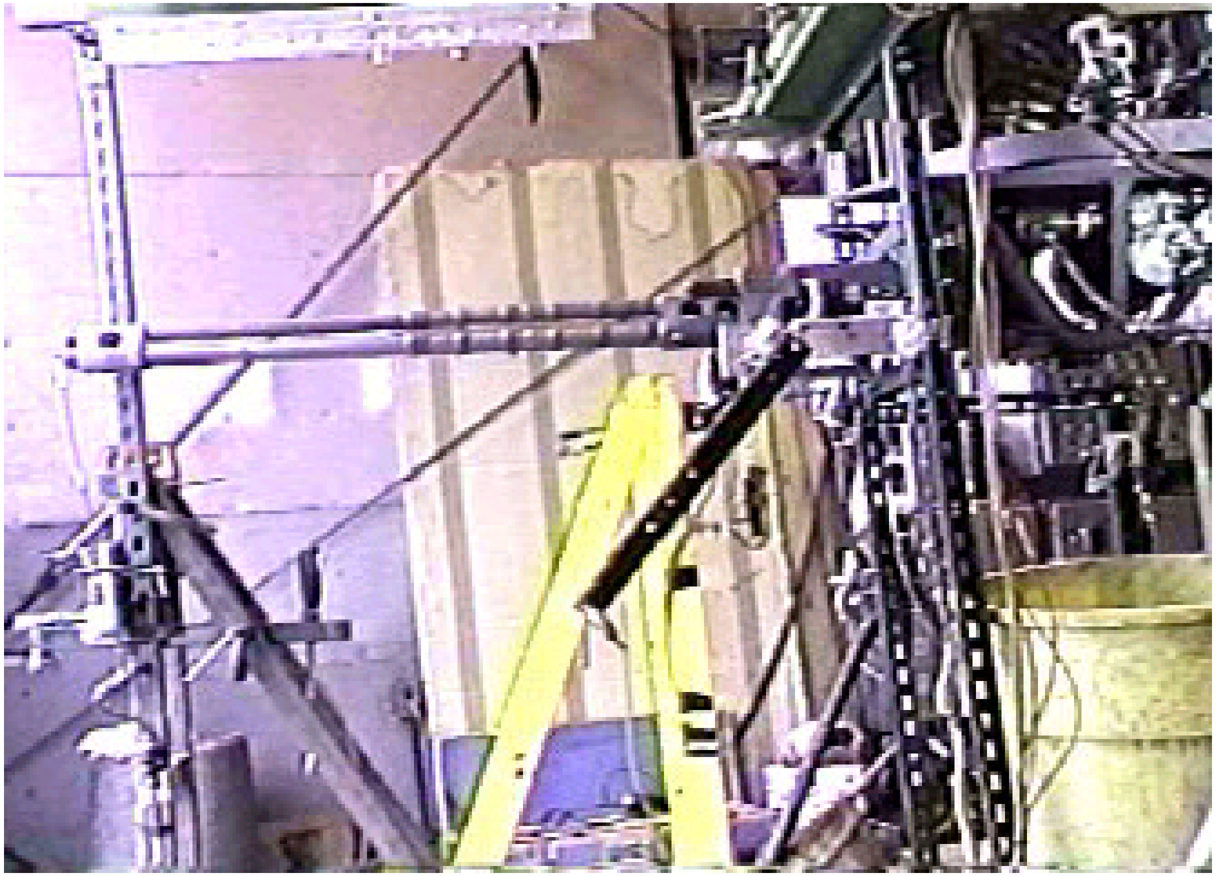


Analytic Modeling Process

- Objective: To Obtain a Correlated Model for system design studies and requirements flowdown
  - ➢ Traditional Linear Finite Element Analysis (FEA) Approach
  - ➢ New Non-Linear Rigid and Flexible Body Dynamics (ADAMS) Approach
  - ➢ Integrate ADAMS non-linear model with control system algorithms

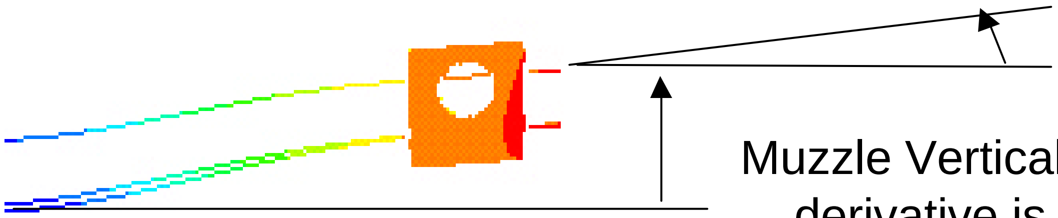


Turret Configuration 33 Round Burst

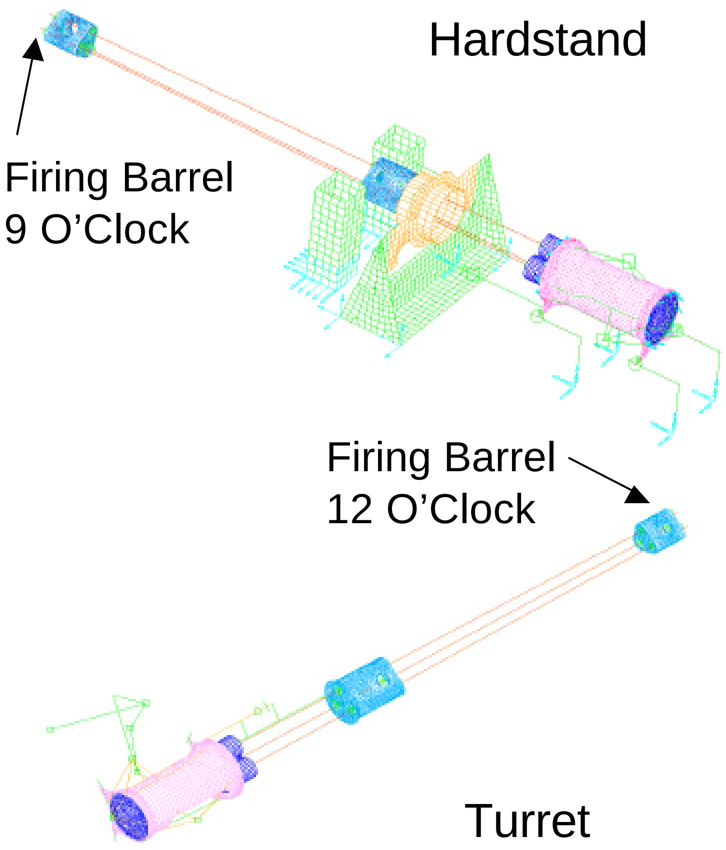


Correlation Parameters

- Three key elements are compared in the direction of large MPI shift
  - Targeting Point of Impact (PI) comparison (Hardstand and Turret)
    - muzzle pitch angle
    - muzzle translational velocity effects
  - Barrel bending shape (Hardstand)
  - Interface loads (Hardstand)

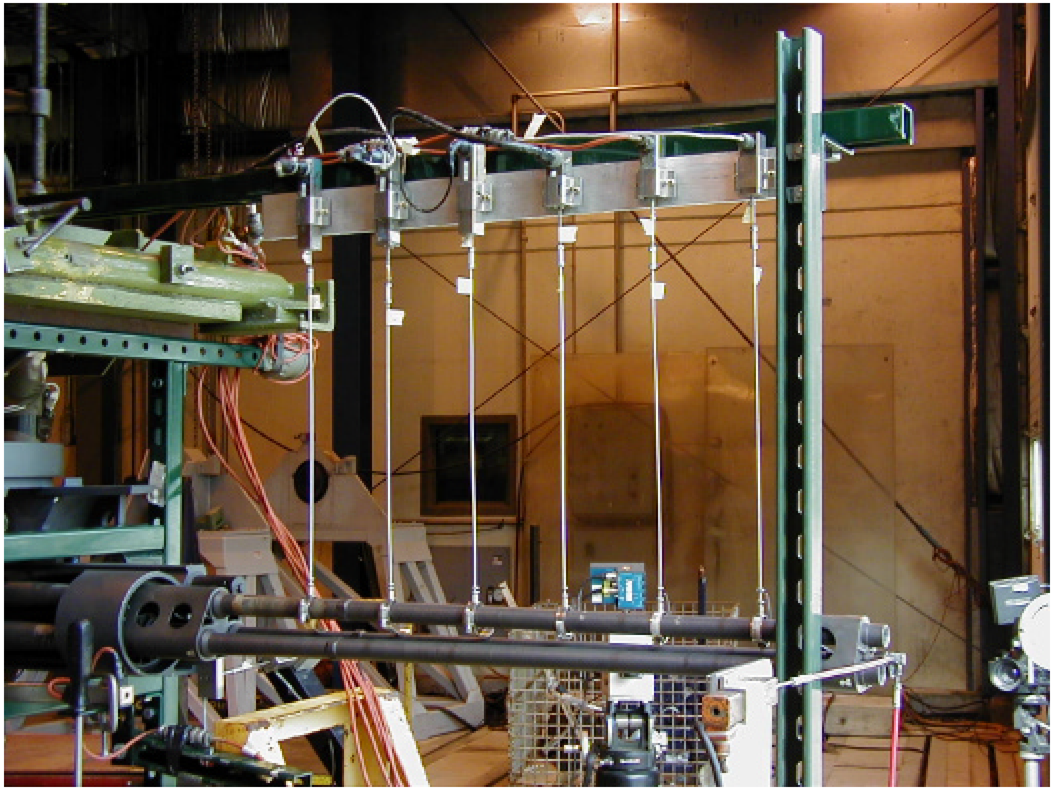


Linear Finite Element Models



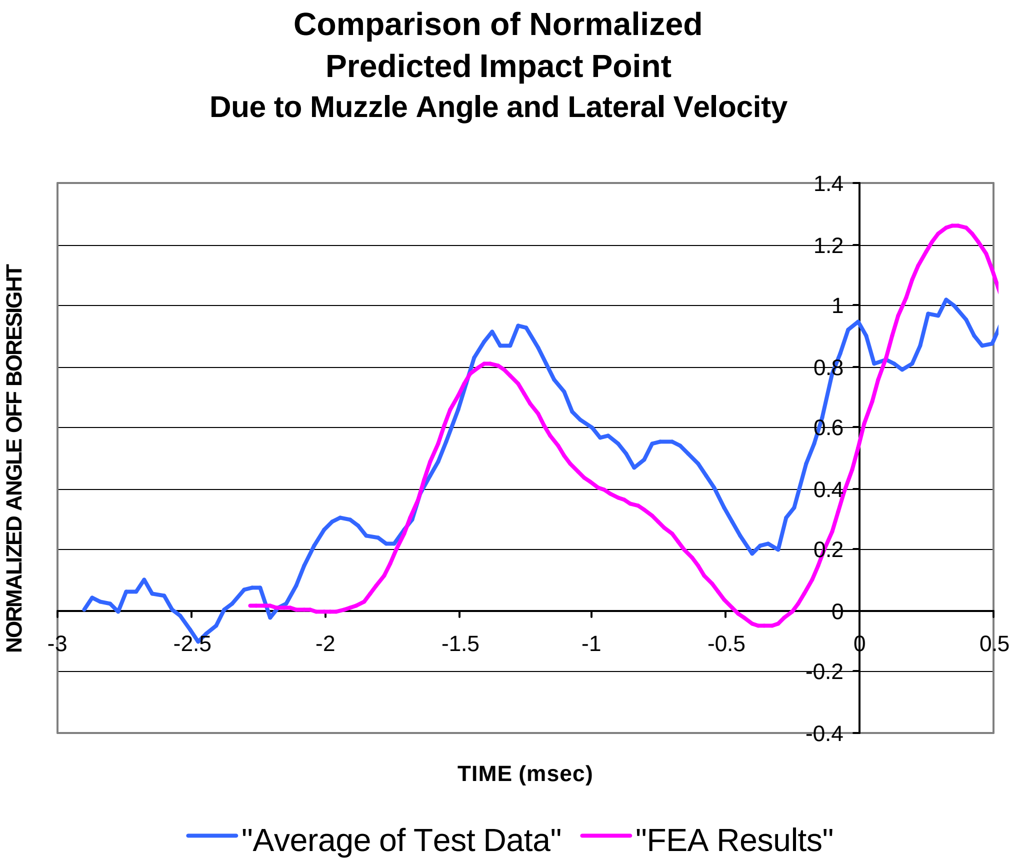
- Small Deflections (No spinning barrel cluster)
- Linear system
  - Linear recoil adapter
  - No gaps
  - Fixed boundary conditions at motor
- Fixed temperature
- Mass of all components match weight reports or measurements
- P-T curve applied at barrel breech
- Turret is modeled as a lumped mass spring system using stiffness values from test

Tests Performed in Support of Correlation



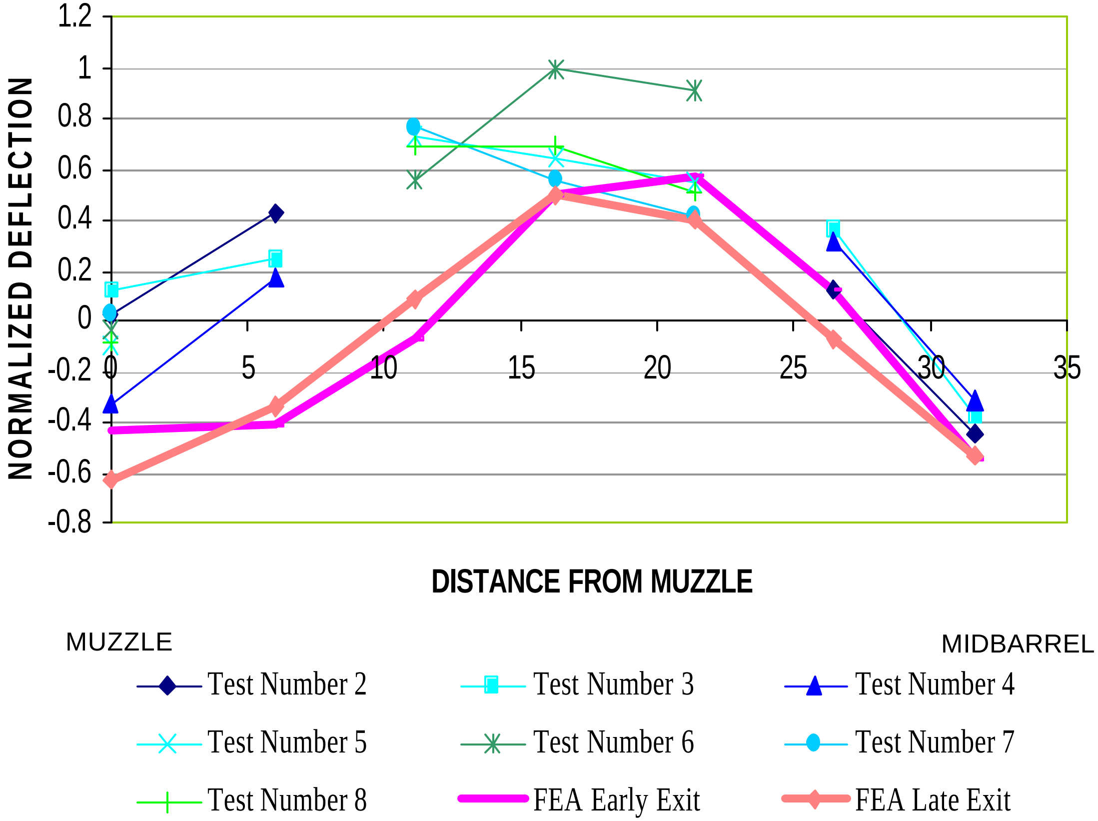
- Gun in Hardstand and Turret Configurations
  - ➢ Modal Testing
  - ➢ Fire Testing of Static (non-rotating) Single Shots for muzzle angle and barrel shape measurements
  - ➢ Burst Fire Testing
- Turret Stiffness Measurements

Hardstand Correlation for Normalized Predicted Impact Point



- FEA results follow shape of test measurements
- Key Metric is Slope
- Projectile exit occurs within +/- .05 msec of 0 on the X axis
- Small differences in frequency between FE model and actual hardware make a significant difference in predicted target

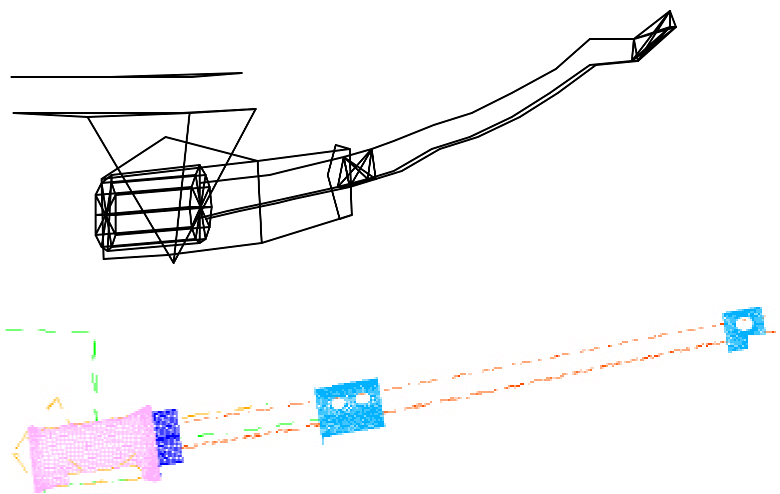
Hardstand Barrel Deflection Correlation



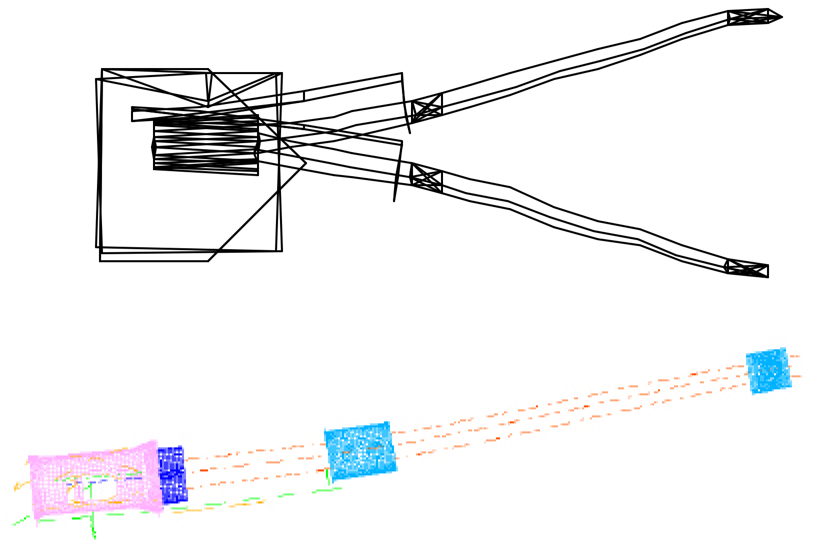
- Predicted shape is similar to measured shape

Modal Correlation in Turret Configuration
1st Elevation and Azimuth Modes

Elevation



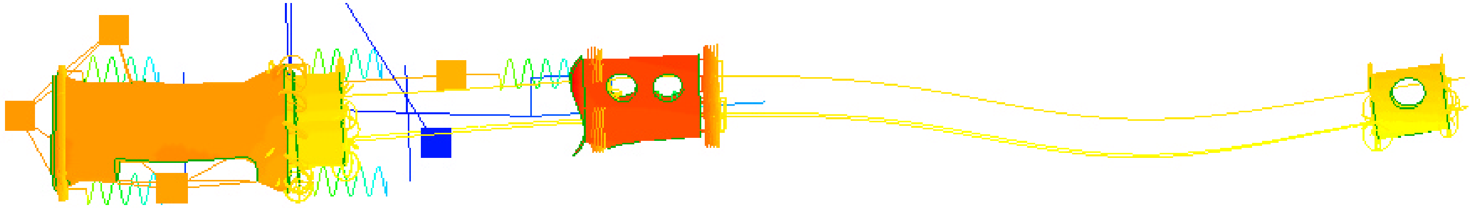
Azimuth



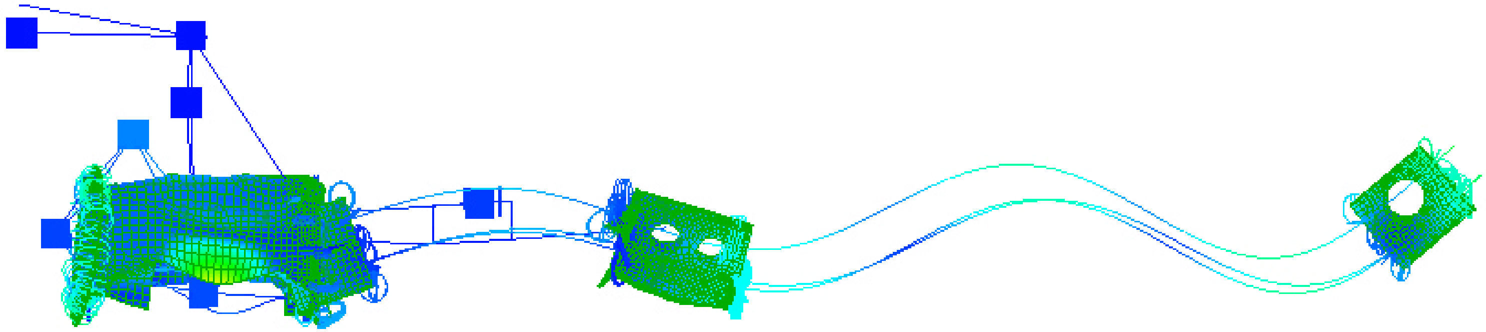
- Close comparison
- Most predictions up to 200 Hz within 7%

High Frequency Barrel Bending Mode

- Barrel Deflected Shape at Projectile Exit



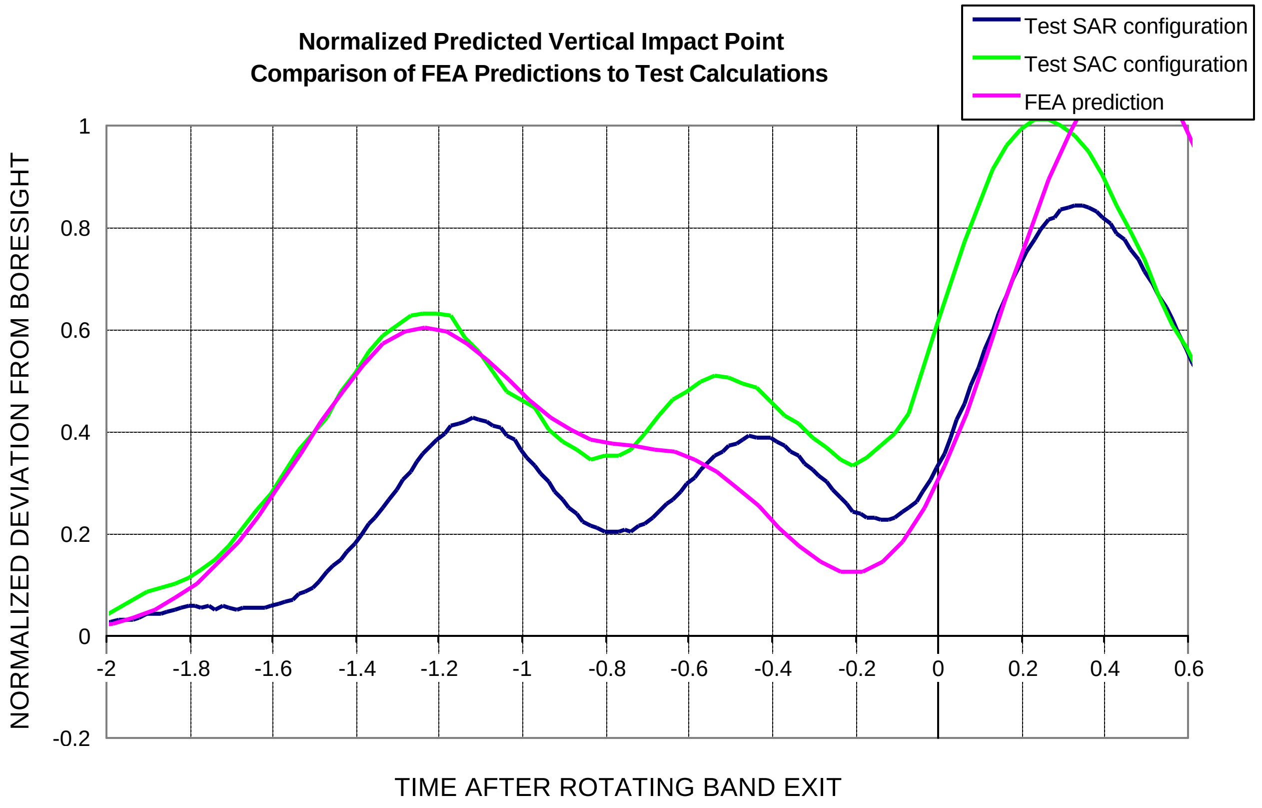
- Most Significant Barrel Bending Mode



This mode is excited by high frequency pitching/yawing excitation due to

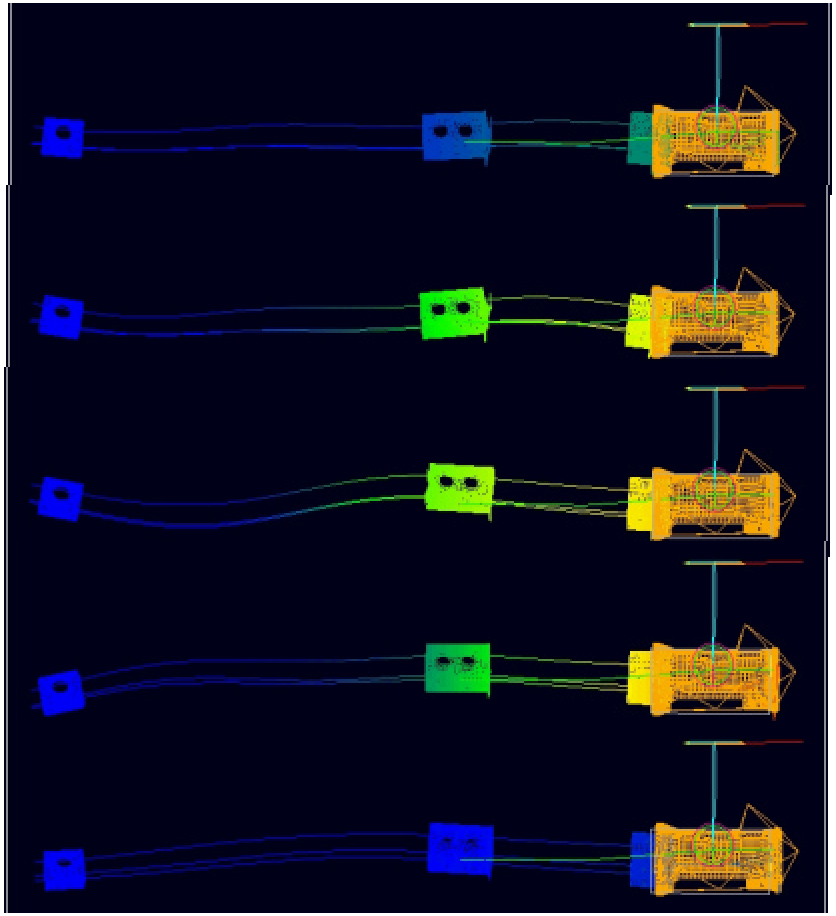
- Off center firing impulse which contains high frequency content
- Muzzle axial fixity (firing barrel recoil imparts moment at muzzle)

Correlation of Predicted Impact Point in Turret Configuration



- Most significant barrel bending mode is evident
- FEA results follow shape of test data
- Projectile exit occurs within +/- .05 msec of 0 on the X axis.

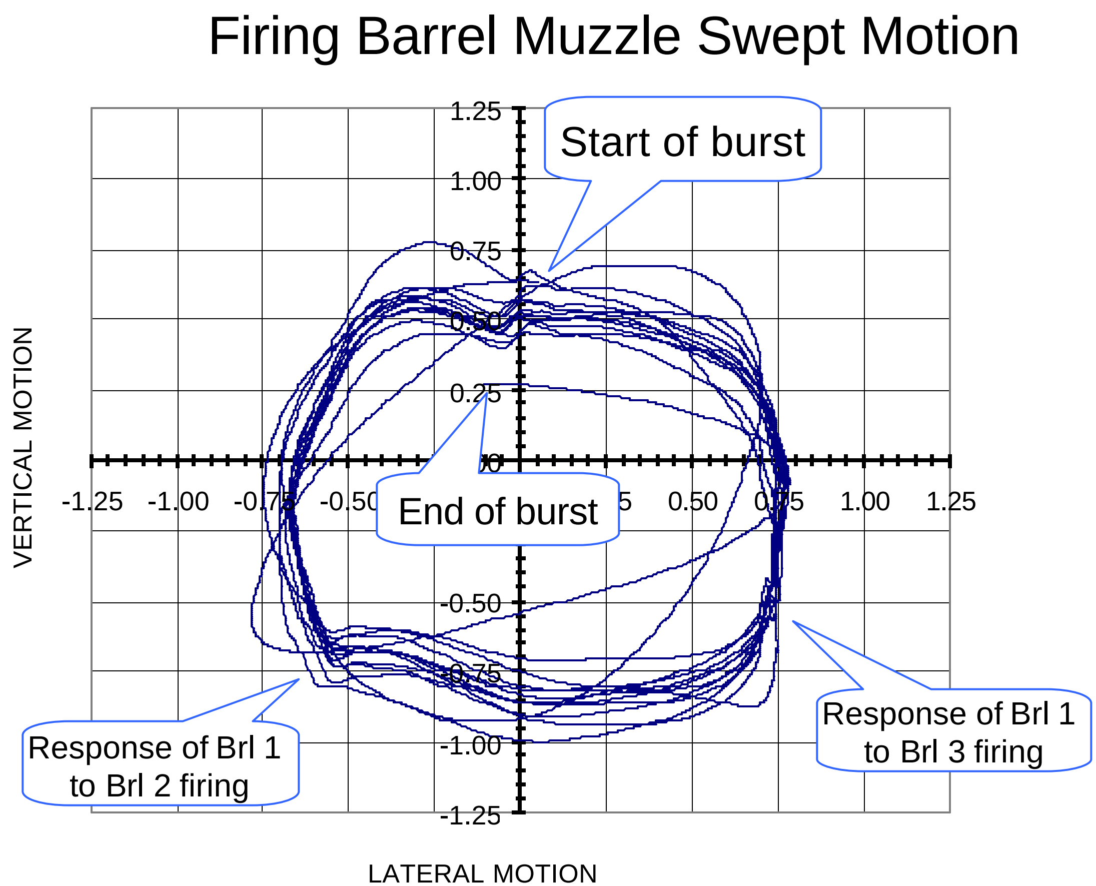
Non-linear ADAMS Model: Firing Animation



- Non-linear recoil adapter
- Spinning barrel cluster
- Flexible barrel cluster and housing
- Does not include modeling of friction or clearances

Barrel deflection is highly exaggerated

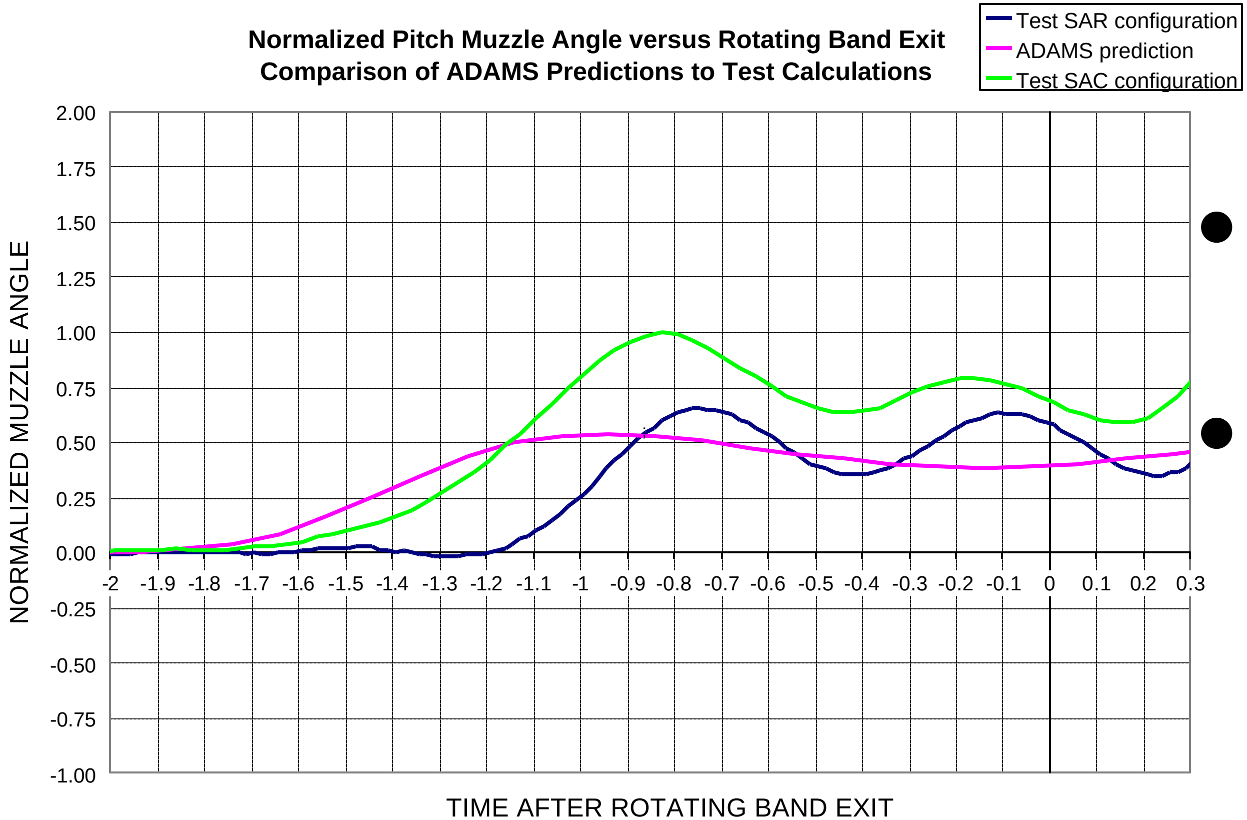
Non-linear ADAMS Model: Barrel X-Y Plot



- Traces position of top barrel during spinning (counter clockwise)
- (0,0) center of muzzle cluster before gravity
- Exhibits deflection from gravity
- Exhibits barrel deflection when each barrel fires

ADAMS Muzzle Pitch Angle Comparison

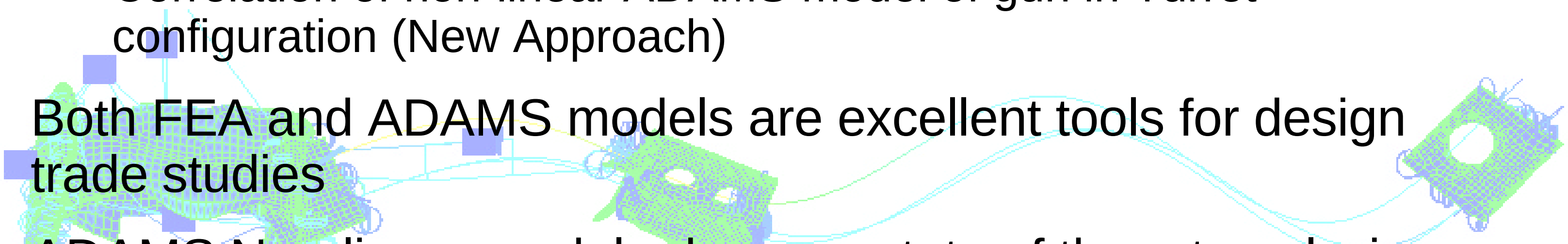
Normalized Muzzle Pitch Angle



- Shape of muzzle angle prediction is similar to test data
- High frequency components missing

Analytic Modeling

- Most Comprehensive and Successful Gun and Turret Correlation to Date
  - Correlation of linear FEM of gun in Hardstand and Turret configurations (traditional method)
  - Correlation of non-linear ADAMS model of gun in Turret configuration (New Approach)



- Both FEA and ADAMS models are excellent tools for design trade studies
- ADAMS Non-linear model advances state of the art analysis techniques for:
  - Greater fidelity of interface load calculations
  - Spinning stability evaluation including gravity effects
  - System failure mode evaluation