UTILIZATION OF FAST RUNNING MODELS IN BURIED BLAST SIMULATIONS OF GROUND VEHICLES FOR SIGNIFICANT COMPUTATIONAL EFFICIENCY

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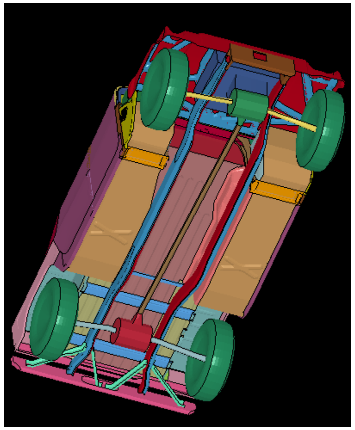
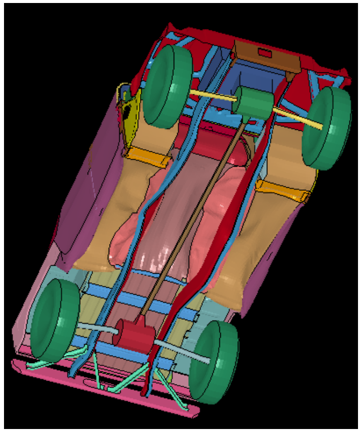
Outline

- Objectives
- Methods
  - Fast Running Models
  - Blast Event Simulation sysTem Methodology and Validation
- Case Study: Notional V-hull Structure
- Future Applications and Development

Objectives

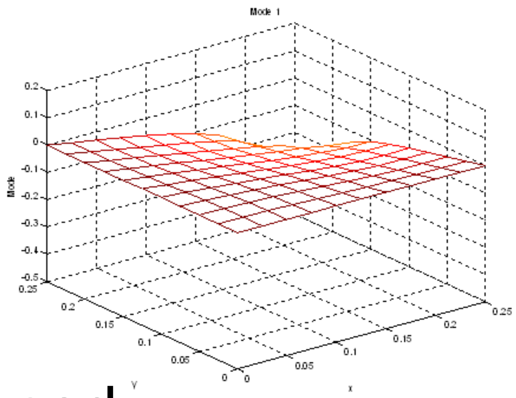
- Survivability assessment requires thorough and systematic exploration of threat effects
- Current computational approaches require significant wall-clock time
- Fast Running Models (FRMs) are paired with the Blast Event Simulation sysTem (BEST) to accelerate analysis

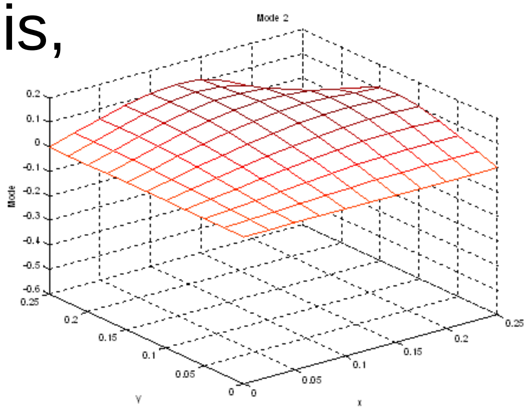

Fast Running Models

- FRMs comprise a reduced-order modeling approach that captures relevant physics governing relationships between input parameters and output effects
- Scenario parameters are input and time-series effects are output, much like complex multi-physics computational analysis
- Results are computed in seconds
- FRMs are a fusion of Principal Component Analysis (PCA) and Kriging

Principal Component Analysis



- Reduce dimensionality of data set
- Distill blast loading histories into 'modal' information
- No linear limitations, PCA isolates fundamental characteristics that can be used as an expansion basis
- PCA used for nonlinear structural analysis, image processing, shock analysis, automotive crash analysis, molecular dynamics and more



Principal Component Analysis

- Decompose response matrix X:

$$X = \begin{bmatrix} x_1(t_1) & \dots & x_1(t_k) \\ \vdots & \ddots & \vdots \\ x_J(t_1) & \dots & x_J(t_k) \end{bmatrix} \Rightarrow X = USV^T$$

$$\Downarrow$$

$$\mathrm{X} = [\Phi \quad \Phi_\tau] \begin{bmatrix} \mathrm{D} & 0 \\ 0 & \mathrm{Z} \end{bmatrix} \begin{bmatrix} \eta \\ \eta_\tau \end{bmatrix}$$

$$[U] \qquad [W] \qquad [V]^T$$

Each column is a "mode"

Only diagonal terms energy in each "mode"

Modal participation terms at each time step

Kriging and Metamodels

- Time-dependent, reduced-order model:

$$[X(\gamma)] = [U(\gamma)][W(\gamma)][V(\gamma)]^T$$

- Matrices generated by metamodels (Kriging):

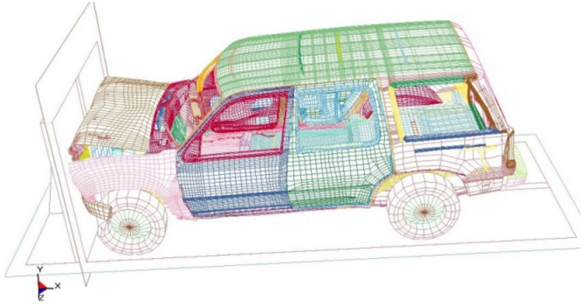
$$[U(\gamma)],\ [W(\gamma)],[V(\gamma)]^T$$

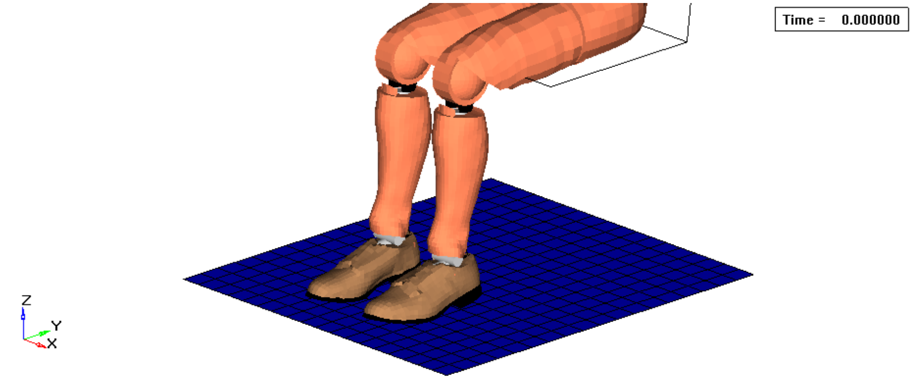
- Analyses are performed **at a limited number of training points**

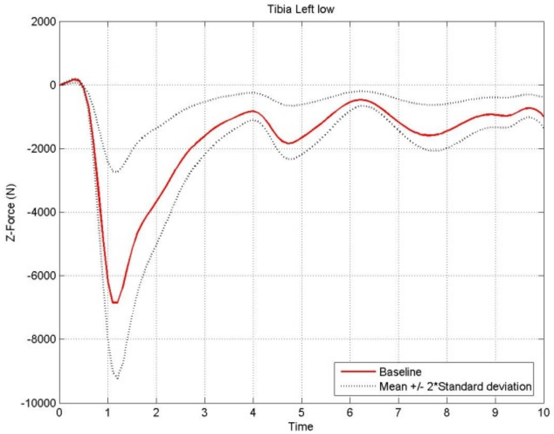
- The values for [U], [W], [V] at the training points are used for developing the metamodels

Previous Applications

- SAE-2005-01-2373 surface ship shock analysis
- SAE-2007-01-1744 automotive crash analysis
- SAE-2006-01-0762 uncertainty analysis for occupant safety under blast loads

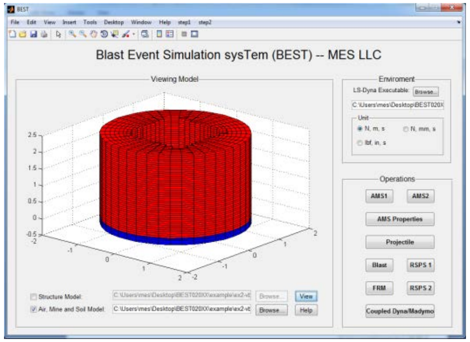


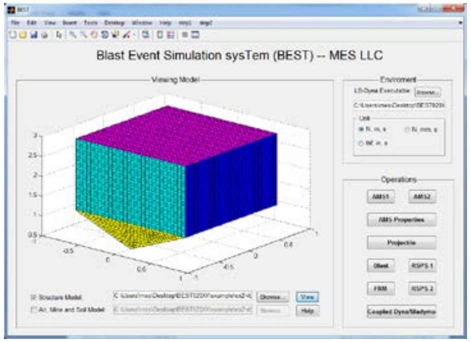


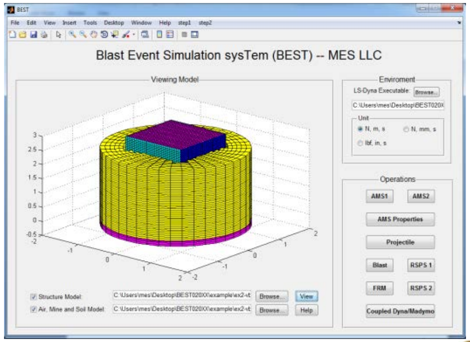


Blast Event Simulation sysTem

- Series of nested panels with buttons, input boxes, and drop down menus
- Organizes and automates mesh generation and simplifies simulation and post-processing
- Capable of defining and launching simulations and creating post-processing files through command line prompts and a suite of Fortran executables
- The FRM capability was developed within BEST

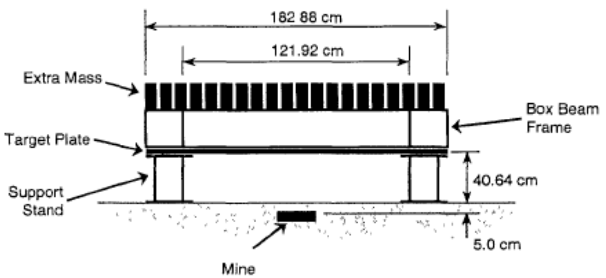


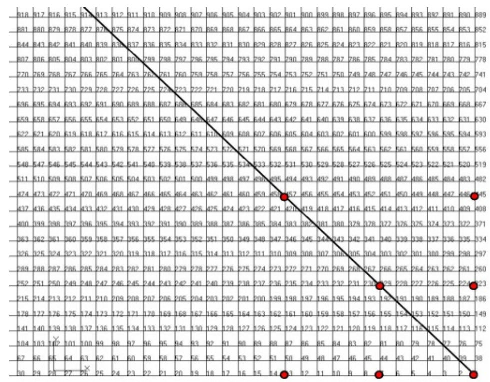


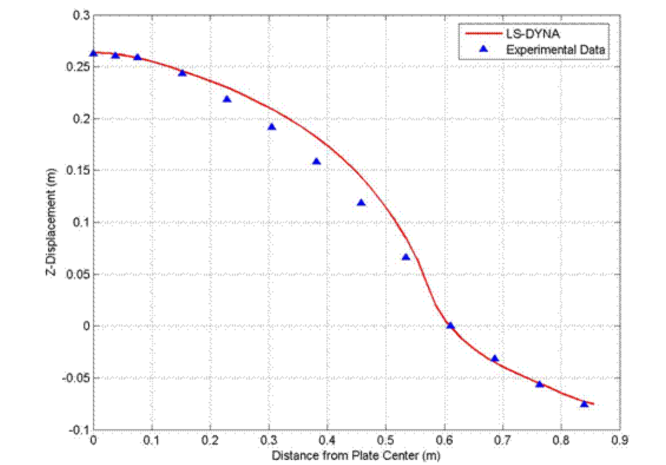


Previous Validation

- SAE-2008-01-0781

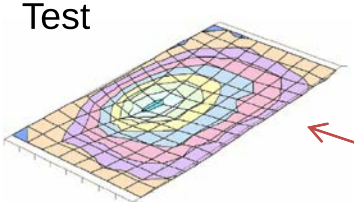


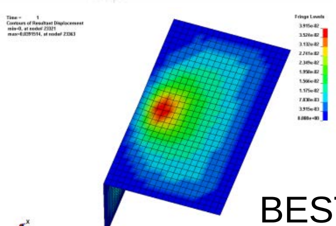




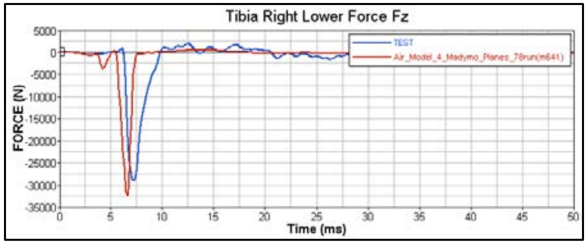
- Vlahopoulos et al., Army Science 2010

Test

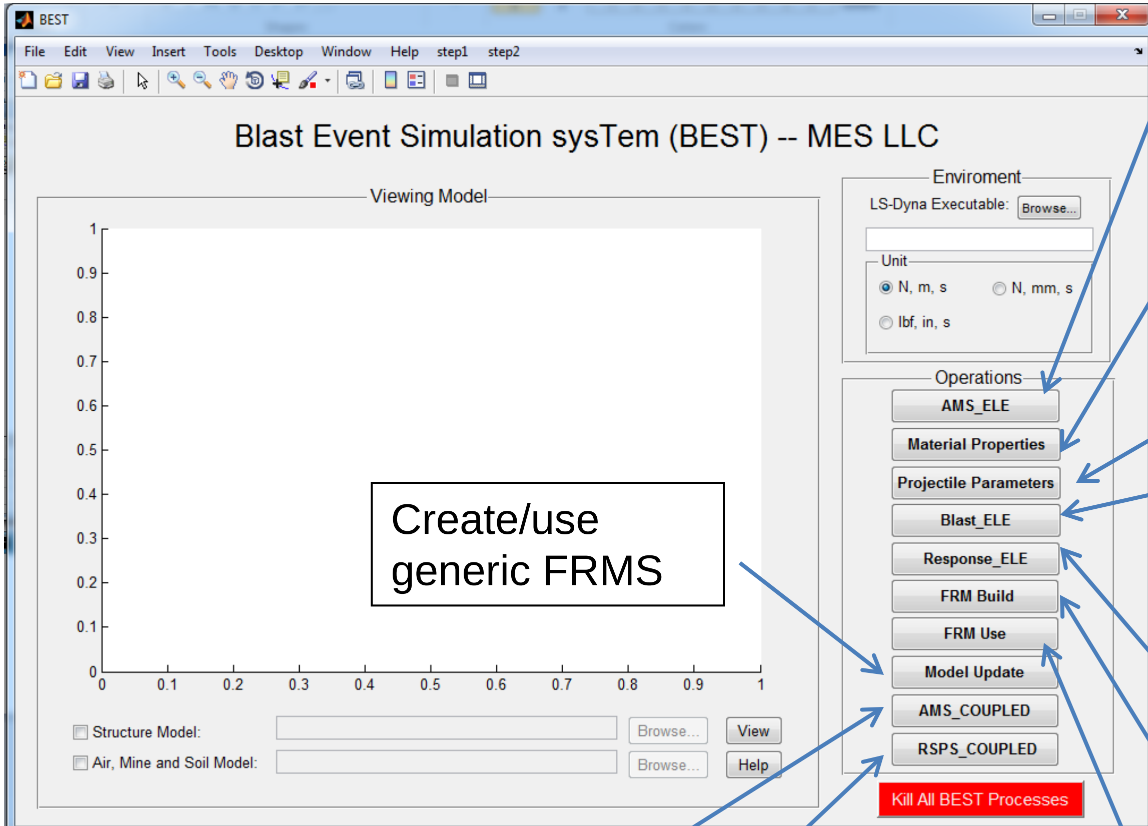




BEST



BEST Structure



Generate air/soil/explosive model for 2-stage analysis

Material definition for soil, air, explosive. Varies due to moisture content.

Creation of projectiles as part of the explosive threat

LS-Dyna Eulerian analysis for 2-stage analysis

LS-Dyna Lagrangian analysis for 2-stage analysis

Create fast running models for underbody blast studies

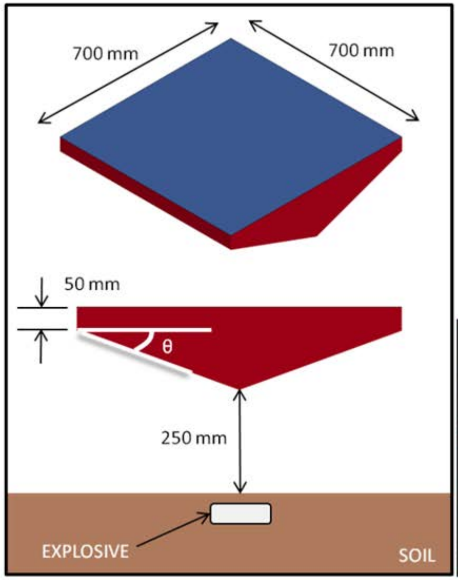
Use fast running models for underbody blast studies

Create/use generic FRMS

Generate air/soil/explosive model for coupled analysis

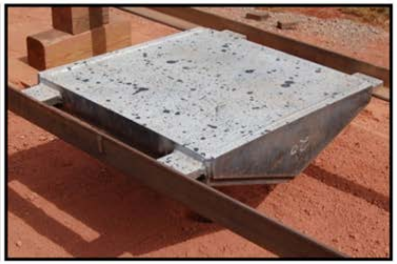
LS-Dyna Lagrangian analysis for 2-stage analysis

- Emerging validation results for v-hull structure with varying geometry and charge size

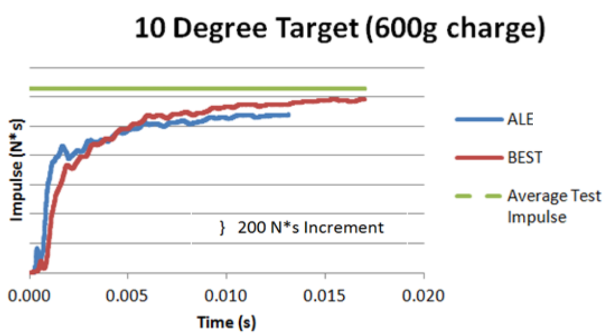


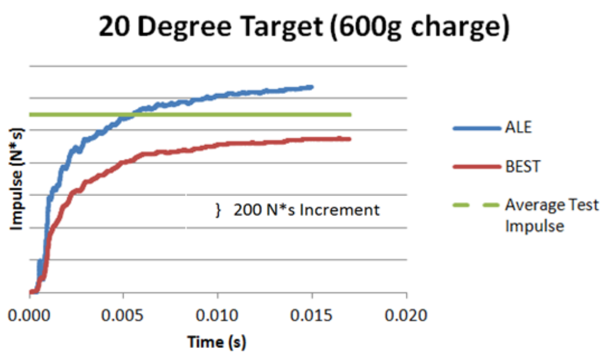
Test matrix:

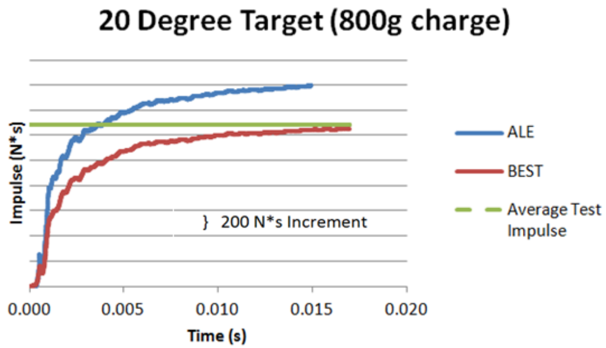
Geometry (θ)	10 Degree	20 Degree		30 Degree	
Charge	600 g	600 g	800 g	600 g	Total Tests
Number of Tests	4	4	4	4	16

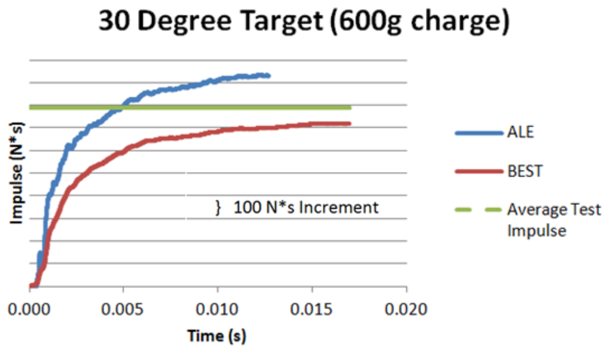


- Emerging correlation results with averaged experimental tests are at least as strong as fully-coupled ALE simulations



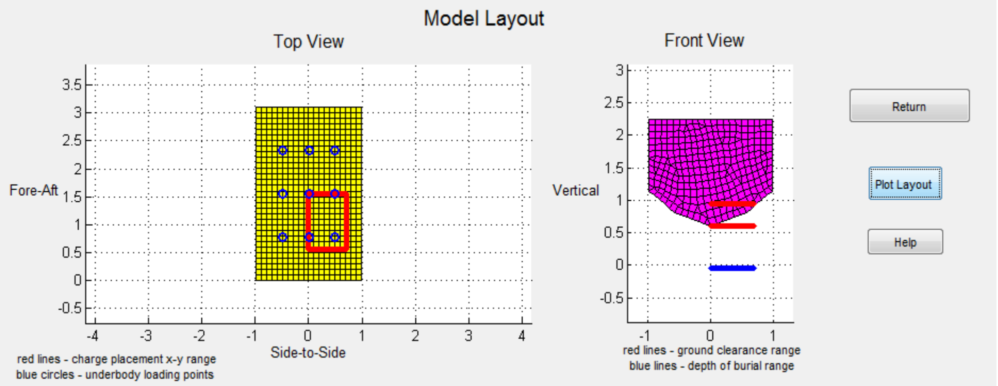


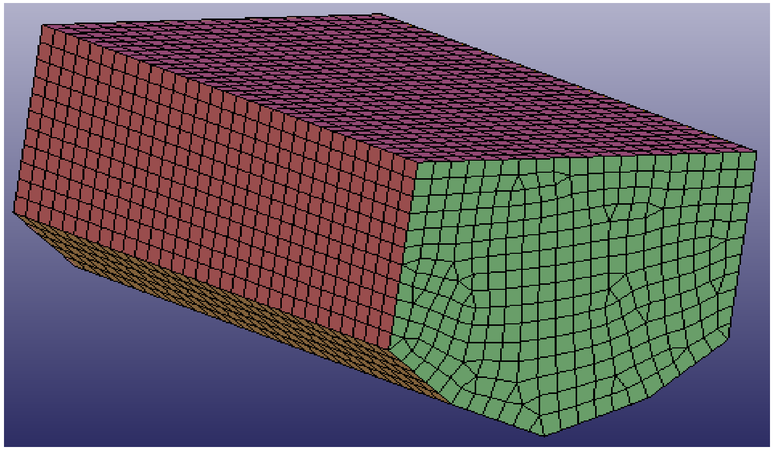


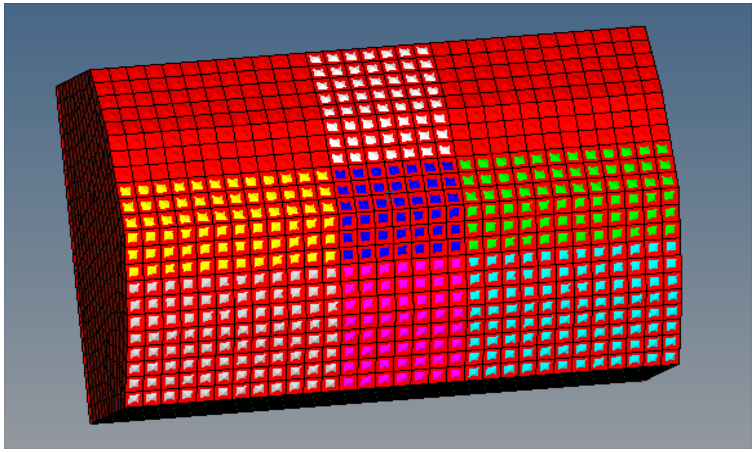


FRM Terminology

- Input parameters
- Training points
- Loading points
- FRM applicable range







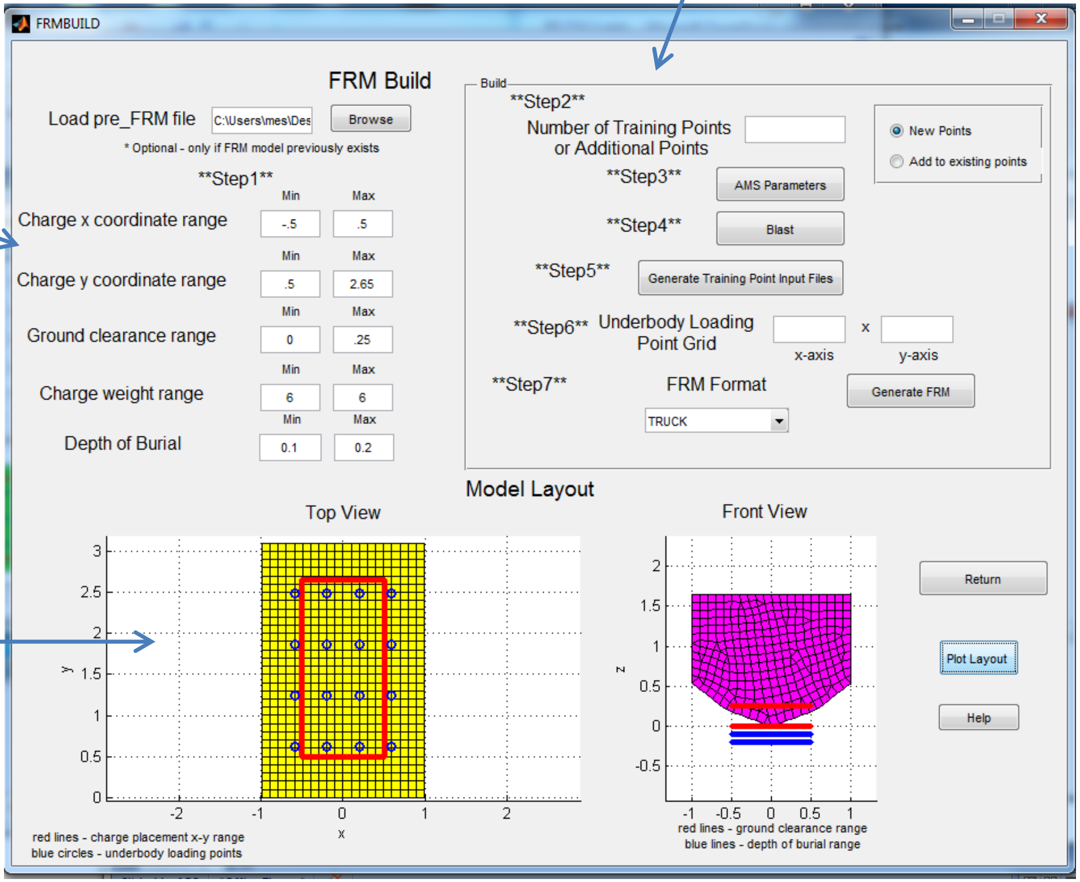
BEST FRM Build Interface

MSTV
MODELING AND SIMULATION, TESTING AND VALIDATION

Build training point files and FRM

Specify parameter ranges

View loading point and FRM configuration

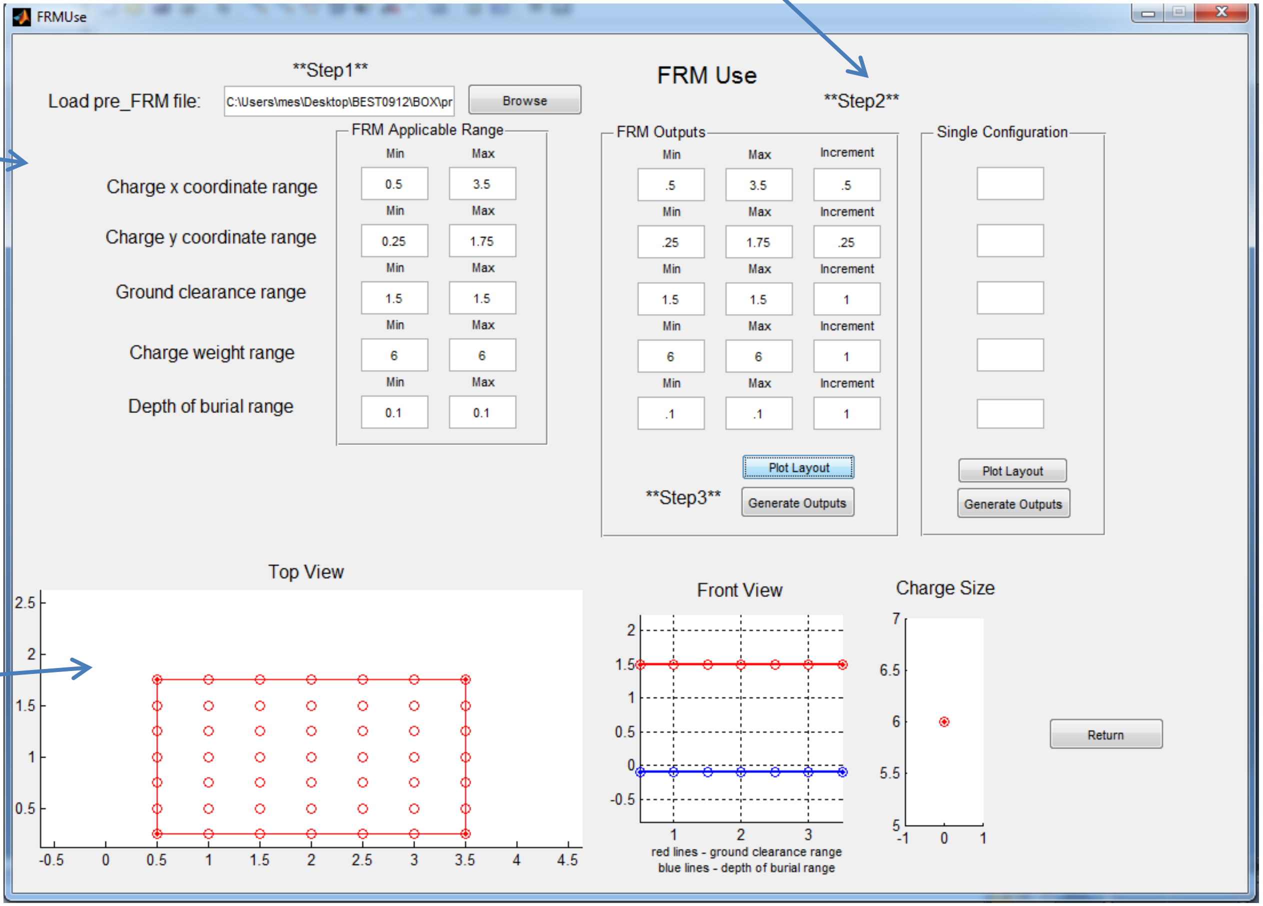


BEST FRM Use Interface

Desired mine/ vehicle configurations for response study

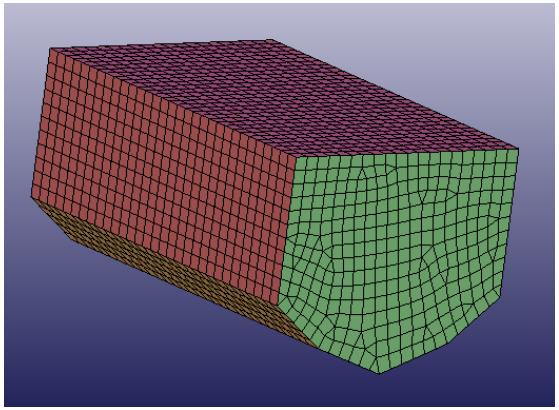
Automatically populated applicability ranges

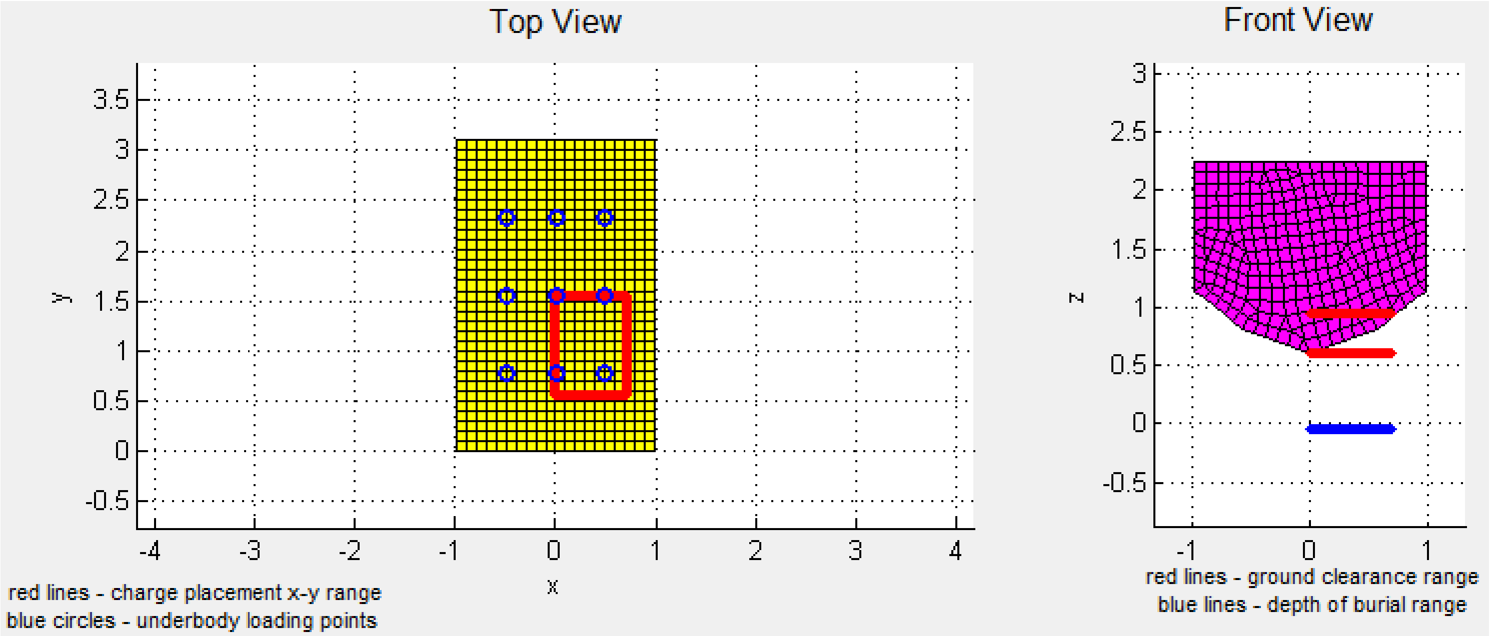
Visual representation of FRM applicable ranges



Case Study - FRM

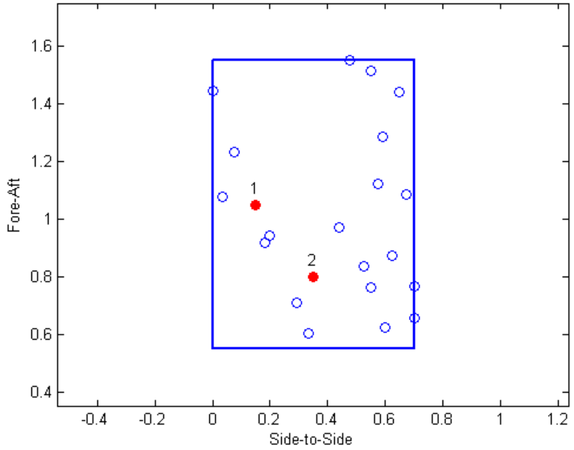
- TARDEC V-hull
  - 20 Training Points
  - 9 Loading Points
  - 2 Evaluation Points

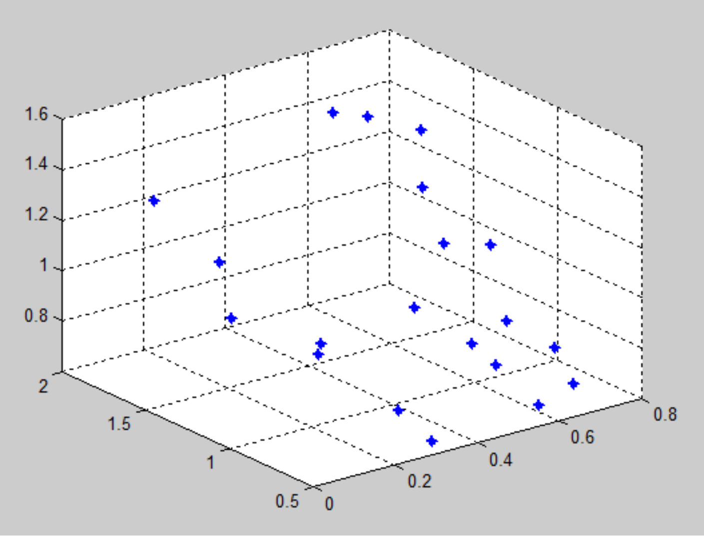




Training Points

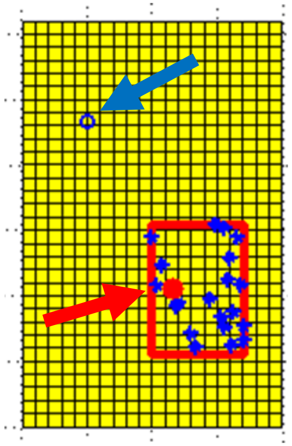
- Training point ranges:
  - x location range: 0.7m
  - y location range: 1 m
  - ground clearance range: 0.65 m
  - depth of burial: 0.0508 m
  - charge size: Stanag Level 2
- Vehicle Dimensions:
  - width: 1.978
  - length: 3.1025
  - height: 1.6499

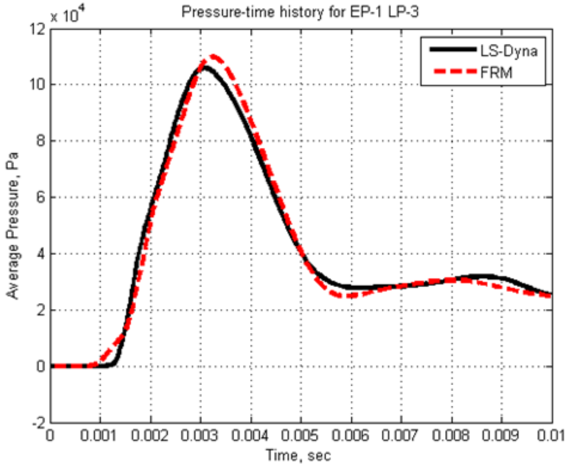




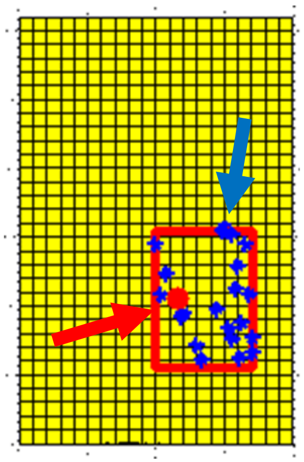
FRM Results

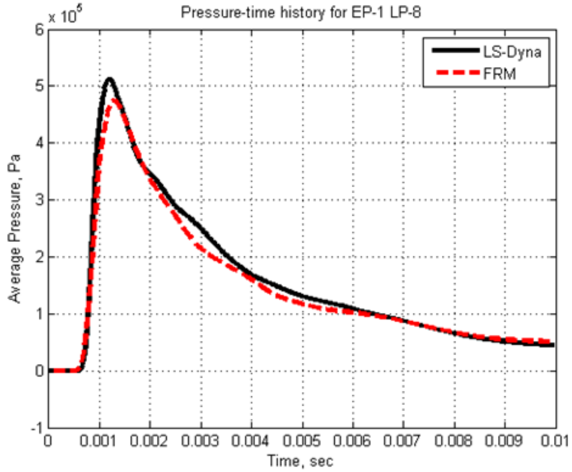
- EP-1 LP-3:



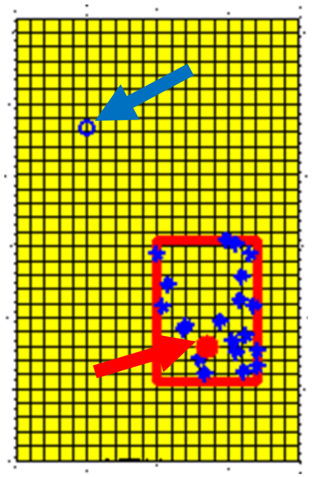


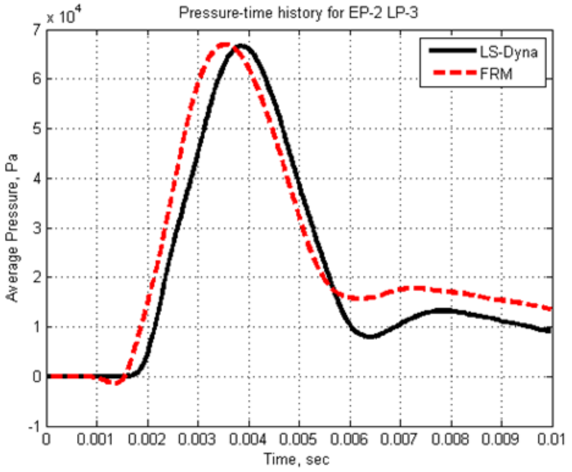
- EP-1 LP-8:



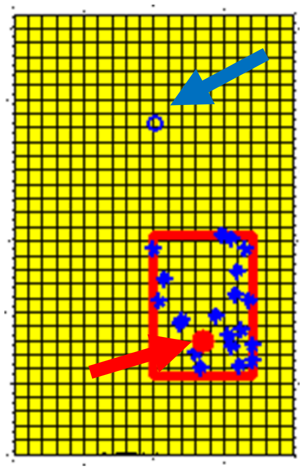


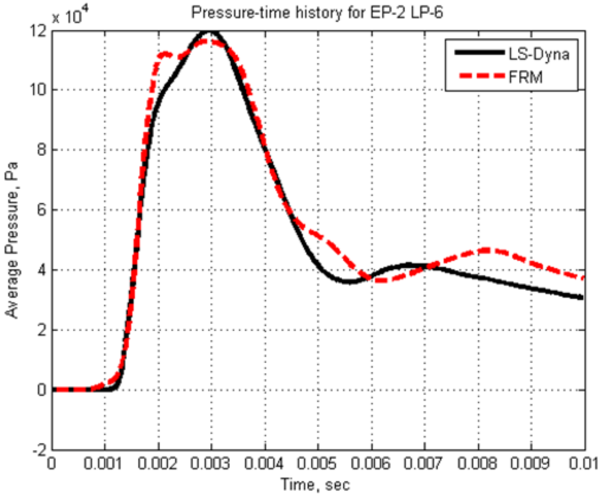
- EP-2 LP-3





- EP-2 LP-6





Case Study - Metamodel

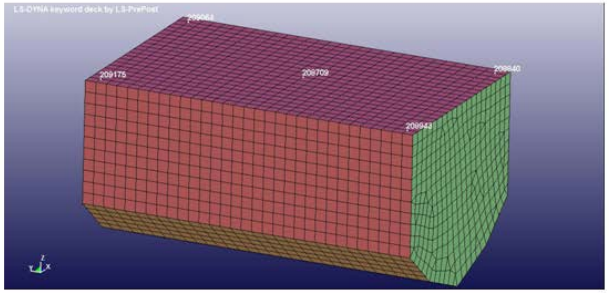
- FRMs can also be utilized to predict structural response
- Displacement of vehicle underbody tracked at all bottom nodes (630 total) to study **maximum displacement**
- Roof velocity tracked at 5 locations on roof to study **maximum average velocity**

Maximum Average Velocity $\overline{V}_{Max}$ at One Surface of Hull: (Four Sides and Roof).

$$V_j(t_k) = \sqrt{V_{xj}^2(t_k) + V_{yj}^2(t_k) + V_{zj}^2(t_k)}$$ **(jth Node at time step t_k)**

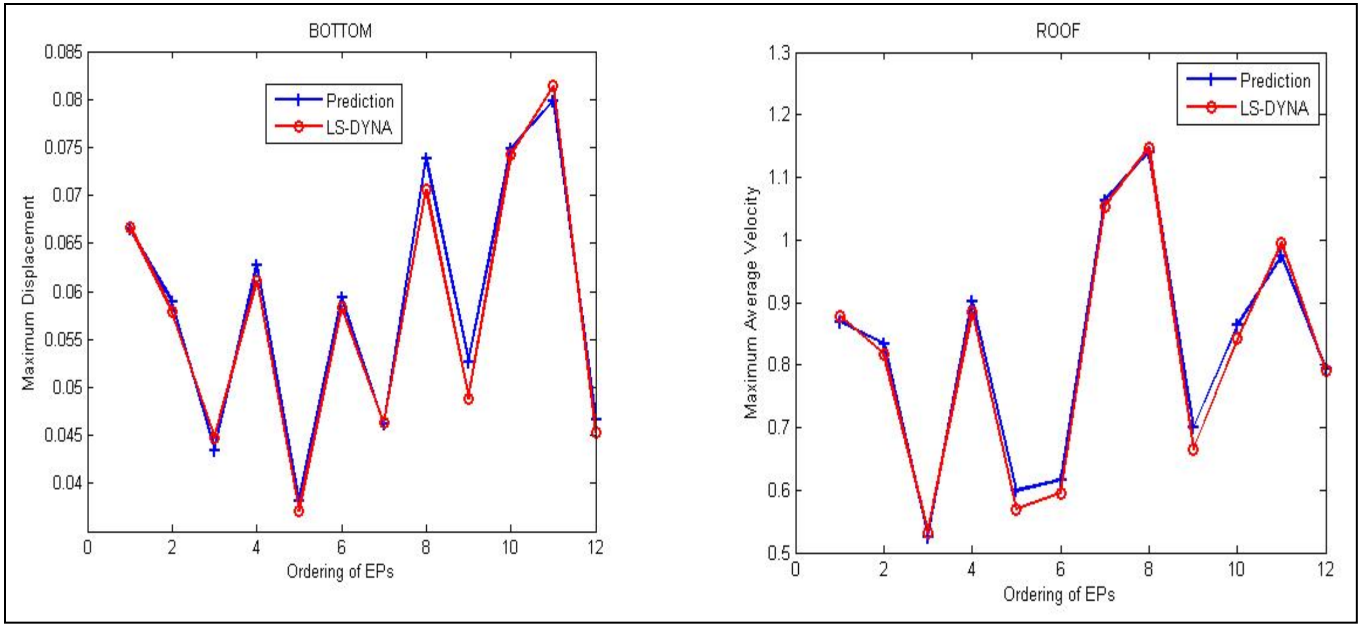
$$\overline{V}(t_k) = \sqrt{\sum_{j=1}^{N} V_j^2(t_k)} \Big/ N$$ **(N=5) at time step t_k**

$$\overline{V}_{Max} = Max[\overline{V}(t_k)]$$



Metamodel Results

- Both the maximum displacement and the maximum average velocity results correlate well with LS-DYNA simulation over 12 evaluation points



Conclusions

- FRMs enable rapid evaluation of an entire matrix of vehicle/explosive configurations

- Both blast histories and structural responses can be modeled using FRMs

- The FRM capability has been incorporated in BEST to model any time-domain based physical event

Backup Slide 1

- Two-step BEST approach justification: