



An Acoustic Liner with a Multilayered Active Facesheet

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Background

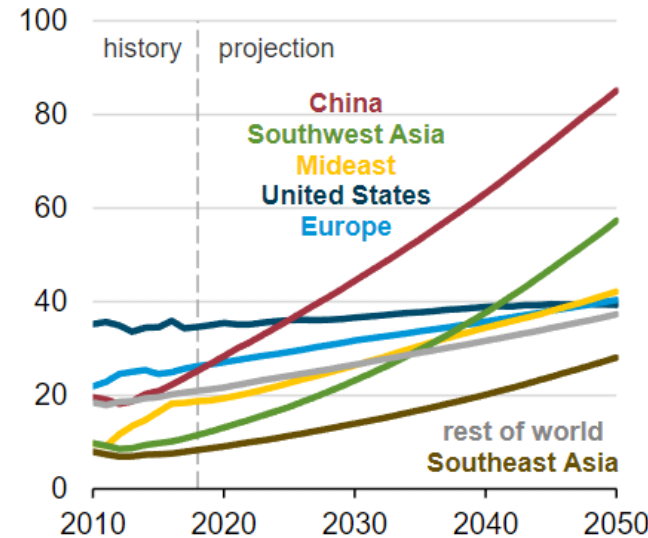


Driving forces:

- Continued growth in air travel
- Community impact
- Sustainable aviation

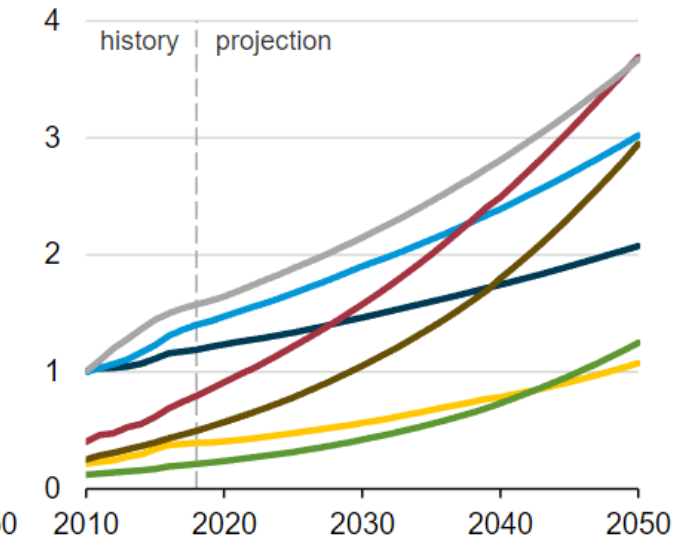
Freight air transport demand (2010-2050)

billion revenue ton miles



Passenger air travel demand (2010-2050)

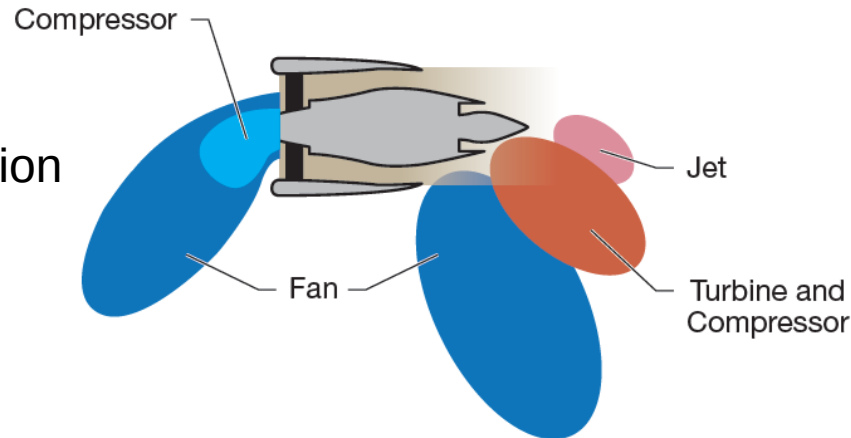
trillion seat miles



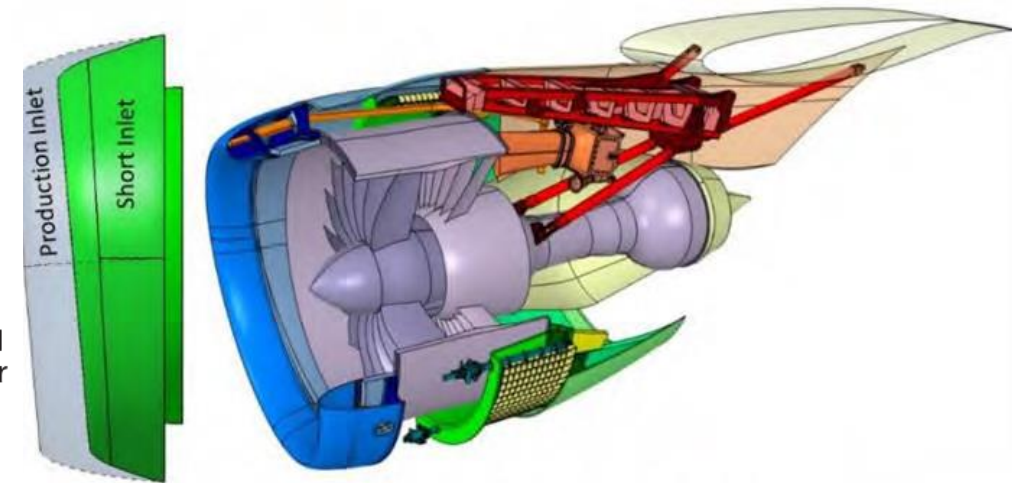
Source: U.S. Energy Information Administration, International Energy Outlook 2019

Liner challenges:

- Low-frequency absorption
- Broadband attenuation
- Reduced nacelle size



Turbofan Noise Sources

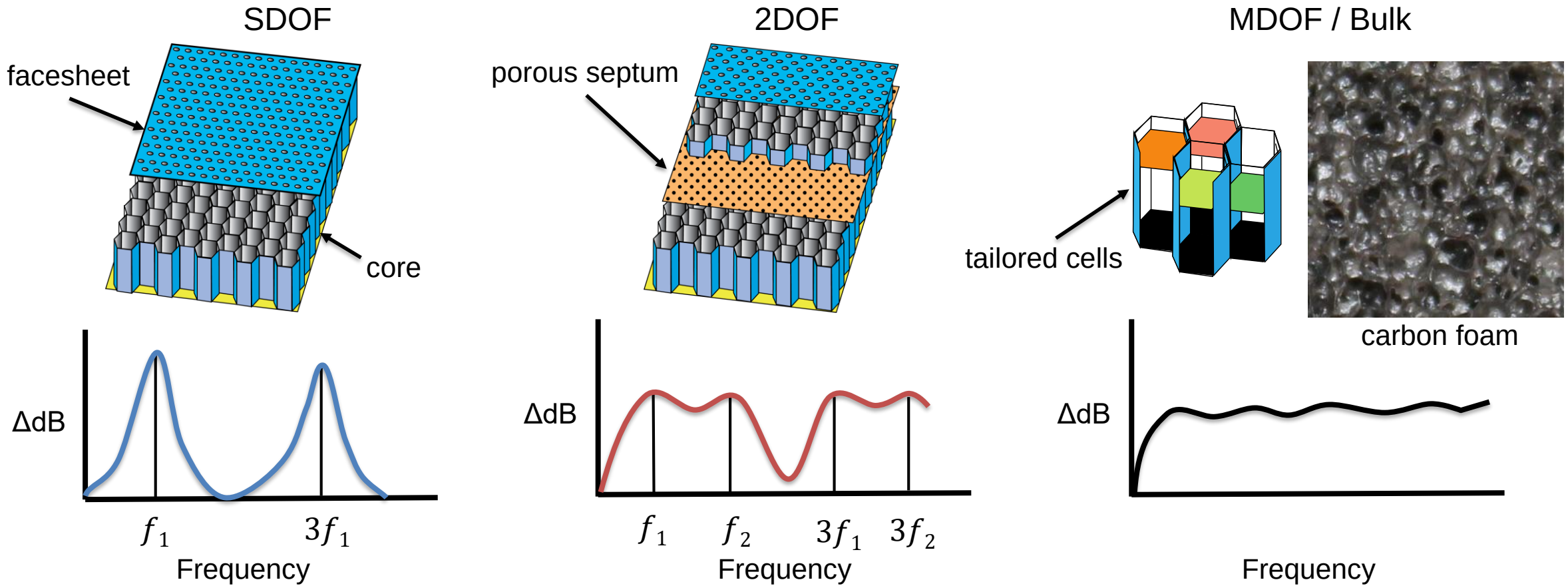


Notional Compact Nacelle

Background



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

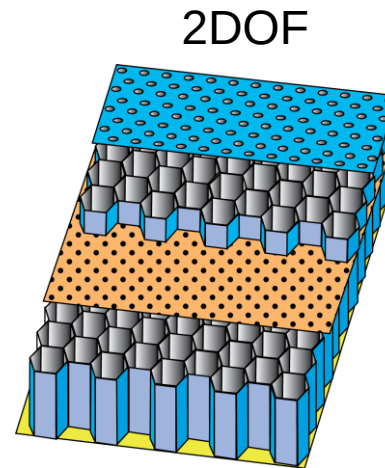
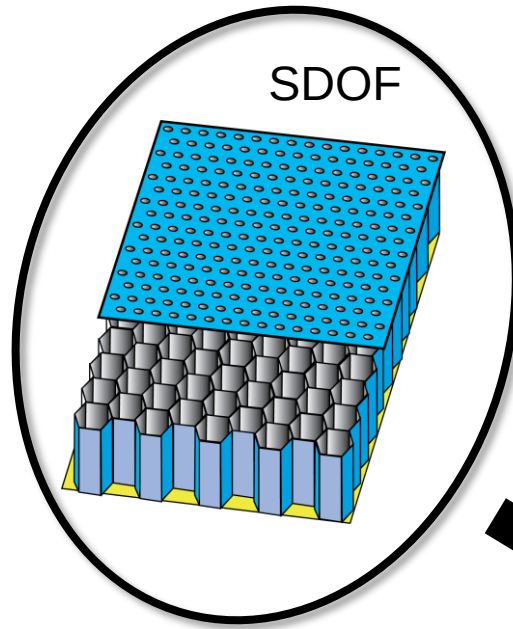


Problem: Maximum attenuation has to be traded for bandwidth

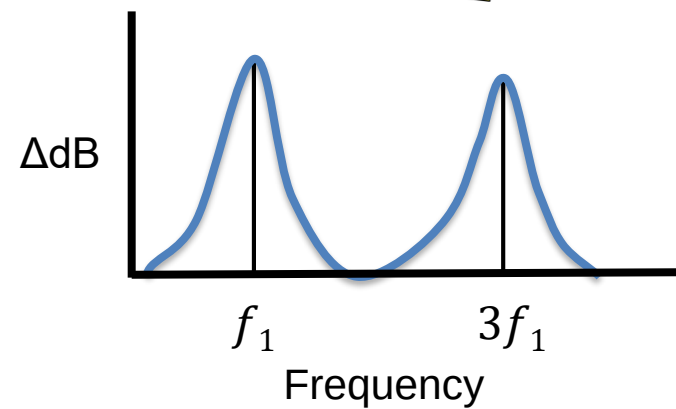
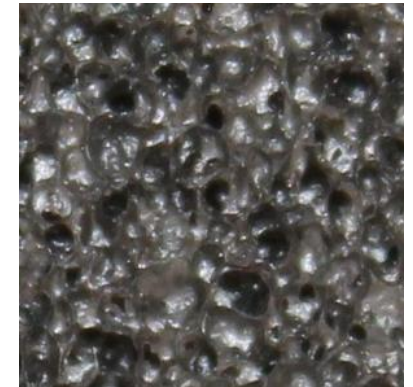
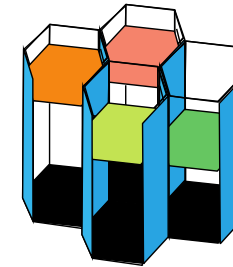
Background



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



MDOF / Bulk



How can we improve liner efficiency without losing broadband performance? **ACTIVE LINER**

Background



Goal: *Modulate impedance for different flight phases*



Maximum power



Reduced power



Low power

Methods:

- Porosity
- Cavity Depth
- Membranes/Septa
- Backplate compliance
- EMHR
- Bias flow

Purpose of Study: Demonstrate an active liner concept employing controlled variable porosity



Trade noise for lower drag?

Concept - Active Liner



Active Facesheet (FS) Components

- FS comprised of three-layered perforate
- Slide layer moves relative to other layers (changes effective POA)
- Computer-controlled heating of embedded Shape Memory Alloy (SMA) wire to actuate slide layer
- Embedded superelastic wire to provide restoring force

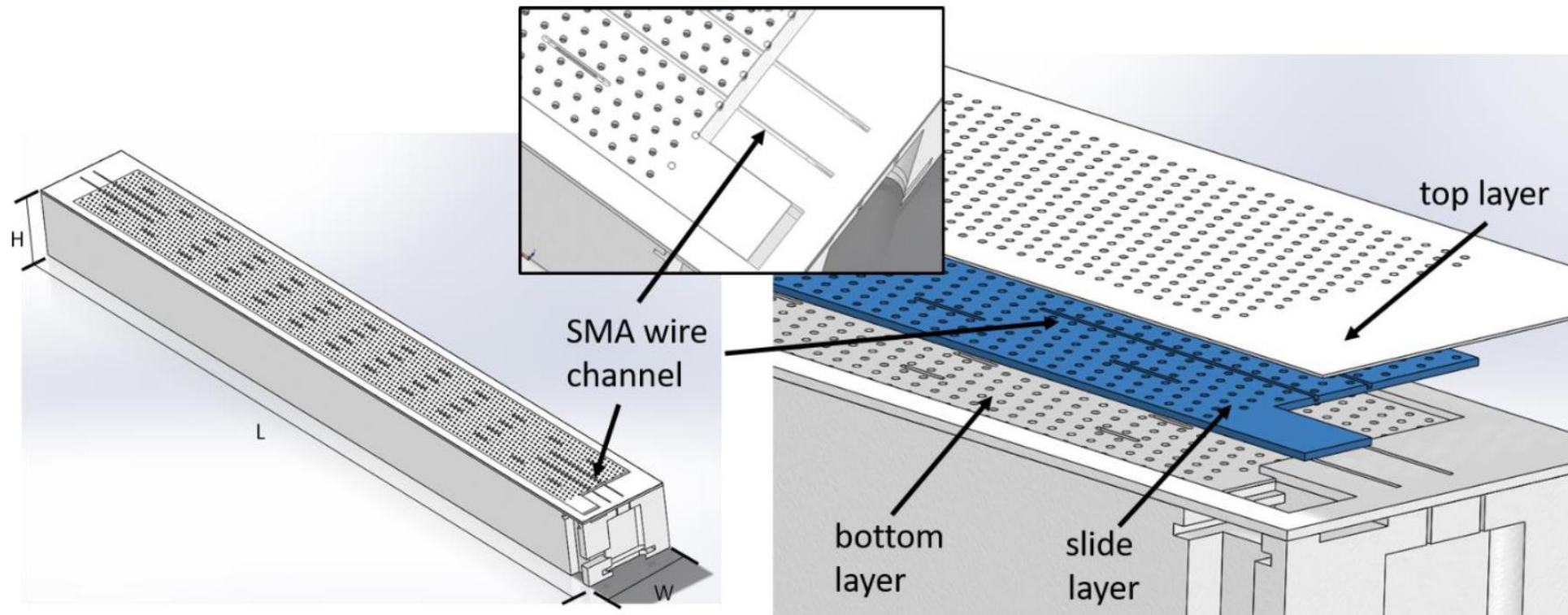


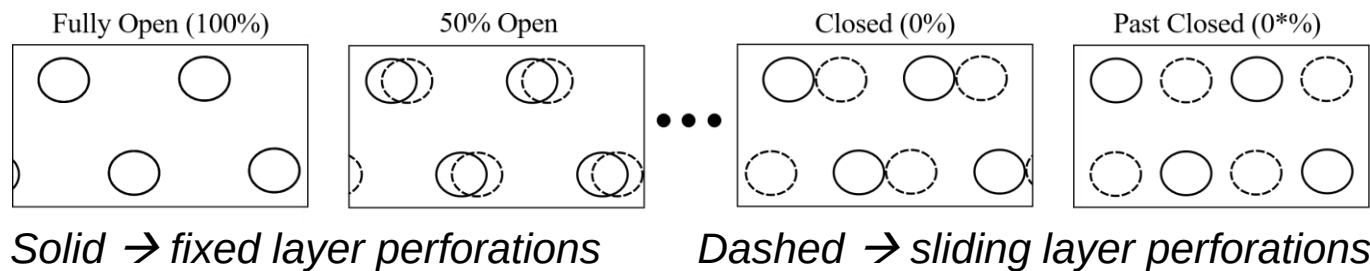
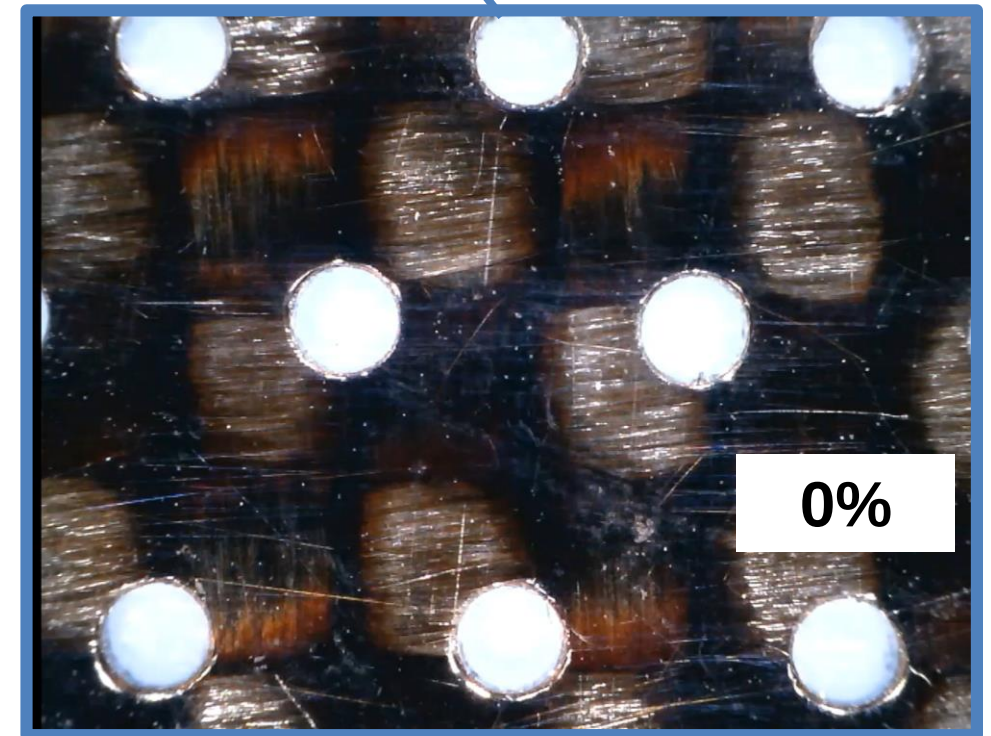
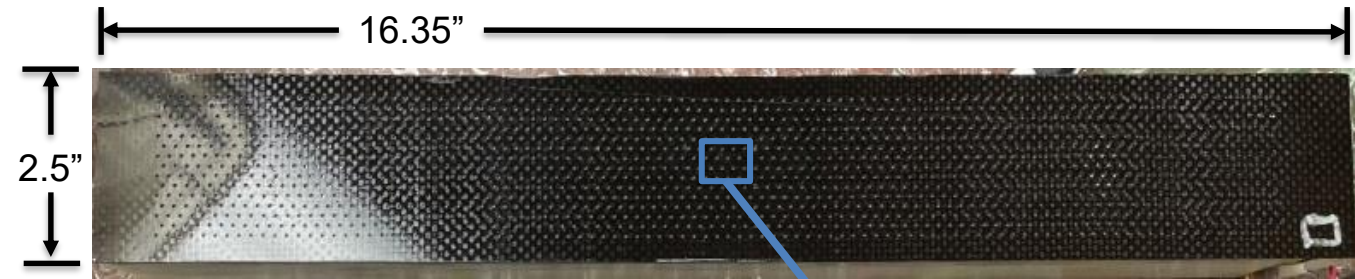
Figure from Kreitzman et al. "Active Acoustic Liners enabled by Shape Memory Alloy Technology," AIAA Aviation 2020. Used with permission.

Experiment - Active Liner

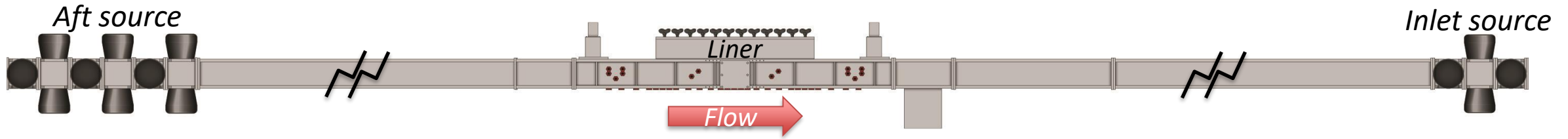


Characteristics:

- 8.5% max POA
- Perforate diameter $\rightarrow 0.046''$
- Facesheet thickness $\rightarrow \sim 0.1''$ (atypical)
- Core depth of 1.7''
- Porosity continuously variable from 0% to max POA
- Eight perforate settings tested (percent):
0*, 0, 5, 10, 25, 50, 75, 100



Experiment

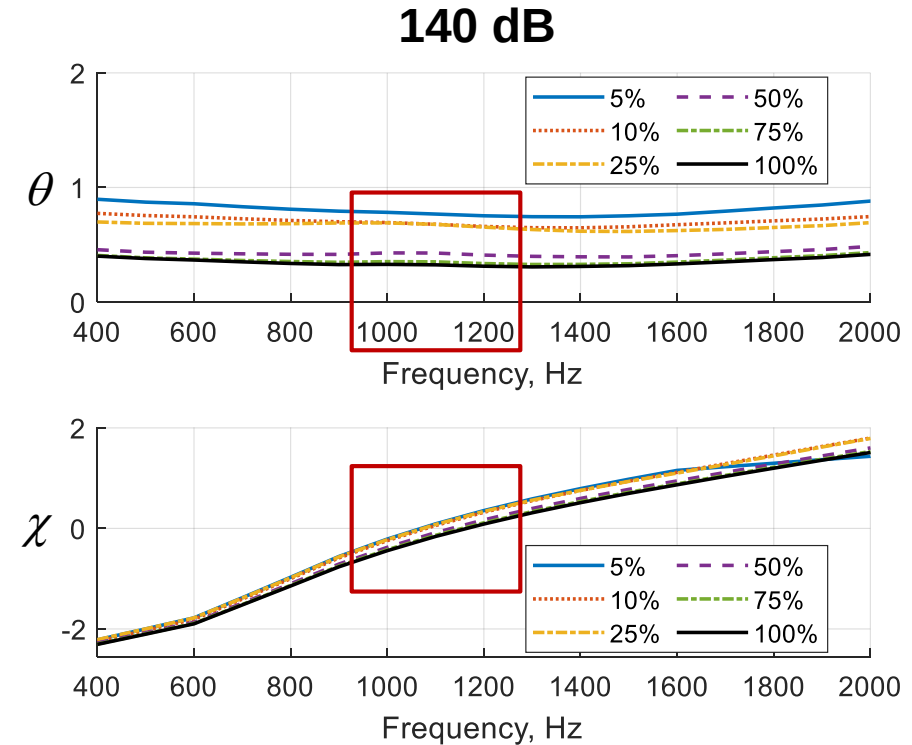
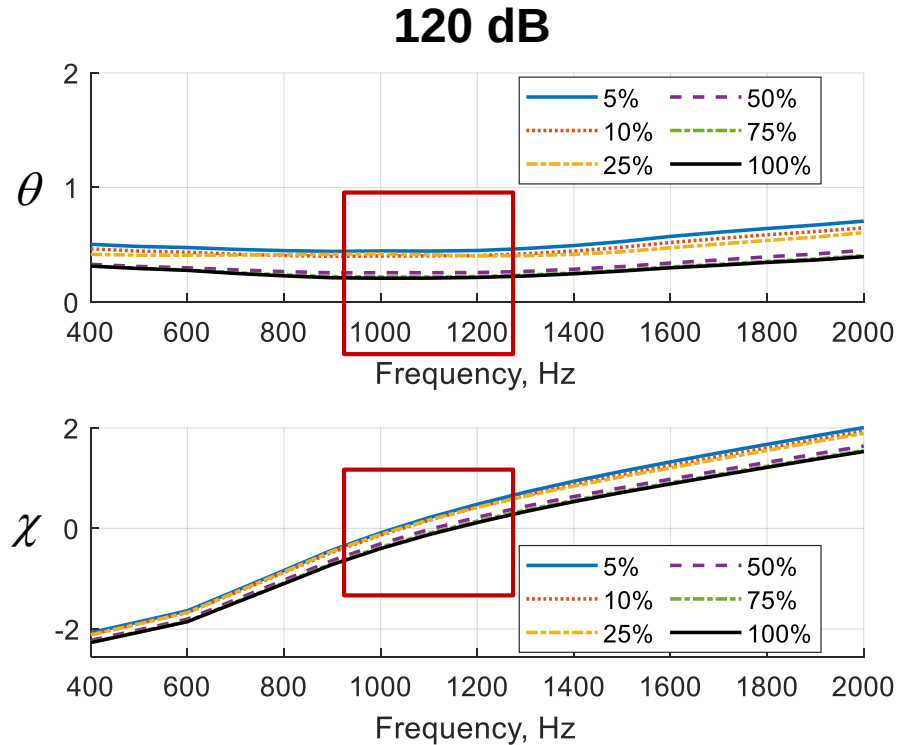


NASA Langley Grazing Flow Impedance Tube (GFIT)

- Flow Mach #'s of 0.0, 0.3, 0.5
- Tonal acoustic excitation from 400-3000 Hz
- Source levels of 120 and 140 dB
- 95-microphone acoustic array
- Data acquired every 100/200 Hz (tone) or 10 Hz (sweep)
- Impedance eduction
 - Convected Helmholtz Eq. (indirect)
 - Prony (direct)

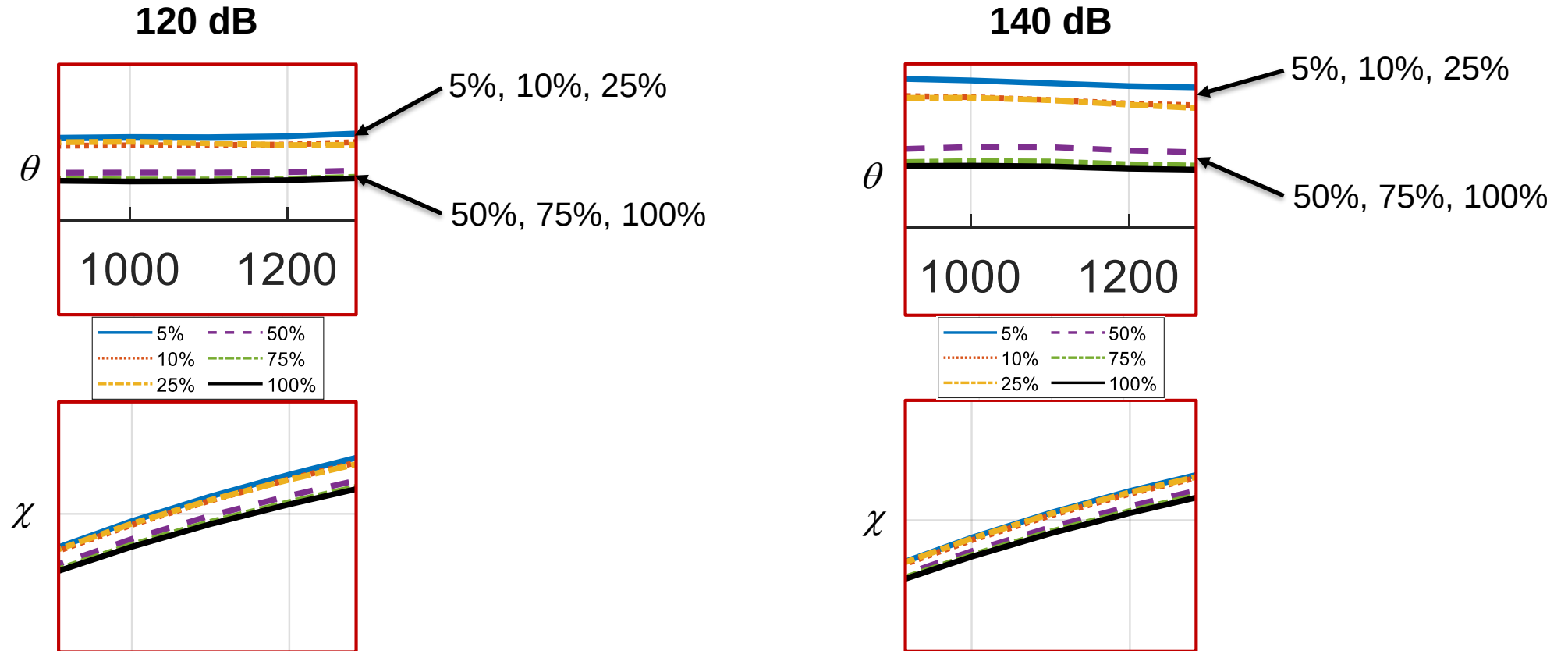


Results - Active Liner (M=0.0)



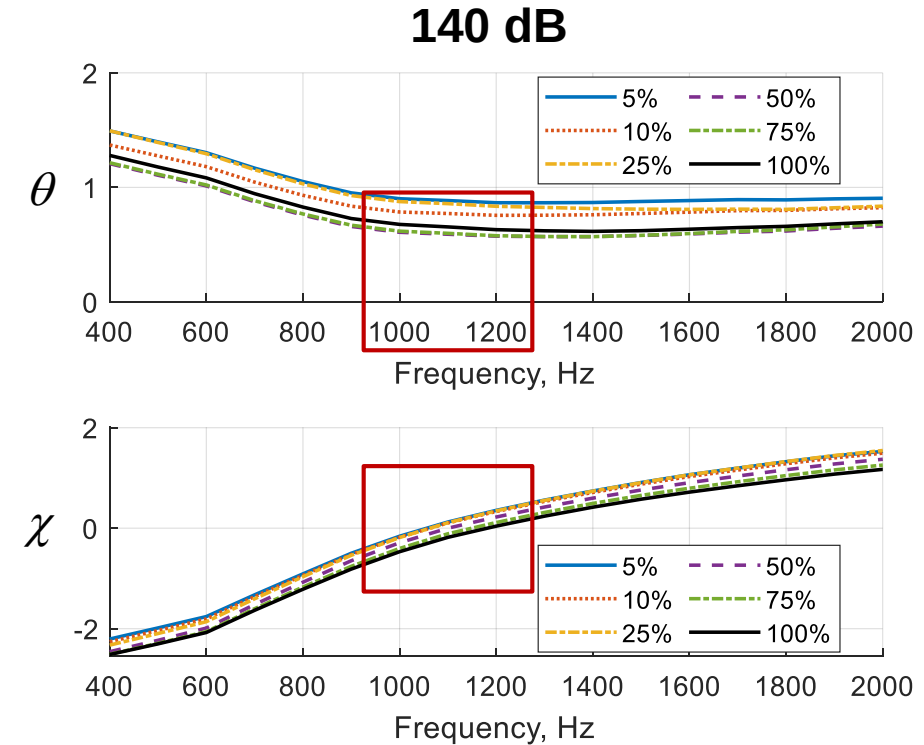
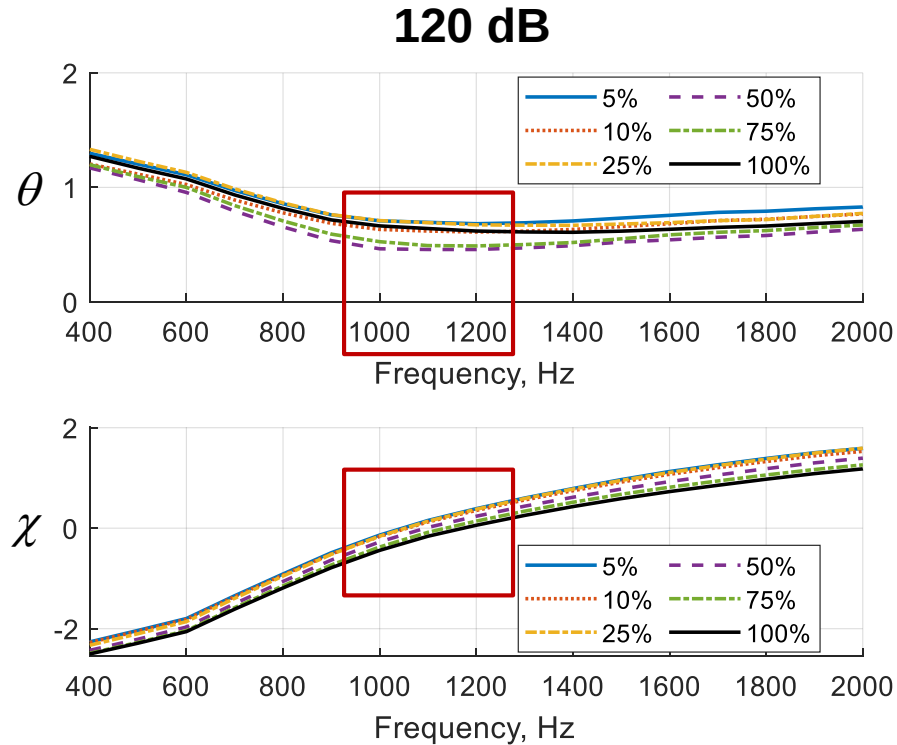
- Truncation of frequency range due to anomalous behavior
- Variation in impedance with porosity
- Resistance nonlinearity with SPL
- Resistance spread widens with SPL

Results - Active Liner (M=0.0)



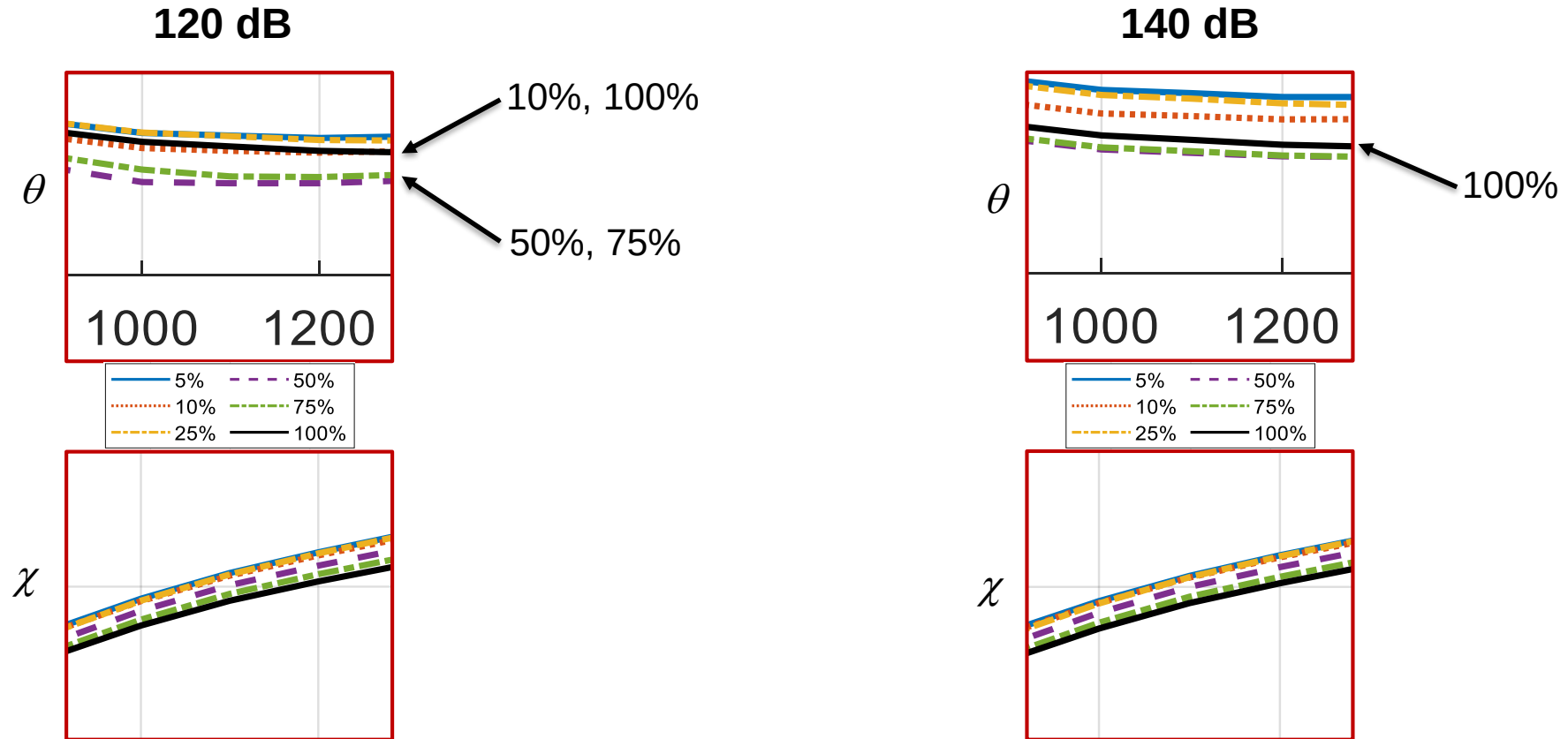
- Grouping of resistance curves between those <25% and >50%
- Nominal resonance shift of ~150-200 Hz depending on percentage

Results - Active Liner (M=0.3)



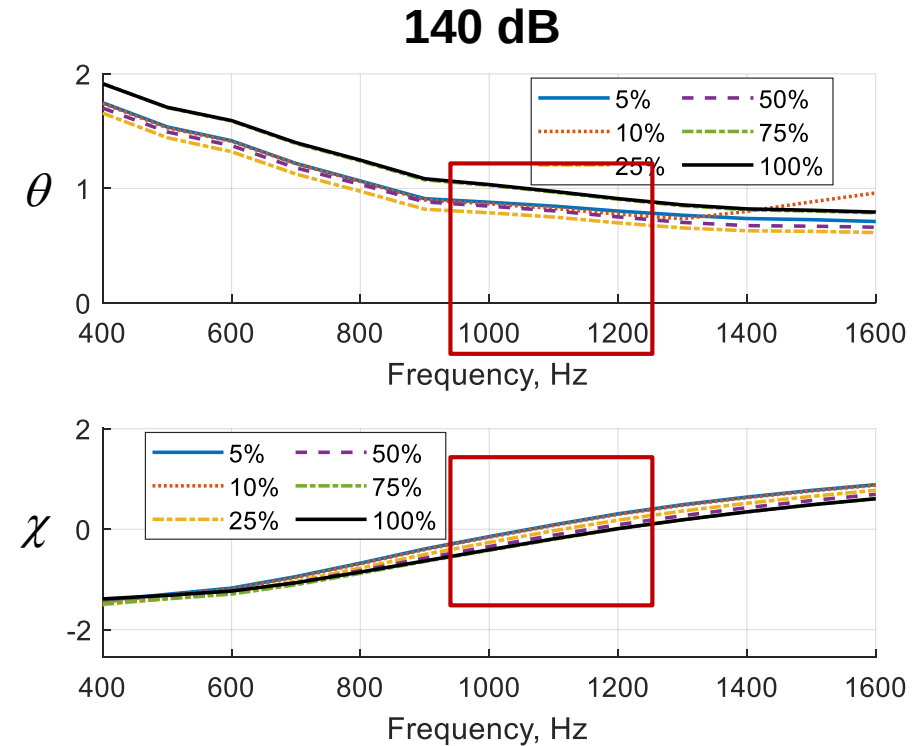
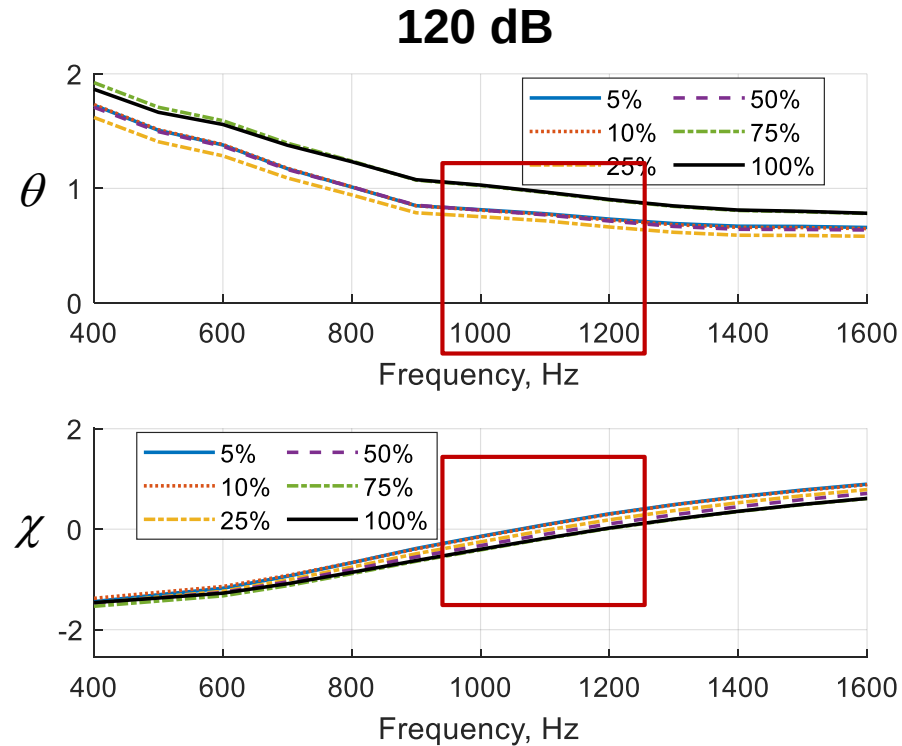
- Resistance increases with Mach # (expected)
- Greater reactance spread vs. M=0.0
- Resonance shift similar to M=0.0

Results - Active Liner (M=0.3)



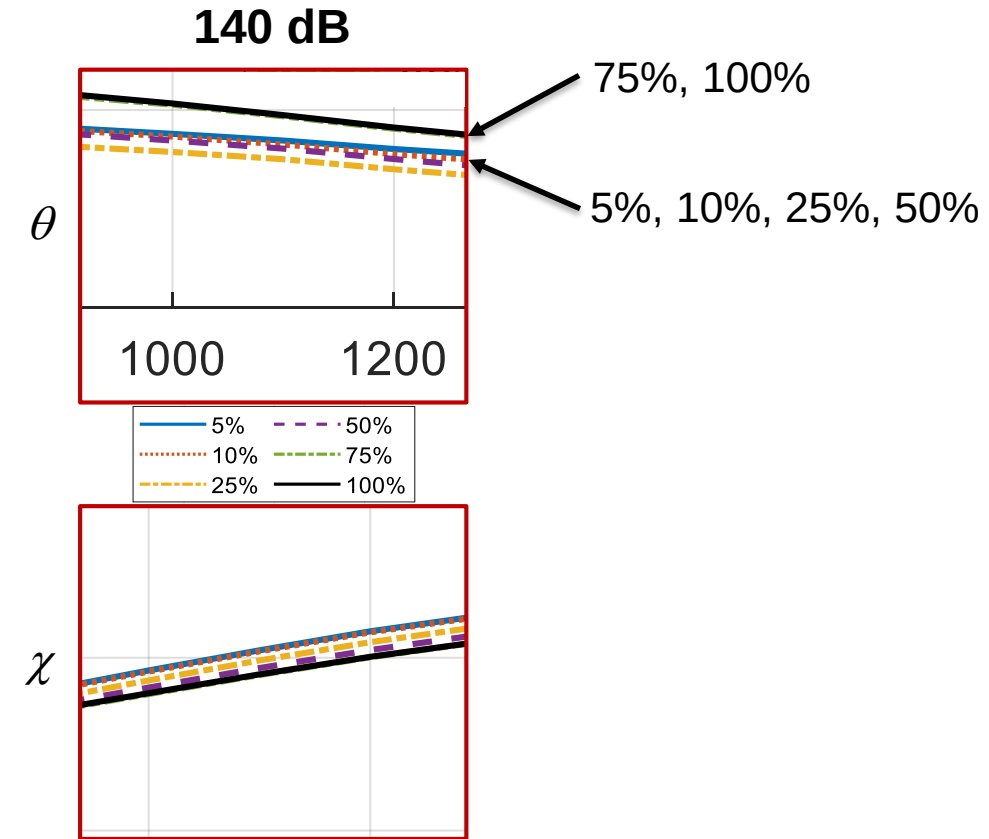
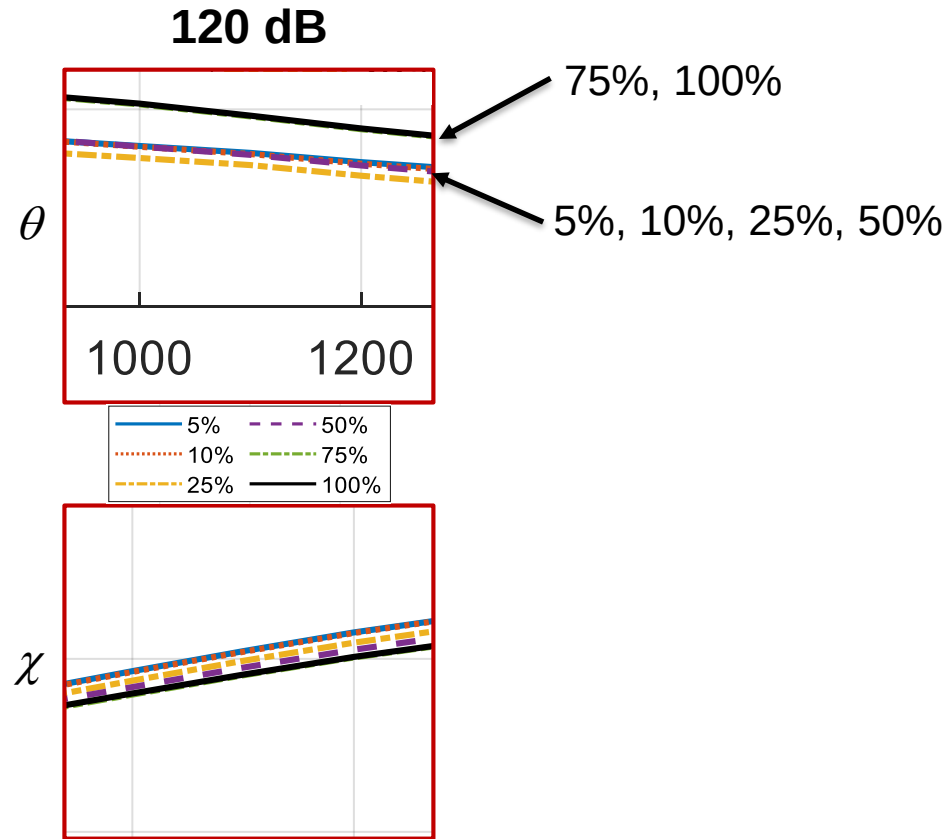
- Trend of decreasing resistance with increasing porosity breaks down
- Reactance ordering unaffected

Results - Active Liner (M=0.5)



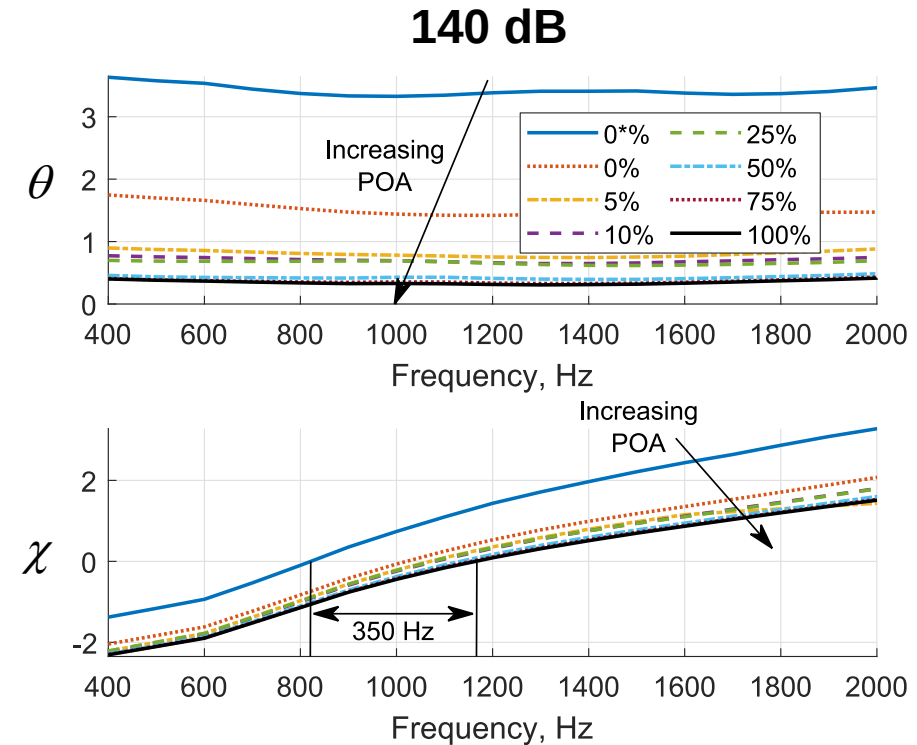
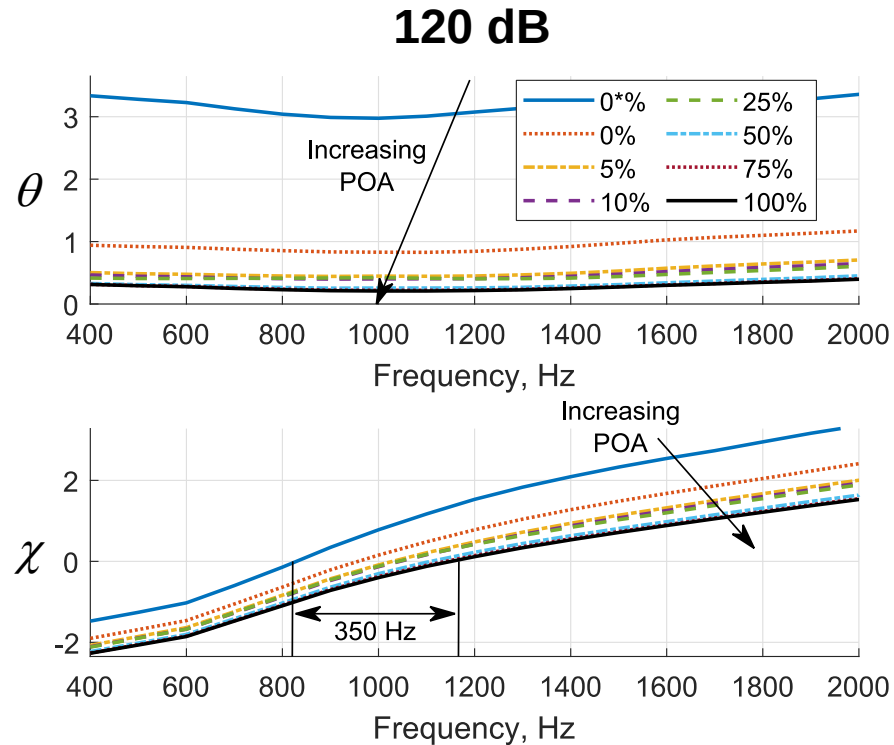
- Low-frequency resistance increases further
- Flattening of the reactance spectra → Greater resonance shift

Results - Active Liner (M=0.5)



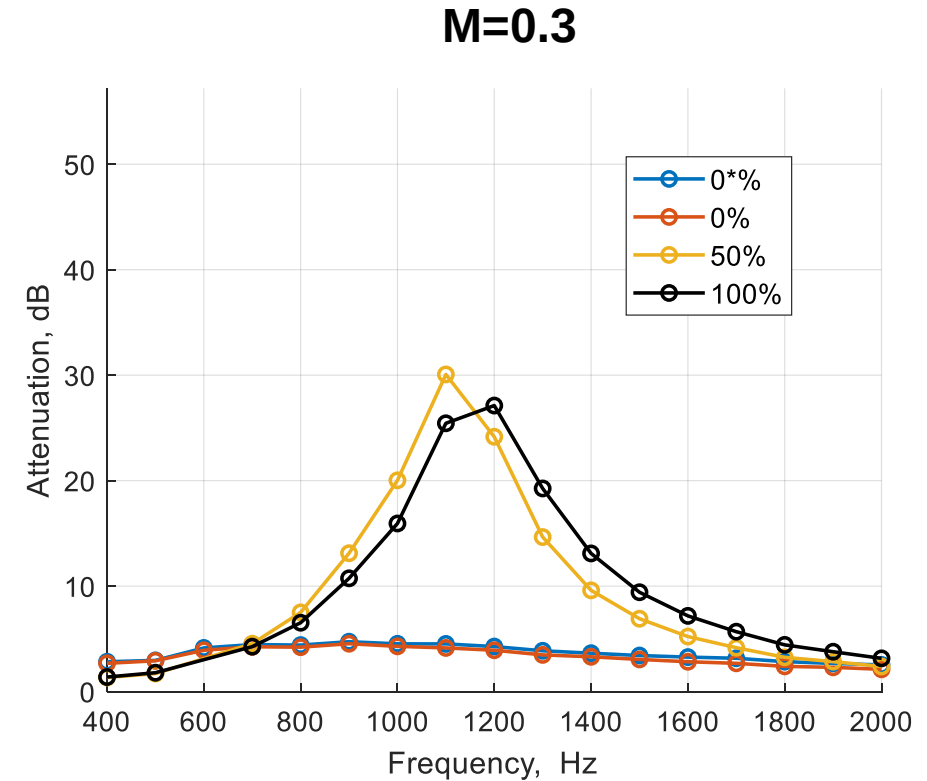
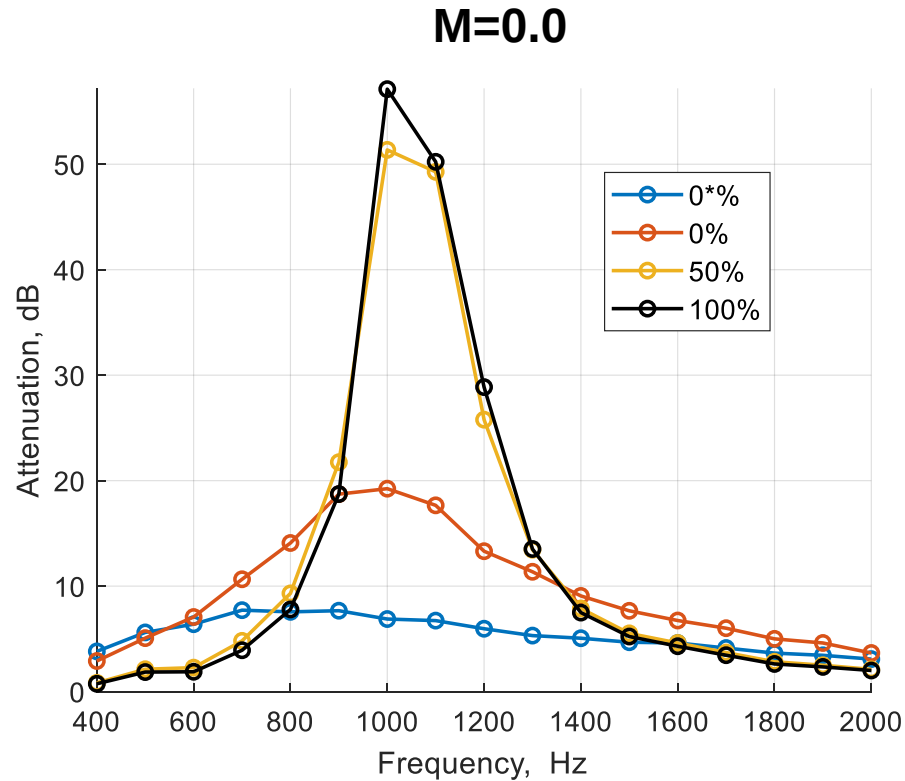
- Highest % open cases, 75% and 100%, have greatest resistance (unexpected)
- Continues trend seen from M=0.3 data

Results - Active Liner (M=0.0)



- Closed cases, 0% and 0*%, have highest resistance but still 'useable'
- 0% resistance lower than 0*%
- Resistance for closed cases lower than expected (should simulate hardwall)
- Significant resonance shift between 0* and 100% cases

Active Liner - GFIT Results (140dB)



- Attenuation as expected in the open positions
- Values decrease with flow
- Significant attenuation in the closed positions (unexpected)

$$\text{Attenuation} = SPL_{\text{upstream}} - SPL_{\text{downstream}}$$

(downstream propagating waves only)

Hypothesis: Are impedance and attenuation results due to the gaps between facesheet layers?

Experiment - Static Liner

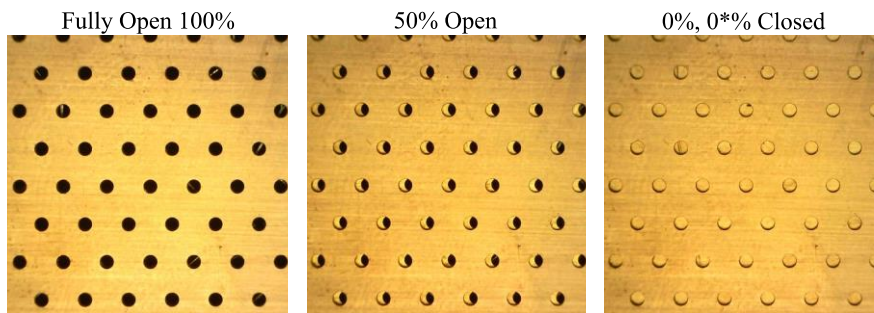


Static version of Active liner:

- Facesheet comprised of 3 perforate layers
- Four versions of the middle layer: 100% open, 50% open, closed (0%), and past closed (0*%)
- Controlled gaps between layers using shims (simulate Active liner gaps)

Key differences from Active liner:

- Effective facesheet thickness is 0.04" thinner (manufacturing differences)
- Longer liner: 24" (Static) vs. ~16" (Active)
- Honeycomb core depth: 1.5" (Static) vs. 1.7" (Active)



Facesheet cutaway through perforation



Fully Open 100%



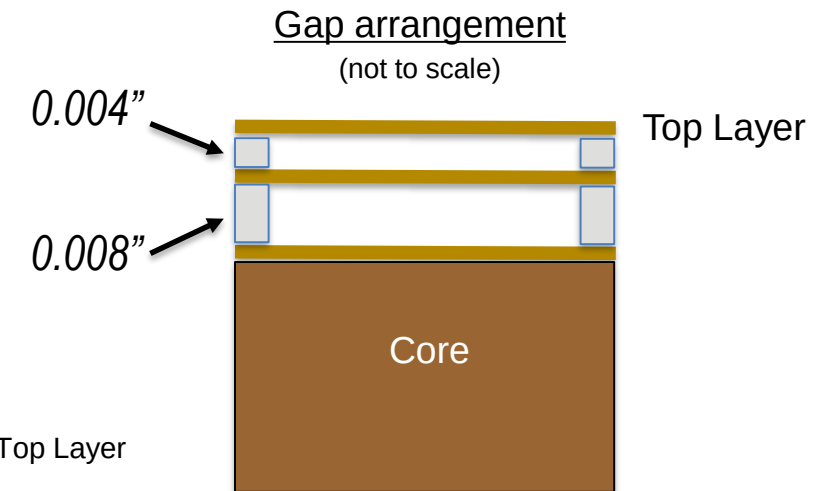
50% Open



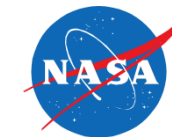
0% Closed



0*% Closed

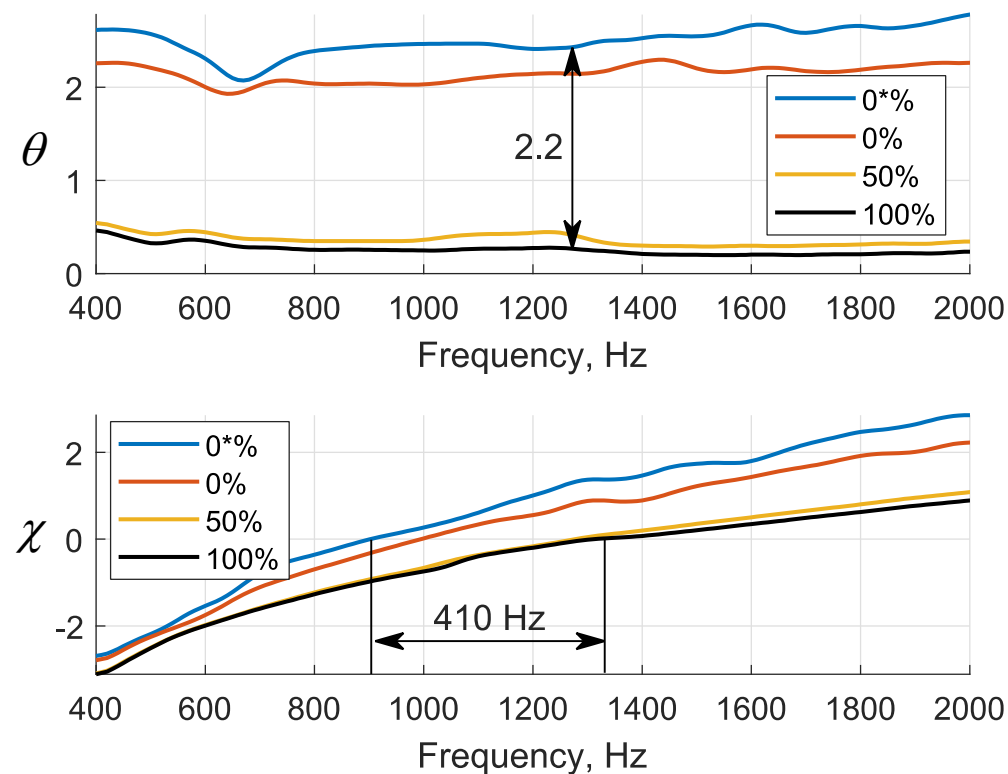


Results - Static Liner (w/ Gap)



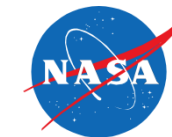
- Similar trend to the Active liner
 - Higher resistance and lower resonant frequency for closed cases
 - Open cases have similar impedance spectra
 - Impedance spectra for closed cases in 'useable' range
- Spread in resonant frequencies
 - Closed cases behave like a deeper liner
 - Increased hole offset of 0* further lowered resonant frequency
 - Wider spread than Active liner

M=0.0, 140 dB



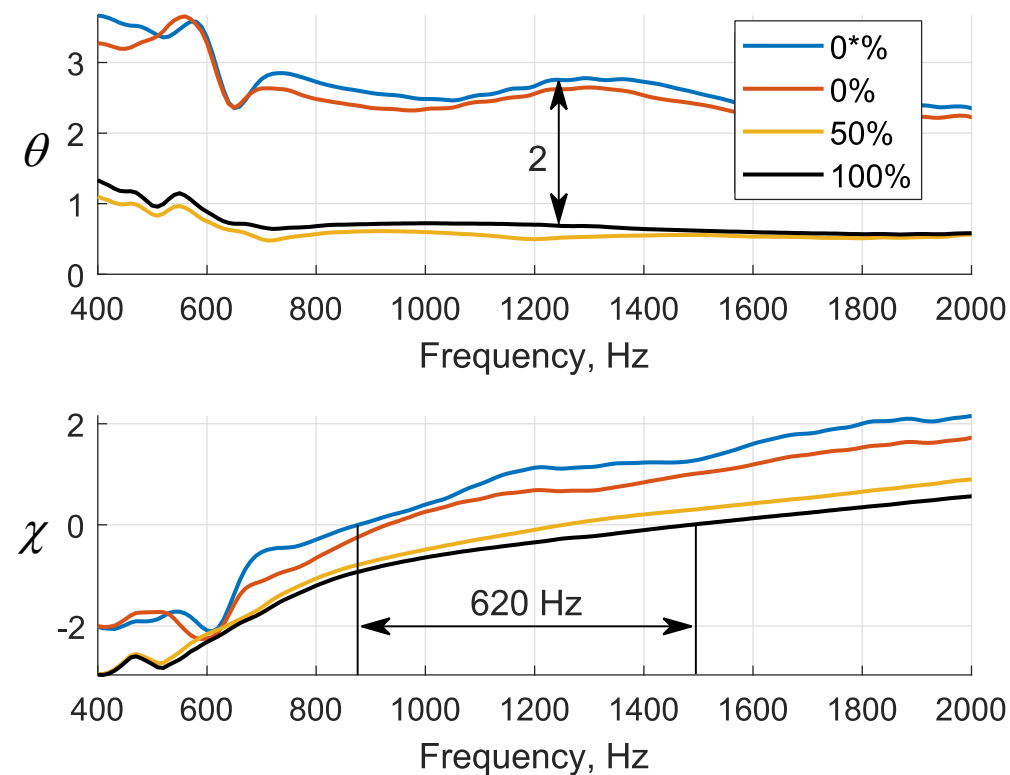
Note: Swept-Sine acquisition used for increased frequency resolution

Results - Static Liner (w/ Gap)



- Resistance
 - Increases with flow
 - 100% more resistive than 50% (same as Active)
 - Narrower spread between open and closed cases
- Reactance
 - Spectra 'flattened' relative to Mach 0.0
 - Increased hole offset of 0* case lowered resonant frequency
 - Resonant frequency shift equivalent to a **1.5" increase** in liner depth

M=0.3, 140 dB

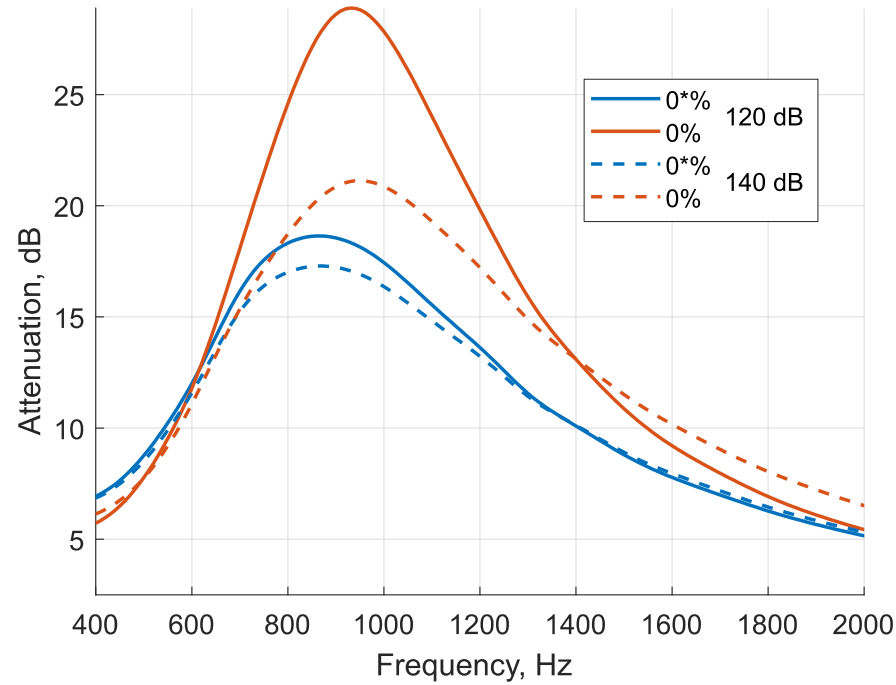


Could gaps between facesheet layers provide an additional impedance adjustment parameter?

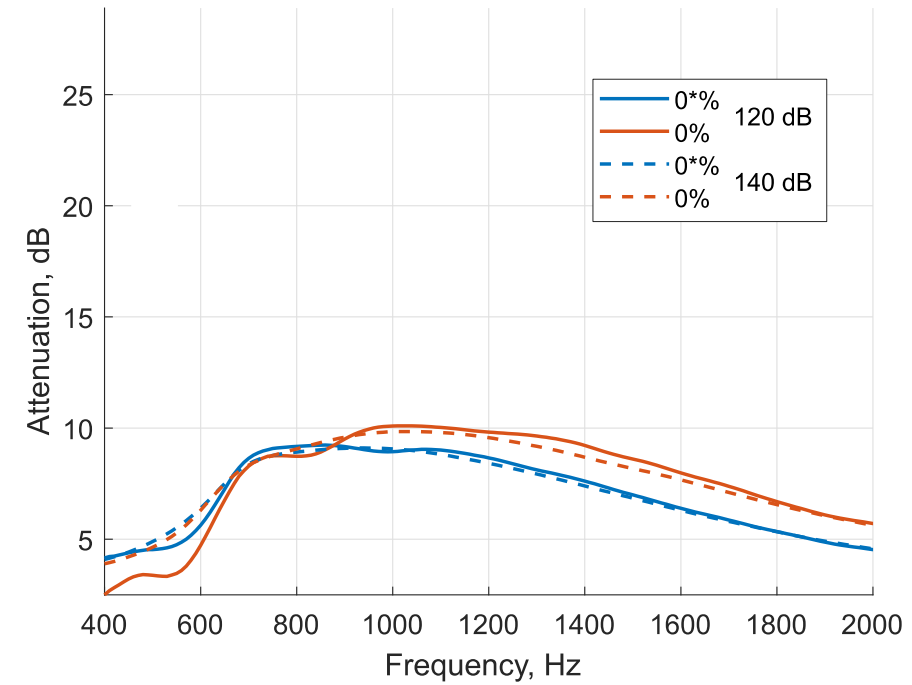
Static Liner - GFIT Results (w/ Gap)



M=0.0



M=0.3



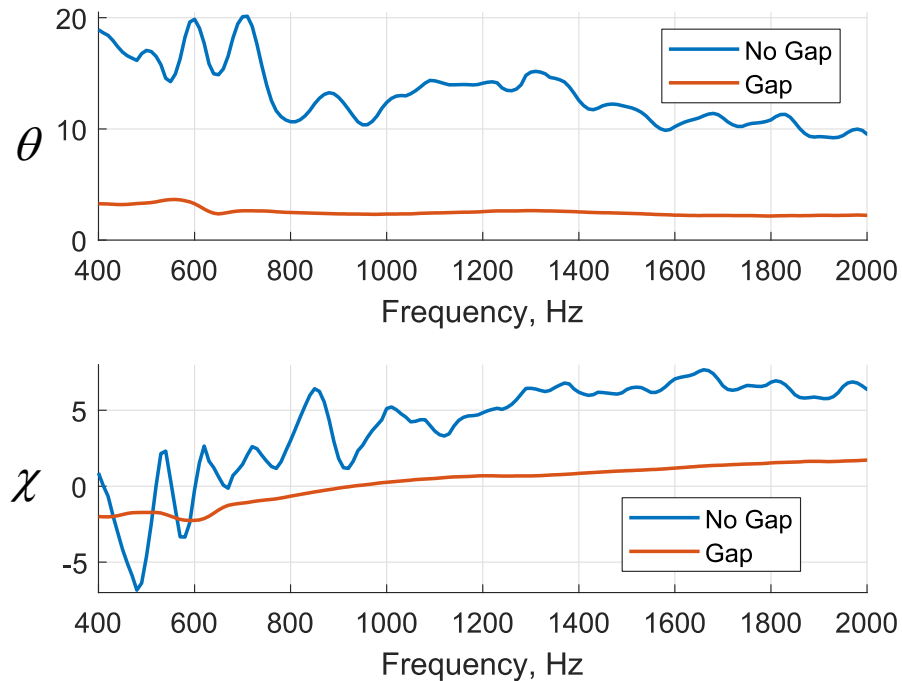
- Mach 0.0: Substantial attenuation for all conditions
- Impedance for 0% better matched to GFIT for absorption
- Increasing SPL reduces spread between 0% and 0*%
- Mach 0.3: Flow effects reduce performance and variation

Similar trends to the Active liner
imply the Static liner is correctly
replicating the physics

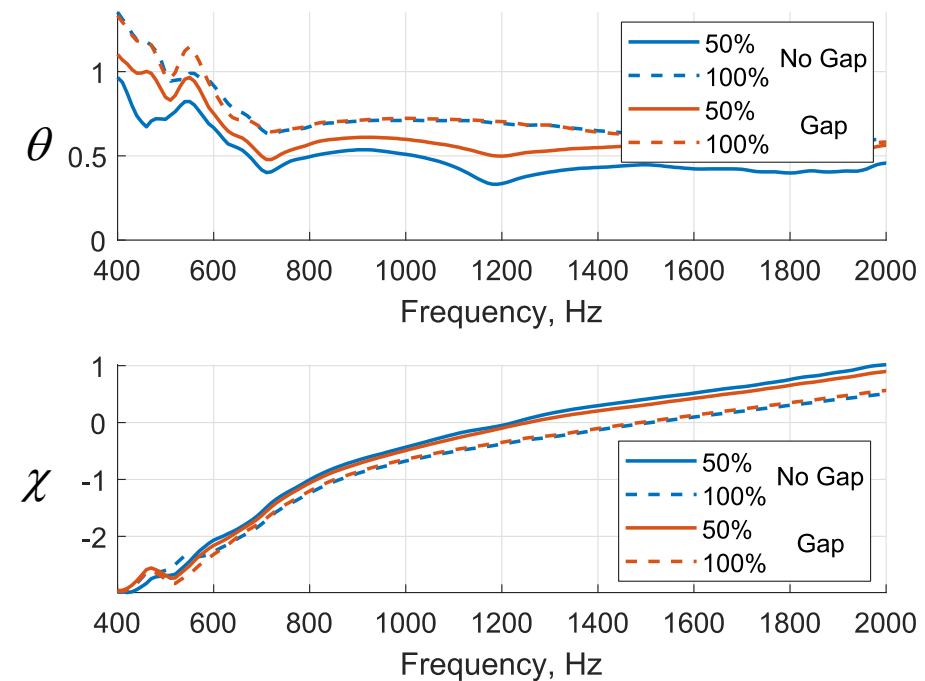
Results - Static Liner (M=0.3, 140dB)



Closed (0%)



Open

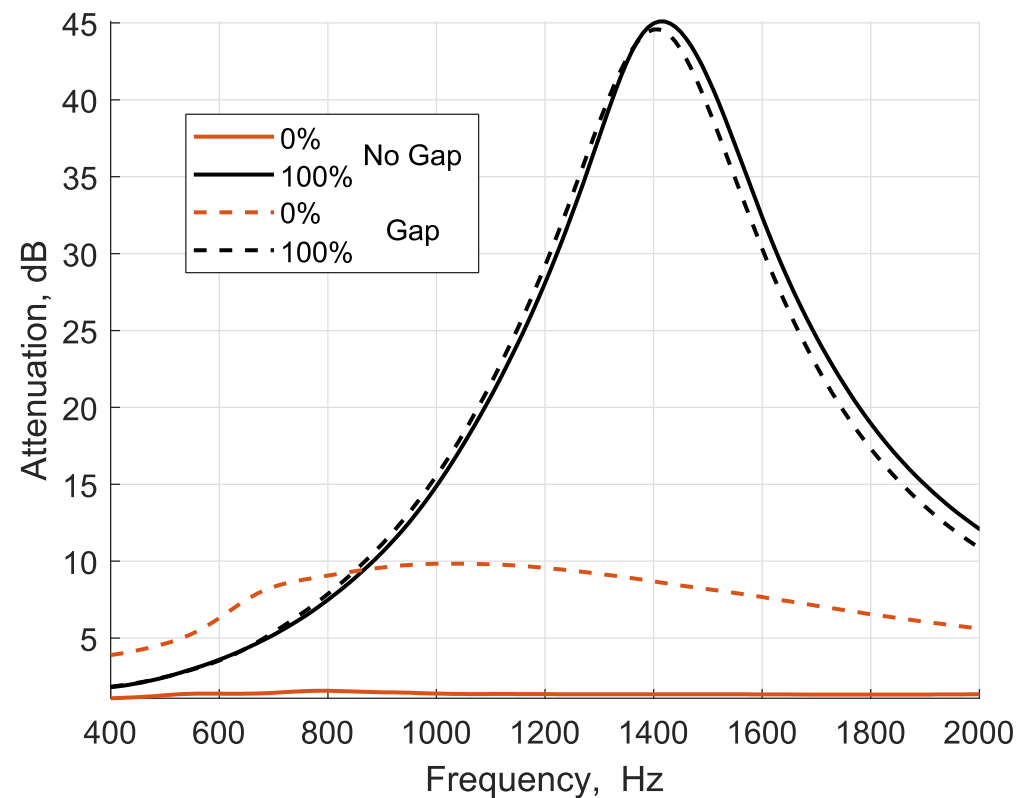


- Closed case: substantial impedance shift w/ gap
- Impedance for 0%, no gap case similar to hardwall as intended
- Resistance unexpectedly higher for 100% cases (same as Active)
- Some gap effect for 50% causing increased resistance

Results - Static Liner (M=0.3, 140dB)

- Obvious effect of gap on attenuation for 0% case
- Almost no effect for the 100% case
- 50% case not shown (technical issue) but should have a gap effect based on impedance data

Gaps between facesheet layers alter liner impedance characteristics (in a potentially advantageous way)



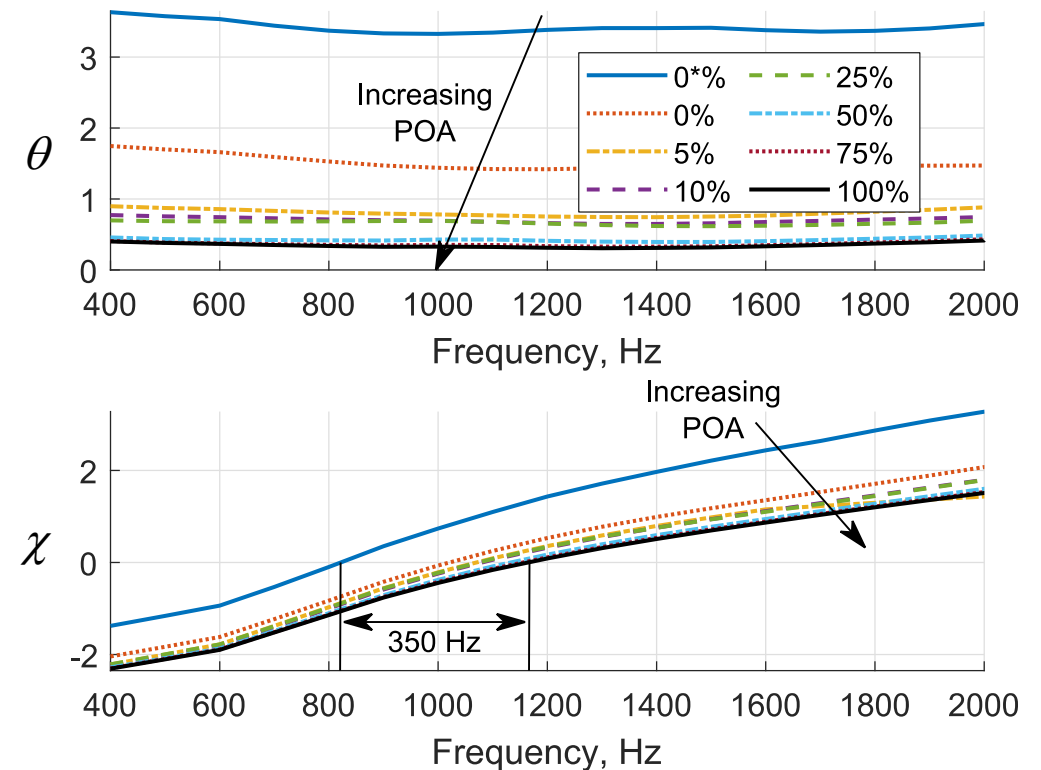
Conclusions



- Active liner can vary impedance by changing porosity
 - Resistance modification
 - Resonance frequency shift
- Gaps between facesheet layers alter impedance characteristics
 - Effect reduced as porosity/Mach# increased
 - ‘Closed’ cases produce useable effective impedances
 - Potential for low-frequency attenuation in a compact liner
- Static liner offers controlled way to study gap effects

Future Work

- Vary gap sizes
- Additional porosities to capture trends
- Drag effects
- Modeling



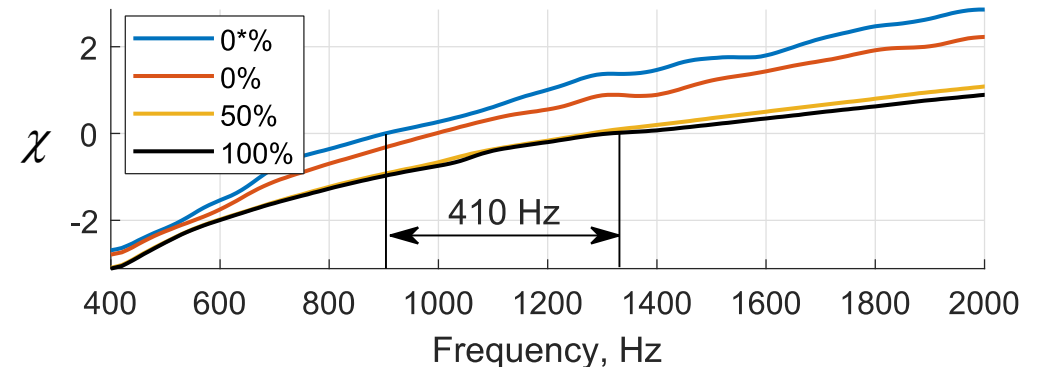
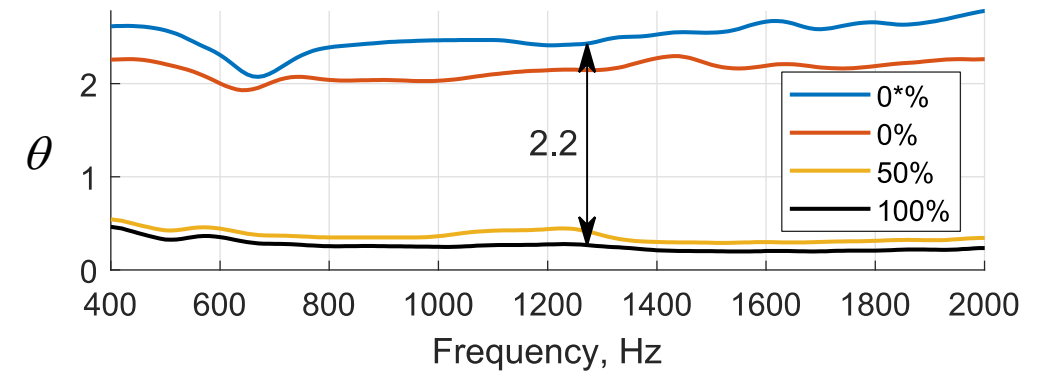
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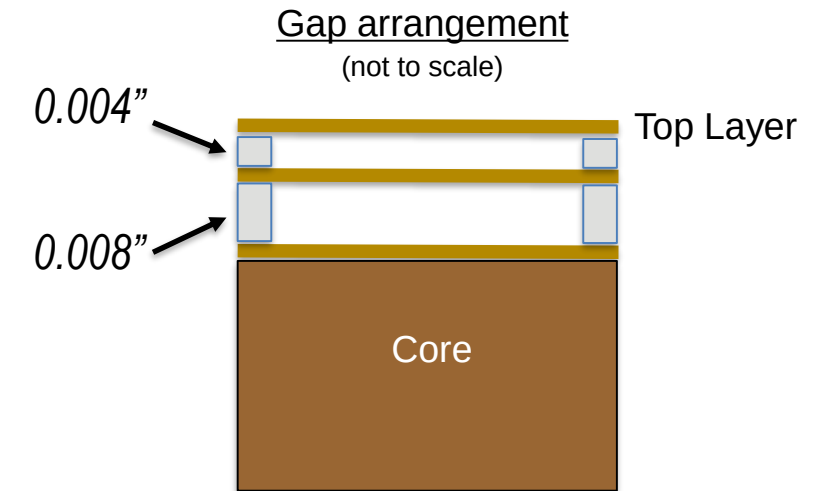
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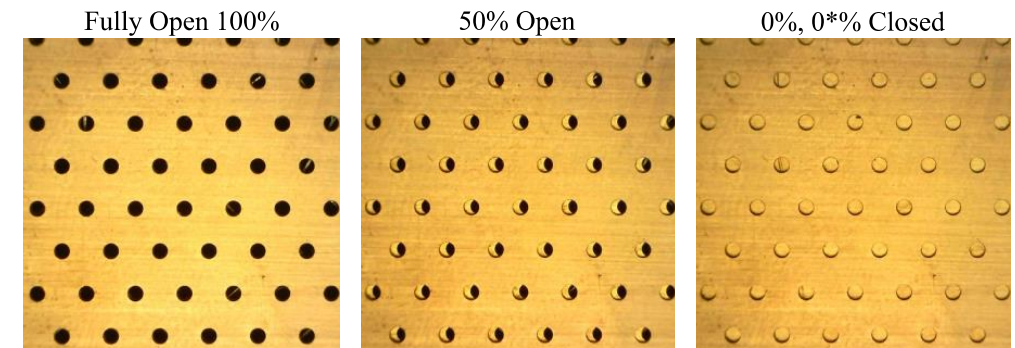


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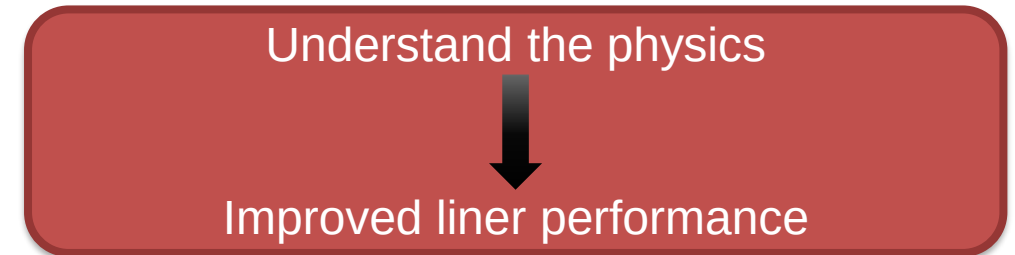
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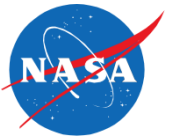
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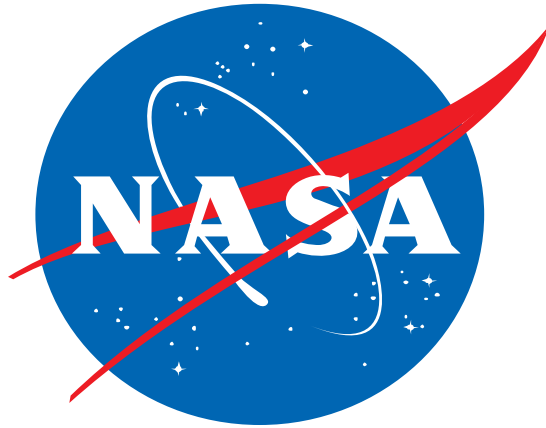
Acknowledgements

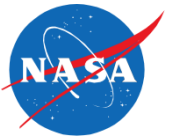


Funding for this work provided by the:

Advanced Air Transport Technology (AATT) Project
as part of

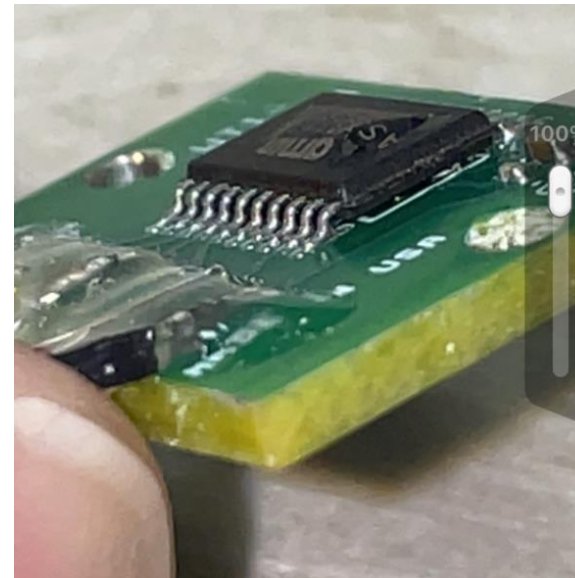
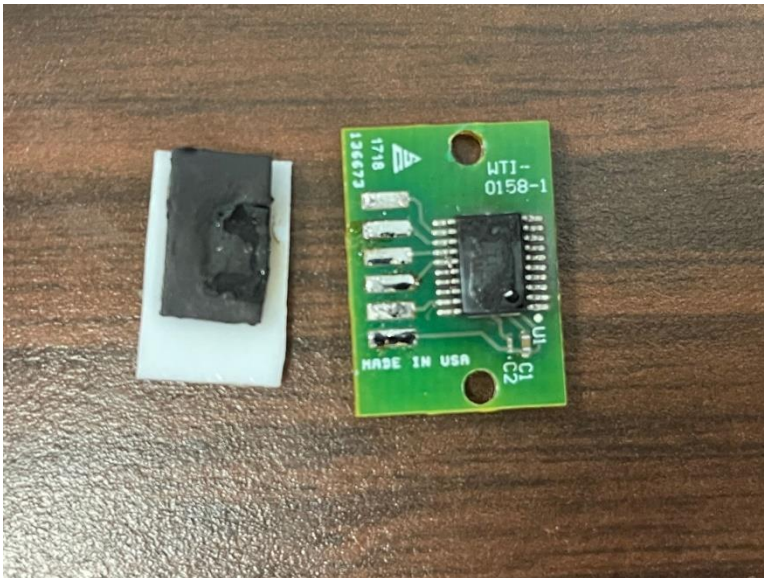
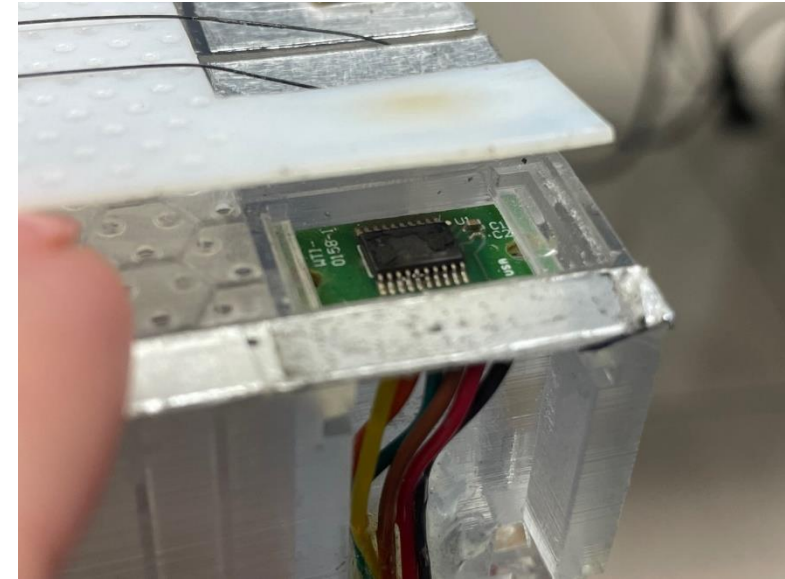
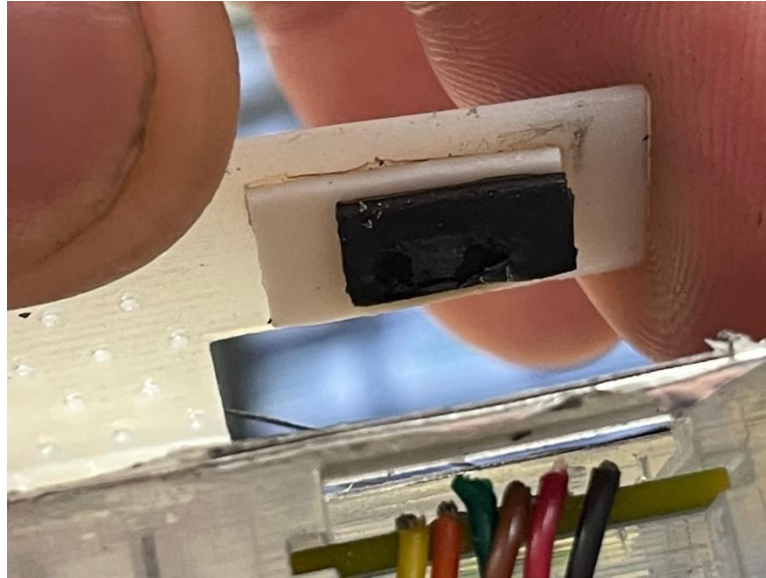






Backup Slides

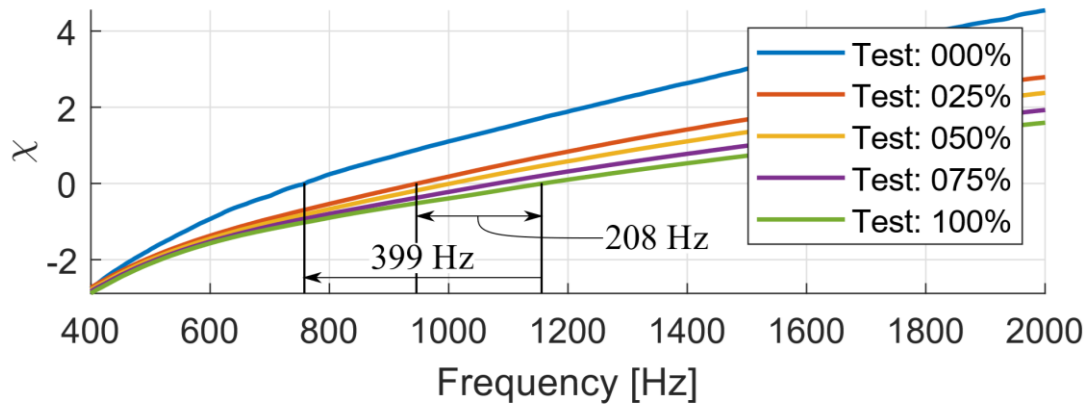
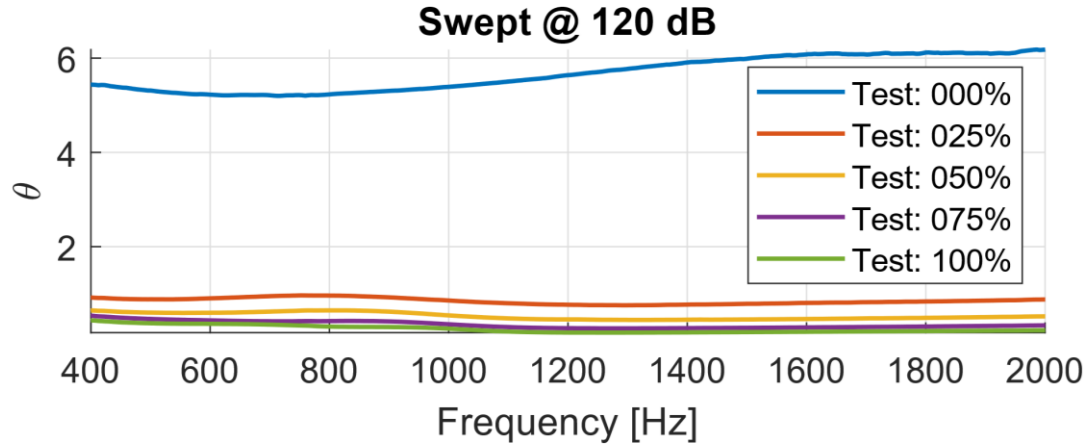
Appendix: Encoder Photos



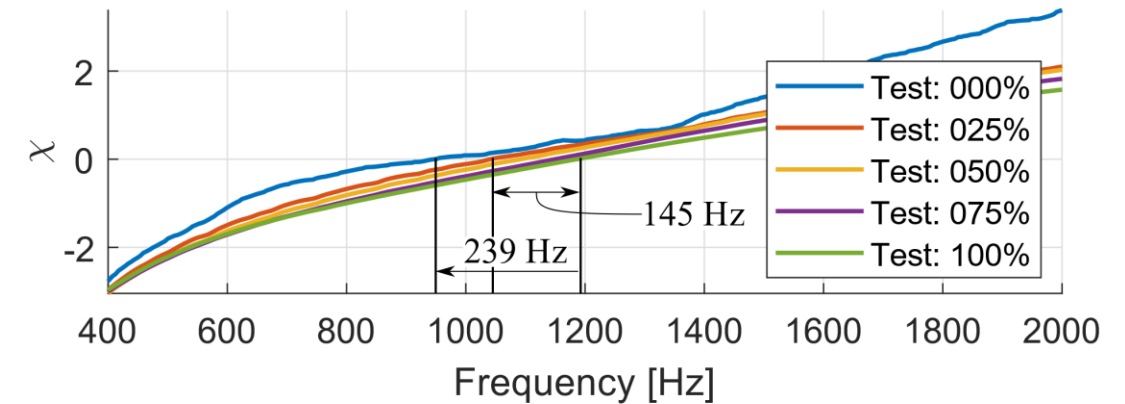
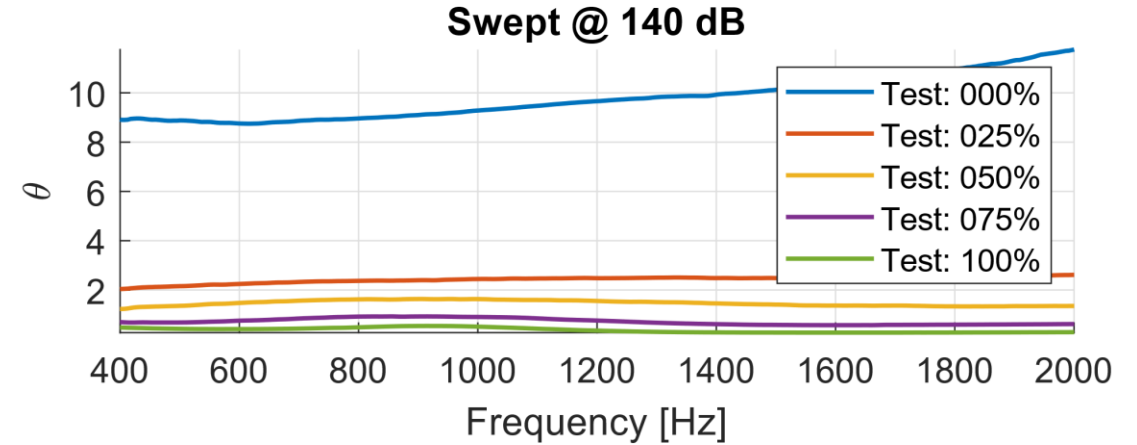
Appendix: NIT Results: Center of Sample



- Swept at 120 dB



- Swept at 140dB

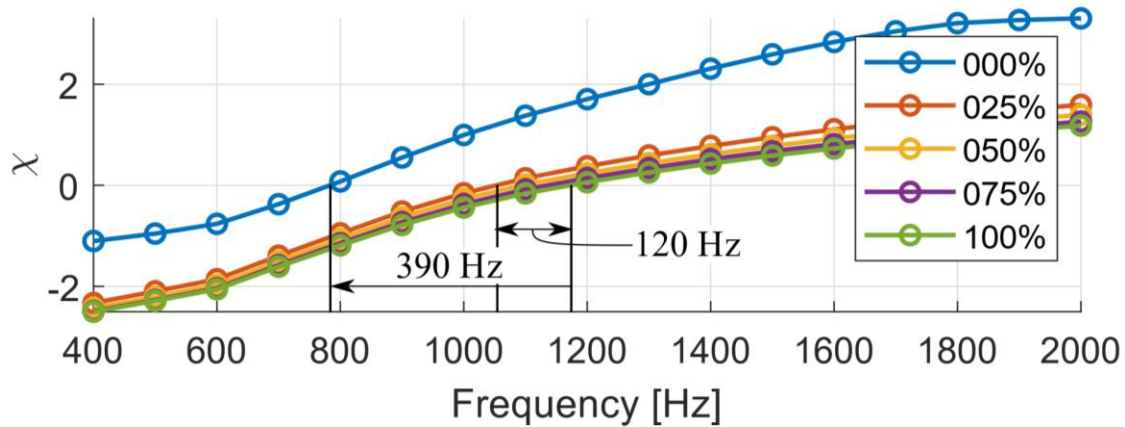
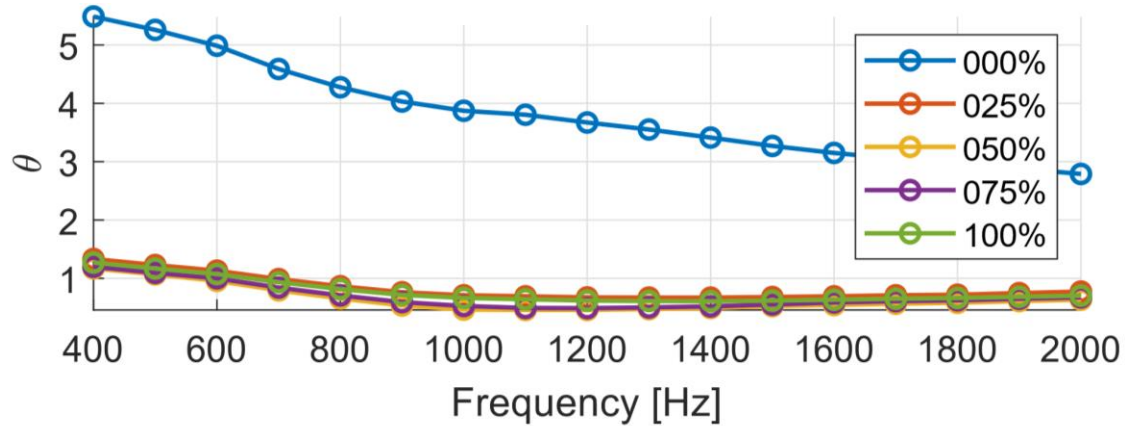


% Open	0	25	50	75	100
Resonance (Hz)	759	950	1008	1080	1158

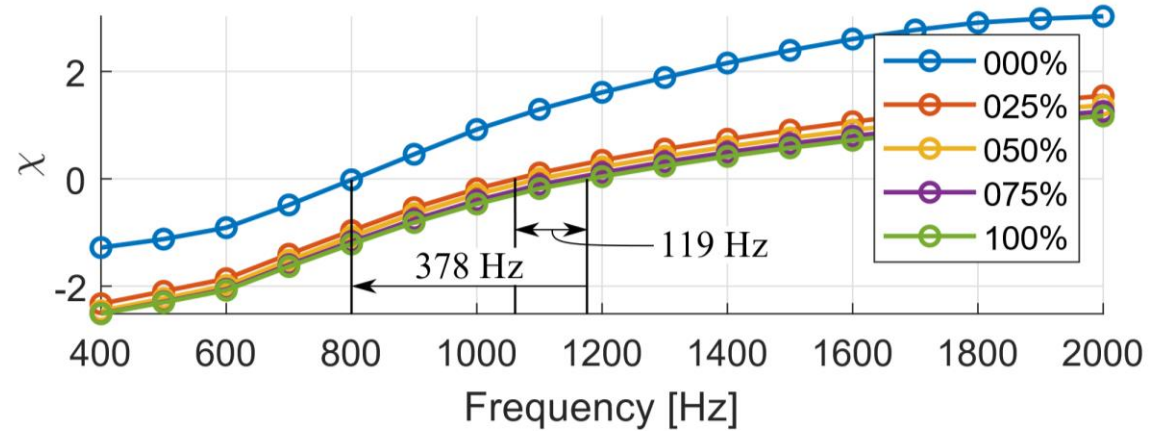
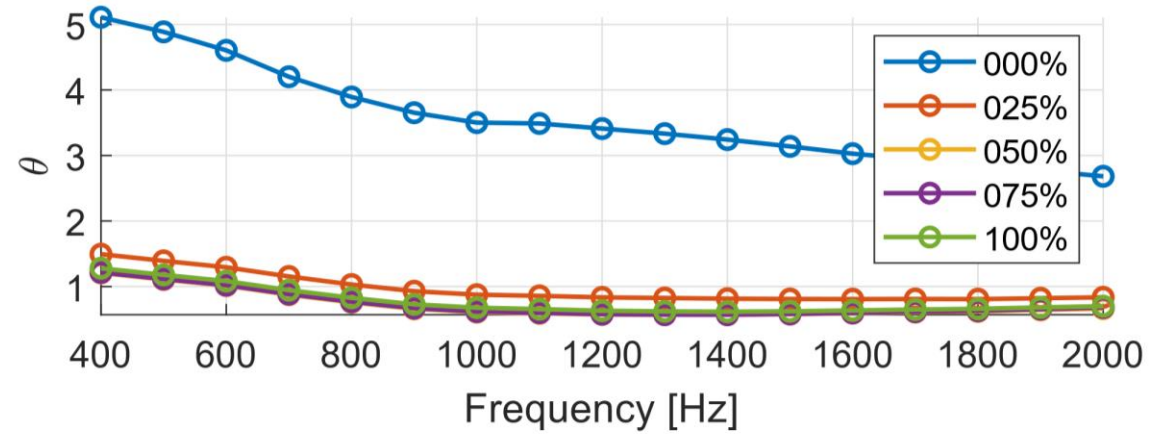
% Open	0	25	50	75	100
Resonance (Hz)	950	1044	1096	1153	1189

Appendix: GFIT Results

• 120 dB



• 140dB

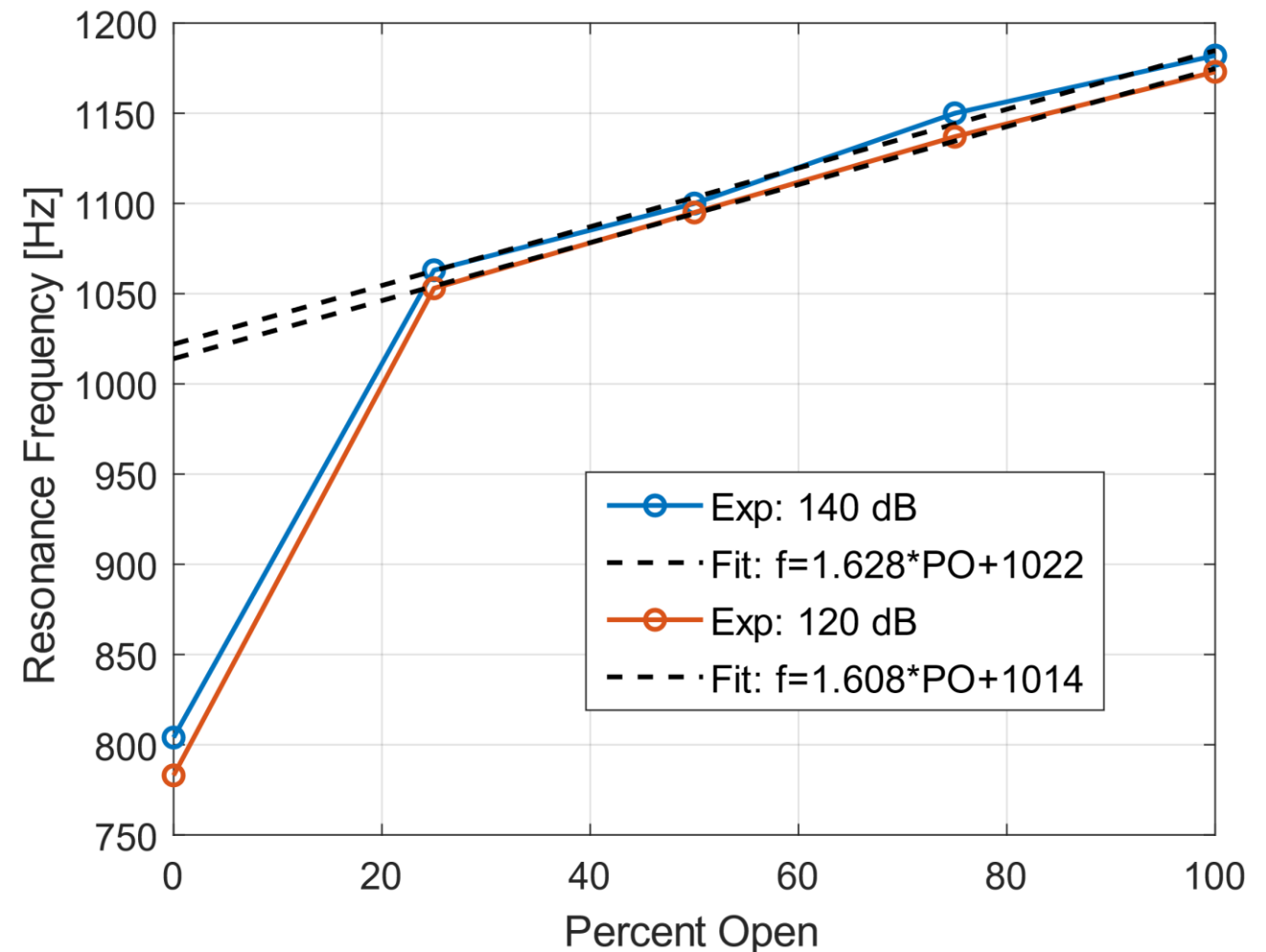


% Open	0	25	50	75	100
Resonance (Hz)	783	1053	1095	1137	1173

% Open	0	25	50	75	100
Resonance (Hz)	804	1063	1100	1150	1182

Appendix: Resonance Frequency Tune

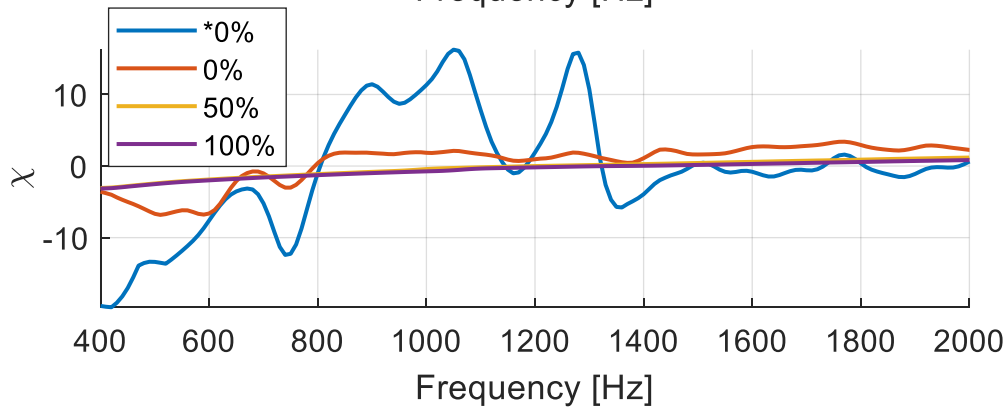
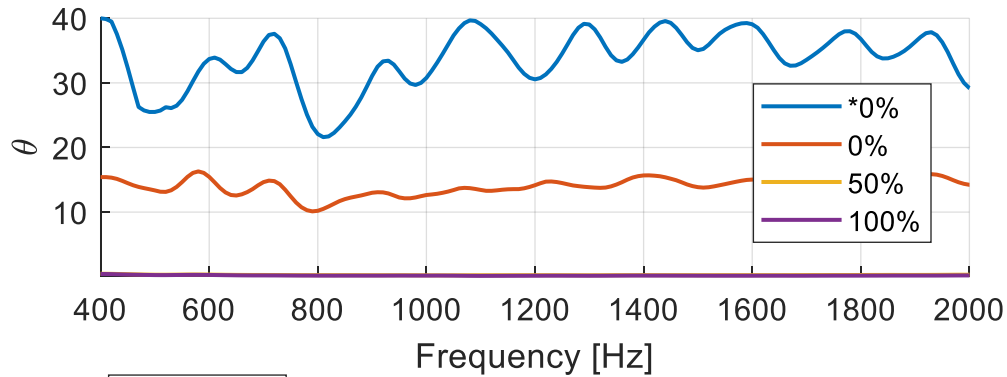
- How resonance changes with percent open of hole, where 100 is fully open and 0 is fully closed
 - Resonance frequency is taken from GFIT results
- 120 dB and 140 dB are shown
- Conclusion: We can target a resonance frequency during testing for the different SPLs



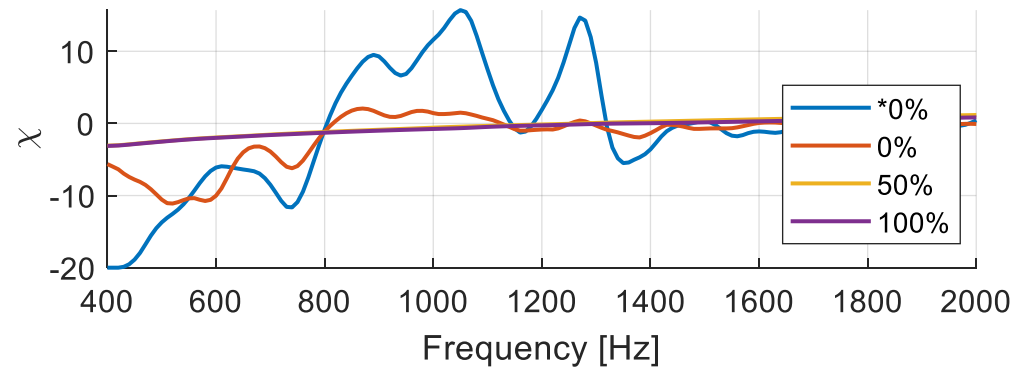
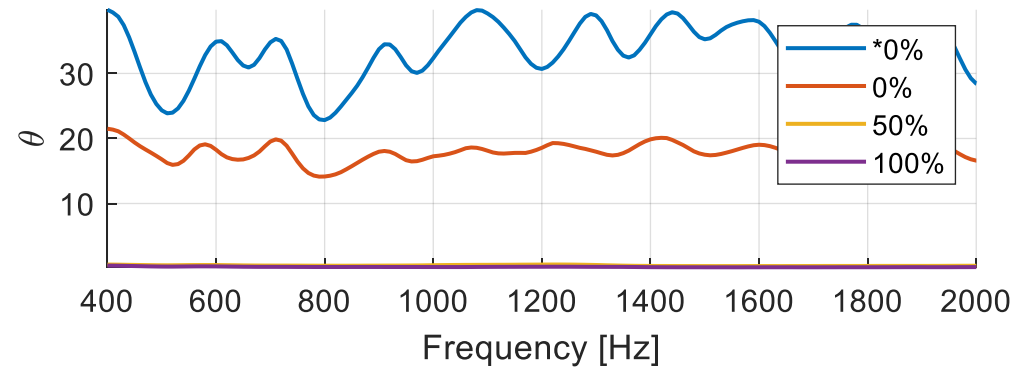
Appendix: GFIT Impedance Results of Static Liner



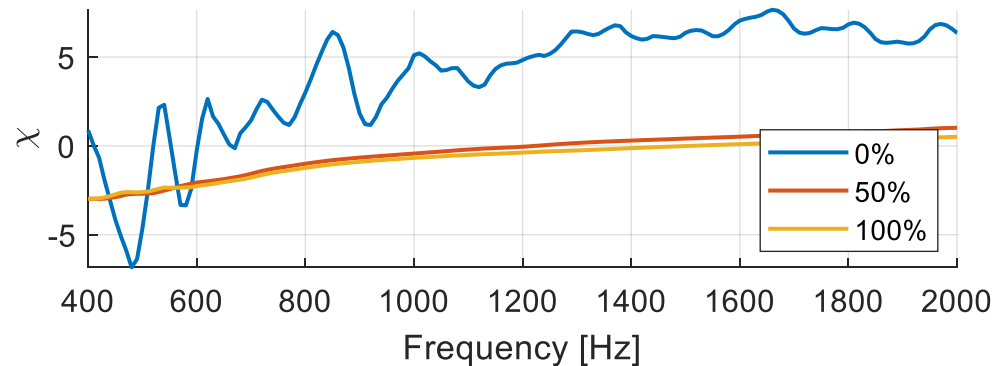
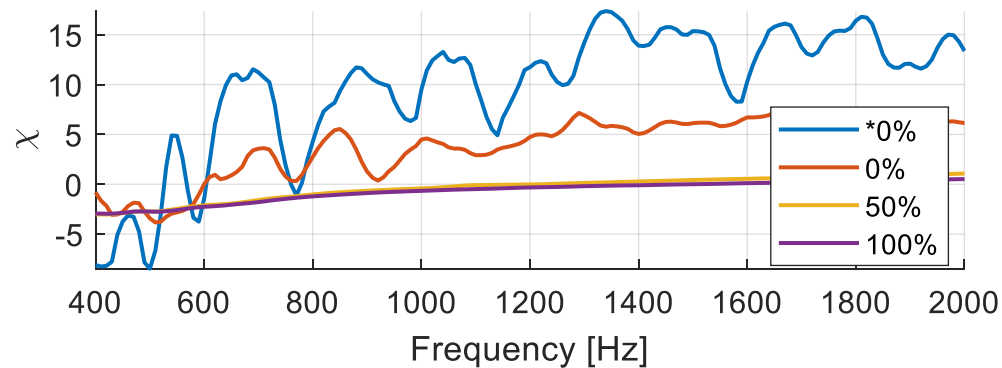
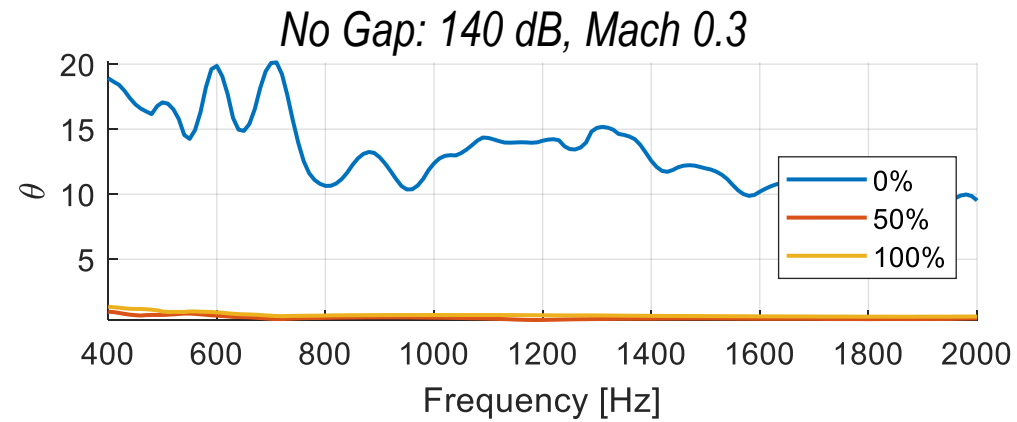
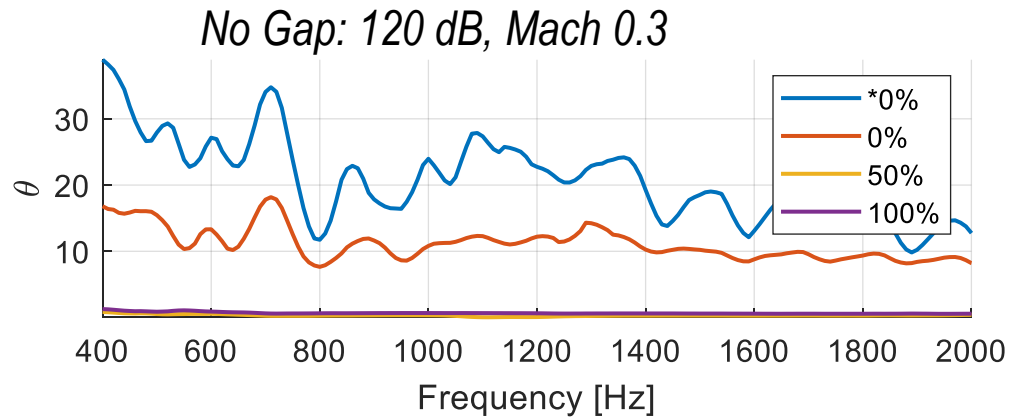
No Gap: 120 dB, Mach 0



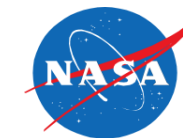
No Gap: 140 dB, Mach 0



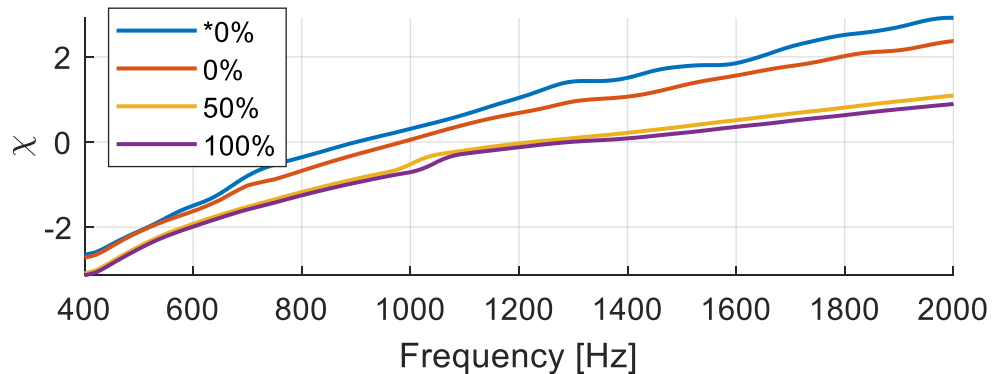
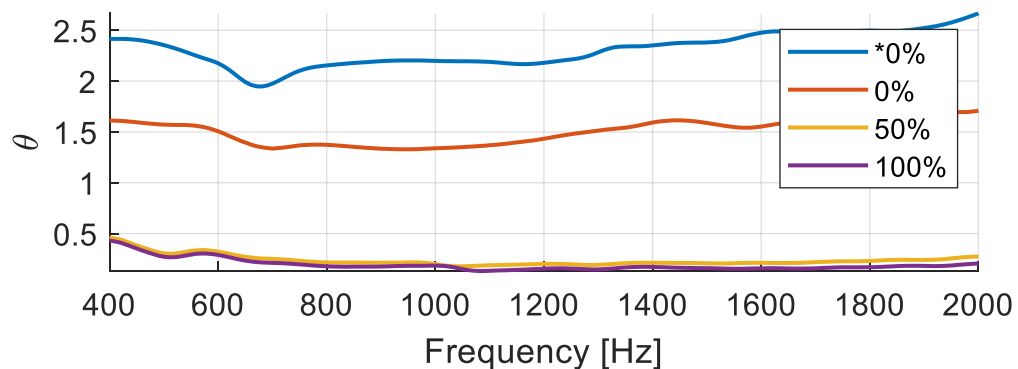
Appendix: GFIT Impedance Results of Static Liner



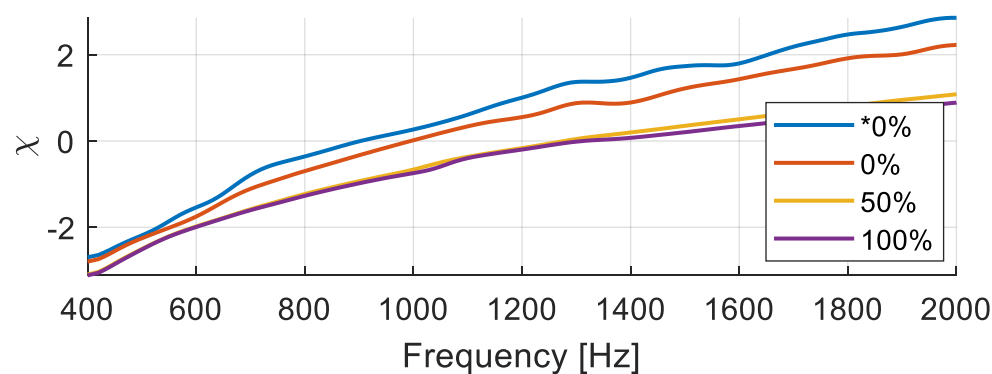
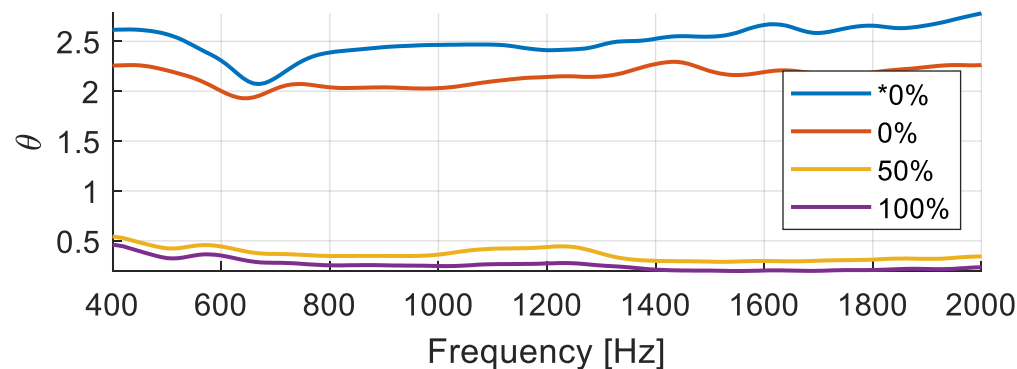
Appendix: GFIT Impedance Results of Static Liner



Gap: 120 dB, Mach 0



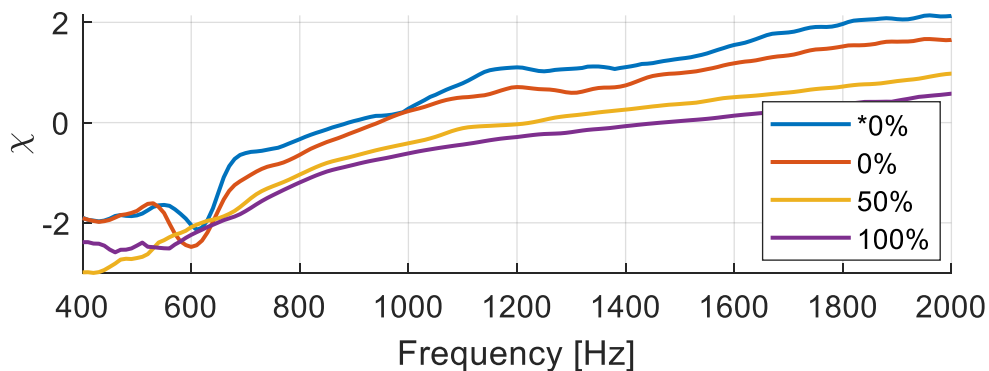
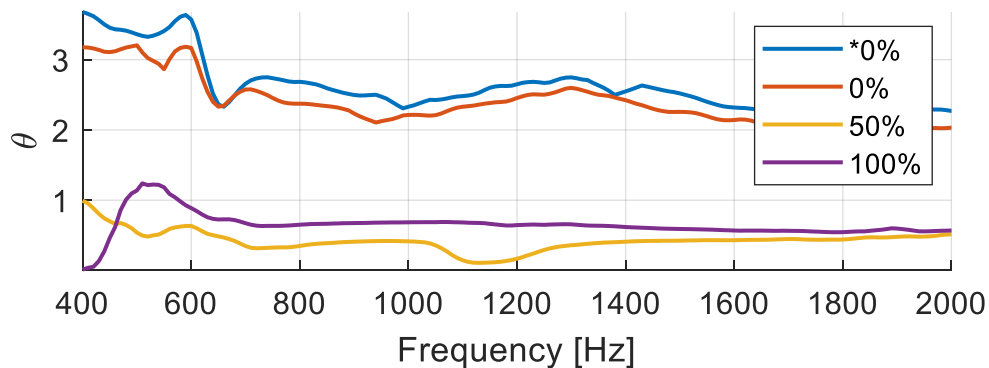
Gap: 140 dB, Mach 0



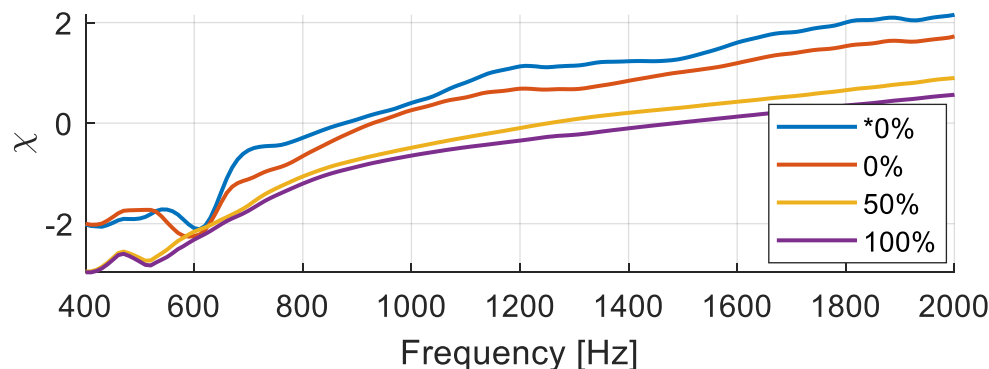
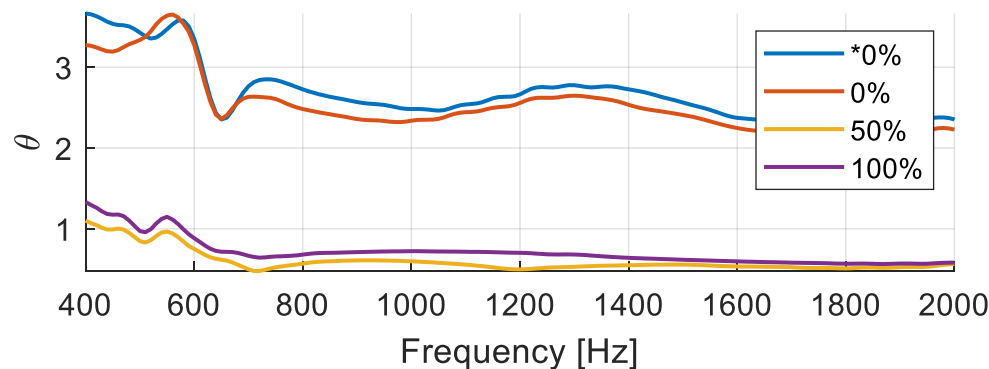
Appendix: GFIT Impedance Results of Static Liner



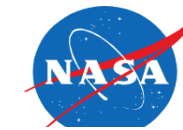
Gap: 120 dB, Mach 0.3



Gap: 140 dB, Mach 0.3

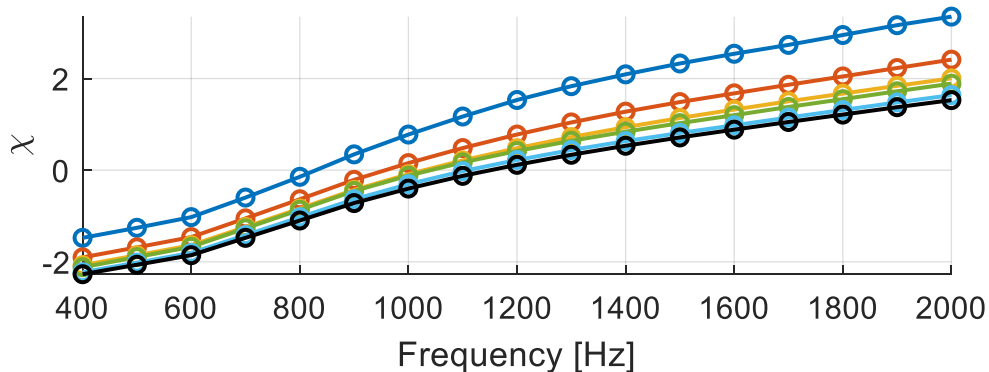
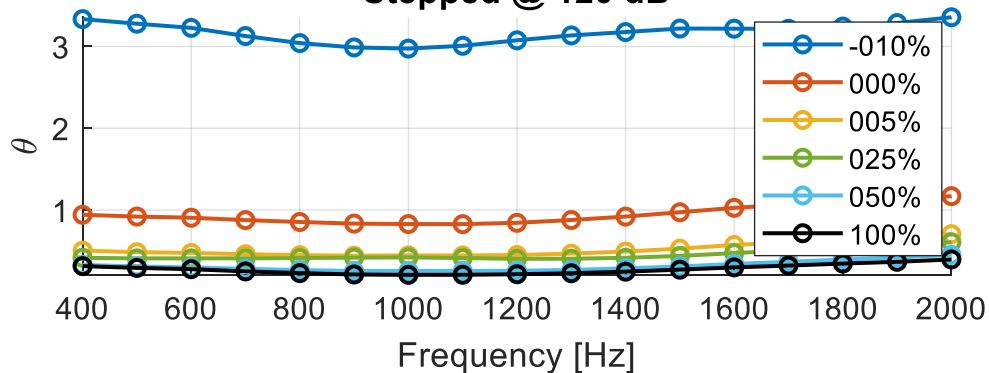


Comparison active vs static: Mach 0, 120 dB

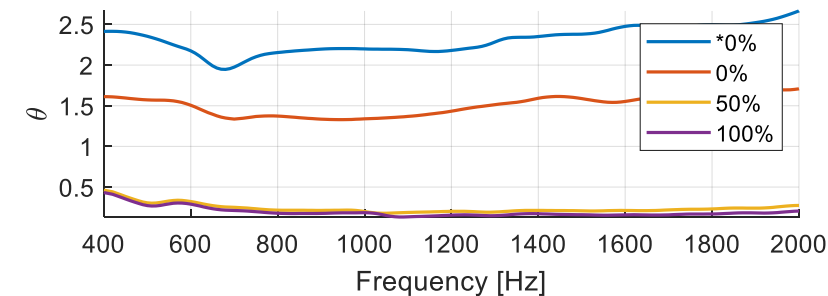
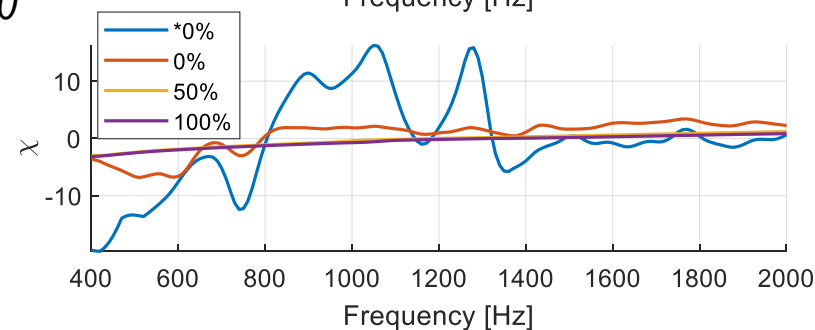
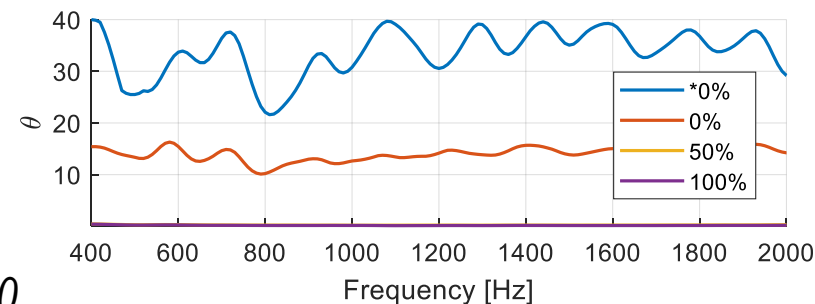


Active Sample: 120 dB, Mach 0

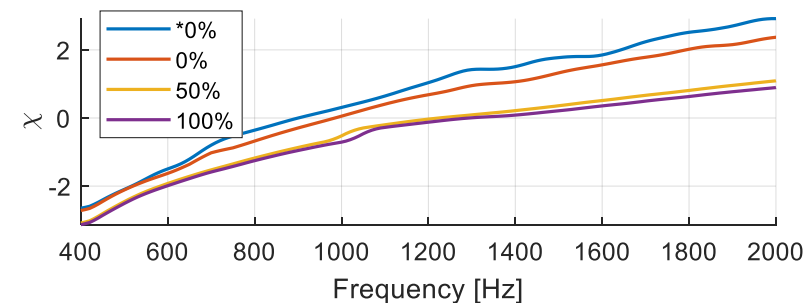
Stepped @ 120 dB



No Gap: 120 dB, Mach 0



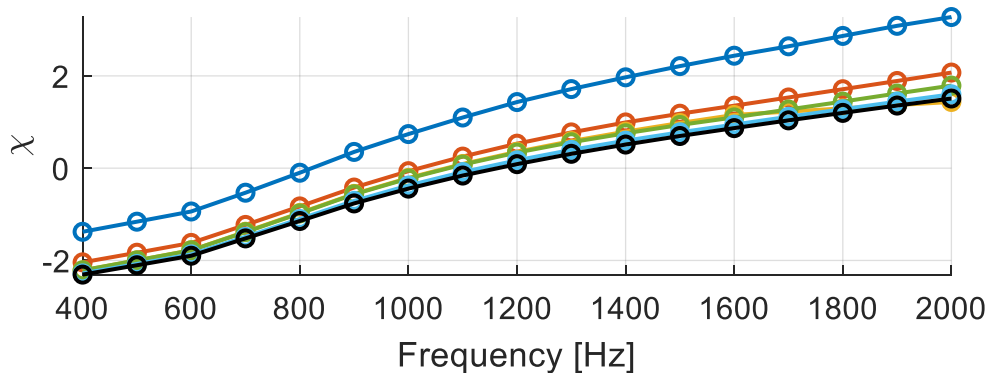
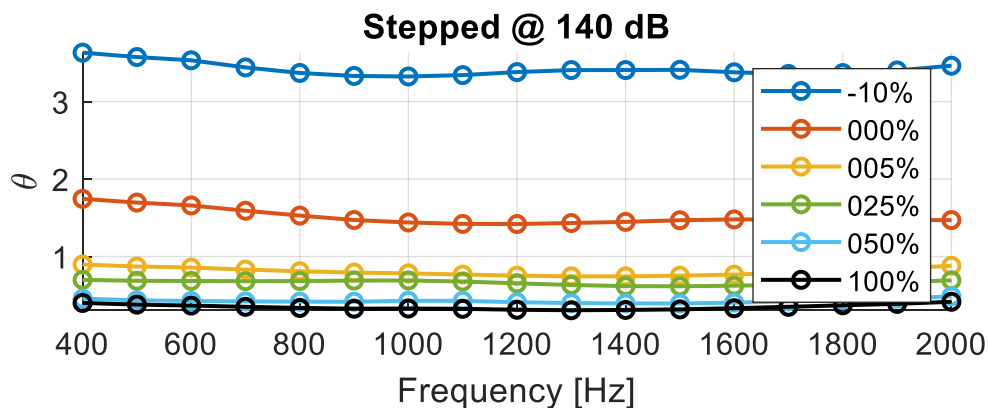
Gap: 120 dB, Mach 0



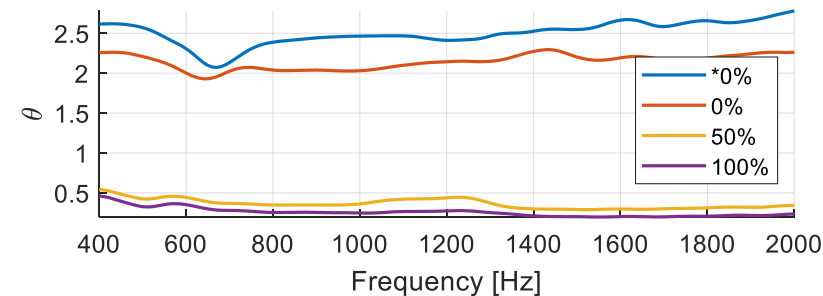
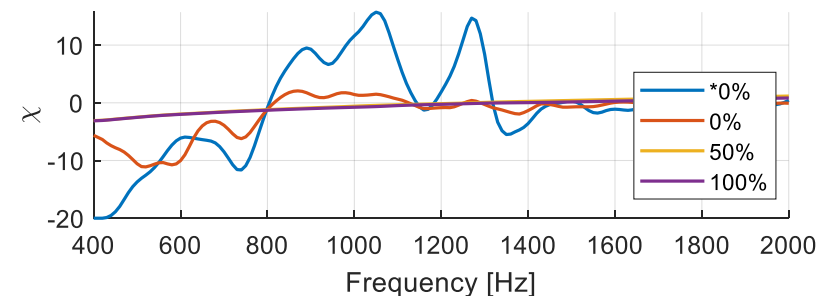
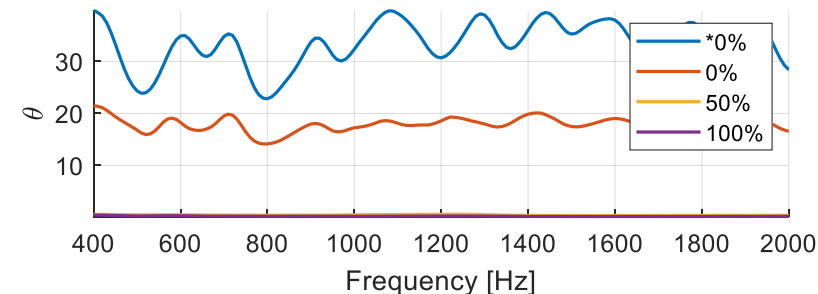
Comparison active vs static: Mach 0, 140 dB



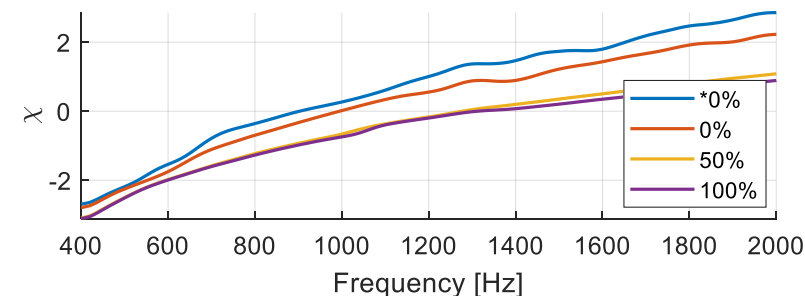
Active Sample: 140 dB, Mach 0



No Gap: 140 dB, Mach 0



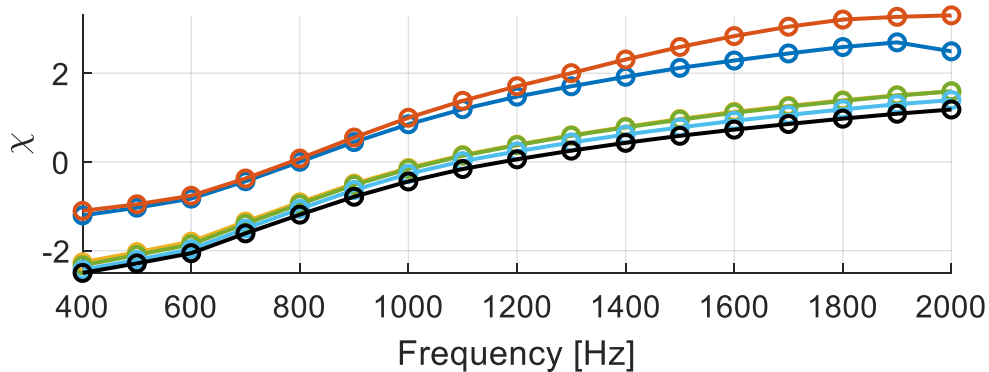
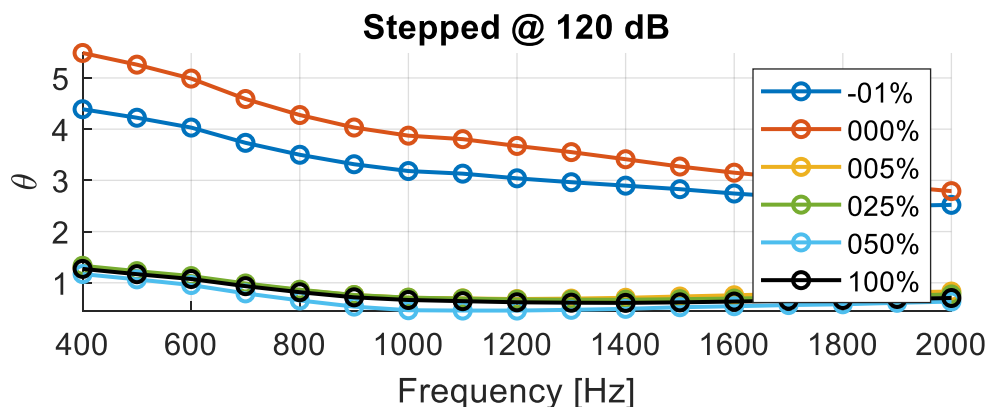
Gap: 140 dB, Mach 0



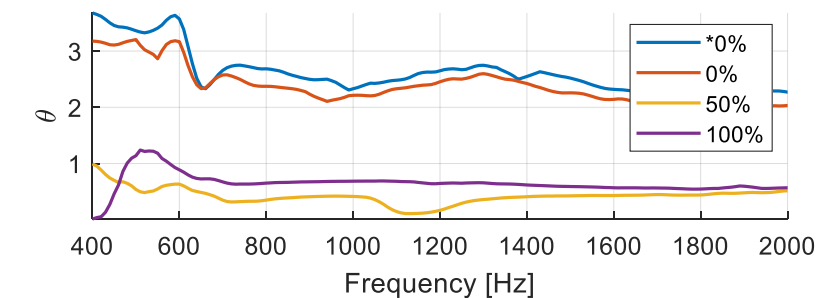
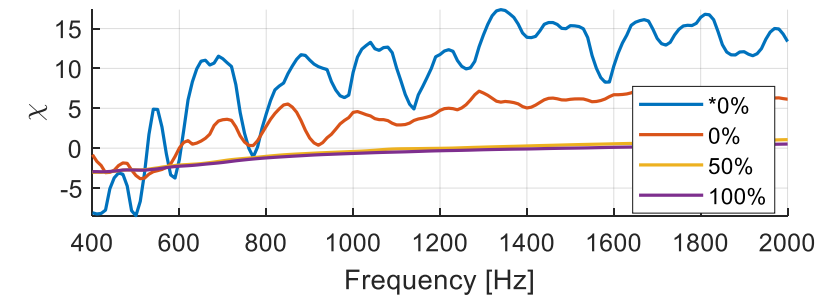
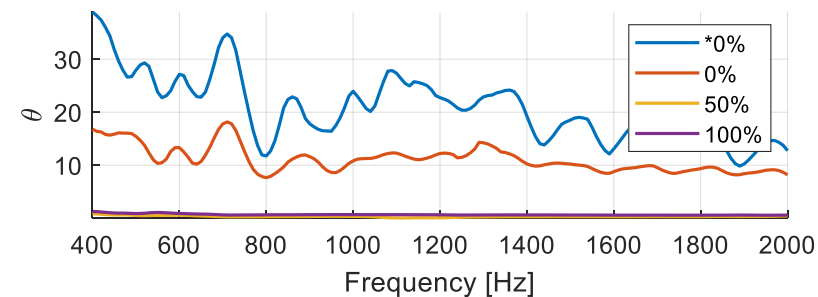
Comparison active vs static: Mach 0.3, 120 dB



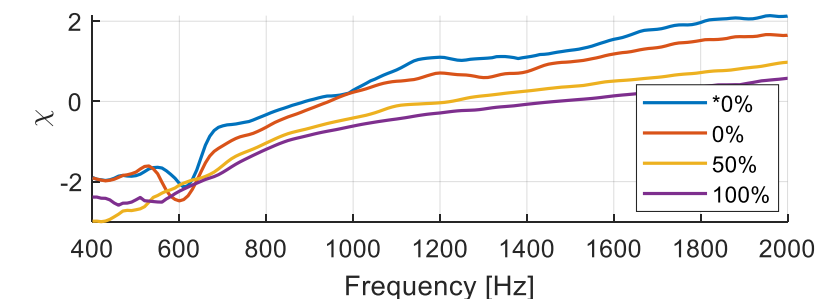
Active Sample: 120 dB, Mach 0.3



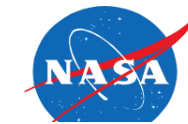
No Gap: 120 dB, Mach 0.3



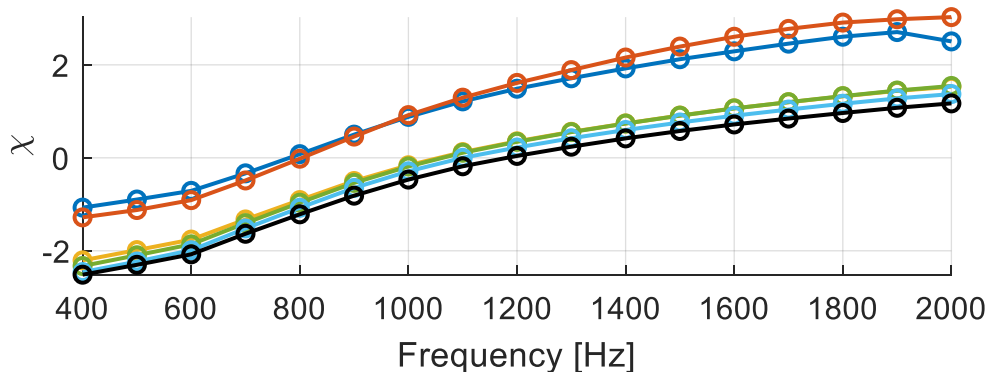
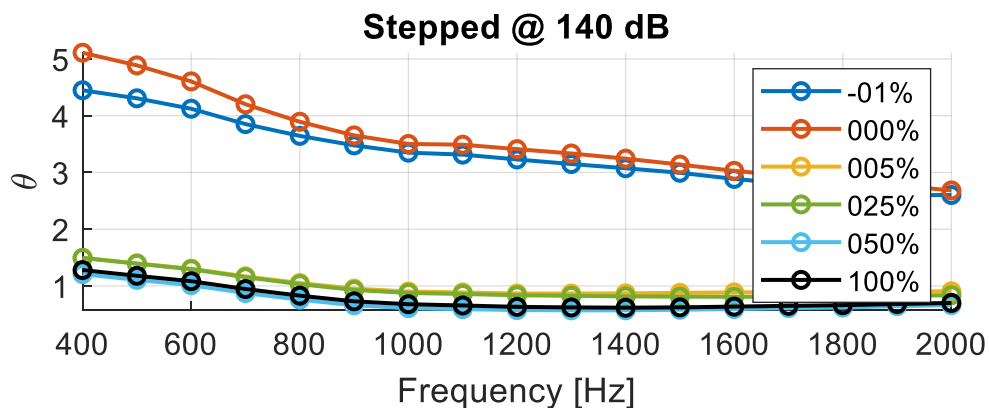
Gap: 120 dB, Mach 0.3



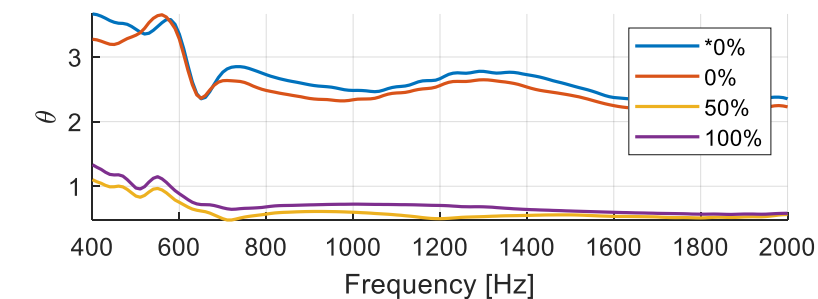
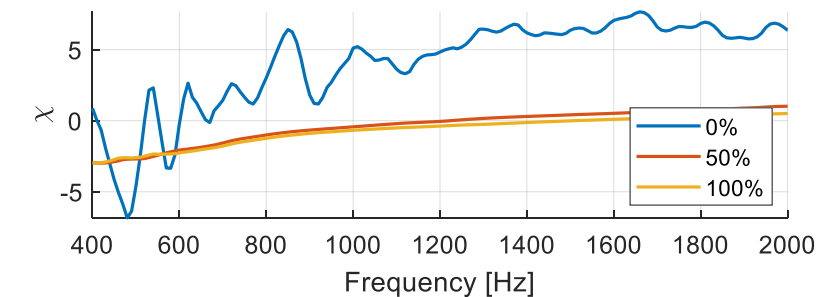
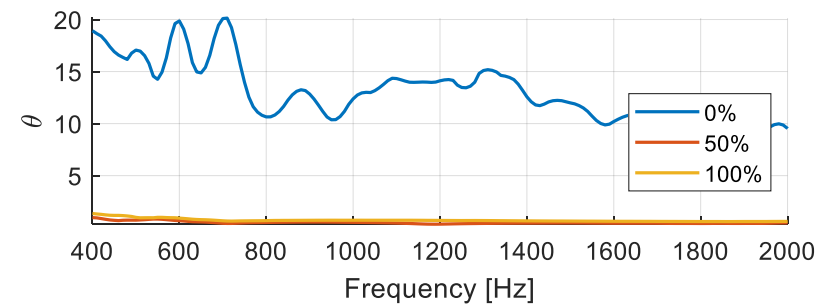
Comparison active vs static: Mach 0.3, 140 dB



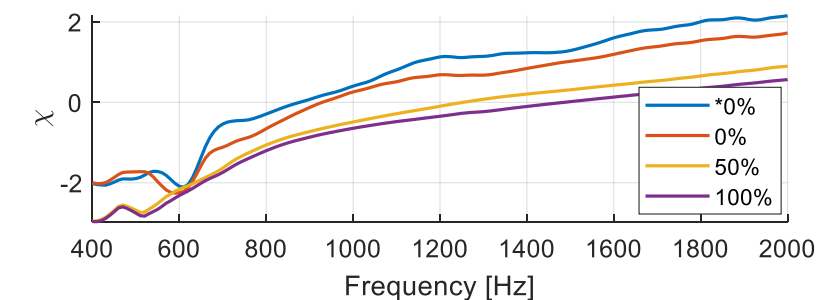
Active Sample: 140 dB, Mach 0.3



No Gap: 140 dB, Mach 0.3



Gap: 140 dB, Mach 0.3

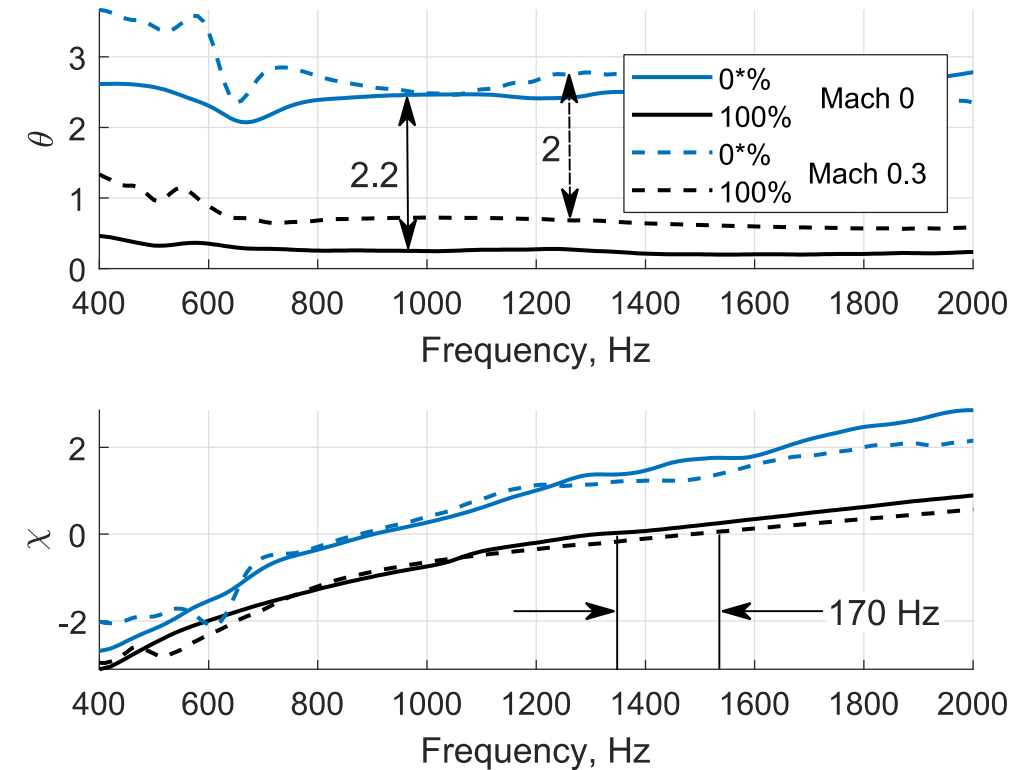


Results - Static Liner (w/ Gap)

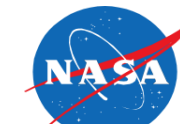


- Increasing Mach number reduces $\Delta\theta$ between 0* and 100%
- Resonance has slight flattening with flow (similar to Active liner)

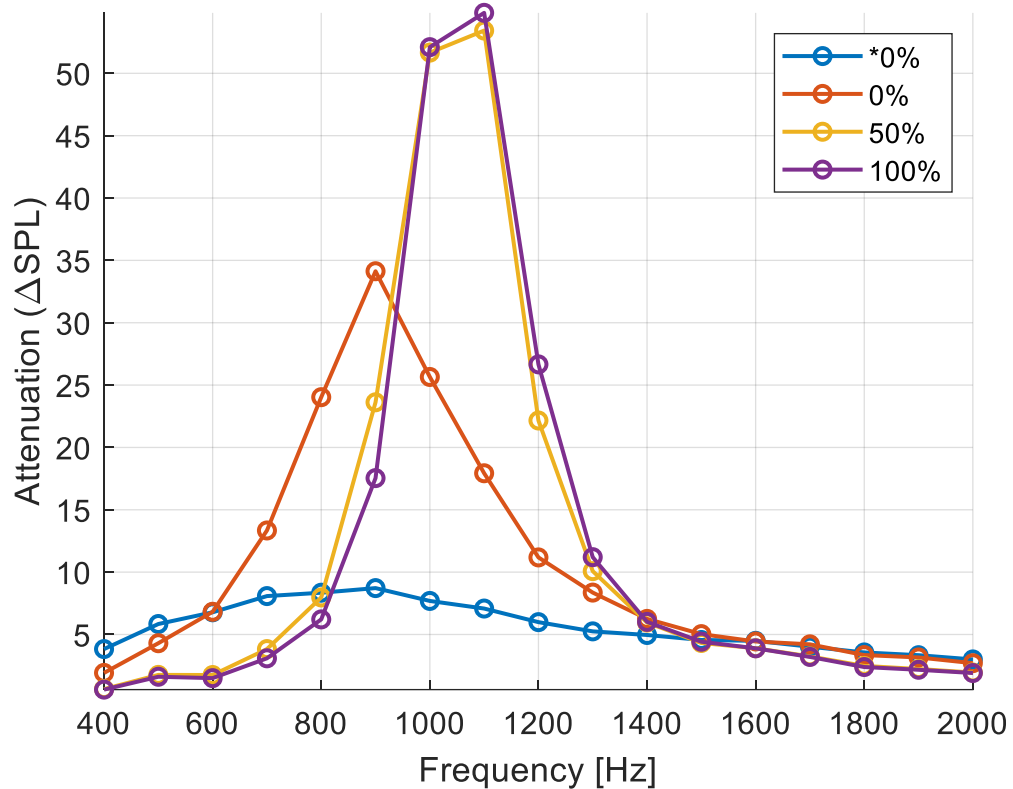
140 dB



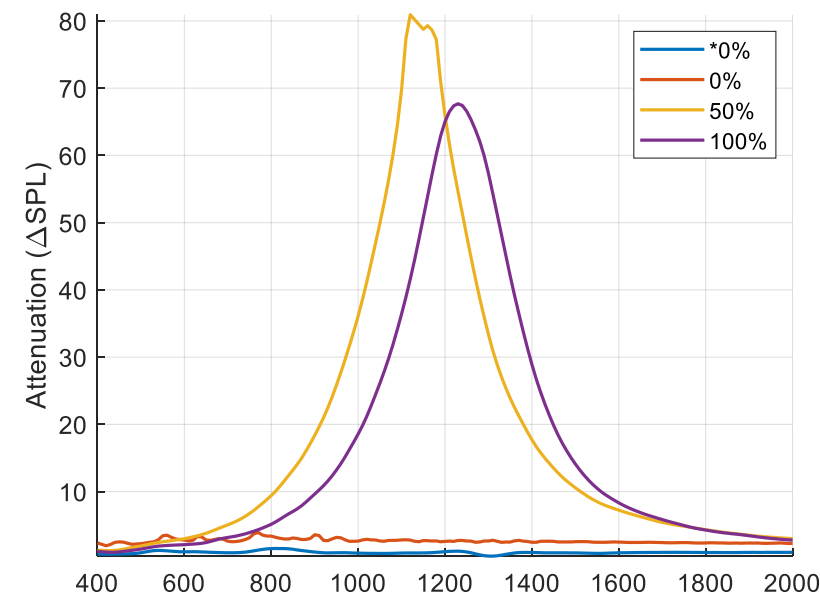
Comparison active vs static: Mach 0, 120 dB



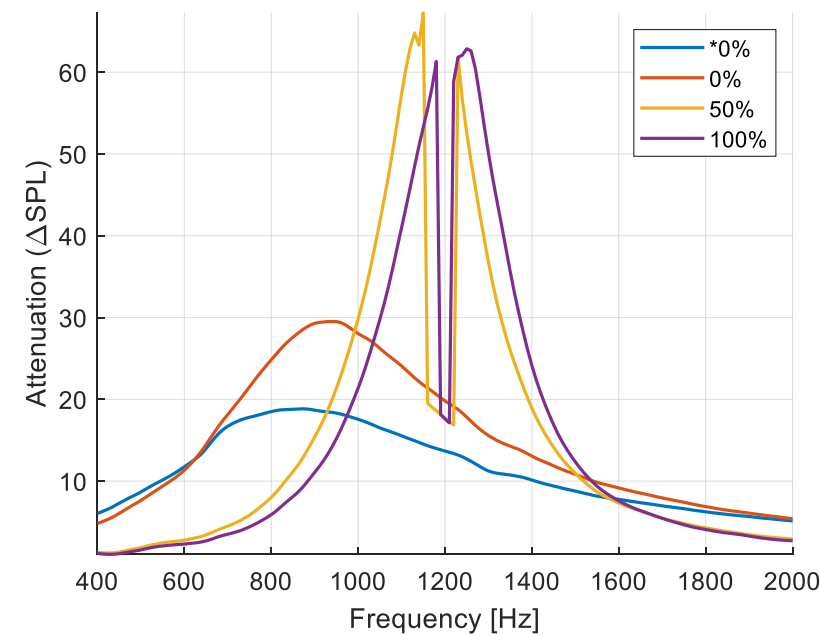
Active Sample: 120 dB, Mach 0



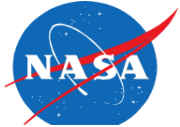
No Gap: 120 dB, Mach 0



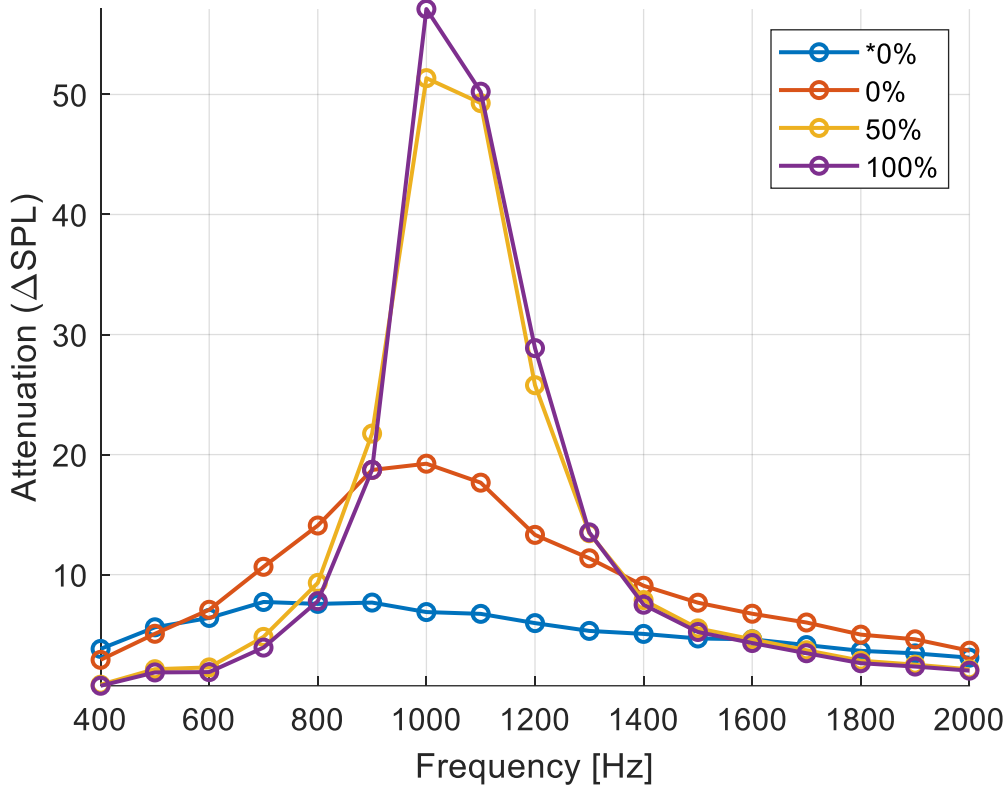
Gap: 120 dB, Mach 0



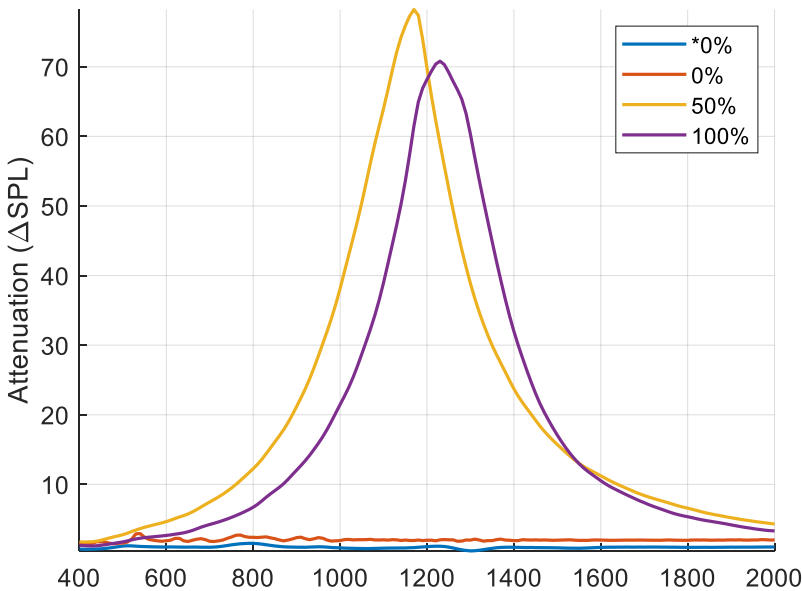
Comparison active vs static: Mach 0, 140 dB



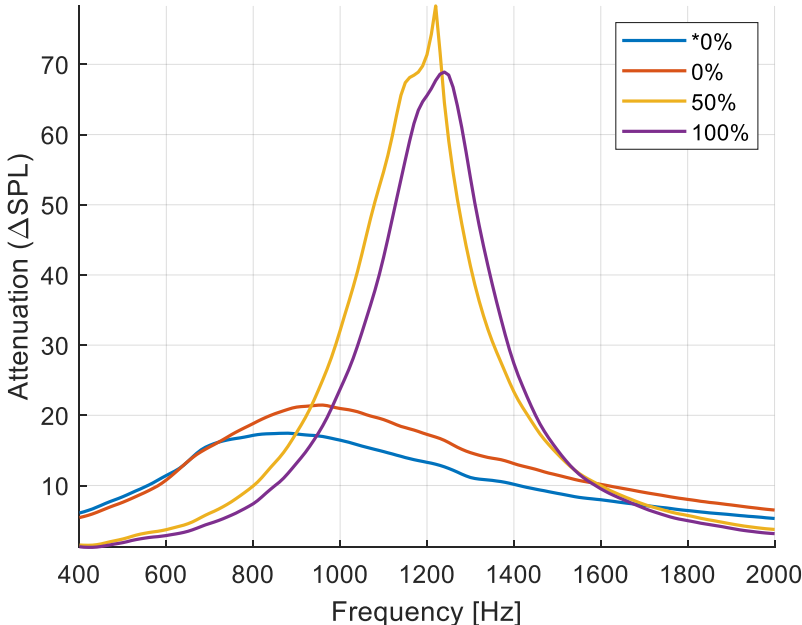
Active Sample: 140 dB, Mach 0



No Gap: 140 dB, Mach 0



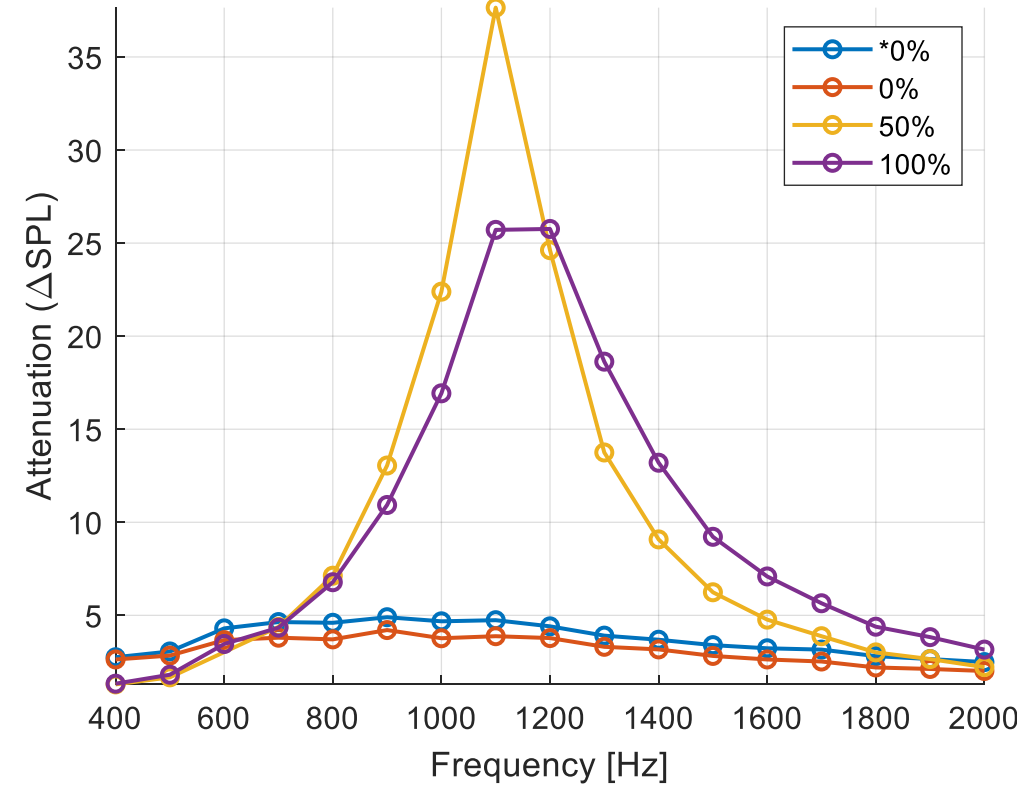
Gap: 140 dB, Mach 0



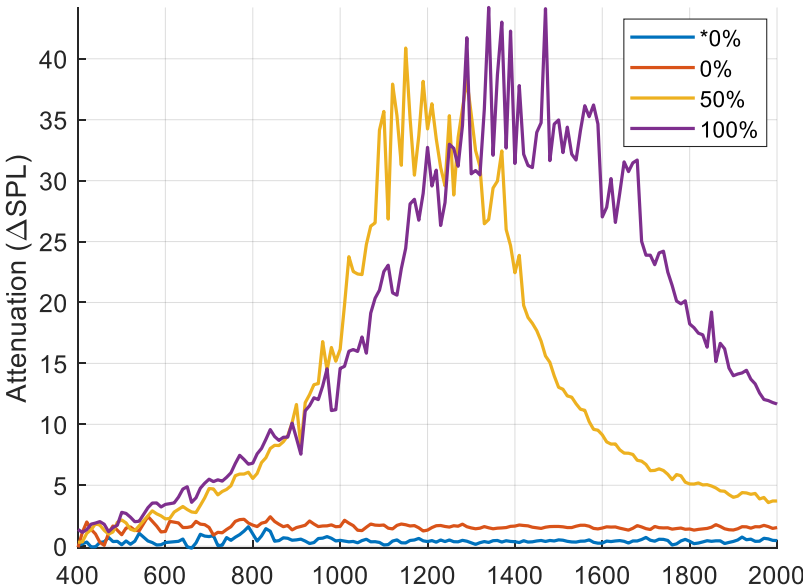
Comparison active vs static: Mach 0.3, 120 dB



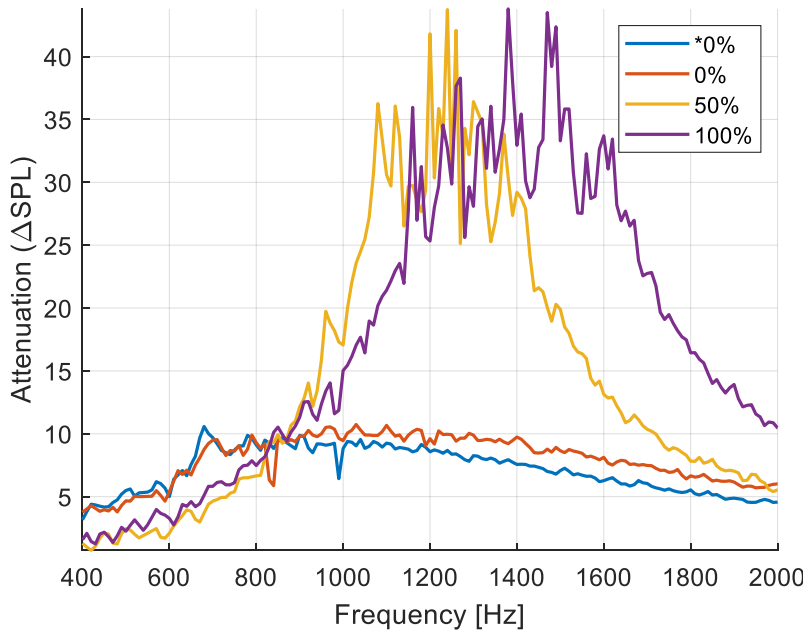
Active Sample: 120 dB, Mach 0.3



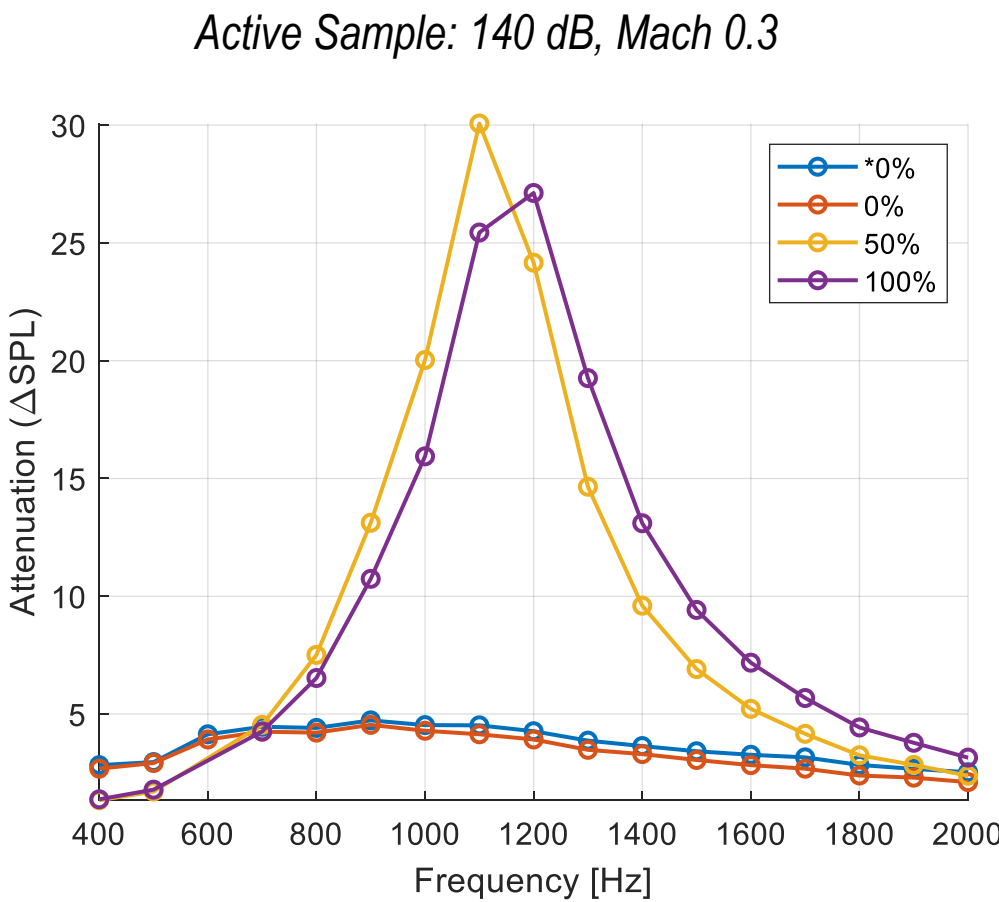
No Gap: 120 dB, Mach 0.3



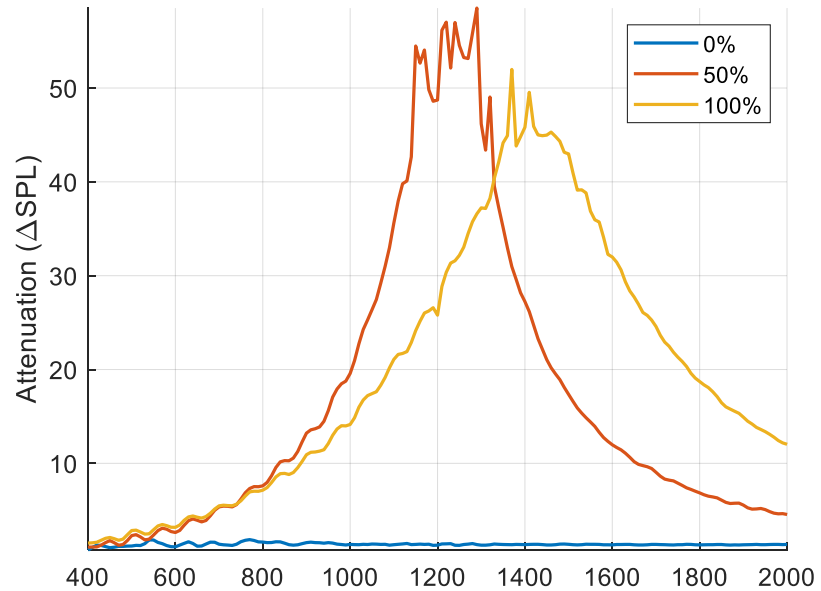
Gap: 120 dB, Mach 0.3



Comparison active vs static: Mach 0.3, 140 dB



No Gap: 140 dB, Mach 0.3



Gap: 140 dB, Mach 0.3

