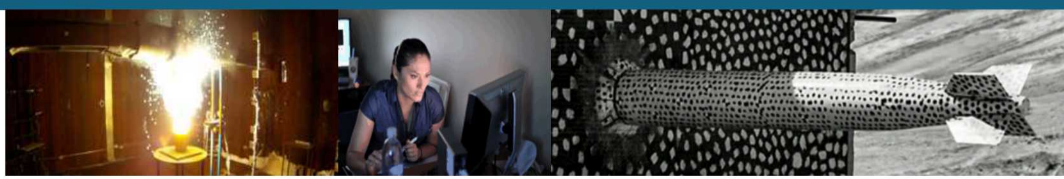
SAND2019-14924C

Large Scale Structural Acoustics in Sierra/SD



Presented By:

Gregory Bunting and Timothy Walsh

Outline

- General Sierra/SD
  - Overview of Sierra/SD
  - History of Sierra/SD
  - Basic Structural Acoustics Capabilities
- Research Areas in Sierra/SD Acoustics
  - Parallel Scalability
    - (Bunting) Strong and Weak scaling of the Sierra/SD Eigenvector Problem to a Billion Degrees of Freedom
  - Parallel Computing on the GPU
  - ~~Pelements – Ultra High Frequency~~
    - Rouse, Thursday 8:05 "The Pollution Effect and Novel Methods to Reduce its Influence in the Mid-Frequency Range"
  - ~~Acoustic Metamaterials~~
    - Treweek, Bunting, Walsh, Tuesday 11:20 – "Adjoint-based, Large-scale Optimization of Metamaterials"
  - 2nd Order Structural. Acoustics Coupling
    - (Bunting, Miller) - "Partitioned Coupling for Structural Acoustics" – ASME Journal of Sound & Vibration 2020
  - PML/Infinite elements for large domains
    - (Bunting et al) "Parallel Ellipsoidal Perfectly Matched Layers for Acoustic Helmholtz Problems on Exterior Domains" Journal of Theoretical and Computational Acoustics 2018
  - Fluid-Structure Interaction
  - Moving Acoustic Mesh
- Applications
  - Load Identification
    - (Walsh, Aquino, Ross) – Source Identification in Acoustics and Structural Mechanics using Sierra/SD
  - Orion Capsule in Reverb Chamber
    - (Bunting et al) – Upcoming Acoustics Today Article

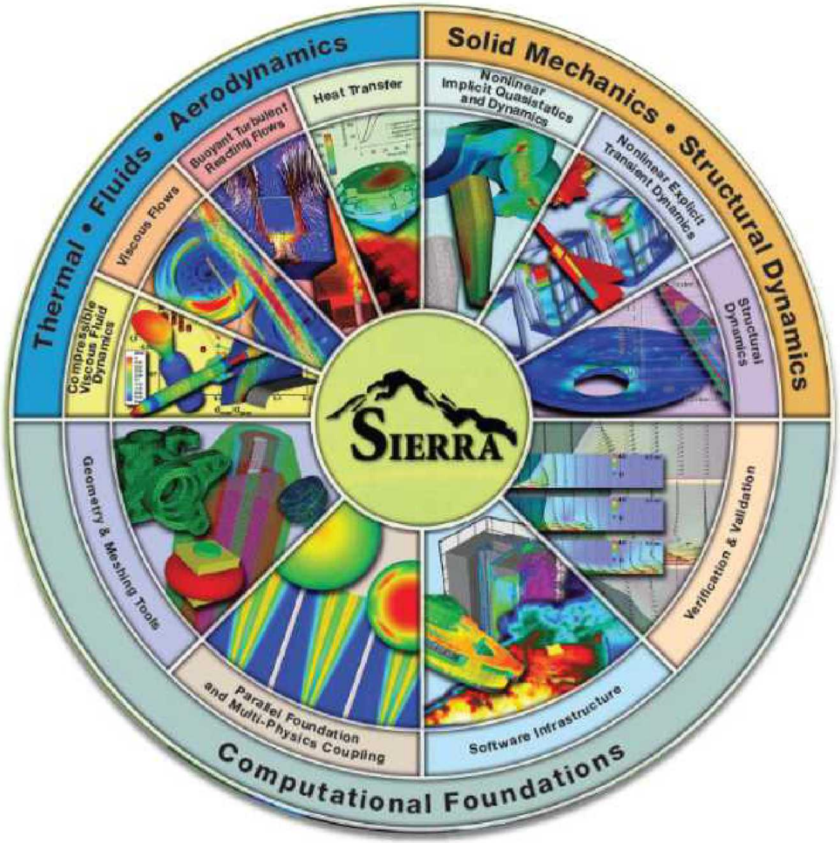
Overview of Sierra Mechanics

Goal: massively parallel coupled multiphysics calculations

Modules for structural dynamics, solid mechanics, fluids, thermal, etc

DOE ASC Funded

- Advanced Simulation and Computing Program



Sierra/SD: A Brief History

Sierra/SD was created in the 1990's at Sandia National Laboratories for large-scale structural analysis

Intended for extremely complex structural and structural acoustics models

- Routinely used to solve models with 100's of millions of degrees of freedom

Scalability is the key

- Sierra/SD can solve n-times larger problem using n-times many more compute processors, in nearly constant CPU time

- Main approach to reduced order modeling
  - domain decomposition
  - parallel iterative solver

Overview of Sierra/SD Structural Acoustic Capabilities

Massively parallel

Hex, wedge, tet acoustic elements (up to order p=6), coupled with both 3D and 2D (shell) structural elements

Allows for mismatched acoustic/solid meshes

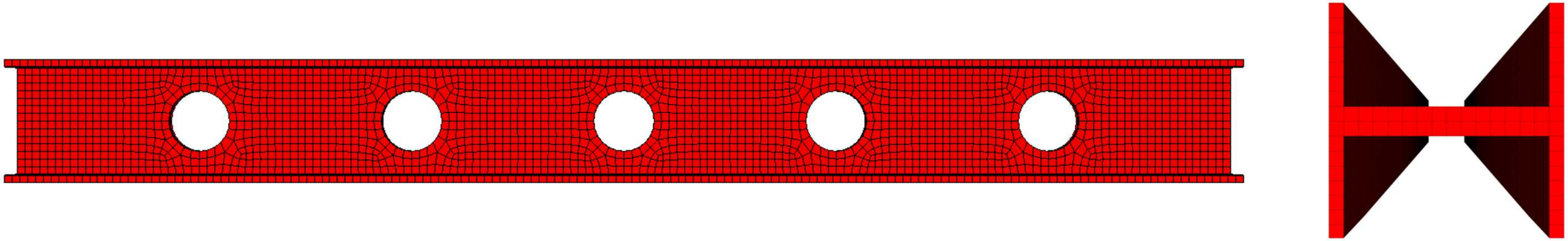
- Mortar or multi-point constraints (MPC)'s

Infinite elements and Perfectly Matched Layers (PML)

Solution procedures:

- Frequency response (frequency-domain)
- Transient (time-domain)
- Eigenvalue (modal) analysis
  - Linear and quadratic (complex modes)

Parallel Scalability of Sierra/SD



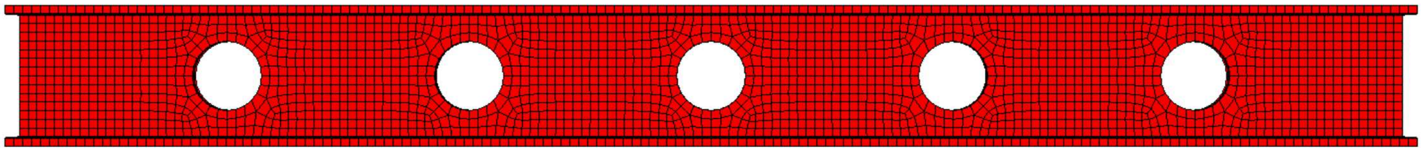
- Goal – Understand current limitations of Sierra/SD on large problems
- All Results are shown with Default Solver Parameters
- 2 Billion DOF limit has since been overcome
- Performed on "**Serrano (84/455)**" and "**Trinity (6/7)**"

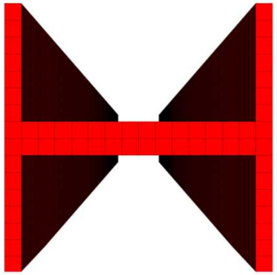
Table 1. Size of Each Finite Element Model

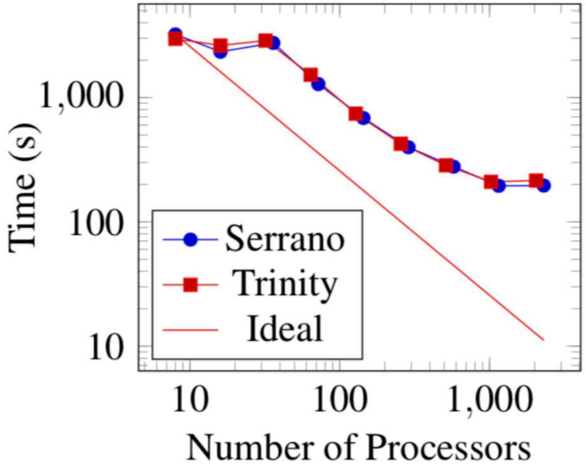
Model	Elements	Nodes	DOFs
Mesh 1	8,980	16,462	49836
Mesh 2	25,734	38,012	114,036
Mesh 3	57,472	76,668	230,004
Mesh 4	118,144	148,460	445,380
Mesh 5	231,690	279,675	839,025
Mesh 6	461,168	537,744	1,613,232
Mesh 7	957,966	1,079,941	3,239,823
Mesh 8	1,941,306	2,136,292	6,408,876
Mesh 9	4,254,244	4,254,244	12,762,732
Mesh 10	7,711,844	8,201,009	24,603,027
Mesh 11	15,240,615	16,012,998	48,038,994
Mesh 12	30,086,430	31,307,640	93,922,920
Mesh 13	61,694,752	63,647,304	190,941,912
Mesh 14	121,924,920	125,009,272	375,027,816
Mesh 15	240,691,440	245,569,752	736,709,256
Mesh 16	493,558,016	501,359,996	1,504,079,988
Mesh 17	975,399,360	987,726,396	2,963,179,188

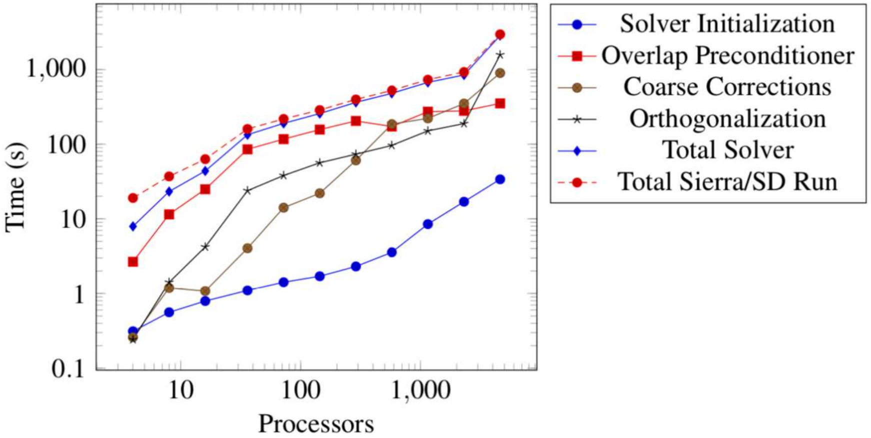
•(Bunting) Strong and Weak scaling of the Sierra/SD Eigenvector Problem to a Billion Degrees of Freedom

Parallel Scalability of Sierra/SD









Strong Scaling (1 Million Nodes)

Weak Scaling (3,500 Nodes / Proc)

•(Bunting) Strong and Weak scaling of the Sierra/SD Eigenvector Problem to a Billion Degrees of Freedom

Sierra/SD on the GPU

- Next Generation of Supercomputers will have (Do Have!) GPUs
- Sierra (2 on Top500.org), LLNL
- Vortex (Sandia Testbed – Sierra Clone)

	Salinas Complete	Solver initialization	Solver solve phase
22 CPU	31:29	16 sec	1830 sec
22 CPU + 2 GPU	12:32	89 sec	621 sec
22 CPU + 4 GPU	9:51	86 sec	463 sec

Partitioned Coupling for Structural Acoustics

Problem:

Can we solve Structural Acoustics with FSI style Partitioned Coupling

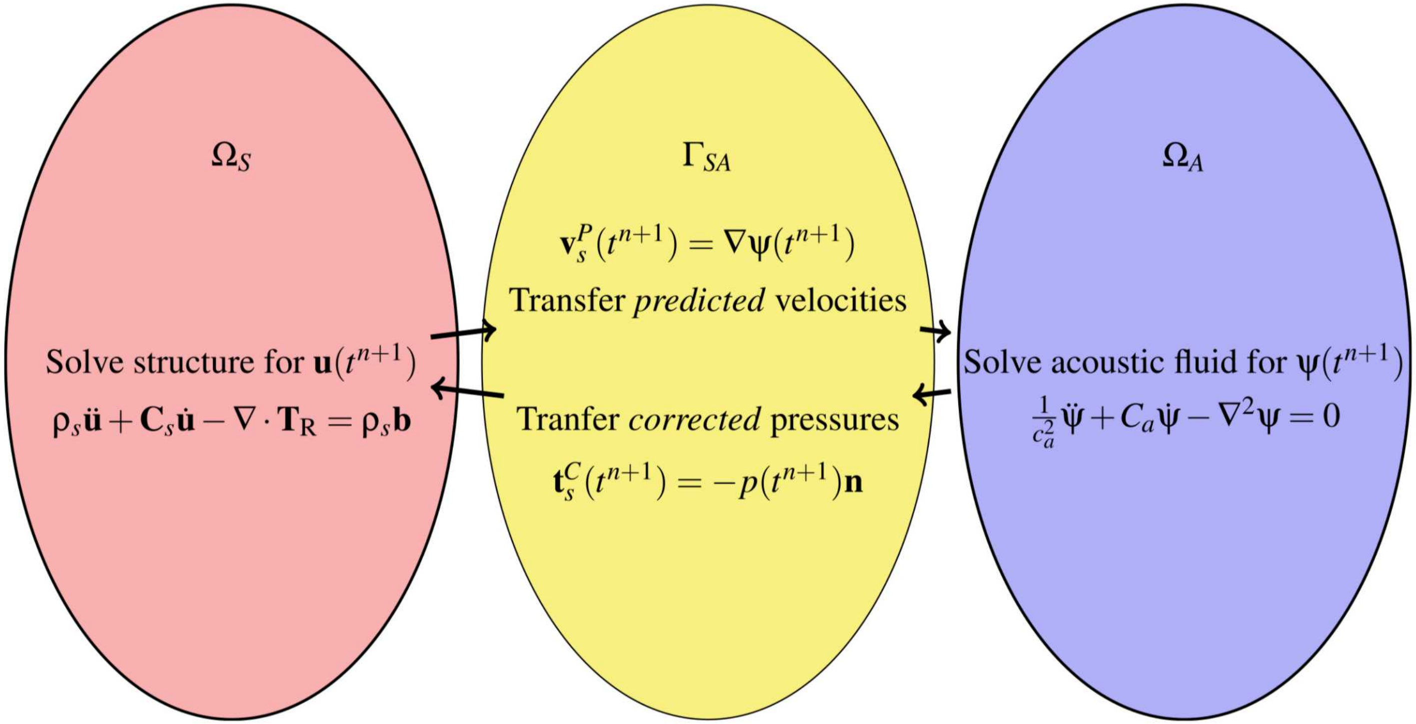
Motivation:

Better matrix conditioning of systems, more accurate solves

Couple large deformation nonlinear code with linear acoustics capability

•(Bunting, Miller) - "Partitioned Coupling for Structural Acoustics" – ASME Journal of Sound & Vibration 2020

Partitioned Coupling for Structural Acoustics

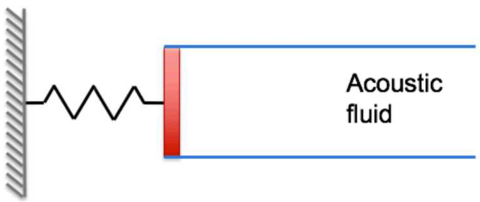


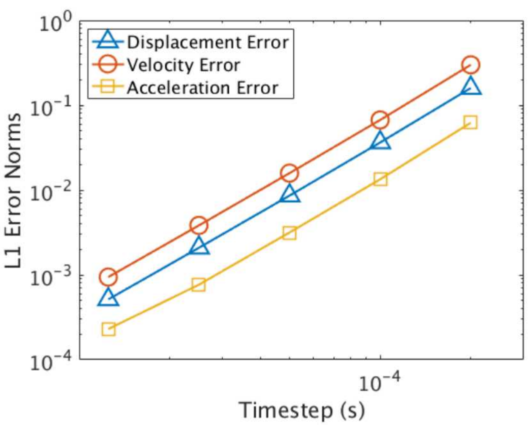
Nonlinear, Large Deformation (Sierra/SM)

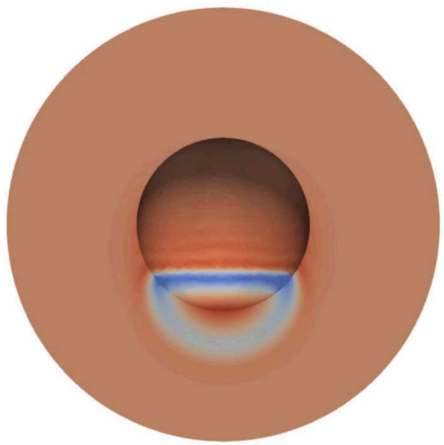
Linear Acoustics (Sierra/SD)

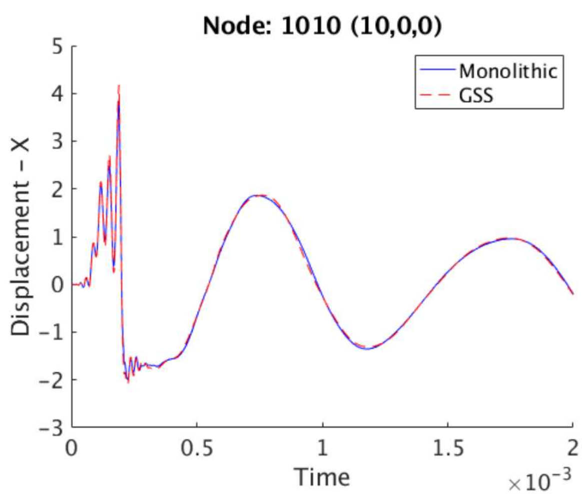
•(Bunting, Miller) - "Partitioned Coupling for Structural Acoustics" – ASME Journal of Sound & Vibration 2020

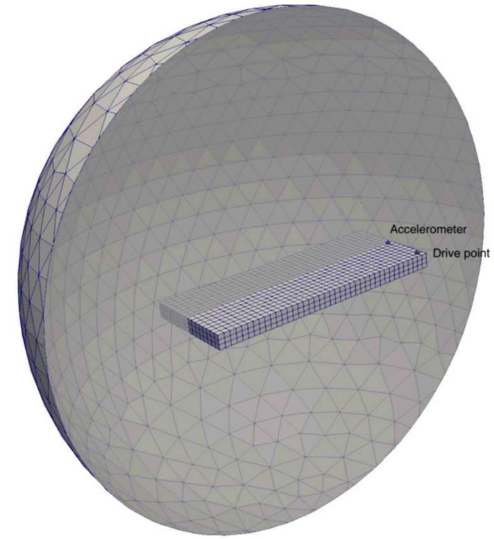
Partitioned Coupling for Structural Acoustics

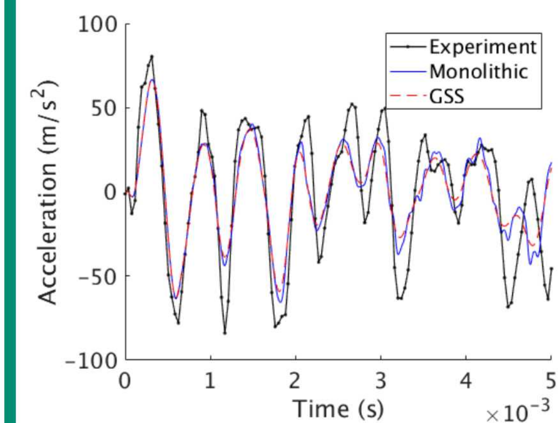












•(Bunting, Miller) - "Partitioned Coupling for Structural Acoustics" – ASME Journal of Sound & Vibration 2020

Infinite Boundaries

Problem:

Can we solve Acoustics Problems in Infinite Domains?

Motivation:

Infinite elements have poor conditioning at large orders and large processor counts

Infinite Boundaries (Absorbing BC, Infinite Elements, PML)

Absorbing BC

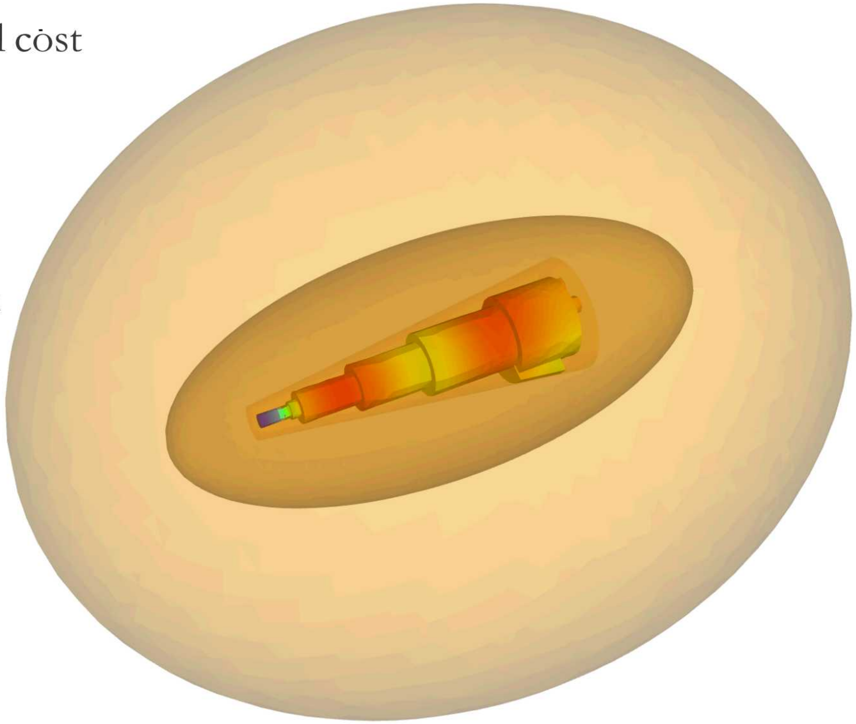
- Simple Implementation, least computational cost

Infinite Elements

- Time Domain, Frequency Domain
- Homogenous Material on External Domain
- Capable of computing far field pressures
- Poor matrix conditioning
- High Computational Cost

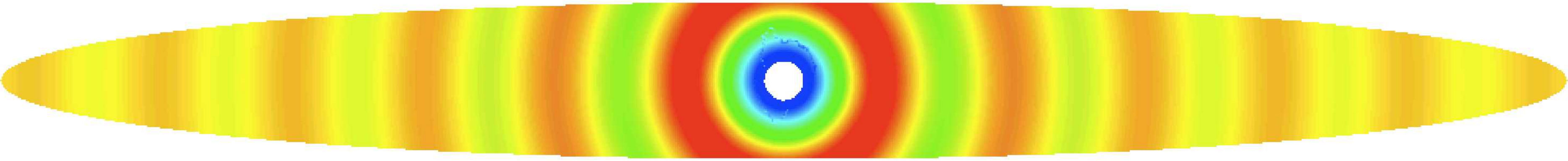
Perfectly Matched Layers

- Implementation restricted to Frequency Domain
- Can absorb evanescent waves



•(Bunting et al) "Parallel Ellipsoidal Perfectly Matched Layers for Acoustic Helmholtz Problems on Exterior Domains" Journal of Theoretical and Computational Acoustics 2018

Results: Infinite Element - PML



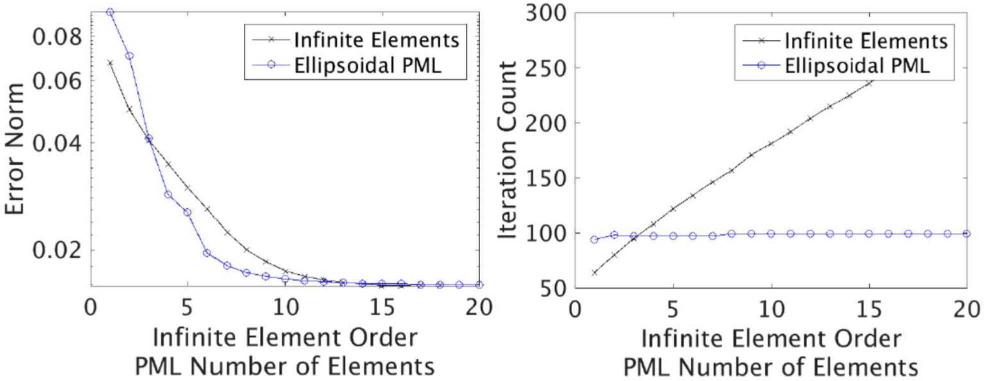
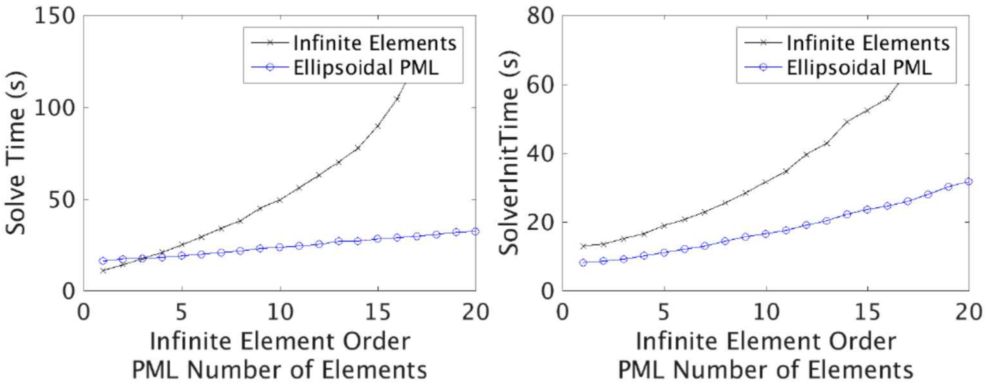


Figure 9: Comparison Between IE and PML (100 Hz)

For a fixed level of accuracy

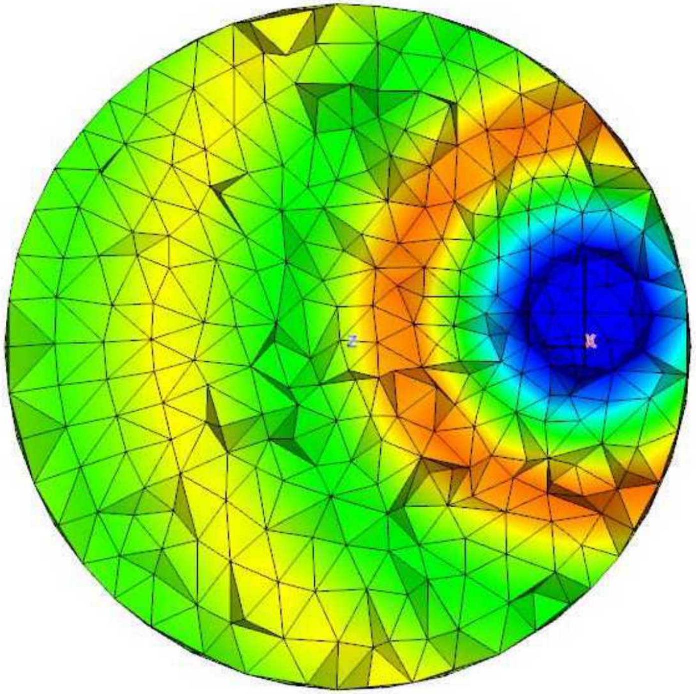
- PML required many less iterations than infinite elements
- PML solution times were much faster
- In frequency domain, PML is clear winner over infinite elements



•(Bunting et al) "Parallel Ellipsoidal Perfectly Matched Layers for Acoustic Helmholtz Problems on Exterior Domains" Journal of Theoretical and Computational Acoustics 2018

Higher Order Elements with Infinite element absorbing boundary

- 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



Handoff from Fluid Codes

Problem:

Can we use acoustics for far field noise

Motivation:

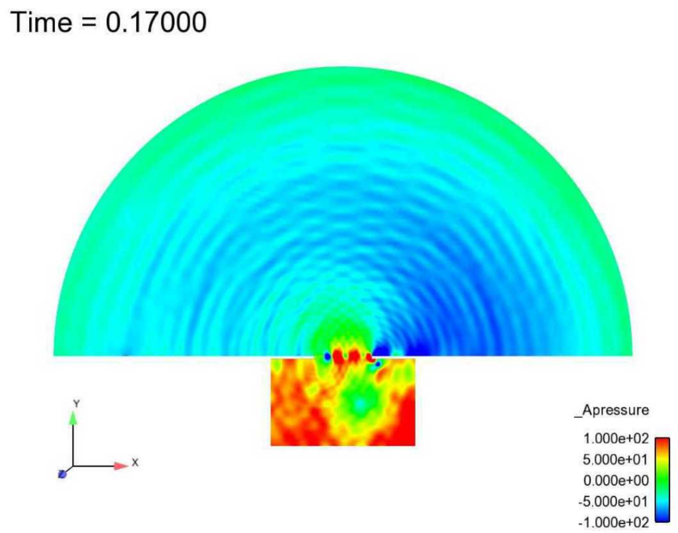
High fidelity fluid codes are expensive over large volumes

Fluid-Structure Interaction with Sierra/TF

Use Sierra/TF (convection) to compute Lighthill tensor as an acoustic noise source
- Expensive, done on small subsection of domain

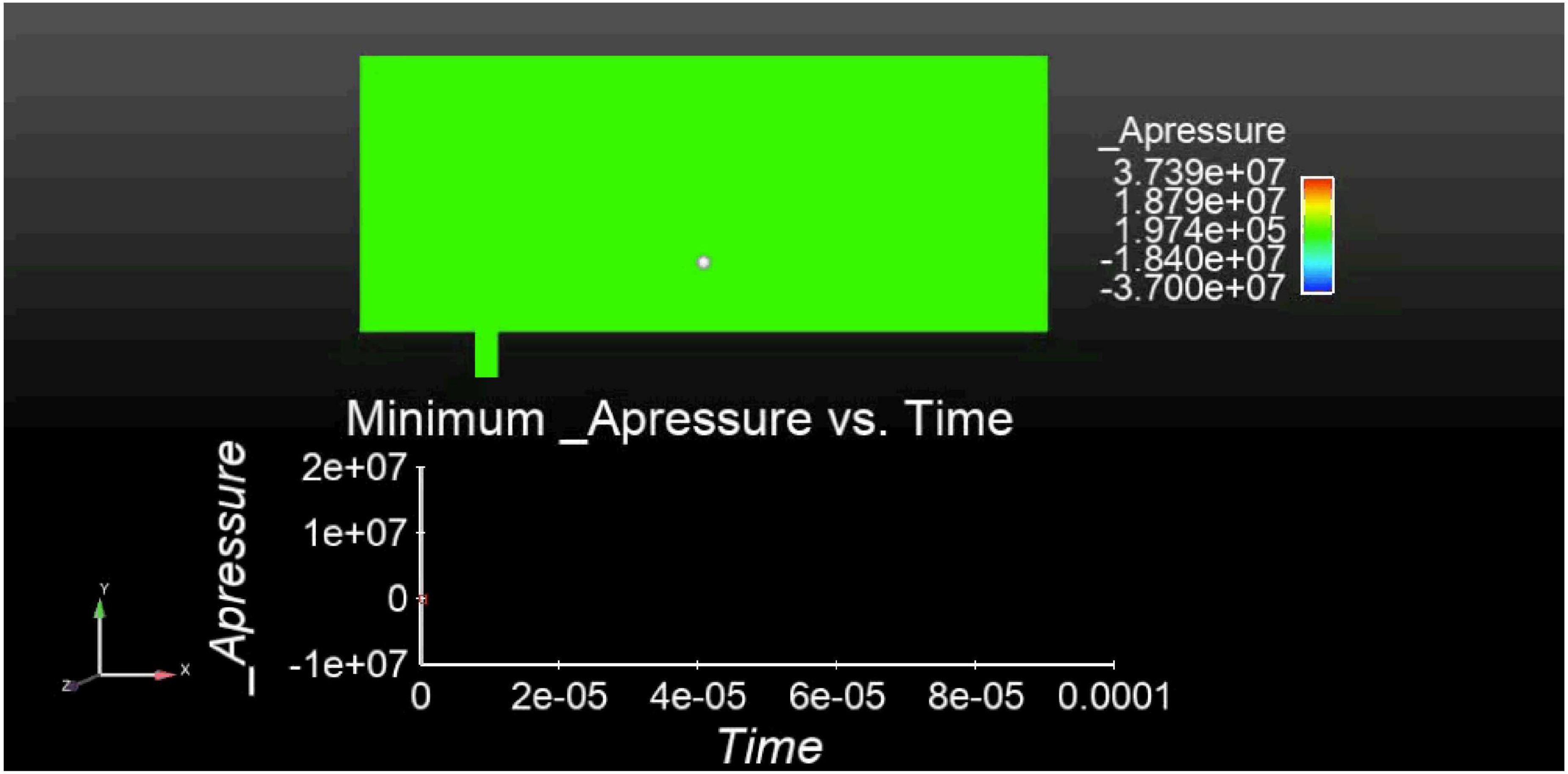
Sierra/TF provides the Lighthill tensors as a nodal variable

Sierra/SD is used for far field acoustic noise modeling

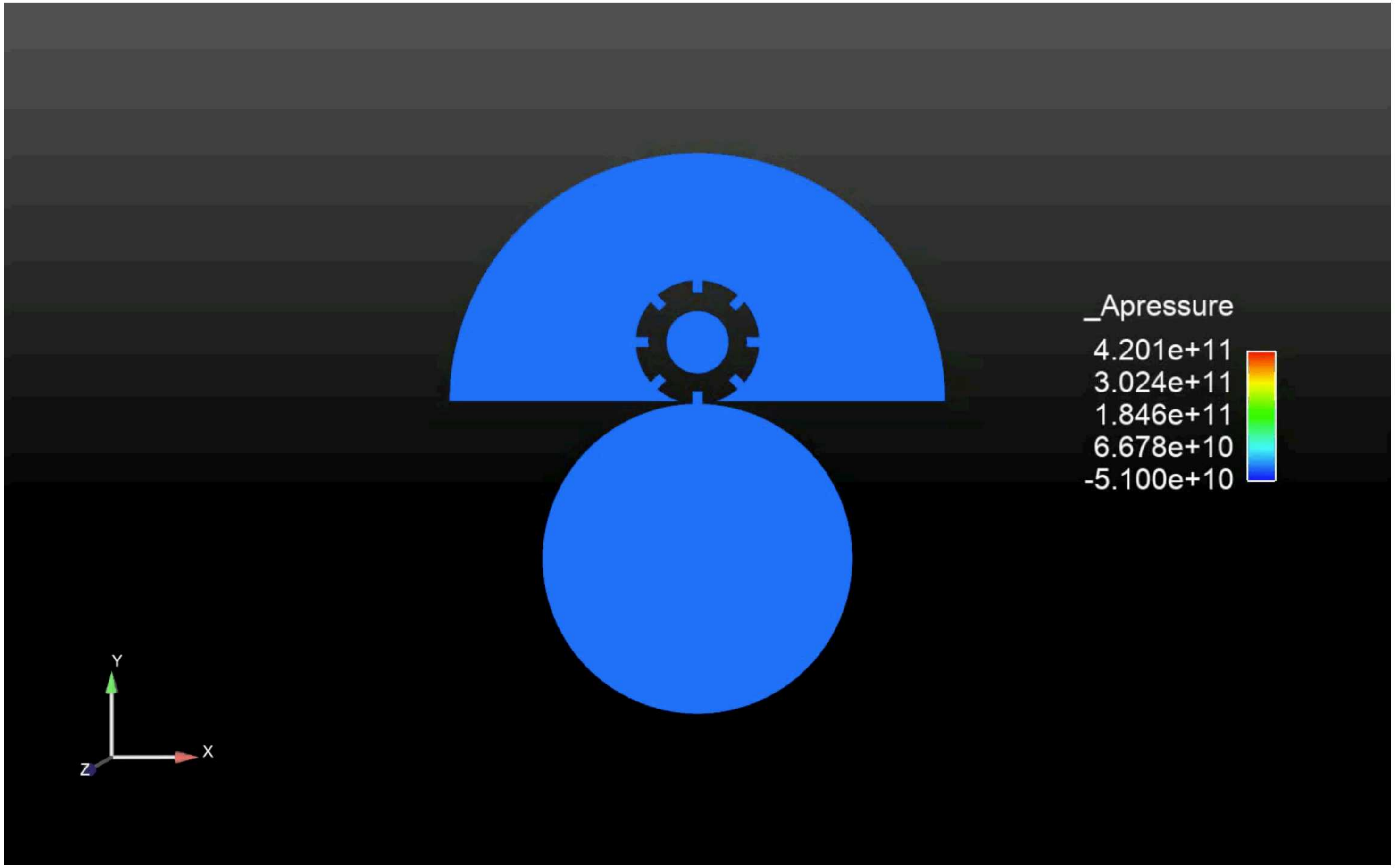


Moving Acoustic Mesh

- Want – Large Scale acoustics of moving pieces
- Time Domain Handoff (one-way coupling) with Sierra/SM
- Generate "Doppler Effect" at a stationary point



Larger Gear Example



Application – Acoustic Source Inversion

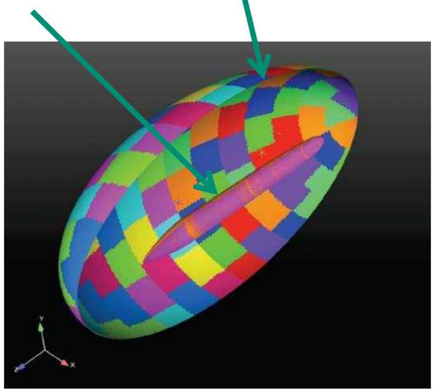
Acoustic source inversion

Goal:

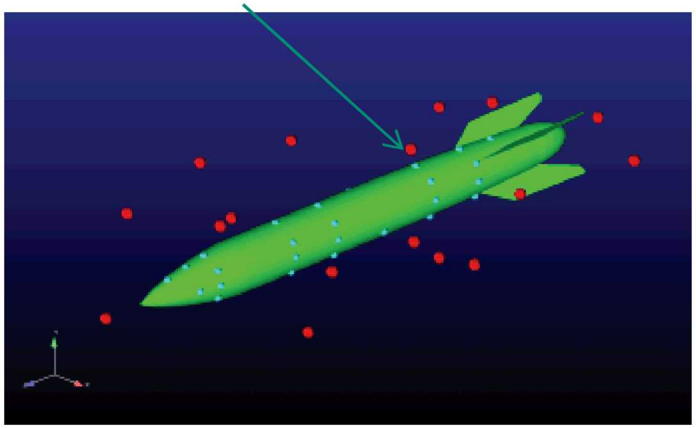
Solve inverse problem to obtain acoustic patch inputs that produce the given microphone measurements. 2 approaches:

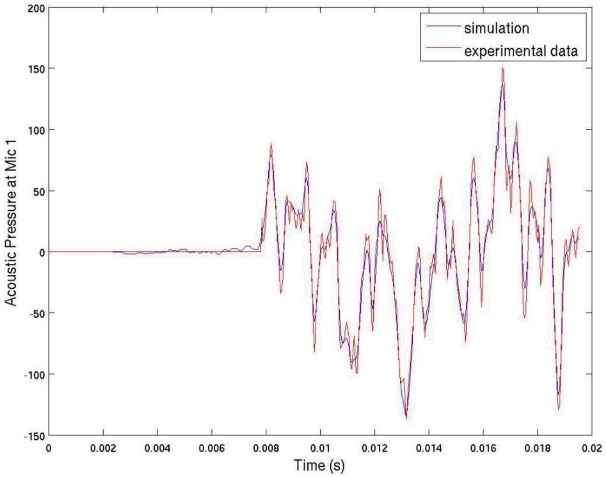
- Frequency domain
-   - broadband frequency sweep
- 2. Time domain
-   - implicit time integration

Surface patches for sources



Microphone locations

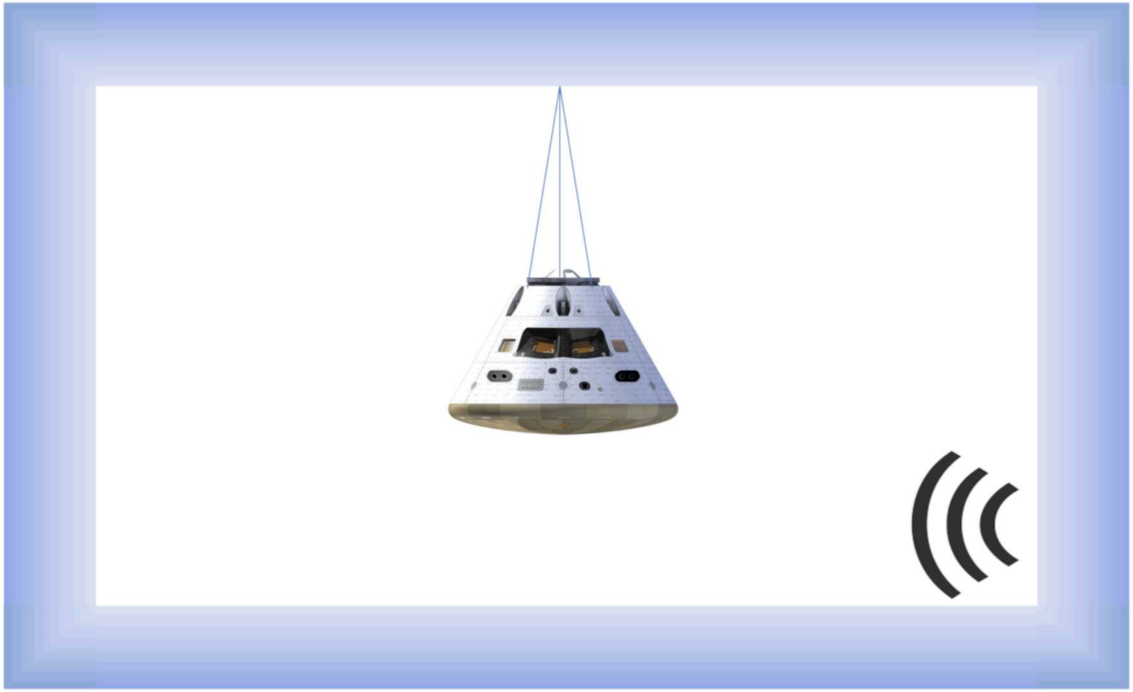




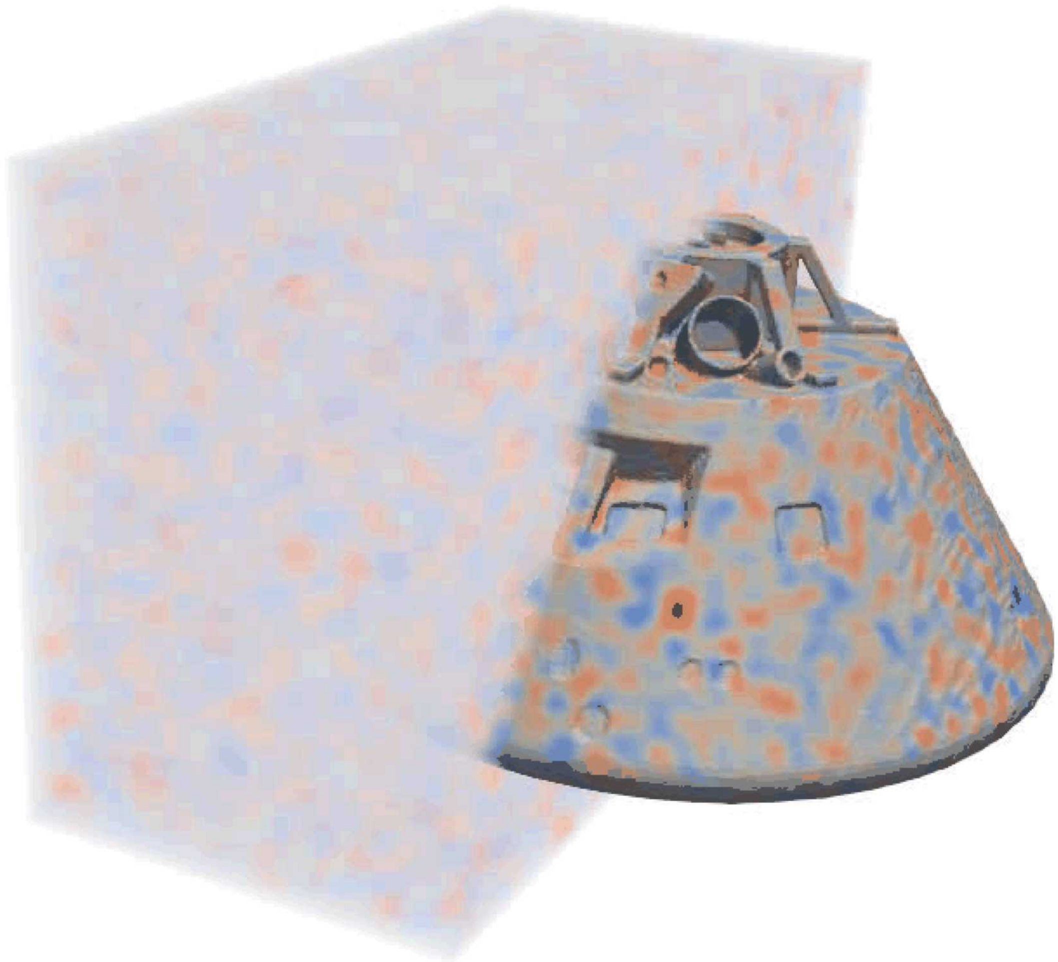
•(Walsh, Aquino, Ross) – Source Identification in Acoustics and Structural Mechanics using Sierra/SD

Application - Orion Capsule in Reverb Chamber

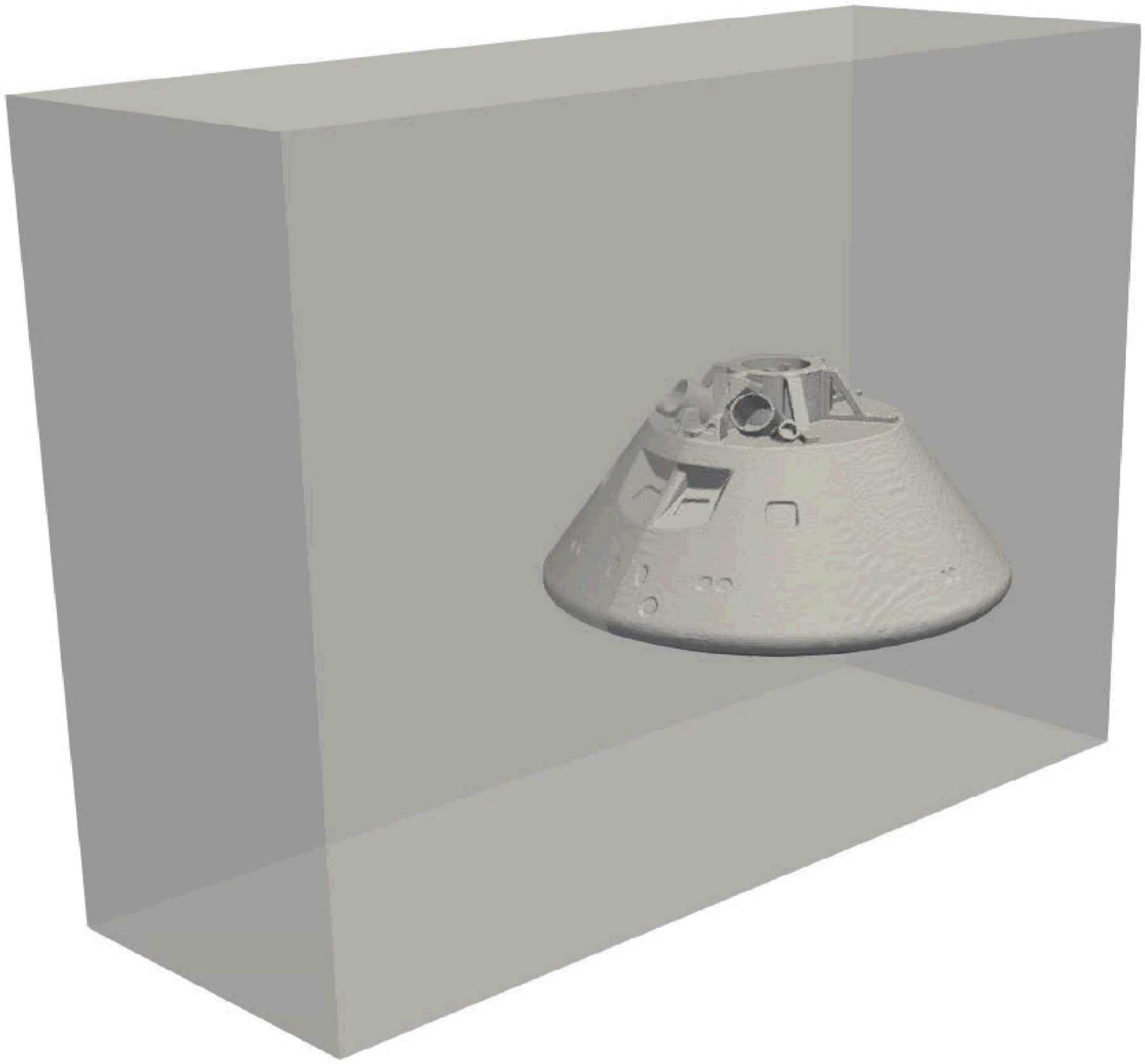
- Publicly available model from NASA (not Sandia application)
- Vibroacoustic Test Facility (VATF)
  - Rectangular Box - 6.58m by 7.50m by 9.17m
- Simulation
  - 140 dB Acoustic excitation provided by loudspeaker in bottom corner of room
  - 2.5 Million Hex20 Elements, 10 Million Dofs
  - 1000 Time Steps, 2 Hours Simulation Time (256 Cores)



Orion Capsule – Diffuse Field



Orion Capsule - Video



Conclusions

Production Finite Element Analysis code used to solve real world problems

Massively parallel finite element structural acoustics capability Sierra/SD has been developed for large-scale analysis

Applicable to large-scale models with many degrees of freedom.

Continuously adding additional capability for specific problems and uses cases

Capability has been applied to a variety of problems inside and outside of Sandia

Acknowledgements

This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

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