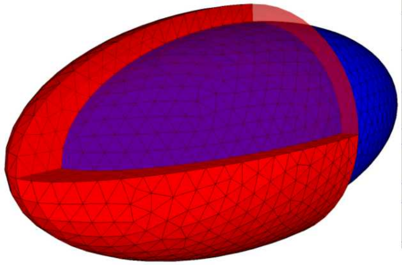
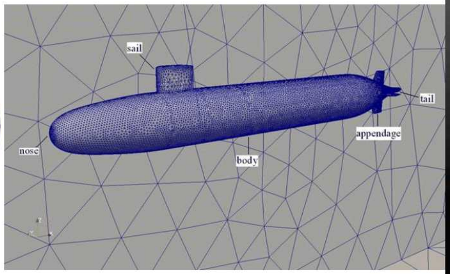
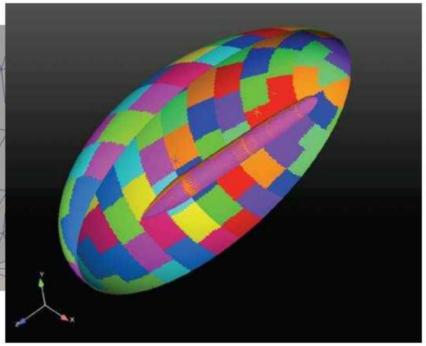
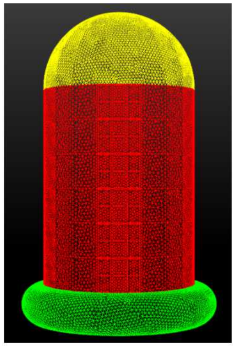
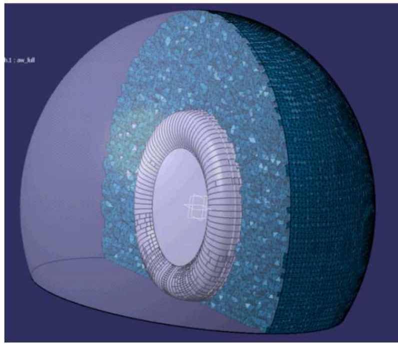
SAND2019-2541C











Structural Acoustic Modeling Capabilities in Sierra-SD

Scott Miller, Lynn Munday, Gregory Bunting

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Higher order elements Sierra/SD

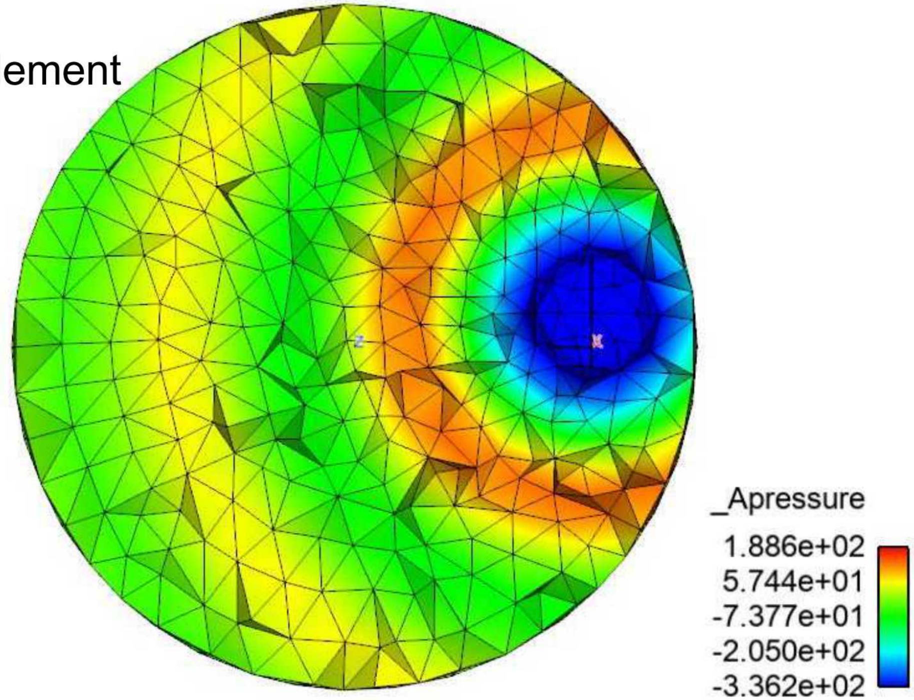
(acoustic formulation only)

- **Element formulation:**
  - H^1-conforming hierarchical p-FEM shape functions*
    - Integrated Legendre polynomials
  - Internal element variables statically condensed
    - vertex, edge and face unknowns remain
- **Implementation:**
  - Based on hp3d code from UT Austin (Demkowicz et al.)
  - Other options possible, but very convenient (free coarse problem, …)
  - Hex8, Tet4 or Wedge6 mesh ⇒ internal edge-face-volume data structures ⇒ dial in polynomial degree on the fly
  - Parallel assembly and solution
  - Planned for Release 4.50 (Summer)
  - Acoustic Only - Elasticity planned for 2019

* *Finite Elements in Analysis and Design* (2010) 474-486

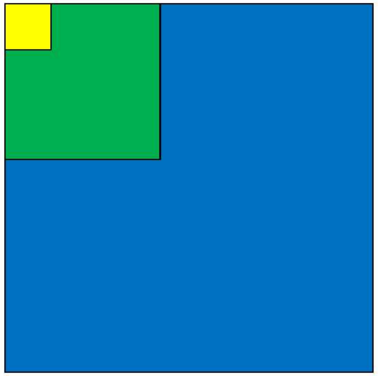
Higher Order Elements with Infinite element absorbing boundary

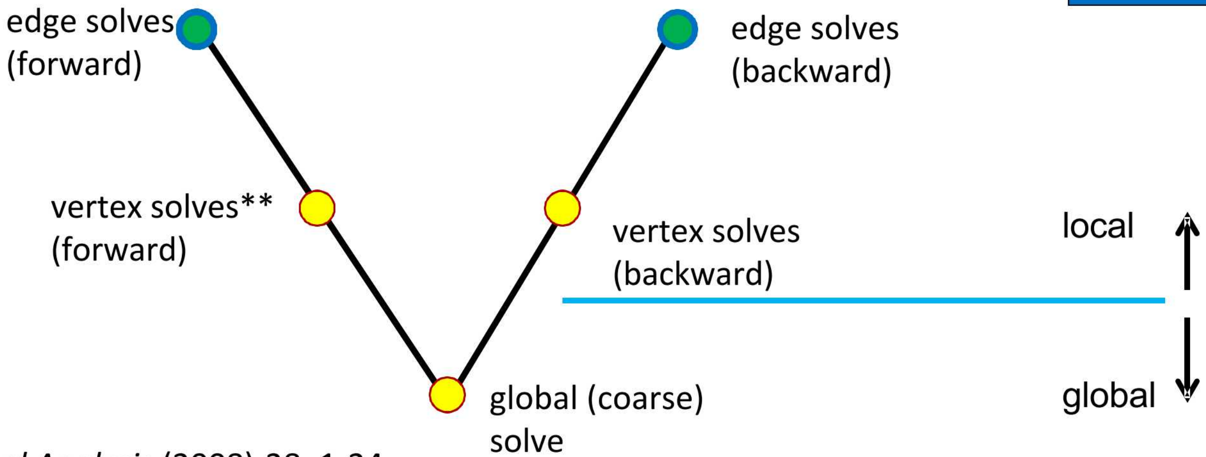
- Test on 1D wave guide
- Test on 3D spherical domain with offset loading –
  - Using 3rd order P-Elements in interior with 6th order Infinite elements
  - Reproduces pressure contours of infinite domain
  - No reflections observed
  - Higher order elements allow us to coarsen mesh – only one element between hollow sphere and boundary
  - Geometry still approximated by linear element



Higher order elements *(local solve strategy)*

- **Preconditioning Strategy**
  - goal: reduce memory and computations
  - local solves associated with edges and vertices
  - global solve for p = 1 sub-block (readily available)
  - Closely related strategy by Schoberl et al.*
  - Symmetric Gauss-Seidel implementation (additive too)



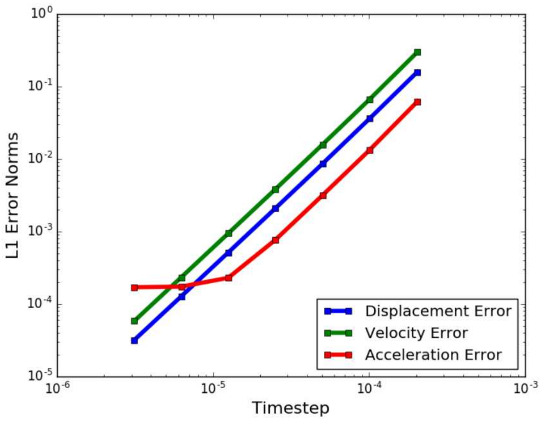


* *IMA Journal of Numerical Analysis* (2008) 28, 1-24

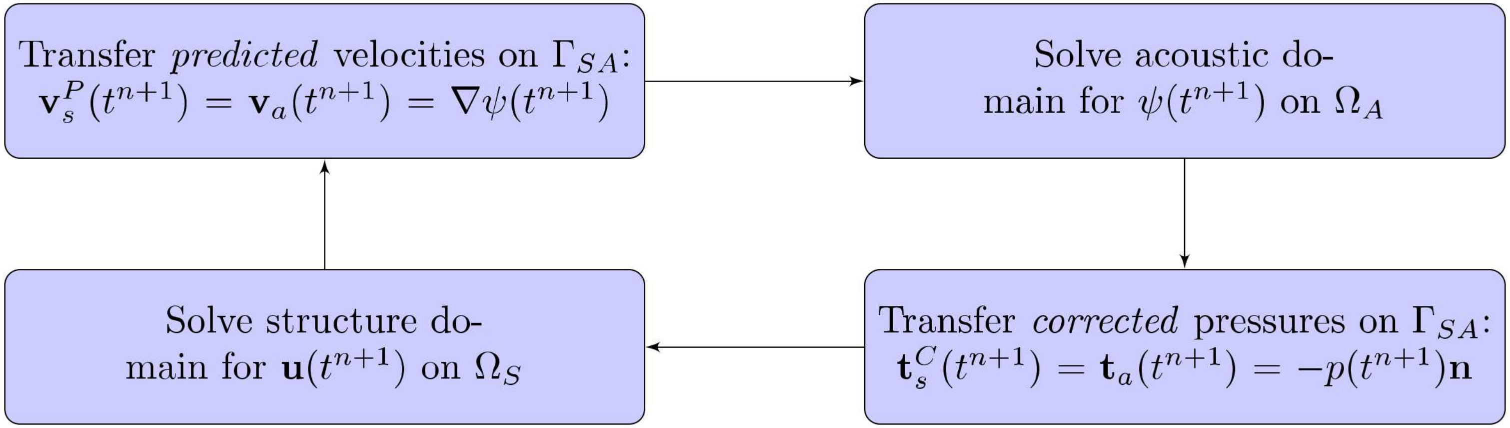
** economic version (energy minimization)

Loosely Coupled Structural Acoustics

- Developed through the use of the Navy Standard Coupler (NSC)
- Allows one executable for Structure subdomain, one for Acoustic subdomain
- Able to achieve 2nd Order Accuracy through GSS method
- Partitioned allows flexibility for MPMD coupling with other software, e.g., Sierra/Solid Mechanics
- Eliminates matrix conditioning issues by separating structure and acoustic matrices
- Predictor/corrector coupling has many options that will be explored in future work



Generalized serial staggered (GSS) algorithm



- Assumptions behind usage
  - Time steps are sufficiently small for accuracy
  - No need for sub-iterations between physics solvers for stability
- Second order accurate predictor + Newmark beta = second order time accurate coupling
- Adams-Bashforth predictor for structural velocities:

$$\mathbf{v}^{n+1^P} = \mathbf{v}^n + \frac{3}{2}\Delta t \mathbf{a}^n - \frac{1}{2}\Delta t \mathbf{a}^{n-1}.$$

Comparison of Infinite Elements and PML

Infinite Elements

- Time and frequency domain formulations are identical (same matrices)
- Restricted to homogeneous media on ellipsoidal domains
- Built-in capability for computing far-field pressures (outside of acoustic mesh)

PML

- Originally restricted to frequency domain solutions
- Works on arbitrarily shaped convex domains (with corners)
- Can also absorb evanescent waves, and in some cases works on heterogeneous domains
- No capability for computing far-field pressure

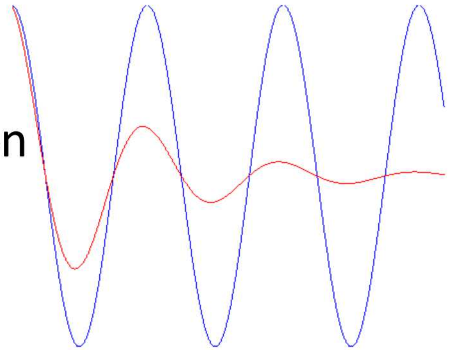
Infinite Elements

- Conjugated Astley-Leis
  - Time Domain, Frequency Domain, Eigen
- Legendre Polynomials to Order 19
- Ellipsoidal Domain
- Walsh *et al* "A comparison of transient infinite elements and transient kirchhoff integral methods for far field acoustic analysis" Journal of Computational Acoustics (2013)

Perfectly Matched Layers

WTF4

- Undamped solution of wave equation: e^{ikx}
  - this wave will propagate indefinitely in the x direction



- Complex Coordinate System:
  - $\tilde{x} = a(x) + ib(x)$
- Wave Equation becomes:
  - $e^{ik\tilde{x}} = e^{i(-ka(x)+ikb(x))} = e^{-kb(x)}e^{ika(x)}$
  - Damped Wave Equation

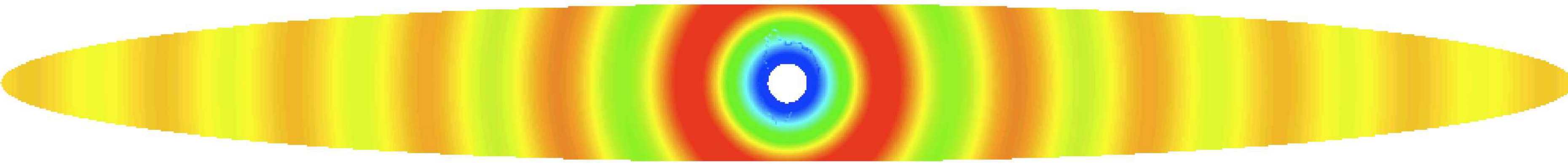
- Bunting *et al*, "Parallel Ellipsoidal Perfectly Matched Layers for Acoustic Helmholtz Problems on Exterior Domains" Journal of Computational Acoustics, 2018
- Frequency Domain Only

Slide 9

WTF4 I would just set a(x) = x

Walsh, Timothy Francis, 7/24/2014

Results: Infinite Element - PML



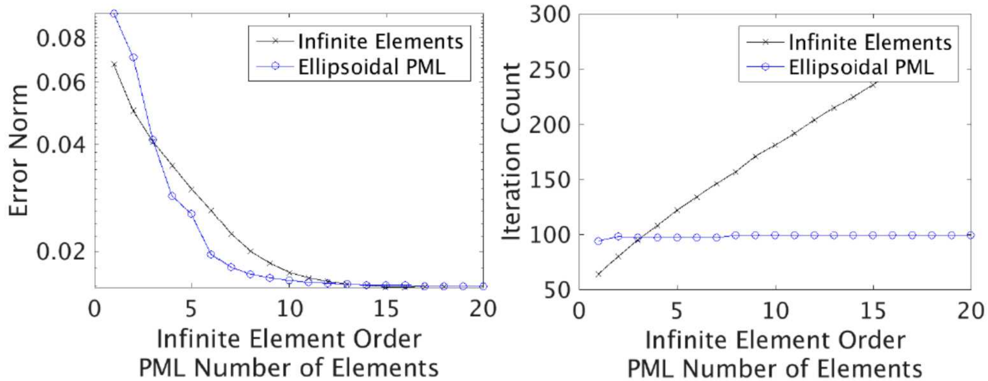
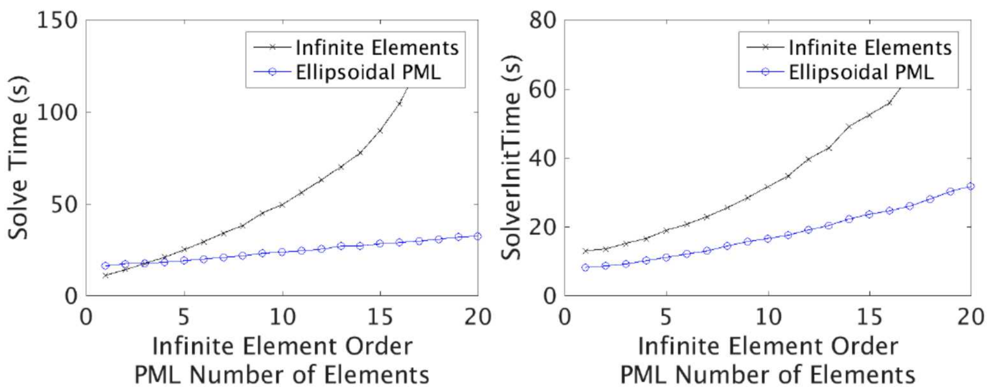


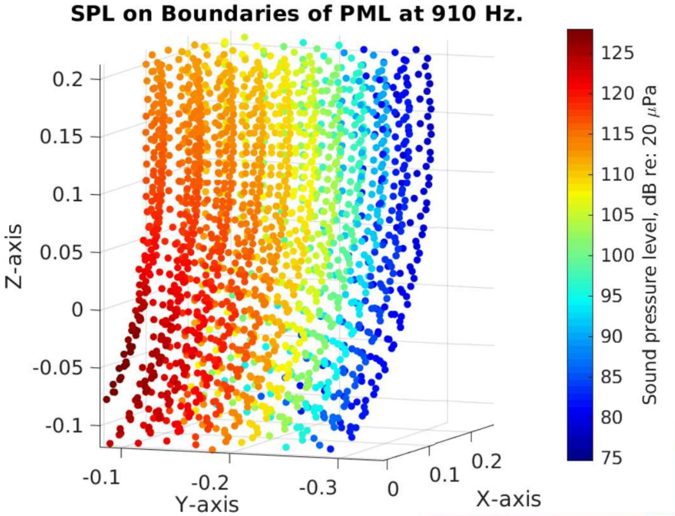
Figure 9: Comparison Between IE and PML (100 Hz)

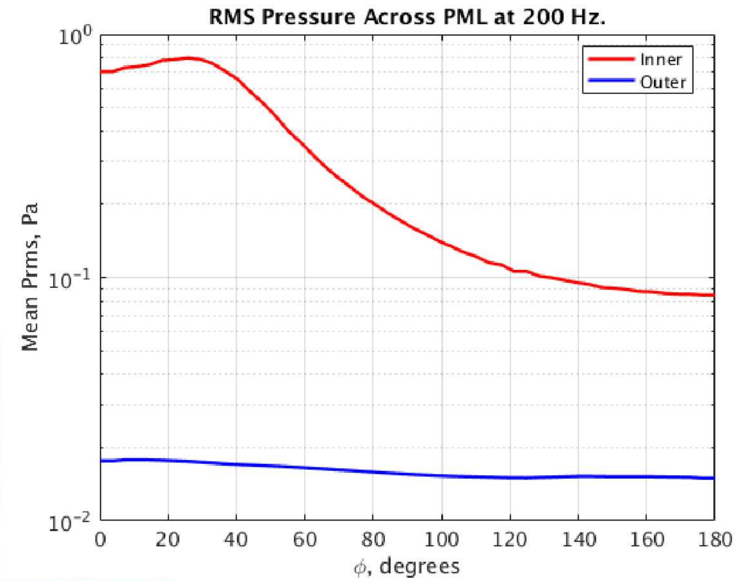


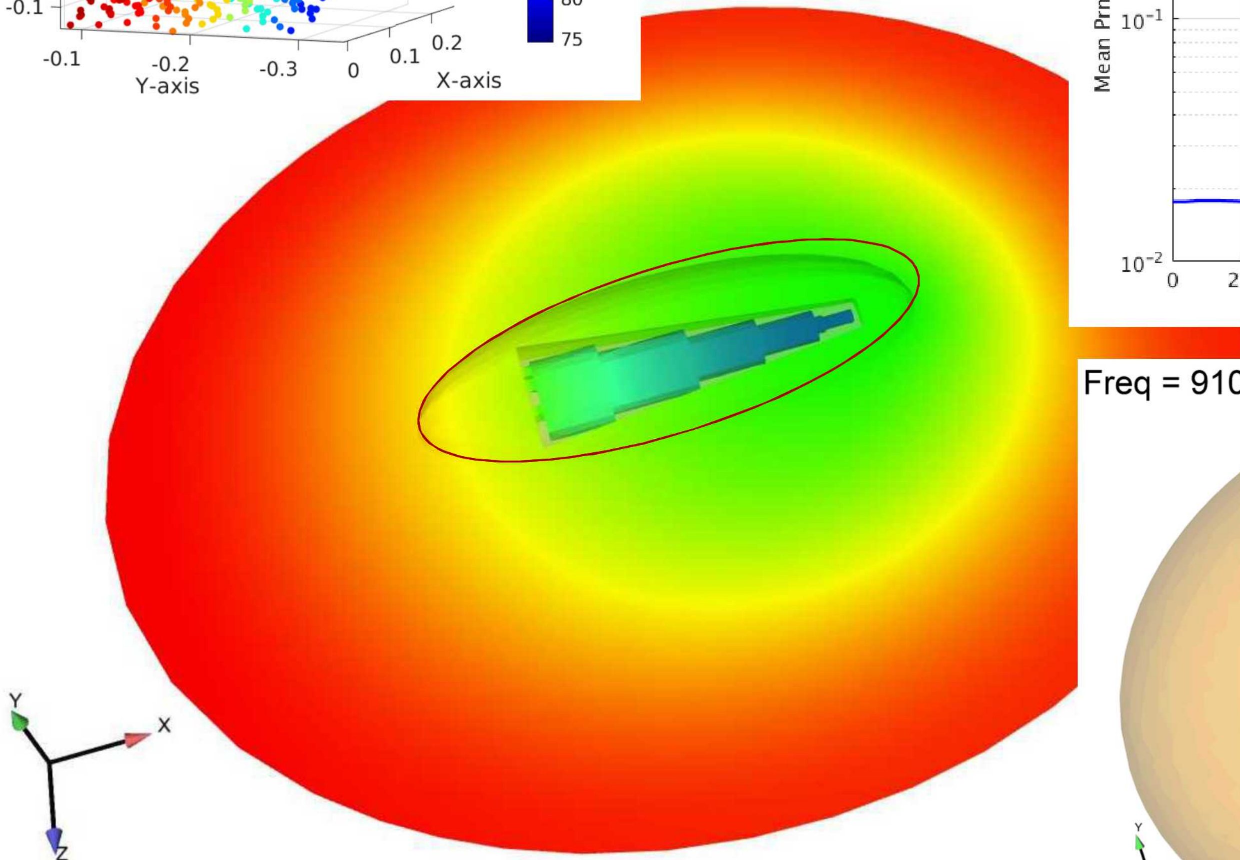
For a fixed level of accuracy

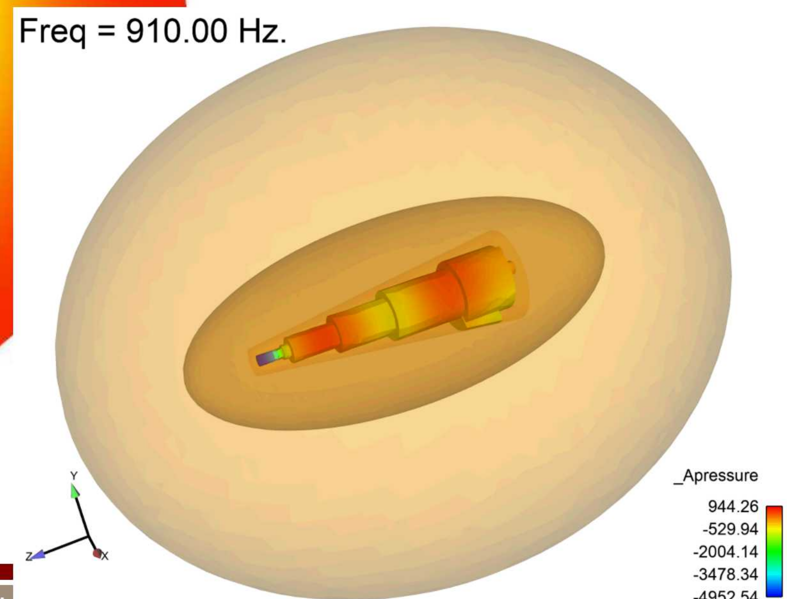
- PML required many less iterations than infinite elements
- PML solution times were much faster
- In frequency domain, PML is clear winner over infinite elements

PML results





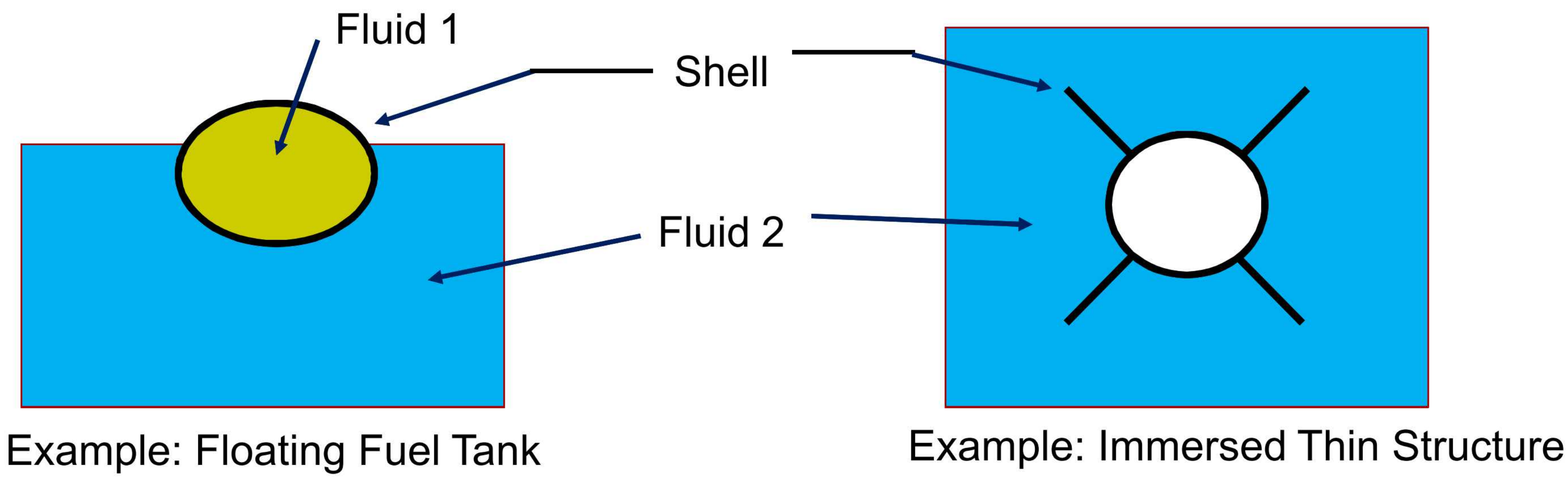




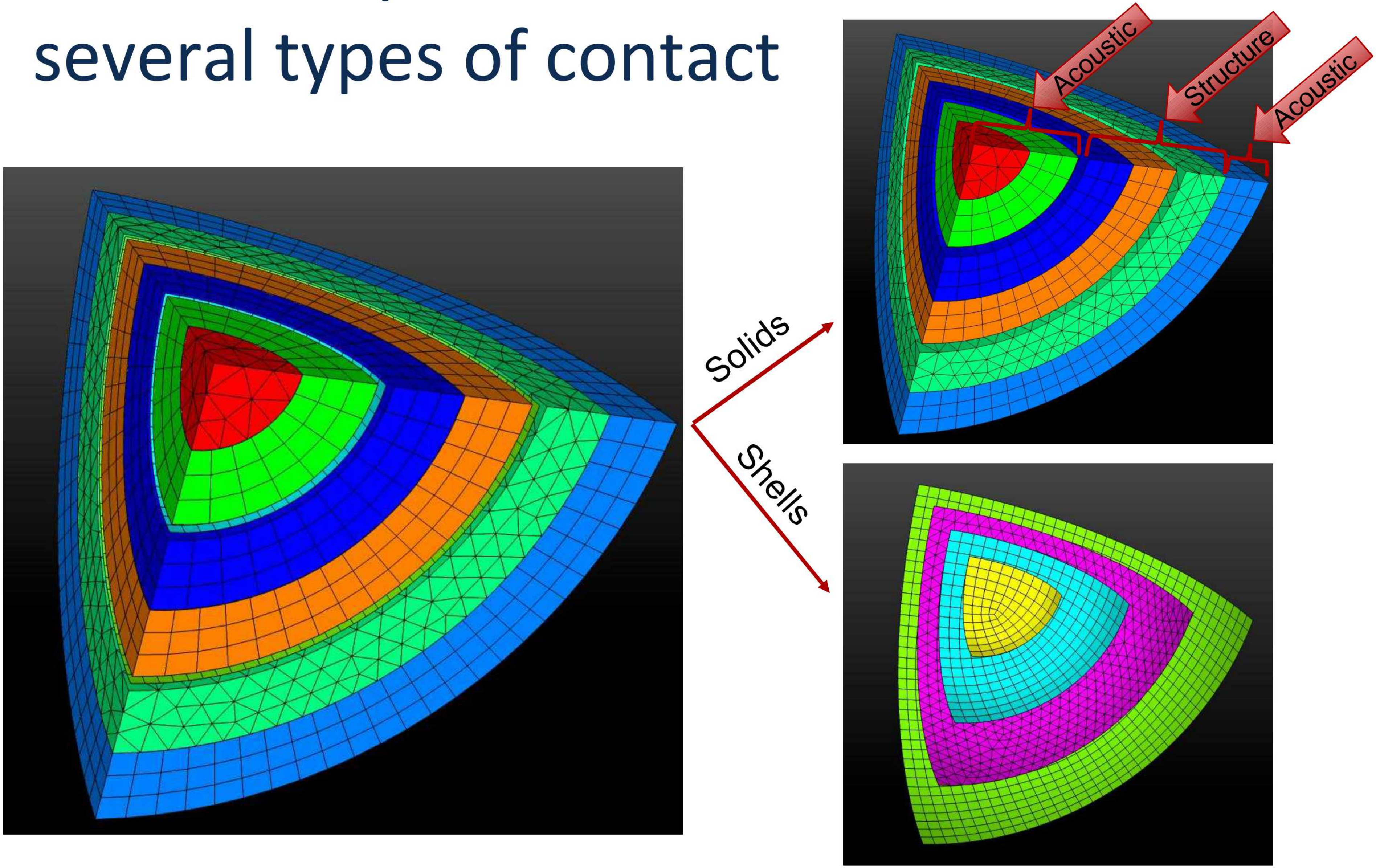
Credit: Jerry Rouse

Doubled Wetted Shell-Acoustics

- Modeling of thin shell structures fully immersed in a fluid.
- Direct request from Navy.
- Hopefully will also be useful for internal use cases

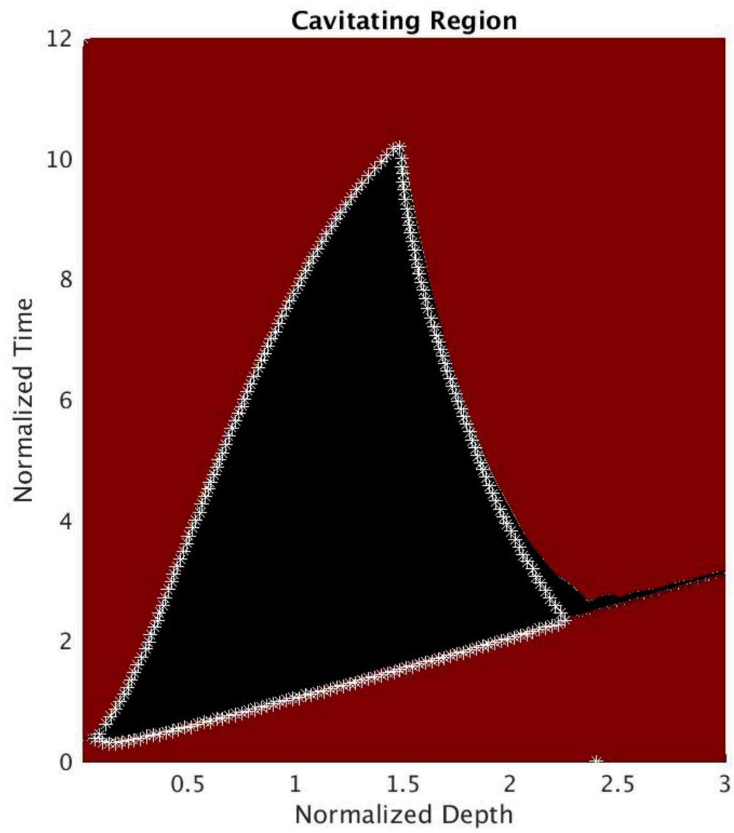


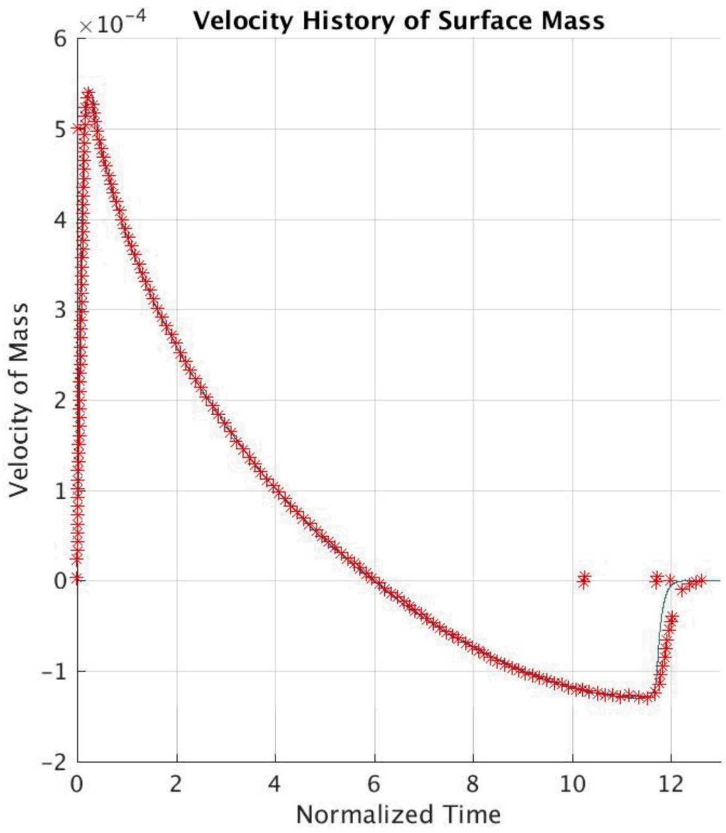
Dash example with several types of contact



Cavitation

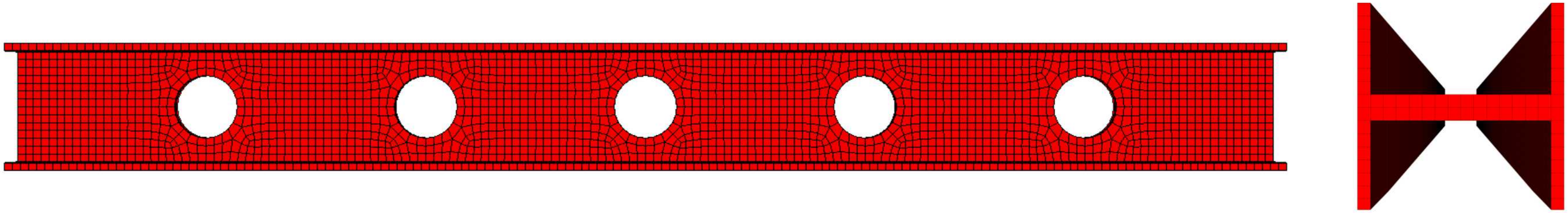
*: Bleich-Sandler (1970) paper; 400 Elements per length scale





Very Large Problems in Structural Dynamics

- How large of a matrix system **A.x=b** can we solve?



High Performance Computing/parallel processor computing

Strong scaling: how the solution time varies with the number of processors for a fixed total problem size

Weak scaling: how the solution time varies with the number of processors for a fixed problem size per processor

“Strong and Weak Scaling of the Sierra/SD Eigenvector Problem to a Billion Degrees of Freedom,” Gregory Bunting, SAND2019-1217

Some scaling results of Sierra/SD

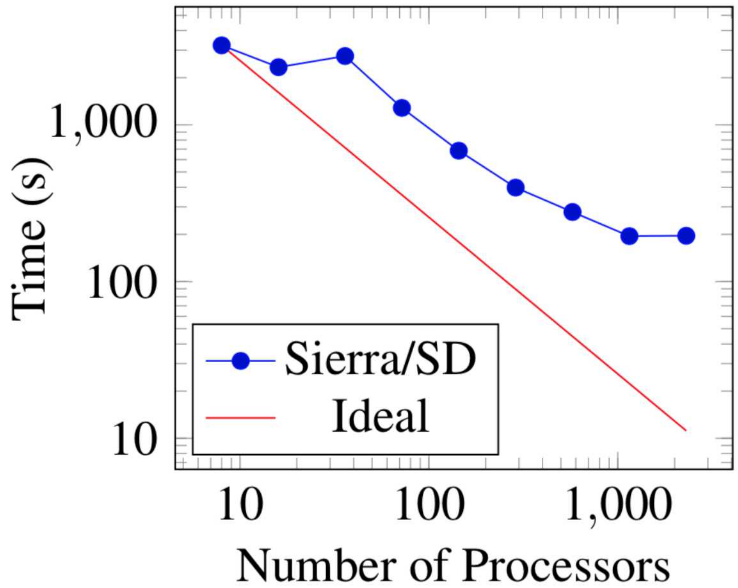
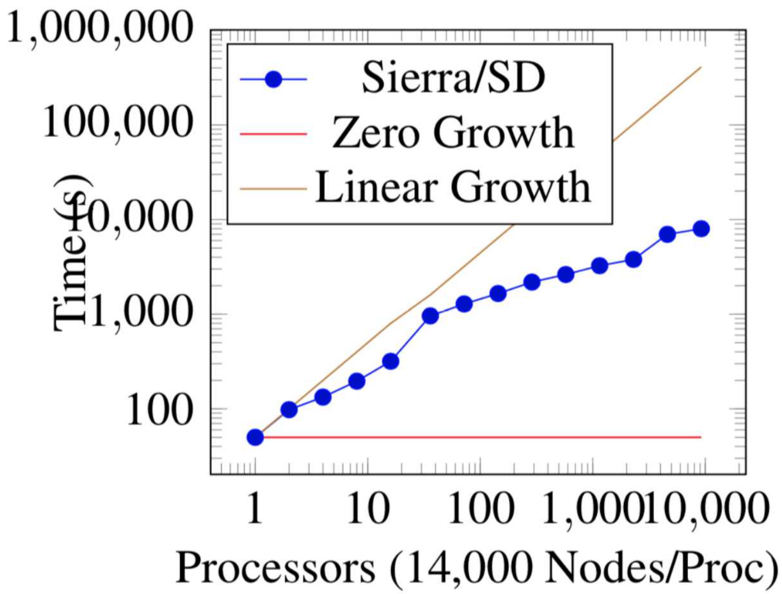


Figure 8. Scaling of Mesh 7 - 1,079,941 Nodes

Strong scaling



Weak scaling

How do you know the number of processors needed?

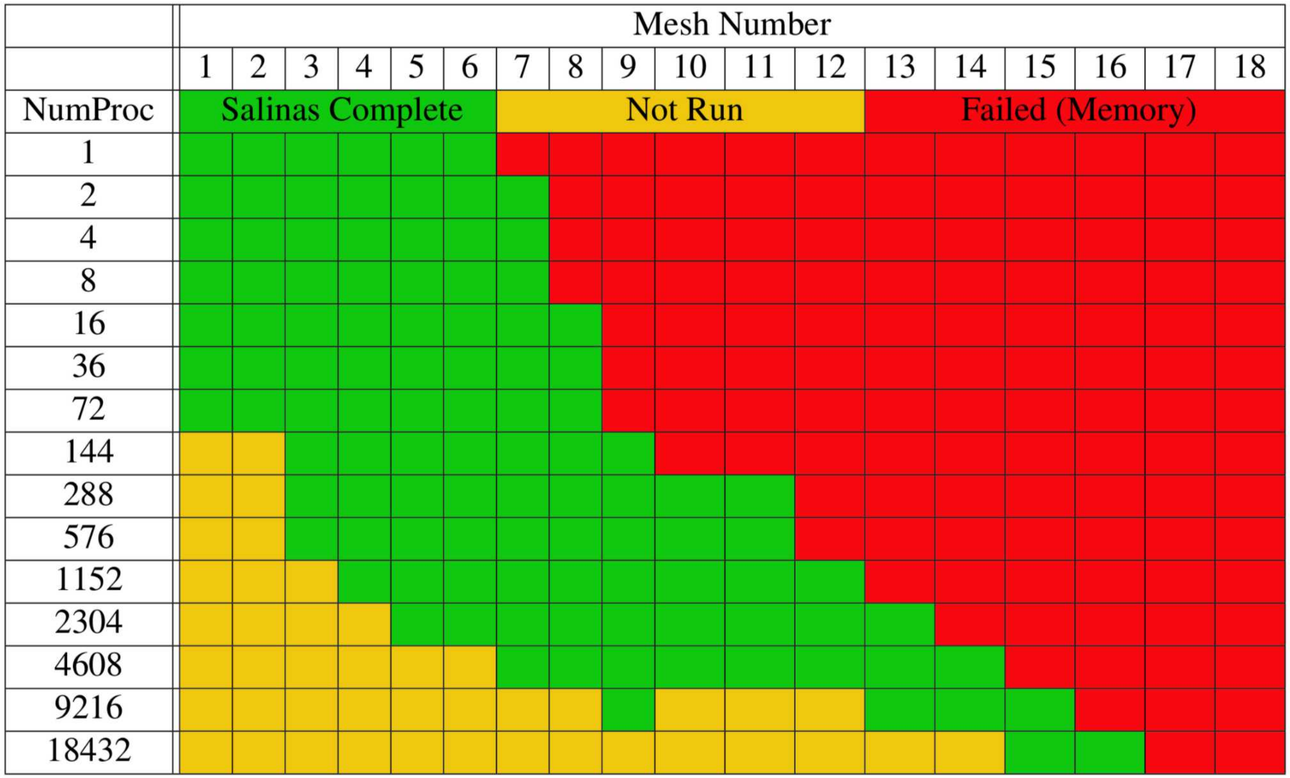


Table 2. Matrix of Successful Sierra/SD Runs

Consider: speed, memory usage, and *availability!*

The End.

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