3-D Finite-Element Gun Launch Simulation of a Surrogate Excalibur 155-mm Guided Artillery Projectile - Modeling Capabilities and its Implications

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Overview

- Objectives
- XM-982 - Excalibur Projectile
- Challenges
- SRV FEM Models
- Results & Impacts to Excalibur Program
  - Validation & Verification.
  - Utility of 3D FE Models.
- Conclusions & Recommendations.

Objectives

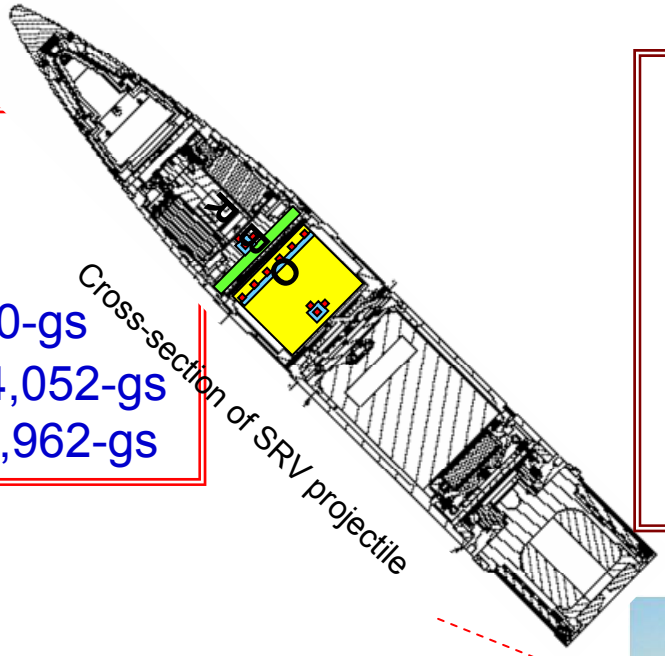
155-mm, extended-range, guided munition

- To develop and validate a 3D FE model capable of simulating launch environment of the Excalibur projectile.
- To predict component loads and support the design of artillery launched guided projectile components.
- To support failure investigation of critical projectile units in an evolving design environment.

XM-982, Excalibur Artillery Launched Guided Projectile

Demanding g Requirements

- In Bore: Axial- 15,800-gs
- Muzzle Exit: Axial - 4,052-gs and balloting 3,962-gs



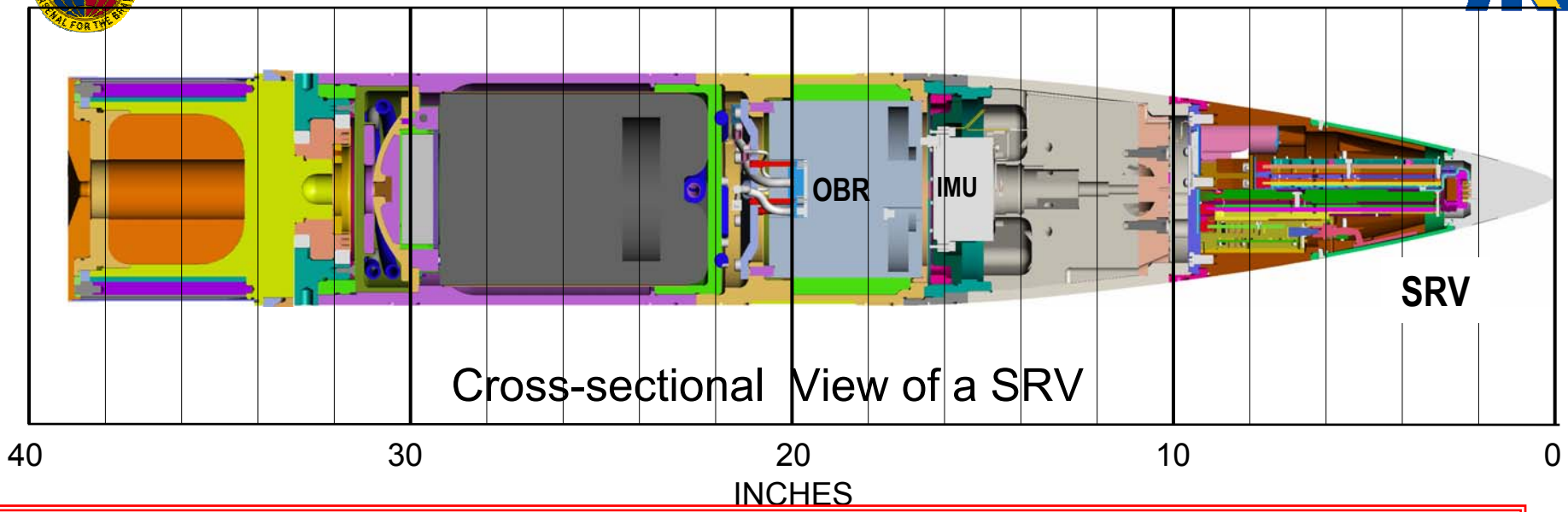
ISSUES

- Increasing use of sensitive electronics in a guided projectile.
- Survivability of MEMS is a major concern.

Design Development Methods

- Limited field tests
- Virtual simulation of launched environment using a detailed 3D FEM.

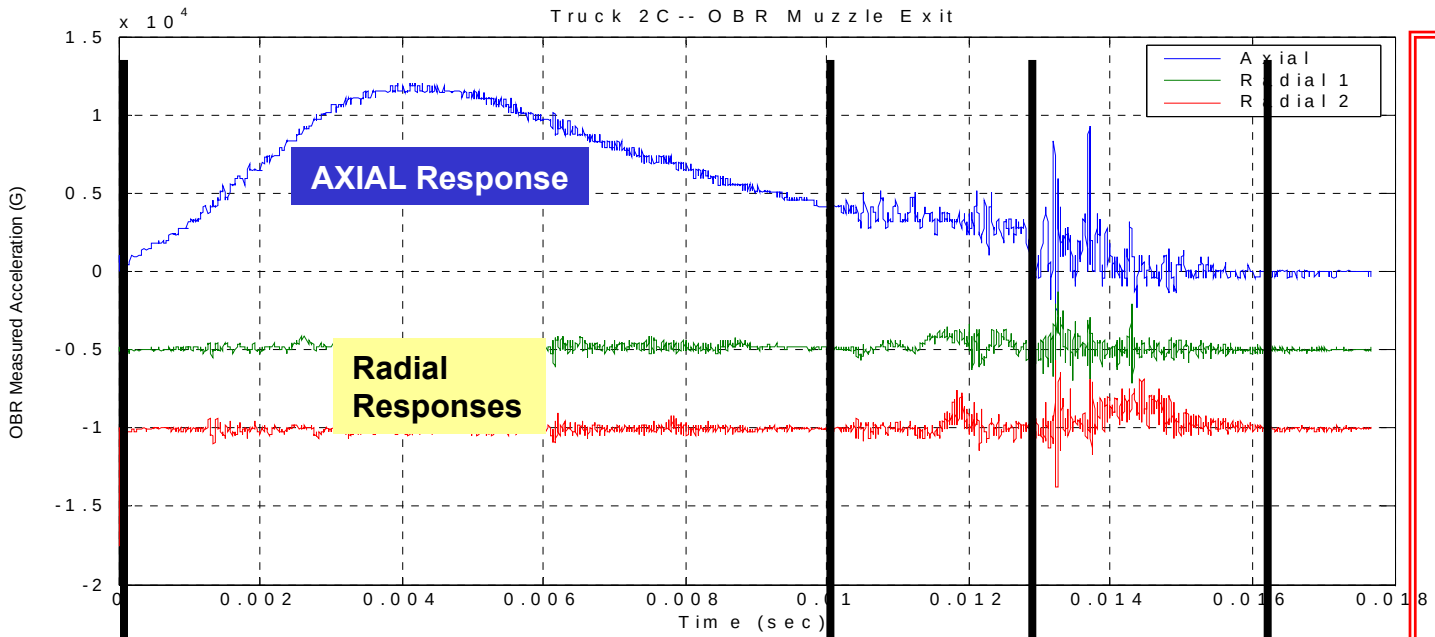
Challenges



- Obtain physics-based representation of a highly complex structural configurations & interactions
- Provide real-time design driving guidance to evolving development of projectile's structure
- Achieve "fast-turn-around" version of a representative 3D transient model inherently "lengthy"
- Obtain accurate & representative validation test data- difficult to keep up with the test program
- Address "test-based" malfunctions or failures

Artillery Launched Guided Projectile –

Typical Launch Response Environment



Demanding Environments

- Accel.
  - ~ 16 k'g - Barrel axial
  - ~ 4 k'g - Balloting
  - ~ 4 k' g - Exit axial
- Pressure
  - ~ 52 ksi - Base
- Frequency (Hz)
  - 33 kHz+ (exit)

Entire projectile inside gun tube	Muzzle Transition	Muzzle Base Exit	
Zone 1	Zone 2	Zone 3	Zone 4
Set Back	Transition	Set Forward	Free Flight

- Strength Based design of subsystems

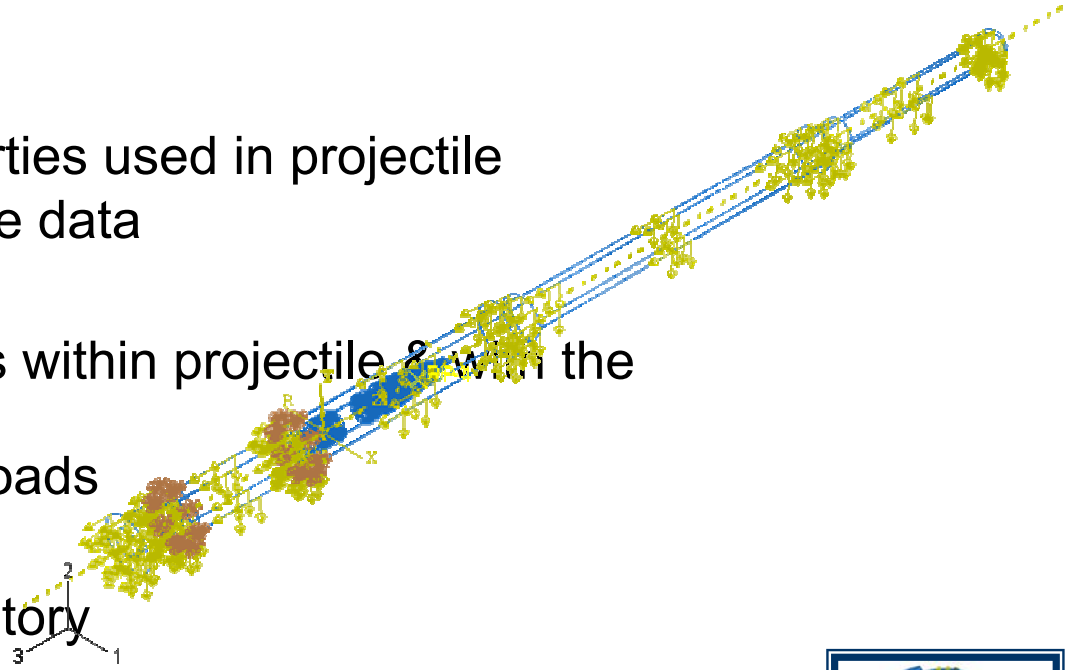
- High-g transient dynamics response based design of guided electronics & their mountings

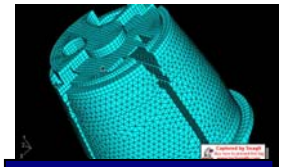
✓ **Uncertain Design Environments**

3D FEM of SRV Projectile –

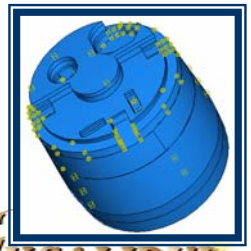
Modeling Barriers & Issues

- Geometry
  - Degree of defeaturing
  - Degree of compatibility of CAD and CAE platforms
  - Art and Science
- Material Models
  - Inexact material properties used in projectile
  - Correlate with response data
- Internal constraints
  - Ties vs contact of parts within projectile & with the gun
  - Joints and transfer of loads
- Loads
  - Base pressure time history
  - Gun & geometry
- Boundary Conditions
  - Trunions' effect





Original



Defeatured

3D FEM of SRV Projectile –

Modeling Cases & Conditions

- Over 50 modeling cases were run including:
  - Projectile systems & variations
  - Subsystem/components – IMU, GNU etc.
  - Gun barrel interactions
  - Spinning and balloting effects
  - Verification/validation/model consistency check
  - Sensitivity analyses
  - Joint compliance/joint loads
  - Gravity gun droop
- A selected subset of cases is discussed next.

3D FEM of SRV Projectile –

NO Gun Barrel in Model (old SRV)

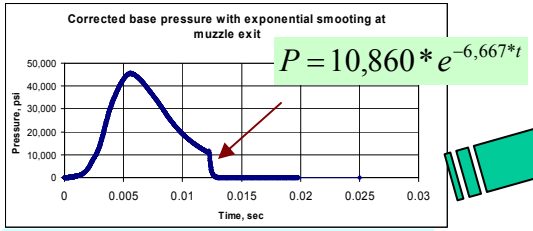
Restraints (pinned), u2 = u3 = 0

Simulated Boundary Conditions (Progressive).

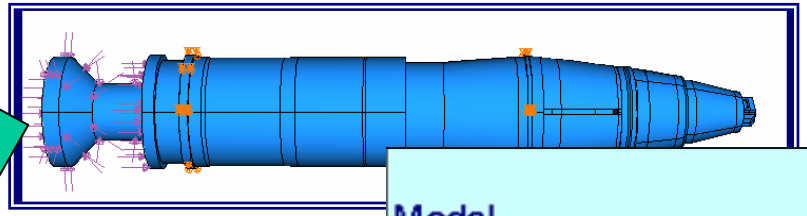
Step 1. Both obturator rings are restrained along radial directions

Step 2. Only back ring is restrained along radial dir.

Step 3. Free- BCs



High-g impulsive thrust **(Typical)**

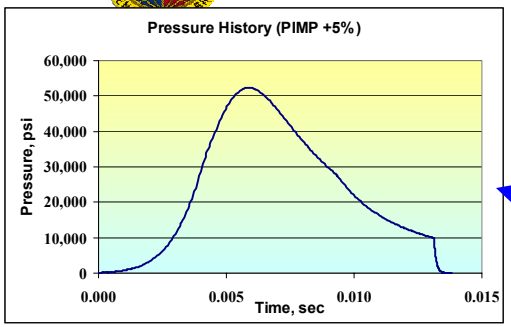


Model	Bp1-Step3-Tie-P76-V5
# DOFs	556,680
# Elements	123,399
Total weight in lbs	104.58
C.G. from the bottom of Boom Base in in.	16.87
CPU Time in sec, 8 CPUs	748.041

"Projectile-only" FEM is capable of predicting Design loads for most subsystem design.

3D FEM of SRV Projectile –

Gun Barrel/Projectile Interaction Model



Typical

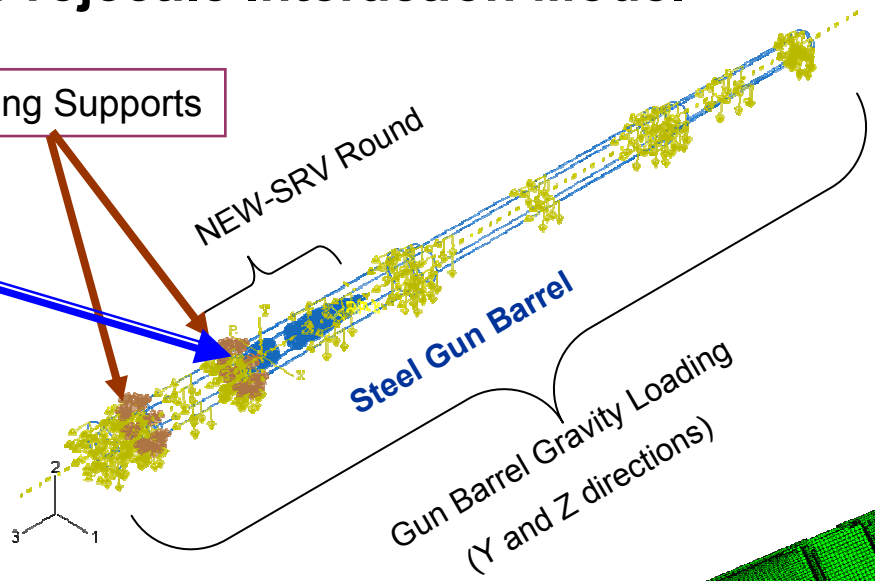
Bearing Supports

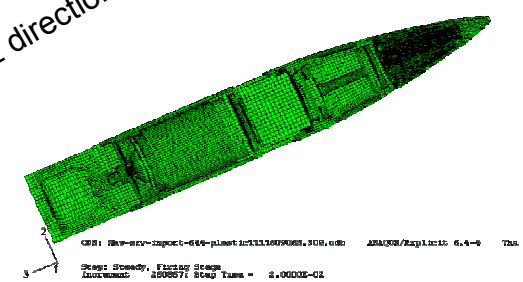
NEW-SRV Round

Steel Gun Barrel

Gun Barrel Gravity Loading (Y and Z directions)

Base Pressure-distribution is shown next





Two-phase FEA Analyses

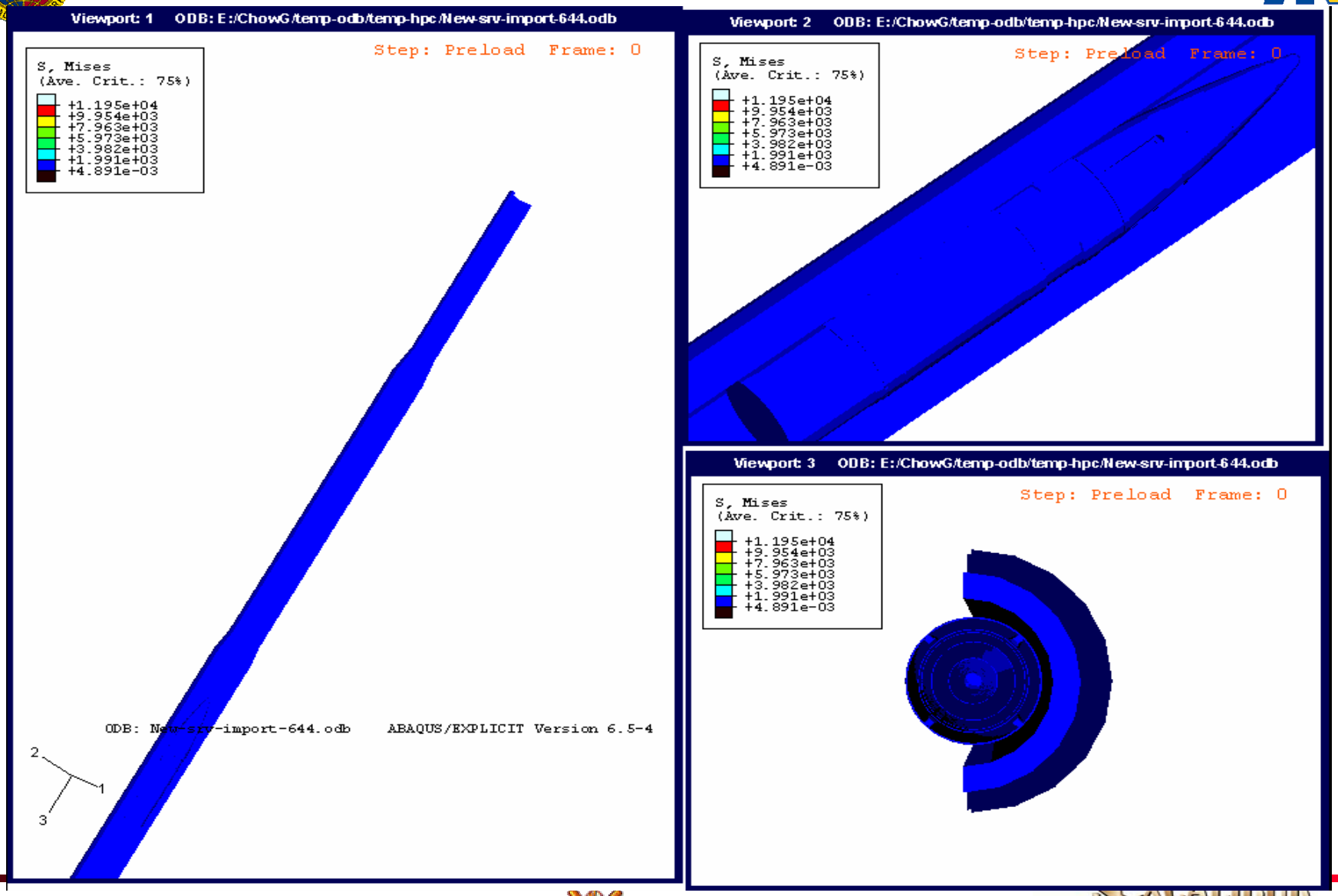
- **Phase 1.** ABAQUS Standard gravity analysis
- **Phase 2.** ABAQUS EXPLICIT Dynamic Analysis

Model	New-SRV-spin-import-644.dat
# DOFs	1,124,979
# Elements	374,992
Total weight in lbs (Projectile)	105.78
C.G. from the bottom of Base in in.	13.78

CPU time r.t. No barrel ~ 3- 4 X

Sample Analysis Results 3D SRV FEM-

Components shock environment



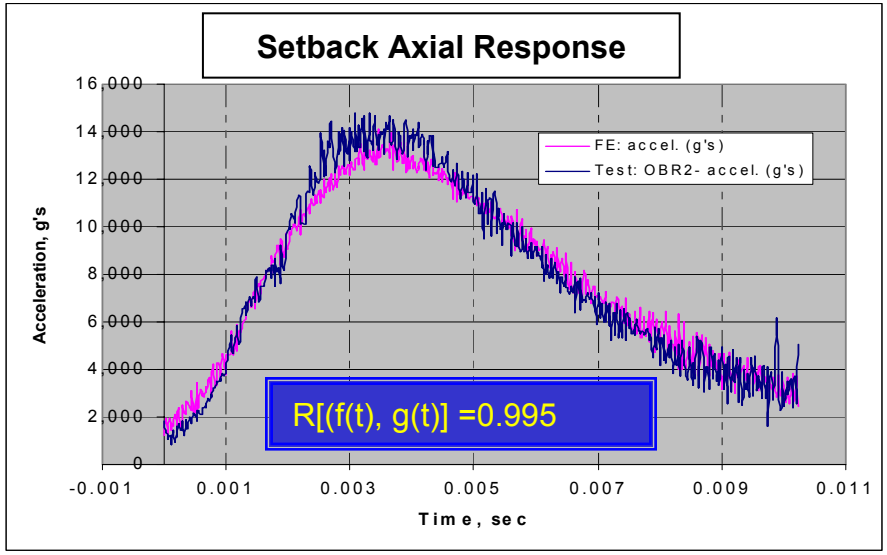
3-D FEM of SRV Projectile –

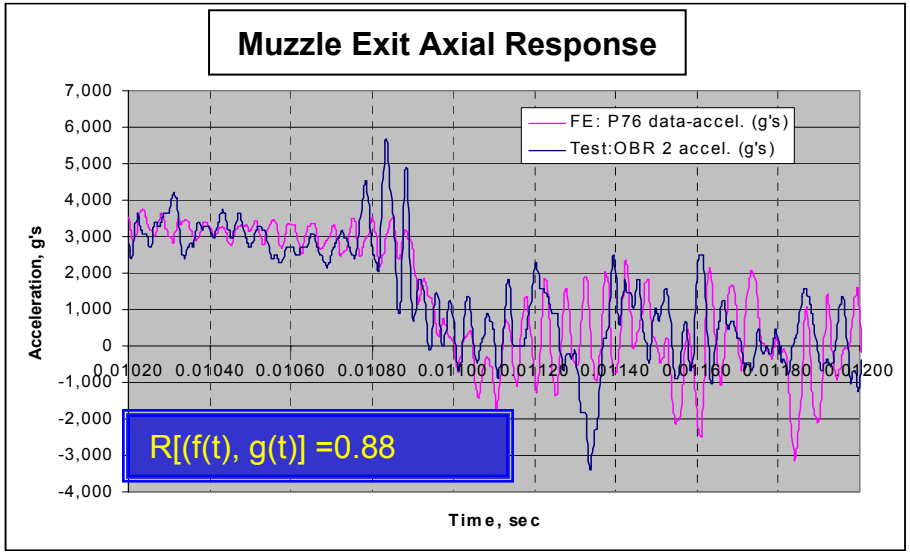
FEM With and Without Gun Barrel – advantages & disadvantages

- **Gun Launch Simulation FEM with Barrel**
  - Increases the computational cost; dof's are almost twice the no-gun simulation case
  - Gun barrel interaction phenomena is critical to electronics' survivability analysis
  - High-g transient load for design of embedded electronics components can be predicted using this FEM.
- **Gun Launch Simulation FEM without Barrel**
  - Design loads for stress adequacy of subsystems can be effectively predicted.

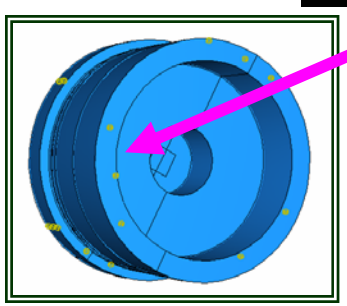
FEM Validation - during launch process in 155-mm Gun

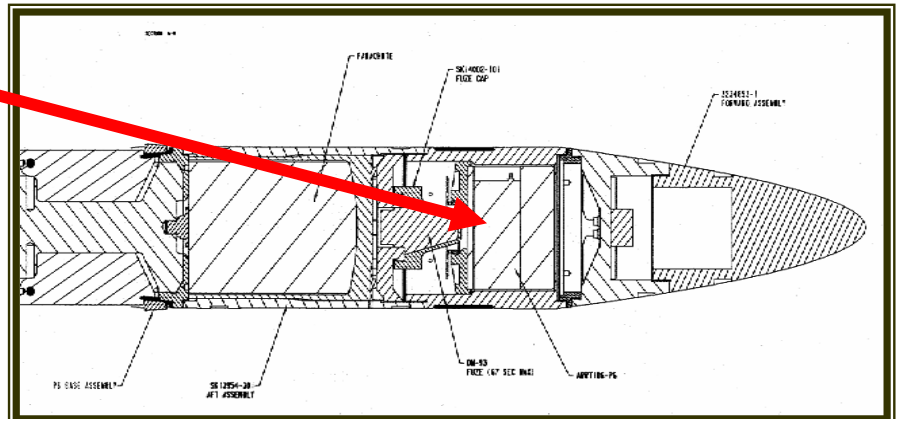
Comparison of Simulation vs. Test response at OBR Location





OBR accelerometer

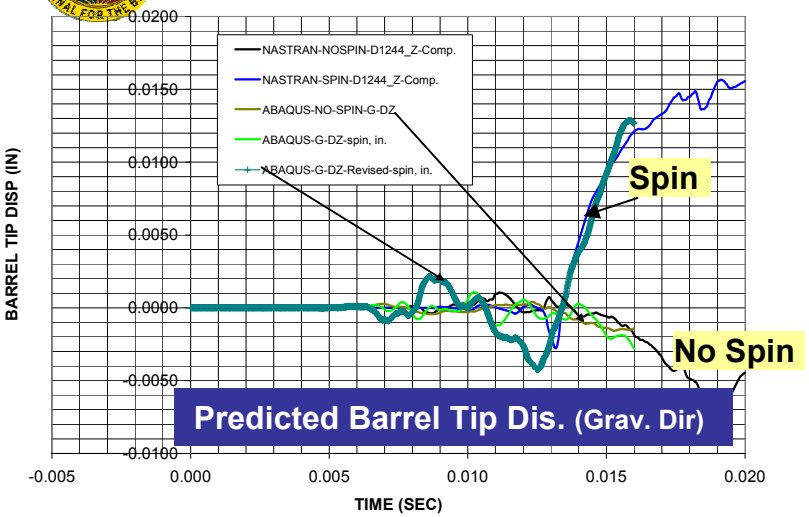




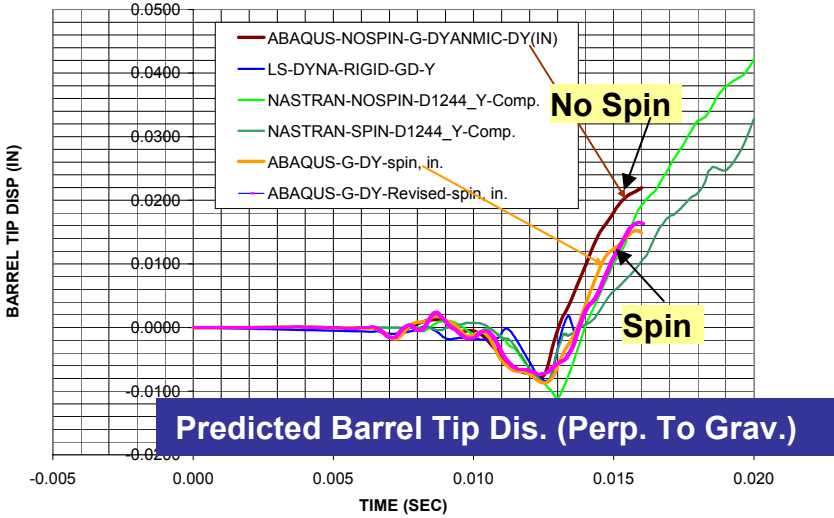
- Predicted and test responses are reasonably well correlated for the event
- BP1 Configuration with NO gun FEM

Multiple FEM Verification – barrel projectile model

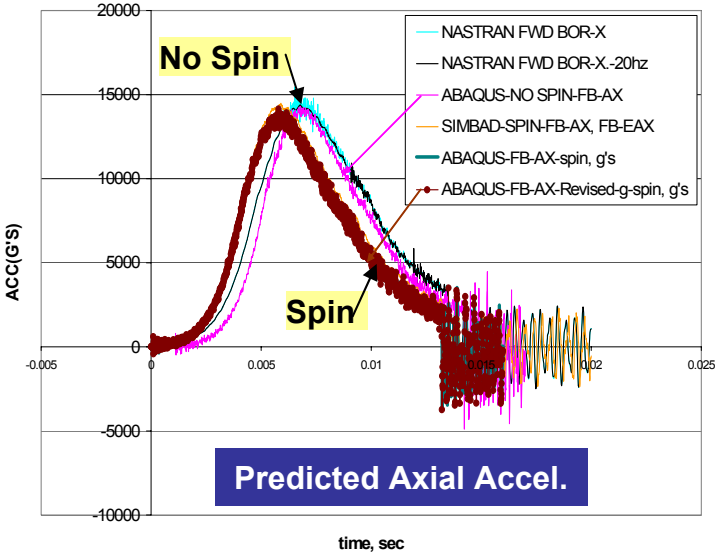
Comparison of Simulated Spin vs. No Spin Responses using Different FE Codes



Predicted Barrel Tip Dis. (Grav. Dir)

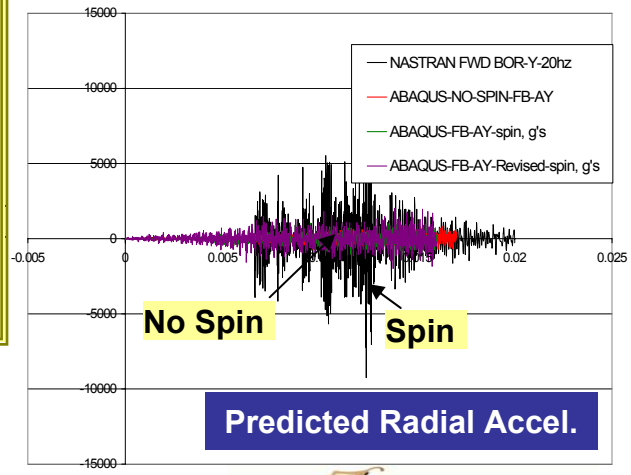


Predicted Barrel Tip Dis. (Perp. To Grav.)



Predicted Axial Accel.

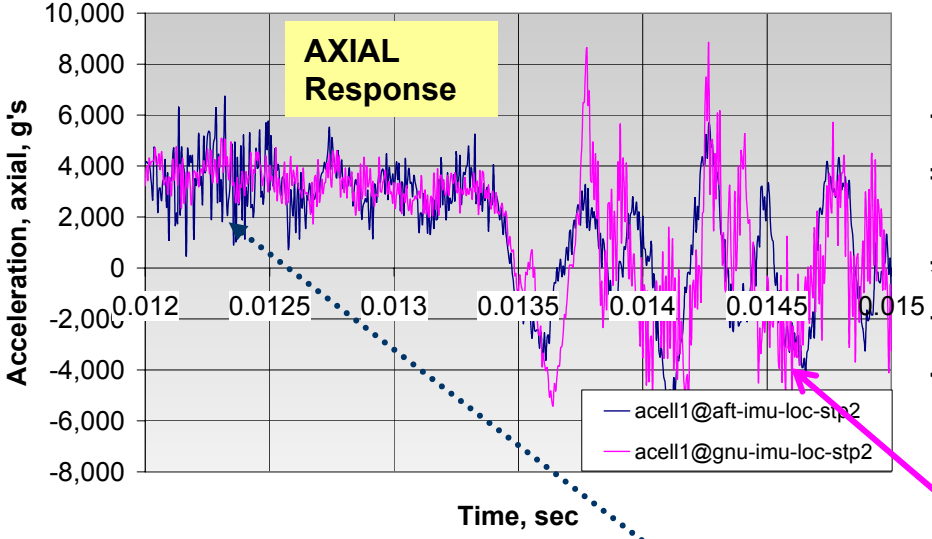
Qualitative agreement among predicted results using various FE codes verifies the effectiveness of the FEM.

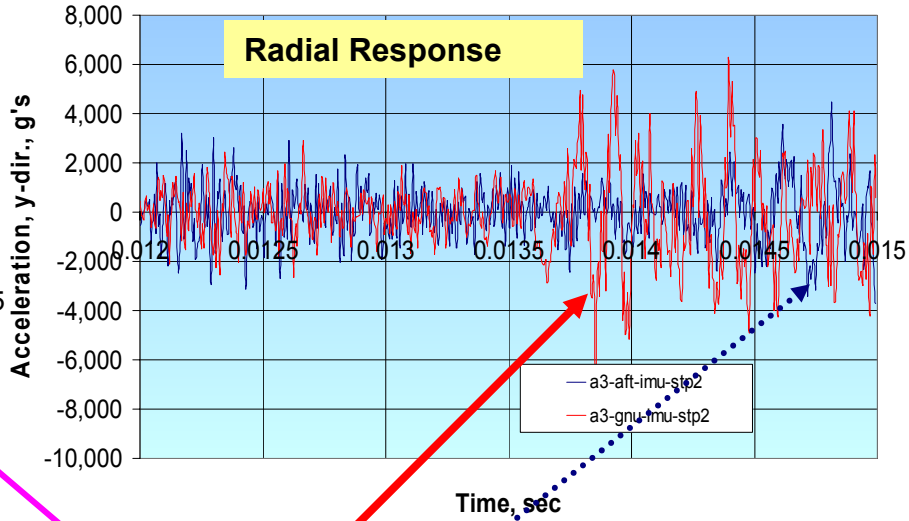


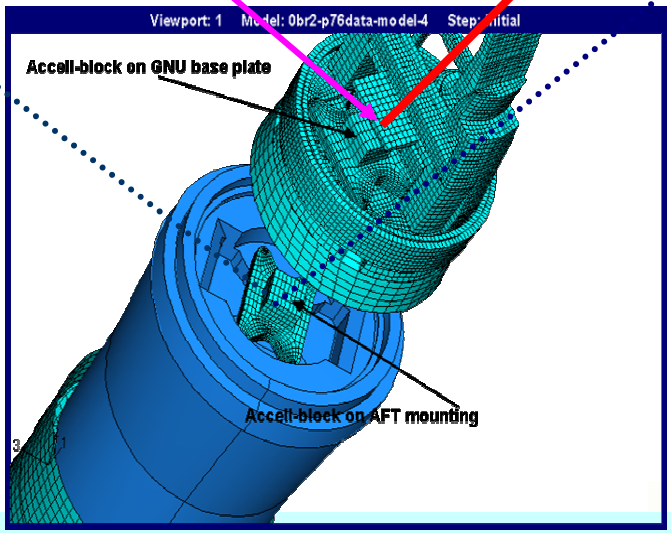
Predicted Radial Accel.

Utility of 3D Transient SRV FEM -

Locating suitable mounting locations of sensitive electronics components







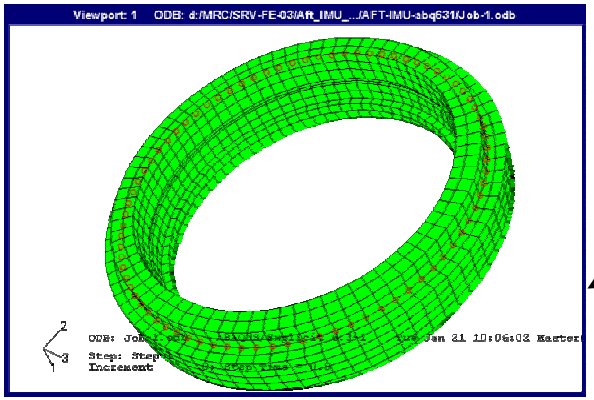
- Comparison of simulated responses:

G's at Forward location ~ 8,500
G's at AFT location ~ 3,000

Demonstrates the effectiveness of FEM in evaluating design concepts.

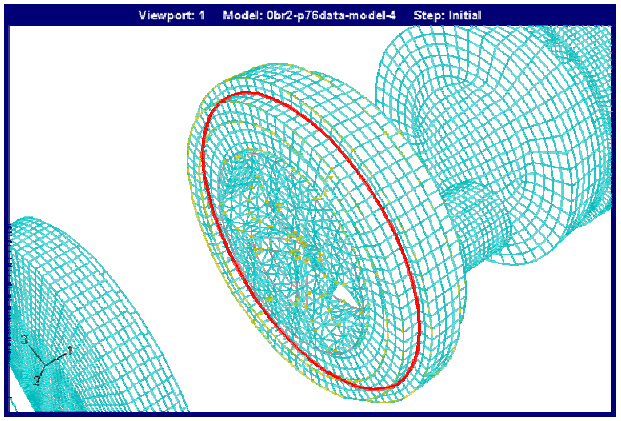
Utility of 3D Transient SRV FEM -

Sub Modeling Analysis –Micro-Level failure Investigation of IMU

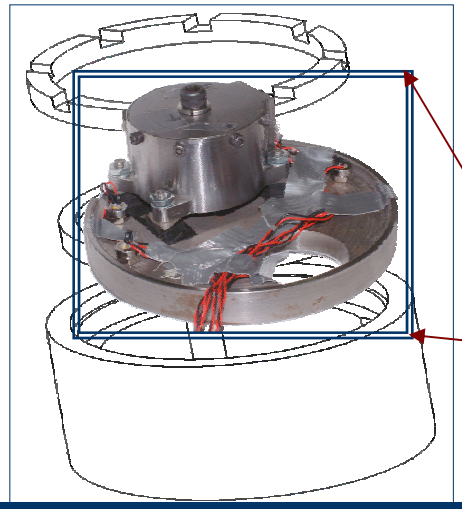


Top Driven Nodes from Global Model

ABAQUS Global Response From 3D FEM



Bottom Driven Nodes from Global Model



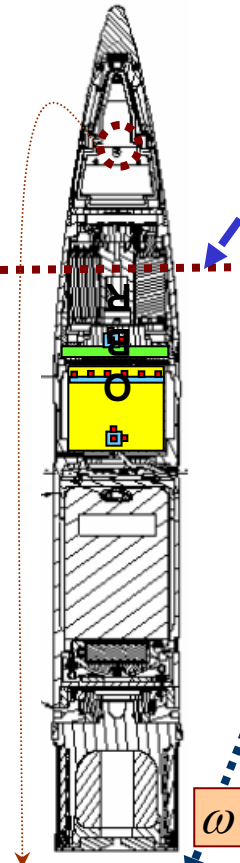
Time Saving Estimate ≥ 10X

- ❖ **Local detail FEM of IMU**
- ❖ **Global FEM provides input loads for this Local FEM**

- **Predicted global Accel. for driven nodes are used for sub modeling evaluation of the IMU device.**
- **Local detail FEM of the IMU is used thereby saving computational time.**

Utility of 3D Transient SRV FEM –

Failure Investigation of MEMS



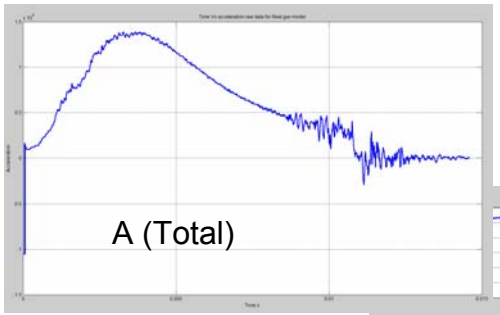
Acceleration Time history at location of interest

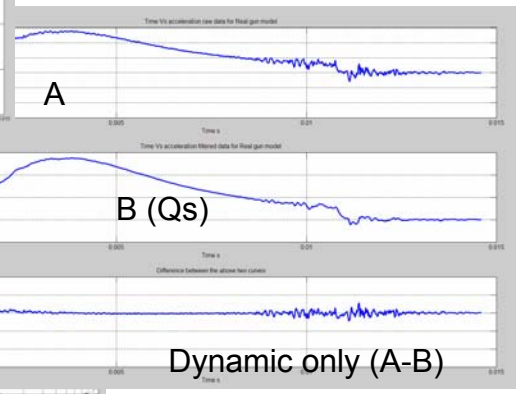
Dynamic Response (extract dynamic load)

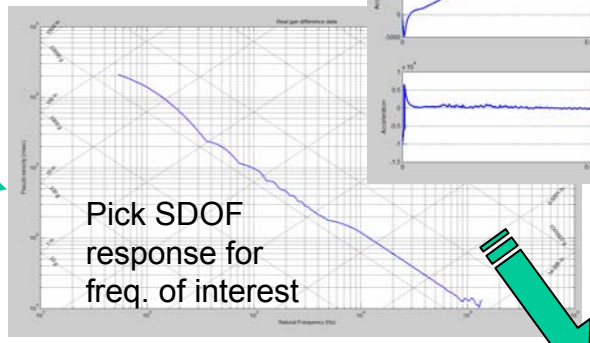
SRS (Shock Response Spectrum)

Stress calculations based on SRS

Component Survivability ??







$$\omega_n = \sqrt{\frac{k}{m}}$$

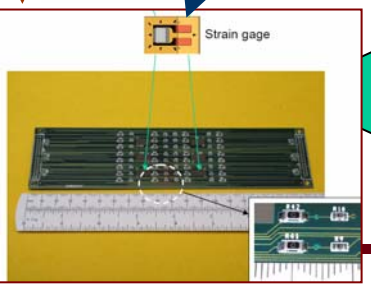
$$\ddot{y}_{max}, \partial_{max}$$

$$\sigma_{max} = \frac{Mc}{I}$$

$$\kappa_{max} = \frac{M}{EI}$$

$$\sigma_{predicted,max} \leq \sigma_{allowable}$$

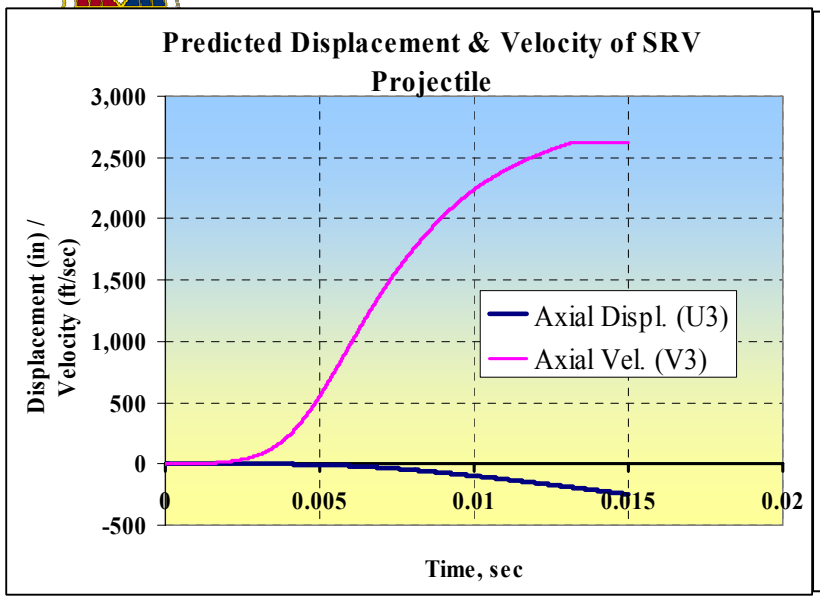
ω?



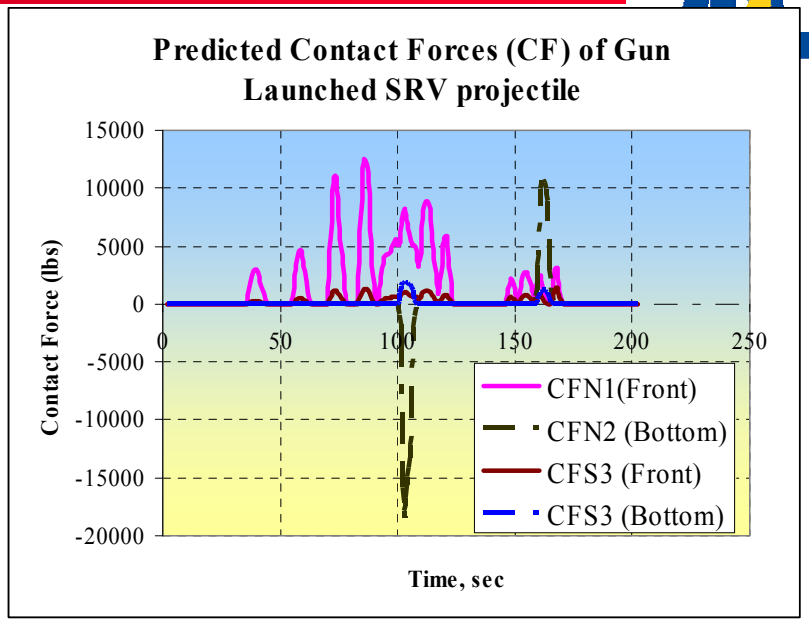
Embedded MEMS

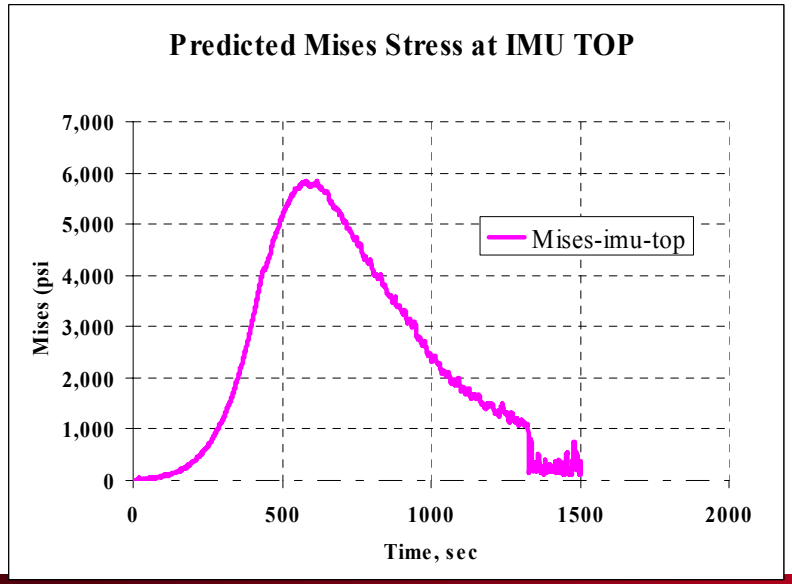
Predictive Capability of SRV FEM-

General behavior is explained

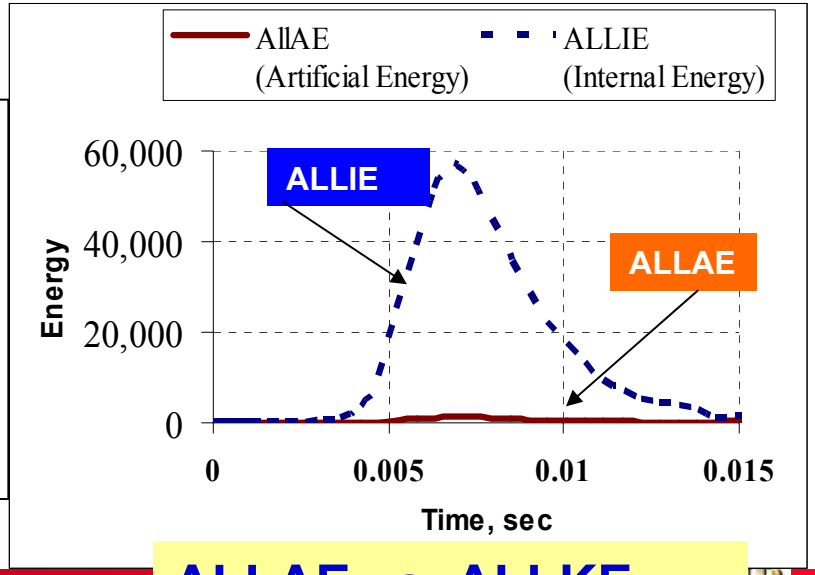


Traveled distance and the muzzle velocity compared closely with field values





Points to insignificant hourglass problem.



ALLAE vs. ALLKE

Conclusions & Recommendations

- Virtual simulation of a system behavior using a validated and verified FEM provides a flexible and powerful design evaluation tool for the future sophisticated systems.
- Gradual development of FEM starting with a simple model and then progressively adding features to improve the model capability is important in the development of a complex system such as the SRV projectile discussed here.
- Validation of FEM with measured results is desired, however, verification with alternative predictive tools may be used as an alternative.