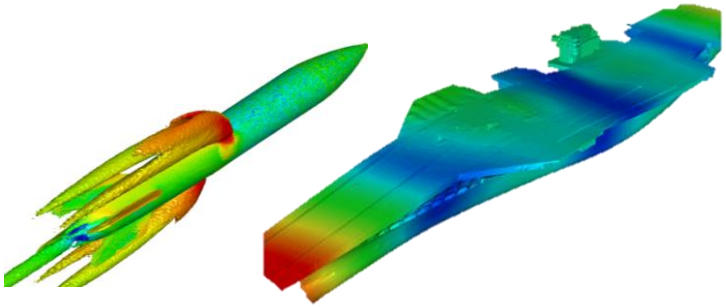
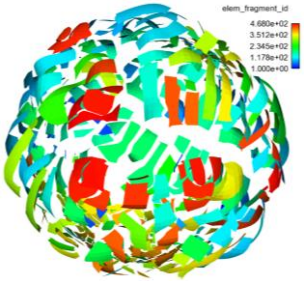
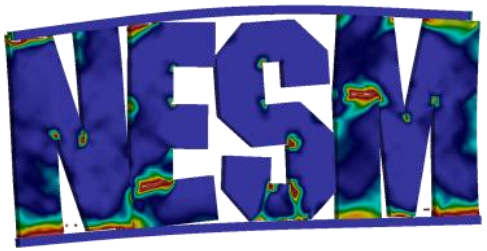
Exceptional service in the national interest

Sandia National Laboratories







COMPSIM
LIKE IT REALLY HAPPENS

Multi-Disciplinary Integration of ModSim for Navy Applications

Greg Bunting, Garth Reese

gbuntin@sandia.gov 505-845-9708

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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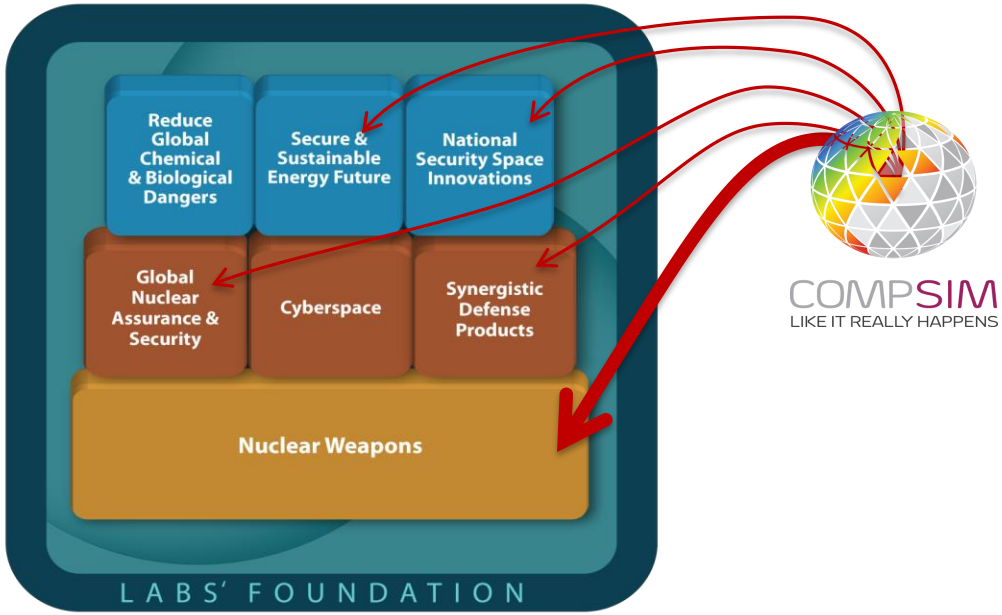
System Integration – Credible Solution

Sandia National Laboratories

Our mission statement …..

Develop and deliver engineering-mechanics simulation applications & expertise for **credible** National Security decision making.



What we offer

SIERRA offers a wide range of simulation capabilities

- Solid mechanics
- Structural dynamics
- Acoustics
- Thermal analysis
- Fluid dynamics
- Aerodynamics

COMPSIM
LIKE IT REALLY HAPPENS

All built on common infrastructure

- Sierra also couples with other Sandia tools
  - Pre and post processing (Cubit, Paraview, SAW)
  - Design and optimization (Dakota)
  - Other computational simulation capabilities (CTH, Alegra, ITS)

Distinguishing strengths are

- Robustness: production code (SQE)
- Performance: parallel scalability, focus on NGP
- Credible: V&V, UQ, QMU
- Multi-scale and multi-physics
- Access controlled code for support of National Security Mission

Our customers

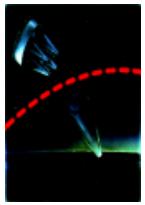
Nuclear Weapons Program & Analysts

- NW Program is the principal driver for Sandia's Computational Simulation efforts

Assured Safety and Security

Delivery

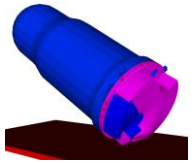
Separation shock/ Aerodynamic Heating



Staging shock

Random vibration

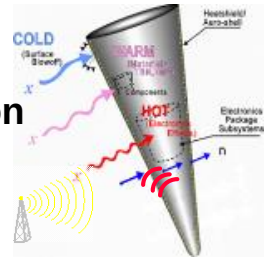
Survivability



Mechanical Insult

Thermal Insult

Electromagnetic Insult



Radiation Effects

Security Components

Assured Performance & Manufacturing

Safe & Secure Transport

SNL Engineering Codes are positioned to support the engineering needs of the complex

Navy Enhanced Sierra Mechanics (NESM) Acoustics

Sandia National Laboratories

COMPSIM STRUCTURAL DYNAMICS

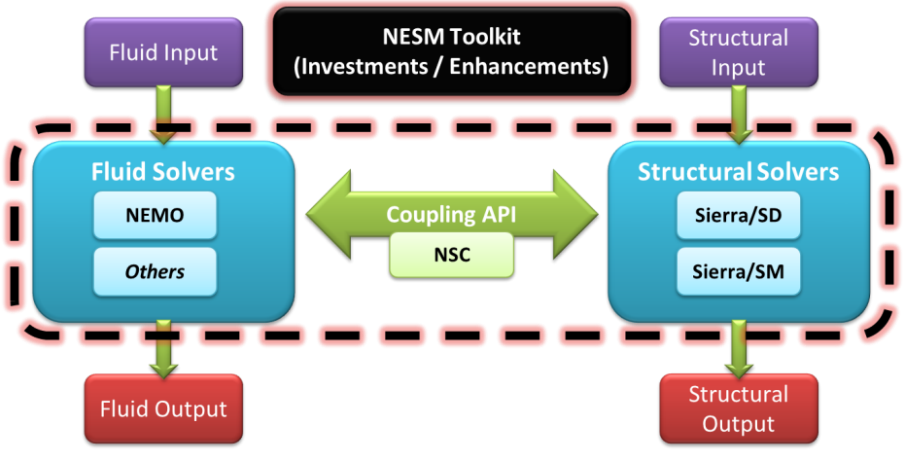
- NESM Capability for transient acoustic loading
  - Acoustic approximation of UNDEX loading
  - Scattering (split-field) formulation to allow for easy specification of sources
  - Various sources: plane/spherical step wave, spherically spreading source, Hicks Bubble.
  - Ellipsoidal infinite elements for far-field boundary condition
    - Allows large aspect ratio ellipsoids for slender structures
  - Parallel and scalable

Overview - NEMO

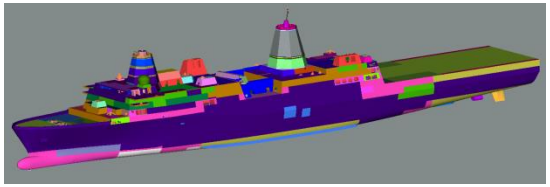
Sandia National Laboratories

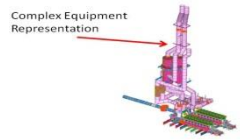
Navy Enhanced Sierra Mechanics (NESM)

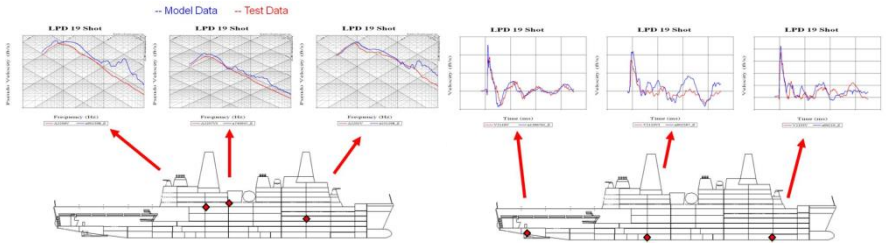
- Massively Parallel, Enhanced, Physics Based M&S Suite For Prediction Of Ship Shock Response & Damage Due To Weapon Engagements
- Modern Software Engineering Designed For Evolution
- Developed To Address Validation Of The Integrated Ship System Shock Hardness IAW OPNAVINST 9072.2A As Well As Live Fire Test & Evaluation (LFT&E) Needs
- **Leverages DOE-ASC Investment In Sierra Mechanics**
- **Leverages ONR Investment In The Implosion Program**

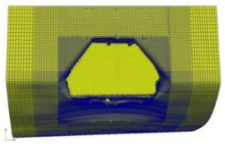


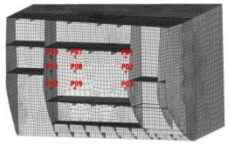
Emphasis on Validation for Both Shock Response & Ship Damage Compared to Physical Testing

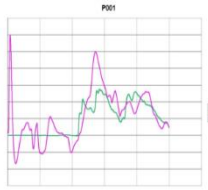


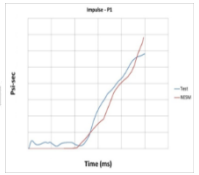












Compsim Organization

Sandia National Laboratories

1) Organized into several SCRUM-Teams, each developing and support a set or products
    1) Structural Dynamics (Linear)
    2) Solid Mechanics (Nonlinear)
    3) Thermal Fluids
    4) Toolkit
    5) Meshing
    6) Dev Ops
    7) Topology Optimization
    8) Verification & Validation

Computational Structural Dynamics

Sandia National Laboratories

COMPSIM STRUCTURAL DYNAMICS

Structural Dynamics – Linear, static, implicit dynamic & modal response

Shared mechanics capabilities

- small deformations, small-strain linear material behavior
- solid & structural elements, constraint elements
- transient–modal–modal transient solution switching, multi-sequence analyses
- non-linear pre-load transfer from Sierra/SM

Time domain, statics & transients

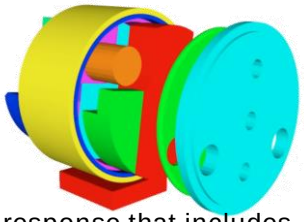
- parallel scalable domain decomposition solver with many constraints
- joint models with dissipation
- material property inversion
- stochastic material (elastic) properties

Frequency domain

- Helmholtz solver, performance

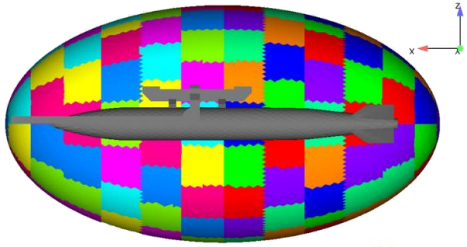
Acoustics – linear

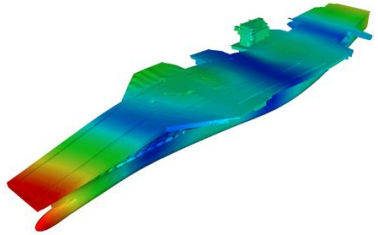
- absorbing boundaries
- acoustic pressure source inversion
- monolithic coupling with structural response



shock response that includes Sierra/SM preloads

acoustic field modeling



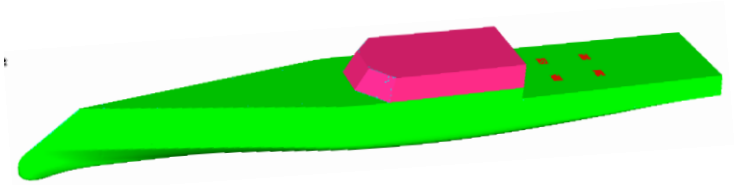


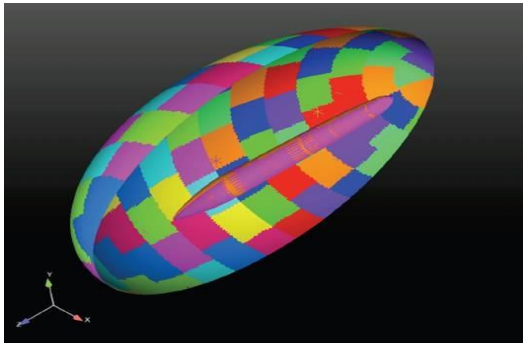
Capabilities Applicable to DoD Needs

Sandia National Laboratories

COMPSIM
STRUCTURAL DYNAMICS

- Full Support for Structural Dynamics
  - Full element library, materials.
  - Modal, Transient Dynamics, Frequency Response. Superelements.
  - SRS, random vibration
  - Quadratic Eigen Value Analysis
  - Geometric and joint-type nonlinearities
- Full Support for Acoustics and Structural Acoustics
  - Mesh tying, infinite elements, PML, mild nonlinearity
  - QEV, Transient, Frequency Domain
- Inverse Methods Capability
- Coupled Physics
  - Fluids: nemo, aero and sigma
  - Thermal (unidirection): fuego
  - Nonlinear Mechanics

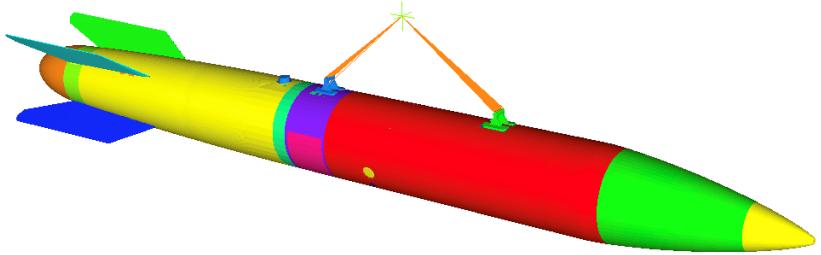


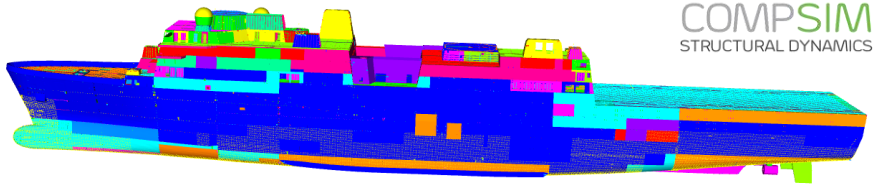


Full Support for Structural Dynamics

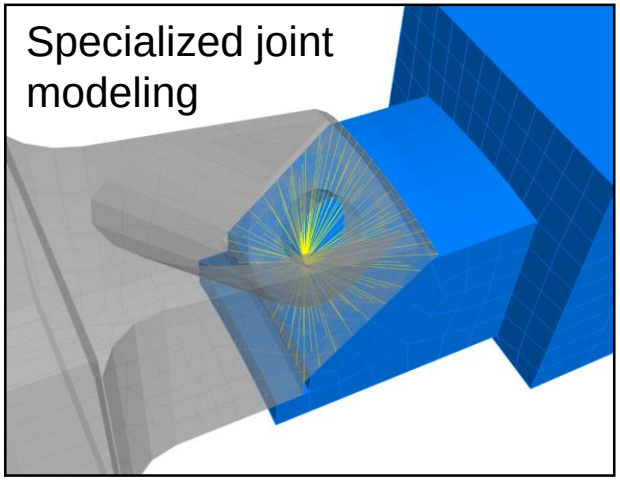
Sandia National Laboratories

COMPSIM STRUCTURAL DYNAMICS





- Modal, modal superposition
- Frf
- Transient Dynamics
- Superelements



Computational Solid Mechanics

COMPSIM
SOLID MECHANICS

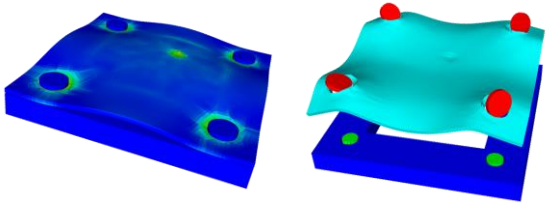
Sandia National Laboratories

Solid Mechanics – Quasi-static, implicit & explicit transient dynamic response

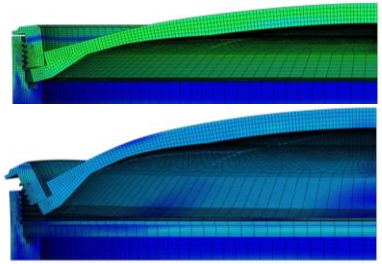
Shared capabilities

- large deformations, large-strain nonlinear material behavior
- implicit-explicit solution switching, multi-sequence analyses
- continuum & structural finite elements, particle methods
- parallel scalable accurate frictional contact
- common & unique material models: 50+
- geometric and temporal multi-scale methods

Implicit→explicit switching



pressure & temperature loading
snap-thru & disassembly



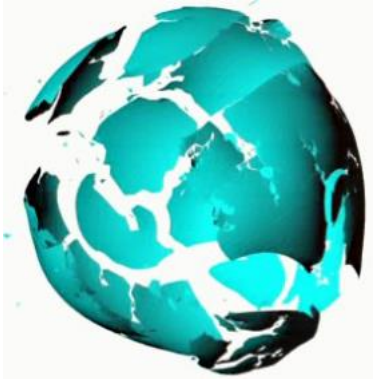
Implicit Solid Mechanics

- coupled thermal-mechanical modeling, with failure
- preloads
- encapsulation & cure, incompressible material behavior

Explicit Solid Mechanics

- energy-dependent material models
- fracture & failure modeling (cohesive zones, XFEM, remeshing)
- empirical blast pressure loads (CONWEP)
- coupled to CTH shock-hydro, Alegra EM

2D XFEM Fracture Simulation

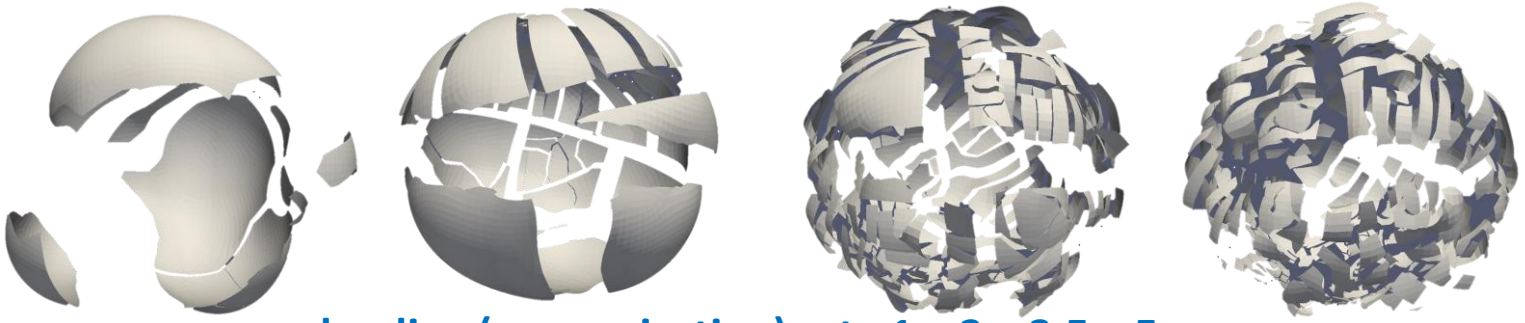


Sierra/SM Capabilities

Recent developments

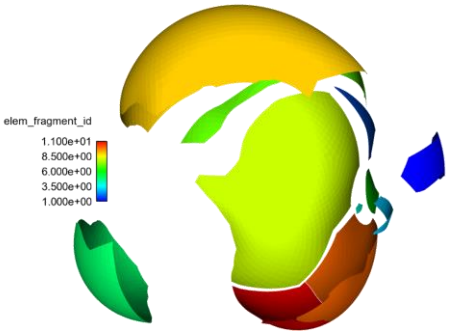
- New XFEM fracture and fragmentation capabilities
- Now production-izing 3D XFEM capabilities (2D in place)

SM brittle fracture modeling



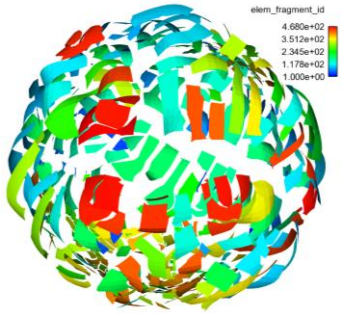
loading (pressurization) rate 1x, 2x, 3.5x, 5x

frag ID, mass balance



Fragment ID	Mass
1	0.106928
2	0.0409208
3	0.024103
4	0.00205816
5	0.553441
6	0.0326549
7	0.144147
8	0.749031
9	1.24167
10	0.382143
11	0.335603
total mass	**3.6127**

Fragment ID	Mass
...	
461	0.00826664
462	0.00932047
463	0.0140141
464	0.0059543
465	0.00110272
466	0.00673505
467	0.0138907
468	0.0111858
total mass	**3.6127**

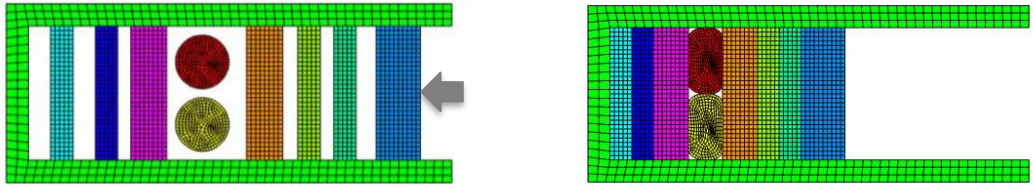


Sierra/SM Capabilities

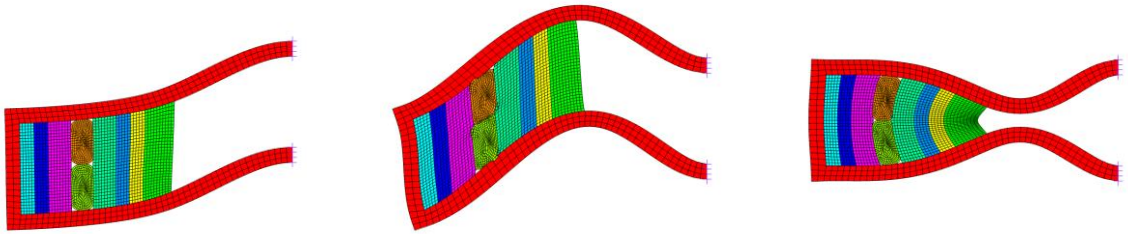
Recent developments

- SM preload effects in SD
  - Improve accuracy of SD direct transient or modal analyses by including the MPCs (thru file) generated from an SM preload

SM preload



SD modal



Mode 1 Mode 2 Mode 3

Sierra/SM Capabilities

Recent developments

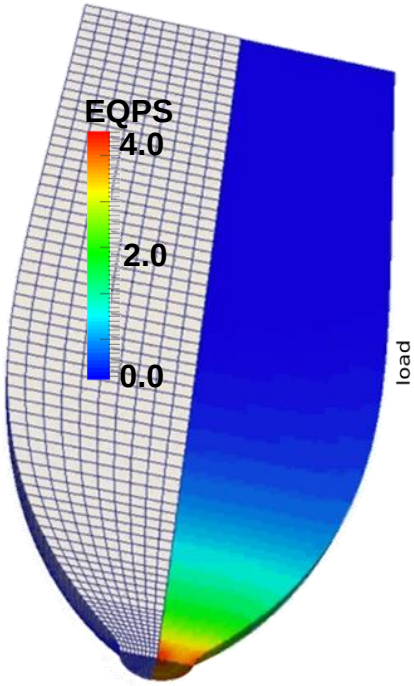
Sandia National Laboratories

COMPSIM SOLID MECHANICS

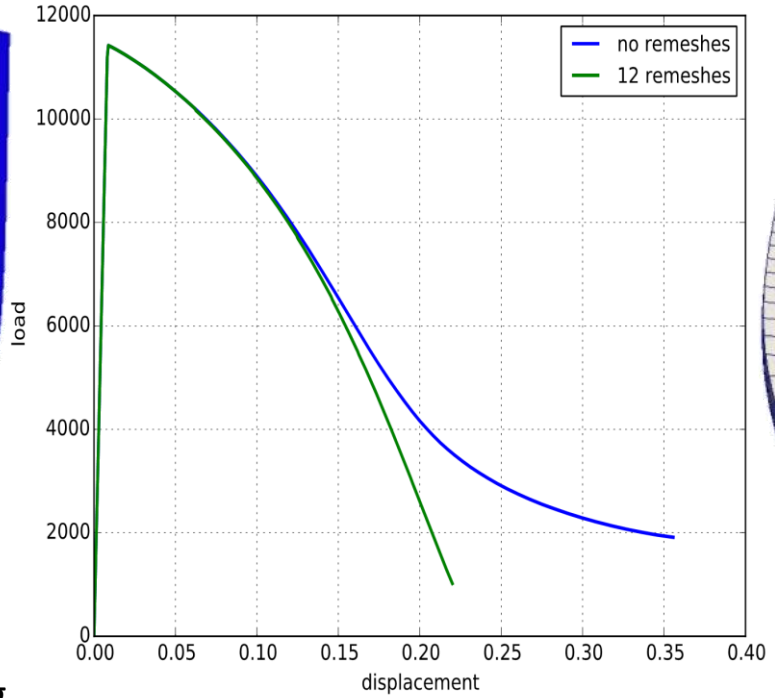
- Large deformation remeshing/remapping in SM
  - Tensor preserving mapping

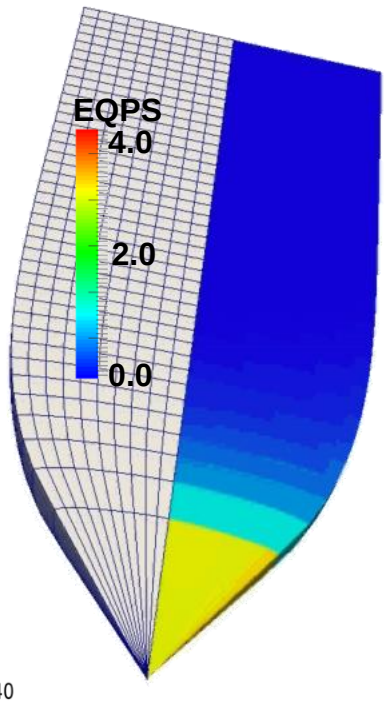
SM material parameter calibration

Global L_2-projection transfer



w/ adaptive remeshing



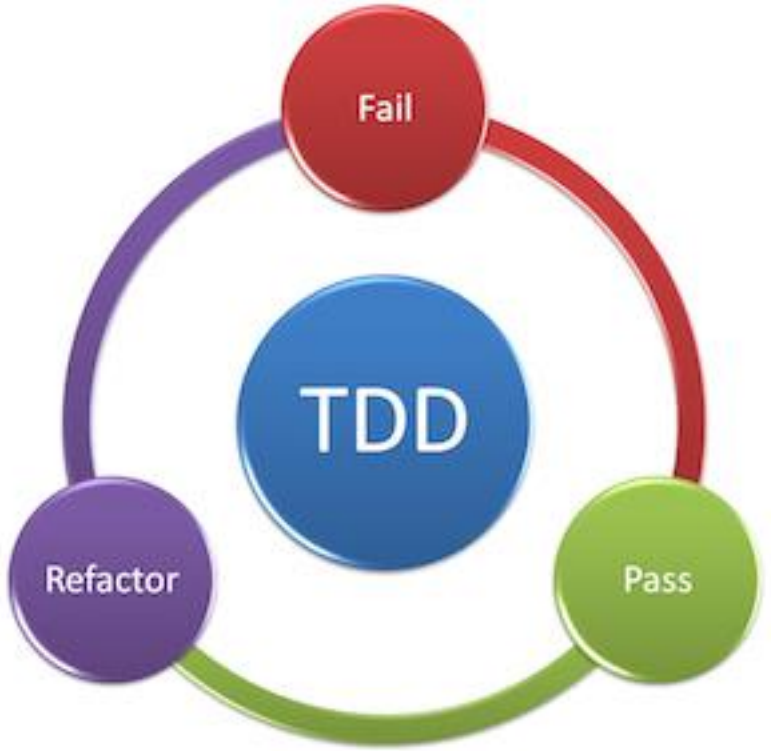


no remeshing

SQE Practices – Test Driven Development (TDD)

Sandia National Laboratories

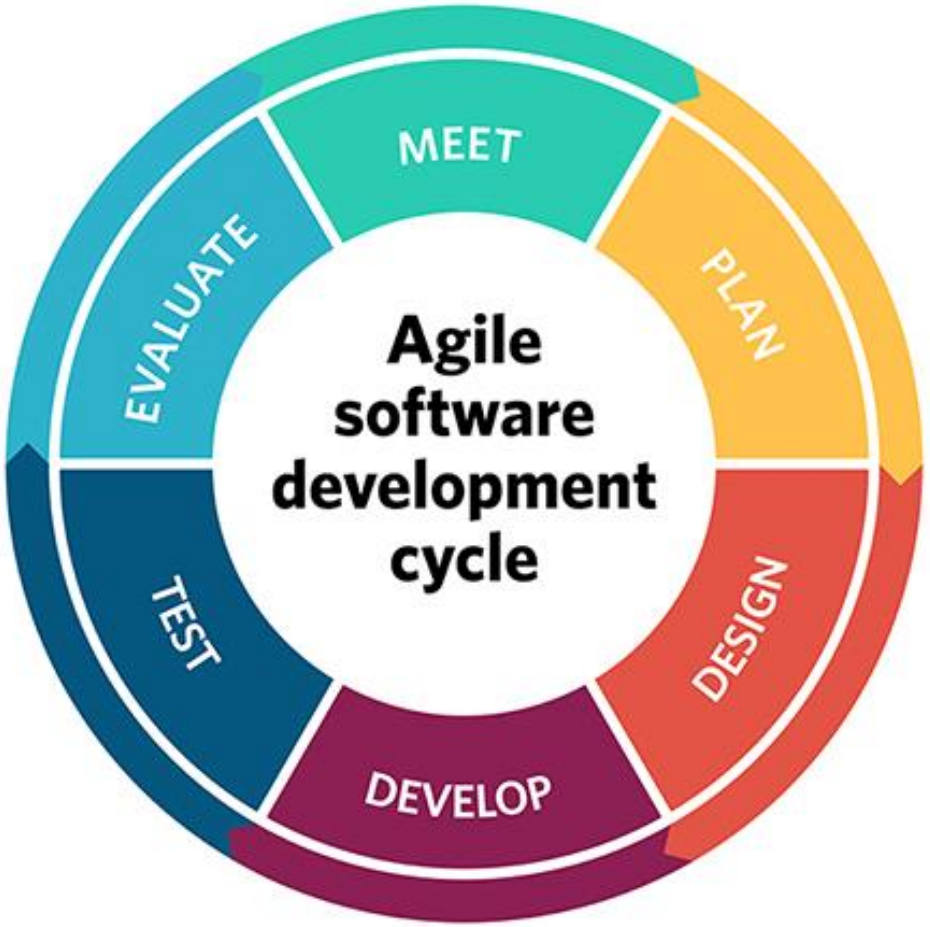
Develop Scalable, Maintainable Software



1. Write a failing test
   - Known Solution
2. Make Test Pass
   - Smallest amount of code possible
3. Refactor
   - Improve code quality

SQE Practices – Scrum / Agile

- React to changing requirements to meet customer needs



Sync Release/Sprint

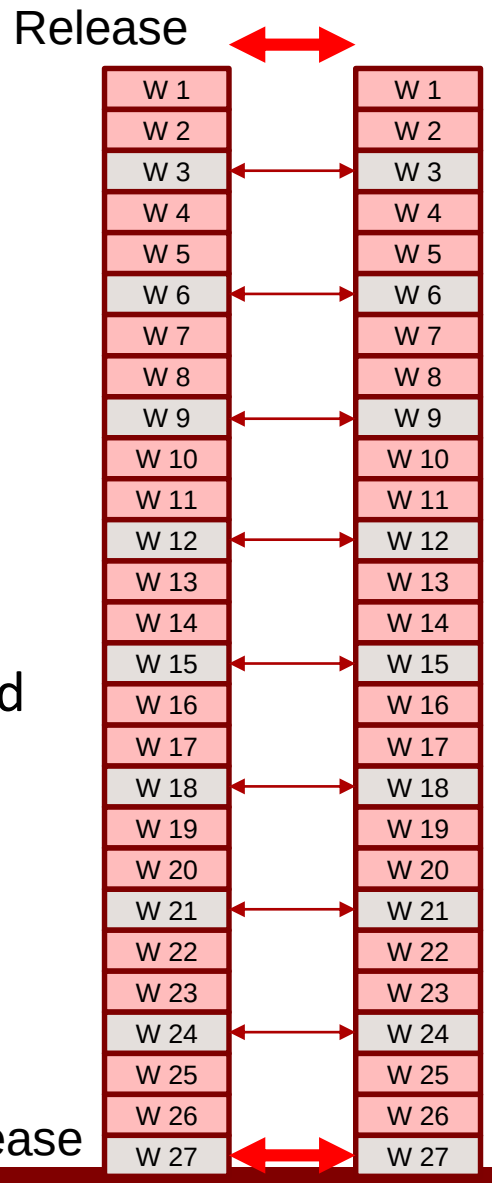
Sandia National Laboratories

Requirements

- Coordinate effort.
- Allow rapid testing of features.
- Avoid unnecessary cost.

Approach

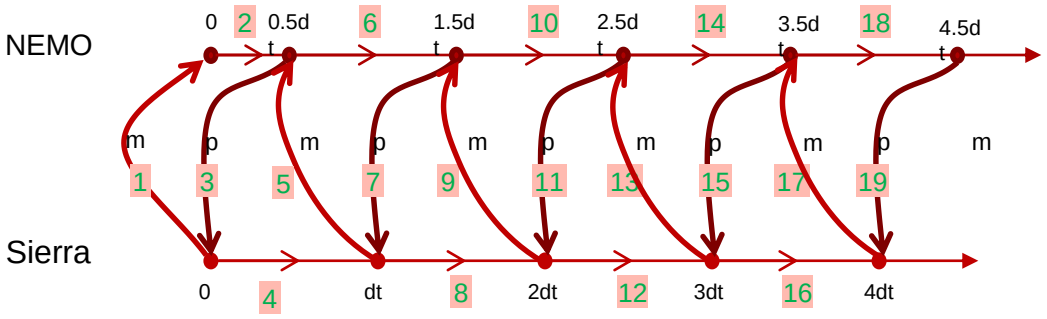
- Use the same Agile sprint boundary.
- Sync code-base at end of sprint.
- Adjust to use the same release cycle
- Communications and data transfer throughout.



The Key is a **collaborative**, partnership relationship.

Flexible Coupling Approaches

- There are many coupling algorithms. For example, iteration may or may not be required on each advance.
- Focus on a flexible strategy that permits evaluation of these algorithms.
- Use standard verification methods to ensure proper accuracy.



Coupler has unit tested capability for each of the steps of the coupling. Surrogate drivers permit integration testing independent of the region.

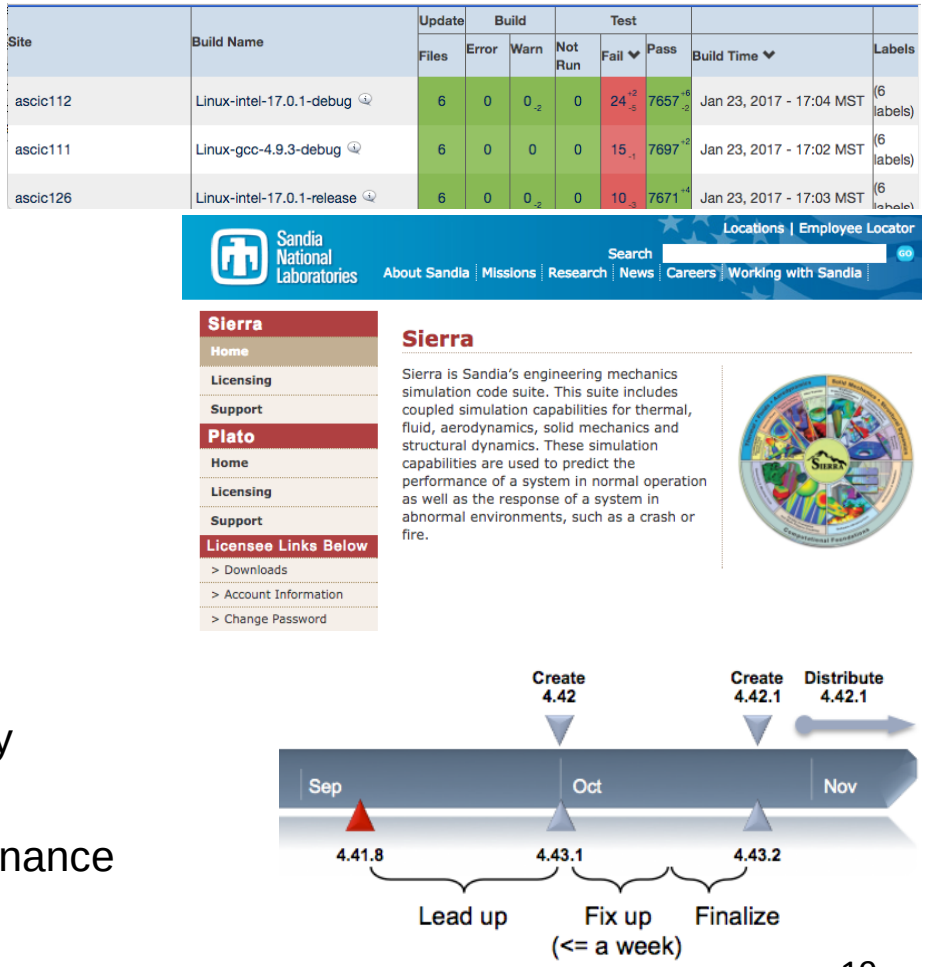
Sierra DevOps

Sandia National Laboratories

COMPSIM DEV OPS

Sierra DevOps team enables development and distribution of the Sierra suite of applications.

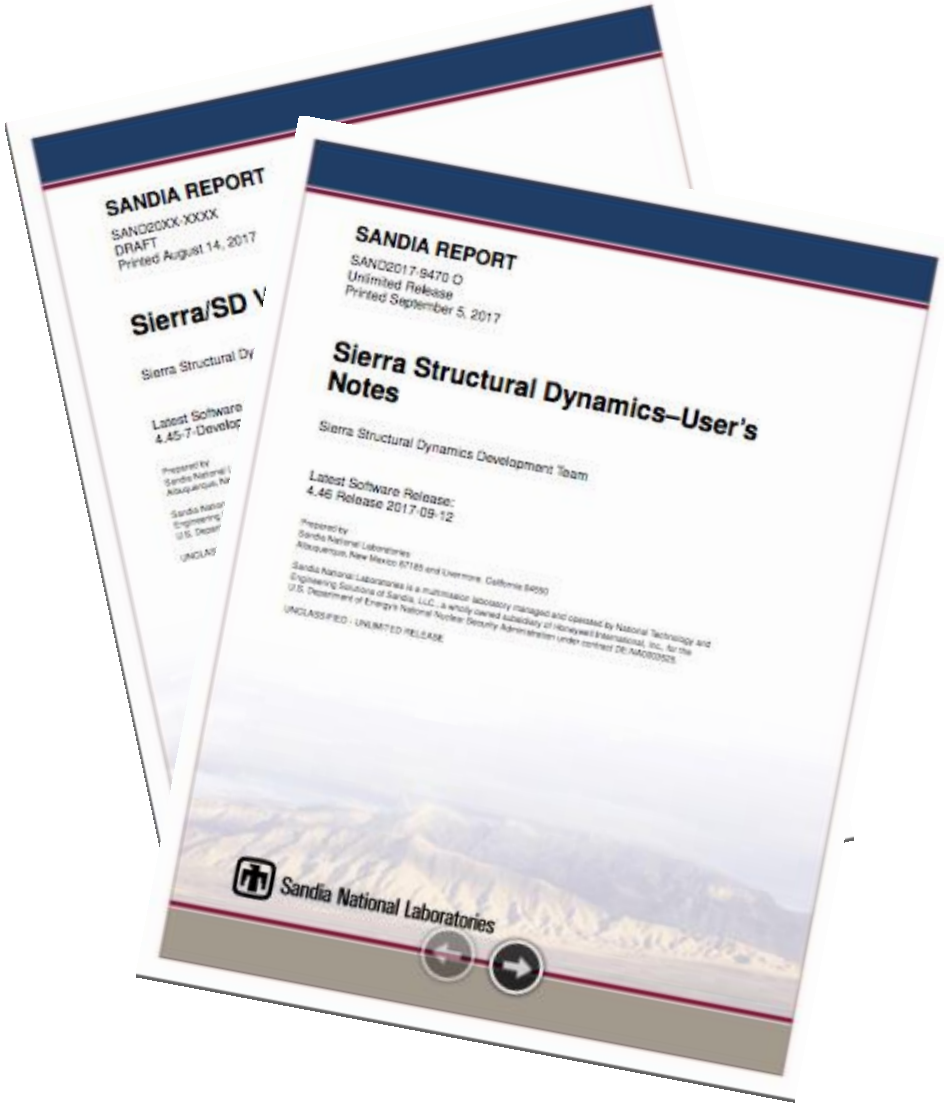
- Tools and configurations for:
  - Build system
  - Test harness
  - Automated testing processes management
  - Testing dashboard
- Configuration & testing for a wide range of compilers and platforms
- Licensing management, packaging tools, internal & external delivery
- Software quality engineering & assurance testing (coverage, memory, static analysis)
- Build, installation, and execution support
- Management of software component & library integration and coupling
- Release branch creation, testing, and maintenance



Integration – Verification Tests

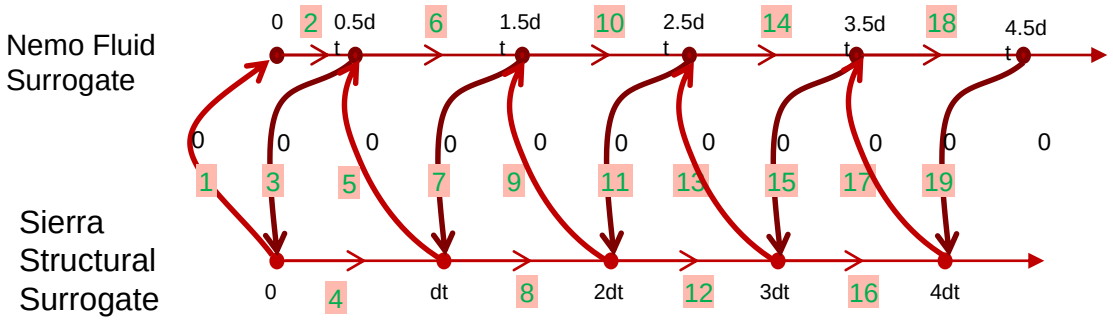
- Small verification tests are performed at Sandia and Document
- Verification tests are run before every sprint and full release
  - Verified and serial and parallel
- Verification document is built from passing tests

- Navy also verifies capability

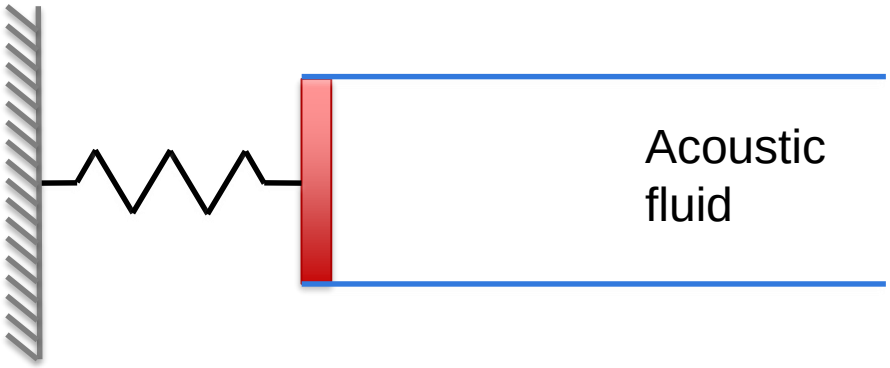


Integration - Surrogates

- Mock executables demonstrating Sierra and Nemo were created to facilitate development efforts
- Surrogates run as executables, but with empty data structures and without solves
- Allow separation between “coupling” error, and “physics” errors



Verification: 1d acoustic piston



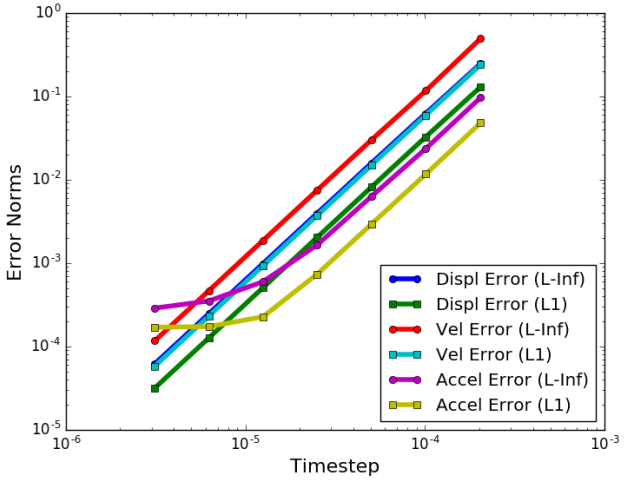
***Goal**: test loosely coupled algorithms to assess temporal accuracy*

Structure displacement

$$u_s(t) = \mathrm{e}^{-dt}\left(a\cos\omega t + b\sin\omega t\right) + \nu(t-\beta)$$

Fluid solution

$$v_a(t) = \dot{u}_s(t - x/c_a)H(t - x/c_a)$$
$$p_a(t) = p_\infty + \rho_a c_a v_a(t)$$



User Support Model

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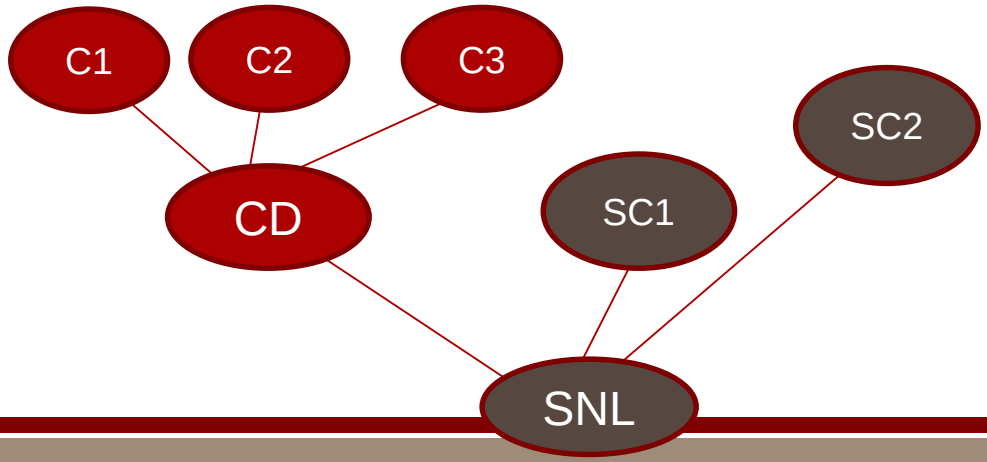
Requirements

- Avoid overload of developers.
- Provide Support as near customer as possible.
- Build a sustainable system.

Approach

- First Line Support at NSWC/CD.
- CD forwards triaged issues to SNL development.
- Support tickets are maintained and tracked at relevant sites.



Applications

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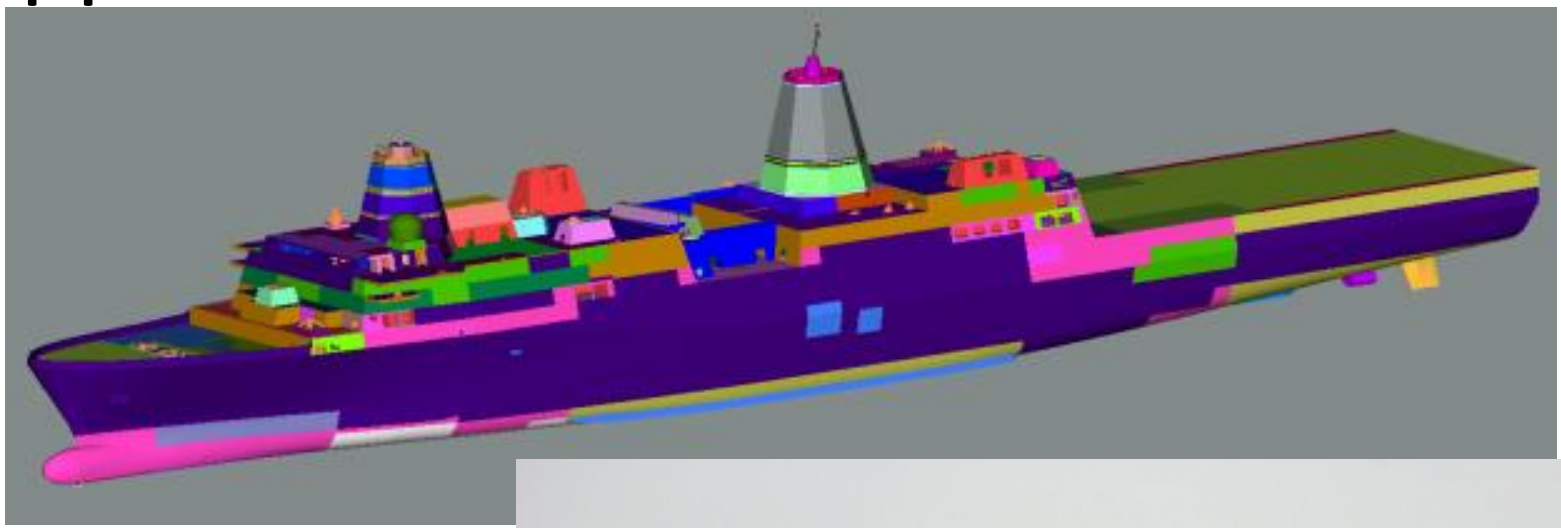

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Questions?