

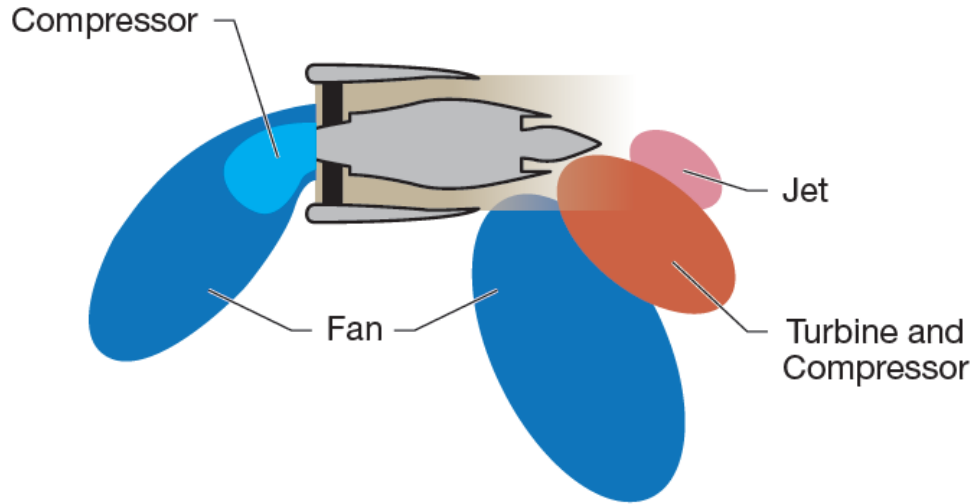
Extending Acoustic Liner Bandwidth with Simple Embedded Septa

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Turbofan Noise Sources



Dominant component: **FAN NOISE**

Liner challenges:

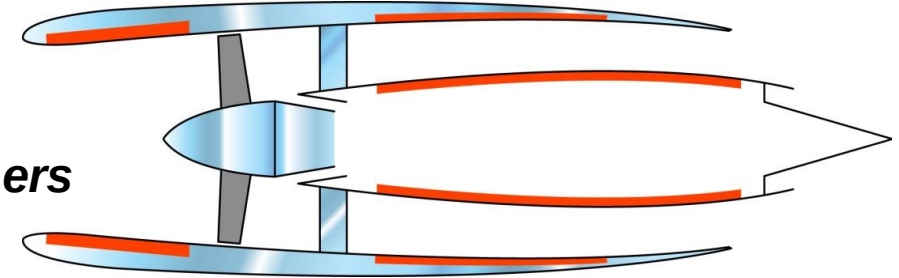
- Low-frequency absorption
- Broadband attenuation

Noise Characteristics

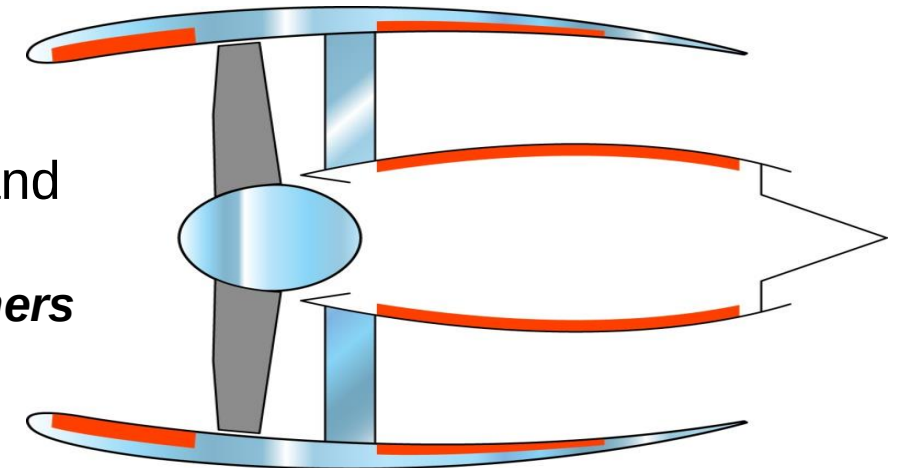
Tone dominated
Need: **Narrow-band liners**

Turbofan Engine Trends

1970s – 1980s: $BPR \sim 4$



1990s – Present: $BPR > 9$

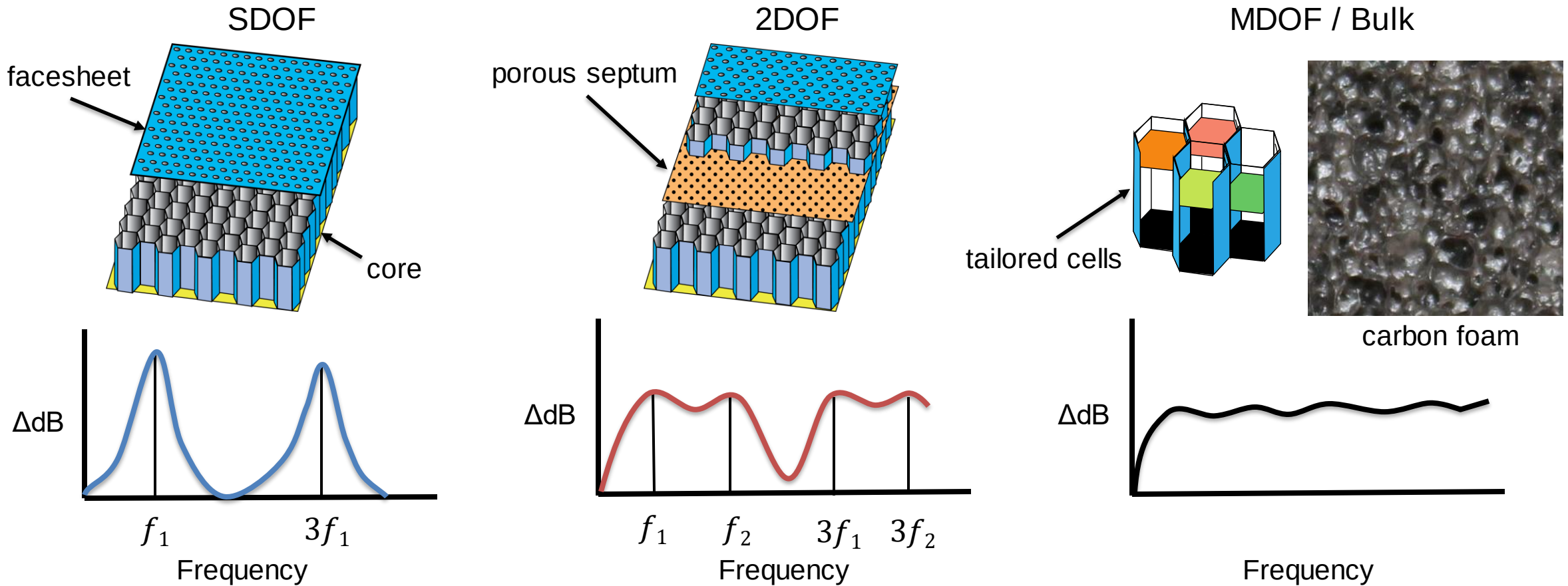


Increased broadband component
Need: **Broadband liners**

Background



- Acoustic liner performance is dependent on matching impedance to the acoustic environment



Increasing liner bandwidth generally comes with higher manufacturing costs

Concept – Simplified Septa Liner



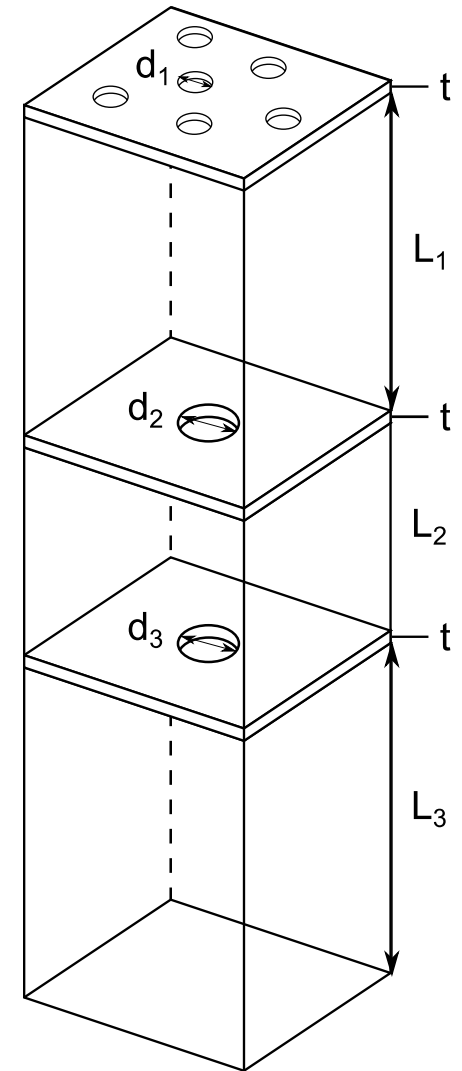
Features

- Conventional perforate facesheet
- Embedded septa using a single perforation
- Number and placement of septa determined through optimization
- Facesheet characteristics determined through optimization
- Replicated unit cell to give uniform impedance

Advantages

- Multiple ways to create perforations in septa
 - drill
 - laser
 - punch
 - additive
- Potential for improved low frequency performance
 - Larger septa perf diameter → Larger end correction
- Broadband performance

Provides an additional means of creating a desired liner impedance



Simplified Septa
unit cell

Concept – Optimization



Liner model: ZKTL impedance prediction code

- Incorporates wave propagation facesheet model
- Based on recent work by Kreitzman and Jones (AIAA 2024-2801)

Optimizer: MATLAB ‘fmincon’ function for constrained nonlinear problems

- Sequential Quadratic Programming (SQP) solver
- Basin hopping/Multiple initial guesses → greater likelihood of global solution

Objective function: maximize absorption over a frequency range

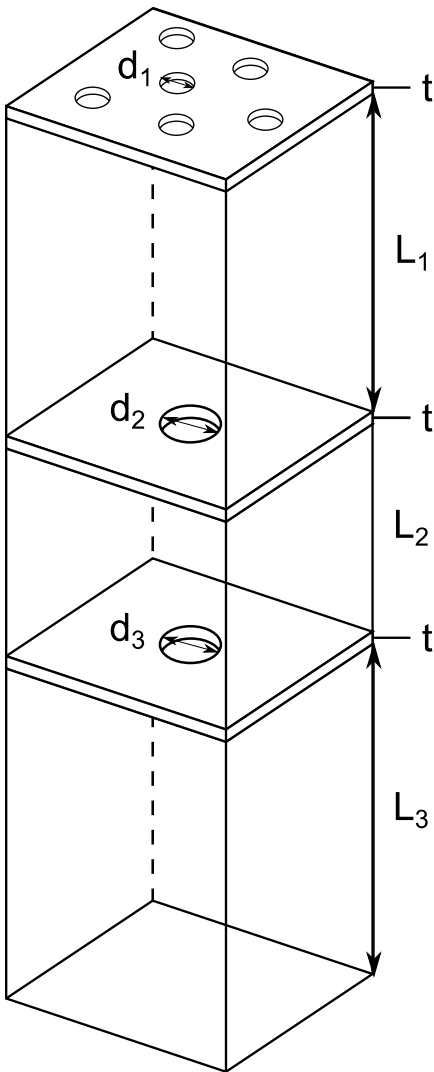
absorption coefficient → $\bar{\alpha} = \frac{1}{f_2 - f_1} \int_{f_1}^{f_2} \alpha(f) df$

$f_1 = 600 \text{ Hz}$
 $f_2 = 3000 \text{ Hz}$

Optimization constraints:

SPL: 120dB

	Description	Lower Bound	Upper Bound
Facesheet and Septa	hole dia. (d _n)	0.51 mm	2.54 mm
	thickness (t)	0.51 mm	2.54 mm
	POA	4 %	16 %
Cavities	total length (L)	0.81 mm	50.8 mm
	L _n	4.57 mm	15.24 mm



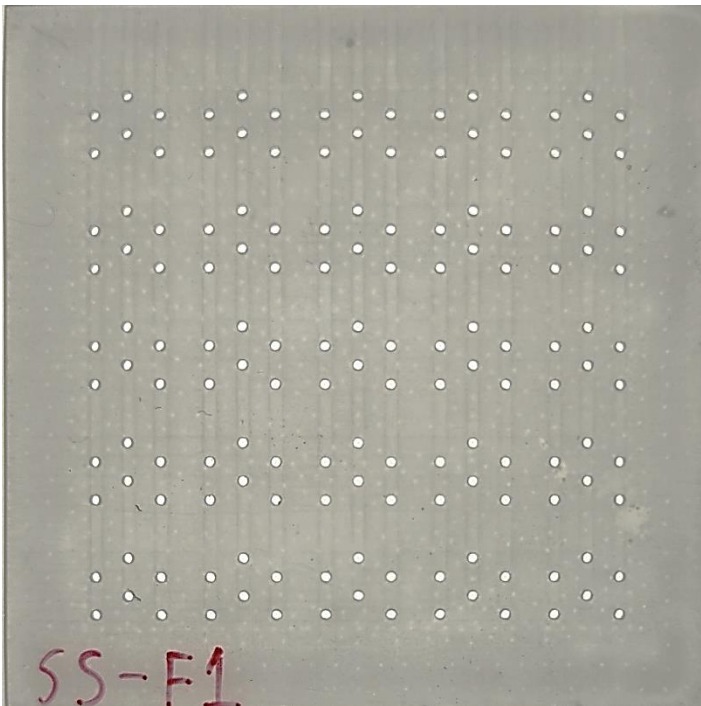
Simplified Septa unit cell

Experiment – Liner Samples

Additively Manufactured (AM) liners:

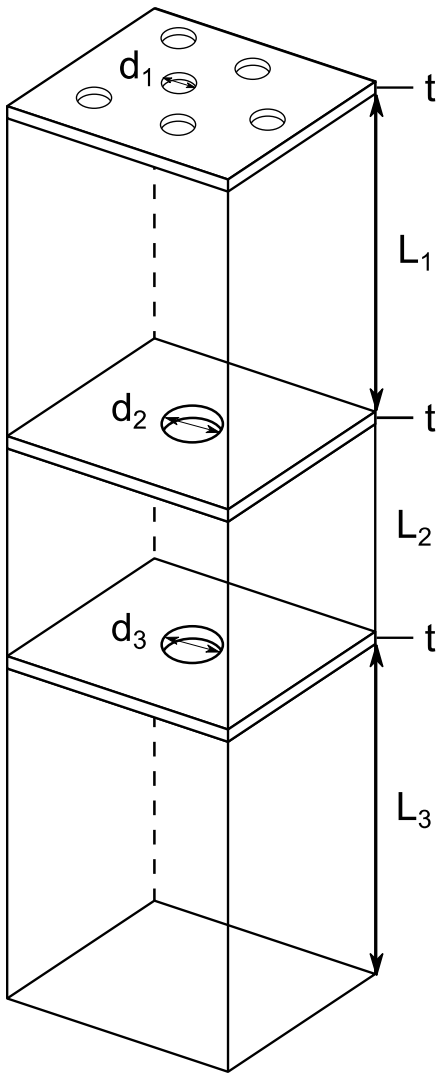
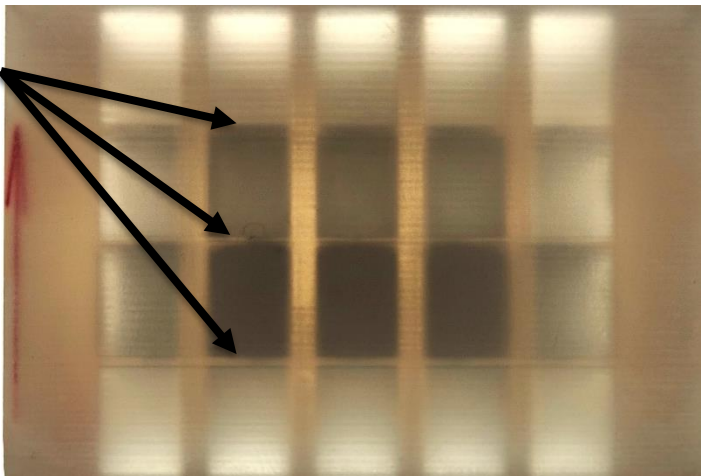
- Common facesheet (3% POA)
- SLA process using Accura 60 resin
- 5x5 grid of unit cells w/ 2.54 mm partitions
- 2- and 3-septa designs (AM2S and AM3S)

Facesheet



Dimension (mm)	2 Septa (AM2S)	3 Septa (AM3S)
t	0.81	
d_1	0.81	
L_1	14.40	10.8
d_2	1.07	2.00
L_2	10.49	10.8
d_3	0.64	0.81
L_3	7.52	10.8
d_4	N/A	0.81
L_4	N/A	10.8
Total Length	34.03	45.62

embedded septa



Simplified Septa unit cell

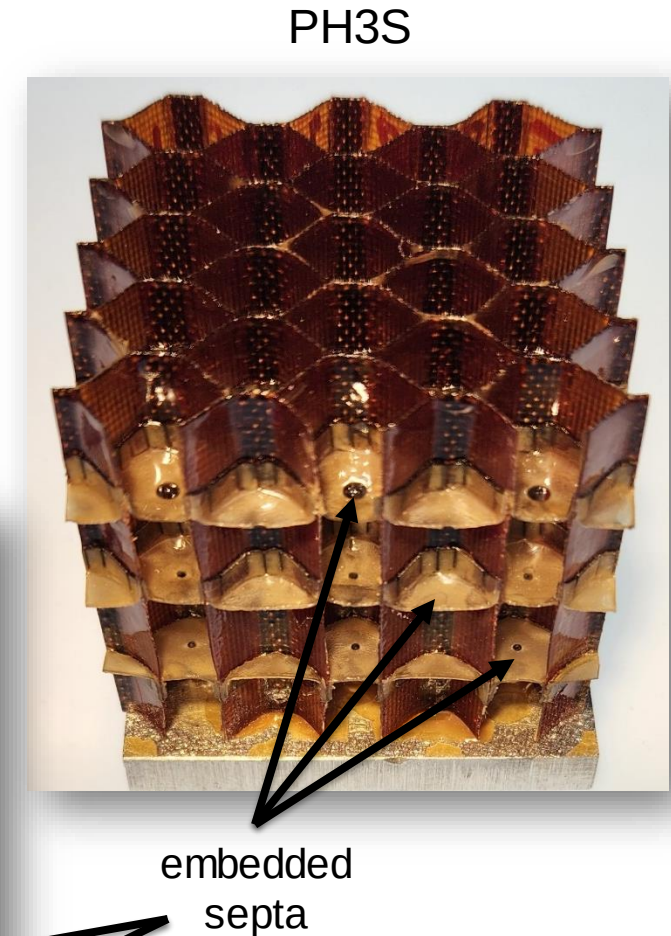
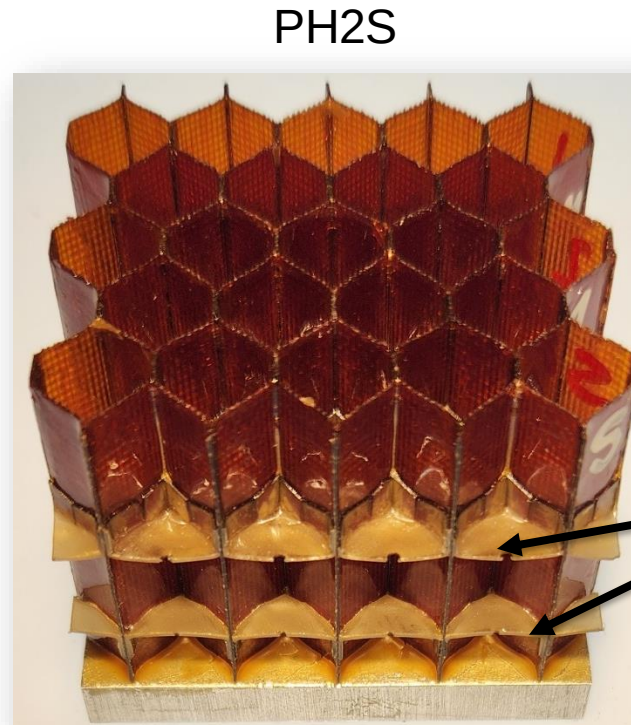
Experiment – Liner Samples (Phenolic Honeycomb)



Phenolic Honeycomb (PH) liners:

- State-of-the-art construction
- Common facesheet (27 cgs Rayl mesh)
- Hexcel Acousti-Cap process
- 9.5 mm cell width, 0.25 mm thick septa, 0.5 mm partitions
- Same total length, perforate size and septa placement as the AM samples
- 2- and 3-septa designs (PH2S and PH3S)

Note: As the AM and PH samples share common total length, septa placement and perforate diameter, overall impedance characteristics should be similar but not exactly match

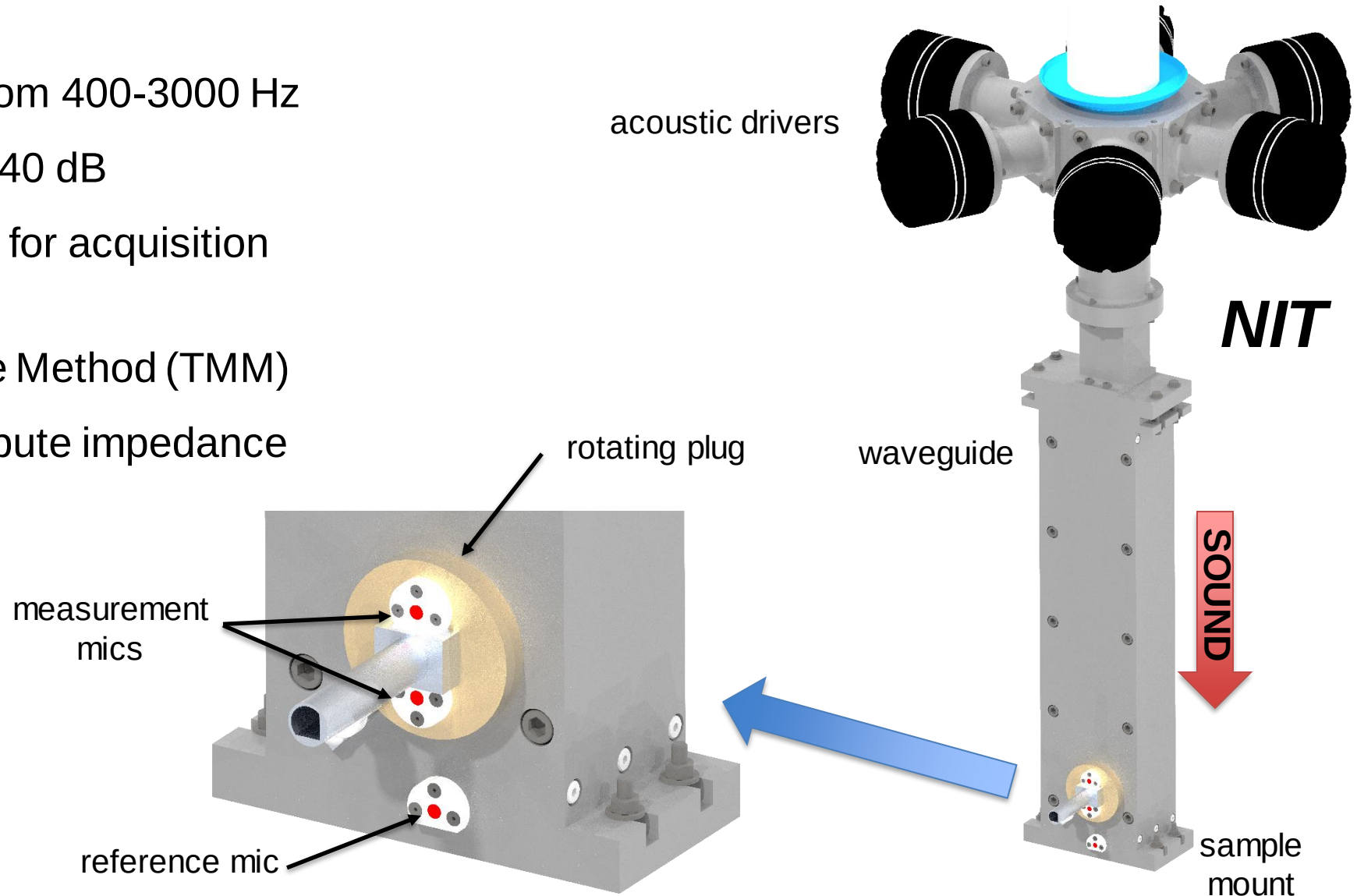


Experiment – NASA Normal Incidence Tube (NIT)

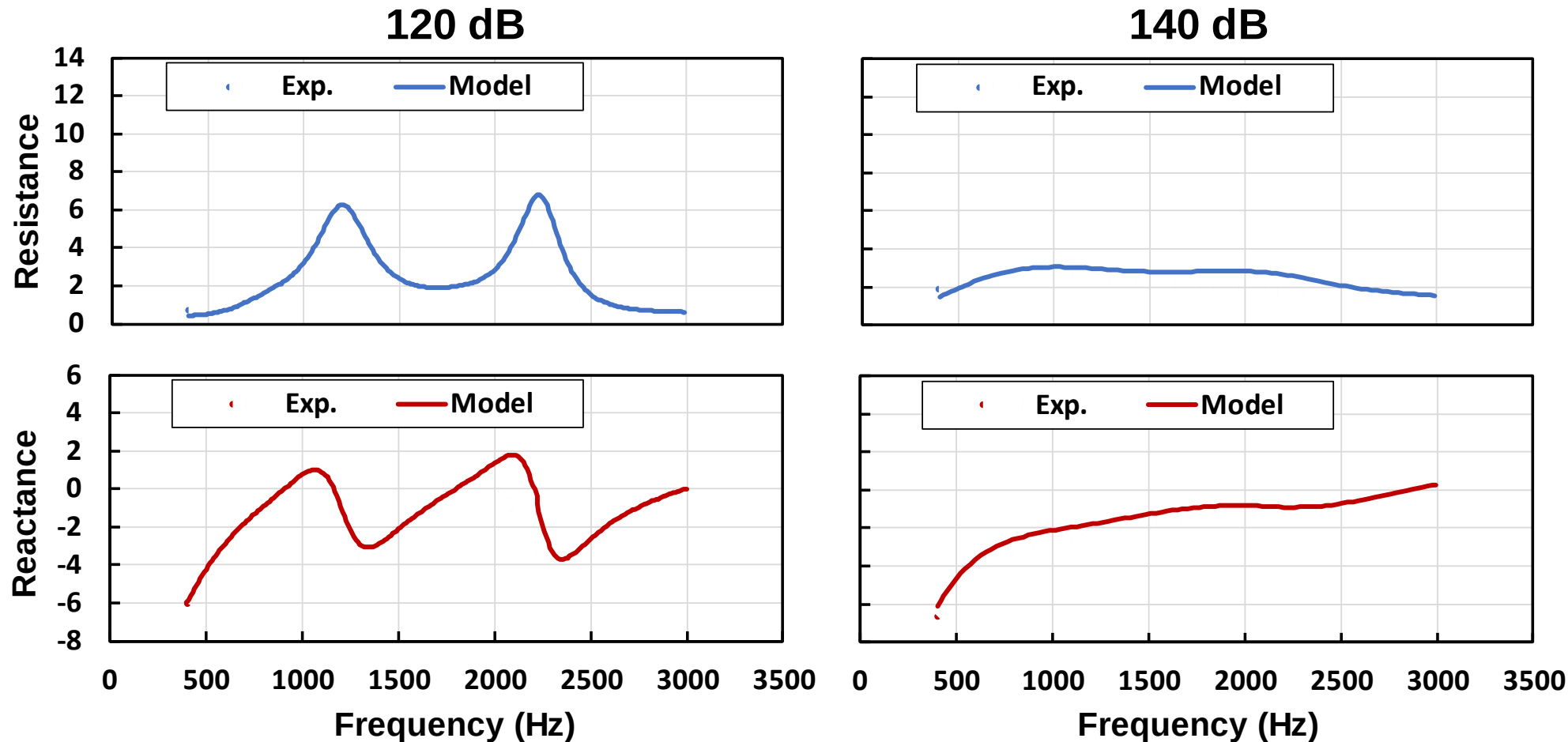


Test Parameters:

- Tonal acoustic excitation from 400-3000 Hz
- Source levels of 120 and 140 dB
- Swept-Sine Method (SSM) for acquisition (5 Hz resolution)
- Switching Two-Microphone Method (TMM)
- Multi-Point Method to compute impedance

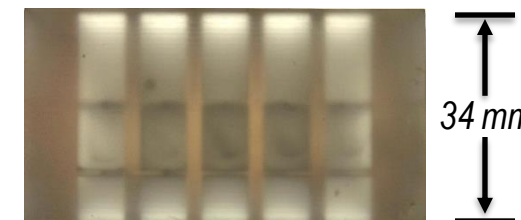


Results – AM2S (Additive Manufactured, 2-septa)

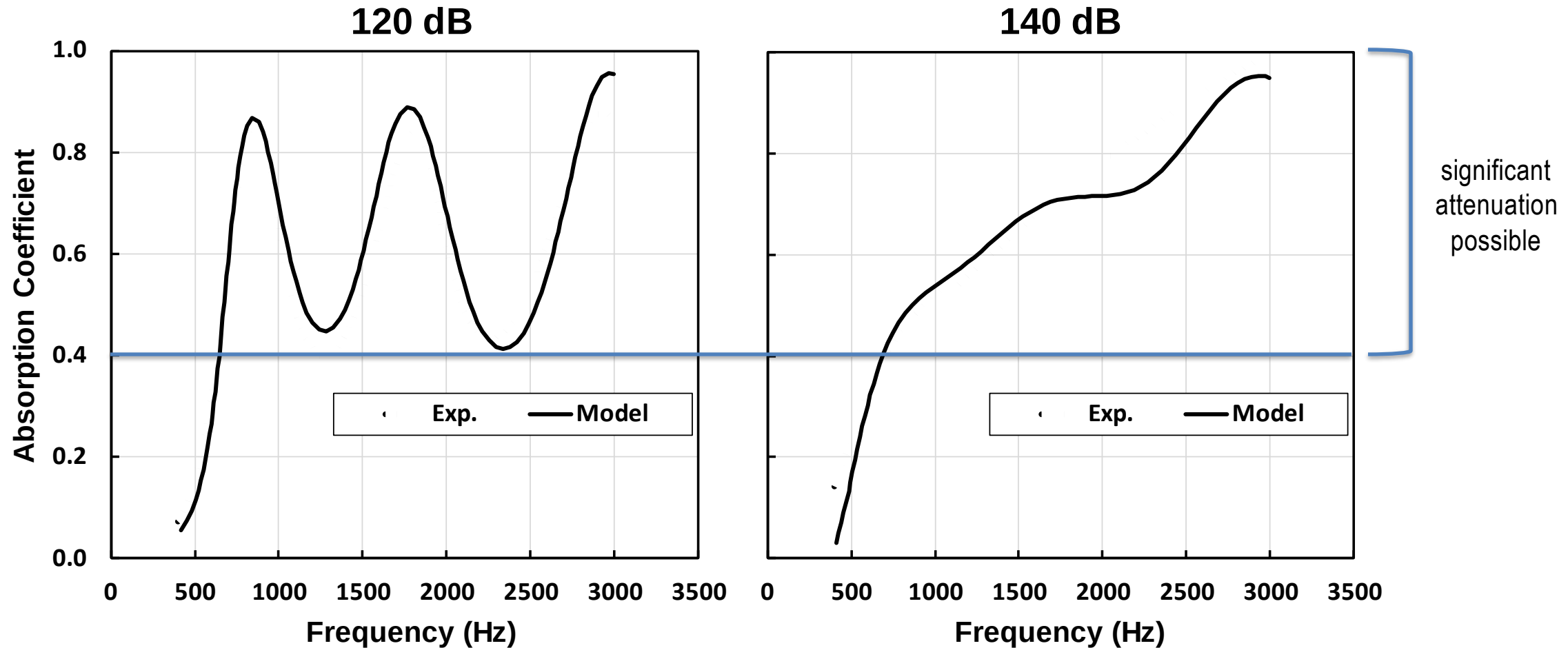


- Sample nonlinear with SPL (as expected)
- Higher SPL → Reduced variation in resistance with frequency
- Good agreement with liner impedance model especially for higher SPL

Side view
AM2S core



Results – AM2S

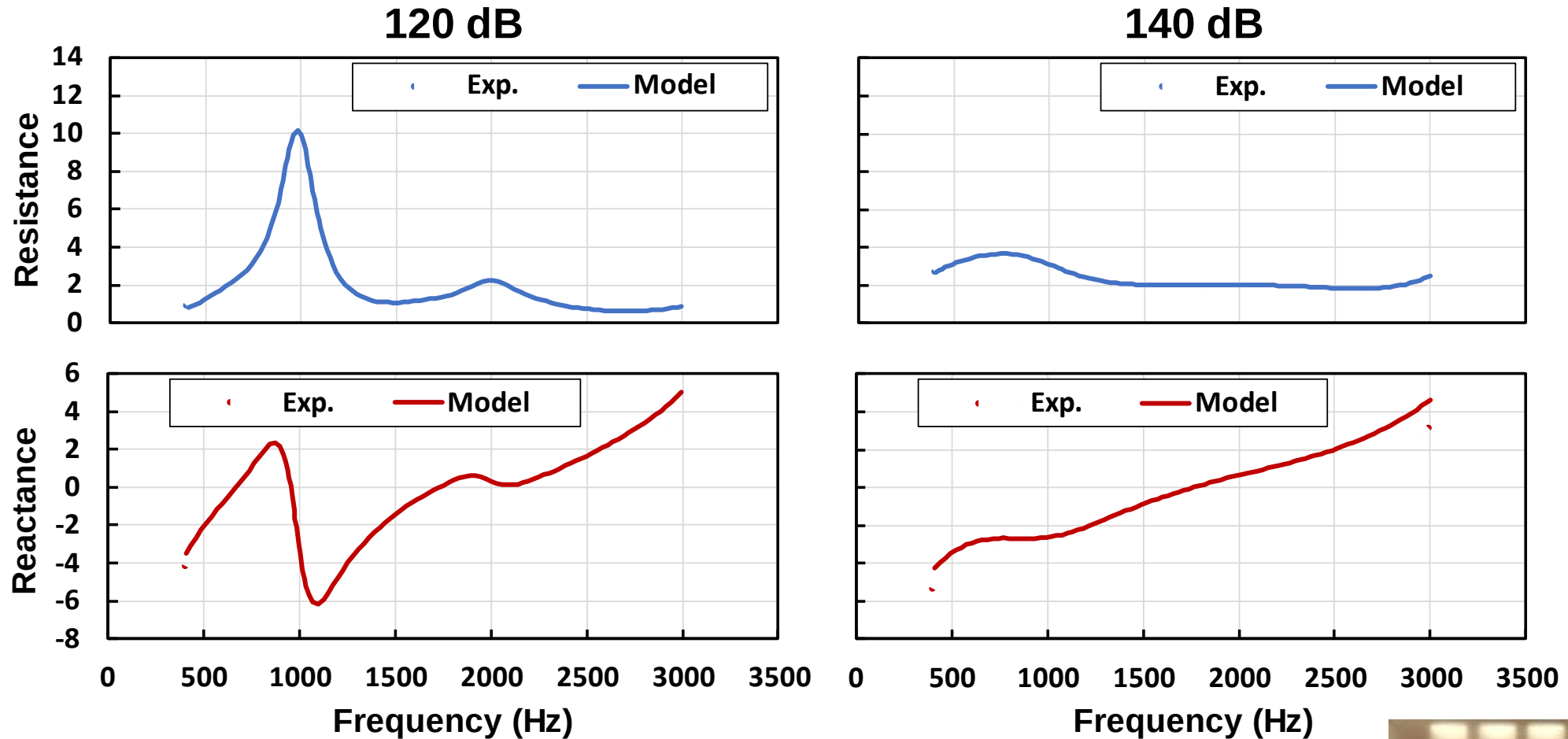


- Significant absorption across a wide frequency range (AC > 0.5)
- Reduced frequency variation with increasing SPL
- Performance predicted well by model

Side view
AM2S core

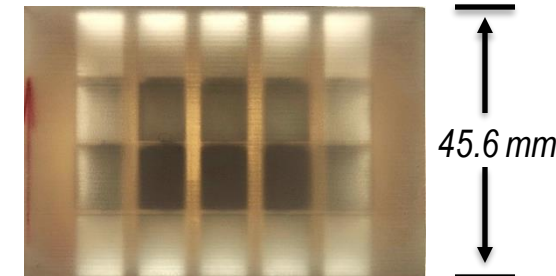


Results – AM3S (Additive Manufactured, 3-septa)

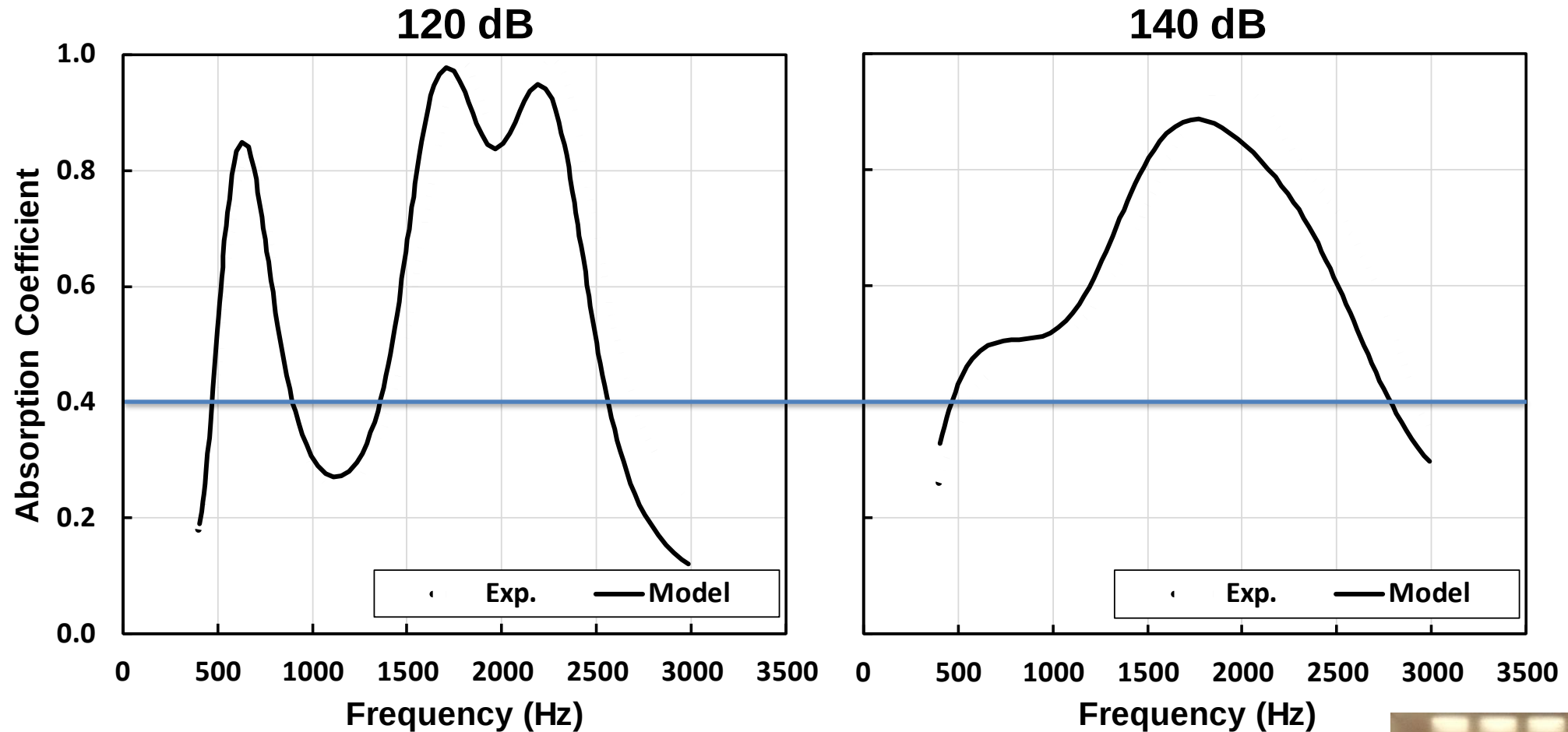


- No obvious resonance associated with 3rd septum
- Reduced frequency variation with increasing SPL
- Excellent impedance prediction by model

Side view
AM3S core

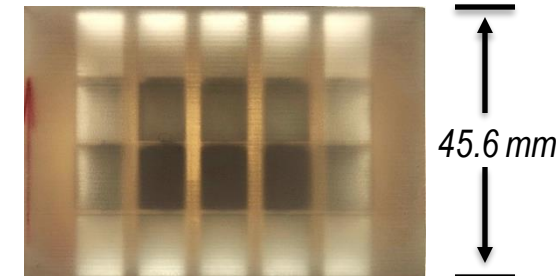


Results – AM3S

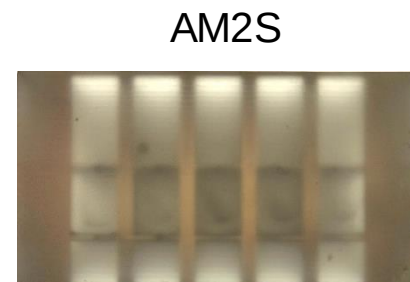
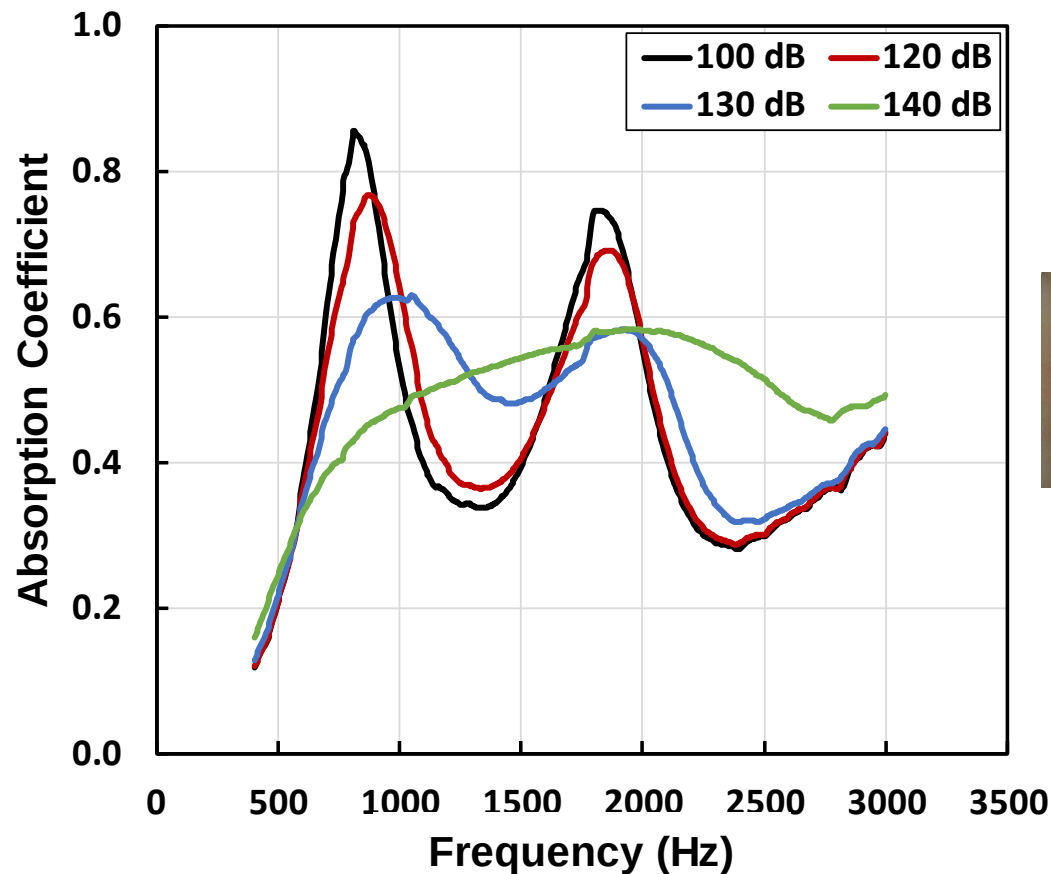
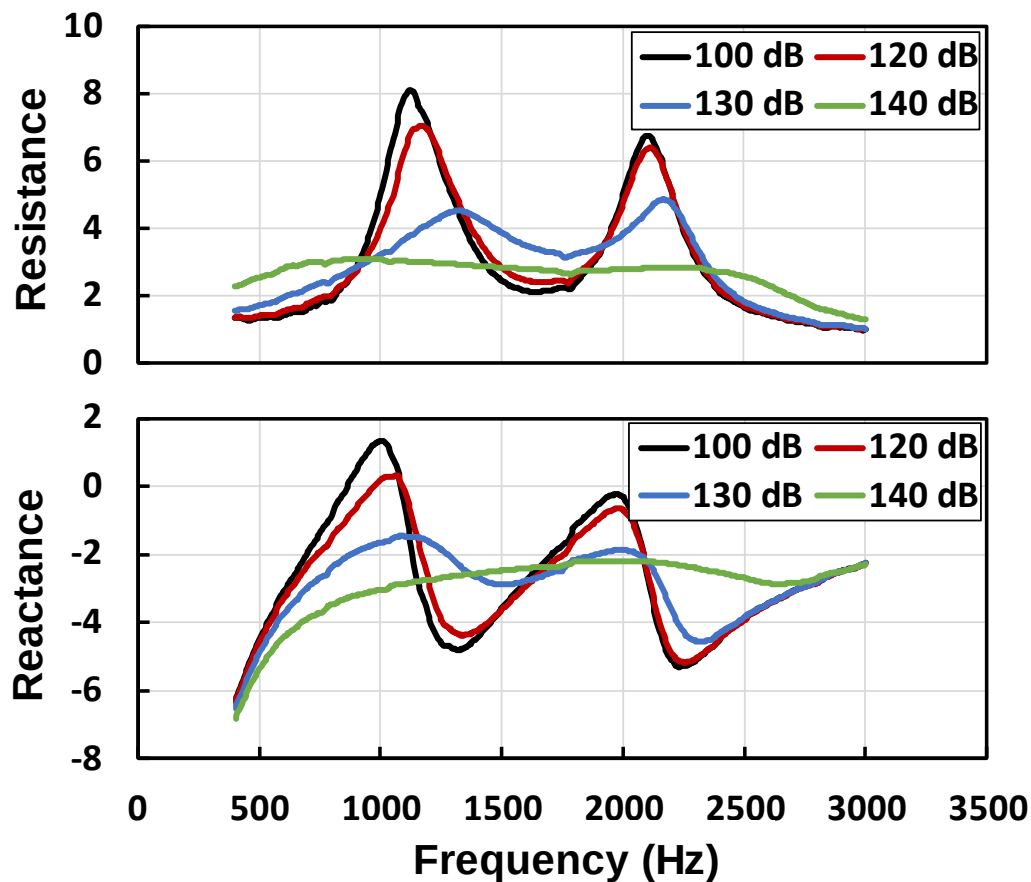


- Increased depth → better performance at lower frequencies
- Reduced performance at higher frequencies relative to AM2S
- Some underprediction at higher frequencies for 140 dB

Side view
AM3S core



Results – AM2S, Linear Facesheet (wire mesh)

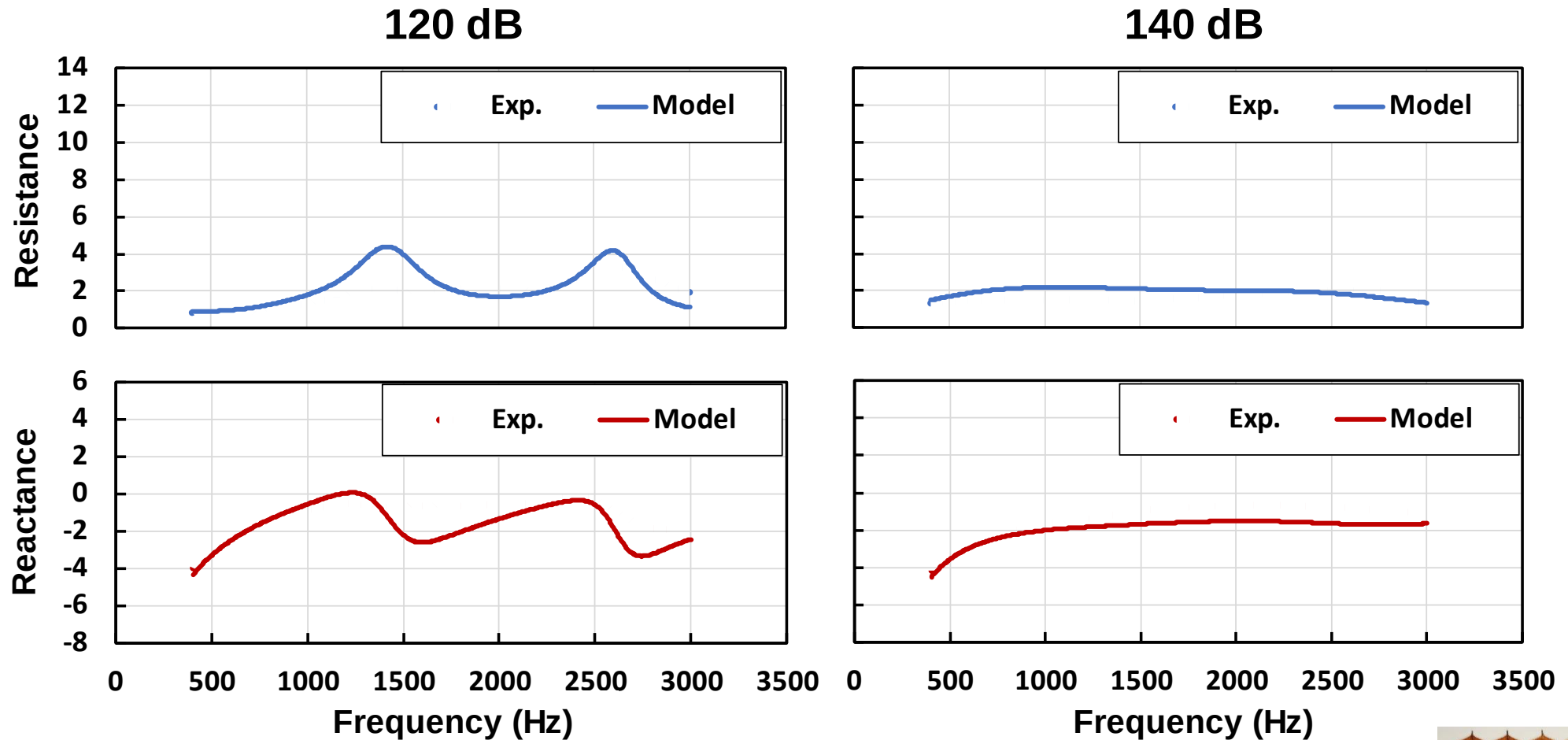


- Increasing SPL → Less impedance variation
- Absorption affected by higher facesheet resistance

Facesheet: 27 cgs Rayl wire mesh

Nonlinear behavior appears to be driven by the core/septa

Results – PH2S (Phenolic Honeycomb, 2-septa)

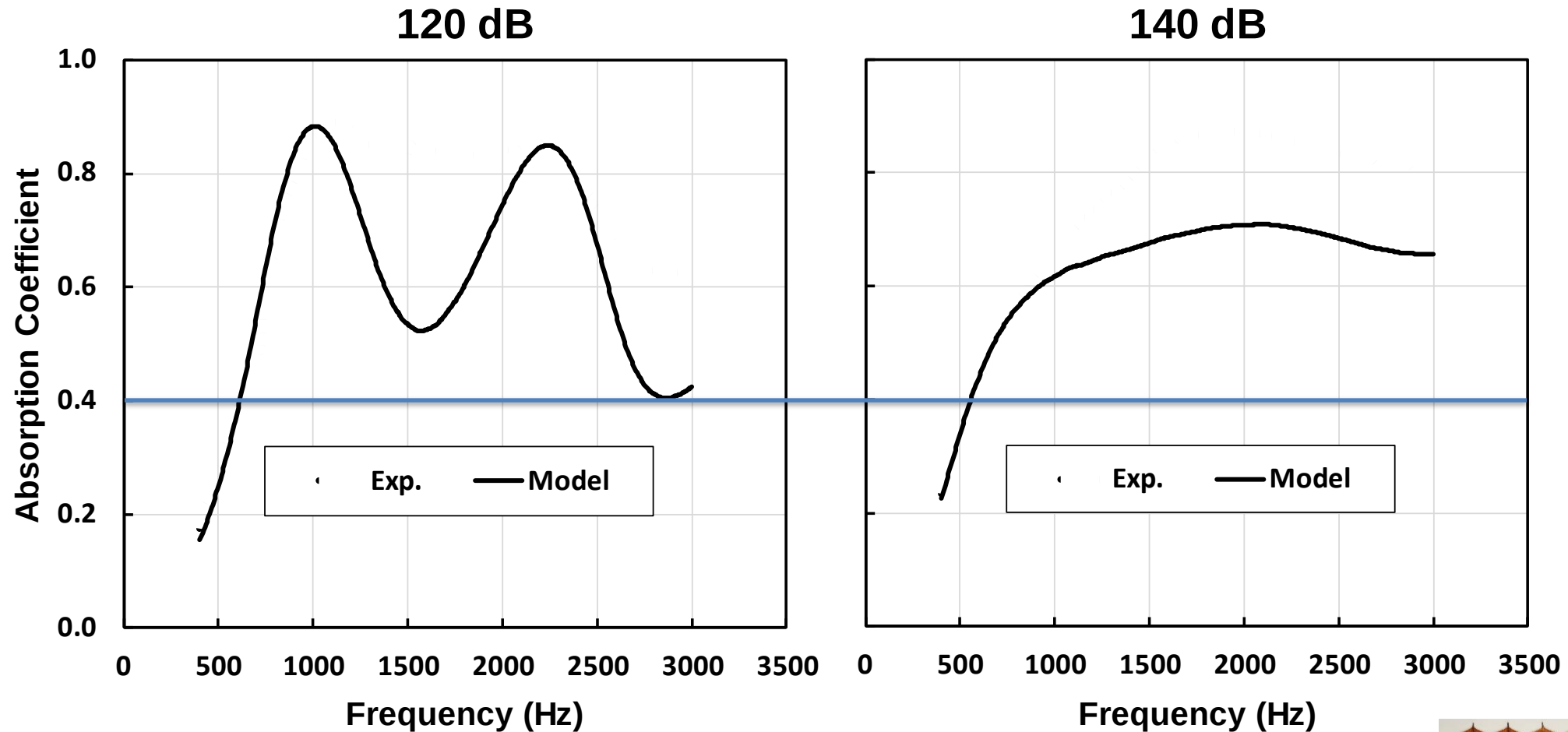


- Less variation with frequency relative to AM2S
- Increasing SPL flattens impedance curves
- Test results not fully captured by model @ 120 dB

PH2S core



Results – PH2S

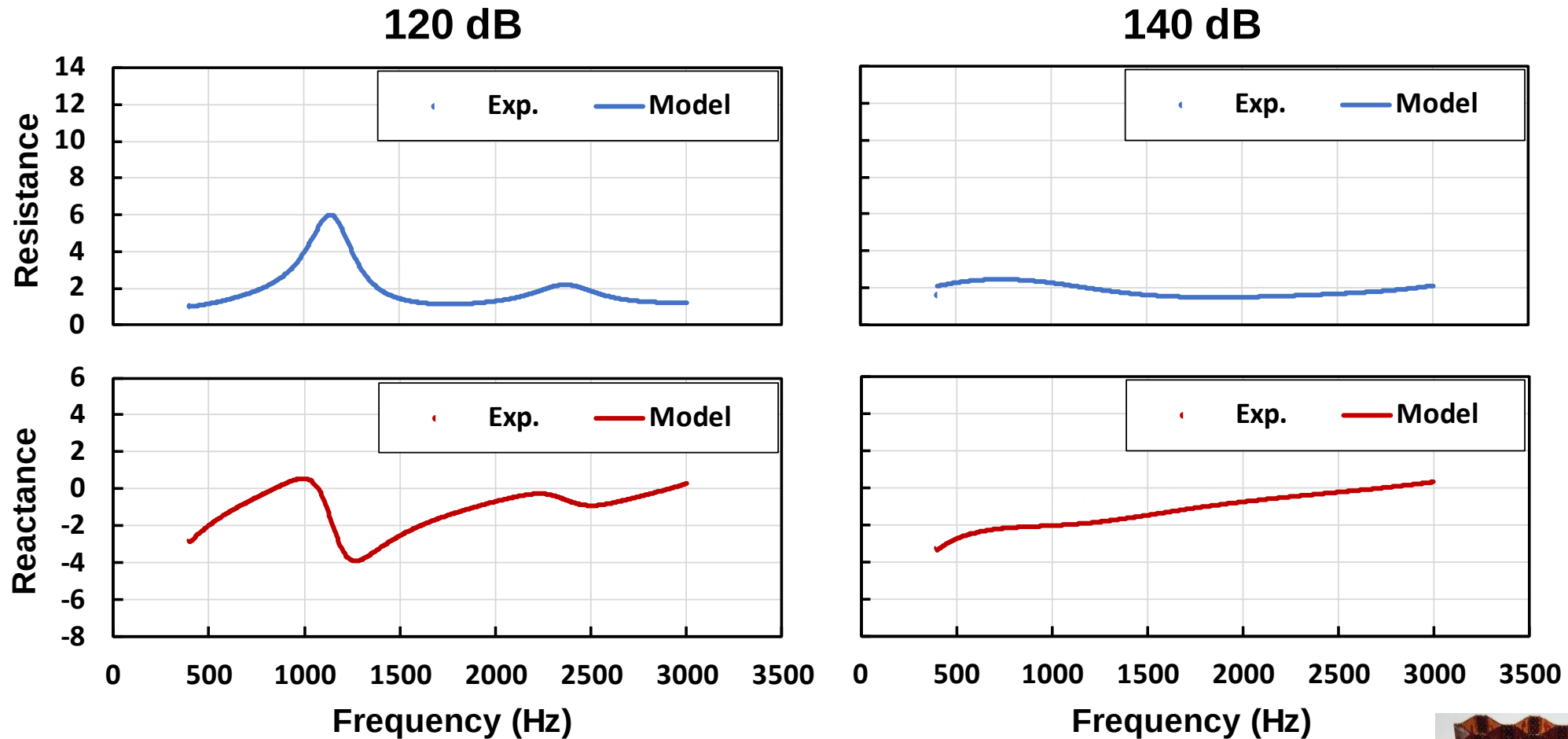


- Absorption performance: PH2S > AM2S
- Broadband performance not diminished by PH construction
- Model comparison degrades after first resonance

PH2S core



Results – PH3S (Phenolic Honeycomb, 3-septa)

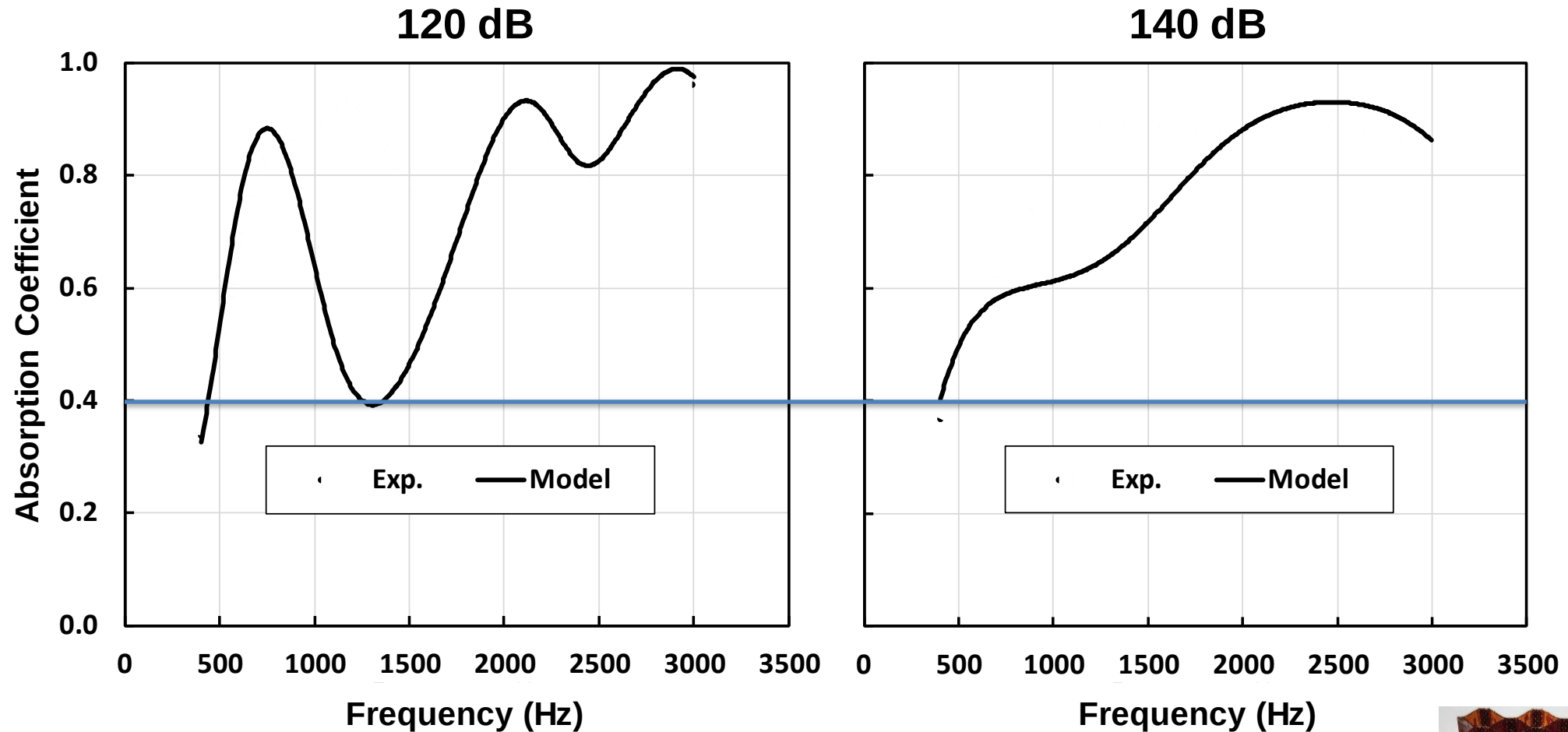


- Similar trends as with PH2S
- Increasing SPL flattens impedance curves
- Test results not fully captured by model for low to midfrequencies



PH3S core

Results – PH3S



- Some absorption improvement relative to PH2S at frequency extremes
- Model fails to predict midrange experimental data

PH3S core

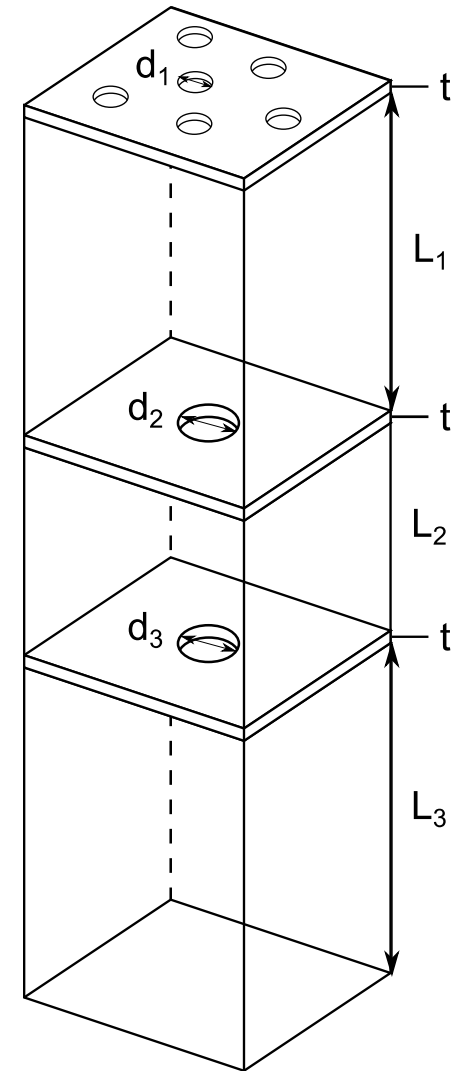


There are liner aspects not included in the model

Conclusions



- Simplified Septa concept developed
 - Single-hole perforate septa
 - Broadband performance
 - Possible manufacturing benefits
- Additive Manufactured (AM) samples
 - Nonlinear with SPL
 - Higher SPL → Reduced impedance variation with frequency
 - Very good agreement between test data and liner model
- Phenolic Honeycomb (PH) samples
 - Construction change did not materially alter performance
 - Improvement in absorption relative to AM samples (bandwidth and values)
 - Issues with model predictions
 - Septa compliance? (assumed rigid)
 - Partial cells
 - Partition geometry



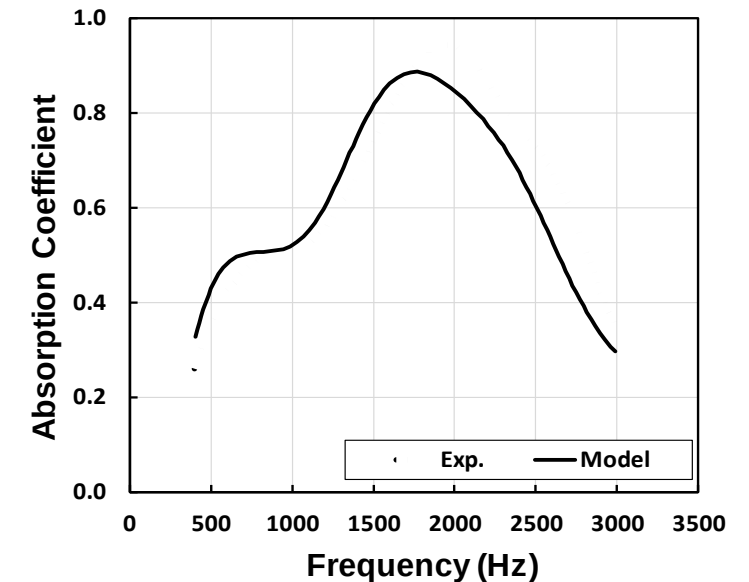
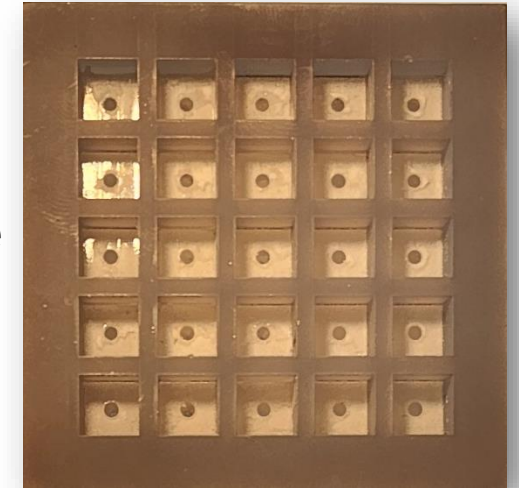
Simplified Septa
unit cell

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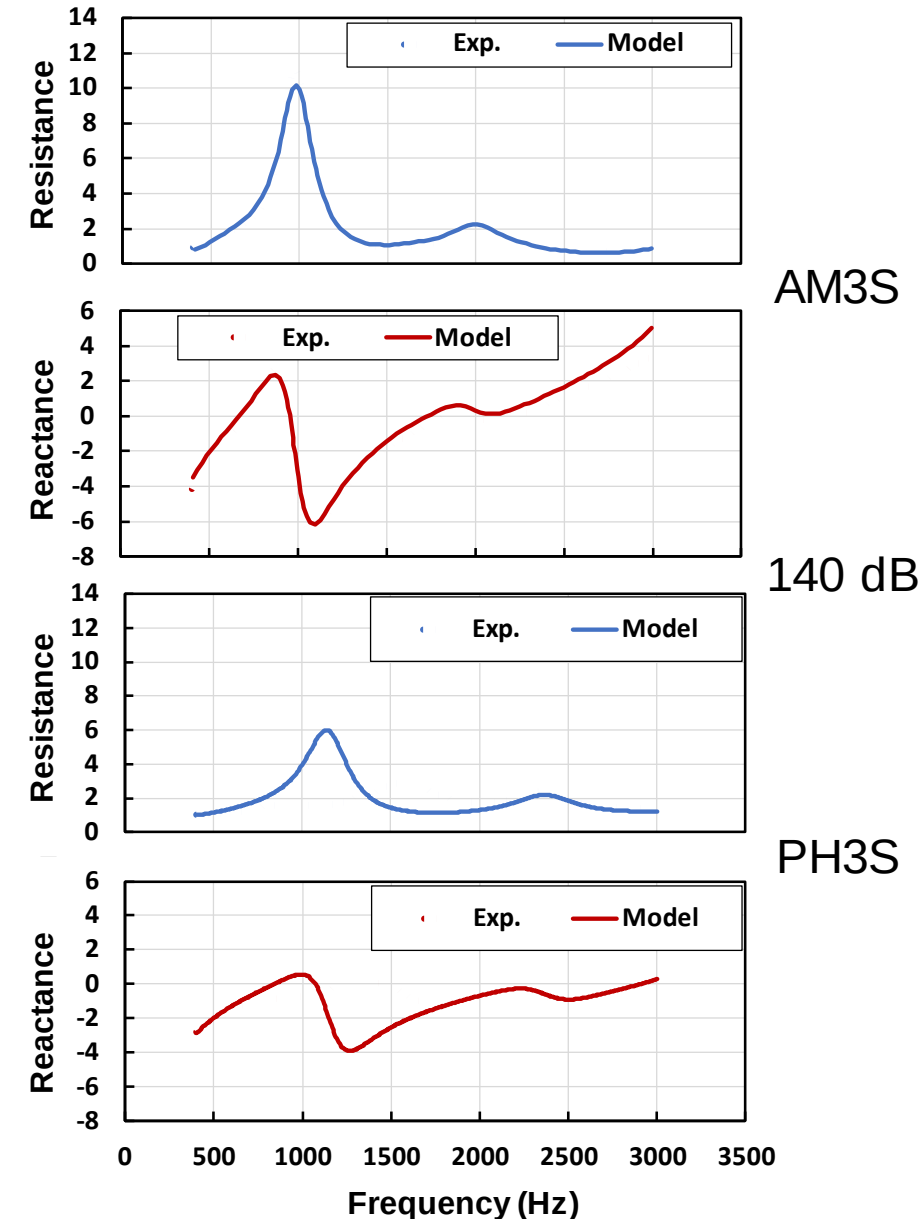
Liner Core



Conclusions



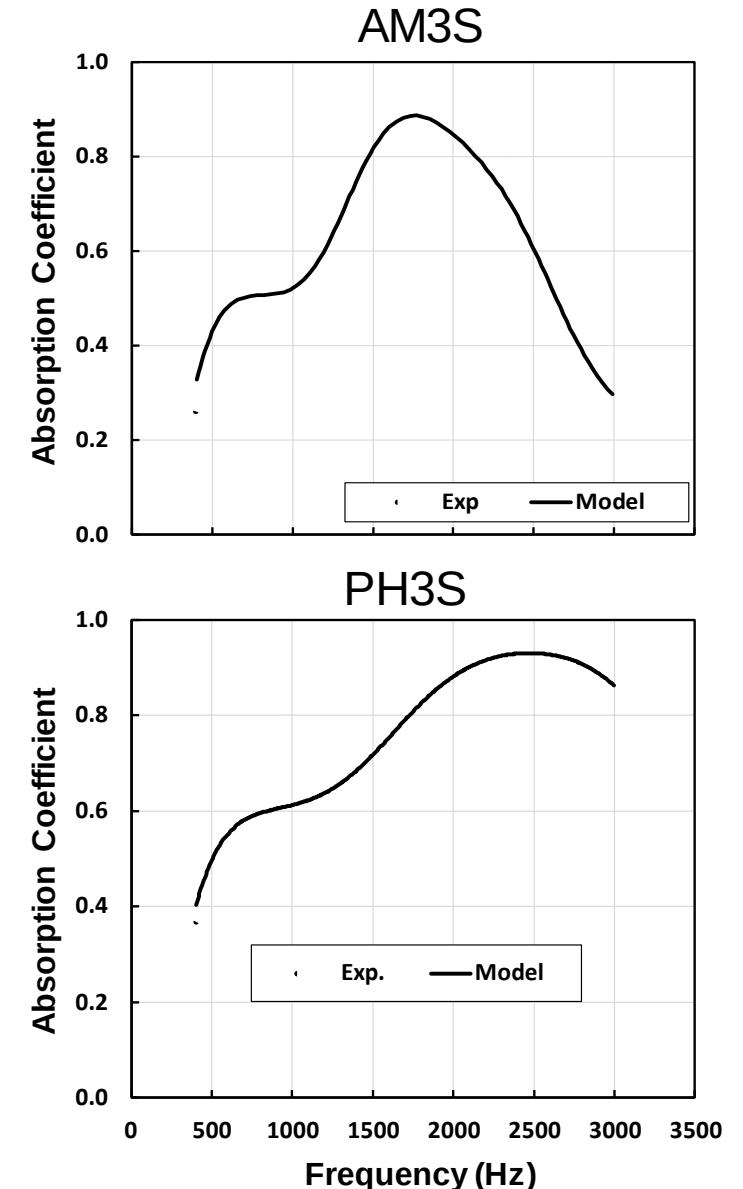
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Future Work

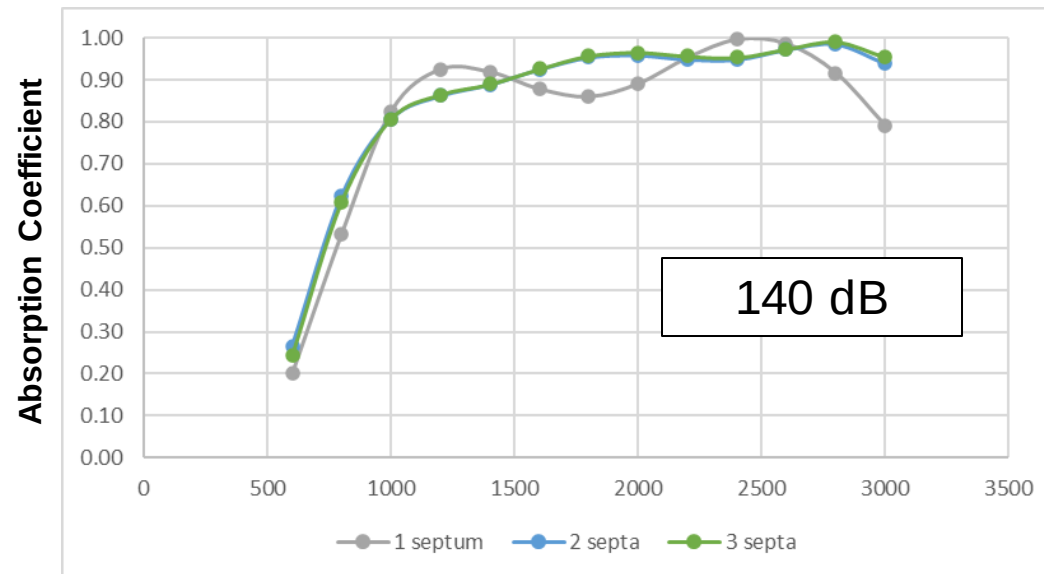


- Model updates
 - Septa compliance terms known
 - Better partition geometry definition
- Method to deal with partial cells (fill or block if needed)
- Reoptimize the AM designs for 140 dB
- Effects of hole placement (Kreitzman and Jones, AIAA 2024-2800)
- Grazing incidence flow testing (GFIT)

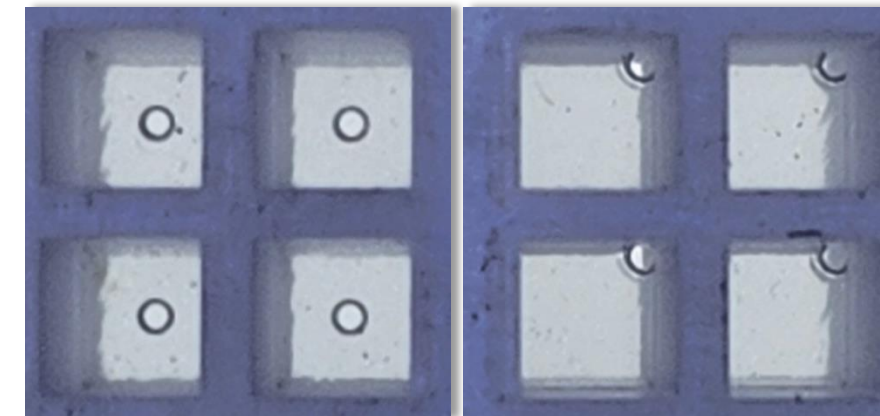
Septa compliance and partial cells



Reoptimized design prediction



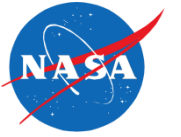
Perforate placement



Centered

Corner

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