NASA Langley Activities on Broadband Fan Noise Reduction via Novel Liner Technologies

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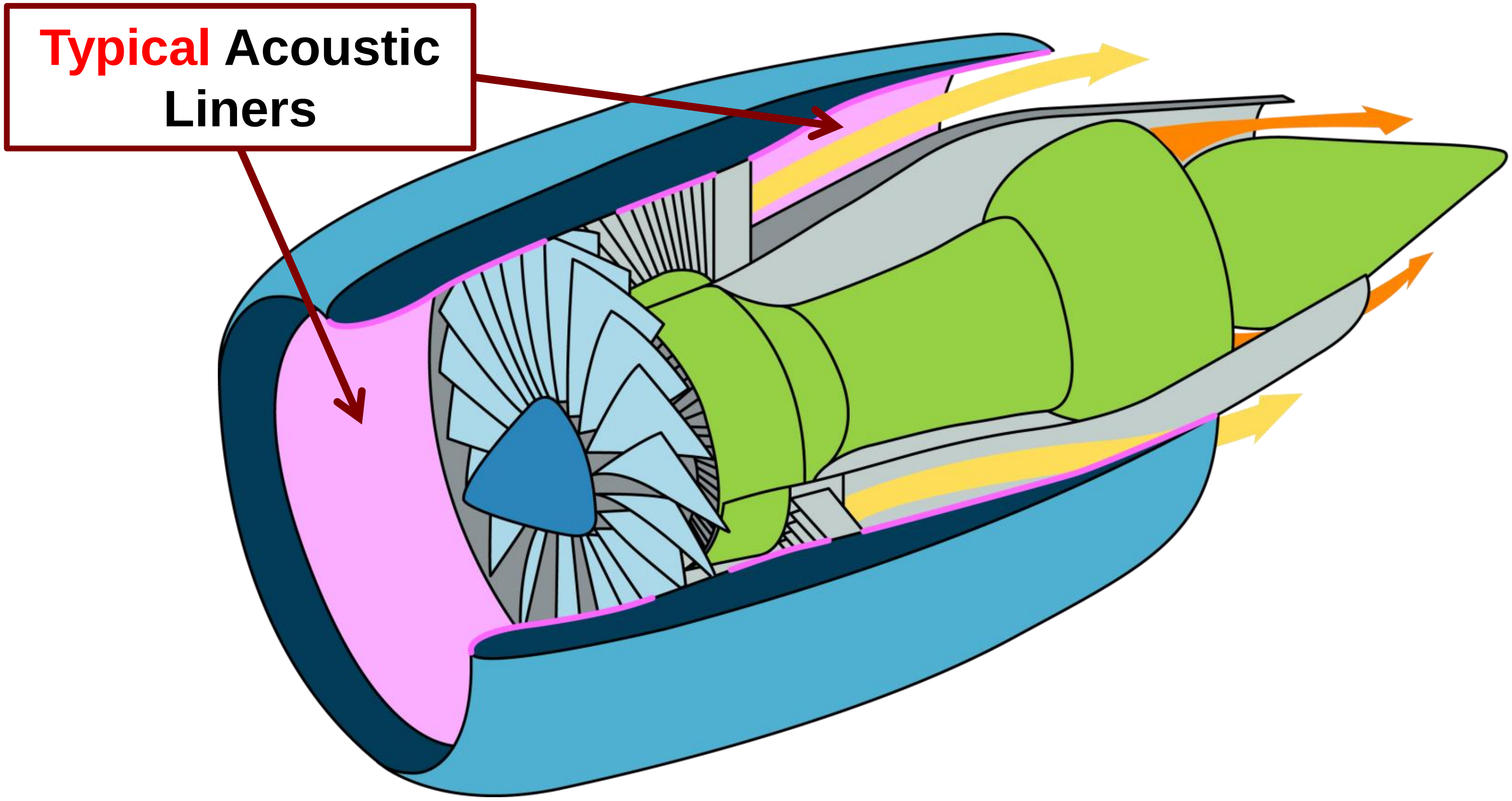
CEAS/X-Noise Workshop on
Broadband Noise of Rotors and Airframe
La Rochelle, France

23 – 25 September 2015

Technical Challenge



Decreasing Length/Diameter
+
Cut-Off Fan Design

→

Change in focus from narrowband to broadband attenuation

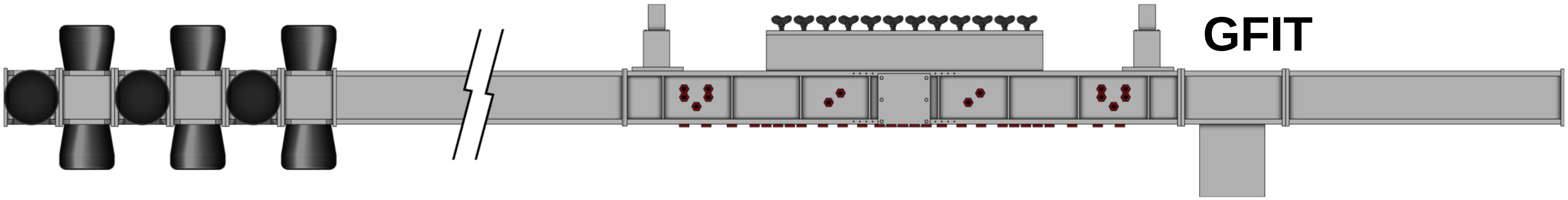
Objective

Brief Review of Five Broadband Liner Concepts

Outline

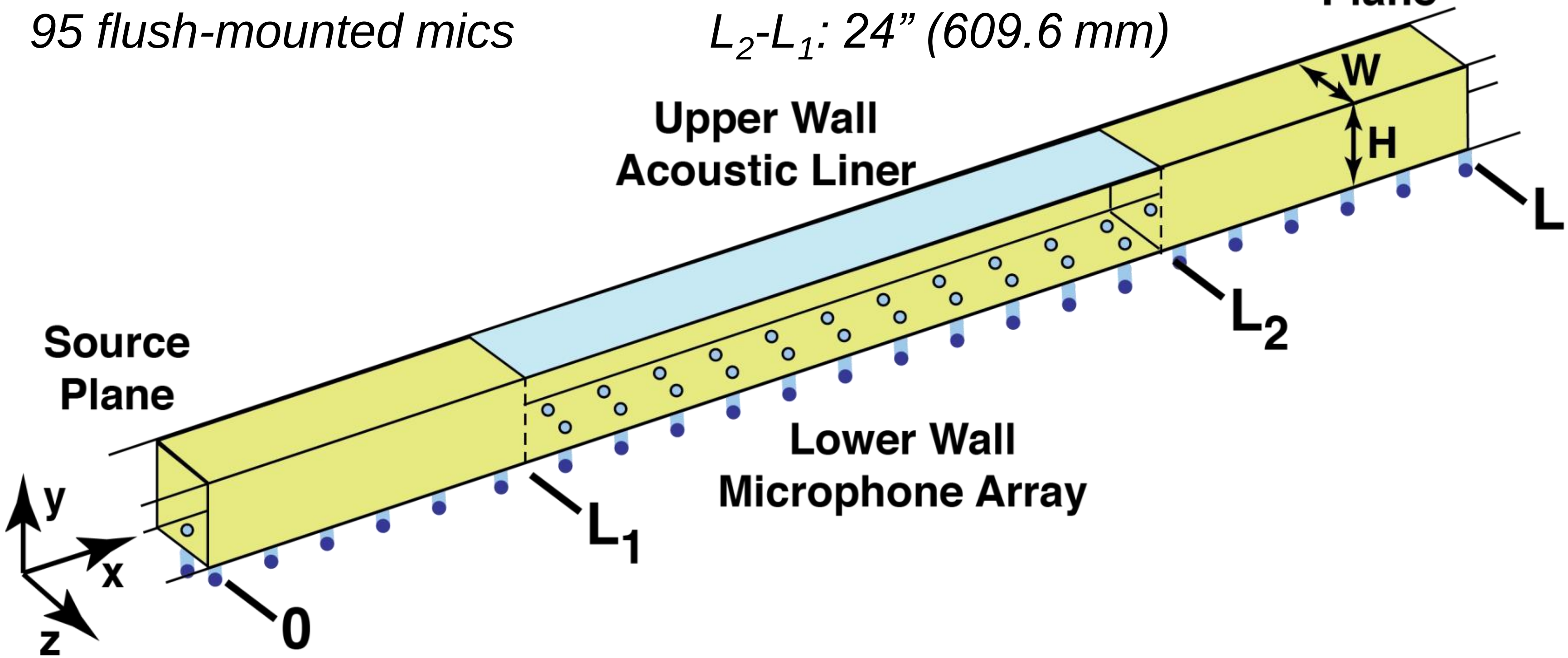
- Grazing Flow Impedance Tube (GFIT)
- Five Broadband Liner Concepts
    1. Extended-Reacting Liner
    2. Multi-Layer Liner
    3. Variable-Depth (small spatial extent) Liner
    4. Variable-Depth (large spatial extent) Liner
    5. Adaptive Liner
- Status Summary
- Acknowledgements
- References

Grazing Flow Impedance Tube (GFIT)



Mach #: 0.0 to 0.6
Frequency: 0.4 to 3.0 kHz
Source SPL: up to ~155 dB
95 flush-mounted mics

Configuration: Inlet or Aft
H: 2.5” (63.5 mm)
W: 2.0” (50.8 mm)
L_2-L_1: 24” (609.6 mm)



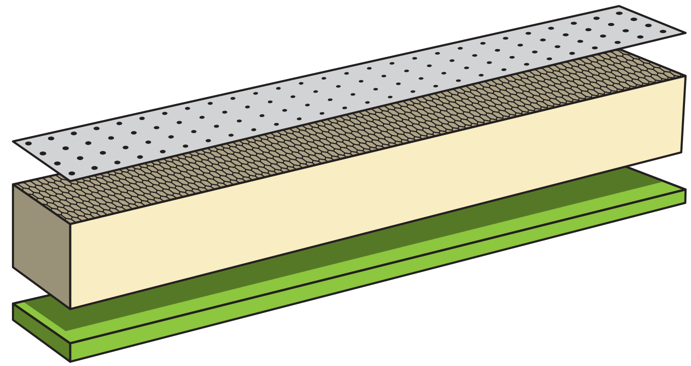
1. Extended Reacting Liners

Start with the Basics

Conventional Local-Reacting Liner

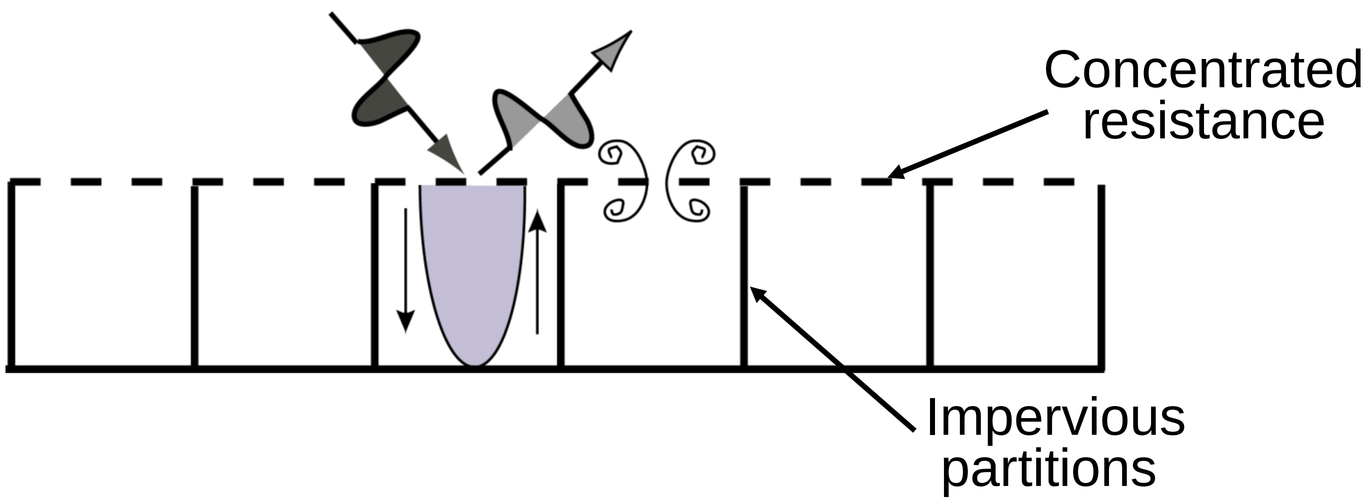
Thin resistive facesheet + blocked lateral wave

- Spatially concentrated absorption
- Enhanced fluid pumping



Salient features

- Strong resonance
- Bandwidth limited absorption
- Very good for tones



Extended-Reacting Liner

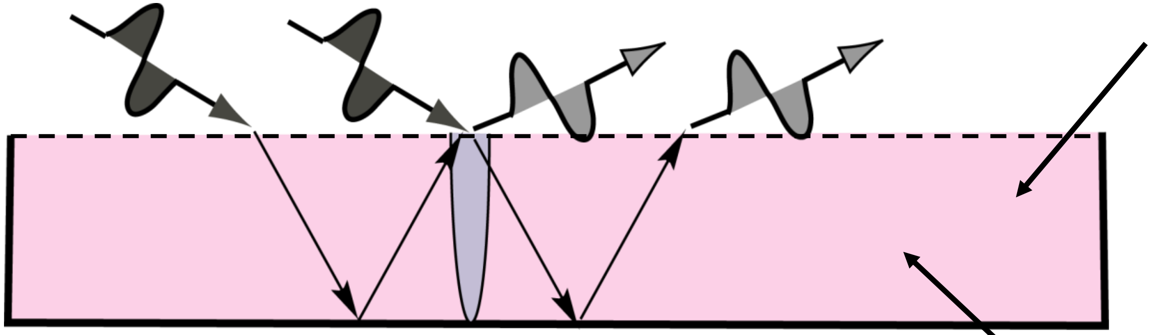
Zero-resistance facesheet + unblocked lateral wave

- Continuous distribution of resistance
- Attenuated internal wave propagation
- Reduced internal sound speed

Metal Foam Liner

Salient features

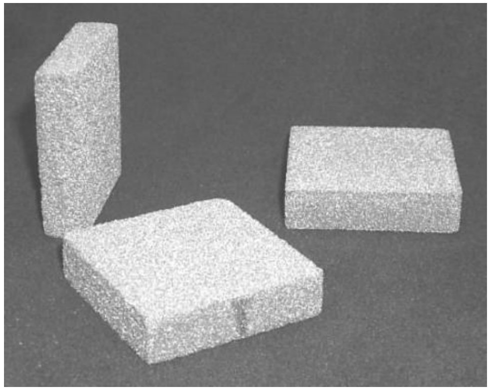
- Subdued depth-related resonance
- Improved absorption bandwidth



Foam Liners

- Conventional Foam (e.g., polyurethane)
  - Pro: Good absorber
  - Con: Weight, contamination, flammable
- Metal Foam
  - Pro: Good absorber, shape to fit, easier to model
  - Con: Weight, cost, brittle

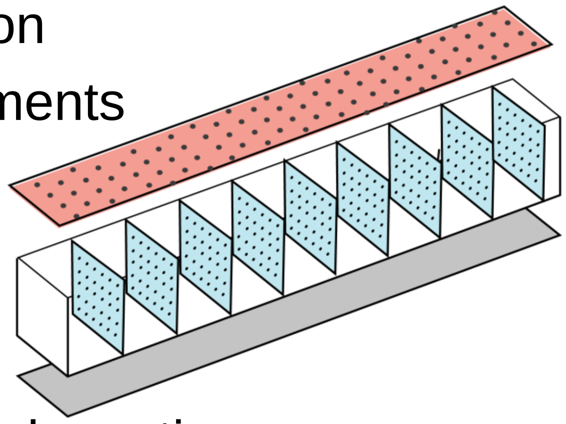
Metal Foam Liners



Hybrid (Porous Honeycomb) Liner

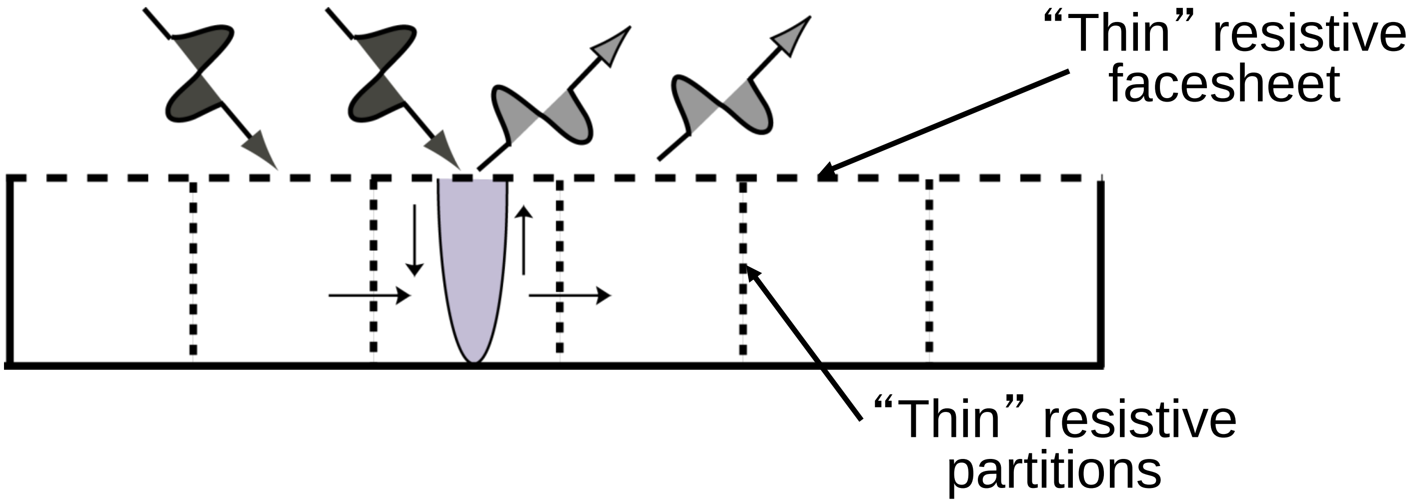
"Thin" resistive facesheet + lateral wave

- Retains spatially concentrated absorption
- Adds distribution of lateral resistive elements

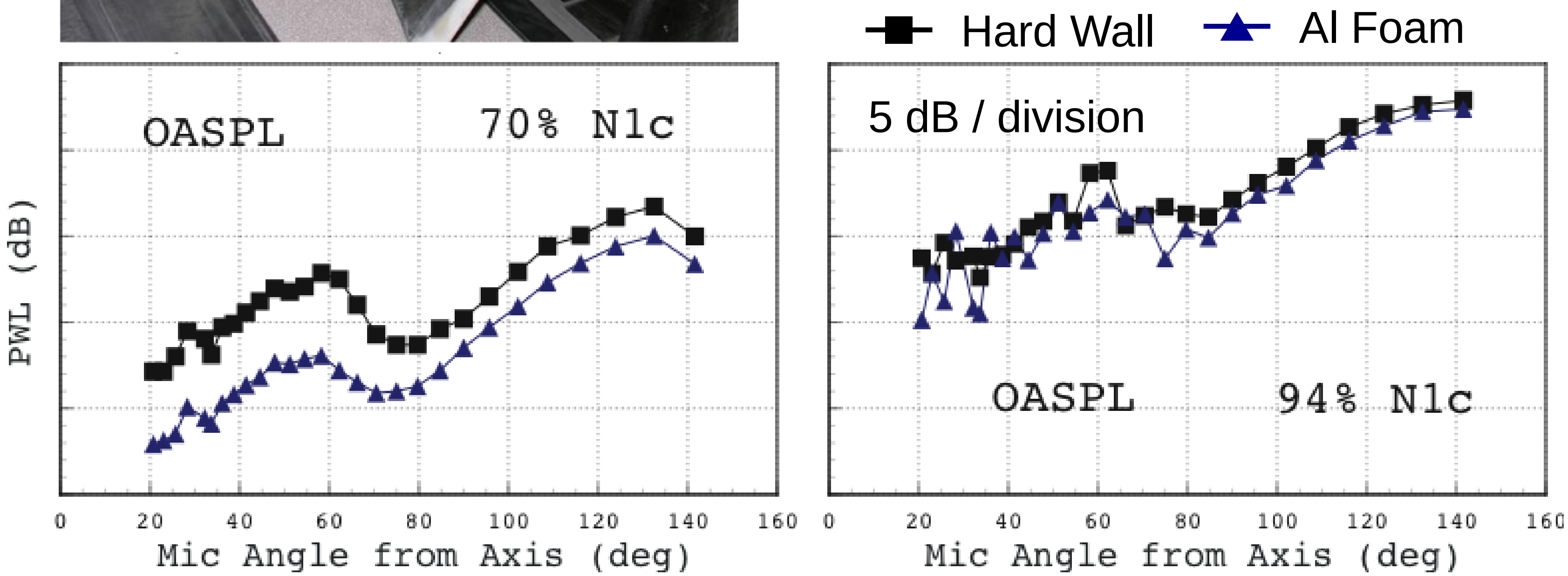


Salient features

- Subdued absorption periodicity
- Combines features of local and extended reaction



Over-the-Rotor Metal Foam Liner



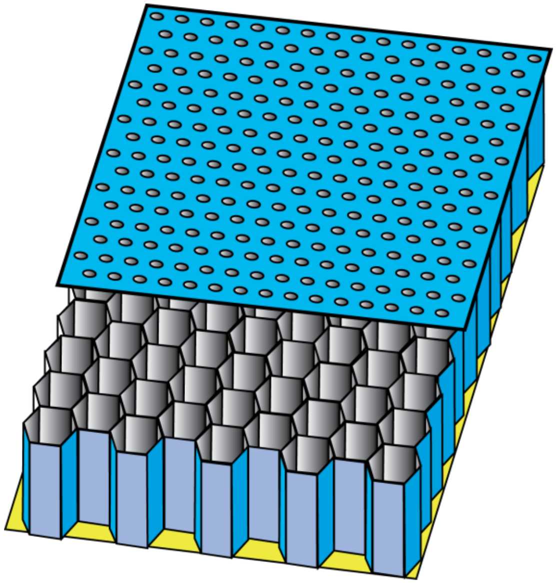
Extended-Reacting Liner

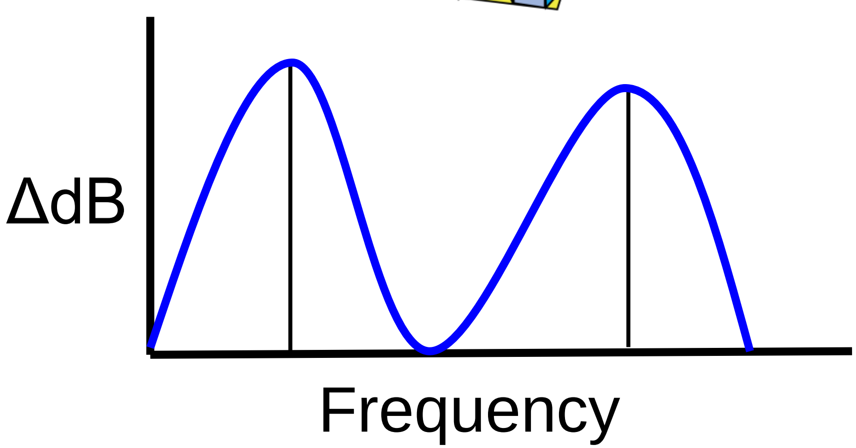
Status

- Continue to revisit:
  - as material properties improve
  - for limited applications where properties are acceptable
- As 3D printing becomes more robust, perhaps consider synthetic foams

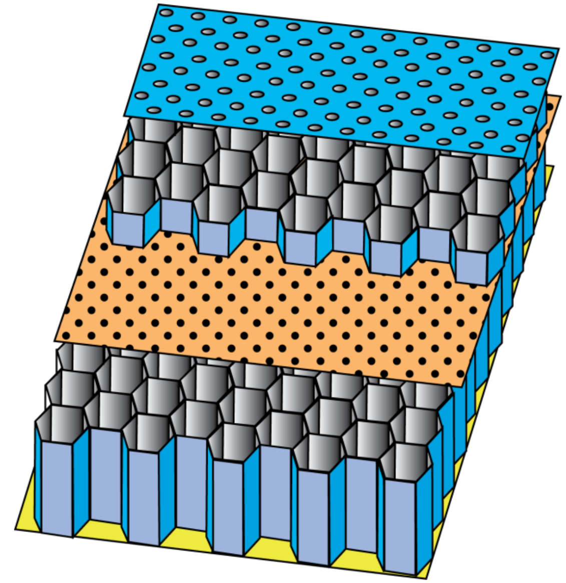
2. Multi-Layer

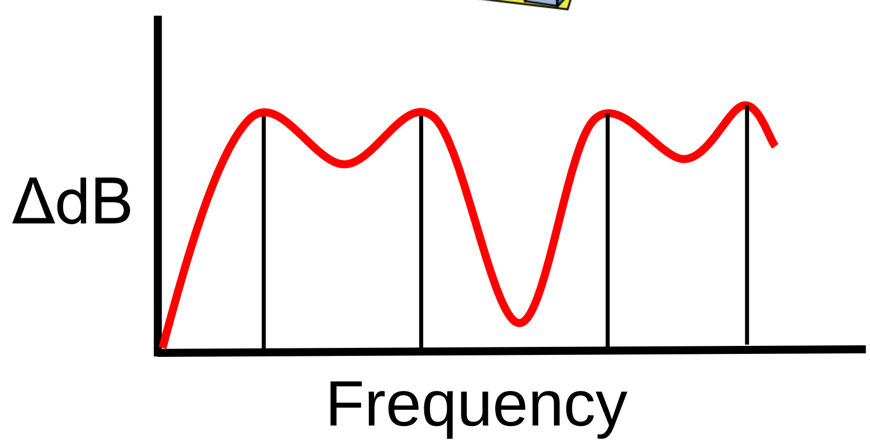
Single-Layer Liner





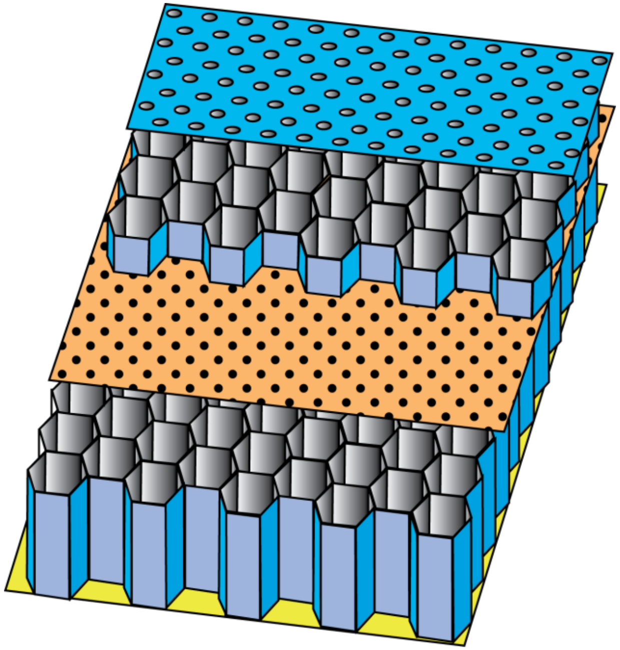
Two-Layer Liner



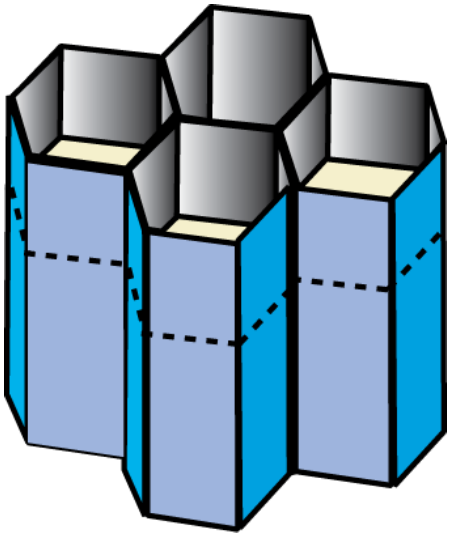


Multi-Layer, Mesh-Cap Liner

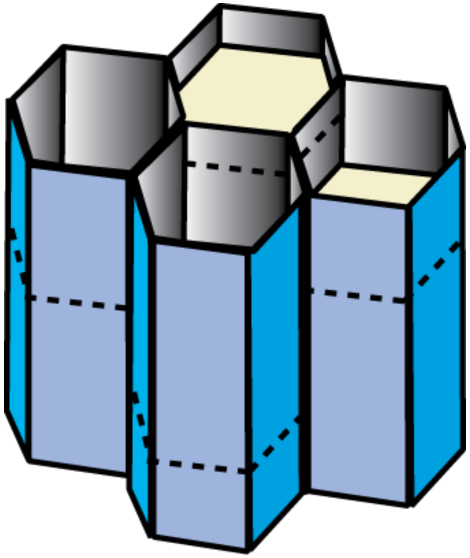
Conventional
Two-Layer Liner



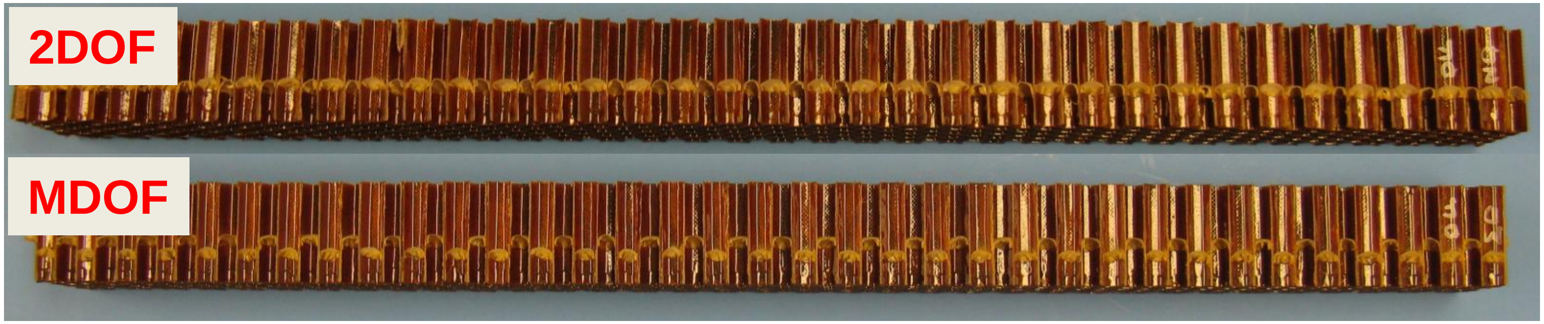
2DOF
Constant Depth,
Constant R_f

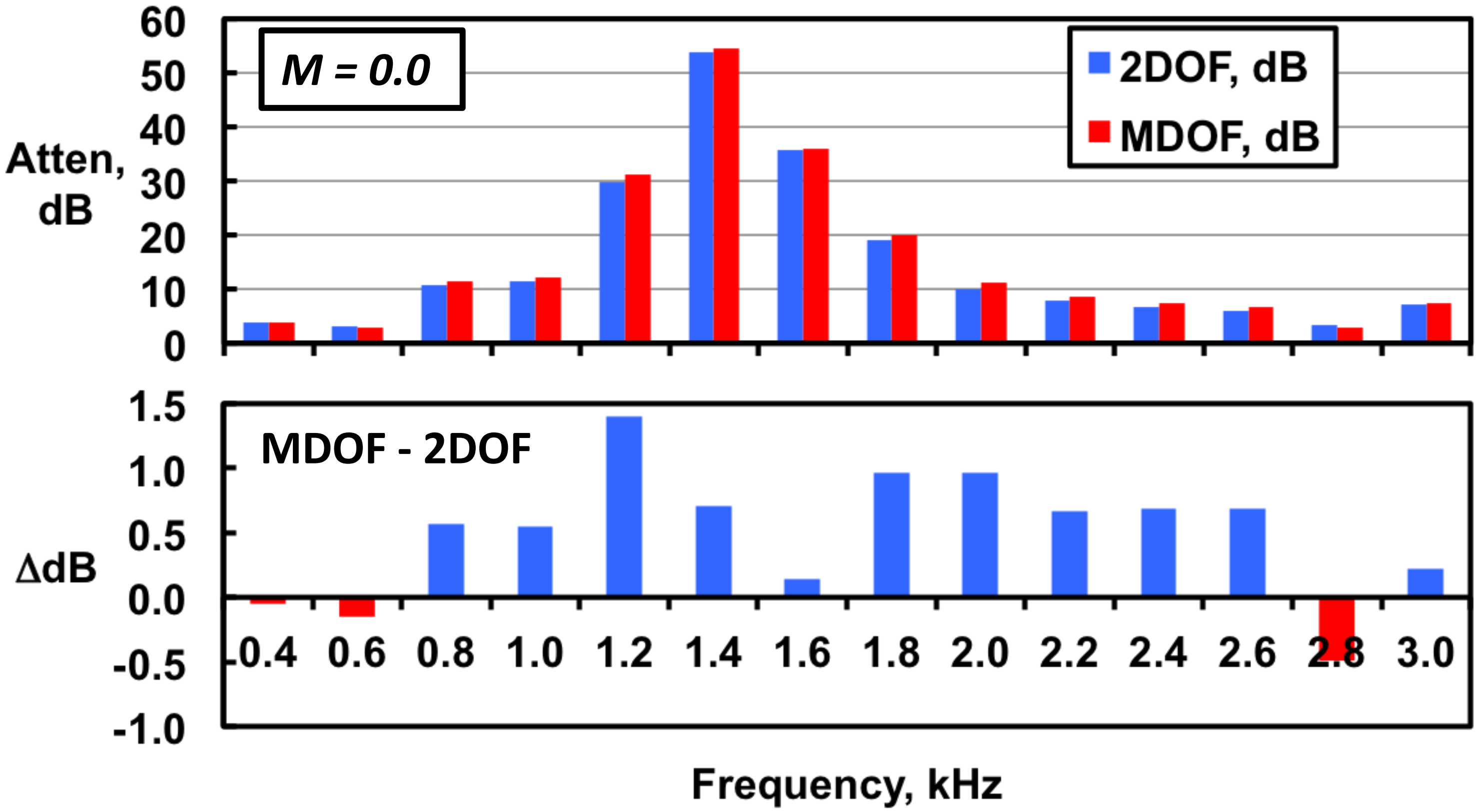


MDOF
Variable Depth,
Variable R_f



Mesh-Cap Liners: 2DOF vs MDOF





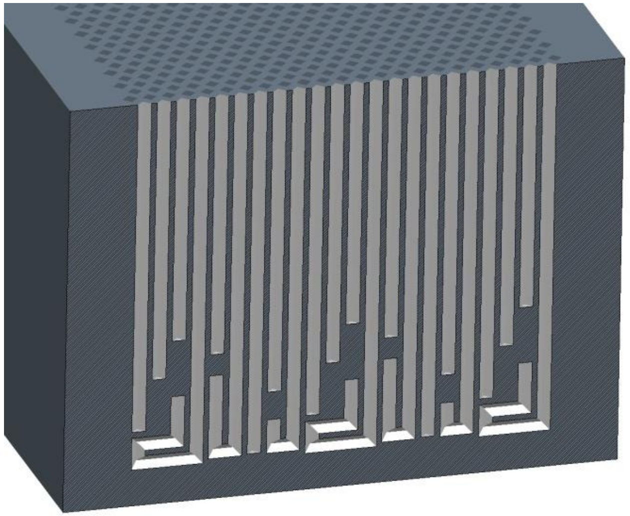
Multi-Layer Liner

Status

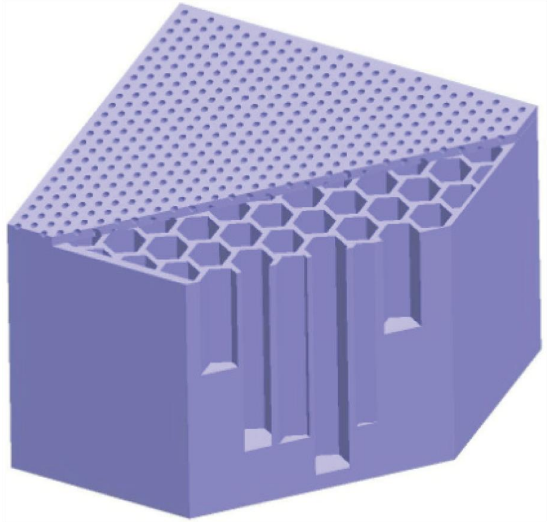
- Method of choice for conventional liner applications
- Mesh-cap approach enables variety of MDOF configurations
- Recent 22” fan rig test in NASA GRC 9x15 Wind Tunnel with MDOF mesh-cap liners
  - Preliminary results look promising
  - Details to be published soon

3. Variable-Depth (small extent)

**Narrow Chamber,
Variable-Depth Liner**



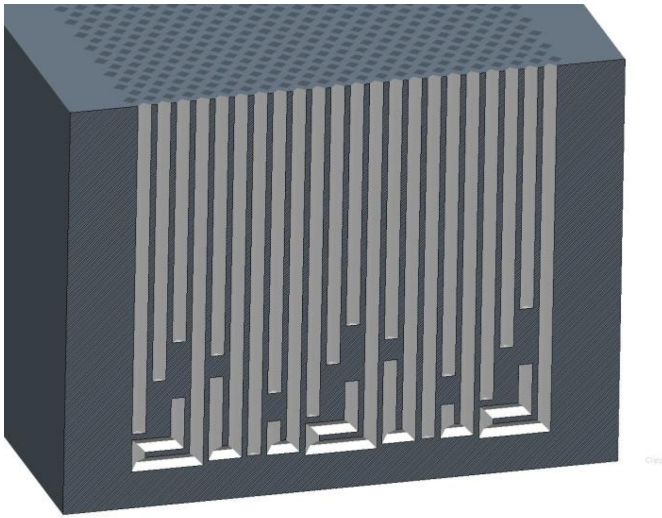
**Wide Chamber,
Variable-Depth Liner**



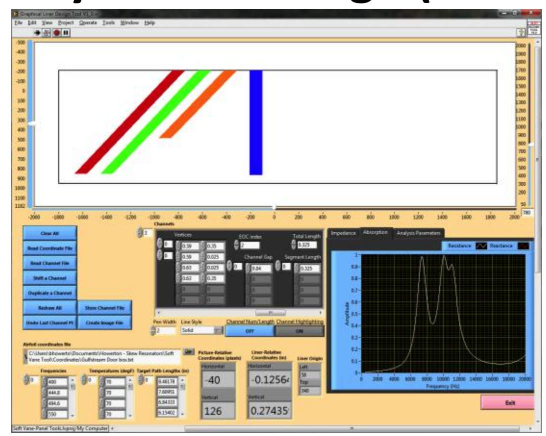
- Combination of chambers tuned to different frequencies
- Rule of thumb – if spatial extent of impedance variability $\leq \lambda/4$, can assume liner impedance is uniformly distributed

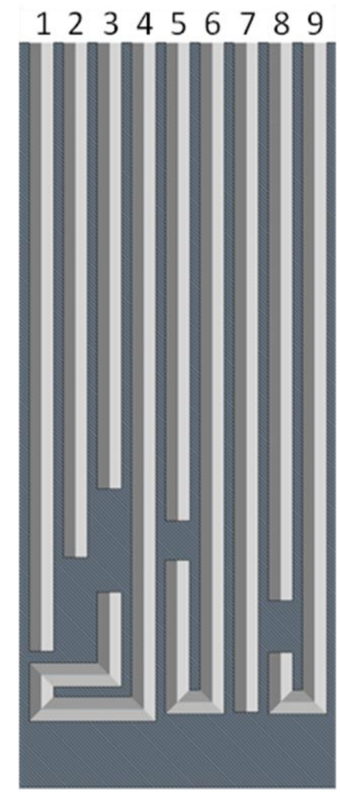
Narrow Chamber, Variable-Depth

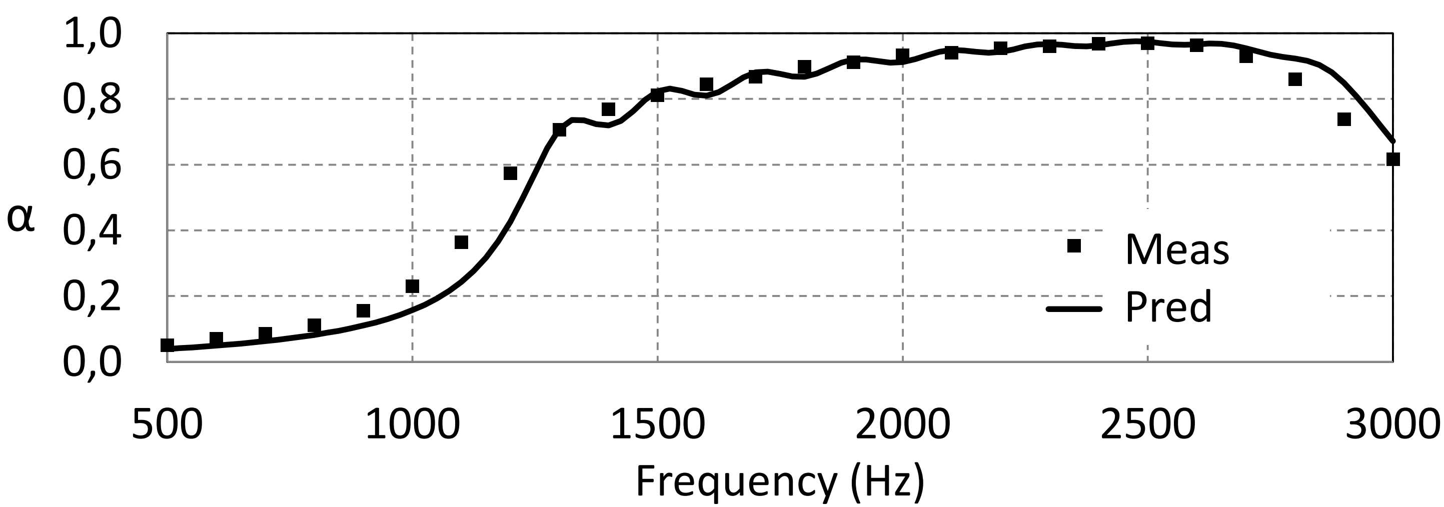
Evaluate effects of variable-depth, small-diameter, bent chambers



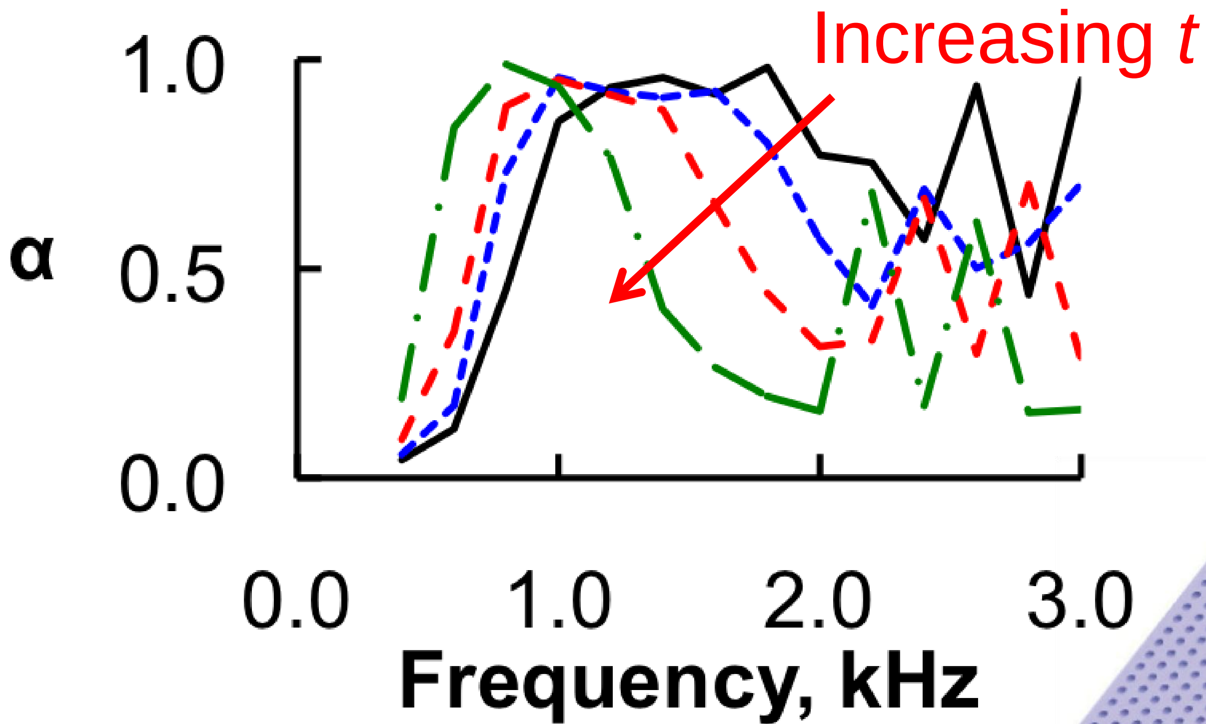
Interactive Liner Impedance Analysis and Design (ILIAD)

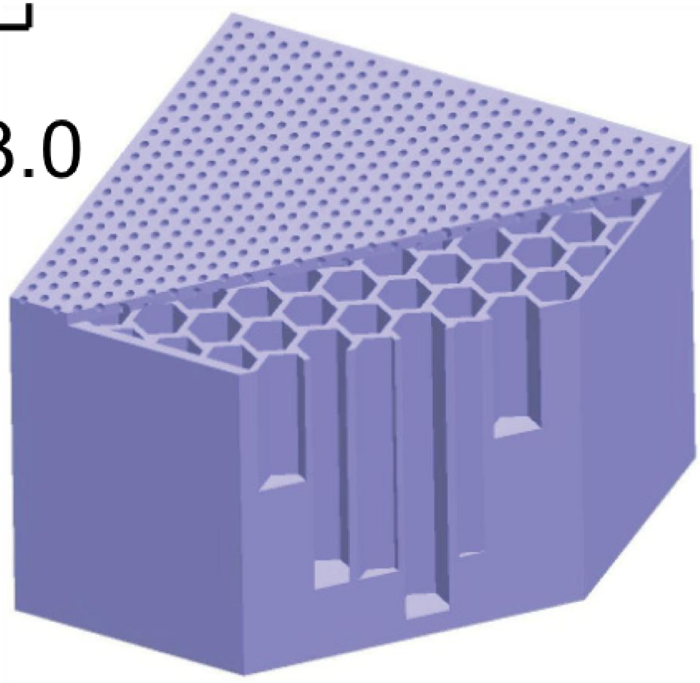




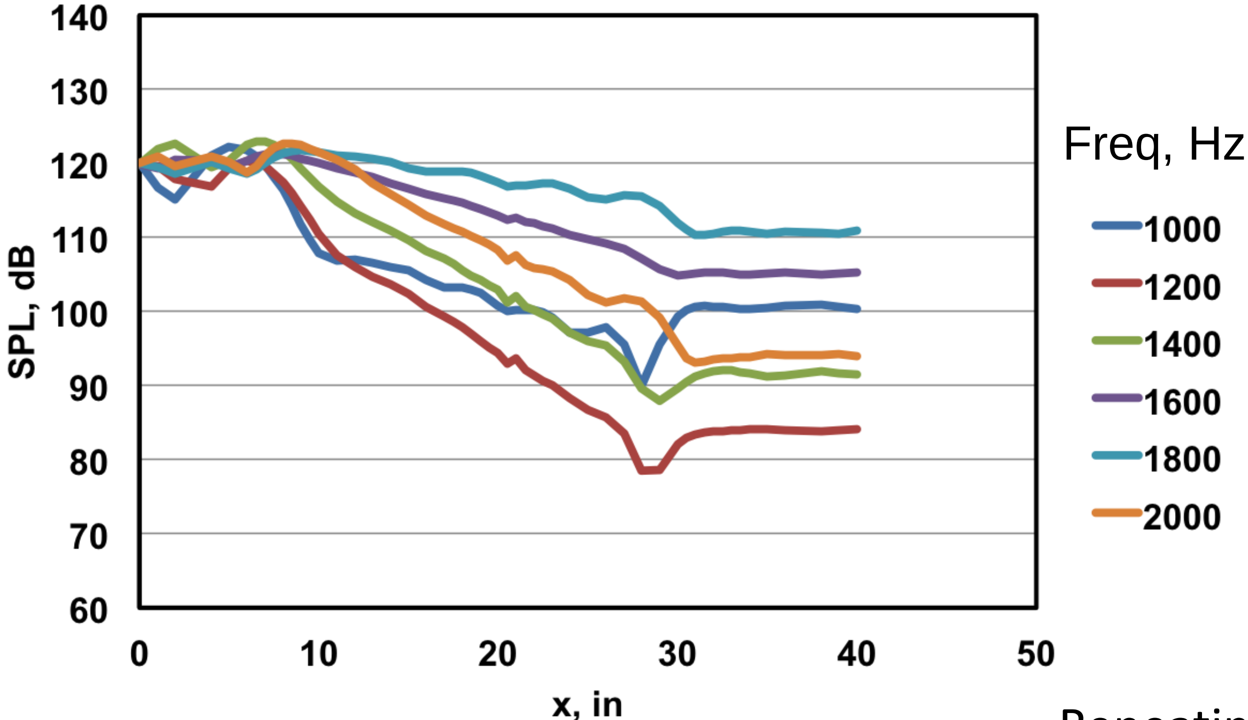


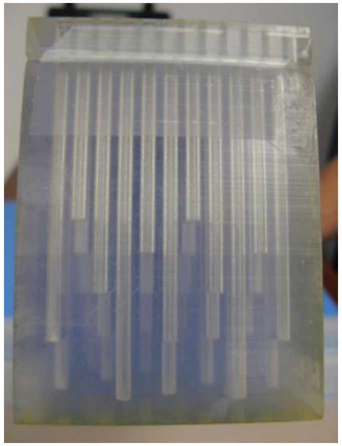
Wide Chamber, Variable-Depth Liners



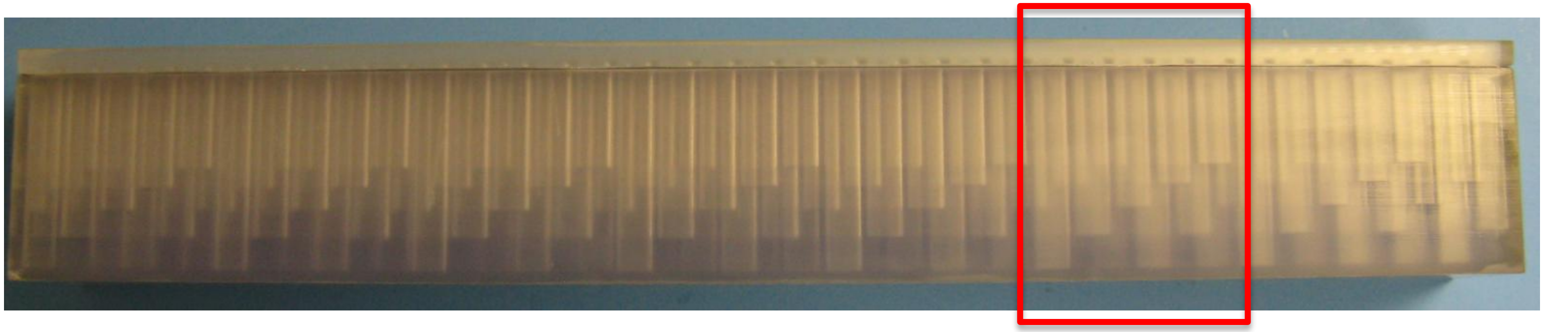


Wide Chamber, Variable-Depth Liners

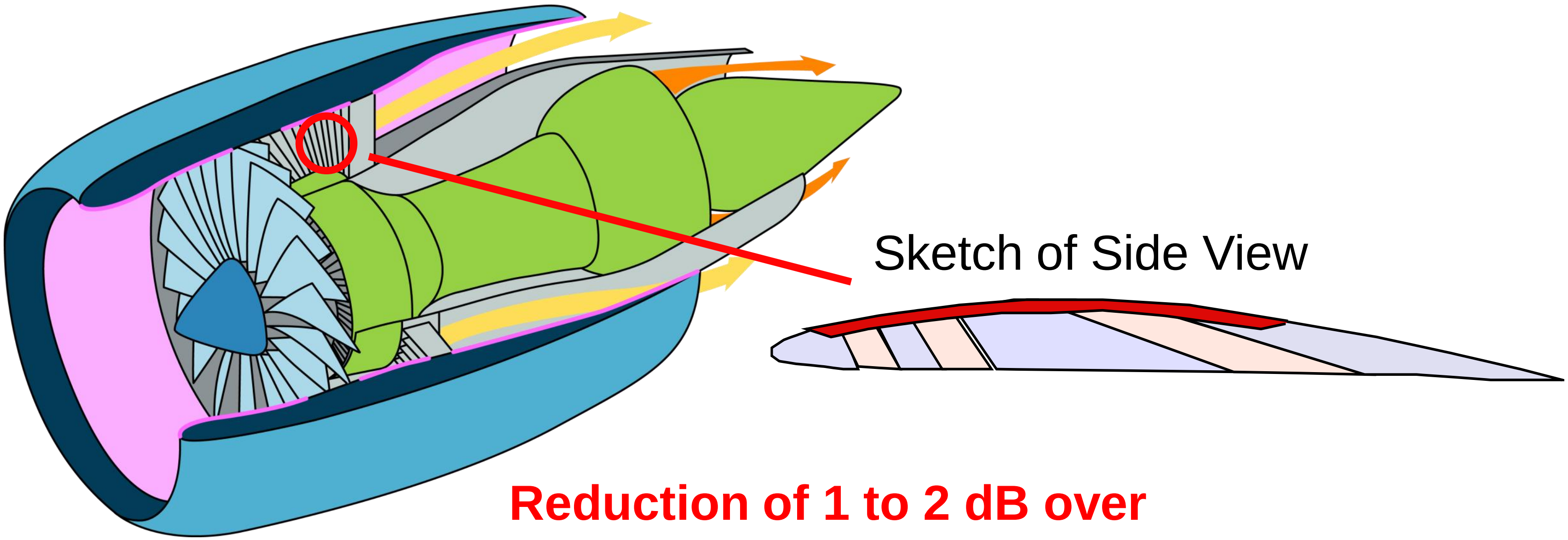




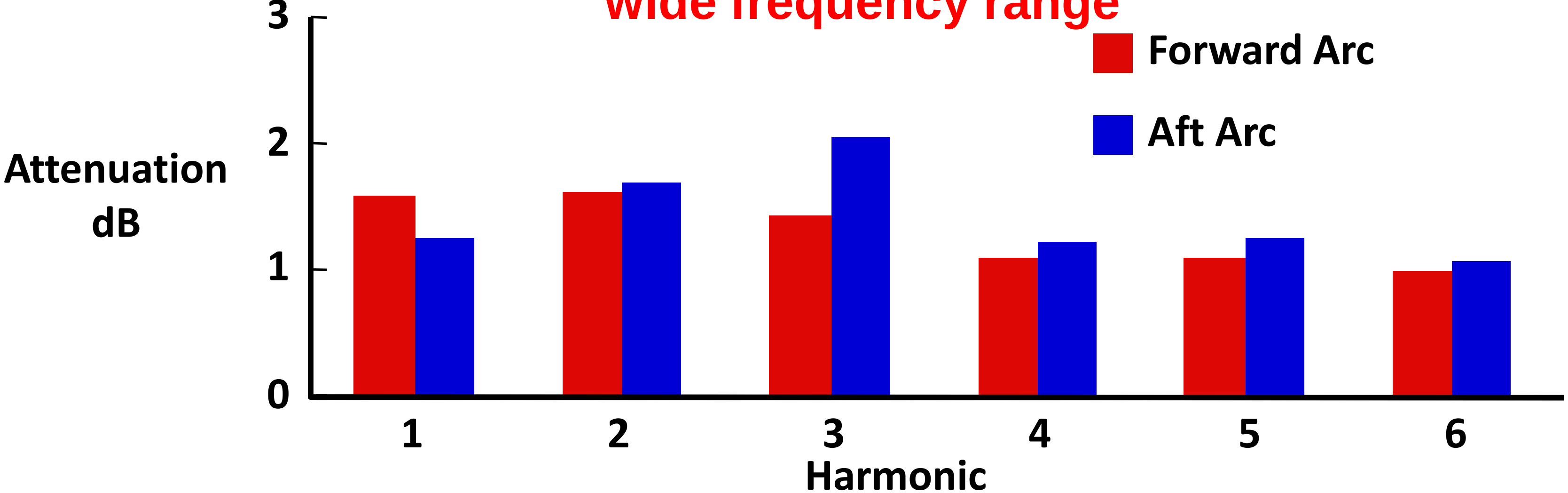
Repeating Pattern



Application: Soft Vane



Reduction of 1 to 2 dB over wide frequency range

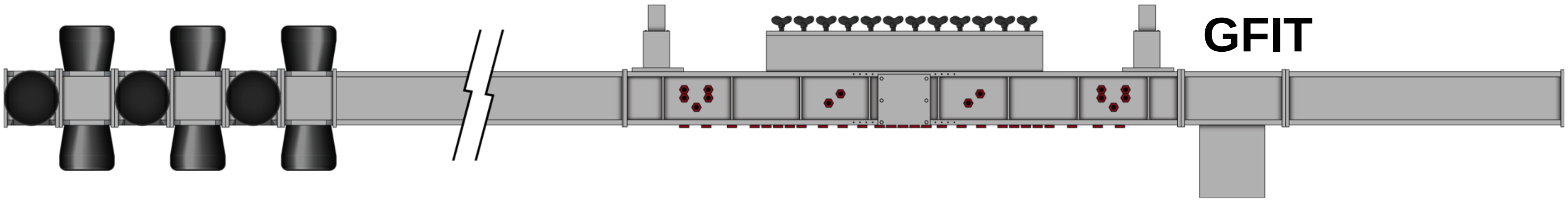


Variable-Depth Liner (small extent)

Status

- Enabled by 3D printers
- Method of choice for novel applications
- Typically limited by weight concerns

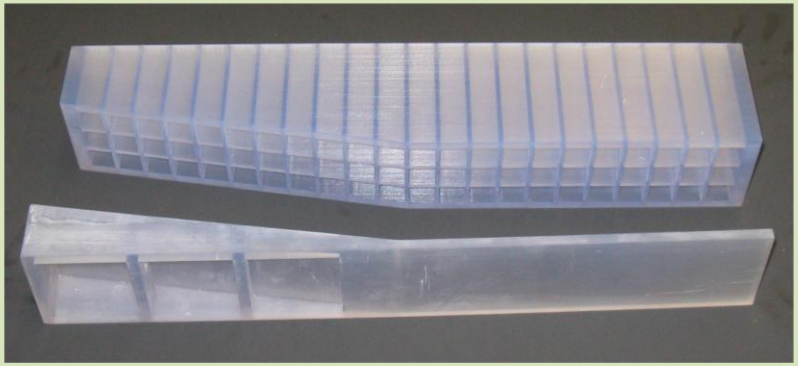
4. Variable-Depth (large extent)



TL1

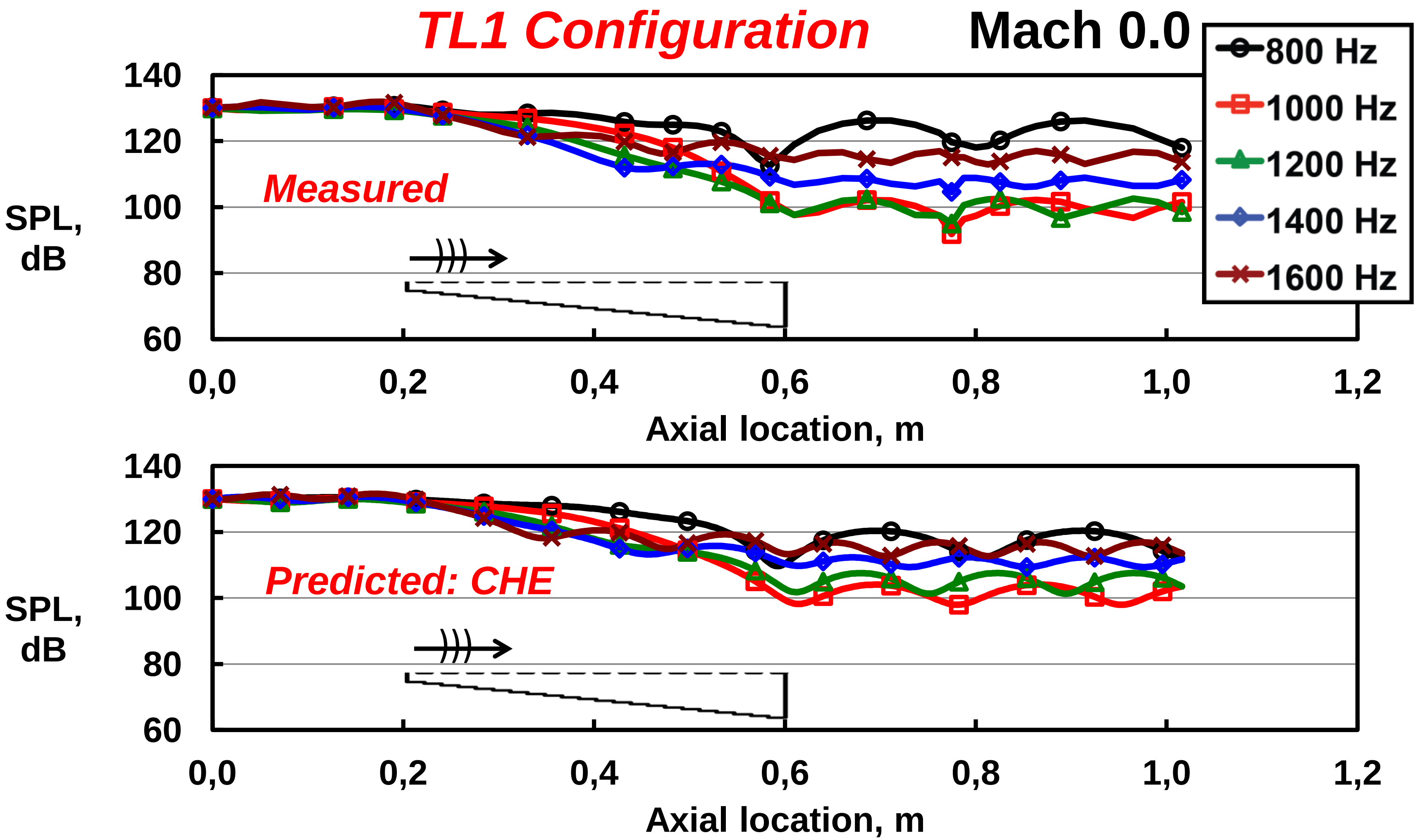
Mach #: 0.0, 0.3, 0.5
Frequency: 400 to 3000 Hz in 200 Hz increments
Source SPL: 130 dB

TL2



	TL1	TL2
Max depth (mm):	76.2	76.2
Min depth (mm):	15.2	46.7

Measured vs Predicted SPL Profiles



Favorable comparison

Comparison improves & attenuation decreases with M increase

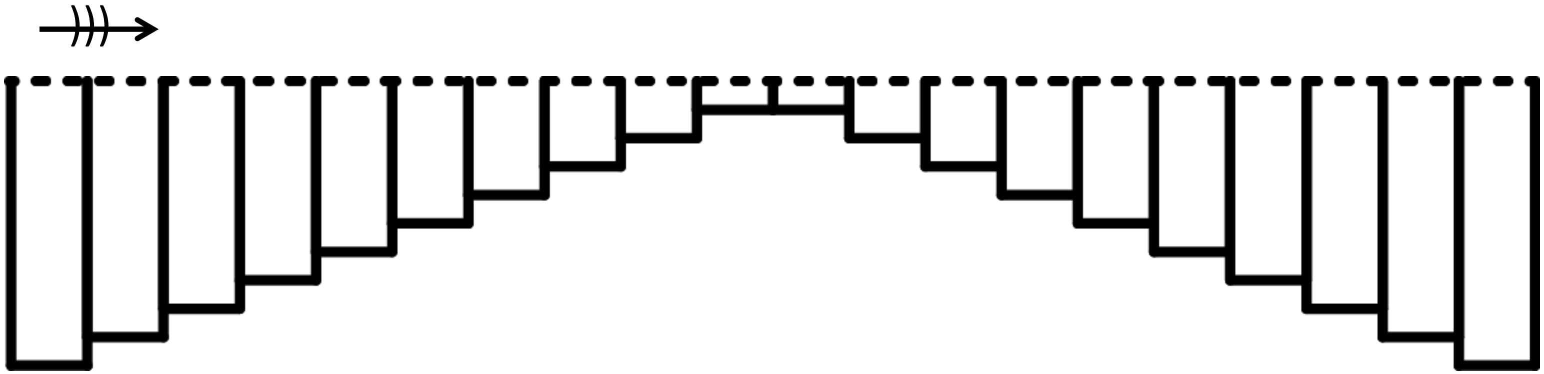
Validation of Predictive Methods

Favorable comparison of measured and predicted results indicates:

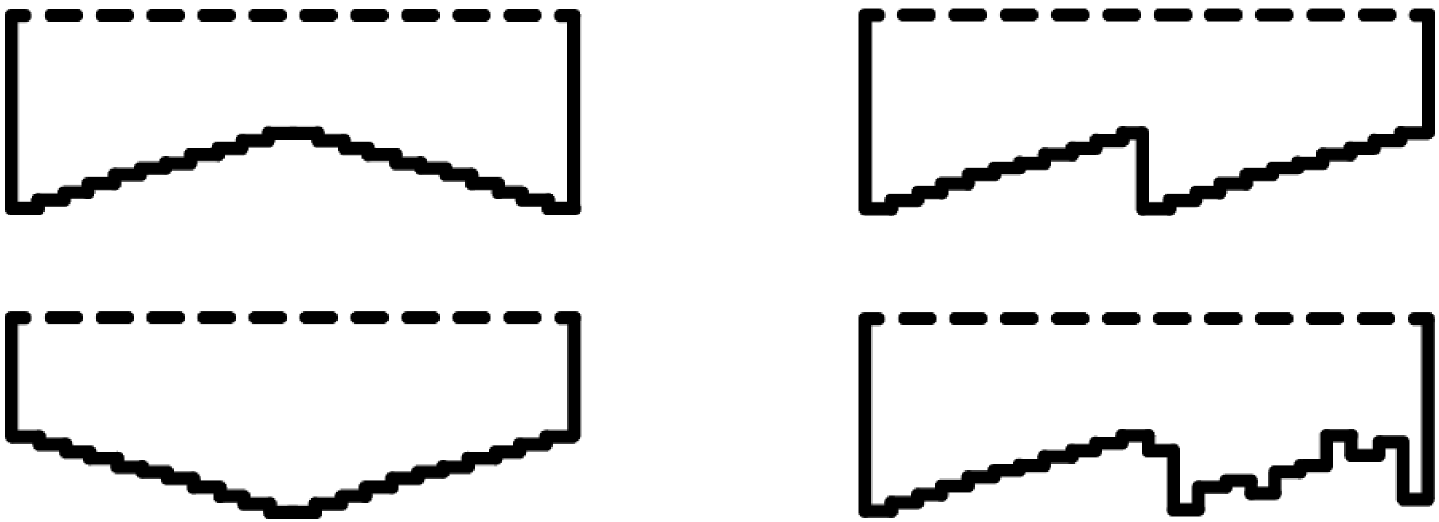
- Impedances for individual cells are predicted correctly

  AND

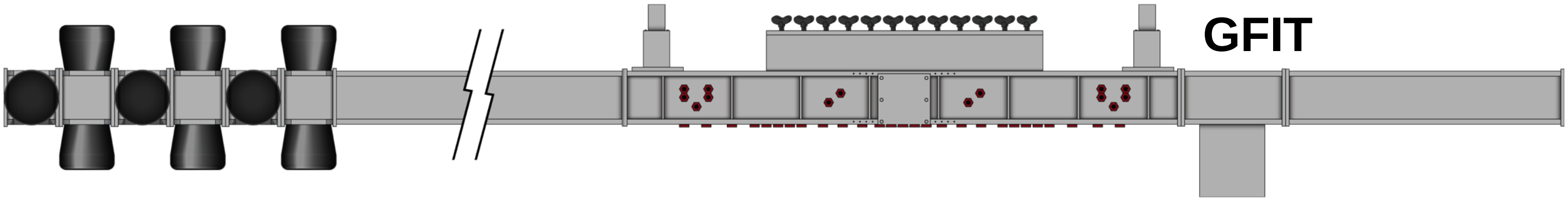
- Effects of impedance are predicted via propagation code with sufficient accuracy to support their use for a variable-depth liner design study



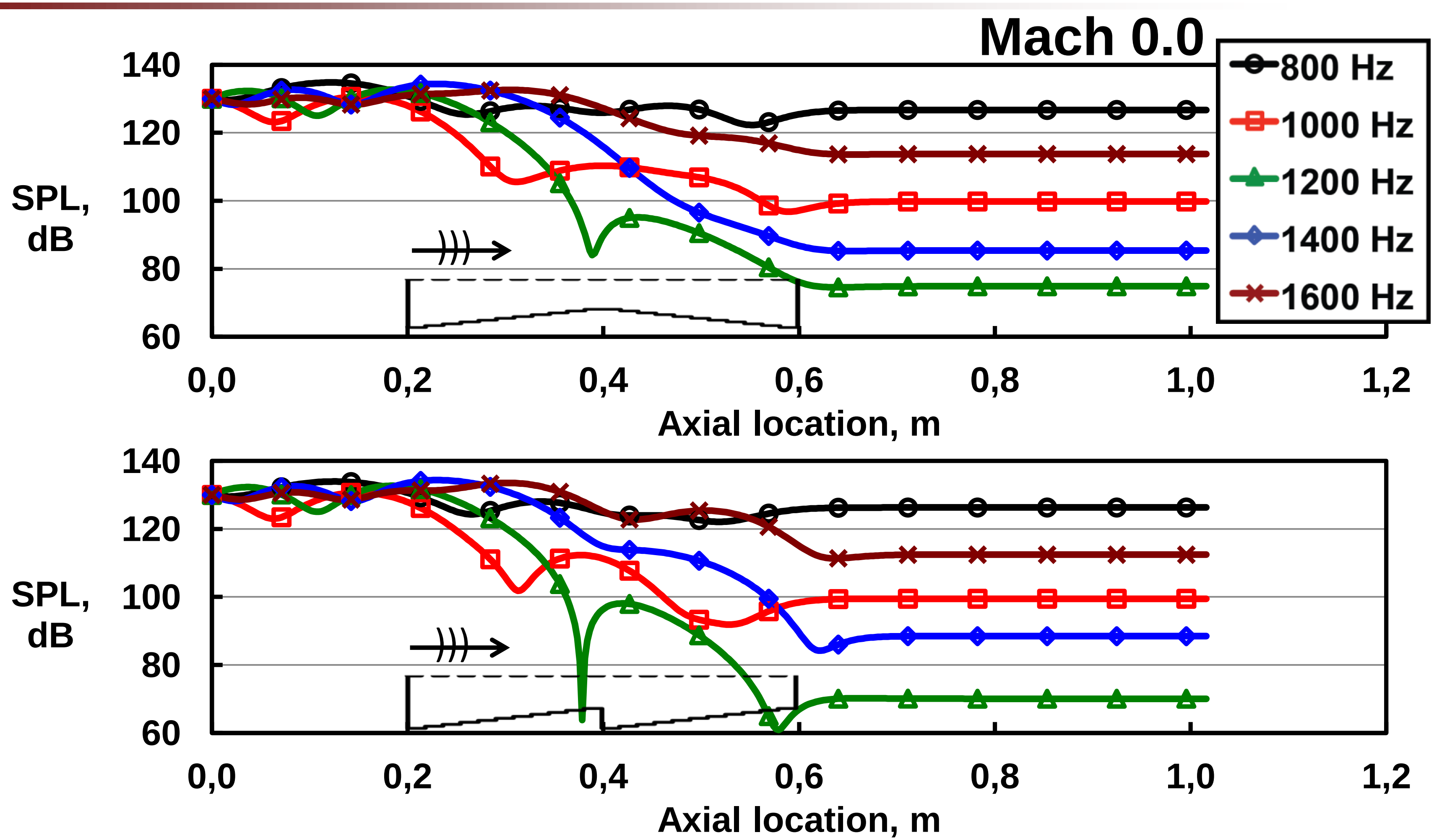
Modeling Study



- Evaluate four distributions of 22 chambers
- Use CHE with ρc termination to predict SPL(f,x)



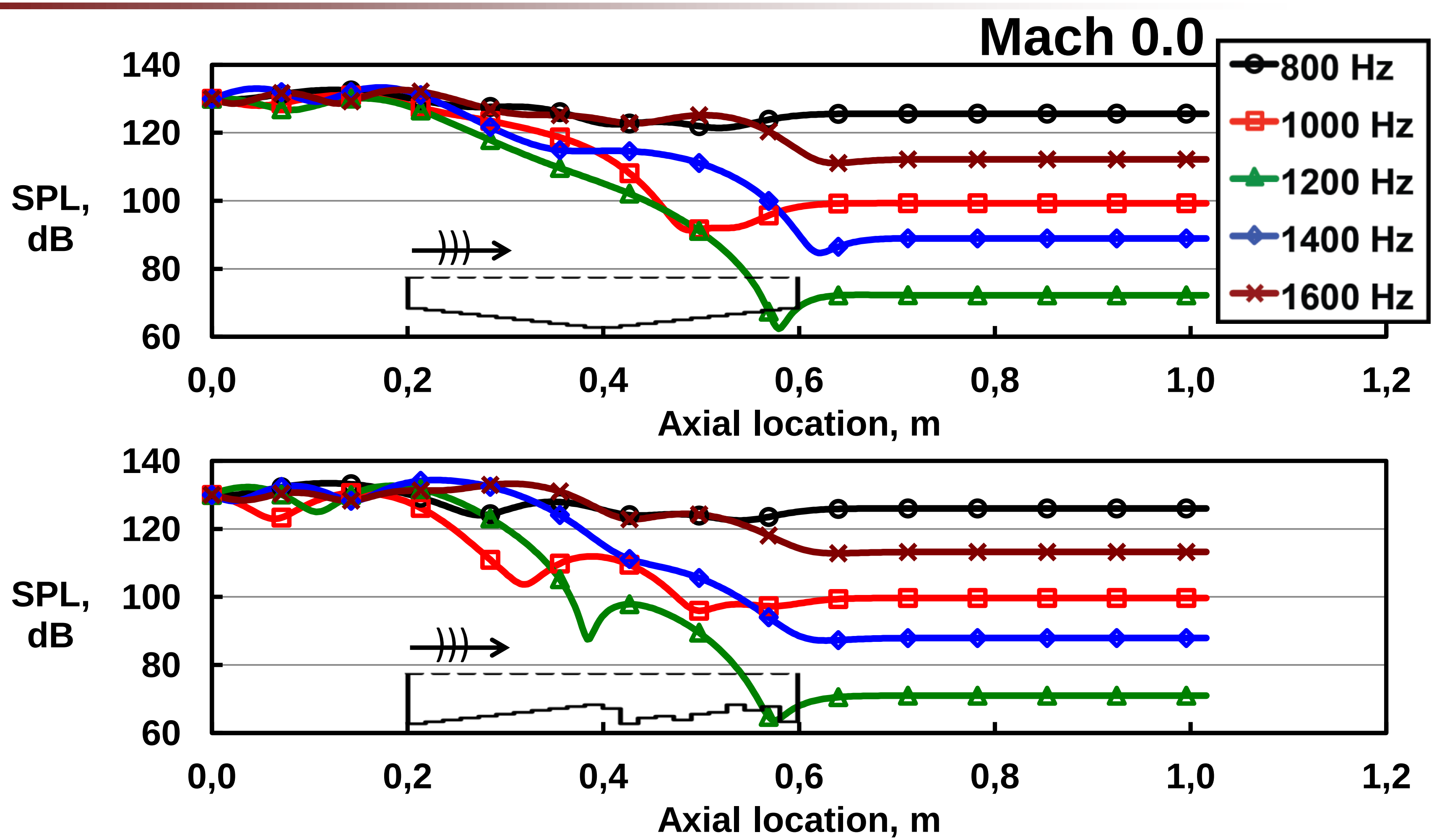
Configuration Effects



Configuration has effect on SPL profile

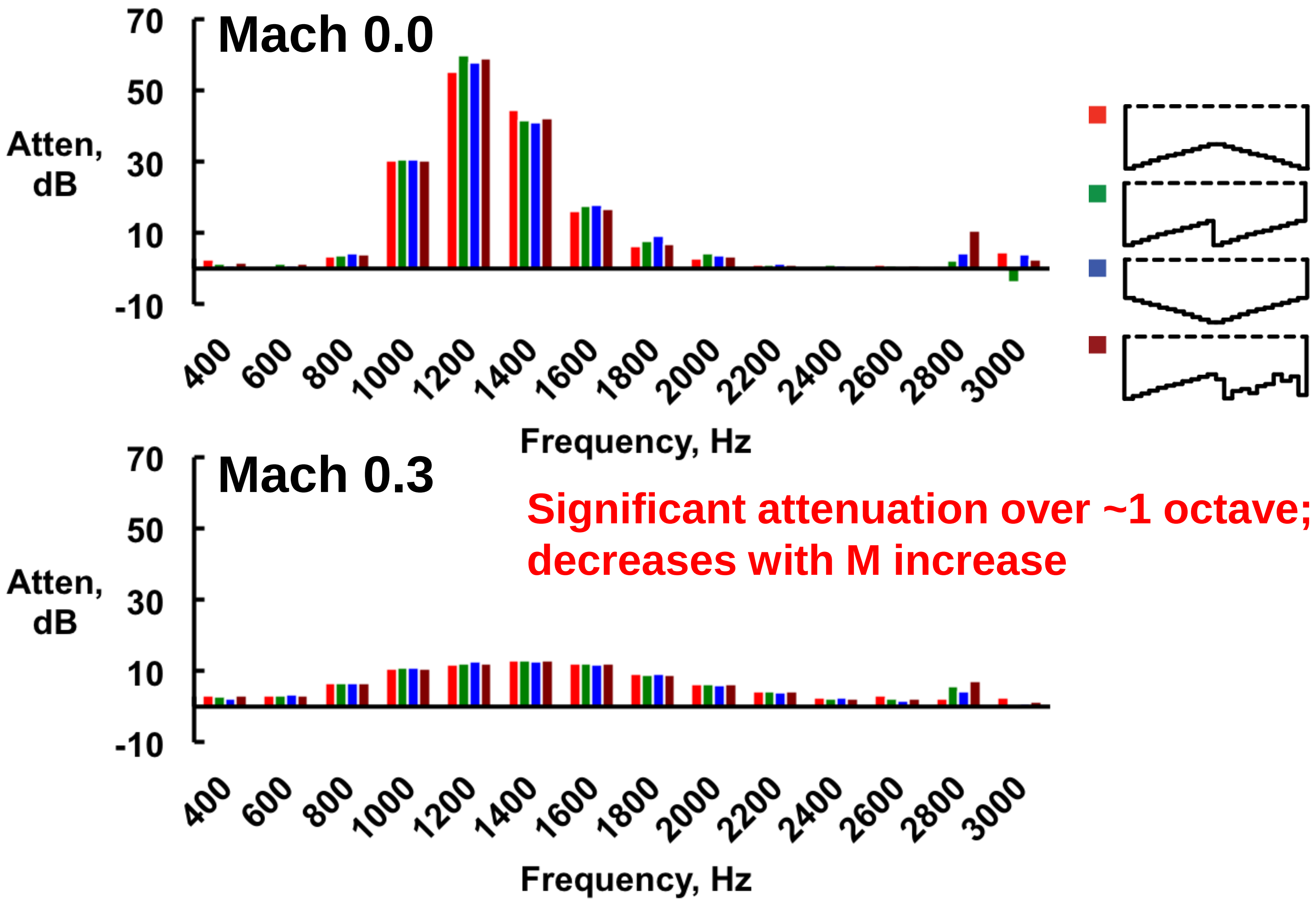
For example, note 1200 Hz reflection at axial midpoint (x~0.4 m)

Configuration Effects



Note smooth pattern at 1200 Hz for upper configuration – axial midpoint chambers are at near-optimal length for this frequency

Configuration Effects

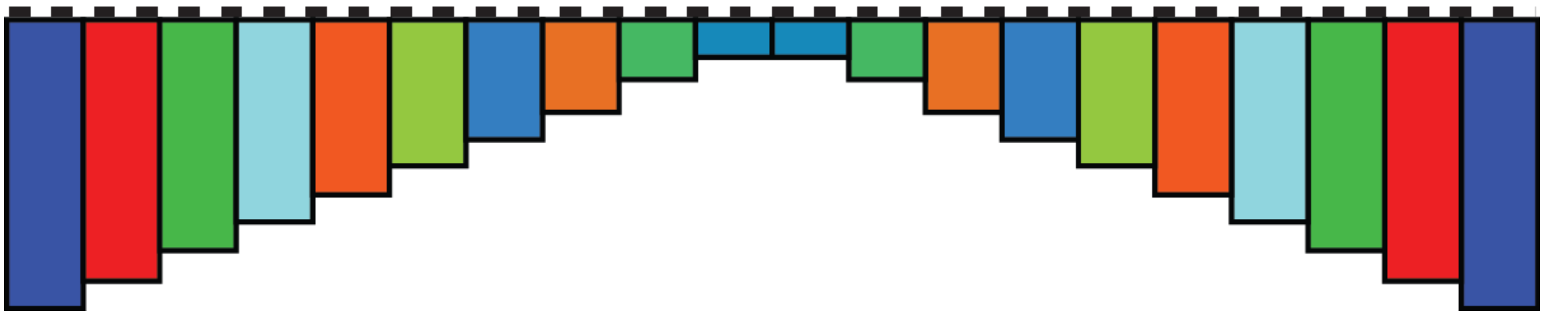


Significant attenuation over ~1 octave; decreases with M increase

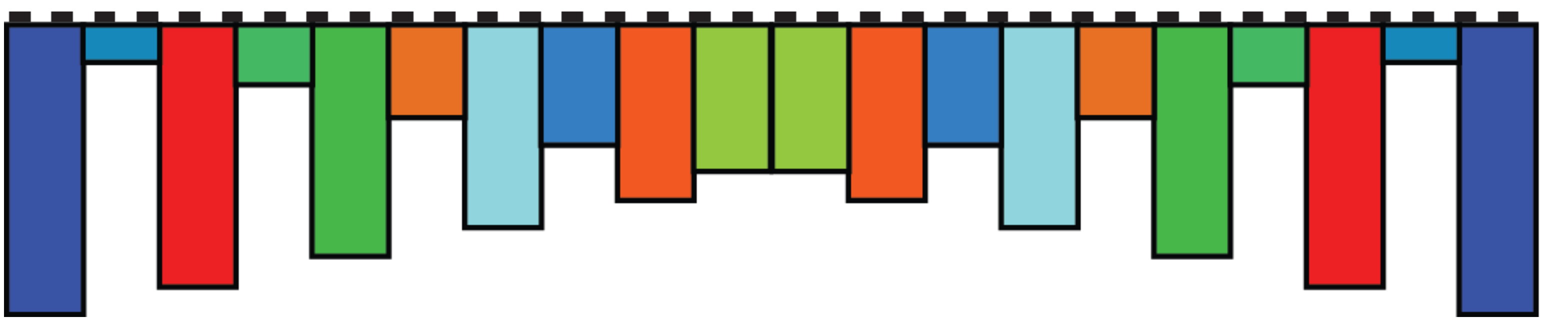
Relatively configuration independent - packaging opportunity?

Repackaging Example

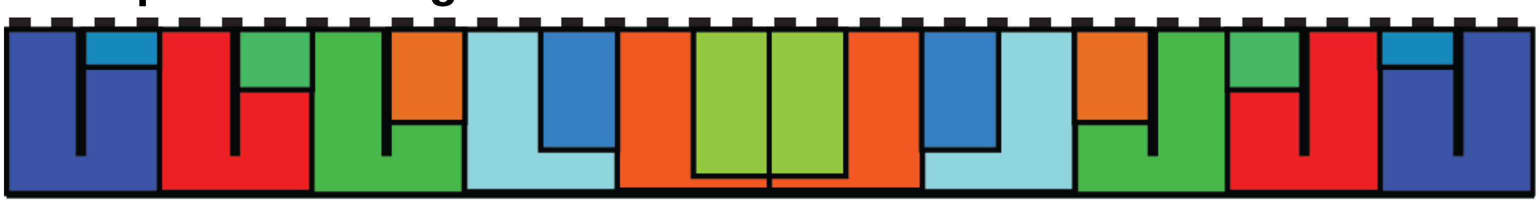
Original configuration



Rearrange order of chambers



Compressed design



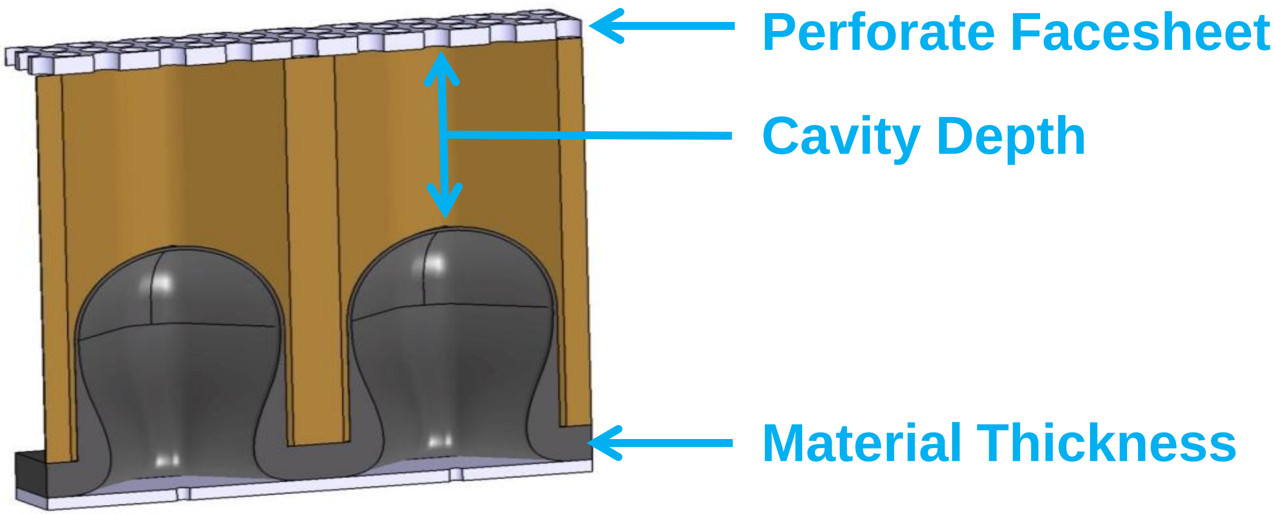
Significant reduction in liner thickness!

Variable-Depth Liner (large extent)

Status

- Enabled by 3D printers
- Potential to enable thinner broadband liners
- Current plan:
  - Design & test configurations optimized for GFIT (plane waves)
  - Design & test configurations optimized for CDTR (higher-order modes)

5. Adaptive Liner



Sketch provided by Cornerstone Research Group

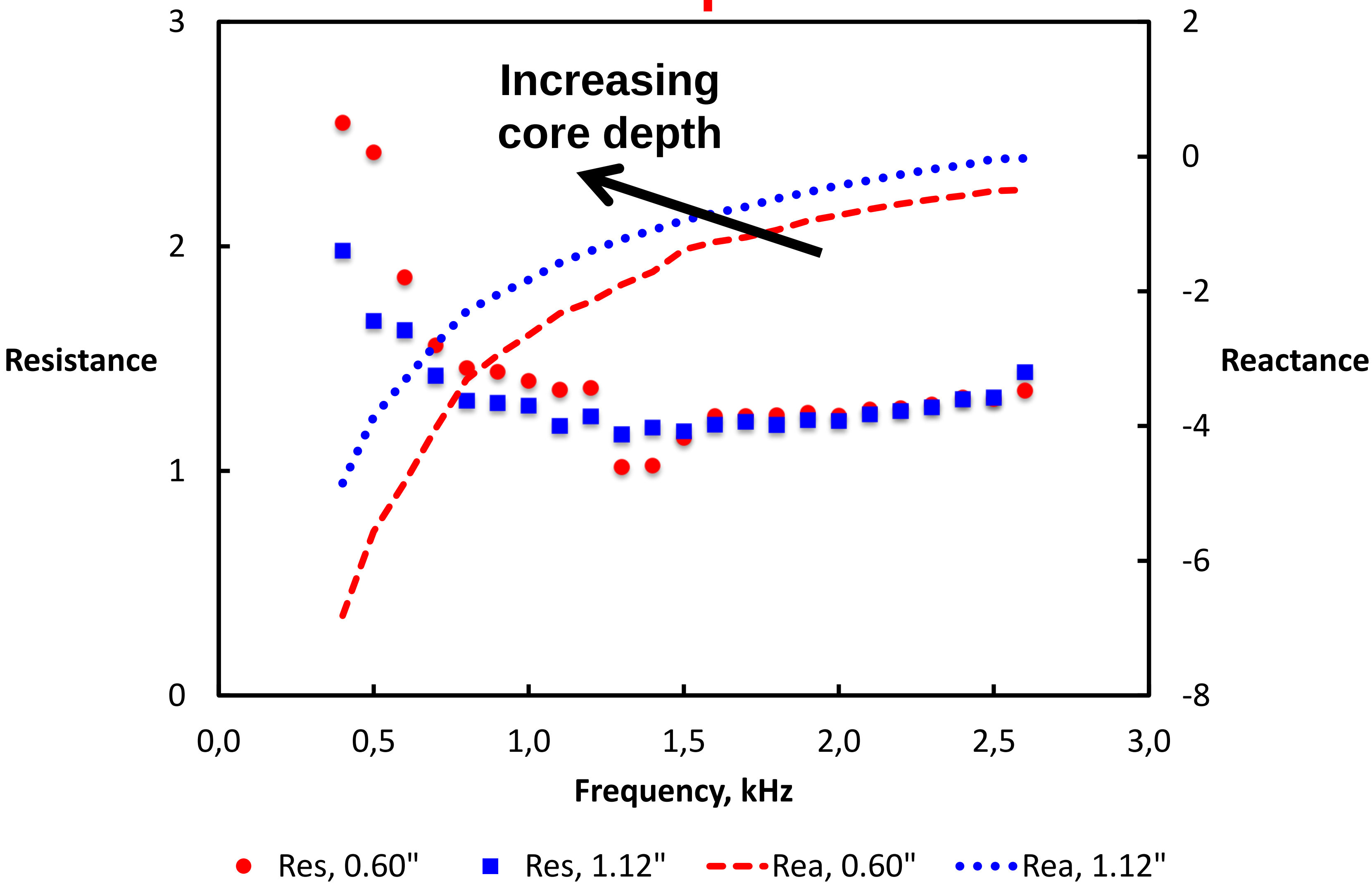
Current adaptive approach

- Add heat to SMP material
- Apply pressure to expand into honeycomb core
- Cool material to lock design
- Release pressure

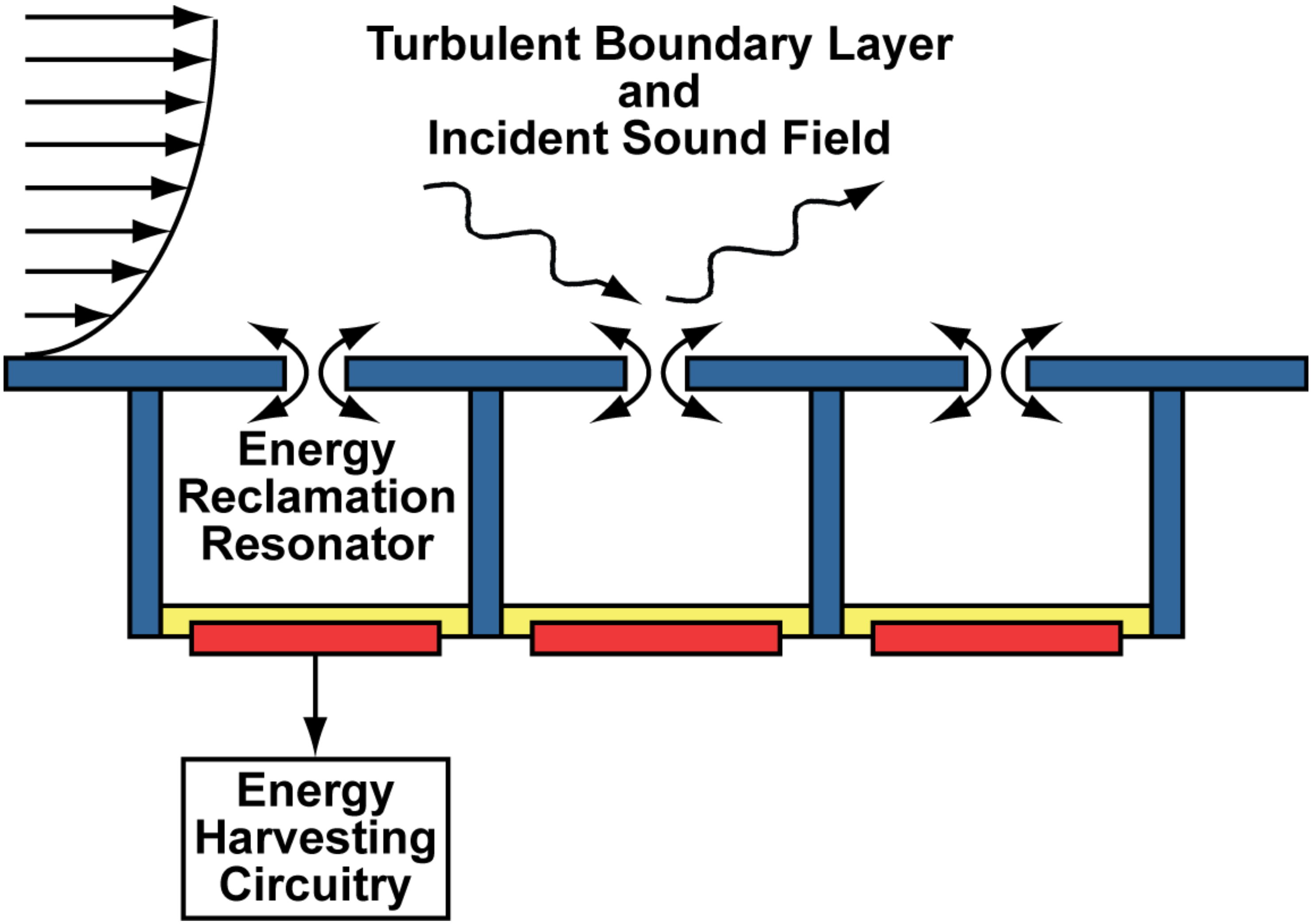
Mounted in GFIT

SMP-Based Adaptive Liner

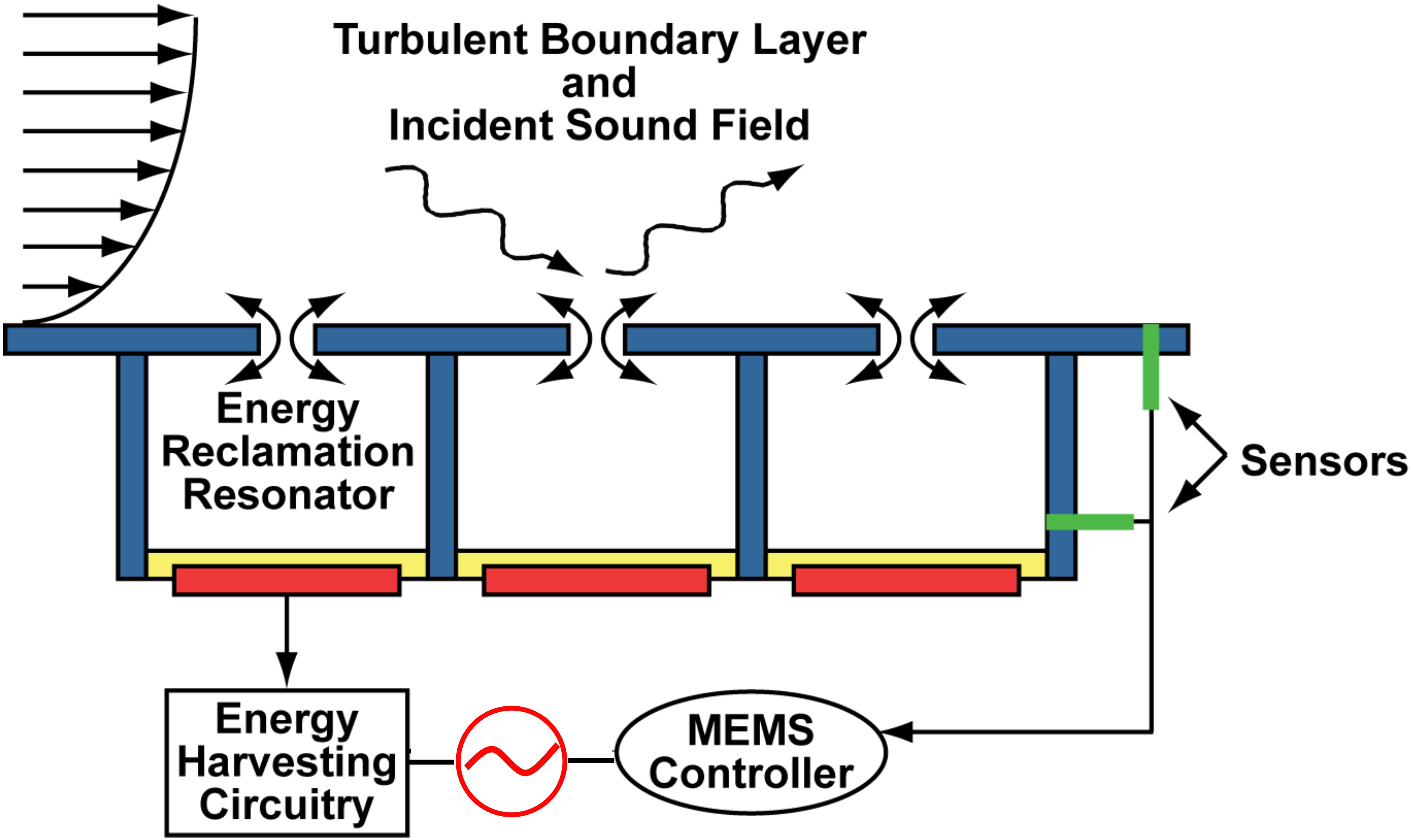
Educed Impedances



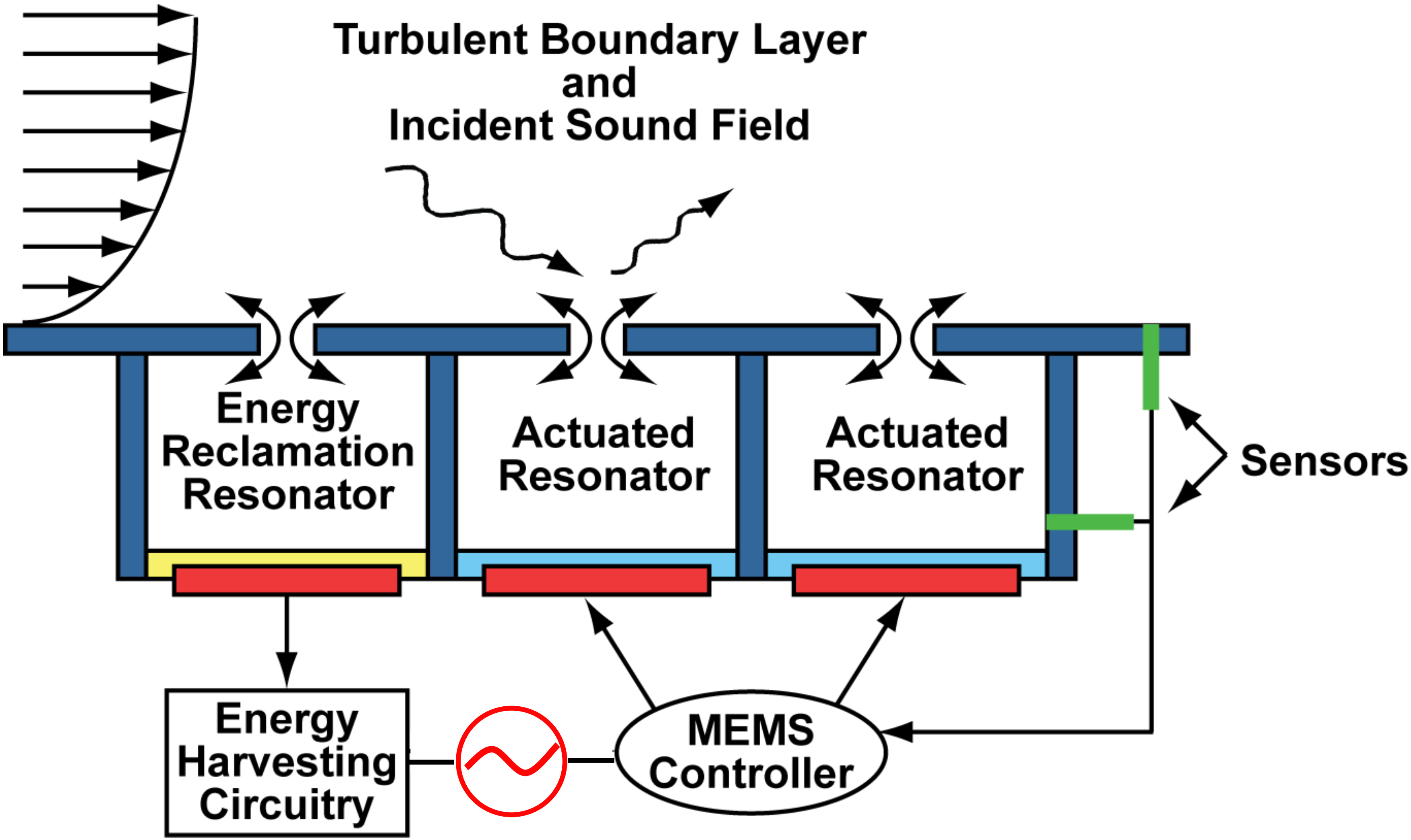
Electromechanical



Electromechanical



Electromechanical



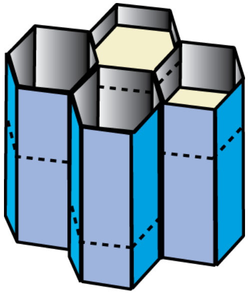
Adaptive Liner

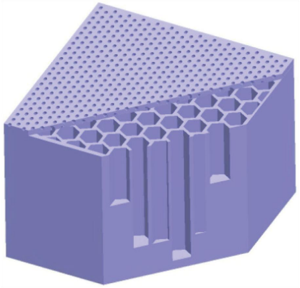
Status

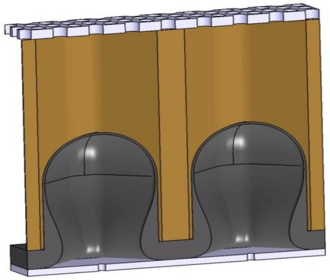
- Currently in development stage
- Great potential, but challenging modeling problem

Status Summary

- Extended-Reacting
  - Revisit as foams (synthetic?) become more viable
- Multi-Layer
  - Method of choice for conventional liner applications
- Variable-Depth (small spatial extent)
  - Method of choice for novel applications
- Variable-Depth (large spatial extent)
  - Evaluation stage
- Adaptive
  - Development stage







Acknowledgements

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Dan Sutliff
Janelle Born
Larry Becker
Tony Parrott (ret.)

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Extended-Reacting

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Multi-Layer

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Variable-Depth (limited spatial extent)

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Variable-Depth (large spatial extent)

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Adaptive

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Variable-Depth Liners: Modeling