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Expansion of Coupled Structural-Acoustic Systems

PRESENTED BY

Ryan Schultz & Dagny Beale

IMAC XXXVIII, Feb. 10-13

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Outline

- Motivation
- Expansion Theory
- Coupled Expansion of a Modal Response
- Coupled Expansion of a Transient Response
- Conclusions

Motivation

[1]

[2]

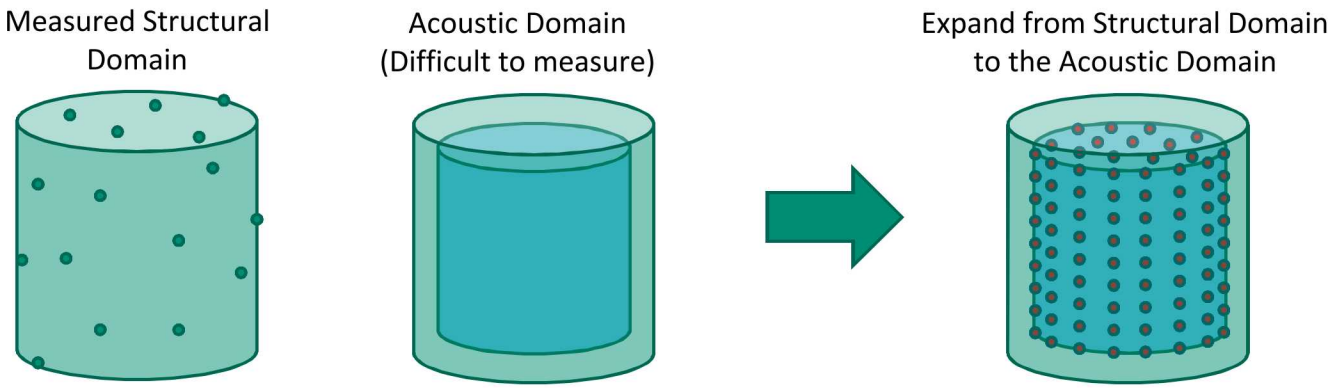
[3]

- Many structures of interest contain acoustic cavities, which are not easily measured
- Most expansion methods have only been applied to structural domains
  - Next talk: Schultz, "*Expansion Methods Applied to Internal Acoustic Problems*"

[1] https://www.energy.gov/eere/wind/how-do-wind-turbines-work, Dennis Schroeder NREL
[2] https://www.consumerreports.org/cars-cars-with-fastest-acceleration-in-consumer-reports-tests/
[3] https://www.nasa.gov/directorates/heo/scan/services/missions/other/AtlasV.html

Motivation

- Want to use data measured in one domain to expand to a different domain of interest
  - Rocket fairing
    - Can measure the fairing, very difficult to measure the internal acoustics
    - Eventually want to expand fairing measurements to the acoustic domain



- First: show that expansion across multiple domains is possible

Expansion Theory – Traditional SEREP

SEREP ⇒ System Equivalent Reduction Expansion Process[4]

Transformation Matrix

a-set
(test points)

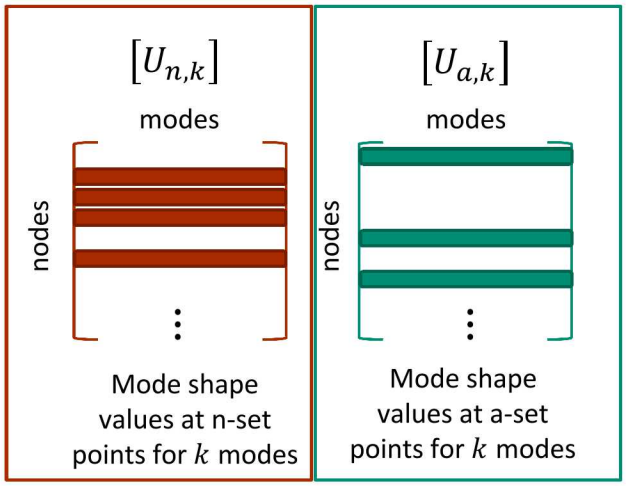
n-set
(expansion points)

$$[T_{n,a}] = [U_{n,k}][U_{a,k}]^{+}$$

Inverse

$$\{x_a(t)\}$$
$$\{E_a\}$$

$$\{x_n(t)\}$$
$$\{E_n\}$$



Modal Expansion

$$[T_{n,a}]\{E_a\} = \{E_n\}$$

Transient Expansion

$$[T_{n,a}]\{x_a(t)\} = \{x_n(t)\}$$

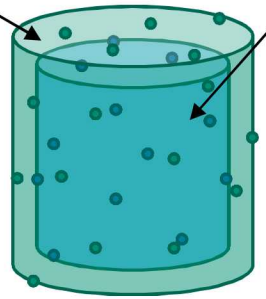
[4] J. O'Callahan, P. Avitabile and R. Riemer, "System Equivalent Reduciton Expansion Process (SEREP)," in Proceedings of IMAC VII, the 7th International Modal Analysis Conference, Las Vegas, NV, 1989.

Expansion Theory – Multi-Domain SEREP

Transformation Matrix

$$T_{n,a}$$

*



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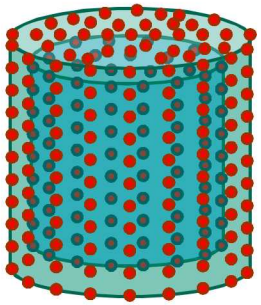
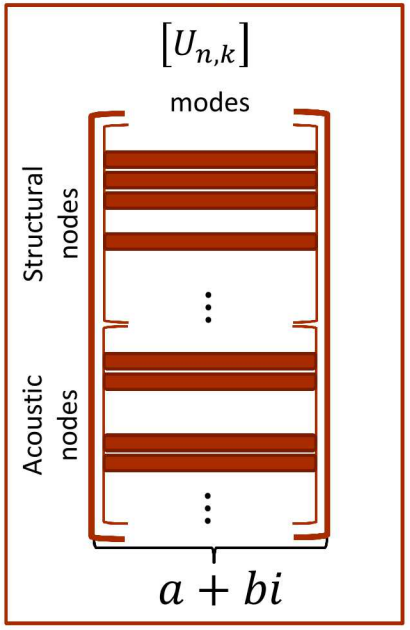


$$[T_{n,a}] = \begin{bmatrix} U_{n,struc} \\ U_{n,fluid} \end{bmatrix} \begin{bmatrix} U_{a,struc} \\ U_{a,fluid} \end{bmatrix}^{+}$$

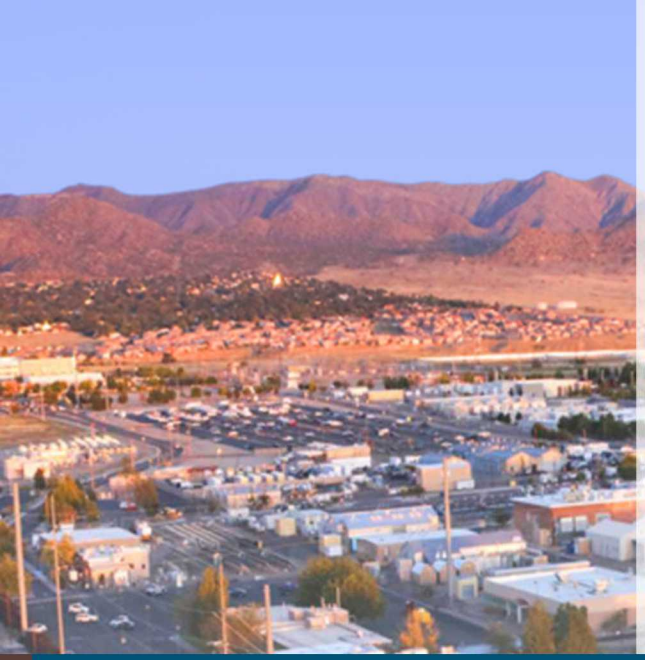
$$\begin{Bmatrix} E_{a,struc} \\ E_{a,fluid} \end{Bmatrix} \qquad \begin{Bmatrix} E_{n,struc} \\ E_{n,fluid} \end{Bmatrix}$$



U_{struc} contains **acceleration or displacement in X,Y, and Z** information

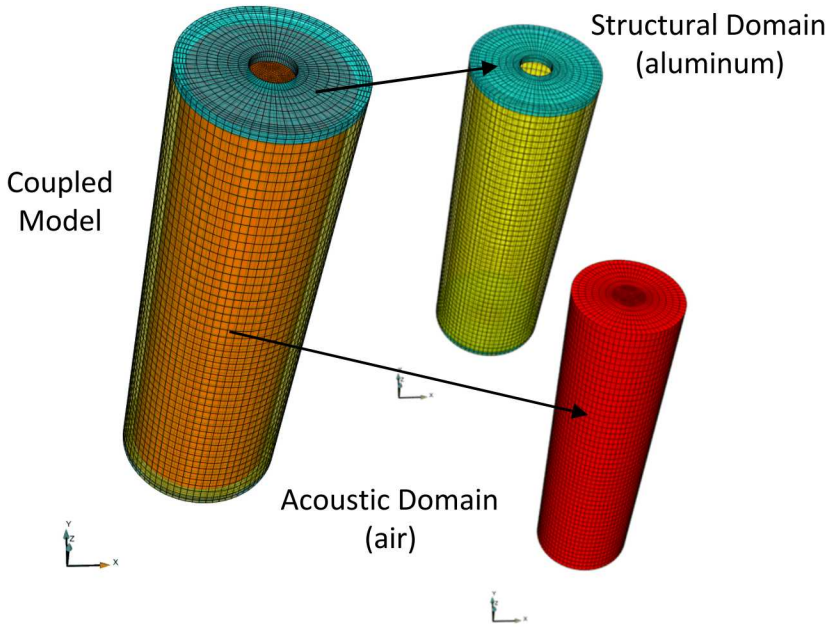
U_{fluid} contains **pressure** information

Structural and acoustic domains tied through the damping matrix

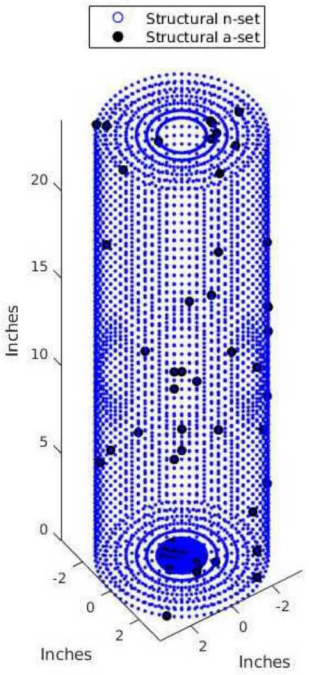


Coupled Expansion of Modal Responses

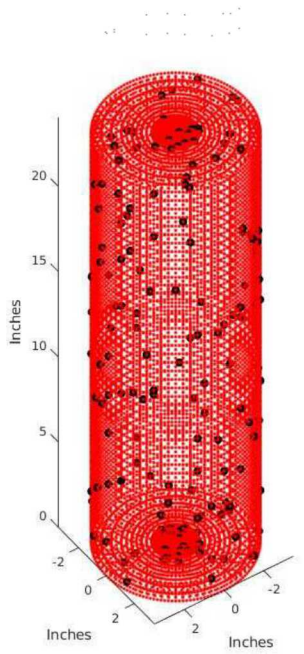
Coupled Structure



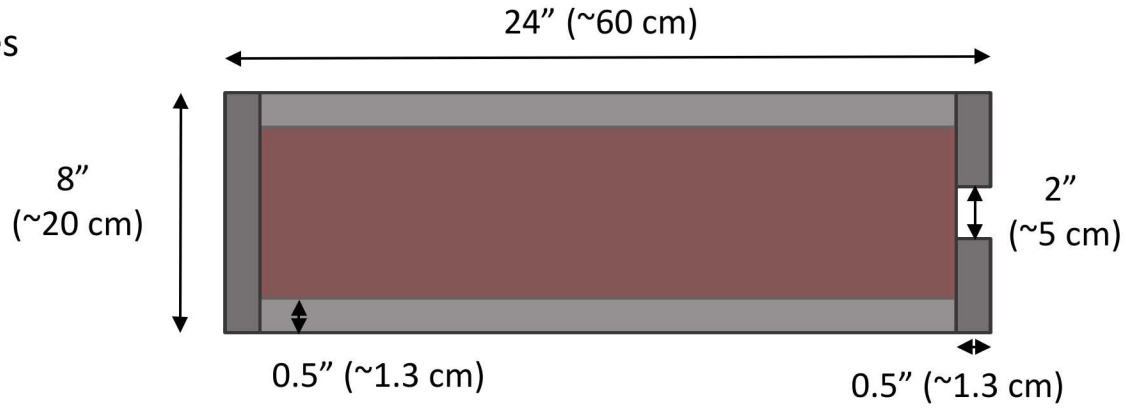
Structural Domain a-set
(50 Points)



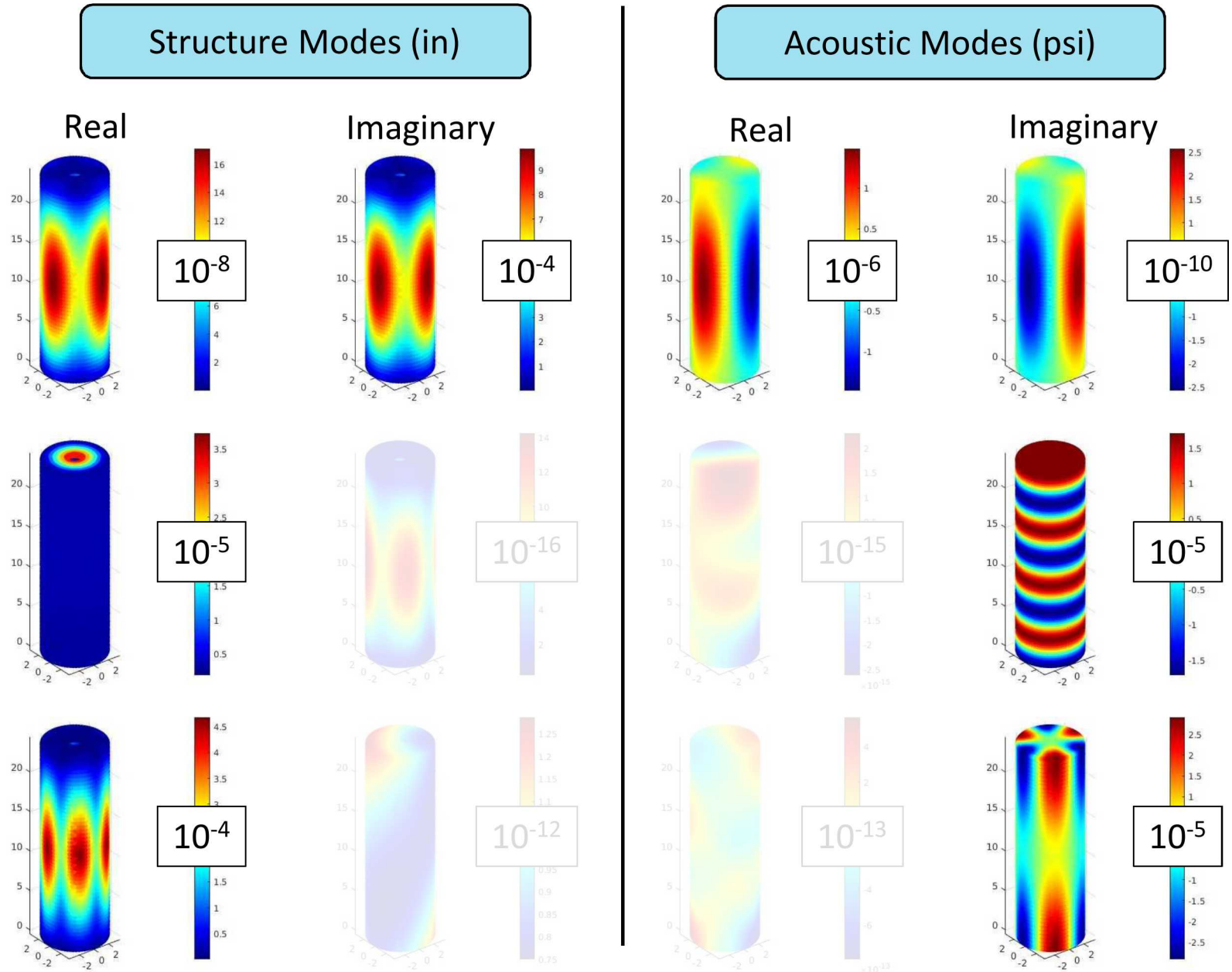
Acoustic Domain a-set
(160 Points)



- Designed to have acoustic modes that couple with structural modes
- Solved for 120 complex-valued modes



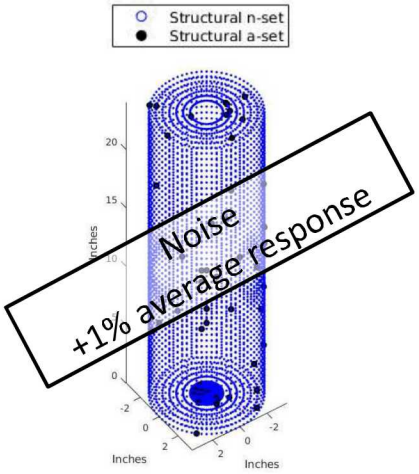
Coupled Modal Response



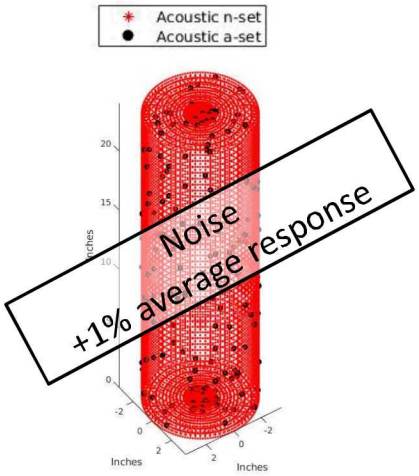
Coupled Modal Expansion – Mode 12

$$\begin{Bmatrix} E_{a,struc} + noise \\ E_{a,fluid} + noise \end{Bmatrix} [T_{n,a}] = \begin{Bmatrix} E_{n,struc} \\ E_{n,fluid} \end{Bmatrix}$$

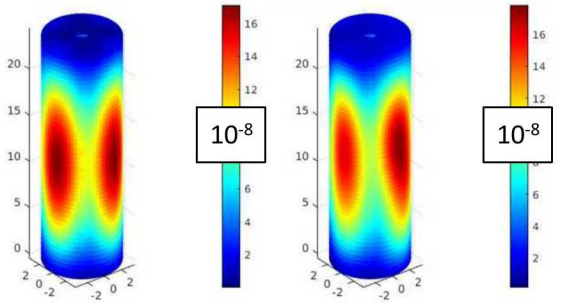
Structural Domain
Subset: 50 points



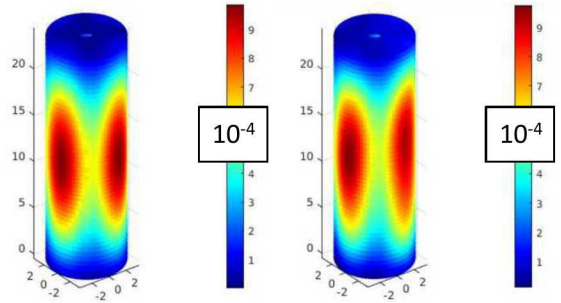
Acoustic Domain
Subset: 160 points



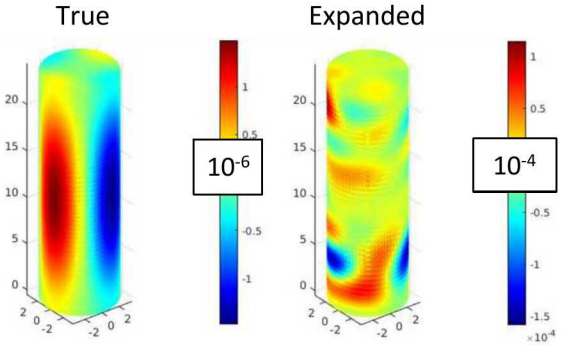
Real Structure Mode (in)



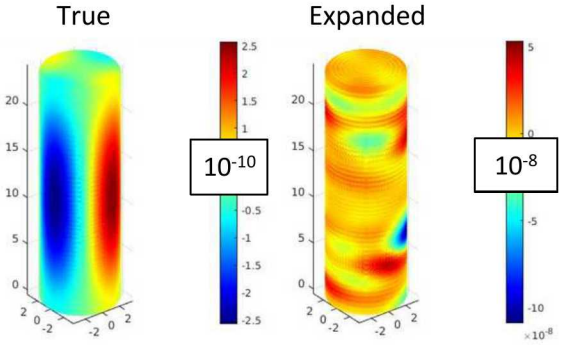
Imaginary Structure Mode (in)



Real Acoustic Mode (psi)

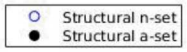


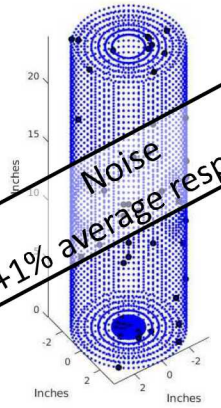
Imaginary Acoustic Mode (psi)



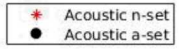
Coupled Modal Expansion – Modes 38 and 66

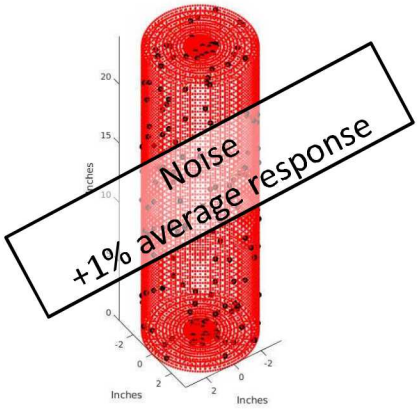
Structural Domain
Subset: 50 points





Acoustic Domain
Subset: 160 points



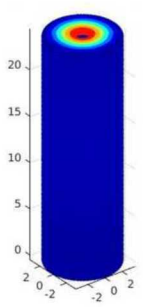


$$\begin{Bmatrix} E_{a,struc} + noise \\ E_{a,fluid} + noise \end{Bmatrix} [T_{n,a}] = \begin{Bmatrix} E_{n,struc} \\ E_{n,fluid} \end{Bmatrix}$$

Mode 38

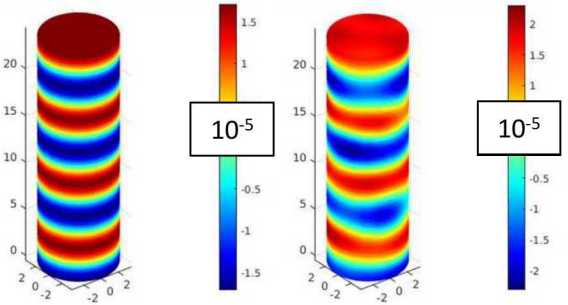
Real Structure Mode (in)

True | Expanded



Imaginary Acoustic Mode (psi)

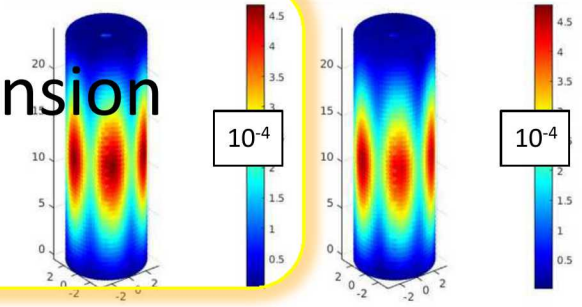
True | Expanded



Mode 66

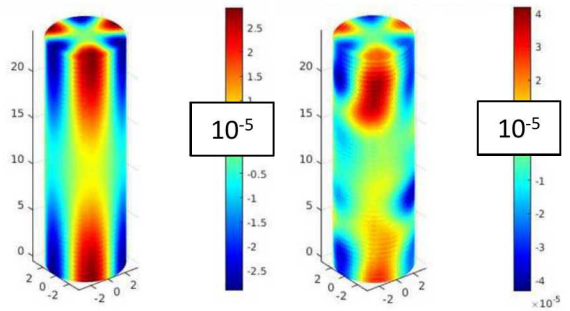
Real Structure Mode (in)

True | Expanded



Imaginary Acoustic Mode (psi)

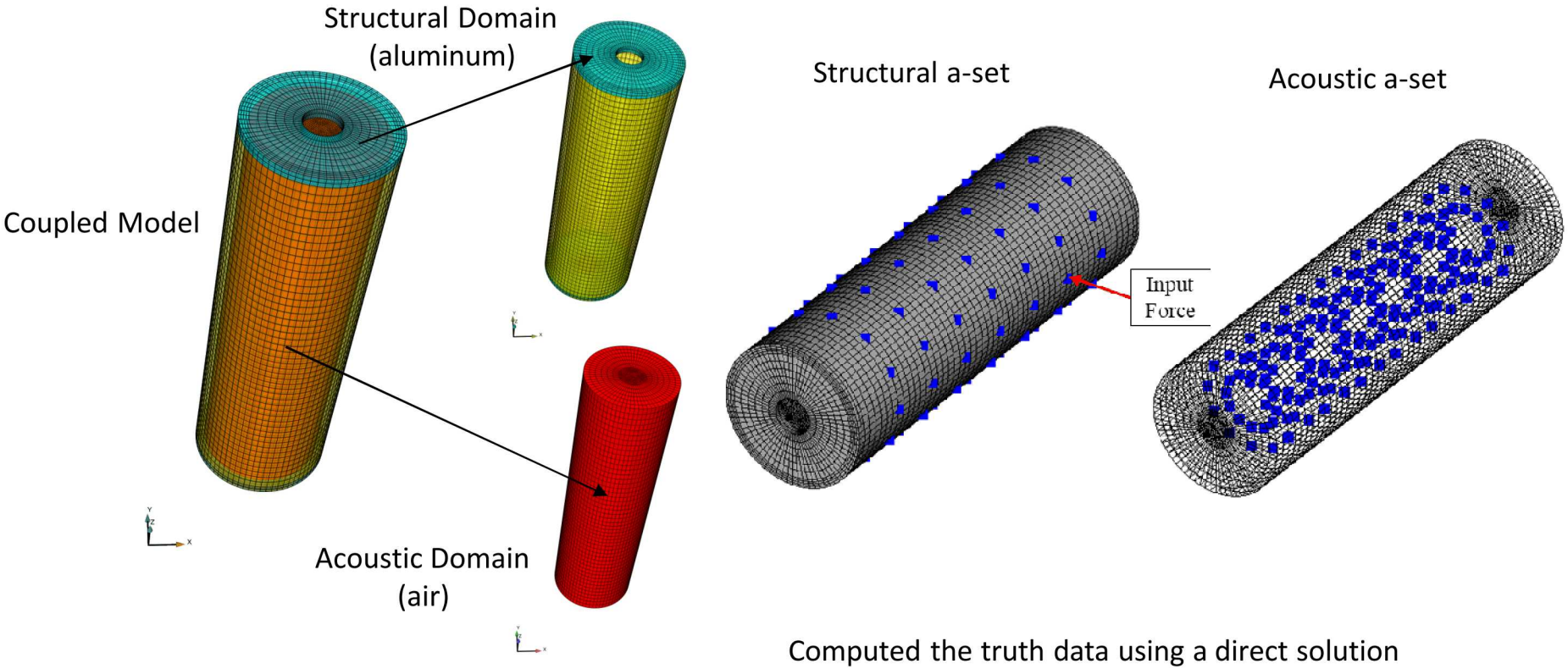
True | Expanded



Coupled expansion works!

Coupled Expansion of Transient Responses

Coupled Transient Expansion



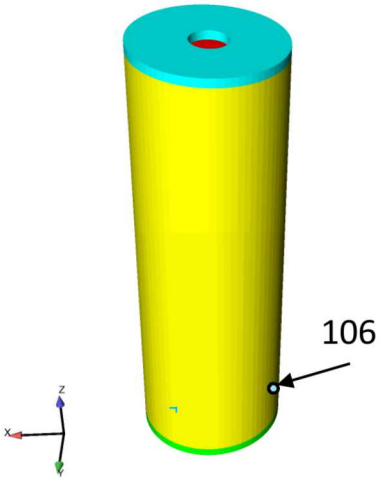
Computed the truth data using a direct solution

First 80 complex modes
(No rigid body)

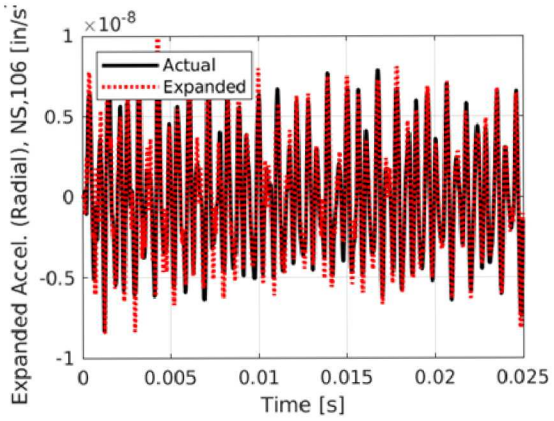
$$[T_{n,a}] \begin{Bmatrix} x_{a,struc}(t) \\ x_{a,fluid}(t) \end{Bmatrix} = \begin{Bmatrix} x_{n,struc}(t) \\ x_{n,fluid}(t) \end{Bmatrix}$$

Expanded Time Responses

Structure

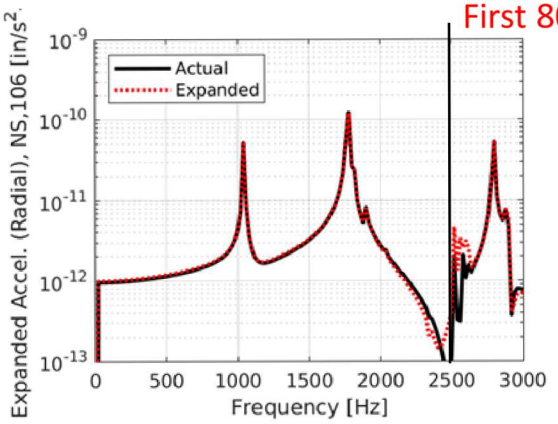


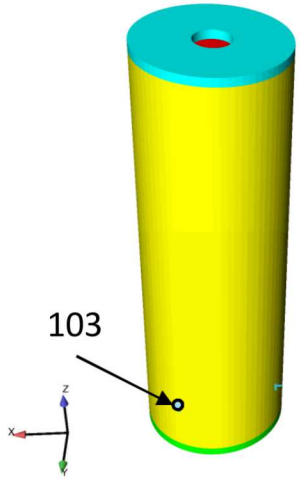
Point 106 Time Response



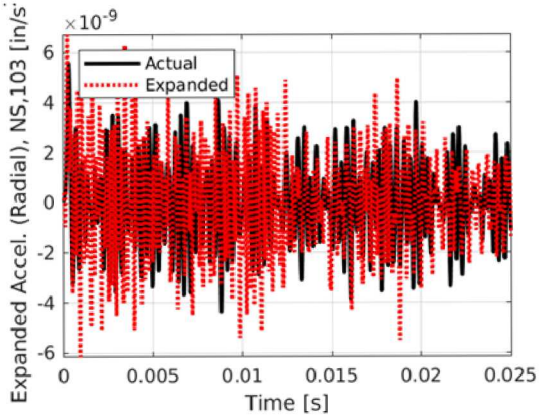
Point 106 Spectrum

First 80 modes



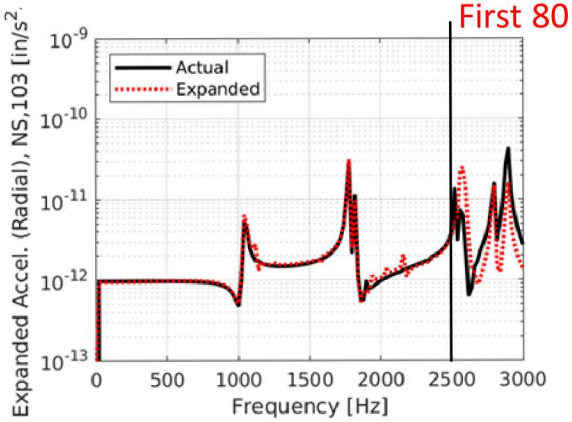


Point 103 Time Response



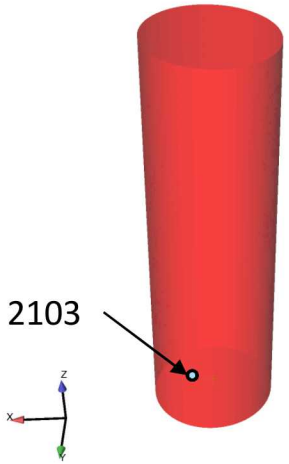
Point 103 Spectrum

First 80 modes

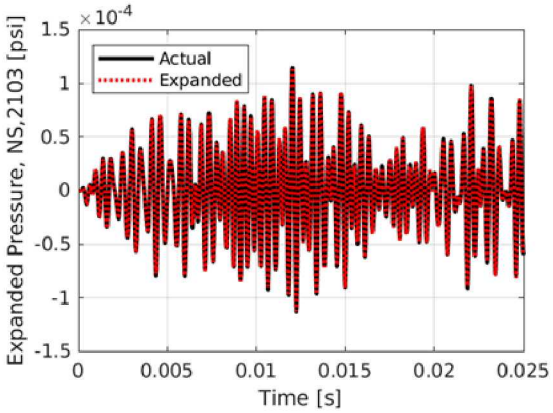


Expanded Time Response's Linear Spectra Magnitude

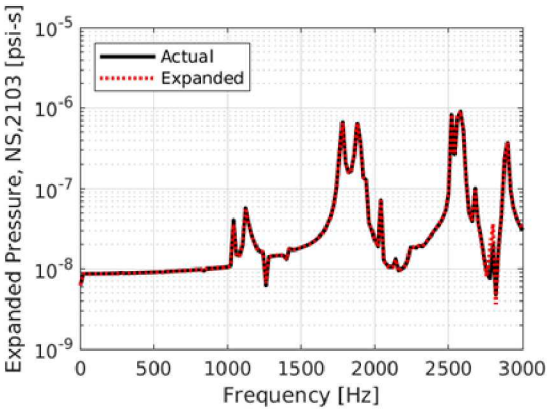
Acoustics

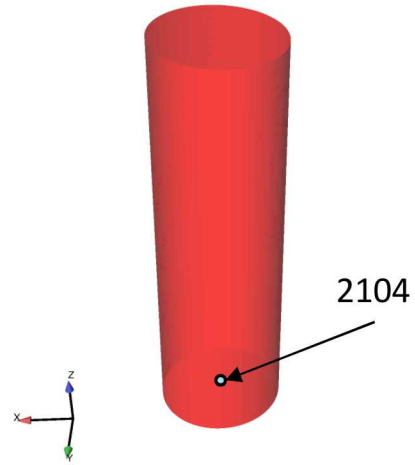


Point 2103 Time Response

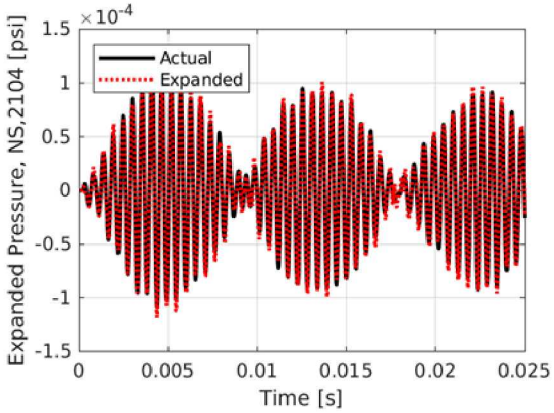


Point 2103 Spectrum

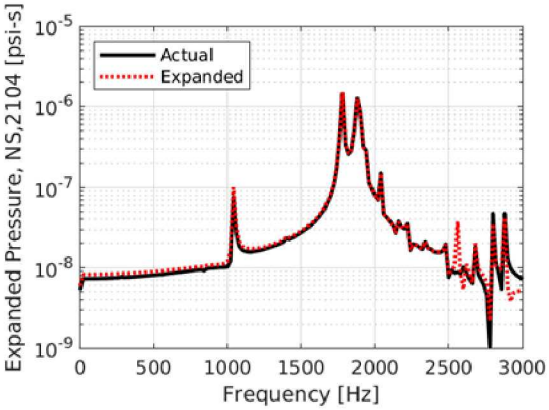




Point 2104 Time Response

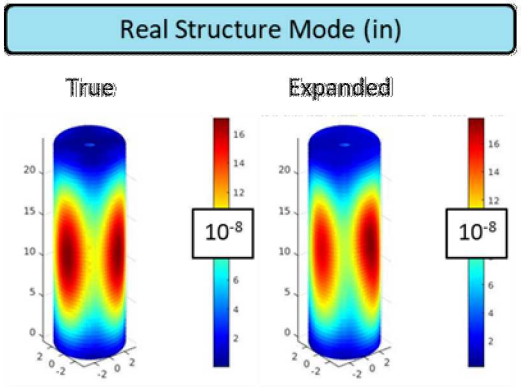


Point 2104 Spectrum

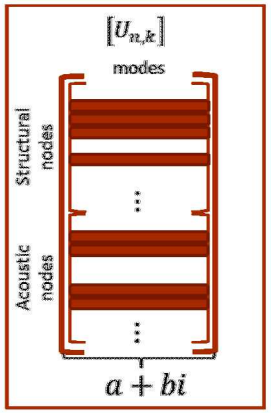


Conclusion / Discussion

- Can expand mode shapes and transient responses in coupled domains!



- Traditional expansion considerations:
  - a-set location was random, should use effective independence
  - Needed to include more modes for the transient expansion
- New considerations:
  Transformation matrix from complex-valued modes
  - Expand real and imaginary portions of the modes separately?



$[T_{n,a}]$ OR $[T_{n,a}]_{real}$, $[T_{n,a}]_{imag}$

- Select modes for expansion
  - Use only acoustically dominant modes to expand to the acoustic domain?

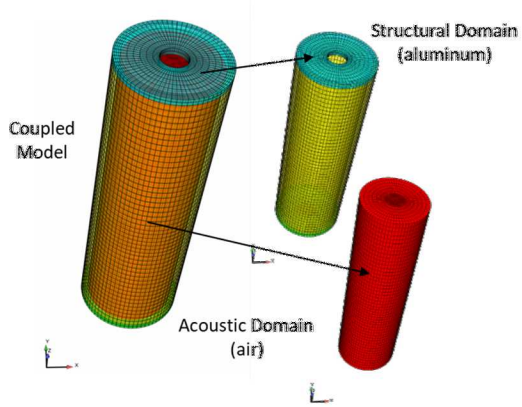
Future Work

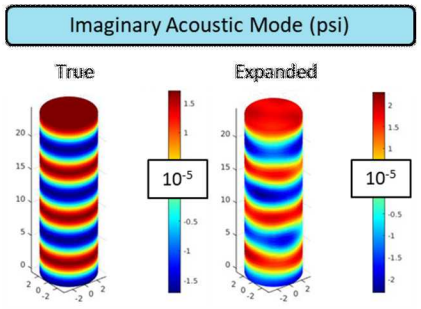
- Use measured structural response to expand to difficult-to-measure acoustic domains

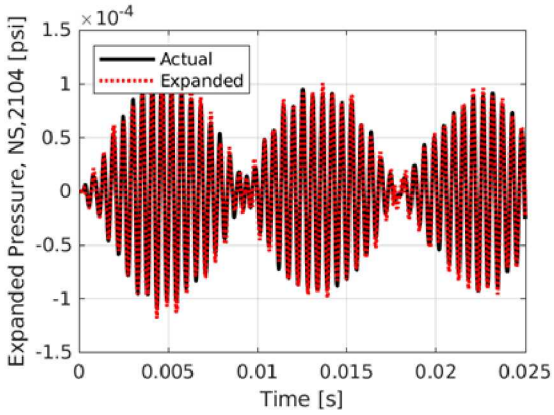
Areas of Study:

- How many degrees of freedom are needed (if any) in the domain of interest?
- How can we improve modal selection of coupled modes?

Expansion of Coupled Structural-Acoustic Systems







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