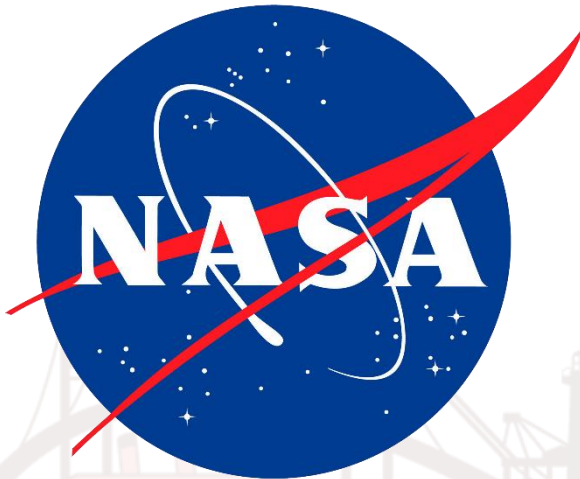




Michigan
Technological
University



Mitigating Grazing Flow Impedance Eduction Errors in Additively Manufactured Porous Liners

Kara Hardy, Anthony Ciletti, Janith
Godakawela, Bhisham Sharma

Michigan Technological University

Martha Brown

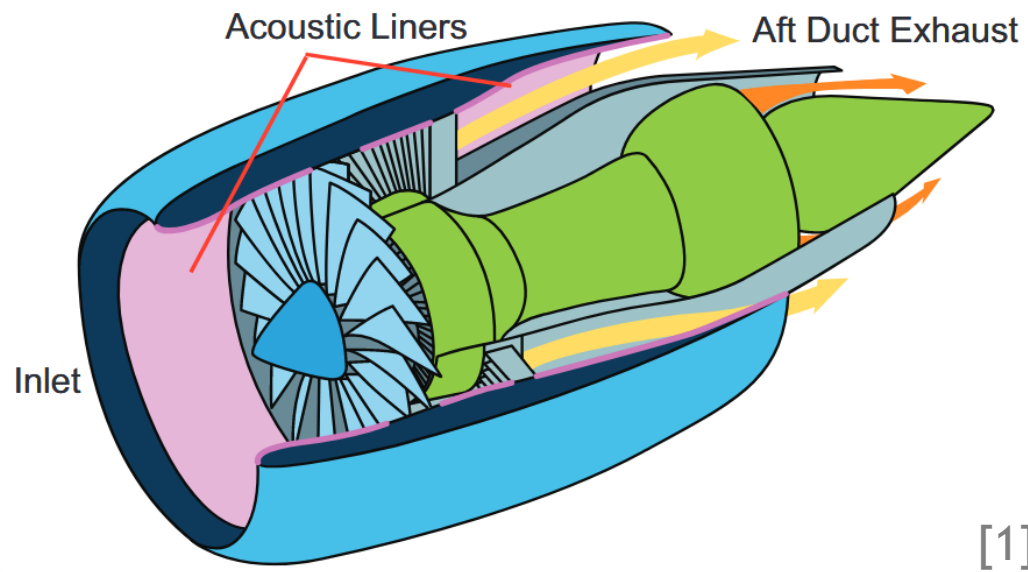
Aeroacoustics Branch, NASA Langley Research Center

Grazing Flow Liner Applications

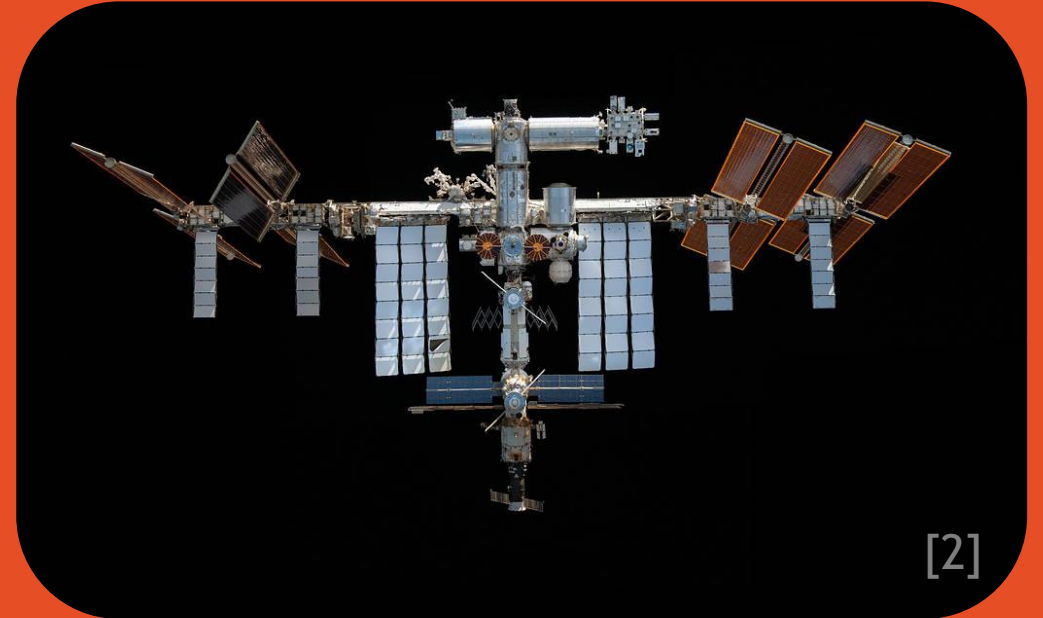
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Aircraft



HVAC (ISS)

Traditional Acoustic Materials Exhibit Significant Shortfalls

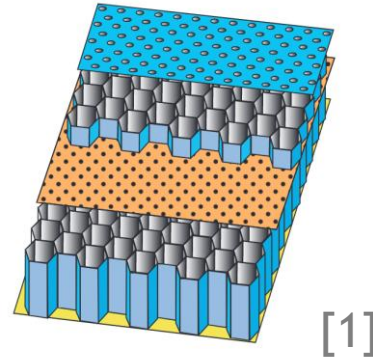
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Honeycomb Absorbers

- Made of composite or metal materials
- Quarter wavelength resonators only target narrow frequency bands



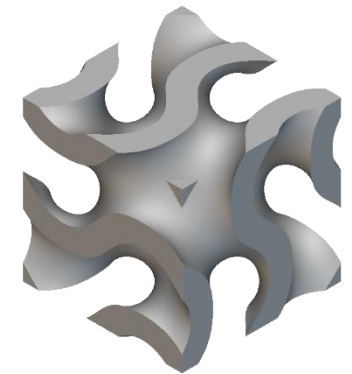
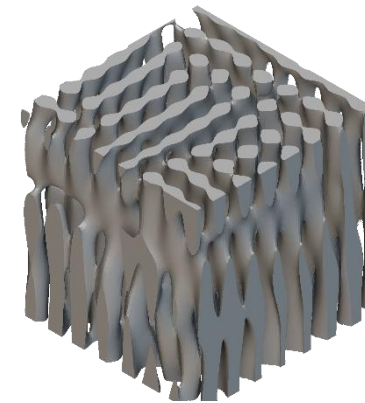
Foams and Fibers

- Lack structural integrity
- Open-celled structure, more broadband absorption



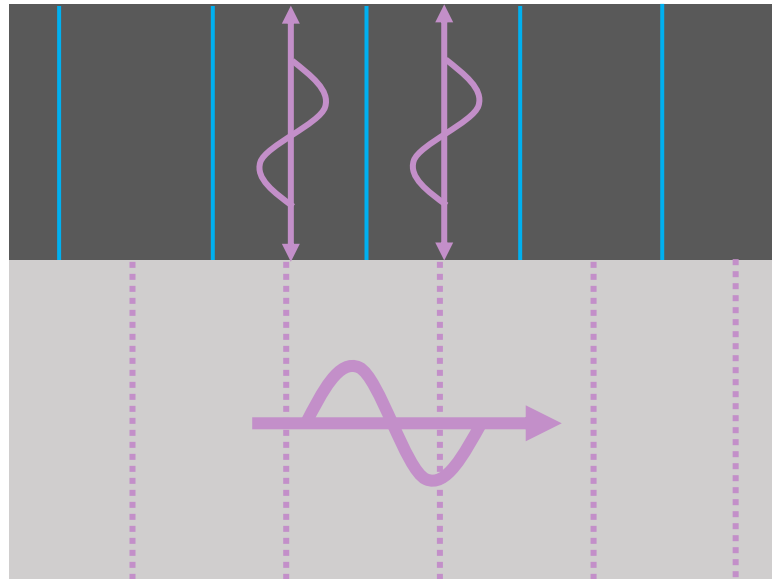
Additively Manufactured Porous Materials

- Engineered with open-celled structures
- Manufactured with a variety of materials from polymers to resins
- Multiple functions - structural, thermal, etc.



These Materials Are Incompatible With Current Grazing Flow Impedance Eduction Processes

Locally Reacting Absorber



Locally-Reacting
Acoustic Absorber

Wave-guide

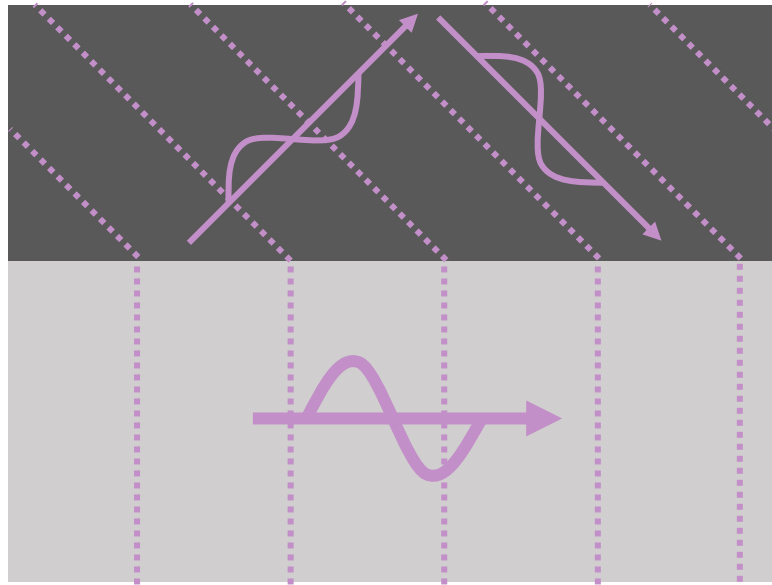
Propagating Waves

Ingard-Myers Boundary Condition

Surface impedance at each
point on the liner surface is
independent from every other
point [4,5]

These Materials Are Incompatible With Current Impedance Eduction Processes

Extended Reacting Absorber



Extended-Reacting
Acoustic Absorber

Wave-guide

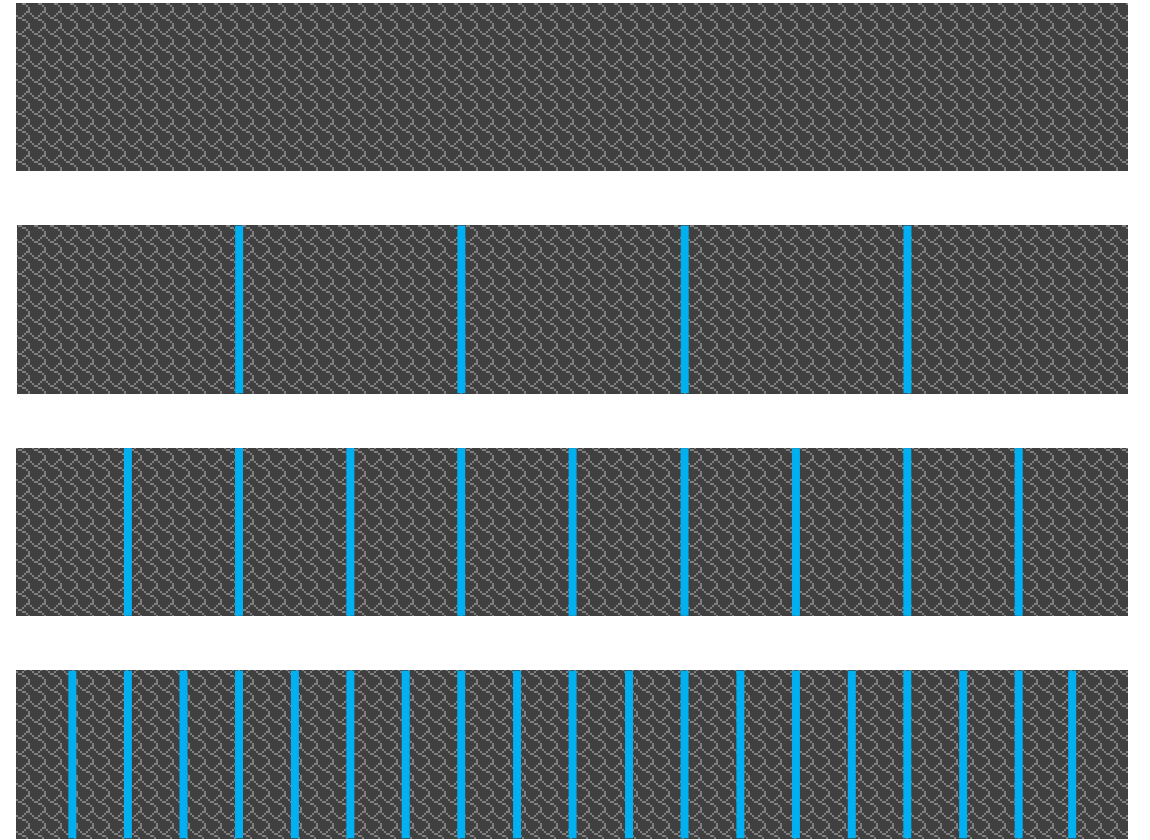
Propagating Waves

Ingard-Myers Boundary Condition

Surface impedance at each
point on the liner surface is
independent from every other
point [4,5]

Because the liner has an inter-
connected pore structure, the
surface impedance is dependent
on the characteristics of the liner
upstream

Does the addition of axial partitions modify extended reacting structures to behave as though they are locally reacting?



Does the addition of axial partitions modify extended reacting structures to behave as though they are locally reacting?

What happens to the characteristics of the liner with axial partitions?

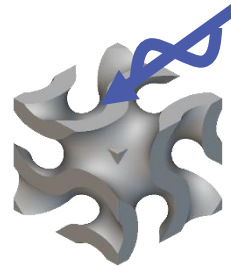
Structures

Partitions

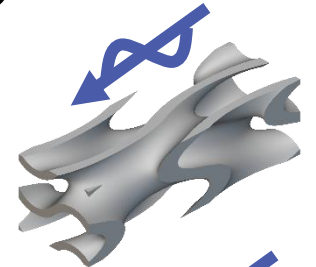
Mesh

Triply Periodic Minimal Surface (TPMS)

Gyroid



Gyroid: X Elongation



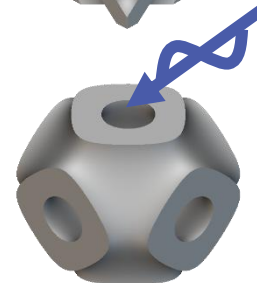
Diamond



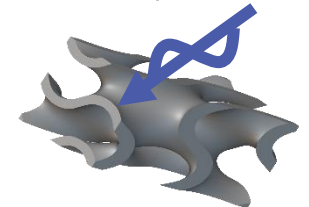
Gyroid: Z Elongation



Primitive



Gyroid: X Elongation,
45 Degree Rotation



Sample Configurations

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Structures

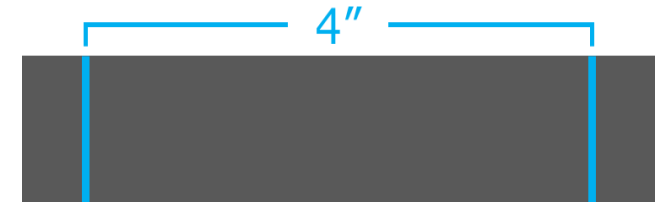
Partitions

Mesh

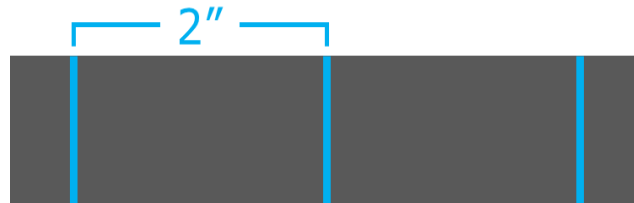
No Partitions



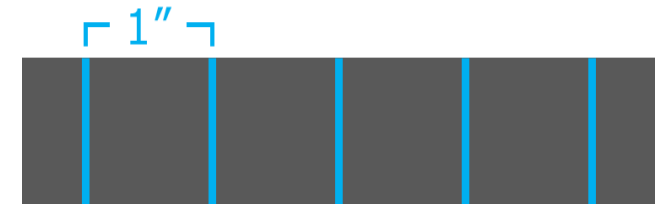
4" Spaced Partitions



2" Spaced Partitions



1" Spaced Partitions



Sample Configurations

NOISE-CON 2026

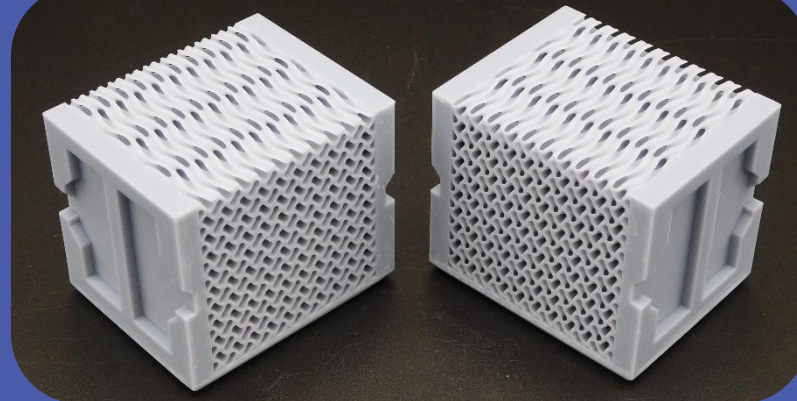


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Structures

Partitions

Mesh



Sample Blocks



Non-Partitioned Joint
Clip

Non-Partitioned Joint

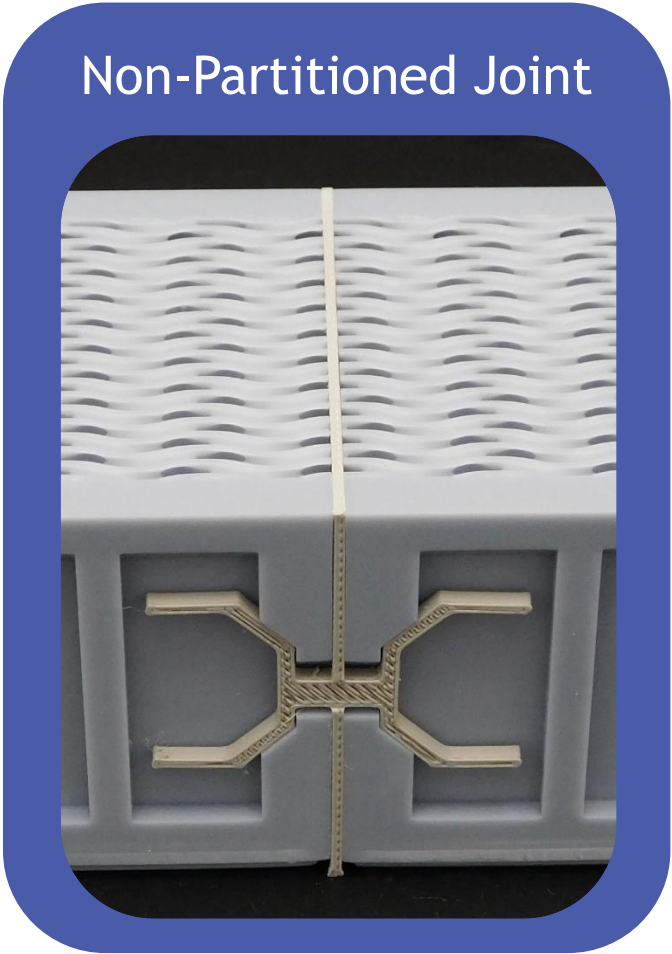
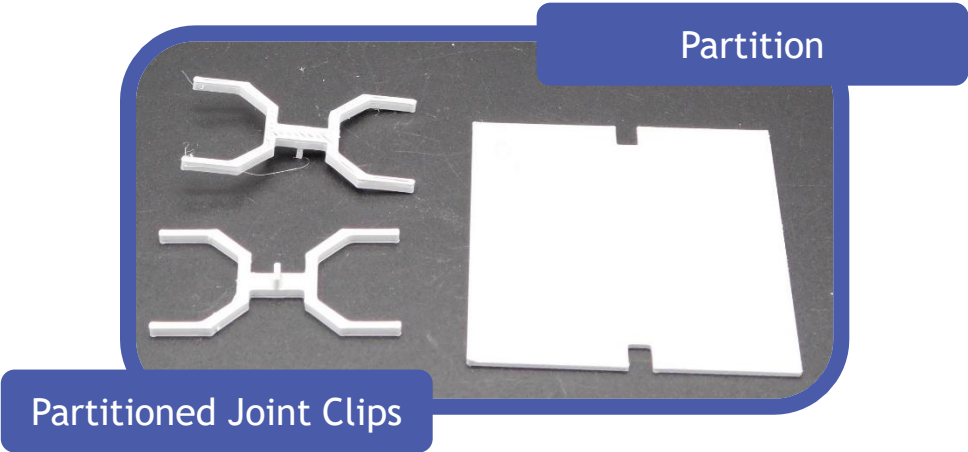
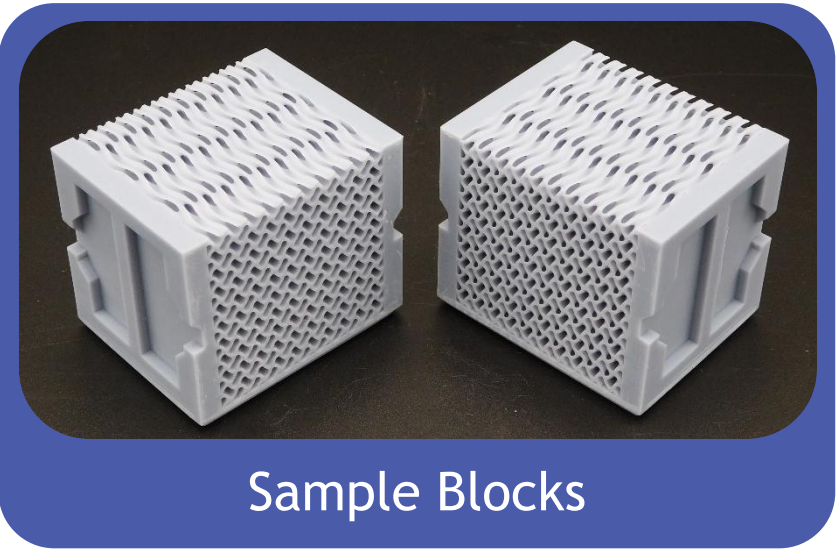


Sample Configurations

Structures

Partitions

Mesh



Sample Configurations

NOISE-CON 2026



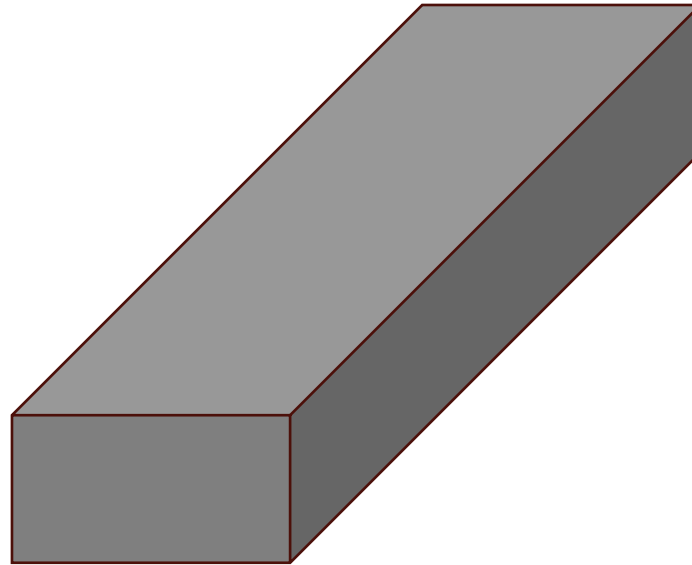
JULY 9-11 • LONG BEACH, CA

Structures

Partitions

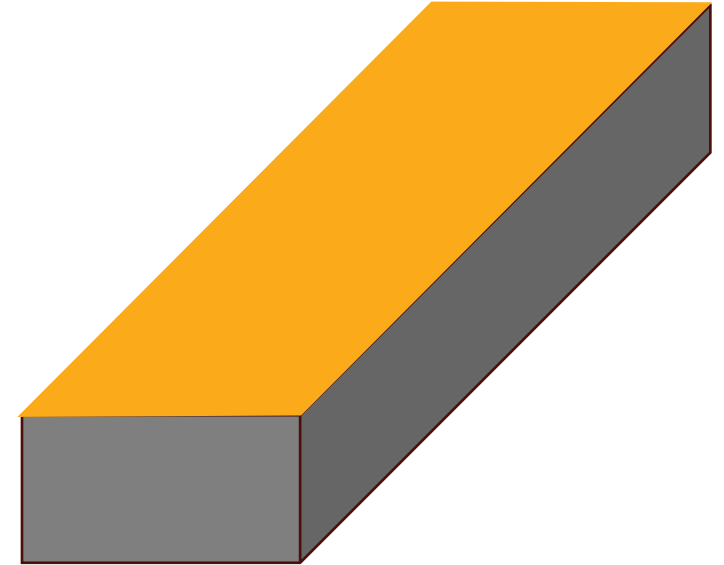
Mesh

No Mesh (No-Flow)



Mesh (Flow and No-Flow)

28 cgs Rayls

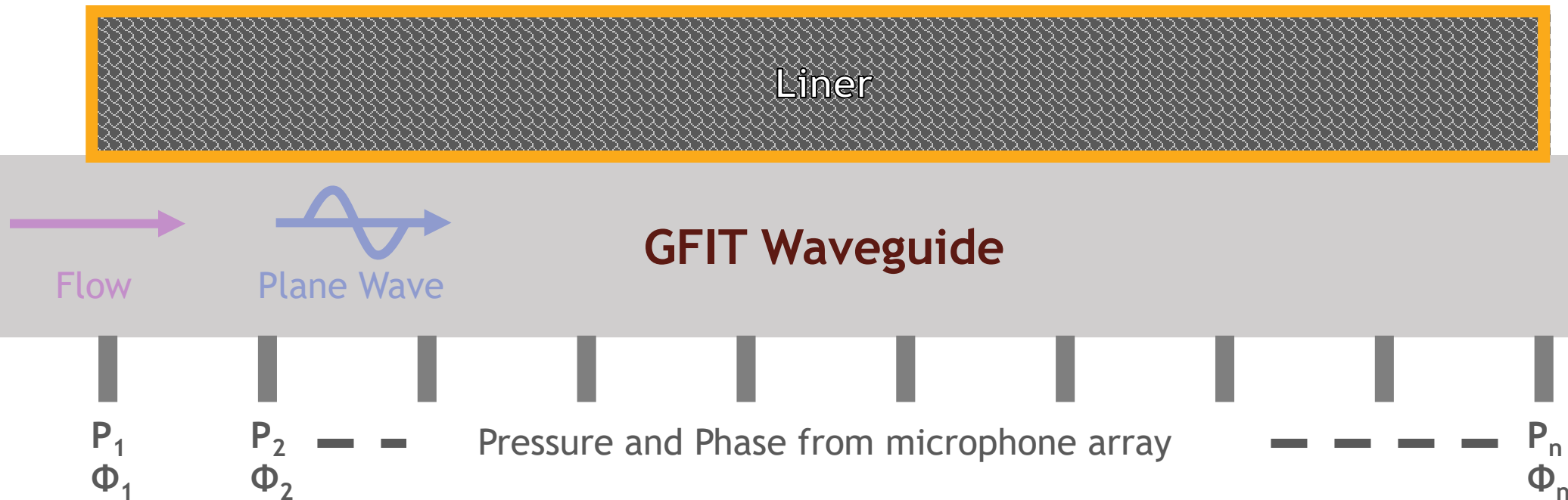
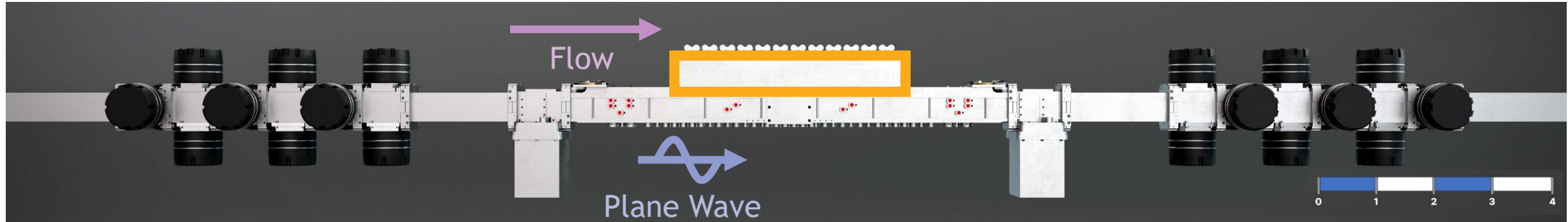


Impedance Eduction with Grazing Flow Impedance Tube (GFIT)

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We use impedance discontinuities and low correlation values to indicate inaccurate education

NOISE-CON 2026

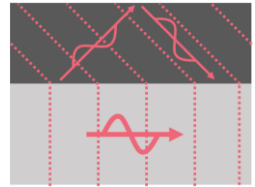

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Impedance educed using a locally reacting assumption should not be expected to accurately characterize an extended reacting liner

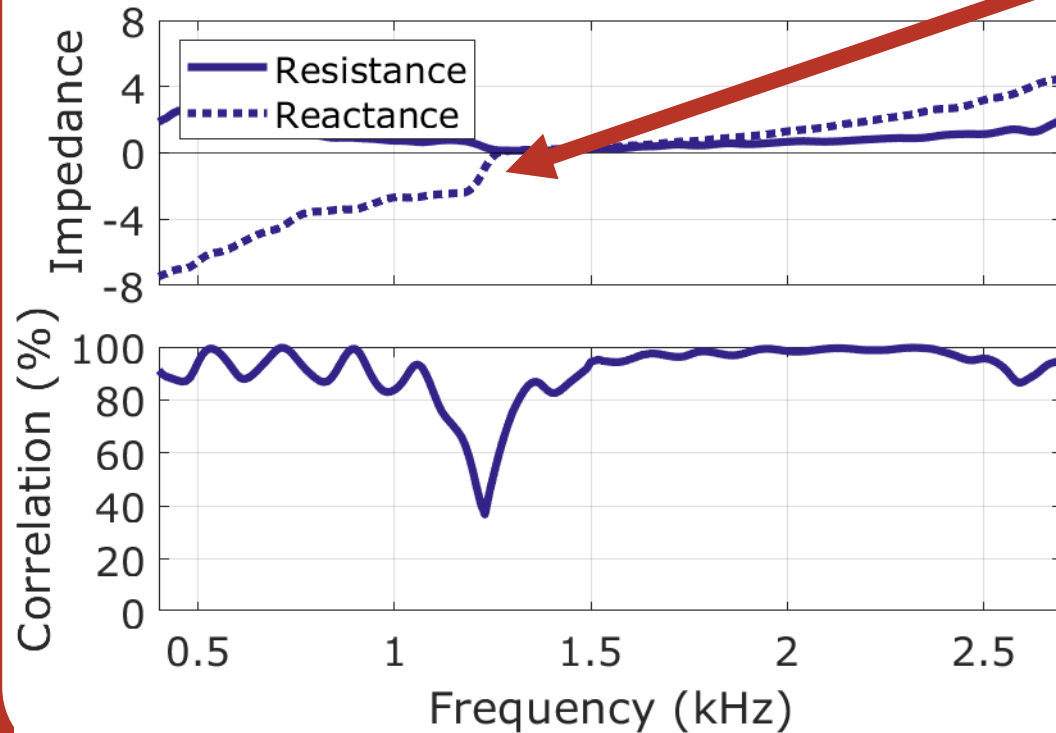
We use impedance discontinuities and low correlation values to indicate inaccurate education

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Extended Reacting Gyroid



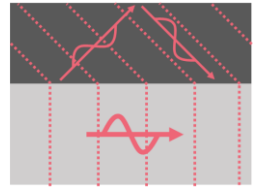
Discontinuities in the educed impedance spectrum

If the impedance discontinuity appears due to the Ingard-Myers boundary condition being violated, then the entire spectrum is untrustworthy

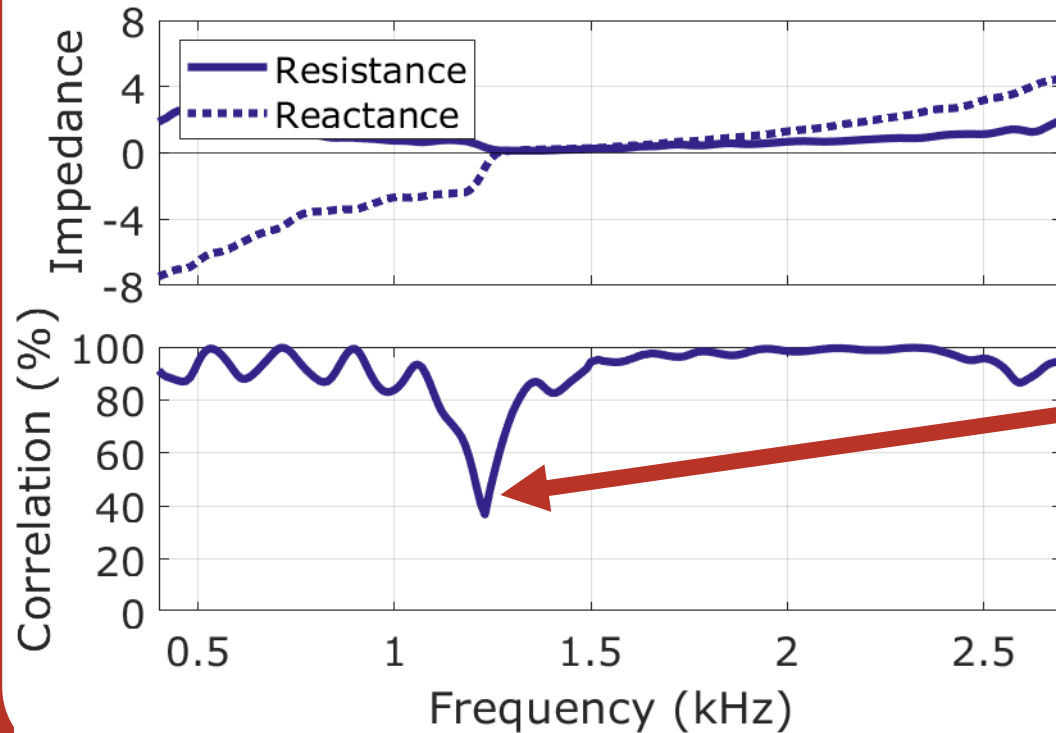
We use impedance discontinuities and low correlation values to indicate inaccurate education

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Extended Reacting Gyroid



Low correlation between the experimental data and the pressure and phase information reconstructed based on the calculated impedance

The educed impedance does not accurately describe the physical behavior of the liner



Does the addition of axial partitions modify extended reacting structures to behave as though they are locally reacting?

For Basic TPMS Unit Cells, Including Partitions Reduces Or Eliminates Discontinuities And Low Correlation Values

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No Partitions, No Mesh



4-Inch Partitions, No Mesh



2-Inch Partitions, No Mesh



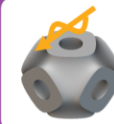
1-Inch Partitions, No Mesh



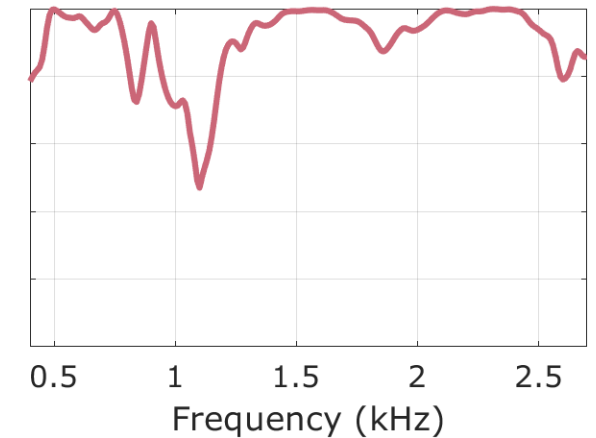
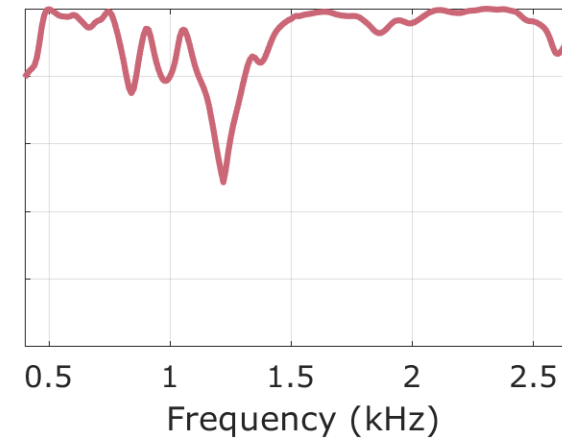
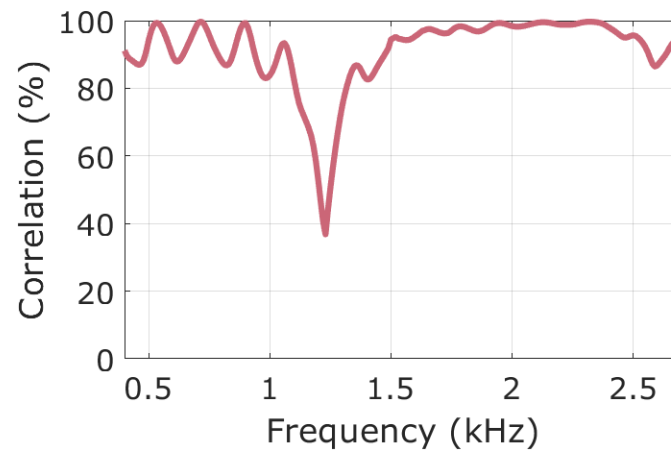
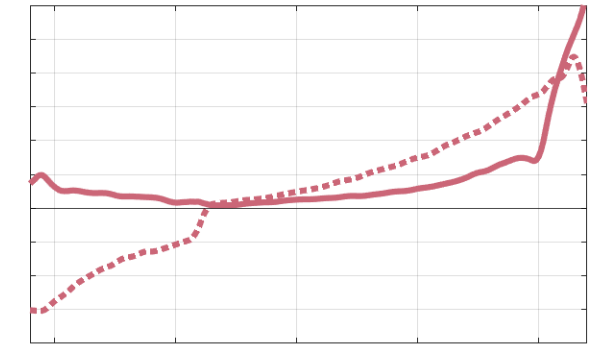
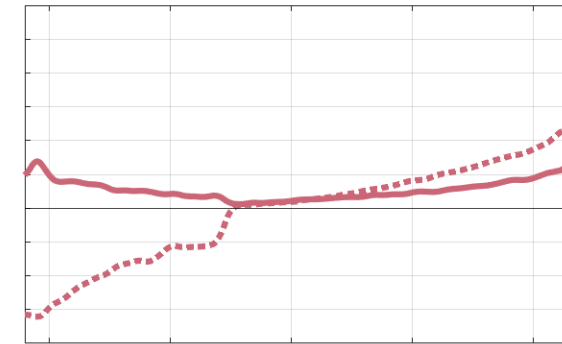
Gyroid



Diamond



Primitive



For Basic TPMS Unit Cells, Including Partitions Reduces Or Eliminates Discontinuities And Low Correlation Values

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No Partitions, No Mesh



4-Inch Partitions, No Mesh



2-Inch Partitions, No Mesh



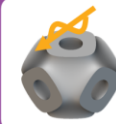
1-Inch Partitions, No Mesh



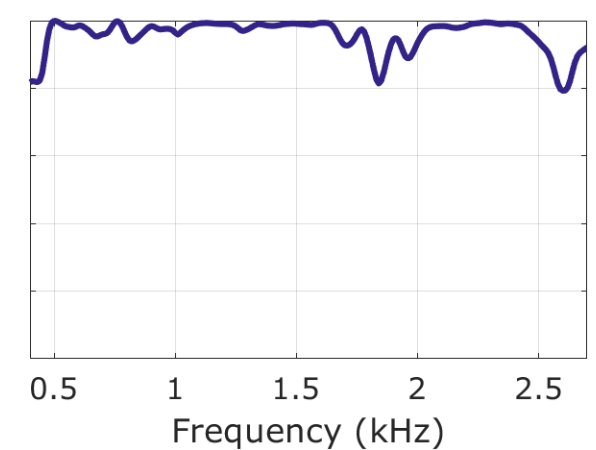
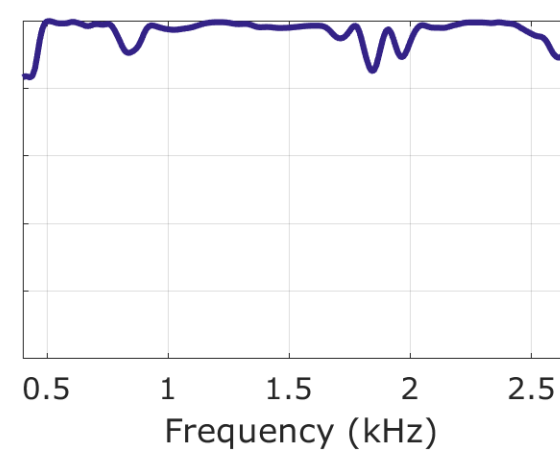
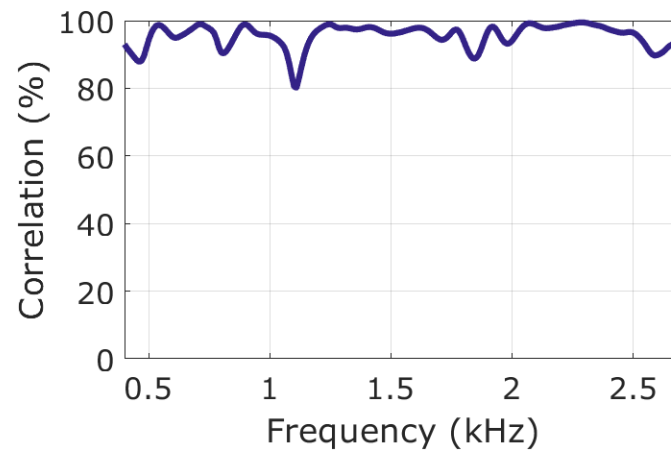
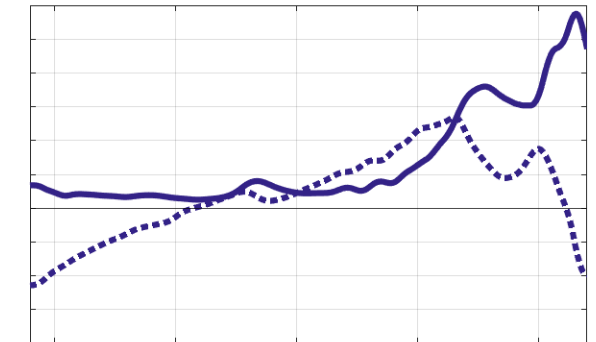
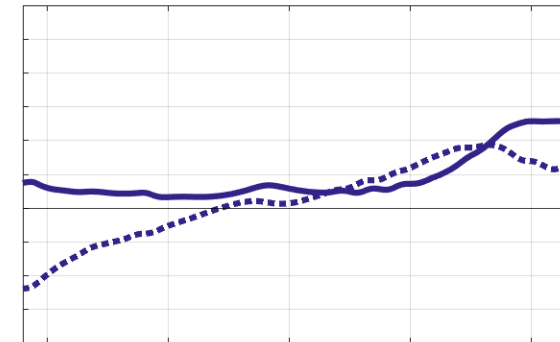
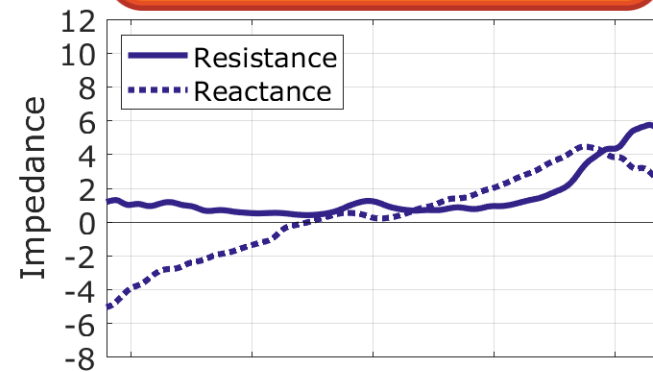
Gyroid



Diamond



Primitive



For Basic TPMS Unit Cells, Including Partitions Reduces Or Eliminates Discontinuities And Low Correlation Values

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No Partitions, No Mesh



4-Inch Partitions, No Mesh



2-Inch Partitions, No Mesh



1-Inch Partitions, No Mesh



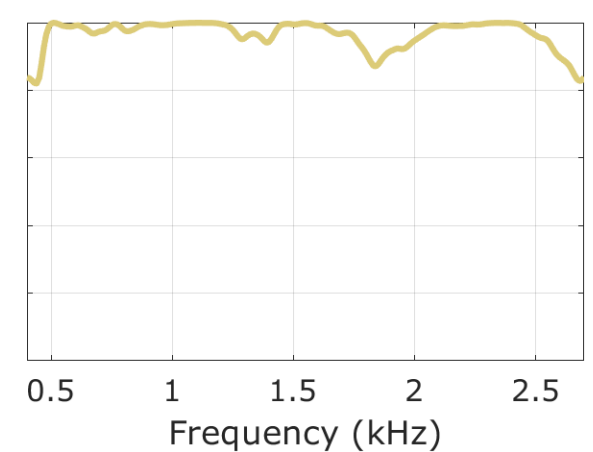
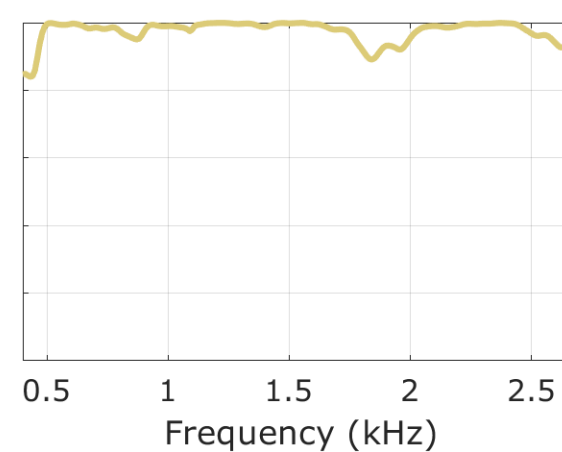
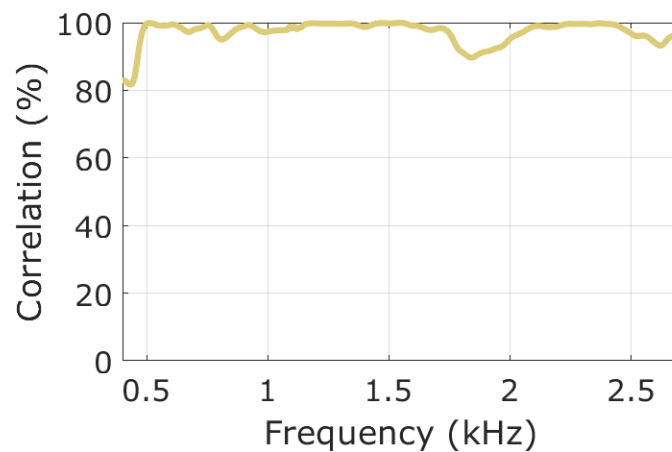
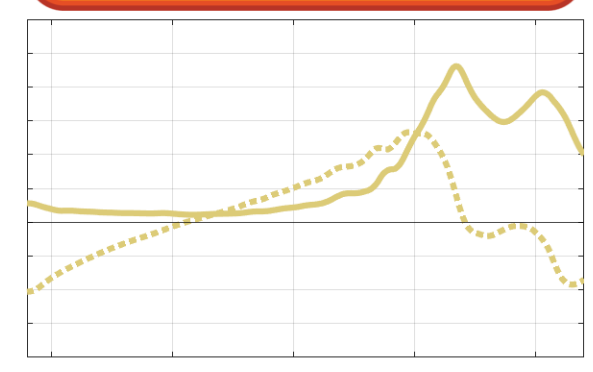
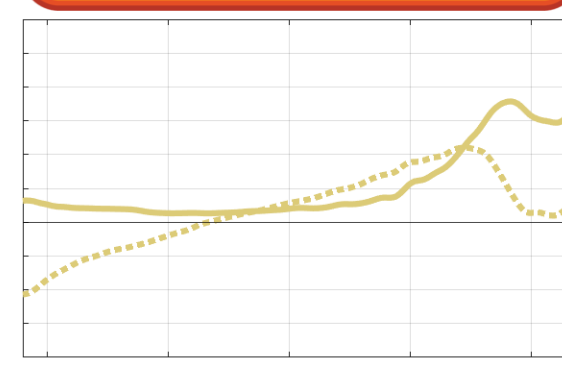
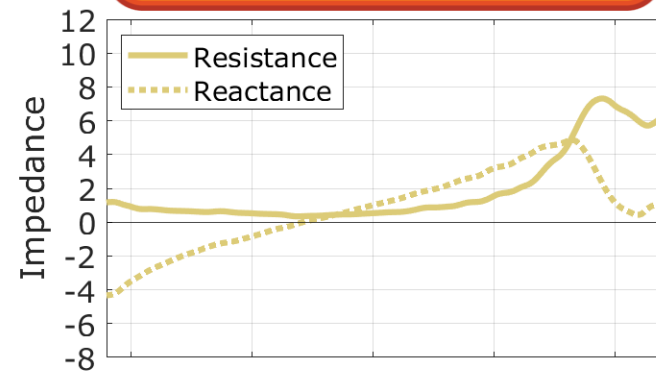
Gyroid



Diamond



Primitive



For Basic TPMS Unit Cells, Including Partitions Reduces Or Eliminates Discontinuities And Low Correlation Values

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No Partitions, No Mesh



4-Inch Partitions, No Mesh



2-Inch Partitions, No Mesh



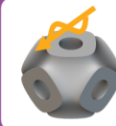
1-Inch Partitions, No Mesh



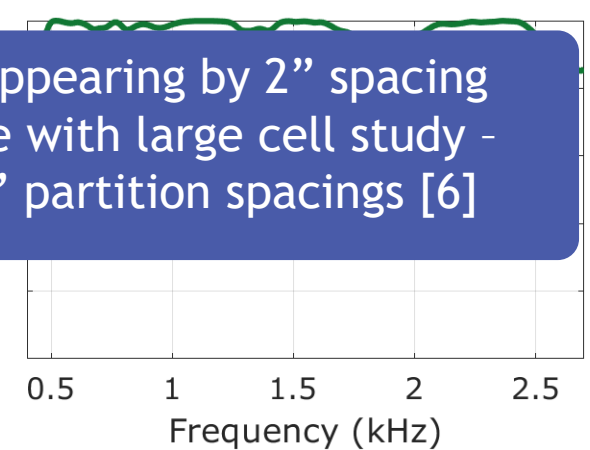
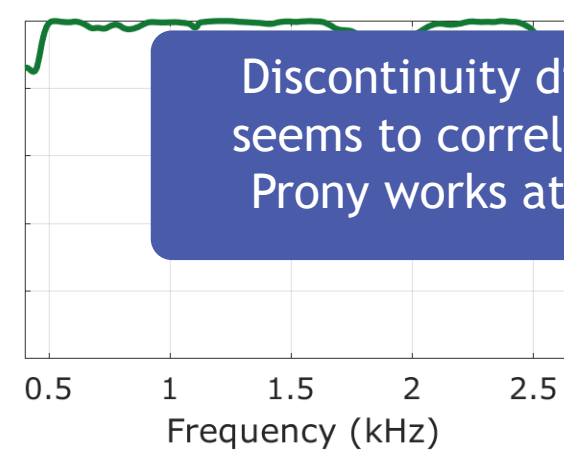
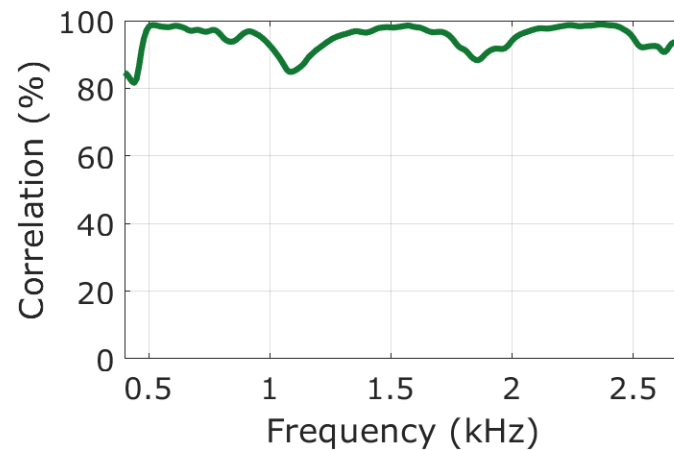
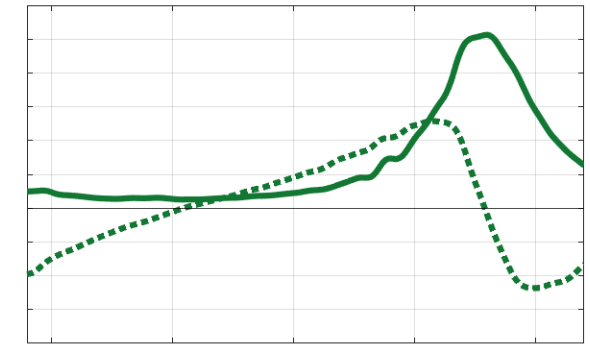
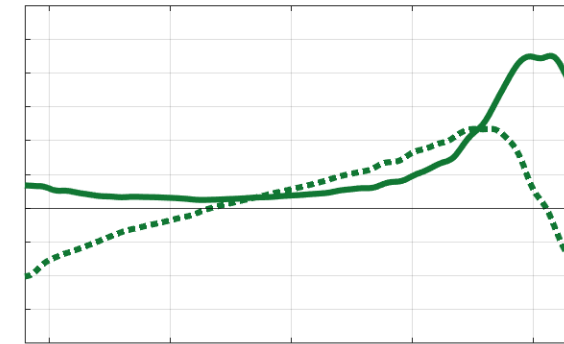
Gyroid



Diamond



Primitive



Discontinuity disappearing by 2" spacing seems to correlate with large cell study - Prony works at 2" partition spacings [6]

The Discontinuities Disappear By The 2-inch Spacing For Modified Unit Cells

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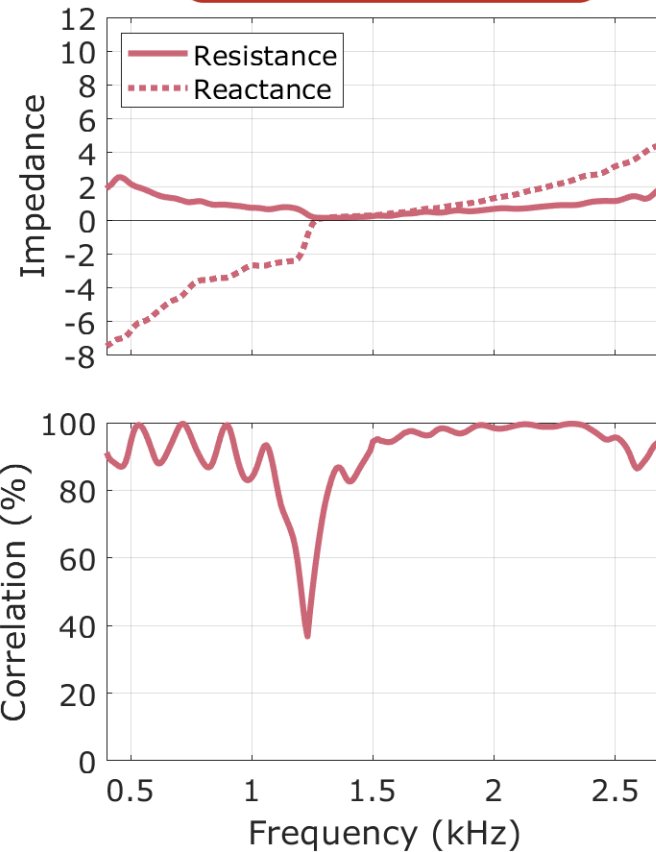
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Control

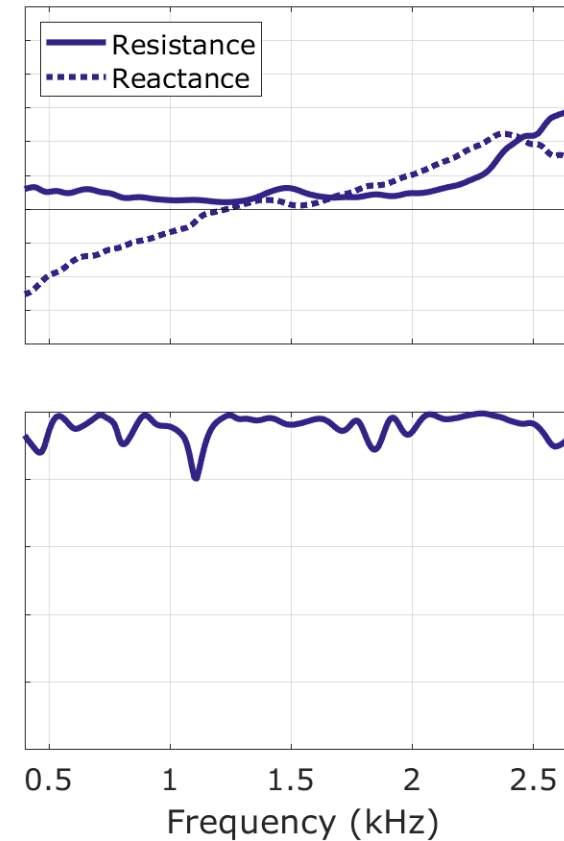


No Mesh
No Flow

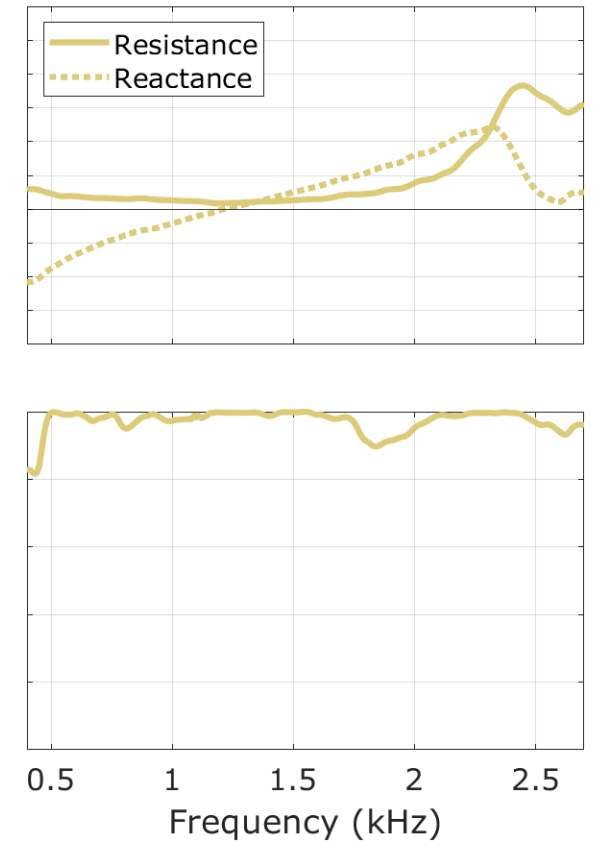
No Partitions



4-Inch Partitions



2-Inch Partitions



The Discontinuities Disappear By The 2-inch Spacing For Modified Unit Cells

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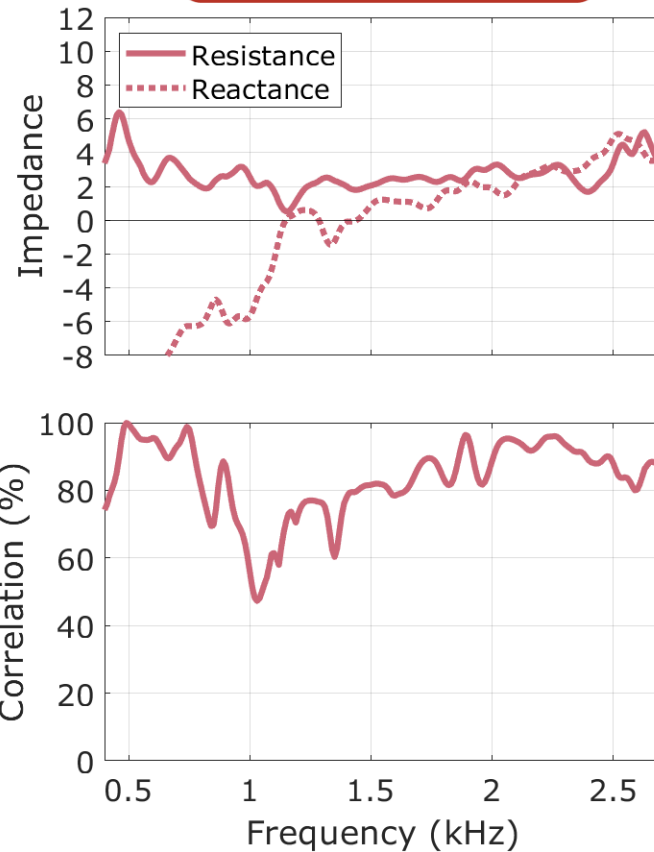
JULY 9-11 • LONG BEACH, CA

Streamwise
Elongated

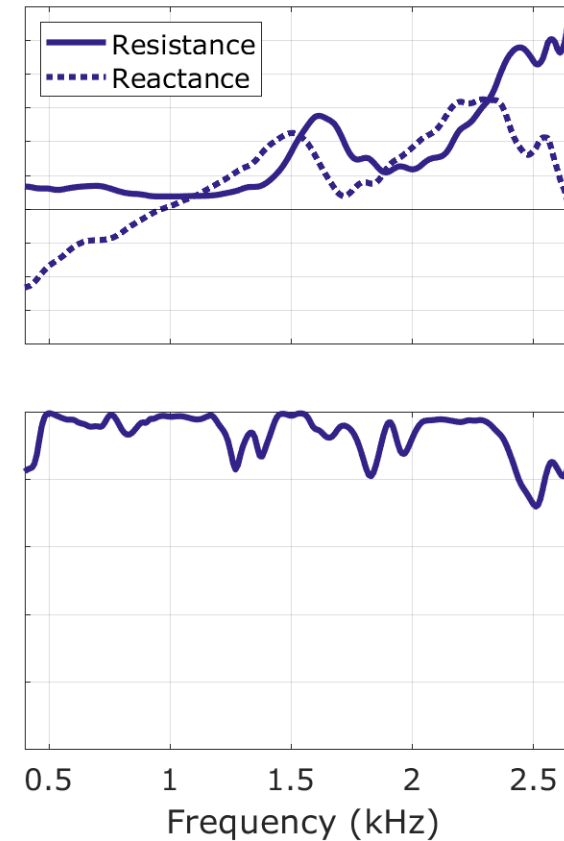


No Mesh
No Flow

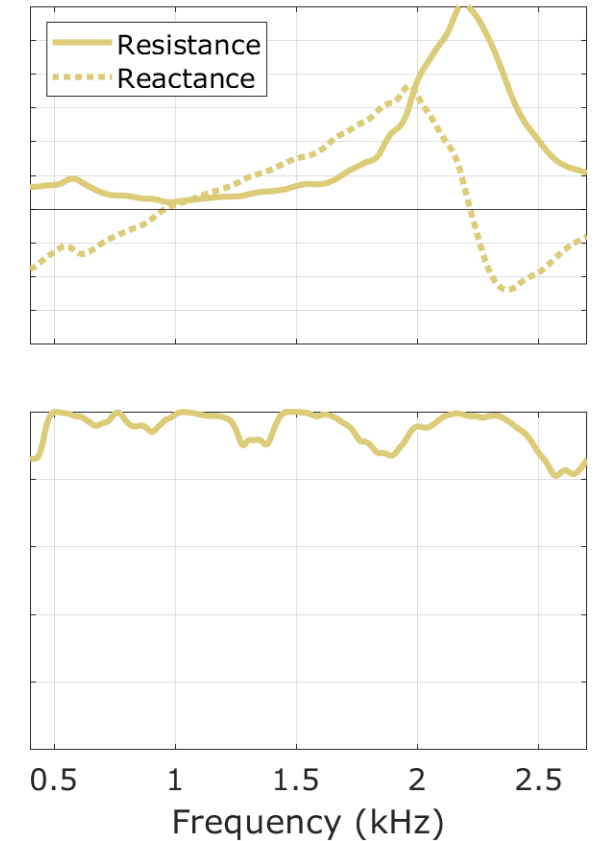
No Partitions



4-Inch Partitions



2-Inch Partitions



The Discontinuities Disappear By The 2-inch Spacing For Modified Unit Cells

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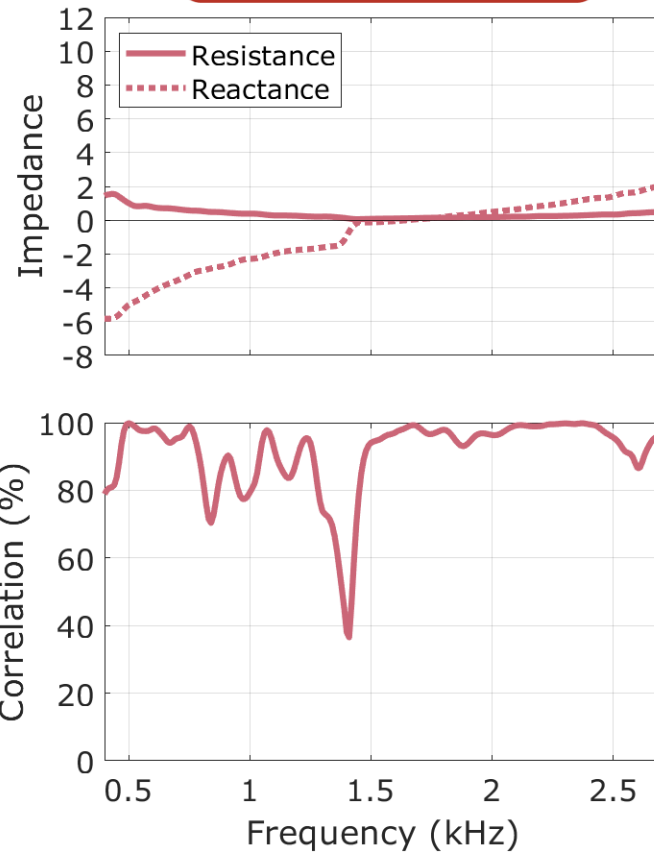
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Depthwise
Elongated

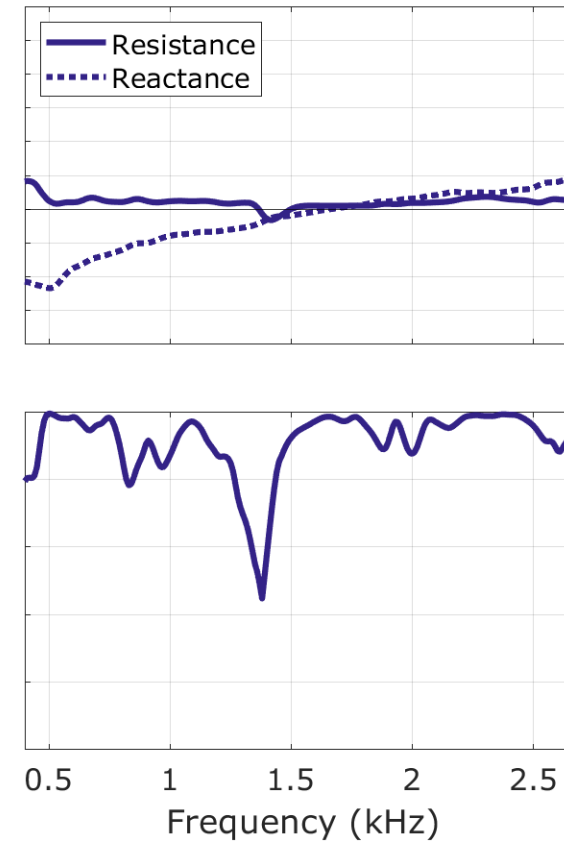


No Mesh
No Flow

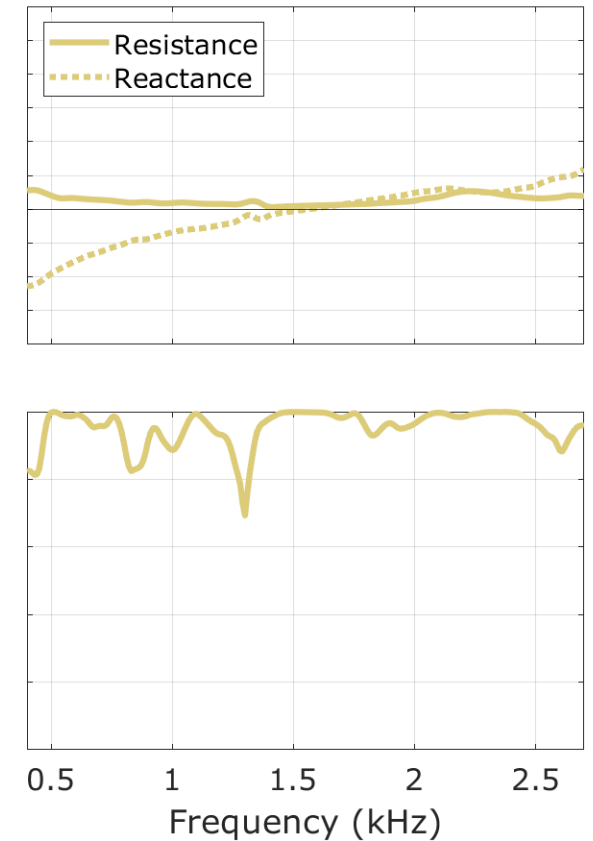
No Partitions



4-Inch Partitions



2-Inch Partitions



With A Mesh And In Mach 0.3 Flow, The Discontinuity Disappears, But The Additions Of Partitions Improve The Eduction Correlation

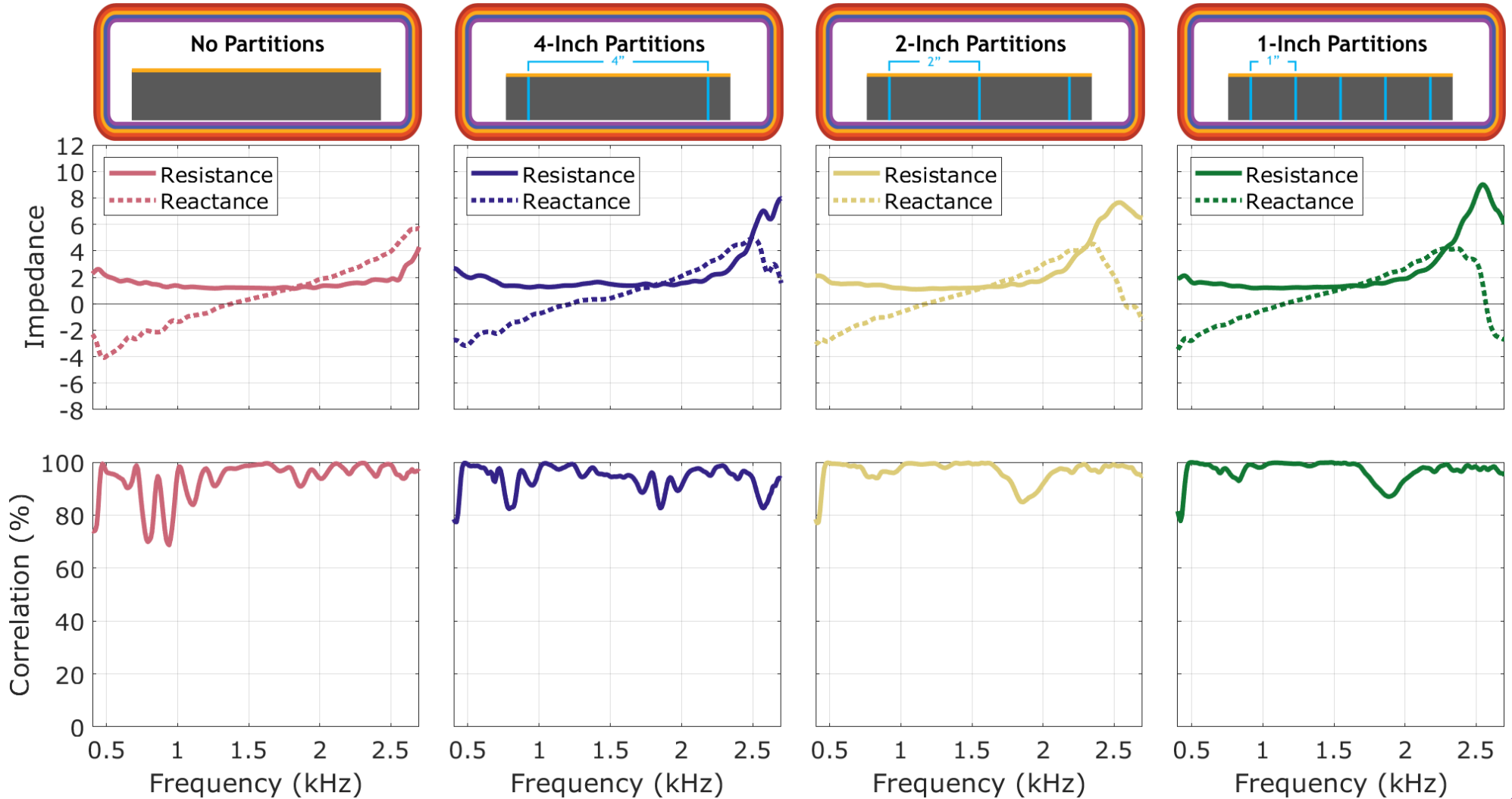
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Control



28 cgs Rays Mesh
Mach 0.3 Flow



Does the addition of axial partitions modify extended reacting structures to behave as though they are locally reacting?

Locally reacting-like behavior occurs at a 2-inch partition spacing for most samples

This rule of thumb may be dependent on the topology of the structure

What happens to the
characteristics of the
liner with axial
partitions?

The Addition Of Partitions Shifts The Resistance Higher In The High Frequency Regime And Lower In The Low Frequency Regime

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No Partitions, Mesh,
Mach 0.3



4-Inch Partitions, Mesh,
Mach 0.3



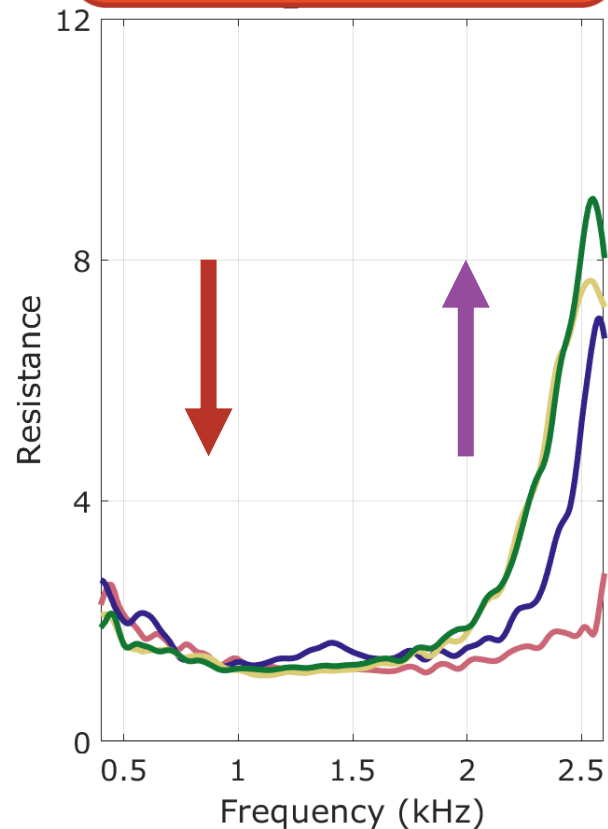
2-Inch Partitions, Mesh,
Mach 0.3



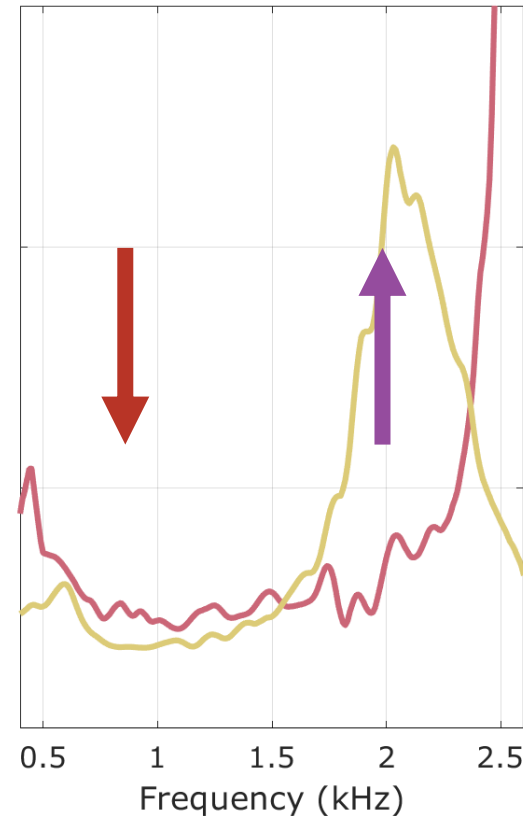
1-Inch Partitions, Mesh,
Mach 0.3



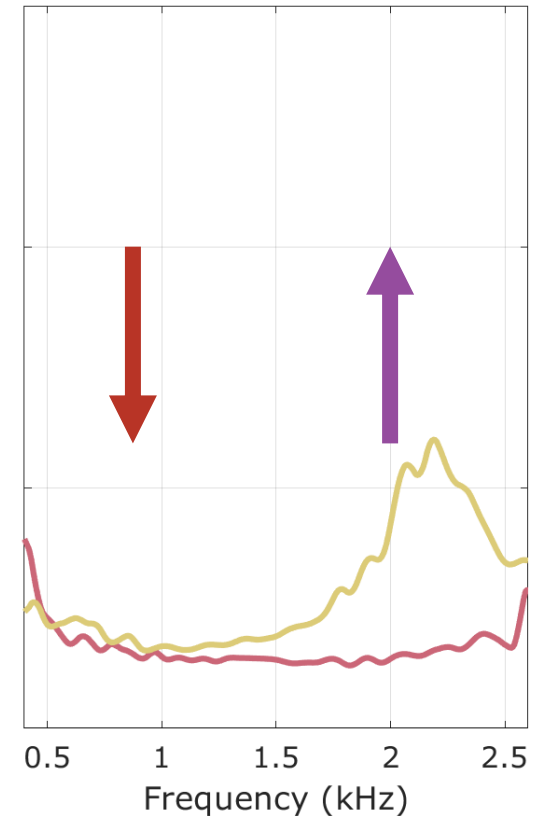
Gyroid



Streamwise-Elongated
Gyroid



Streamwise-Elongated,
45 Degree Rotation
Gyroid



The Zero-Crossing For The Reactance Shifts Lower In Frequency

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No Partitions, Mesh,
Mach 0.3



4-Inch Partitions, Mesh,
Mach 0.3



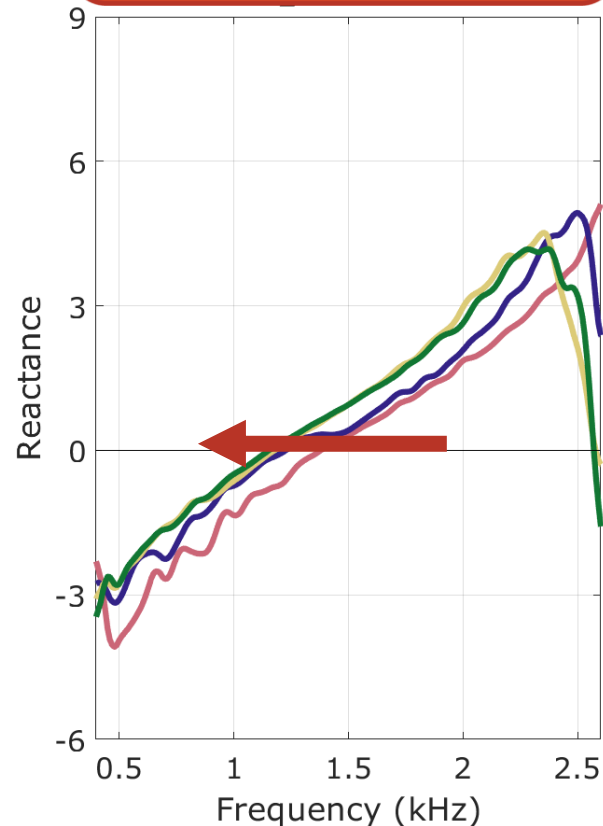
2-Inch Partitions, Mesh,
Mach 0.3



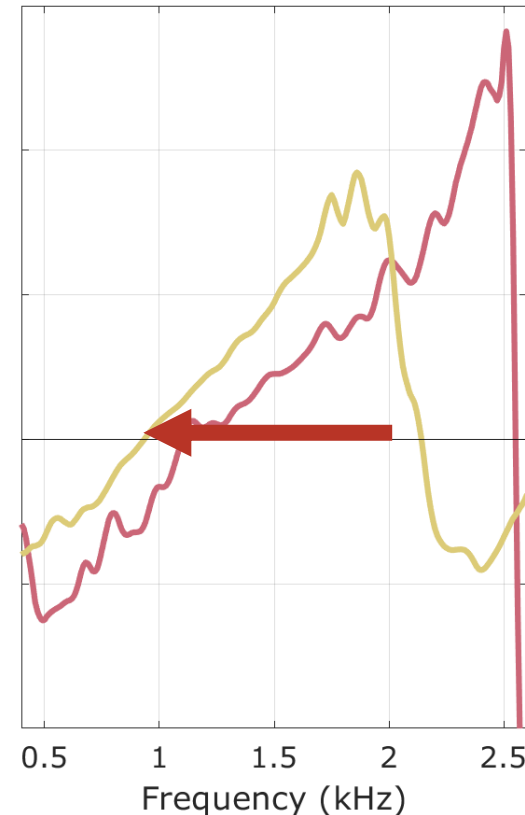
1-Inch Partitions, Mesh,
Mach 0.3



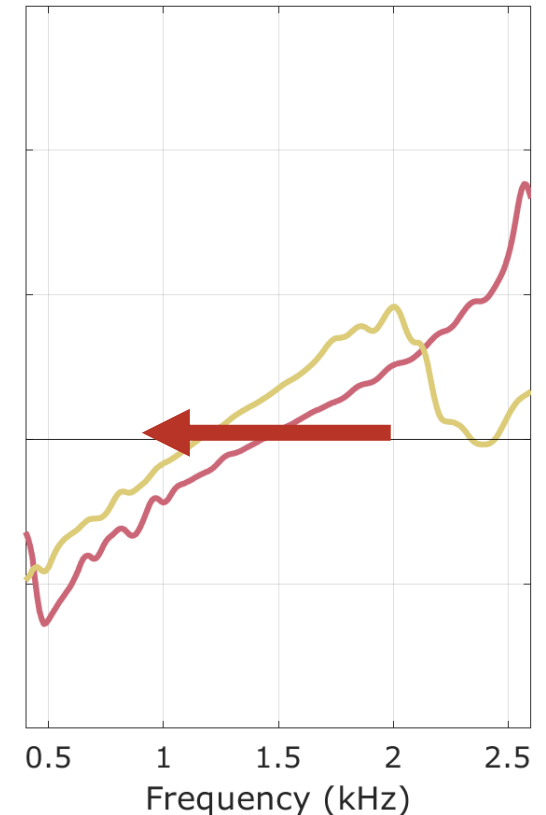
Gyroid



Streamwise-Elongated
Gyroid



Streamwise-Elongated,
45 Degree Rotation
Gyroid



The Addition Of Partitions Shifts The Attenuation Peak Lower In Frequency

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No Partitions, Mesh,
Mach 0.3



4-Inch Partitions, Mesh,
Mach 0.3



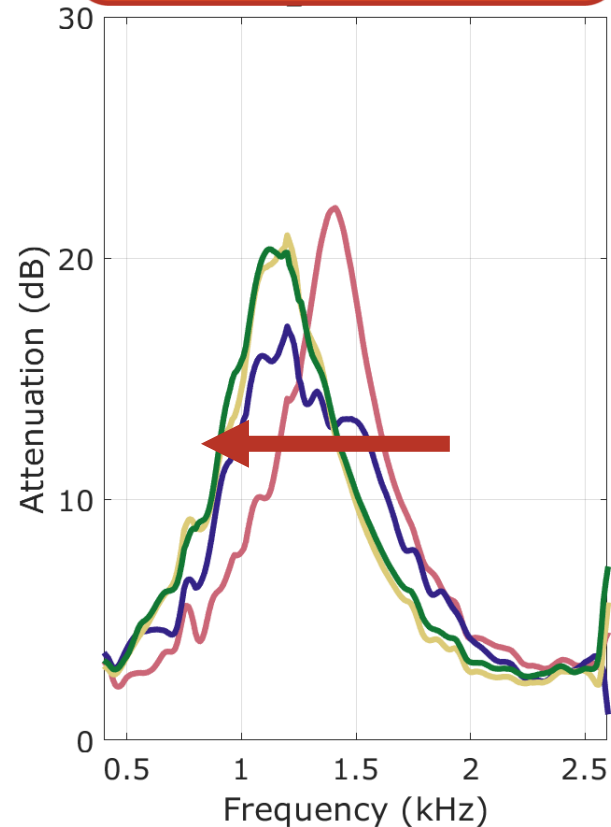
2-Inch Partitions, Mesh,
Mach 0.3



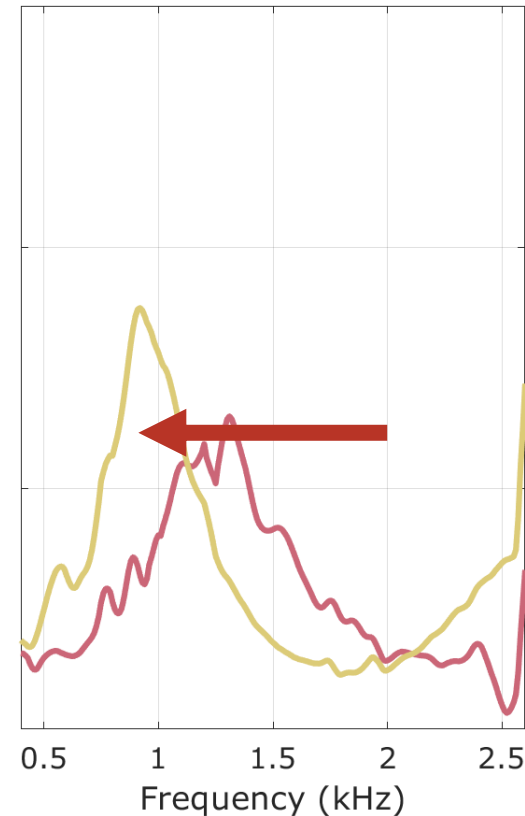
1-Inch Partitions, Mesh,
Mach 0.3



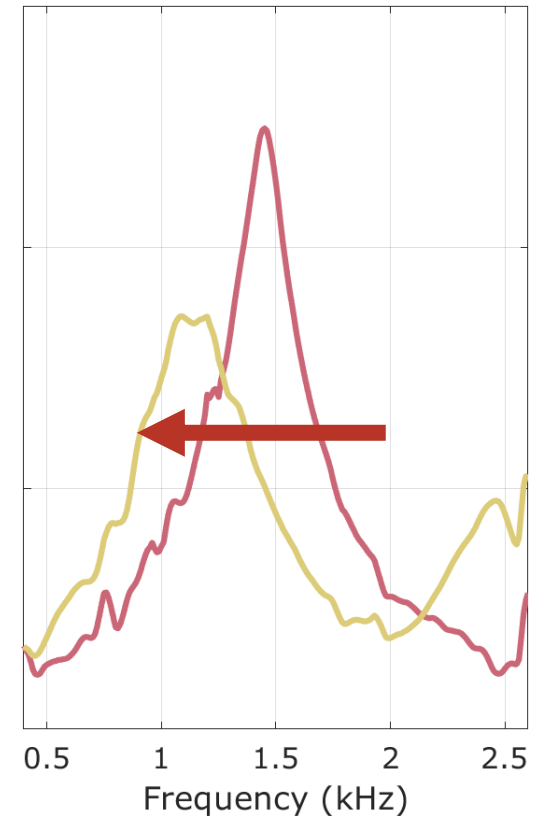
Gyroid



Streamwise-Elongated
Gyroid



Streamwise-Elongated,
45 Degree Rotation
Gyroid



For Most Samples, The Attenuation Peak Also Broadens In Frequency

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No Partitions, Mesh,
Mach 0.3



4-Inch Partitions, Mesh,
Mach 0.3



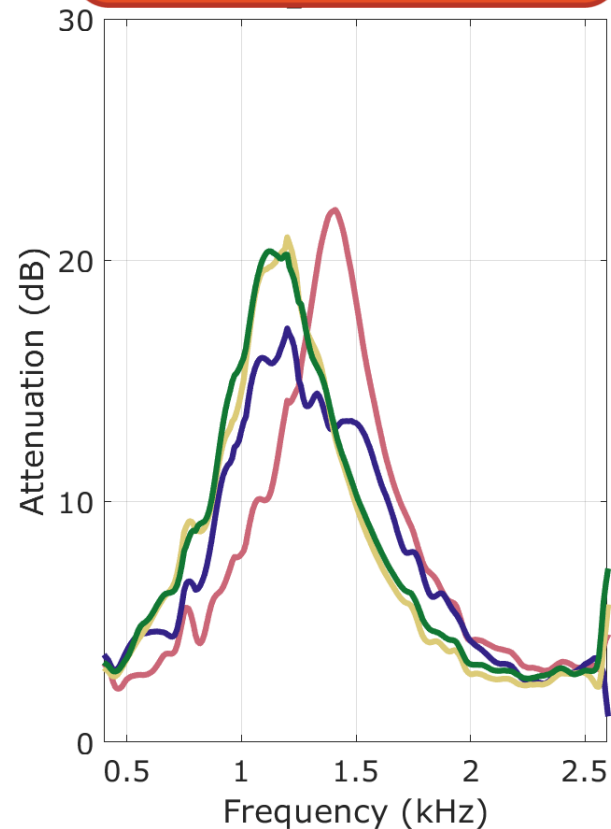
2-Inch Partitions, Mesh,
Mach 0.3



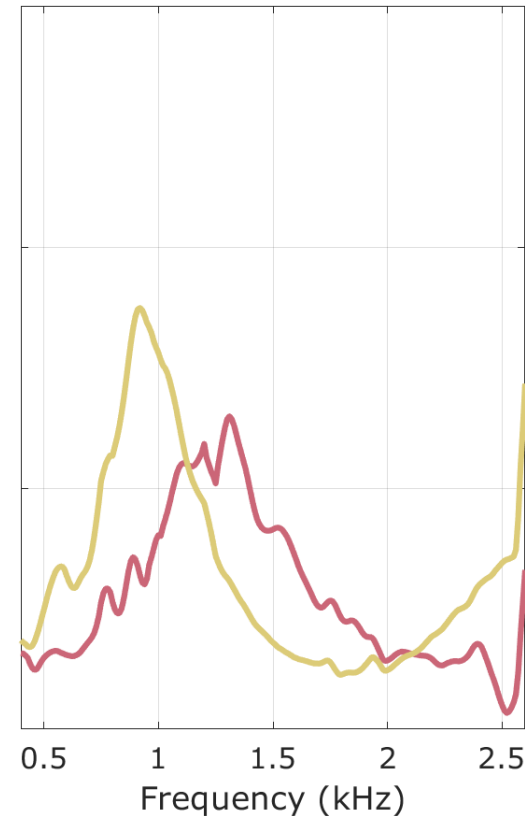
1-Inch Partitions, Mesh,
Mach 0.3



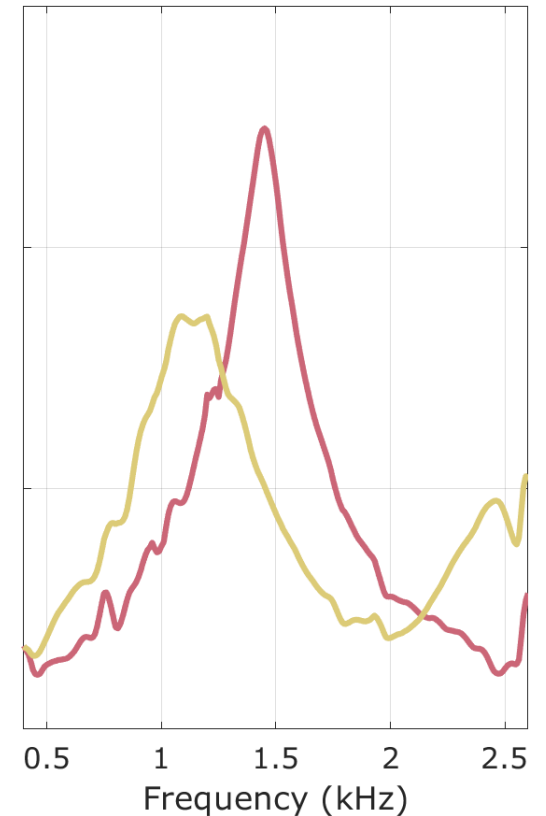
Gyroid



Streamwise-Elongated
Gyroid



Streamwise-Elongated,
45 Degree Rotation
Gyroid



What happens to the characteristics of the liner with axial partitions?

Resistance shifts down in the low frequency range and up in the high frequency range

The zero-crossing of the reactance shifts lower in frequency, bringing the frequency of peak attenuation down

Partitions can be used not only to induce locally-reacting behavior, but can also be used as a design feature

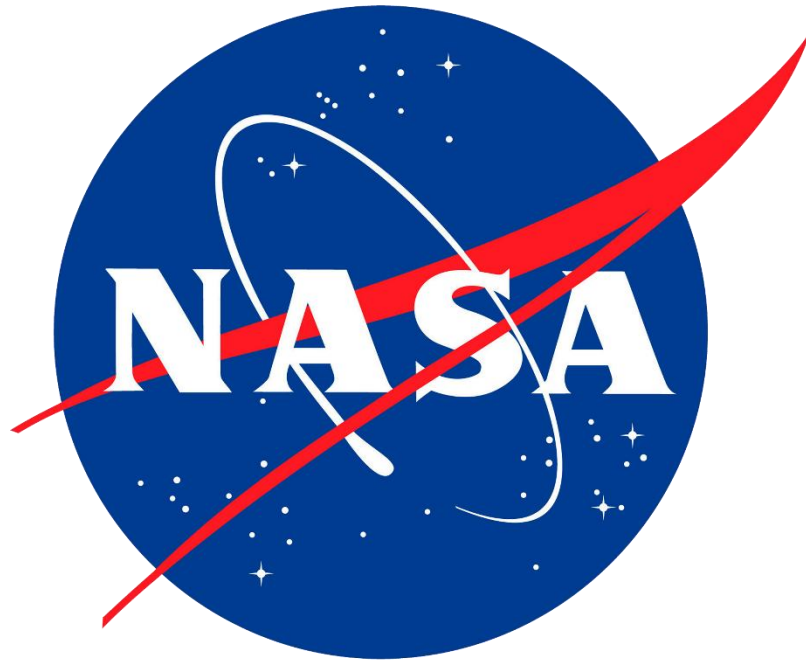
Future Work

Perform more experiments with 1" partition spacings to further investigate the behavior of low resistance samples

Isolate the physics underlying the experimental observations and why discontinuities are appearing

Build predictive models which incorporate partition spacing

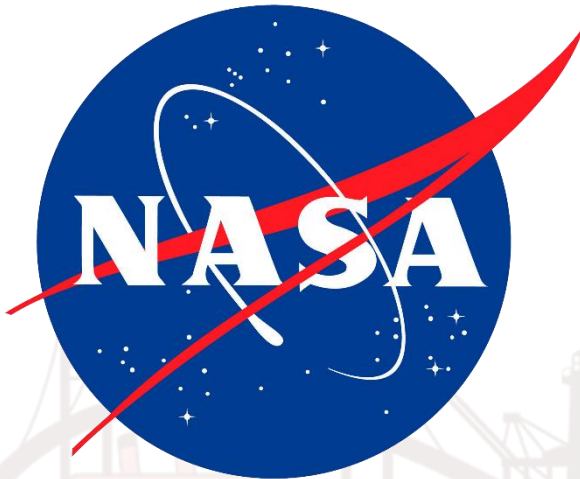
- [1] M. G. Jones, W. R. Watson, D. M. Nark, B. M. Howerton, and M. C. Brown, "A Review of Acoustic Liner Experimental Characterization at NASA Langley," 2020, doi: [10.13140/RG.2.2.15613.10720](https://doi.org/10.13140/RG.2.2.15613.10720).
- [2] Nasa.gov, 2021. https://www.nasa.gov/wp-content/uploads/2023/03/jsc2021e064215_alt.jpg (accessed Jun. 05, 2026).
- [3] "Amazon.com: Ikaufen 48 Pack Pyramid Designed Acoustic Foam Panels, 12 x 12 x 2 Inches Sound Proof Foam Panels, High Density and Fire Resistant Acoustic Panels, Sound Panels, Studio Foam for Wall and Ceiling : Musical Instruments," Amazon.com, 2026. <https://us.amazon.com/Ikaufen-Pyramid-Designed-Acoustic-Resistant/dp/B0BZJ4RXSW> (accessed Jun. 05, 2026).
- [4] U. Ingard, "Influence of Fluid Motion Past a Plane Boundary on Sound Reflection, Absorption, and Transmission," *The Journal of the Acoustical Society of America*, vol. 31, no. 7, pp. 1035–1036, Jul. 1959, doi: [10.1121/1.1907805](https://doi.org/10.1121/1.1907805).
- [5] M. K. Myers, "On the acoustic boundary condition in the presence of flow," *Journal of Sound and Vibration*, vol. 71, no. 3, pp. 429–434, Aug. 1980, doi: [10.1016/0022-460X\(80\)90424-1](https://doi.org/10.1016/0022-460X(80)90424-1).
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Mitigating Grazing Flow Impedance Eduction Errors in Additively Manufactured Porous Liners

Kara Hardy, Anthony Ciletti, Janith
Godakawela, Bhisham Sharma

Michigan Technological University

Martha Brown

Aeroacoustics Branch, NASA Langley Research Center

Supporting Material



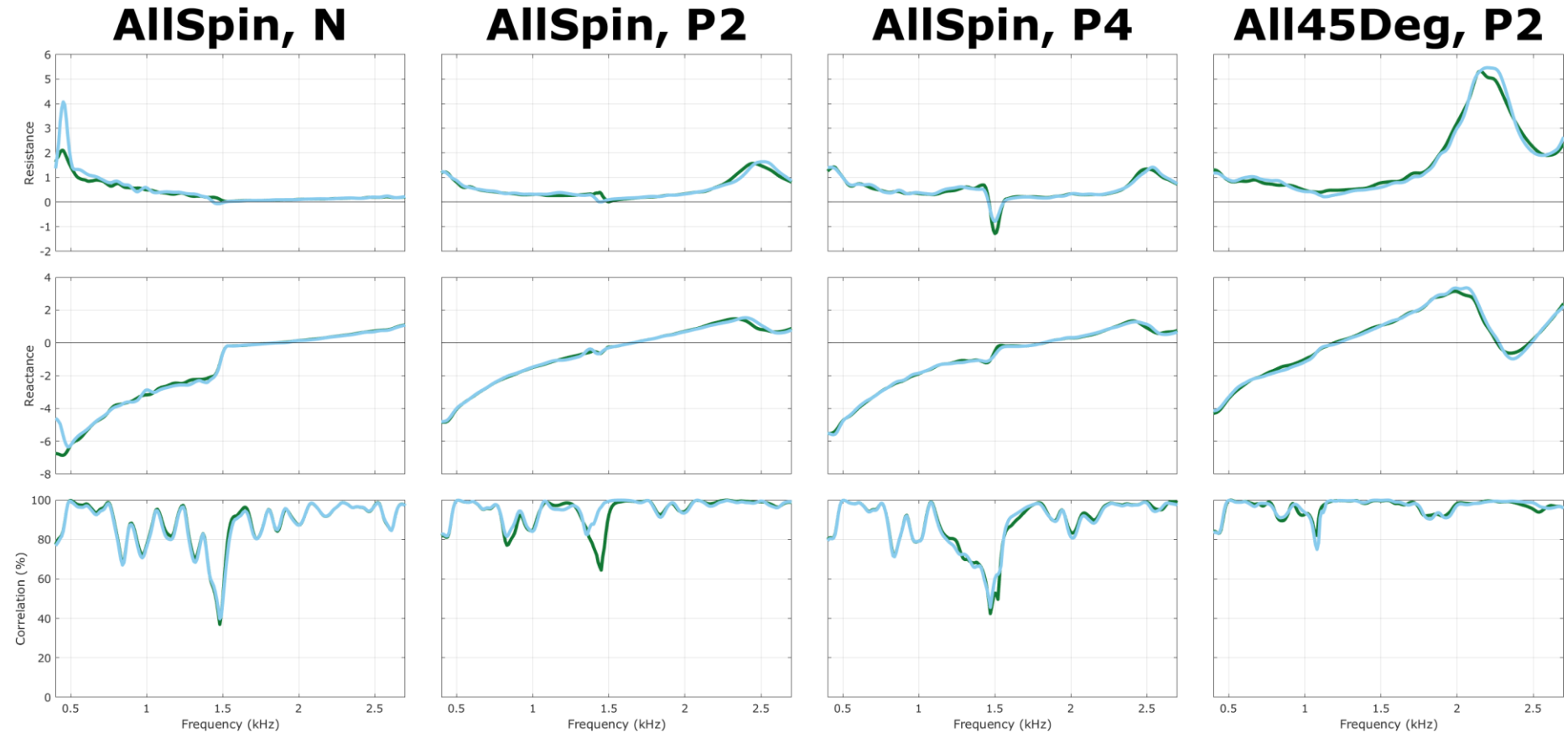
Impedance discontinuities are repeatable

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This graph shows reruns of the same sample configurations. The discontinuities appear in the same locations and the correlation similarly dips.



The joints do not have a significant effect on the response

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Two samples with the unmodified Gyroid unit cells were printed. One had a block length of 4" and the other had a block length of 2". This figure shows the non-partitioned, no mesh, no flow results.

AllControl, N

