Prediction Of Ship Shock Response & Damage w/ The Navy Enhanced Sierra Mechanics (NESM) Code

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U.S. Navy Need For Robust Shock/Damage M&S Capability

- Design Support
  - Shock Design Requirements
  - Support Shock Qualification
  - Vulnerability Design Requirements
- LFT&E
  - Assess Ship Vulnerability To Real Threats
    - Reduce Need For Physical Testing, More Focused/Physics Based Testing
- Support Demonstration Of Total Ship Shock Hardness
  - Total Ship Mission Capability Impact Assessment Due To Shock Engagement
  - Reduce/Eliminate Requirements For Full-Scale Physical Testing

Whole Ship M&S

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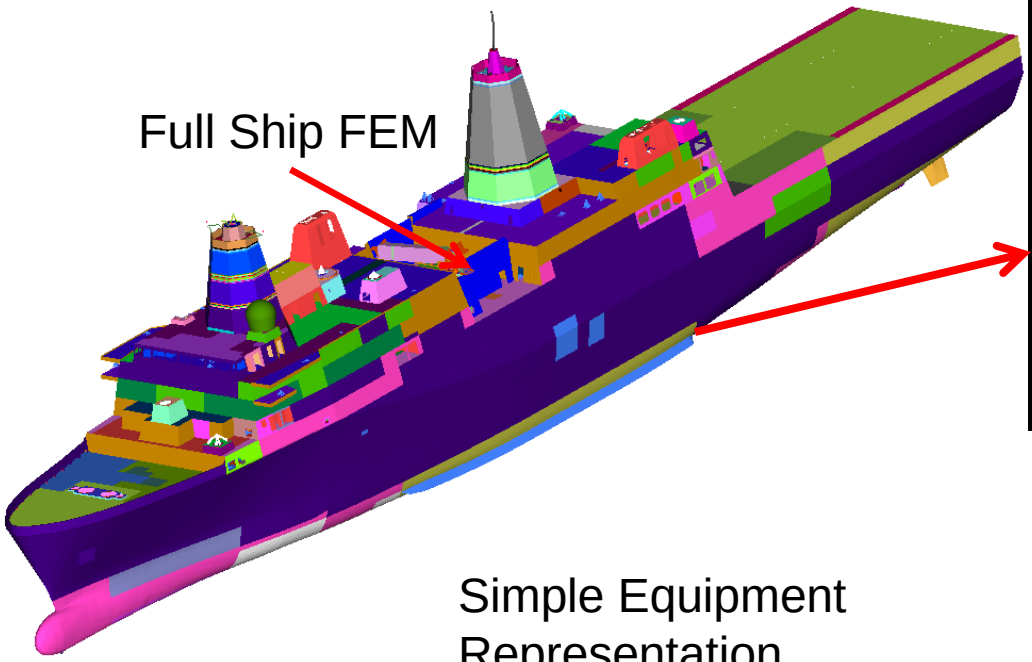
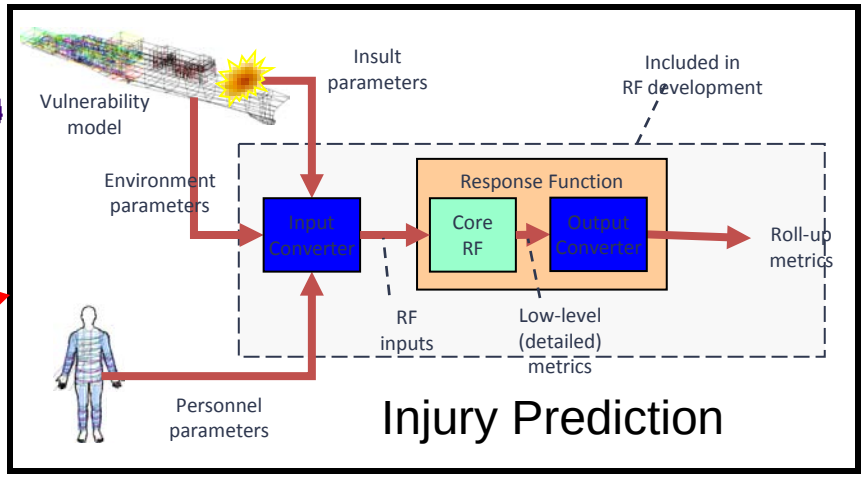
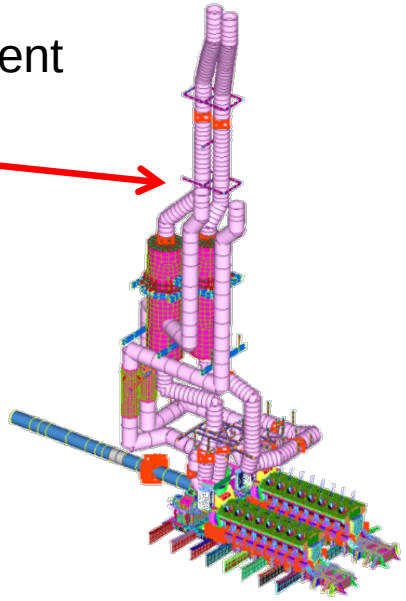
DOD HPC MODERNIZATION PROGRAM

Full Ship FEM

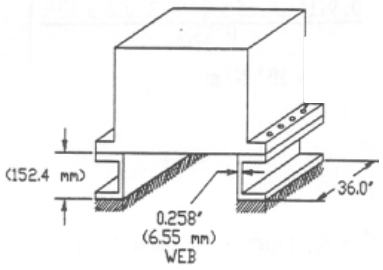


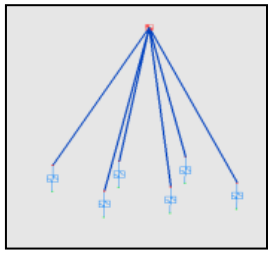


Complex Equipment Representation



Simple Equipment Representation





NESM Solution

- Couple Gemini To The Sierra Mechanics Suite => Navy Enhanced Sierra Mechanics
  - Interface To Sierra Using Standard Coupler Interface (SCI)
- Existing Sierra Capabilities
  - Structural Dynamics (SD)
    - Implicit Structural Dynamic Solver (mainly linear)
  - Solid Mechanics (SM)
    - Explicit (nonlinear) Lagrangian Dynamic Solver
    - Implicit (nonlinear) Lagrangian Dynamic Solver
- Enhance Sierra SD/SM & SCI For Navy Specific Intended Uses For Weapon Effects M&S

Navy Enhanced Sierra Mechanics (NESM) Architecture

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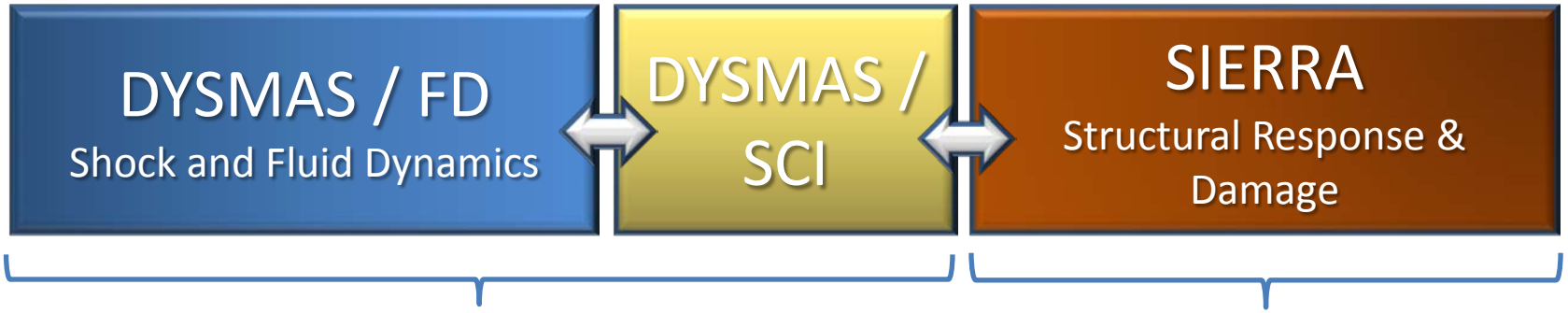
Shock/Fluid Dynamics & Loading | **Fluid-Structure Interaction** | **Structural Response & Damage**



- Joint development between US and German governments
- US effort led by ONR supplemented by HPCMO/CREATE support
- >$50M investment
- Optimized for Navy problems
- Massively parallel, scalable codes
- Extensive V&V documentation for Navy problems

- Product of the DoD/DoE Joint Munitions ASC Program
- Effort led by Sandia Nat'l Lab
- >$50M investment
- Navy specific enhancements/applications
- Massively parallel, scalable codes

Initial NESM Capabilities (FY08-FY10)

Gap Fillers

- NESM v0.1
  - Gemini Coupled To Sierra SD/SM
  - Preliminary Verification & Validation
    - Extensive Verification
    - Fully-Coupled Tests
      - Hydro-bulge
      - DDG 1000 UHWM
      - DDG 1000 Components
  - Demonstrated Scaling
    - Linear Parallel Performance, If Load Balanced

- NESM v1.0
  - Enhanced Beam/Shell Elements
  - Staggered Time Stepping (STS) For Coupler Stability
  - Component Mode Synthesis w/ Mode Control
  - Enhanced Damage Plasticity Model
    - Damage Function Of Strain Rate & Stress State
  - Verification & Validation
    - IFSP
    - DDG 1000 SURFEX Holing
  - Improved Scaling
    - Structural Models ~10,000,000 Elements

NESM v1.1 Highlights (2012)

Gap Fillers

- Acoustic Shock Response For Deep Submergence Targets
- Selective Component Mode Synthesis w/ Automatic Submesh Response (EJOIN)
- DDAM
- Shell Multi-Grid Damage Modeling
- Verification & Validation
  - DDG 81
- Enhanced Coupler Stability/Performance
- Nonlinear Mounts/User Subroutines
  - Common To Sierra SD/SM
- Explicit ⇔ Implicit Handoff (Beta)

Verification & Validation - Ship Response

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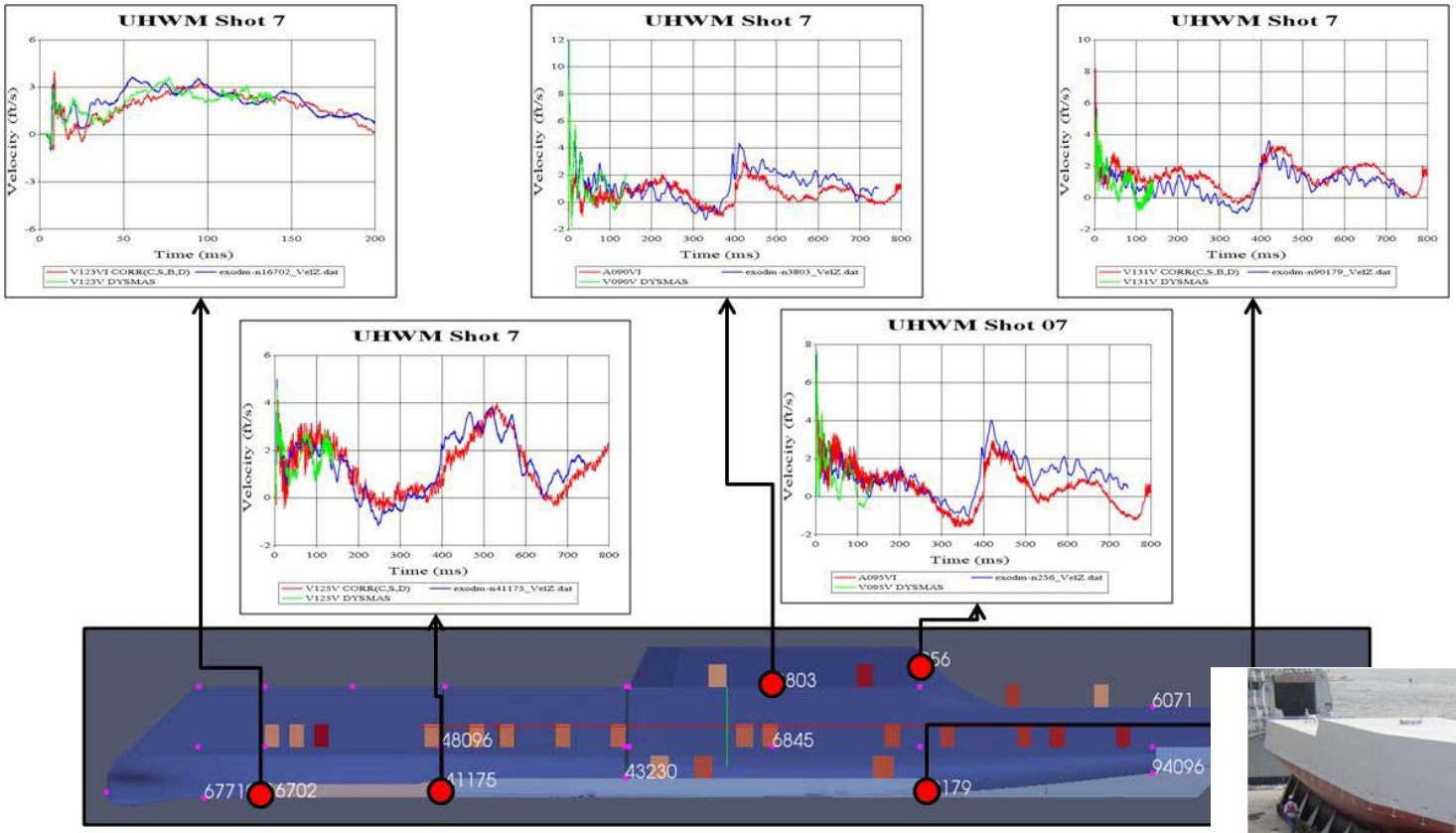
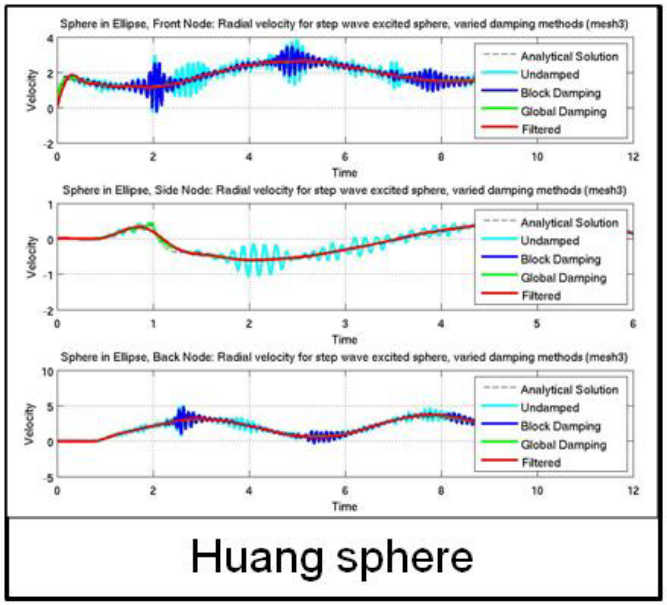


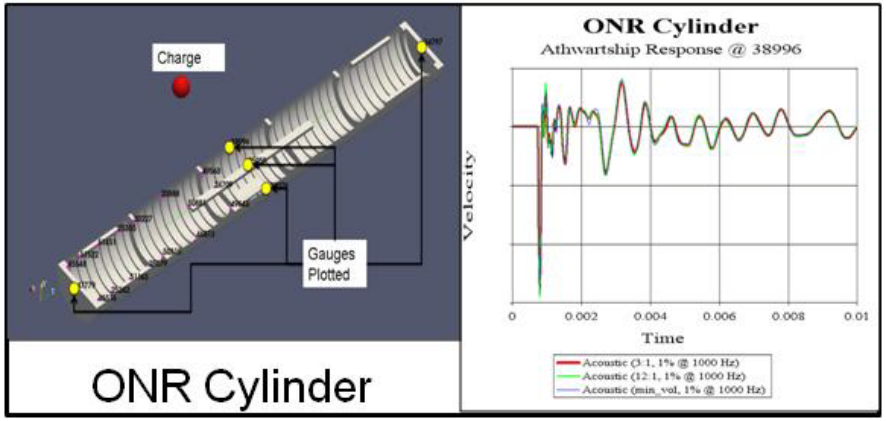
V&V => CRITICAL ELEMENT OF NESM DEVELOPMENT

Acoustic Shock Response

- Massively parallel, arbitrary domain decomposition - acoustic/solid meshes
  - Mismatched acoustic/structural mesh capability
  - Infinite elements on ellipsoidal meshes
    - Variable order infinite elements allow for very tight acoustic meshes
  - Convergent acoustic FEM formulation that avoids limitation of DAA in mid-frequency
- Time-domain formulation targets transient shock problems
- Shock inputs
  - Plane step wave
  - Plane exponential wave
  - Point charge
  - Future development: Hick's bubble …
- V&V
  - Analytic Benchmarks
  - ONR Cylinder



Huang sphere

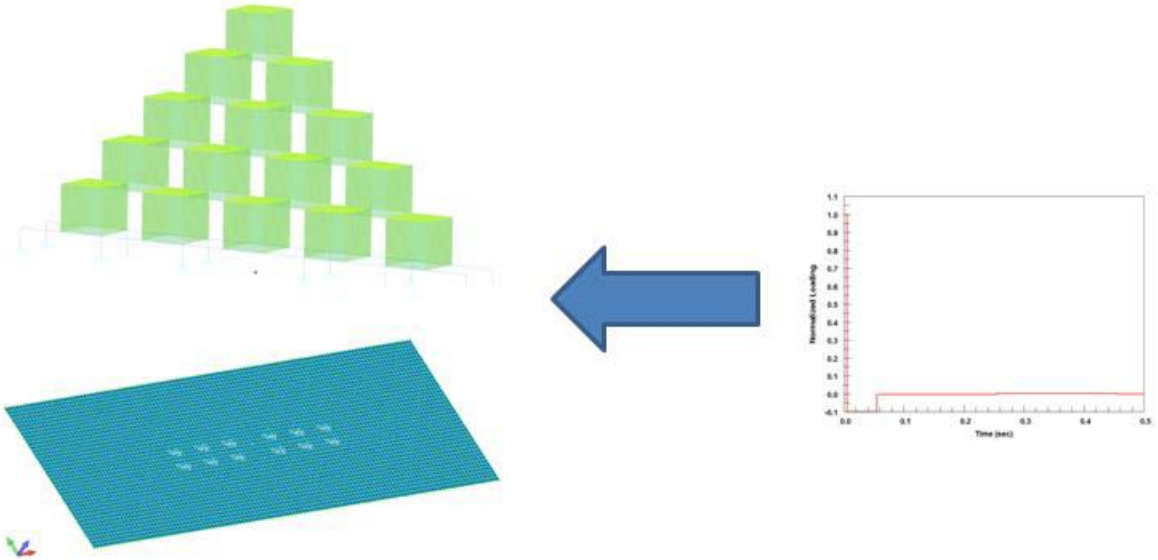


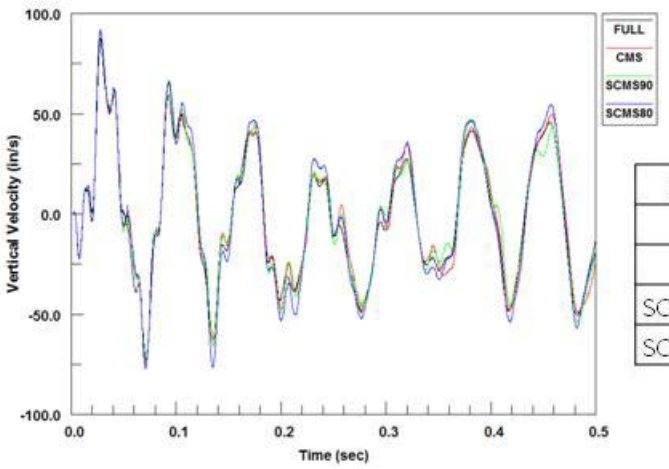
ONR Cylinder

Technical Example – Selective Component Mode Synthesis

- Component Mode Synthesis (CMS) Provides Ability To Include Detailed Equipment/System Model In Total Ship Model With Significantly Reduced DOF
- Selective Component Mode Synthesis (SCMS) Facilitates Further DOF Reduction By Including Only Highly Participating Modes
- CMS Has Been Successfully Used To Support Shock Design/Qualification On:
  - SEAWOLF, Virginia Class Submarine Designs
  - DDG 1000 Surface Ship Design
- NESM Provides The Only SCMS Capability Available (fully scalable) And The Only Fully Scalable CMS Capability

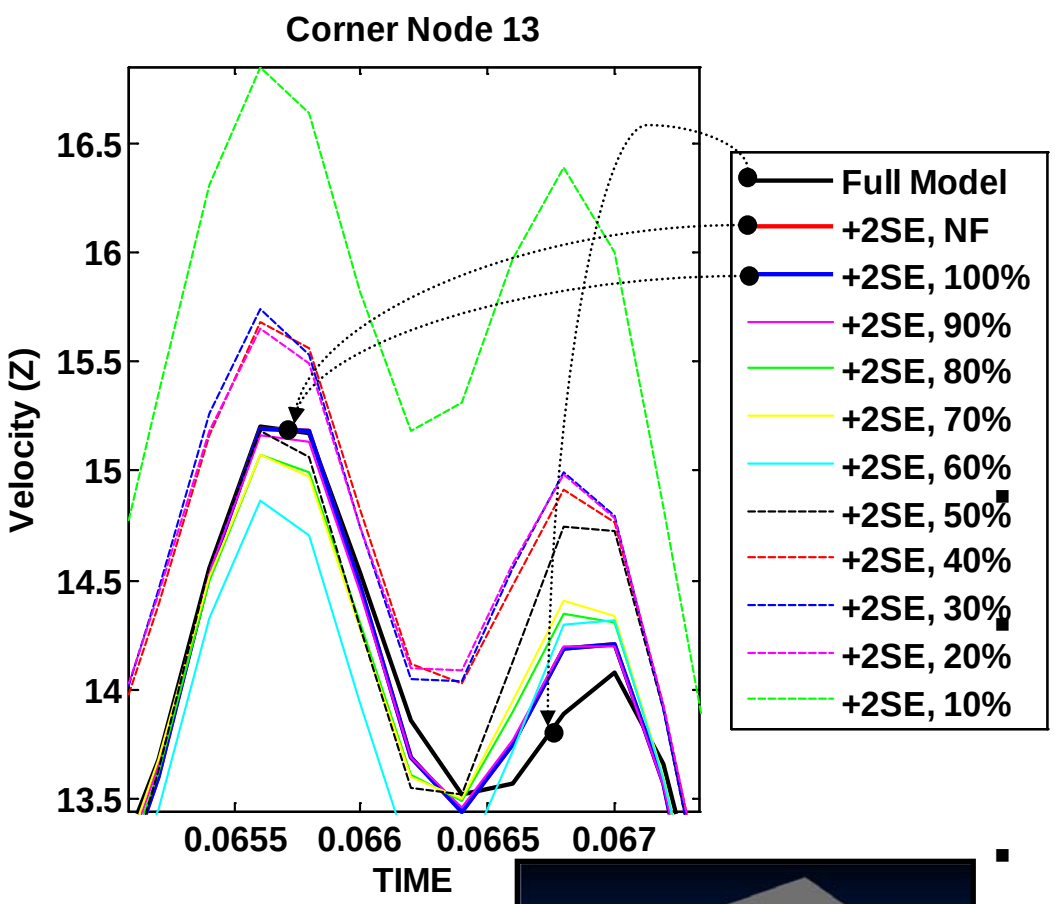
Selective Component Mode Synthesis (SCMS)

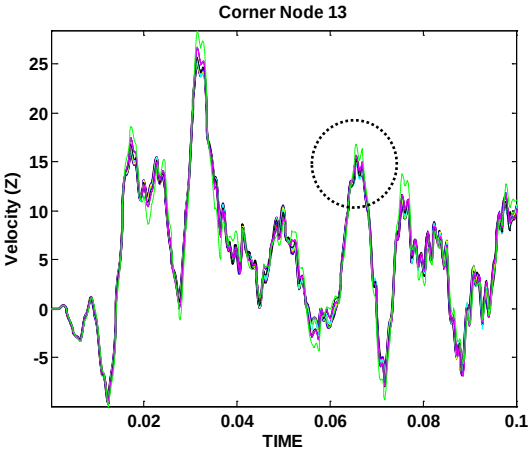




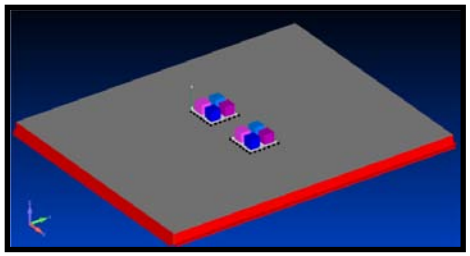
Model	Modes	CPU Time	% Full	% CMS
Full	N/A	16875	100.00	N/A
CMS	803	1539	9.12	100.00
SCMS-90%	160	1354	8.02	87.98
SCMS-80%	99	1309	7.76	85.06

SCMS w/ EJOIN





- NF ➔ modal filter not applied
- 100% ➔ modal filter applied and requesting 100% of all modes be retained during CBR
- NF / 100% overlapping and nearly equal to that of full model



Dynamic Design Analysis Method

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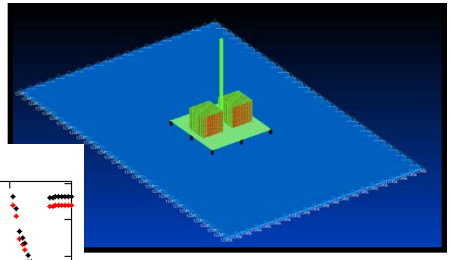
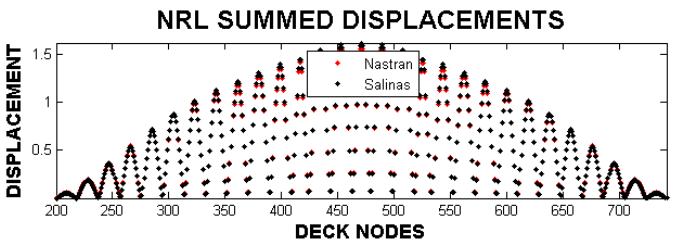
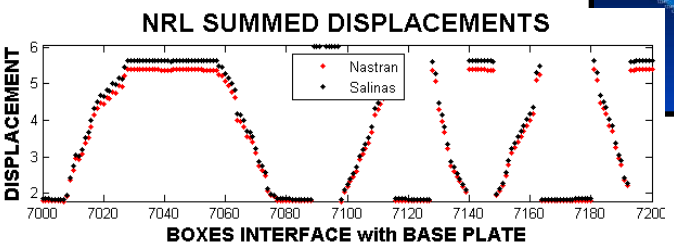
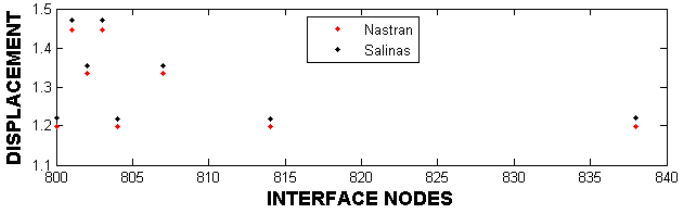
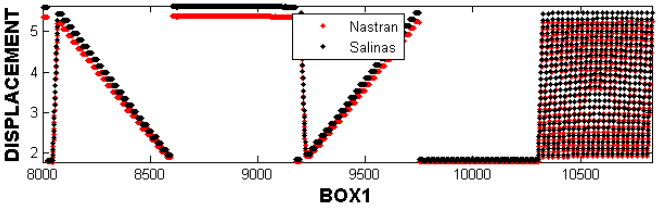
DDAM of Complex Models

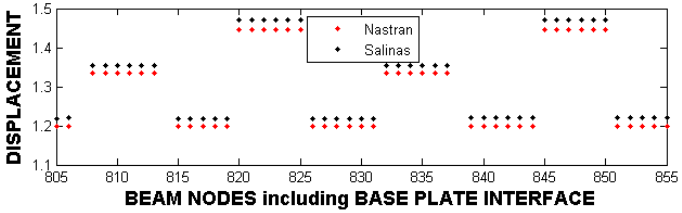


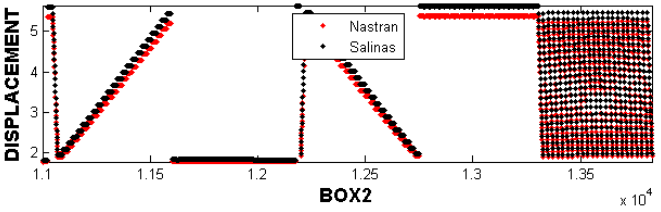


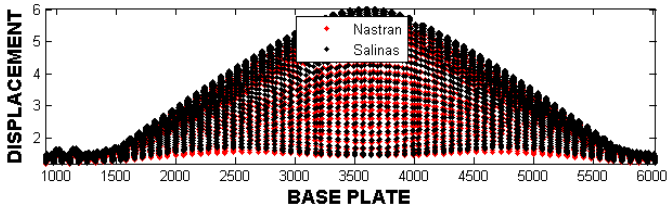


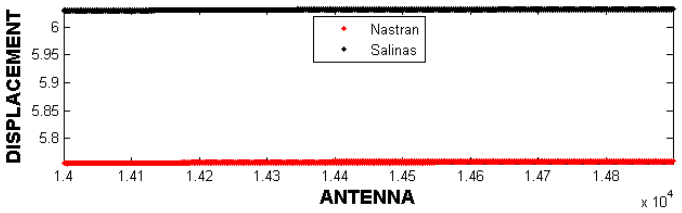




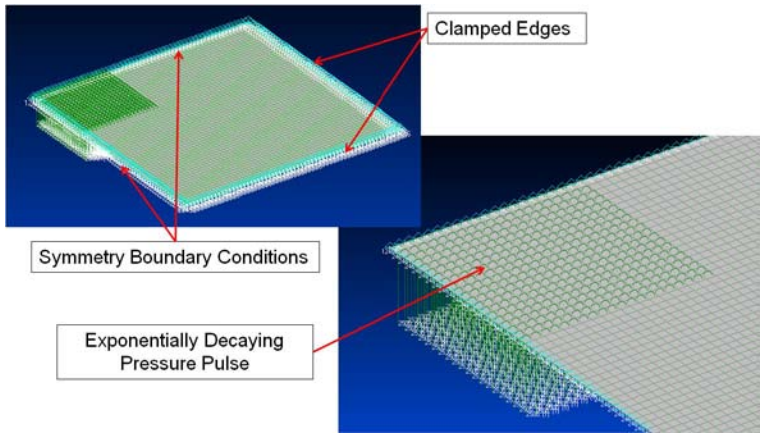


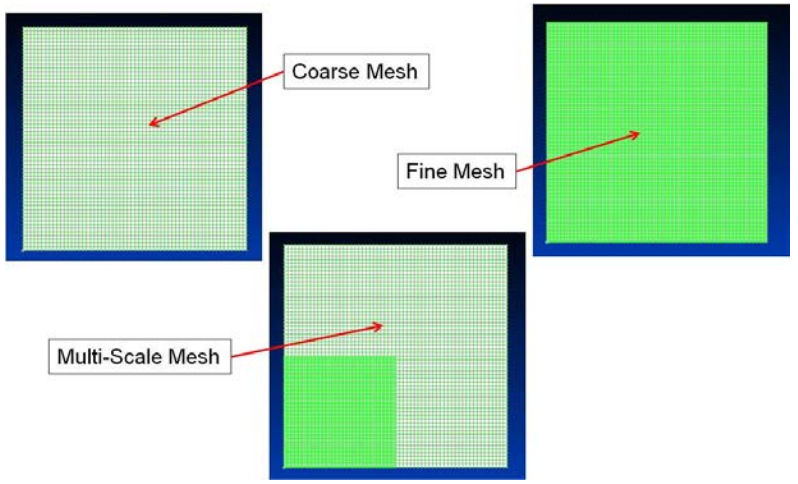


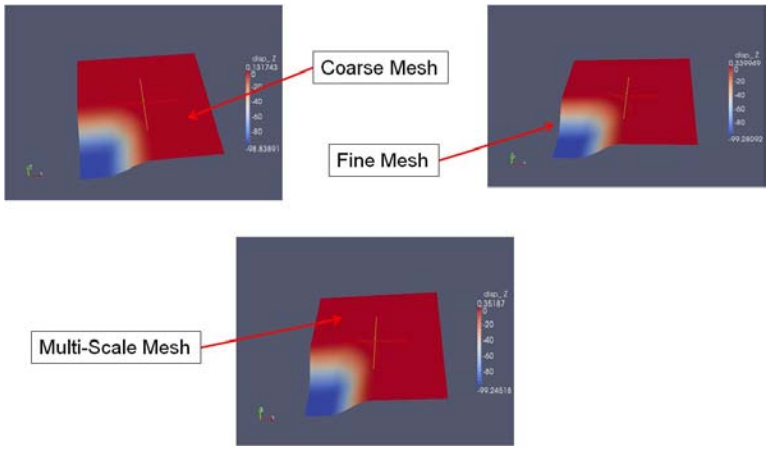


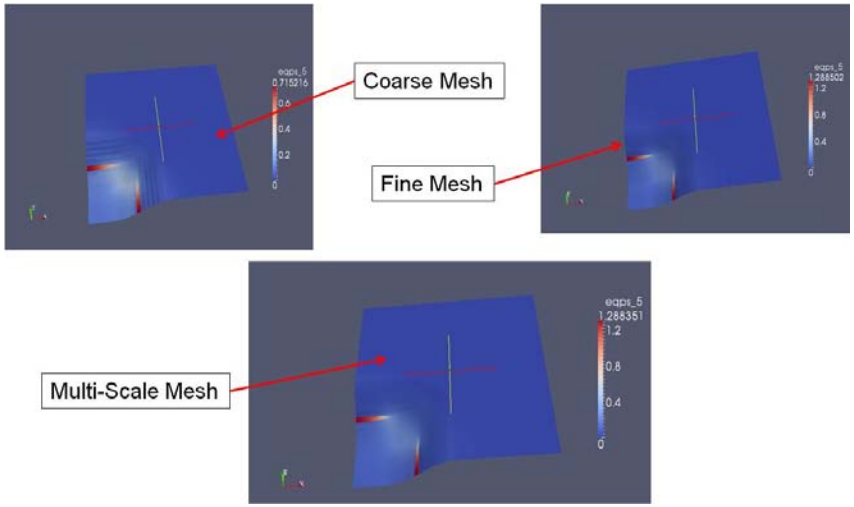


Multi-Scale Model Of Ductile Deformation



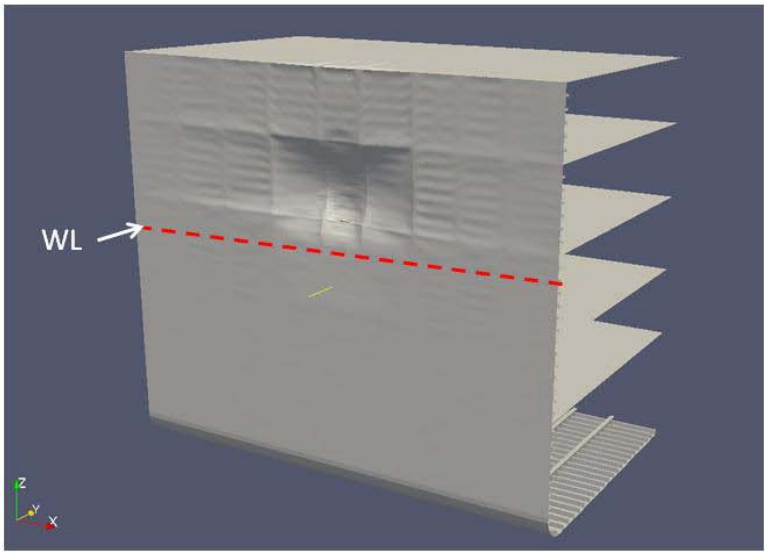


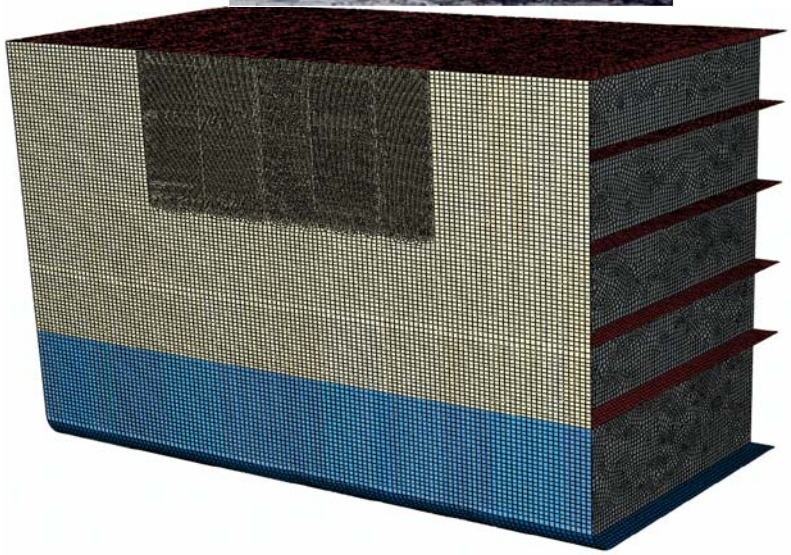


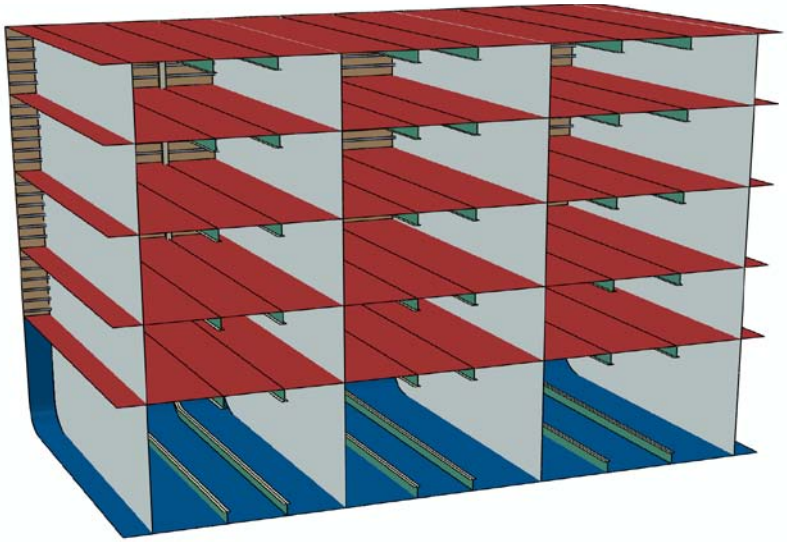


34% Reduction In Computational Cost

NESM V&V/Ship Damage







NESM Planned Evolution => 2019

Gap Fillers

- Adaptive/Multi-Grid Damage Modeling
  - Damage Captured At Material Site By Solid Modeling
  - Shell-Shell ; Shell-Solid Adaptive Multi-Grid
  - Optimal Use Particle Methods
  - STABLE TIME STEP CONTROLLED BY MACRO-GRID, NOT REFINED MULTI-GRIDs
- Fully Integrated Structural Dynamics/Solid Mechanics Analyses (w/ Explicit⇔Implicit automatic switching)
- Enhanced Coupling/Load Balancing
  - Dynamic Load Balancing
  - Dynamic Geometric Interfacing
  - Tight Equilibrium Coupling
- AIREX Loading
  - Combined Blast, Frag & Debris Loading

Summary

- Navy Enhanced Sierra Mechanics (NESM) Being Developed For Prediction Of Ship Shock Response, Damage & Post-Hit Mission Capability Supporting HPCMO/CREATE
- NESM Currently Supports ~50 Users From Industry & Navy Laboratories
  - Usage In Excess Of 3M cpu-hours In FY-12
- NESM Provides U.S. Navy With “Next Generation” M&S Capabilities