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Finite Element Analysis of Seismic/Acoustic Interactions with Salinas

Timothy Walsh[1], Jerry Rouse[2], Garth Reese[1]
[1]Computational Solid Mechanics and Structural Dynamics
[2]Structural Dynamics Engineering

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Salinas – An Overview

- Massively parallel structural dynamics finite element code
- Linear and nonlinear acoustic analysis
- Eigenanalysis, transient and frequency response
- Designed for complex, 3D structures with millions of degrees of freedom
- Coupled to nonlinear codes such as Adagio/Presto

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Salinas Solution Methods

- Eigen
- Complex Eigen
- linear and nonlinear transient dynamics
- linear and nonlinear statics
- direct frequency response
- Random vibration analysis
- modal based solutions for transient dynamics, SRS, frequency response.
- coupled nonlinear-linear analysis (with Adagio/Presto)

Element Library

- Solid Elements
  - Hex8, Hex20, Tet4, Tet10, Wedge6, Wedge15
  - Hex8 variations
- Shell Elements
  - Tria3, Quad4, (Tria6, Quad8 – not really quadratic)
- Bar/Beam Elements
  - Beam2, Truss, Spring, Dashpot
- Point Elements
  - conmass
- Specialty Elements
  - Iwan, Hys, Shys, Joint2G, Gap

Salinas Acoustic Capabilities

- Massively parallel finite elements
- Hex, wedge, tet acoustic elements
- Acoustic coupling with both 3D and shell (2D) structural elements
- Linear and nonlinear acoustics
- Allows for mismatched acoustic/solid meshes
- Solvers: FETI-DP, CLIP/CLOP, and FETI-H (for Helmholtz)
- Solution procedures:
  - Frequency response (frequency-domain)
  - Transient (time-domain)
  - Eigenvalue (modal) analysis

Structural Acoustic Equations of Motion

- **Time domain formulation**

$$\begin{bmatrix} M_s & 0 \\ 0 & -M_a \end{bmatrix} \begin{bmatrix} \ddot{\Delta u} \\ \ddot{\Delta \phi} \end{bmatrix} + \begin{bmatrix} C_s & L^T \\ L & -C_a \end{bmatrix} \begin{bmatrix} \dot{\Delta u} \\ \dot{\Delta \phi} \end{bmatrix} + \begin{bmatrix} K_s & 0 \\ 0 & -K_a \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta \phi \end{bmatrix} = \begin{bmatrix} \mathrm{Re}\, s_s \\ \mathrm{Re}\, s_a \end{bmatrix}$$

- **Eigenanalysis formulation**

$$\lambda^2 \begin{bmatrix} M_s & 0 \\ 0 & -M_a \end{bmatrix} \begin{bmatrix} u \\ \phi \end{bmatrix} + \lambda \begin{bmatrix} C_s & L^T \\ L & -C_a \end{bmatrix} \begin{bmatrix} u \\ \dot{\phi} \end{bmatrix} + \begin{bmatrix} K_s & 0 \\ 0 & -K_a \end{bmatrix} \begin{bmatrix} u \\ \phi \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

- **Frequency-domain formulation**

$$-\omega^2 \begin{bmatrix} M_s & 0 \\ 0 & -M_a \end{bmatrix} \begin{bmatrix} u \\ \phi \end{bmatrix} + i\omega \begin{bmatrix} C_s & L^T \\ L & -C_a \end{bmatrix} \begin{bmatrix} u \\ \phi \end{bmatrix} + \begin{bmatrix} K_s & 0 \\ 0 & -K_a \end{bmatrix} \begin{bmatrix} u \\ \phi \end{bmatrix} = \begin{bmatrix} f_s \\ f_a \end{bmatrix}$$

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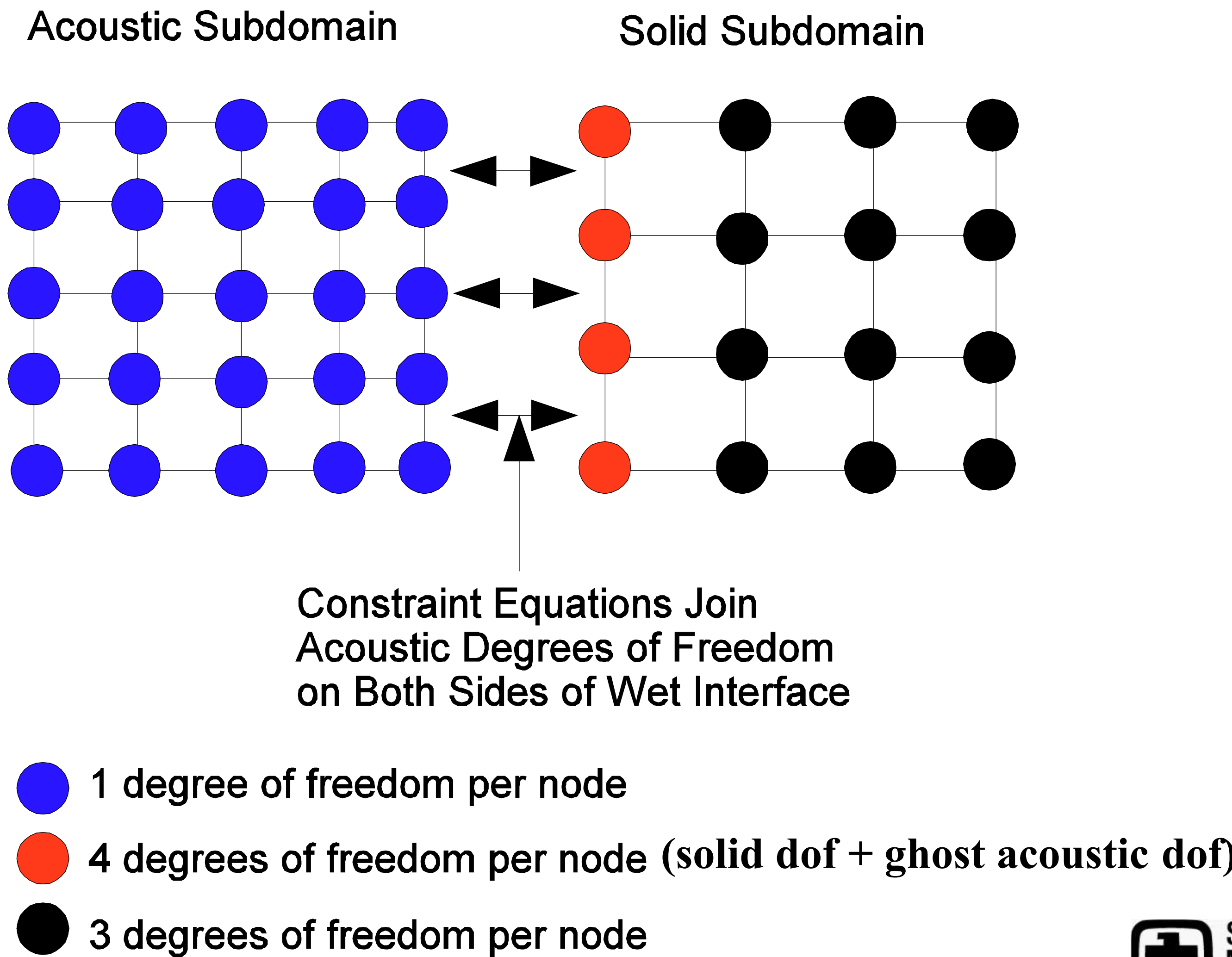
Mismatched Acoustic/Solid Meshes

Our approach:

- Add “ghost” acoustic degrees of freedom to solid nodes on wet interface
- Use conforming coupling operators to couple solid nodes on wet interface to appended acoustic dof
- Couple acoustic dof on both sides of wet interface with constraint equations
    - For conforming meshes, this method reduces to a conforming structural acoustics
    - Same constraint equations for acoustic-acoustic coupling and structural-acoustic coupling

Mismatched Acoustic/Solid Meshes



Why Nonlinear Acoustics?

Linear acoustics is inadequate for many applications

- Resonating cavities
- Large-amplitude sources
- Far-field of explosions

Assumptions of Linear Acoustic Theory

- Small amplitude waves
- Linear Constitutive Fluid
- No fluid convection

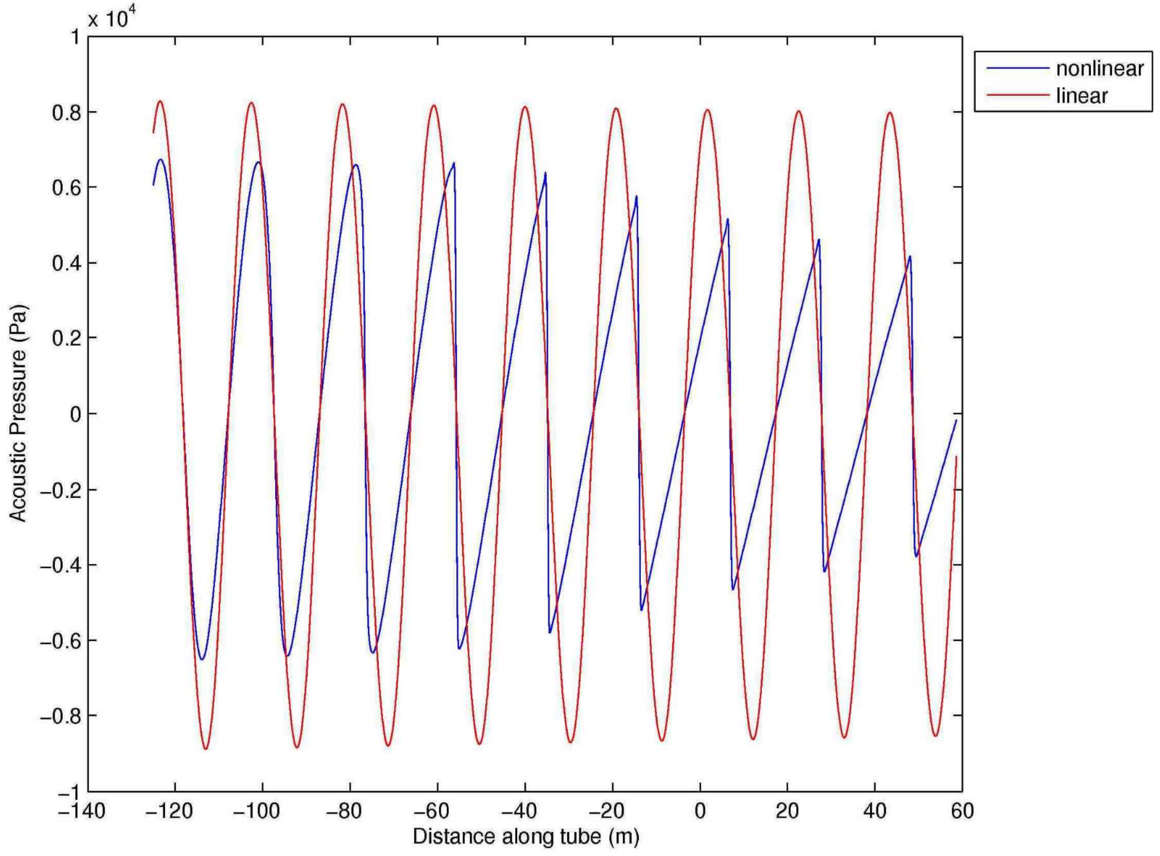
→

Consequences

- Resonance leads to infinite amplitude waves
- "Sine wave remains a sine wave"
- No wave distortion
- Wavespeed independent of stress state in fluid

A Comparison of Linear and Nonlinear Acoustic Results

Shock-tube simulation



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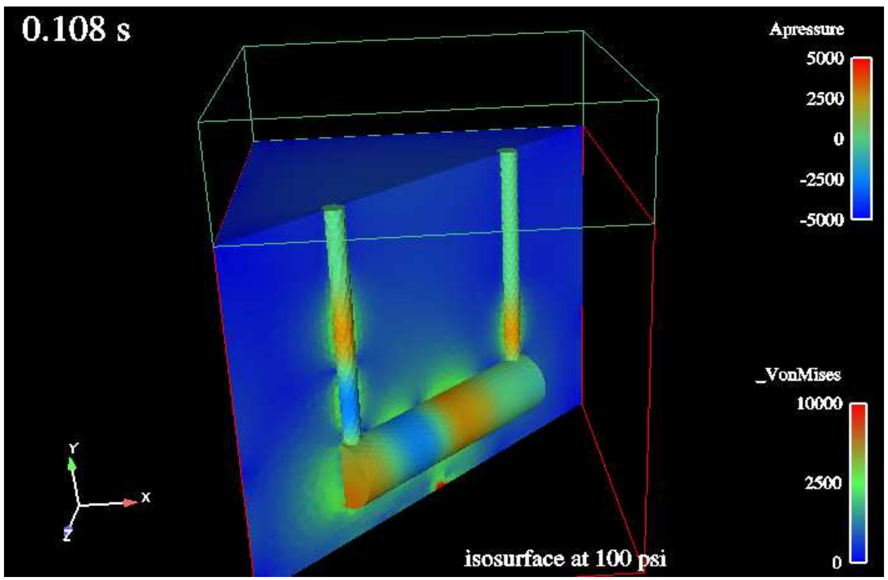
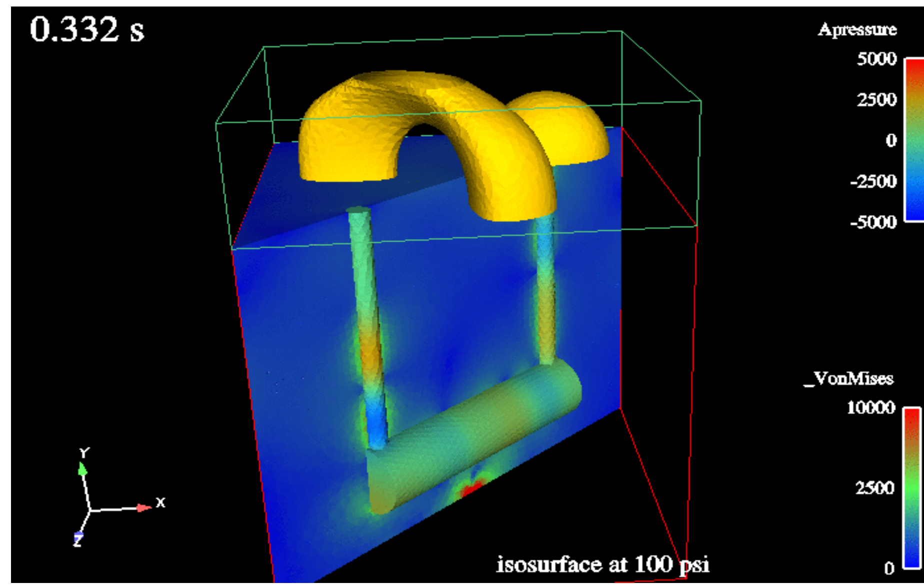
Example Simulations

- Radiation from an acoustic source in a complex tunnel
- Acoustic modal analysis of complex tunnel networks

Surveillance of Deeply Buried Tunnel

Goal: Model acoustic and seismic radiation from deeply buried structures with air portals, for intelligence-gathering purposes.





Time histories of acoustic pressure and structural Von Mises stresses in coupled air tunnel/seismic half-space

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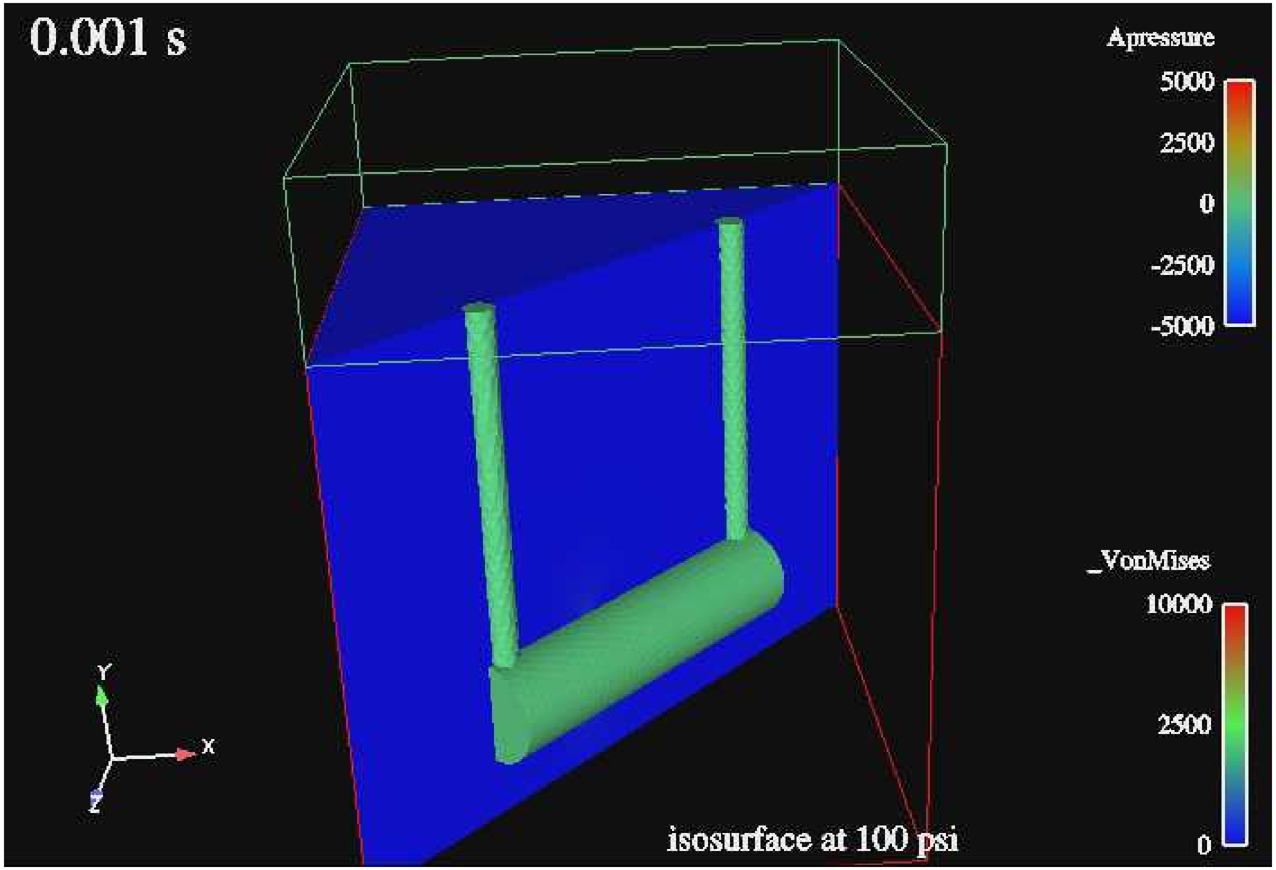

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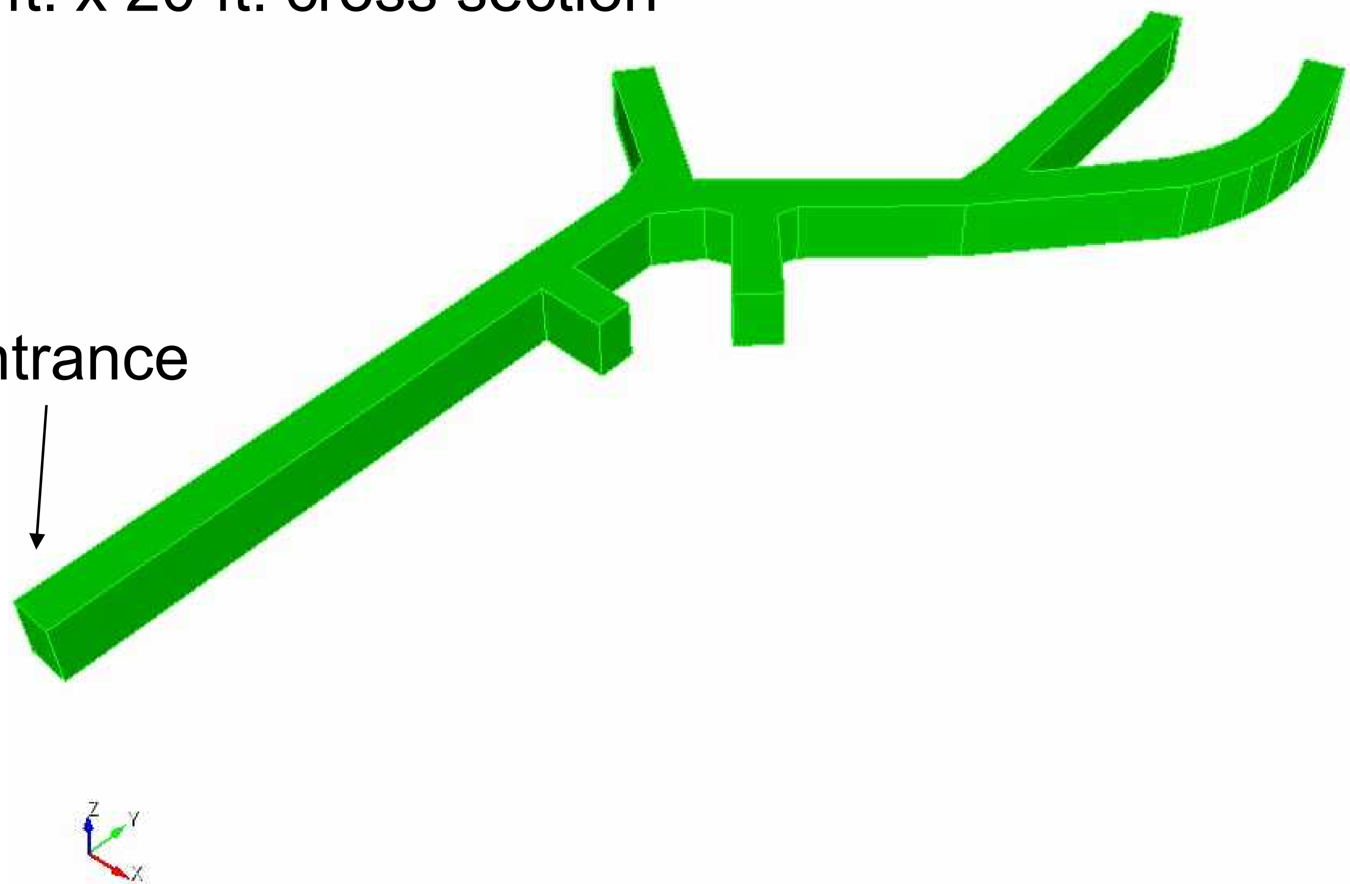
Complex Tunnel Geometry

~ 415 ft. long

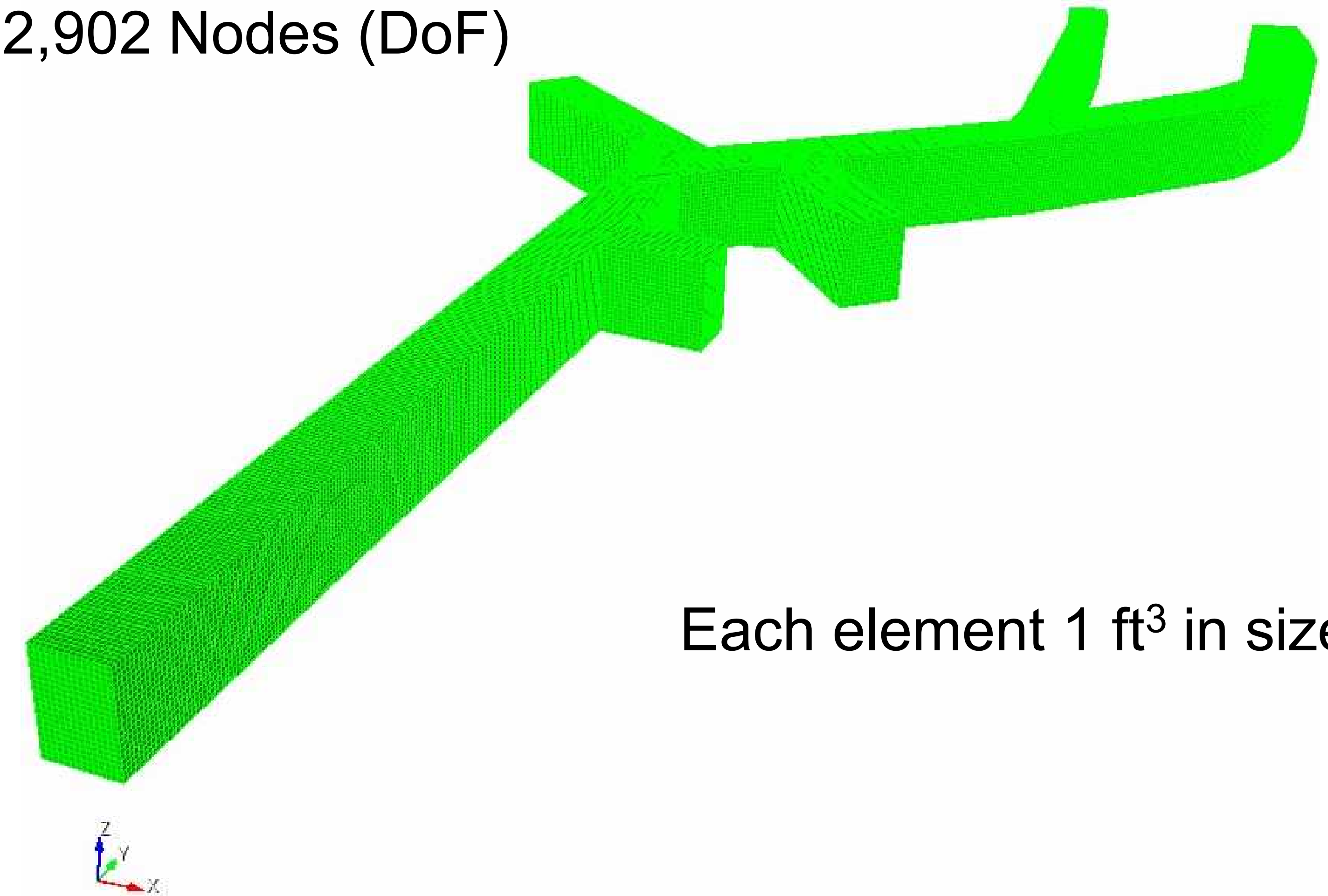
14 ft. x 20 ft. cross section

Entrance



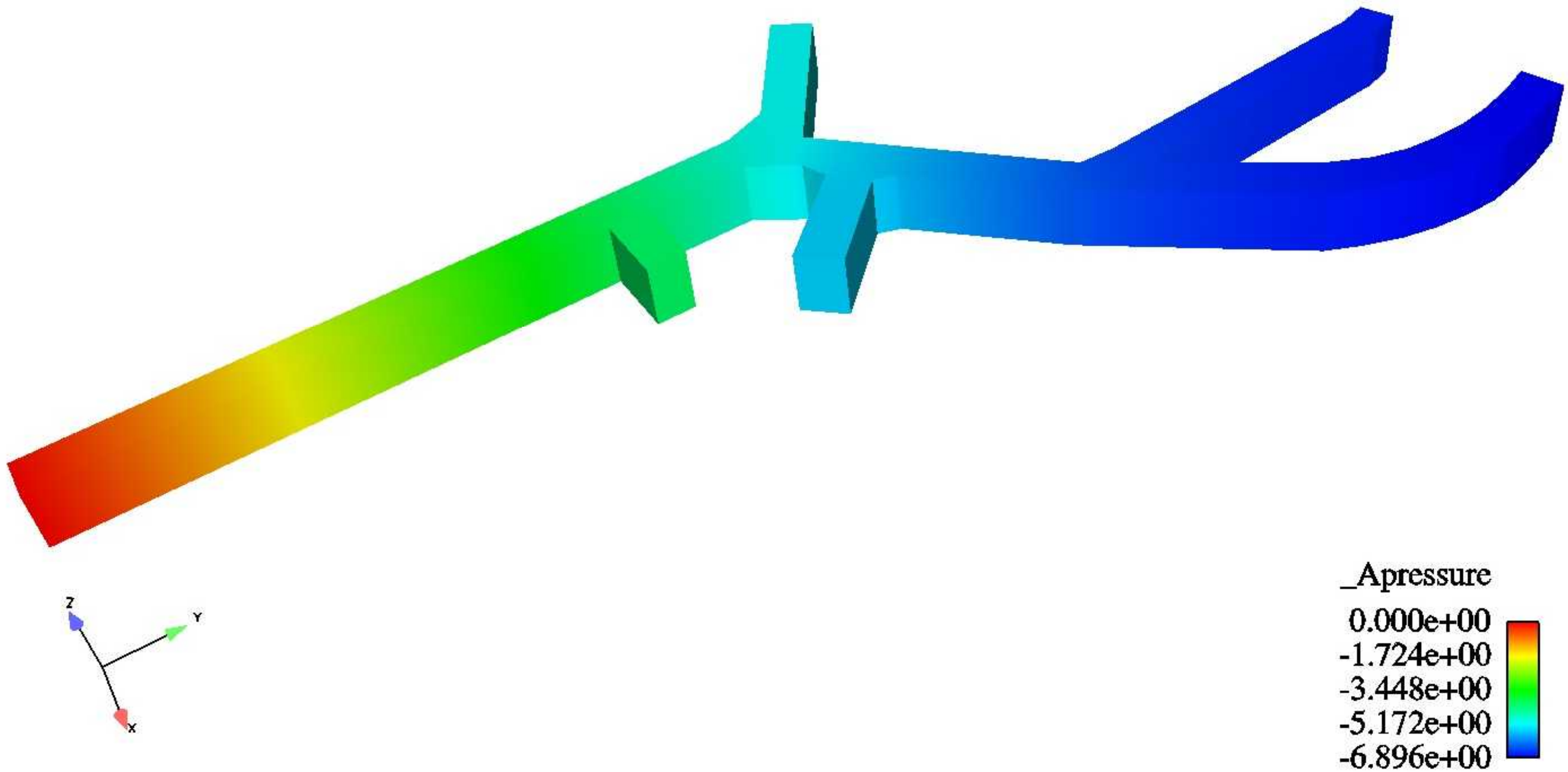
179,360 Elements

202,902 Nodes (DoF)



Each element 1 ft^3 in size

Freq. = 0.4999 Hz.



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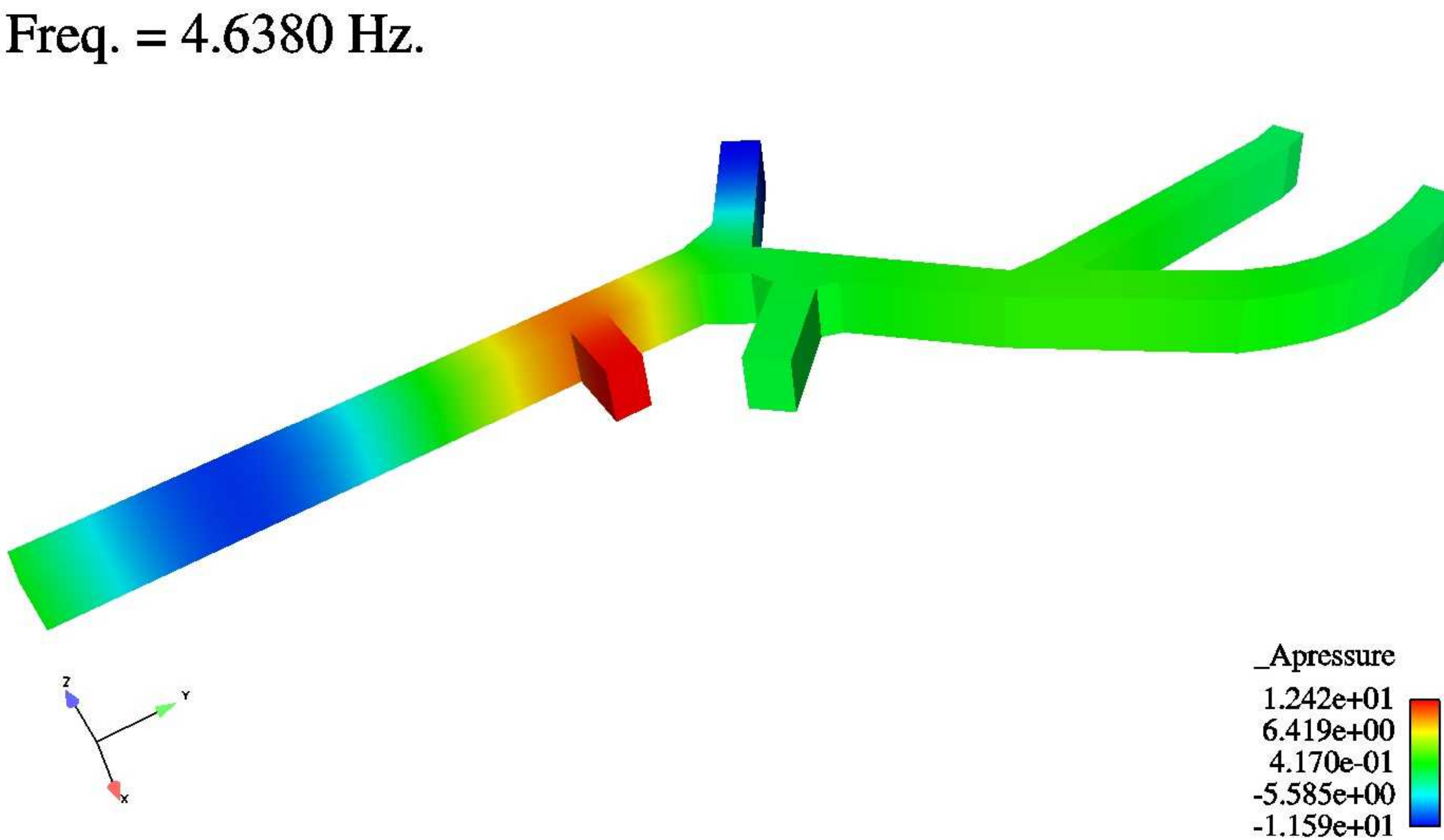
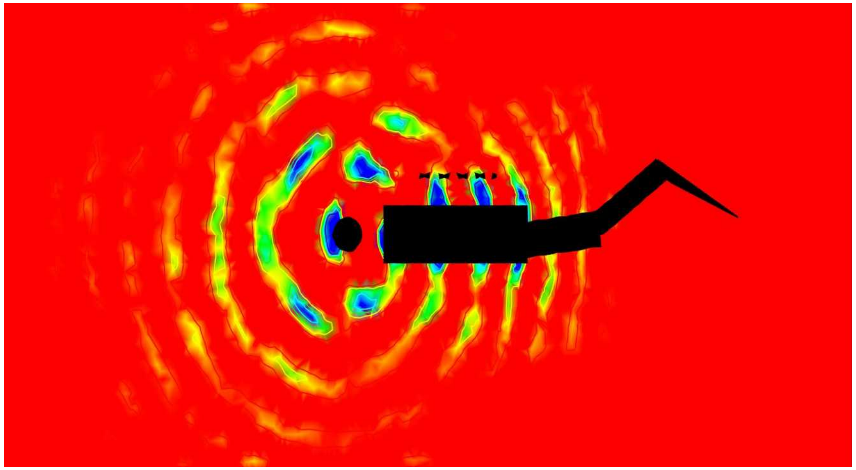
Acoustic Mode Shapes

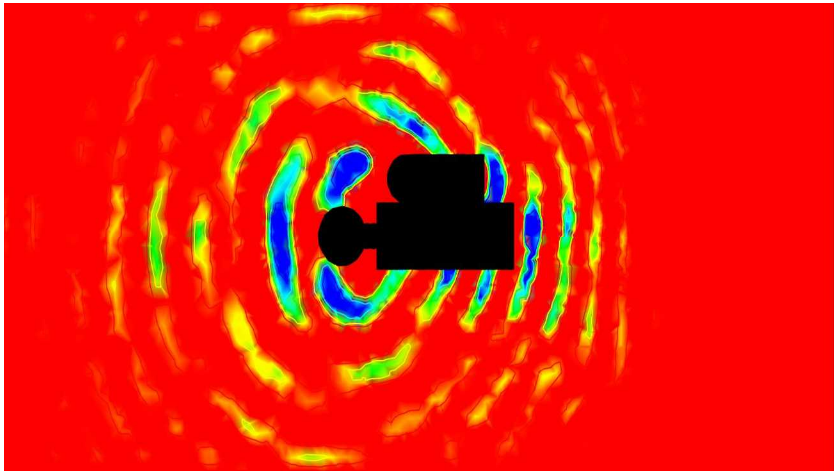


Backscatter from Diver in Shallow Water

Goal: Model the backscatter from divers, mines, and other intruders in shallow coastal waters, for the purpose of designing detection equipment for protecting US coasts.



Acoustic backscatter from diver body



Acoustic backscatter from torso

Conclusions

- Massively parallel capability designed for large-scale, complex acoustic and structural acoustic analysis
- Wide range of analysis procedures: transient (time-domain), eigenanalysis, and frequency domain
- Applied to wide range of applications