U.S. Army Research, Development and Engineering Command

Results and Analysis from Mine Impulse Experiments Using Stereo-Digital Image Correlation

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Outline

- Issue & Objectives
- Experimental Setup/Target Description
- Test Results & Analysis
- Modeling Approach
- Conclusions
- Recommendations

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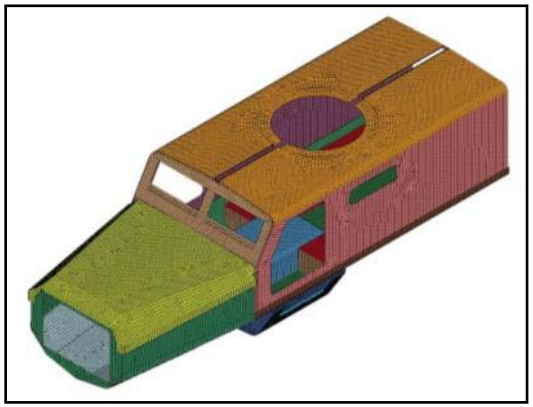
Context for Army Efforts

Issue

Under-body blast is one of the leading causes of casualties in current operations, but our capability to accurately and efficiently assess its effects on both personnel and vehicles is quite limited.

Modeling & Simulation (M&S) Problem

Finite element modeling has not been validated for supporting Army evaluations in the acquisition community. The under-body blast methodology (UBM) program was developed in part for this purpose.



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UBM Program Objective

- To provide a robust M&S capability to the U.S. Army Test & Evaluation (T&E) community by:
  - Understanding the fundamentals of the blast effects of buried charges
  - Validating the use of models, including finite element methods, for under-body blast analysis.

- The M&S capability will be used for:
  - Planning Live-Fire Test and Evaluation (LFT&E),
  - Evaluating expanded problem sets (threats, targets, and engagement conditions),
  - Augmenting test data, and
  - Developing survivability/vulnerability data to support broader Army analyses.

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Test Series Objective

- Develop and analyze experimental mine impulse data for simple v-shaped structures constructed with a top floor plate.
- Measure, with some degree of confidence, the structural responses of simple targets using stereo-digital image correlation.
- Perform a statistical analysis of the resulting data to identify mathematical trends.
- Use various finite element modeling approaches to replicate test events.

Experimental Setup

- Test Matrix: 24 events were completed including 16 centerline and 8 off-centerline tests.

Target Geometry	**20 Degree Target**			**10 Degree Target**	**30 Degree Target**	
Charge:	600g	800g	1000g	600g	600g	Total Tests
Centerline Shots	4	4	-	4	4	16
Off-Center Shots	1	4	3	-	-	8

- Three target geometries were tested; v-hull angles of 10, 20 and 30 degrees.

Geometry 1 - 10^0

Geometry 2 - 20^0

Geometry 3 - 30^0

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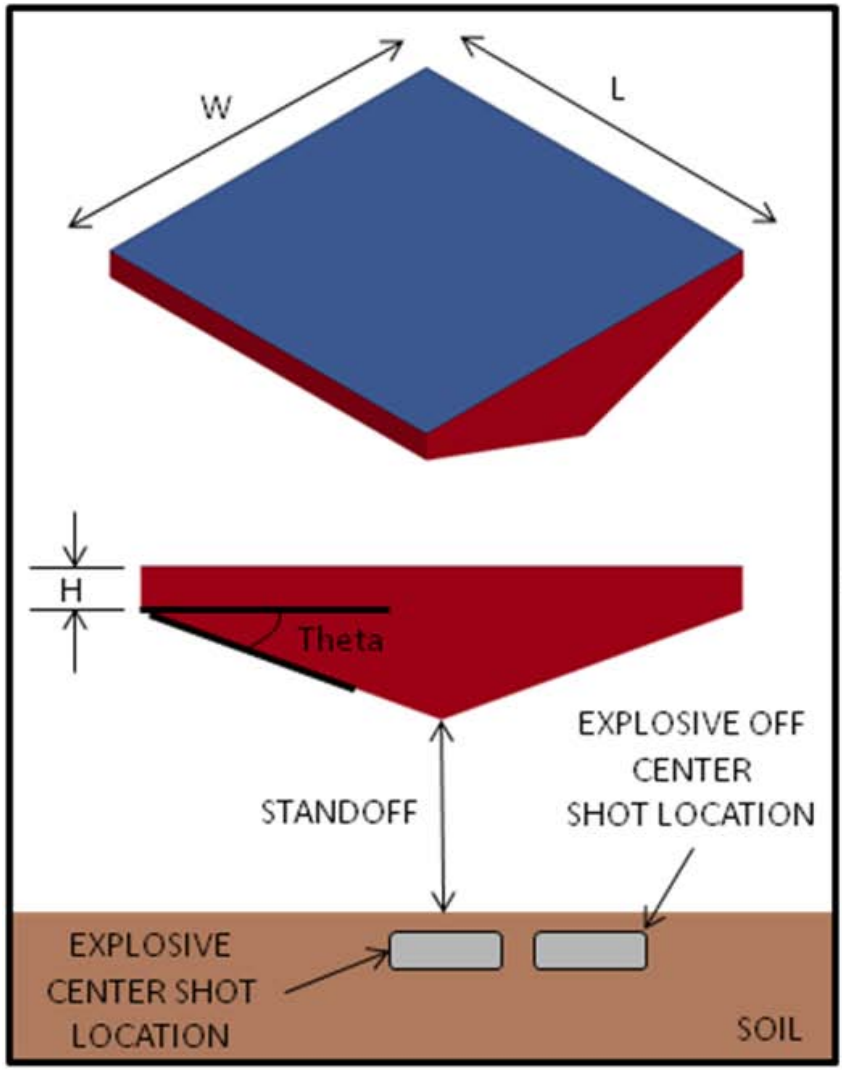
Target Description

- Targets constructed from A-36 Mild Steel.
- Target dimensions:
  - H = 50.8 mm
  - L = 700 mm
  - W = 700 mm
- All tests configured with 250mm standoff and 50mm depth of burial.
- Red clay/sand soil was used at the test facility.
- C4 charges weighing 600g, 800g and 1000g were chosen based on facility capabilities and expected target response.



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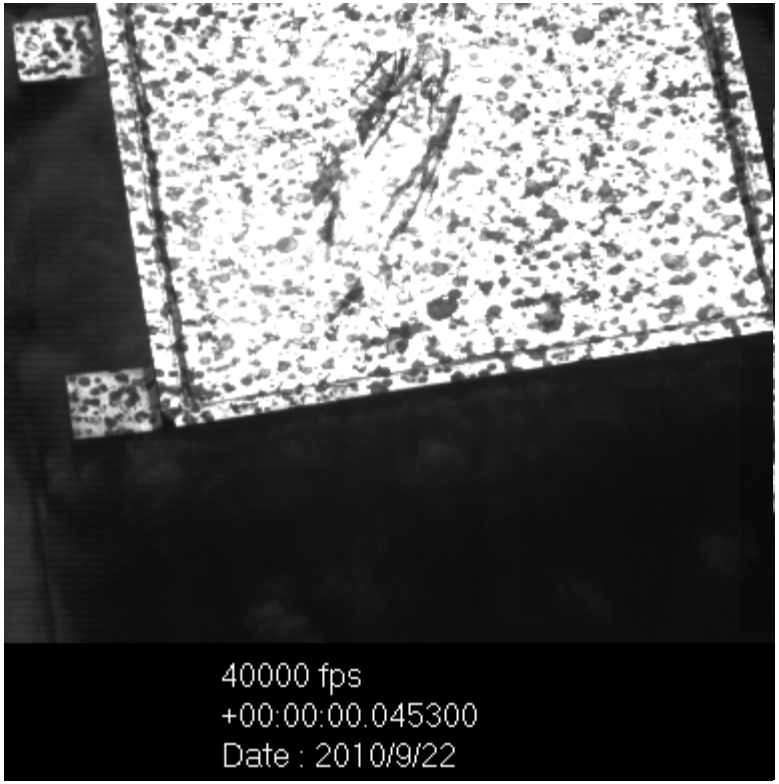
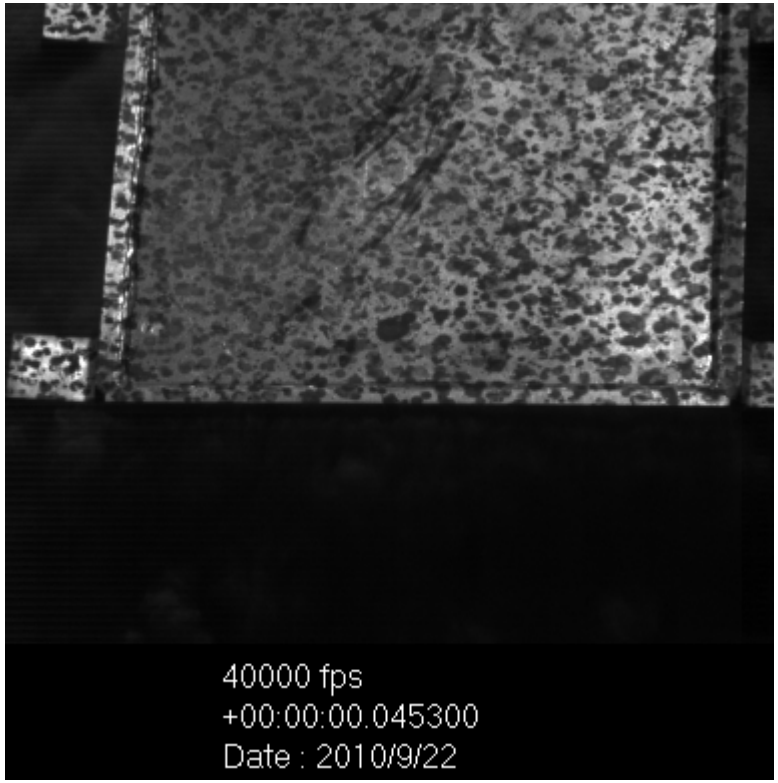
Experimental Data Acquisition

- Target motion data was acquired using two high-speed cameras and processed with stereo-digital imaging correlation software.





- A speckled pattern on the surface of the target provided the software a way to track oscillatory motion as the speckle marks shifted pixels. The motion also provided a method to estimate impulse.

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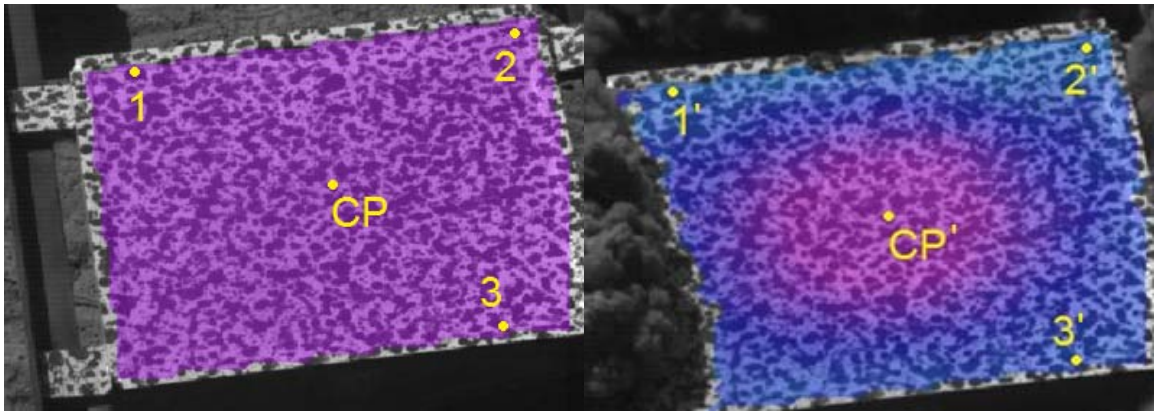
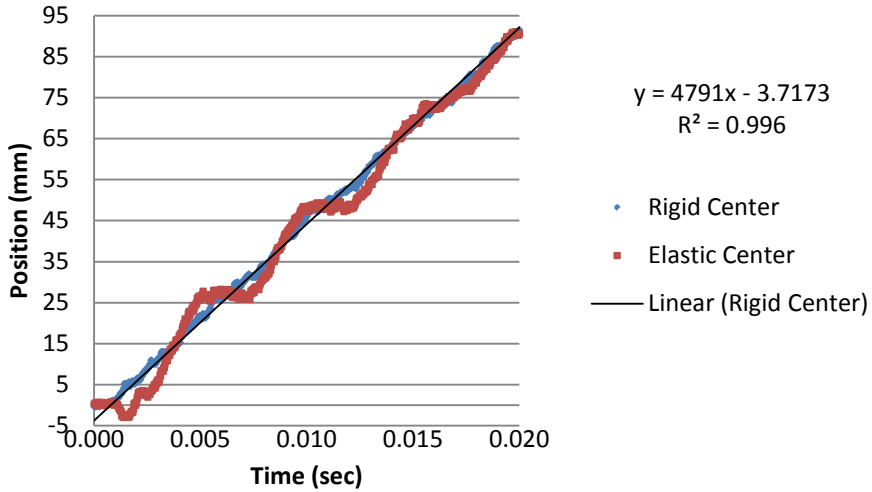
Experimental Data Acquisition

- Impulse to the target was estimated using the velocity determined by the digital image correlation software and the measured target mass.



Position vs. Time (CP)



$$a(x_2 - x_1, y_2 - y_1, z_2 - z_1) + b(x_3 - x_1, y_3 - y_1, z_3 - z_1) = (x_{cp} - x_1, y_{cp} - y_1, z_{cp} - z_1)$$

$$I = m \times v$$

Where: I=impulse, m=mass of the target and v=slope of trend line.

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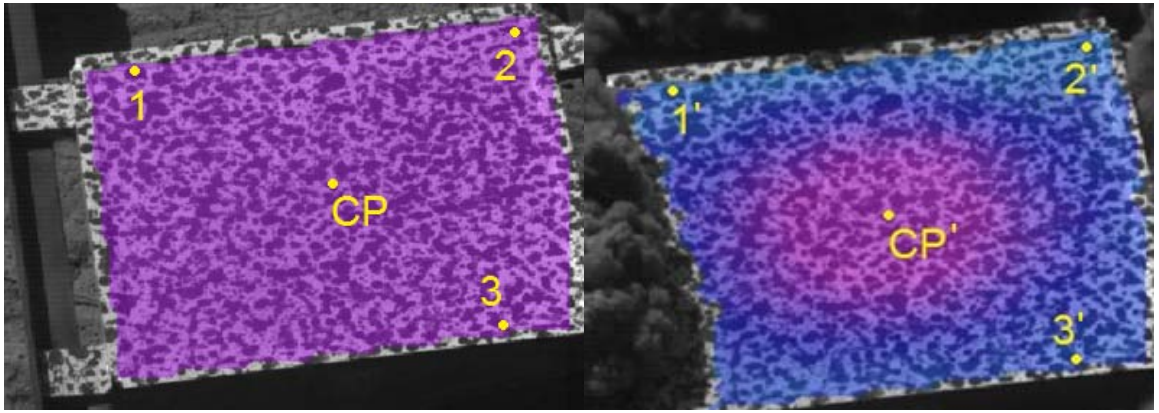
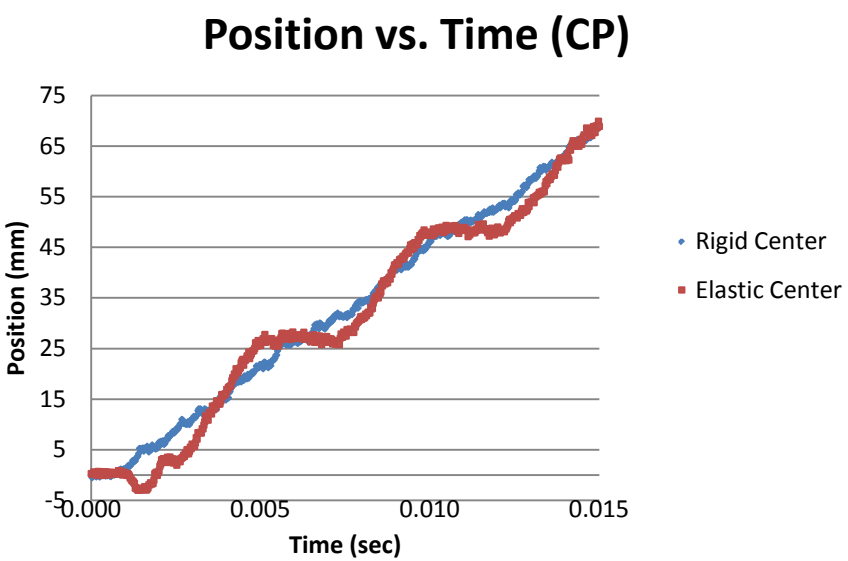
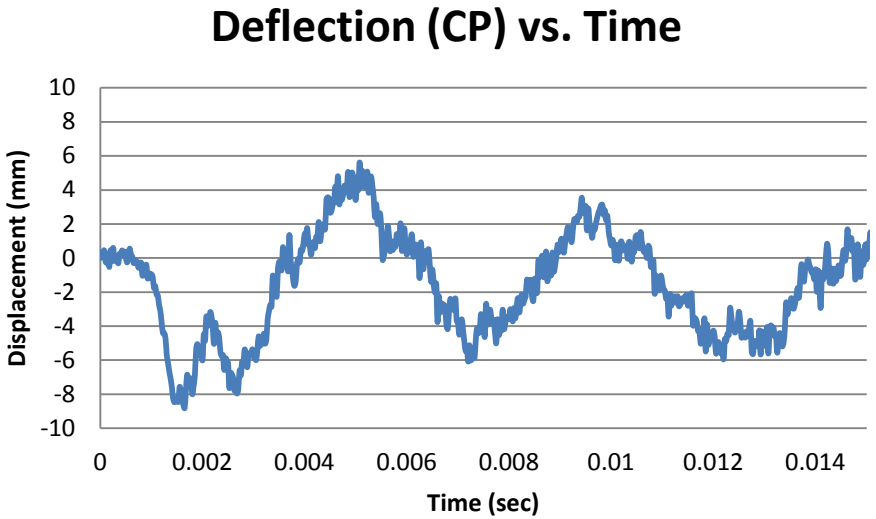
Experimental Data Acquisition

- Structural responses were determined by subtracting the calculated rigid body motion of the target from the elastic plate center (CP) position time history obtained from the digital image correlation software.







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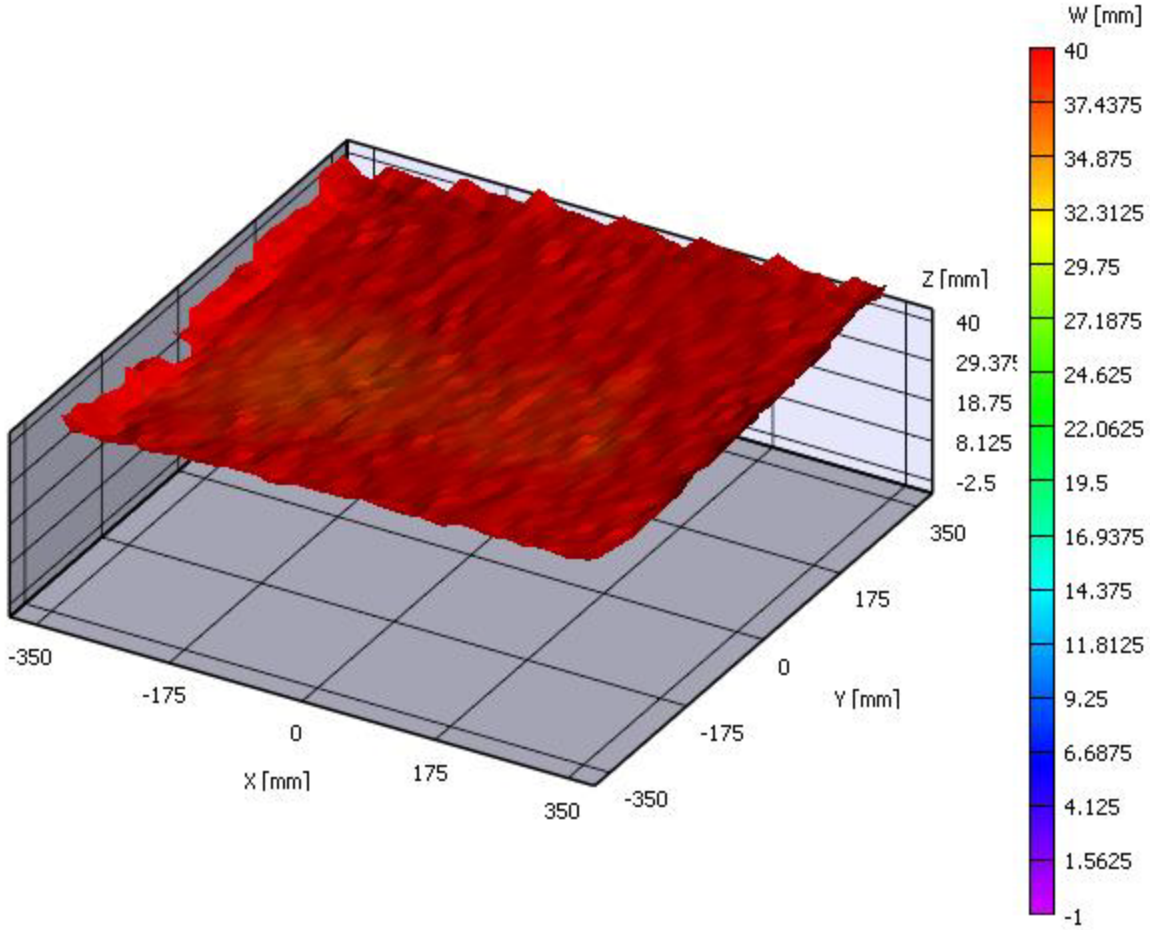
Digital Image Correlation Software



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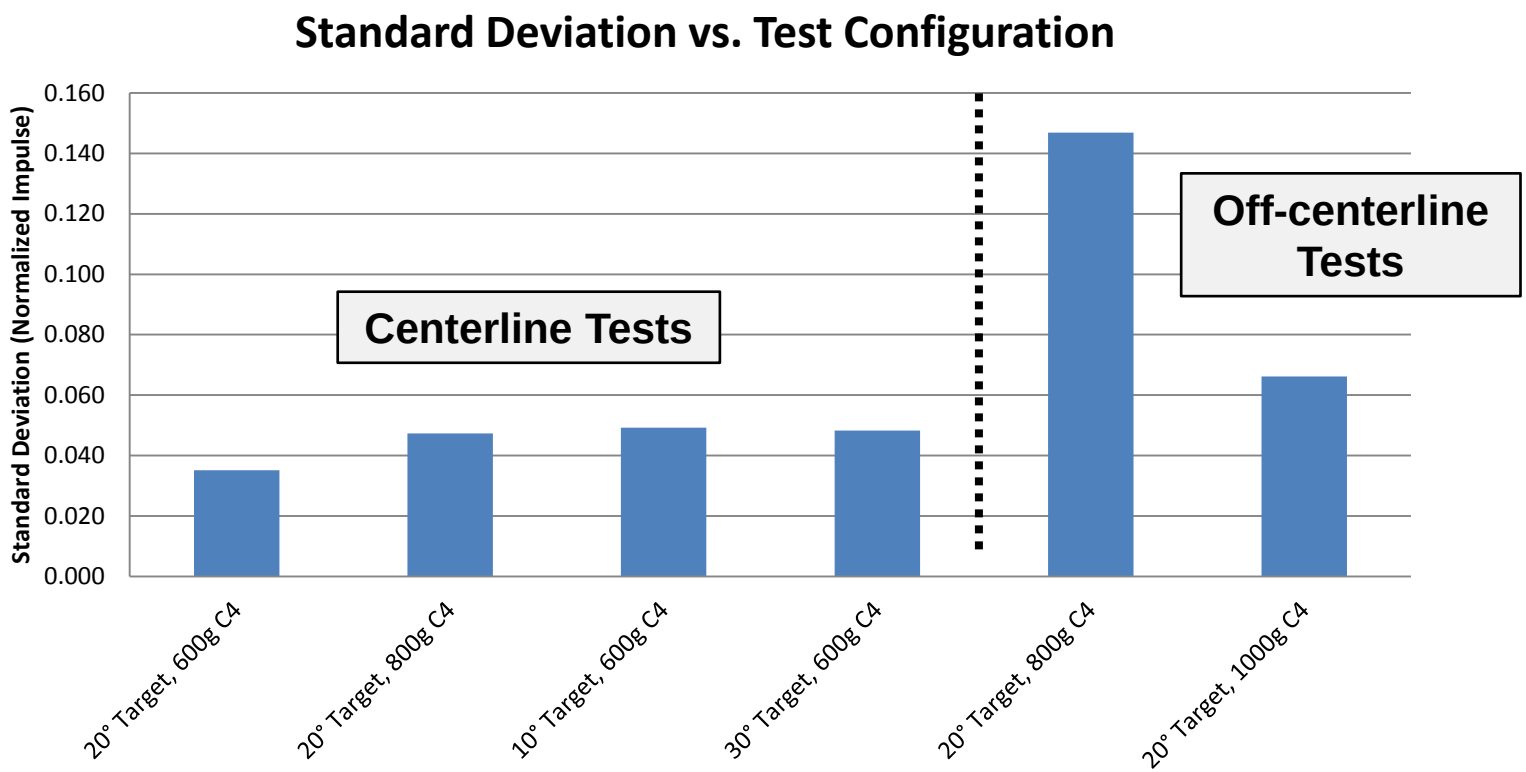
Test Results

- The standard deviation was calculated for various subsets of the overall test data set in order to establish variability from one configuration to another.



- There appears to be an outlier in the 800g off-centerline data set.

- For the centerline tests, the standard deviation is 6% of the mean, on average.

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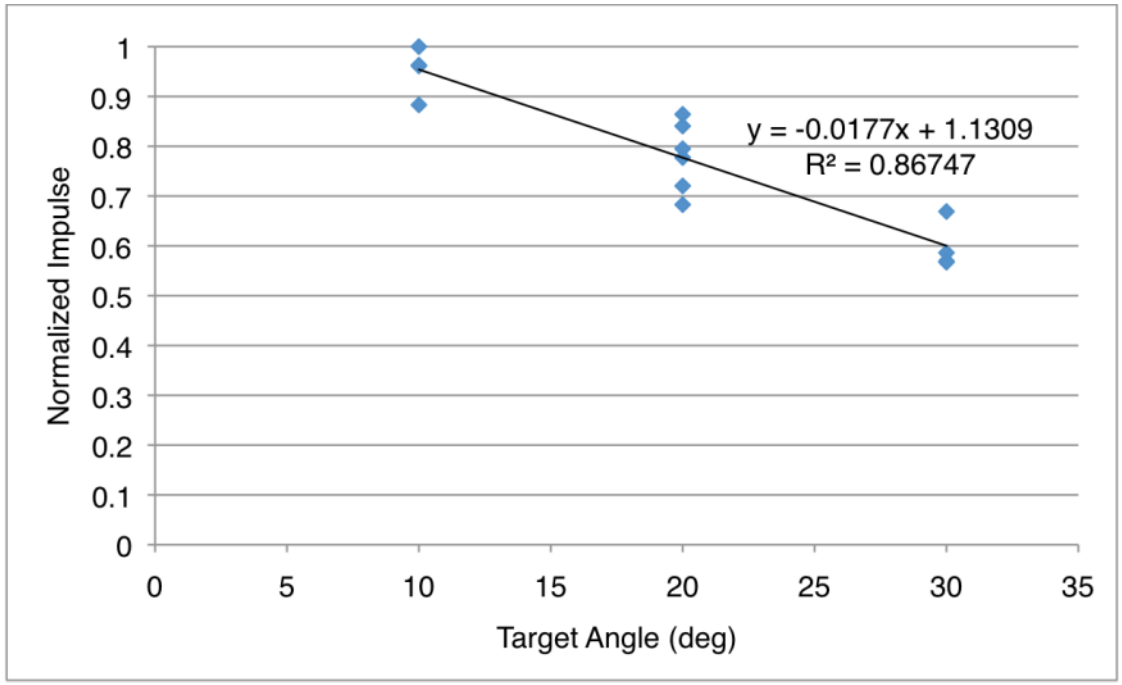
Test Results (continued)

- Normalized impulse as a function of v-shape angle:



- Trend matches expectations: Impulse decreases with increasing v-hull angle.

- Data plotted only includes the centerline test results.

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Statistical Analysis

- Test data was analyzed for correlations:

	Impulse	Charge mass	Target mass	Target angle	Charge offset	Soil moisture
Impulse	1.00					
Charge mass	0.69	1.00				
Target mass	-0.58	-0.07	1.00			
Target angle	-0.52	0.00	0.99	1.00		
Charge offset	0.52	0.69	-0.06	0.00	1.00	
Soil Moisture	0.19	-0.09	-0.13	-0.15	-0.28	1.00

- Statistical analysis of the data determined that the observed impulse difference for the off-centerline and centerline test events were not statistically significant.

- Data collected is <u>insufficient</u> to show that offset shots result in statistically different observed impulse values than the centerline shots.

- Mathematical relations between Impulse and the variables outlined in the correlation matrix were developed with confidence intervals.

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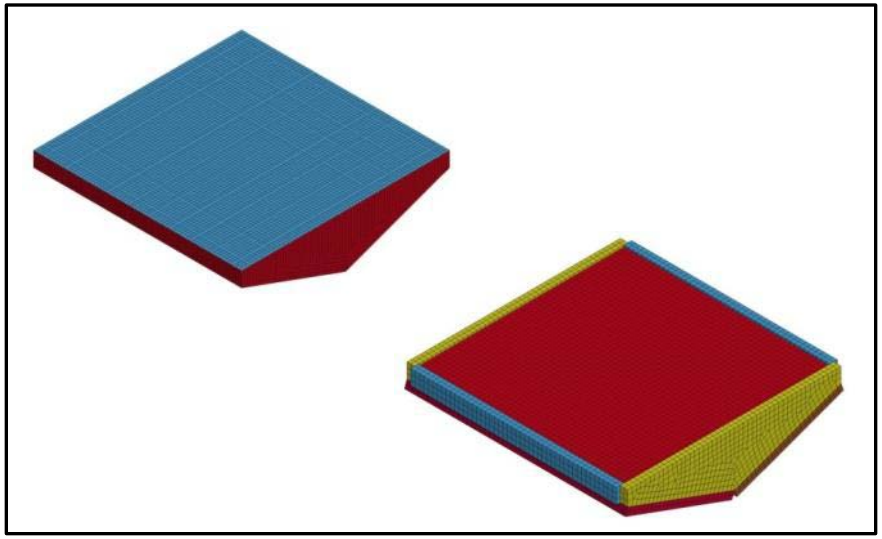
FE Modeling Approach

- Events were modeled using the ConWep air-blast loading model in LS-DYNA.

- Targets were modeled using both shell and solid elements.



- Mesh size was refined until convergence of structural displacements and velocities was achieved.

- A simplified version of the Johnson Cook material model was used.

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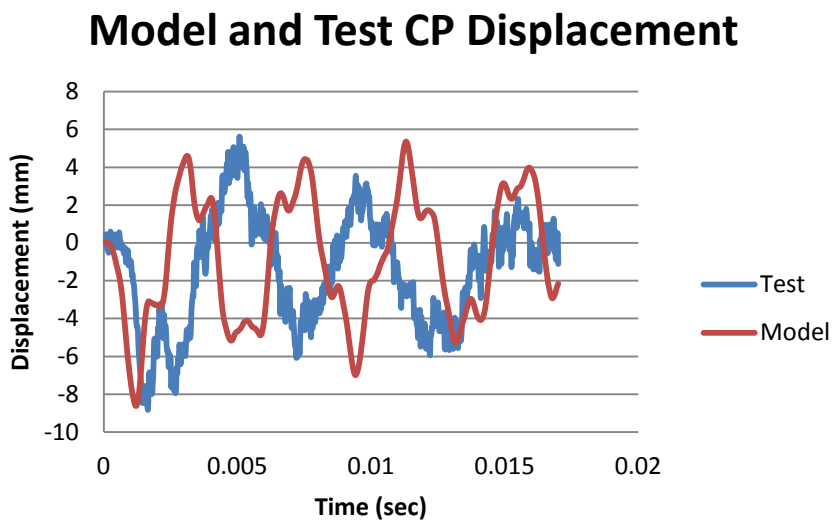
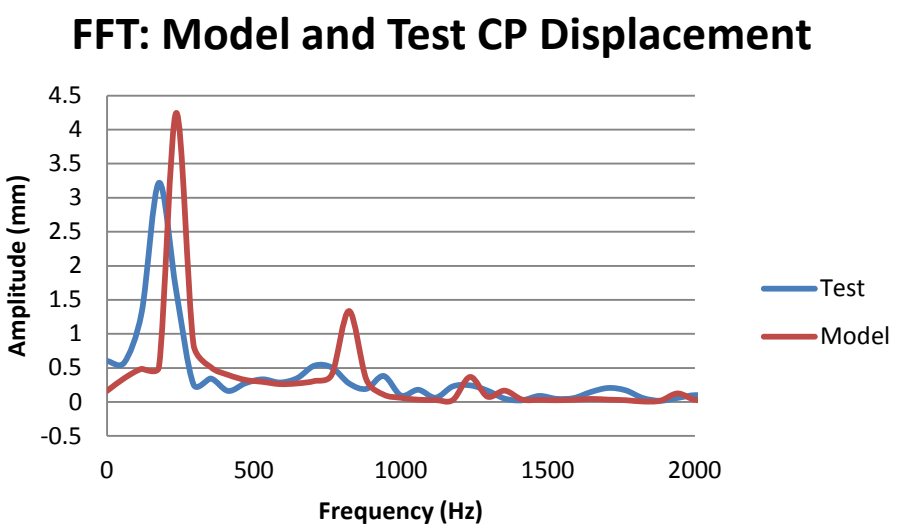
Preliminary Structural Modeling Results

- Test event 1, solid model results and comparison:





- Results were processed in both the time and frequency domains.

- Determining the basis for acceptability has been a challenge for this project.

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Conclusions

- Impulse results obtained from the stereo-digital correlation procedure are consistent with engineering expectations and knowledge from previous tests conducted.

- Structural responses obtained from the stereo-digital correlation process appear reliable. Currently, there is no way to validate the measurement technique.

- The effects of off-center charge locations was not significant, based on the current, limited dataset.

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Recommendations

In support of the Army's goal to develop a robust under-body blast modeling capability able to support the acquisition community, we need to:

- Conduct more testing to expand the blast data set for Army model validation exercises.
- Apply stereo-graphic imaging techniques to larger, more complex structures and validate existing structure mounted sensor measurements.
- Model test events with other loading approaches and investigate accuracy and/or applicability of constitutive models.

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