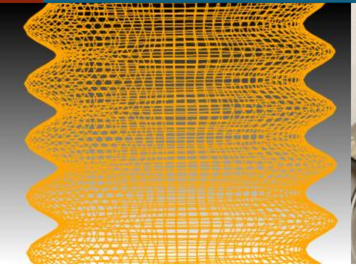
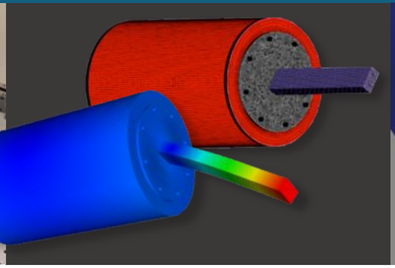
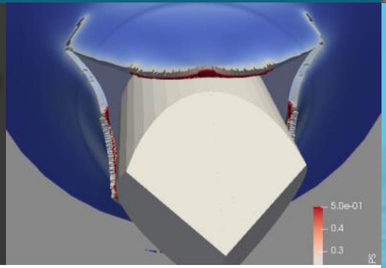
Dynamic Tailoring of Interlocking Metasurfaces (ILMs)







Andrew Hicks, Lindsay Knupp, Carson Wynn

Ophelia Bolmin, Nick Leathe, Joe Bishop, Philip Noell

August 8, 2023

SAND2023-07599PE

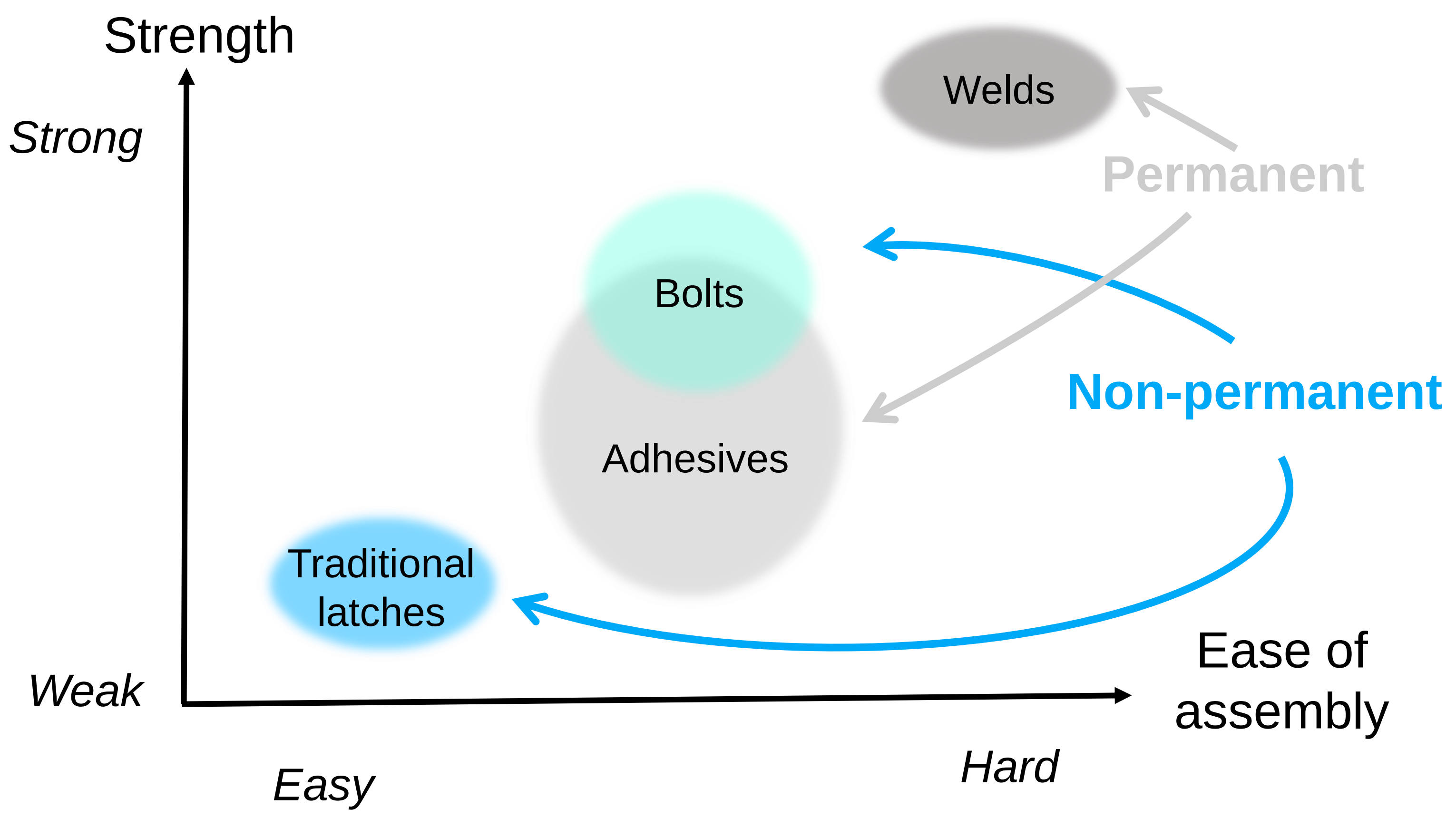
Introducing Us

Andrew
Mathematics
@ Louisiana State University

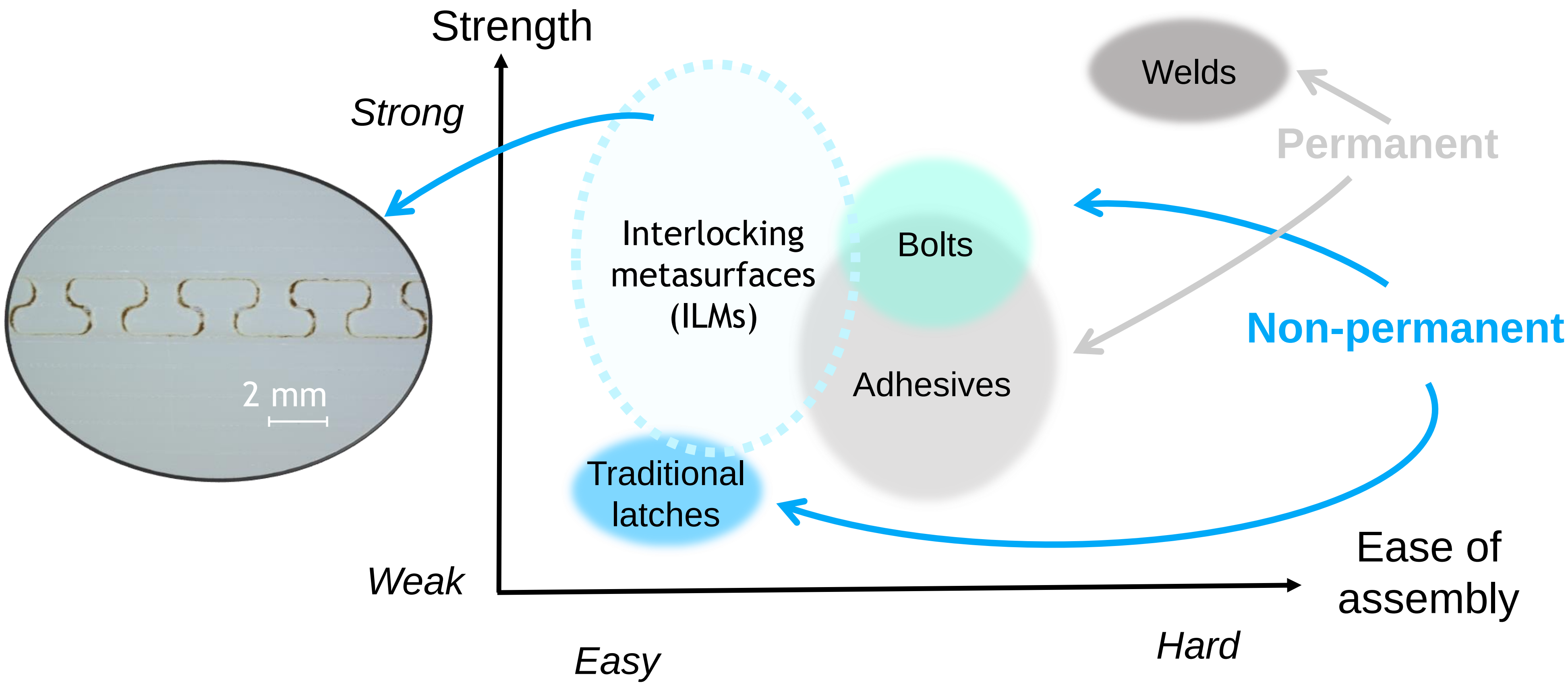
Lindsay
Applied Mathematics
@ UMass Amherst

Carson
Mechanical Engineering
@ Brigham Young University

What are Interlocking Metasurfaces (ILMs)?

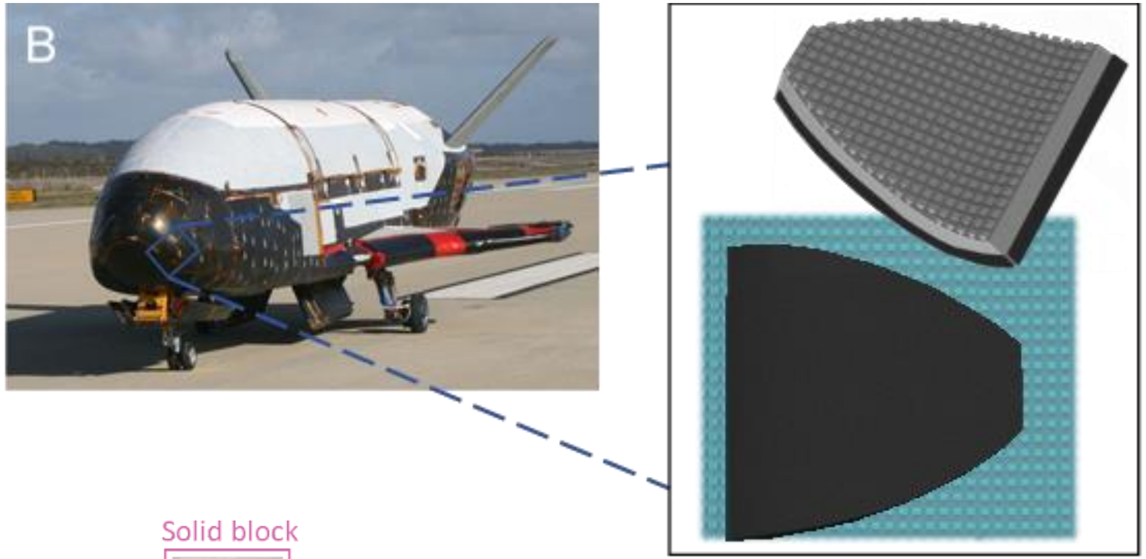


What are Interlocking Metasurfaces (ILMs)?

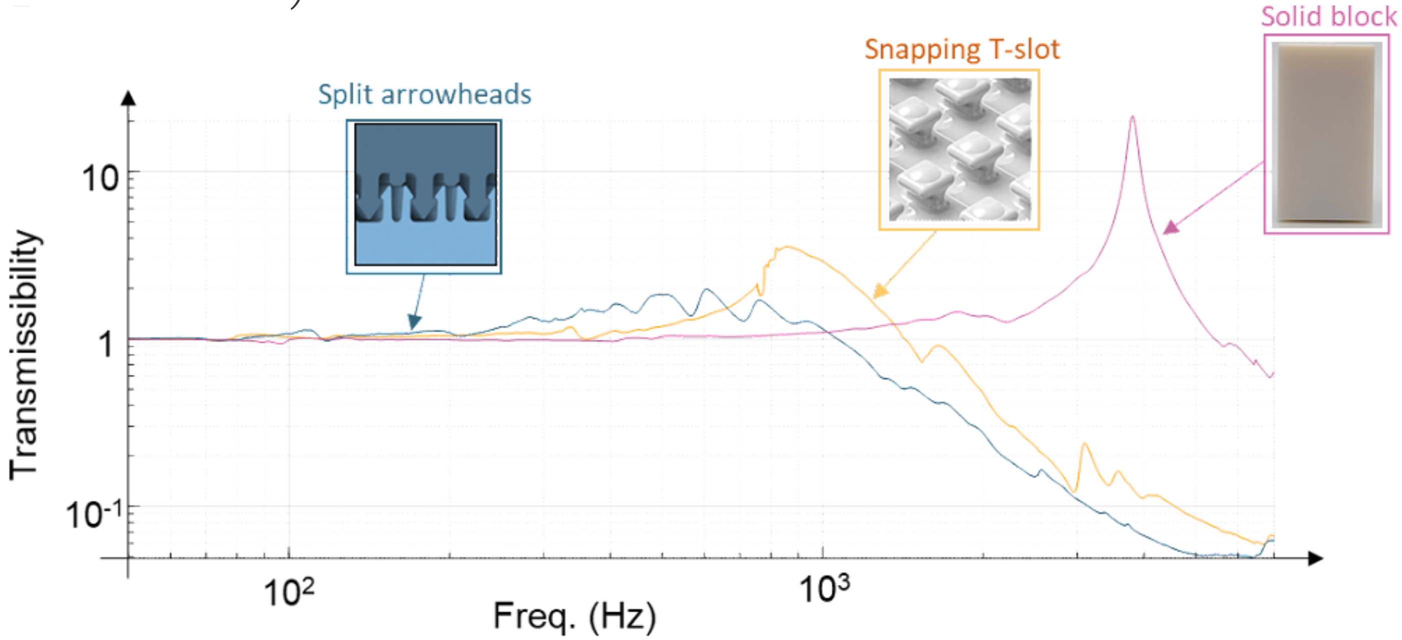


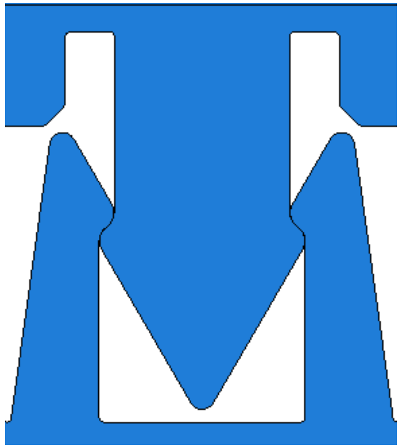
What are Interlocking Metasurfaces (ILMs)?

- Composed of an array of interlocking unit cells
- Wide variety of designs, many of which have already been studied
- Interested in transmissibility of different designs (ratio of output acceleration to input acceleration under vibration)



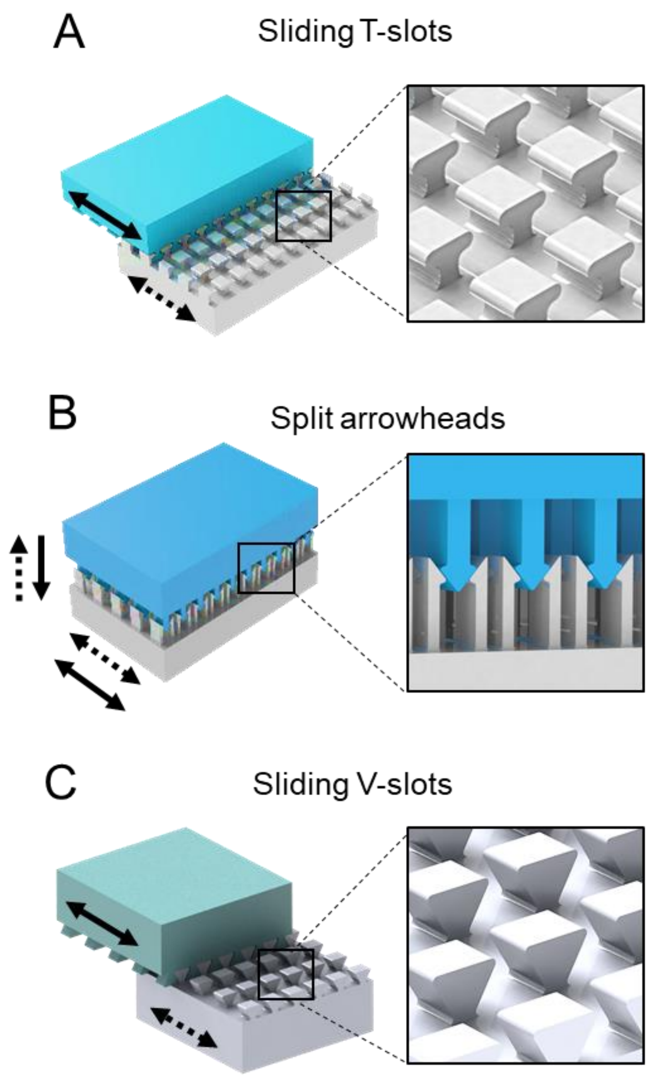
Young et al., Mater. Des., 2023





How do the geometric parameters affect the response under vibration?

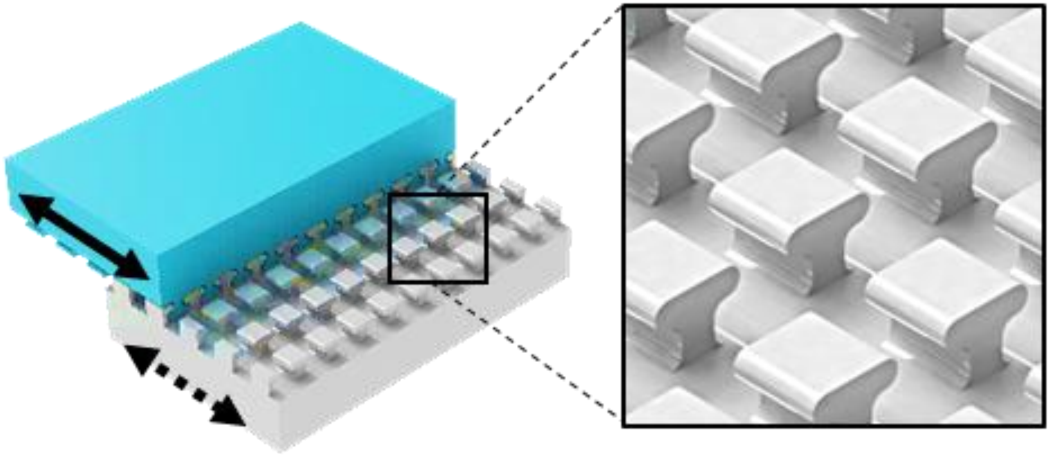
- Optimize the geometry using results from tension tests
- Characterize the response using transmissibility plots from steady state modal dynamics



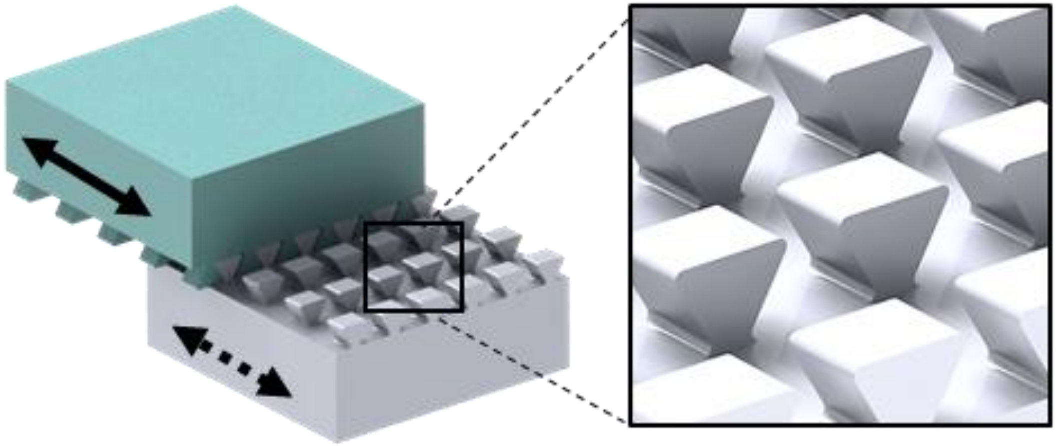
Bolmin et al., JOM, 2023

Studied Designs

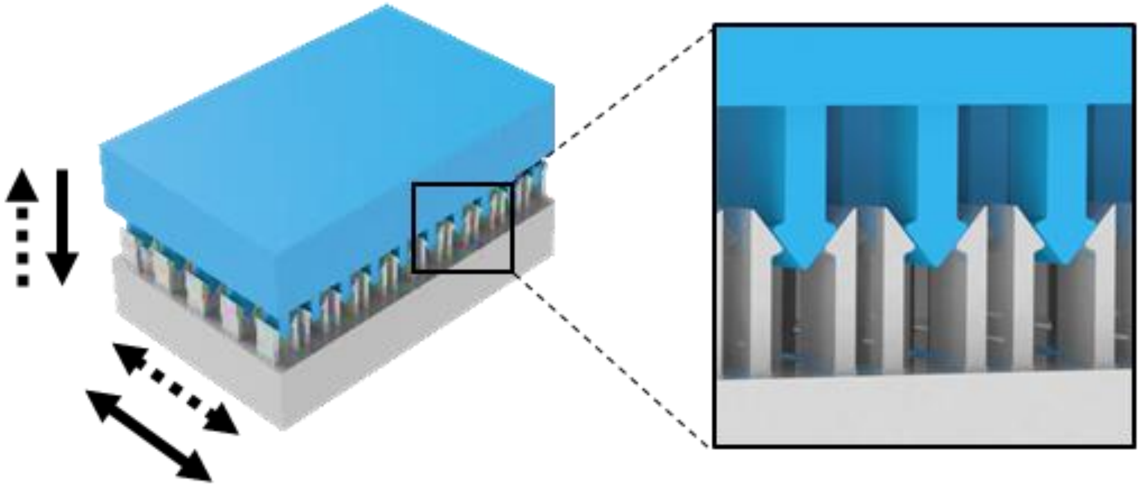
Sliding T Slot - Carson



Sliding V Slot - Lindsay

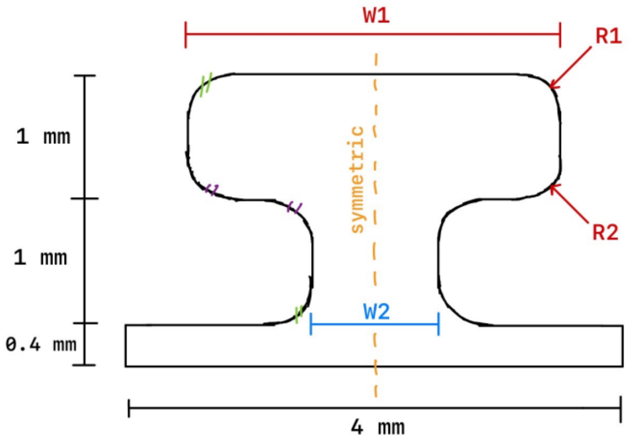


Split Arrowhead - Andrew



Bolmin et al., JOM, 2023

What Parameters Matter?



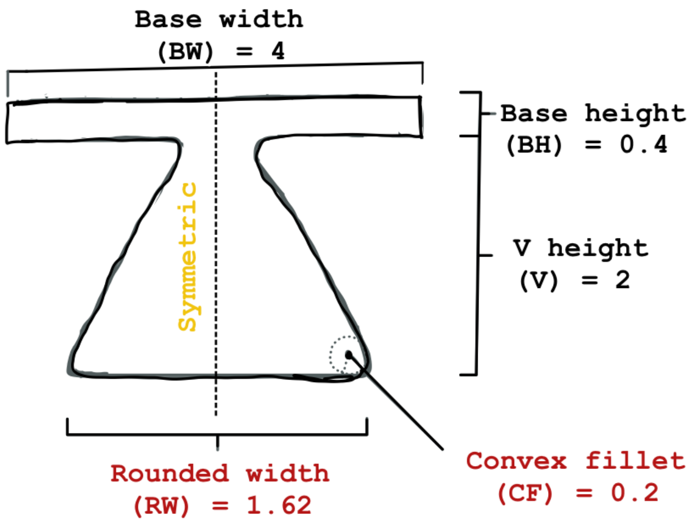
Sliding T-Slot

Parameters (mm)

- W1 = [2.2, 3.8]
- R1 = [0.1, 0.9]
- R2 = [0.1, 0.9]

Constraints (mm)

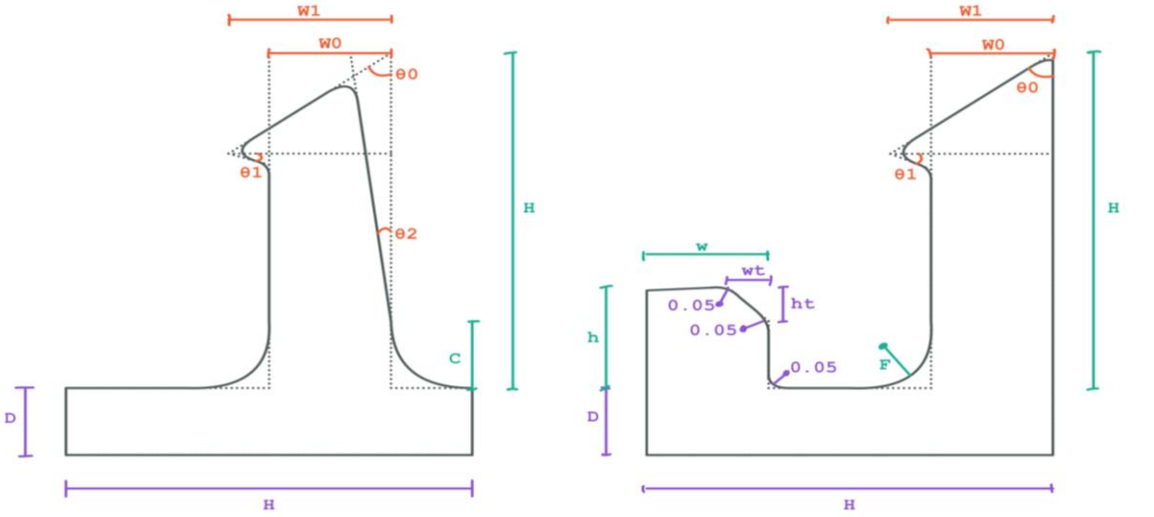
- R1 + R2 < 1
- R2 < 0.5*W1 – 1
- W2 = 4 – W1



Sliding V-Slot

Parameters (mm)

- RW = [1.8, 2.8]
- CV = [0.2, 0.4]



Split Arrowhead

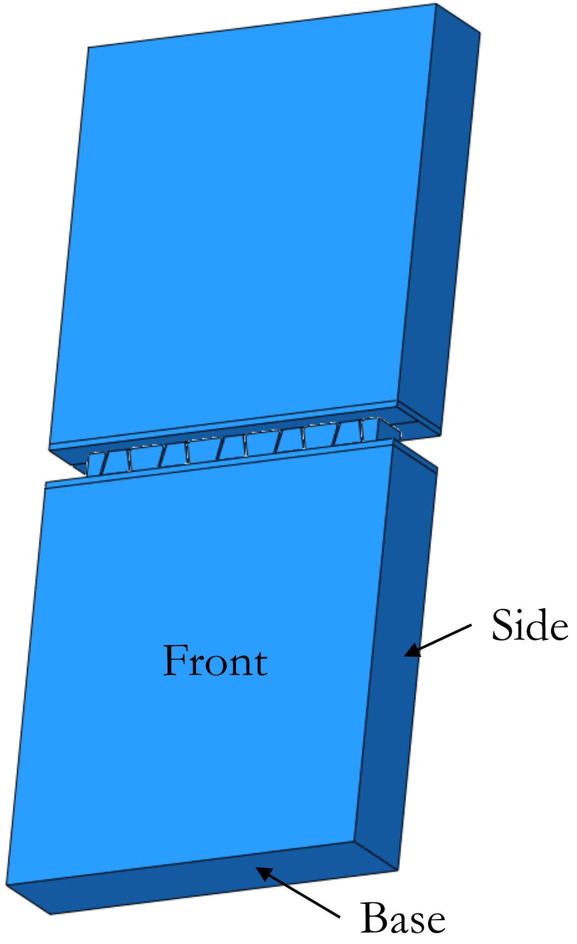
Parameters (mm)

W0 = [0.4, 0.7]　　W1 = [0.71, 0.81]

θ0 = [30,55]　　θ1 = [25, 35]　　θ2 = [2, 8]

FEA Model Setup

- Type of Model (Linear Solvers)
  - Static, General
  - Frequency
  - Steady State Modal Dynamics
- No friction or damping
- "Hard contact" normal behavior
- Parts are in perfect contact (Tension Tests)
- Boundary Conditions
  - Fixed Base
  - X-Symm on sides of mass block
  - Z-Symm on front and back of mass block
- Parametric Optimization

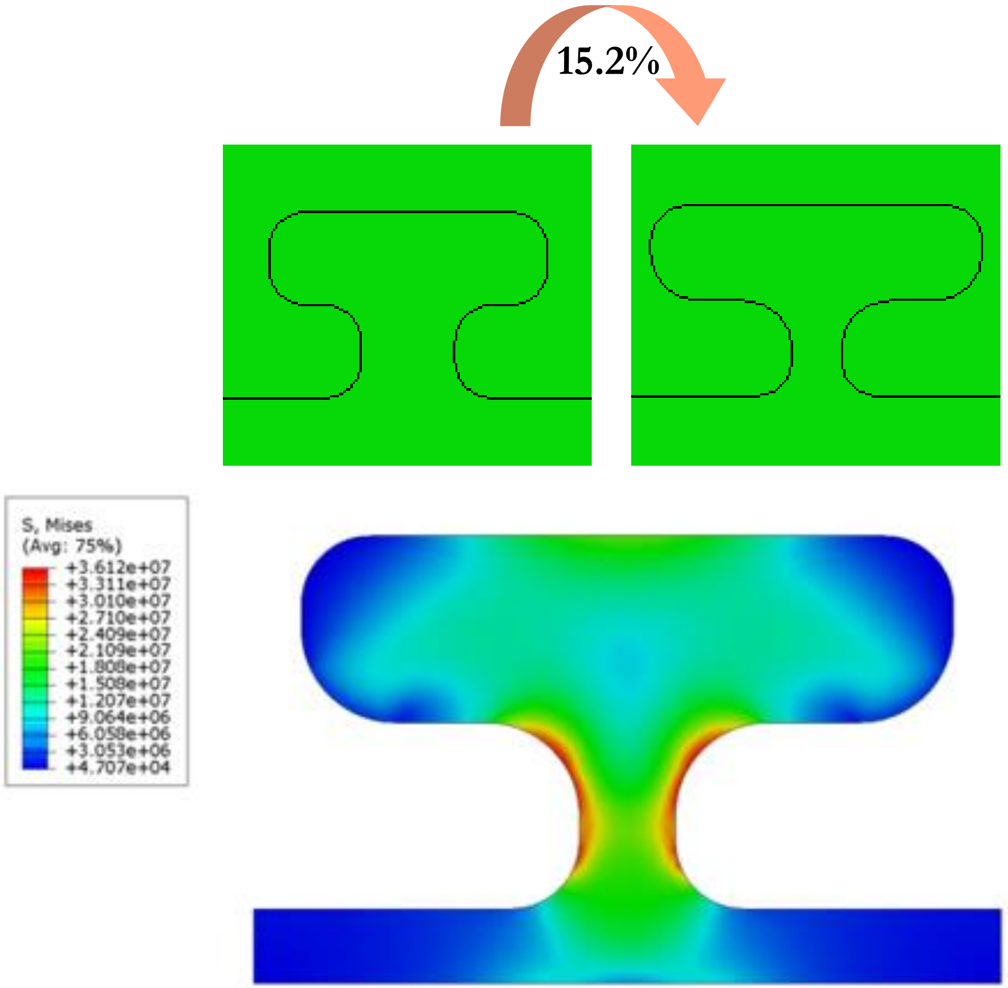


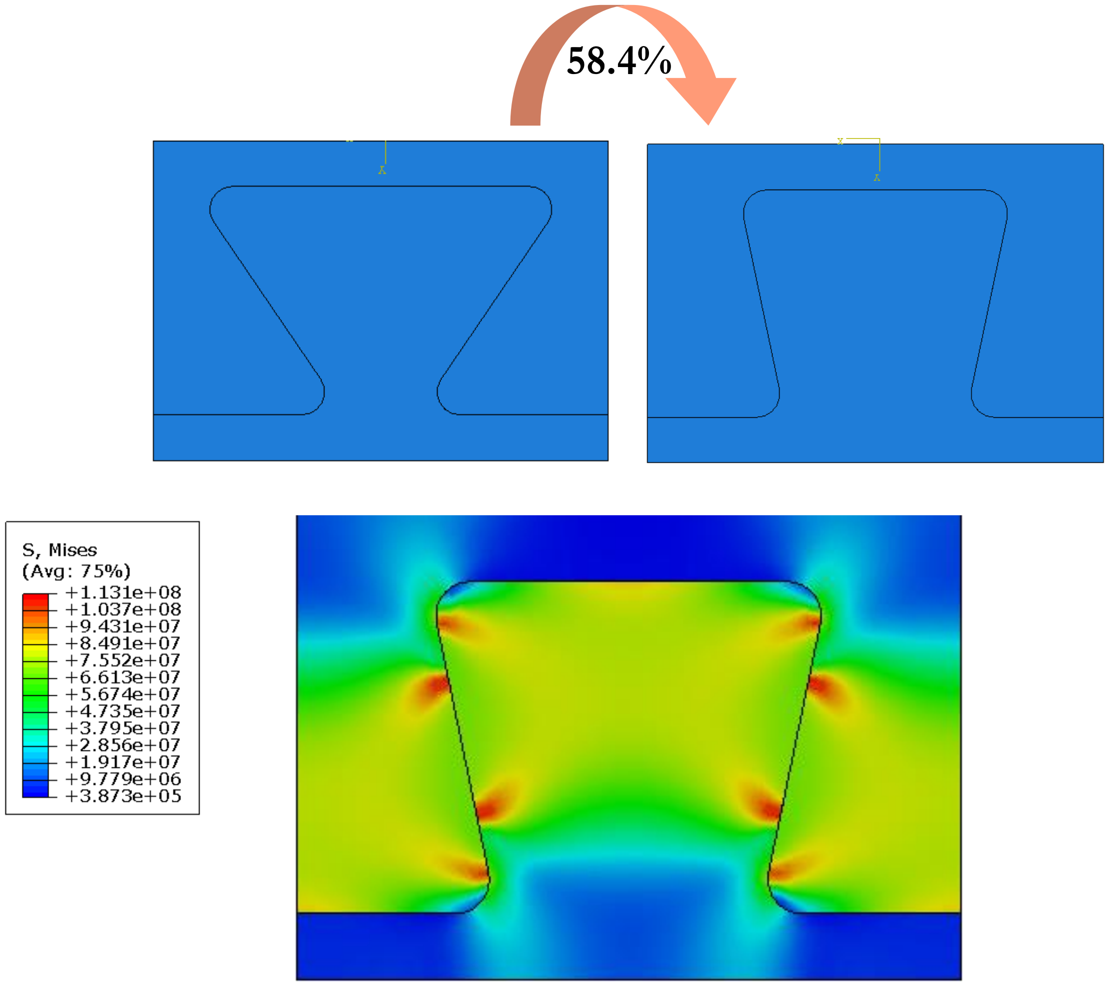
Material Properties – Vero White (photocurable polymer)

- Density – 1174 kg/m^3
- Youngs Modulus – 2.06 GPa
- Poison's Ratio – 0.4
- Yield Strength – 46 MPa

Optimization Results

- Percent decrease in maximum Von Mises stress from original design to optimized design

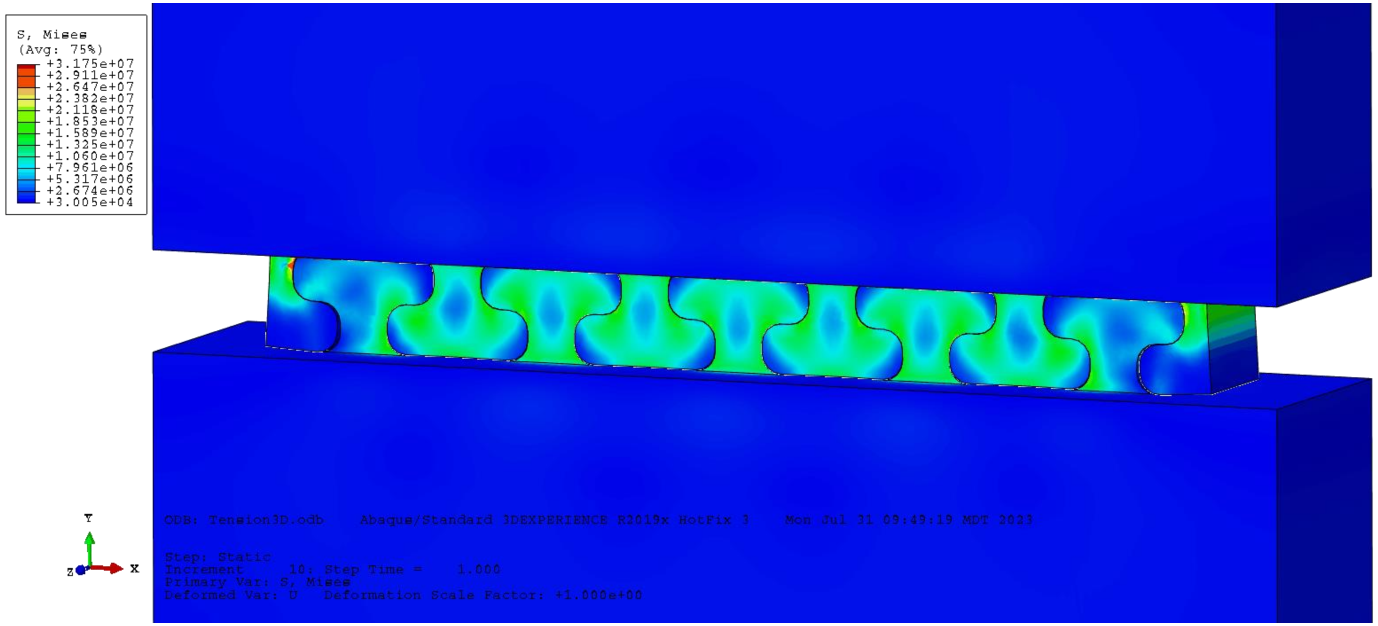




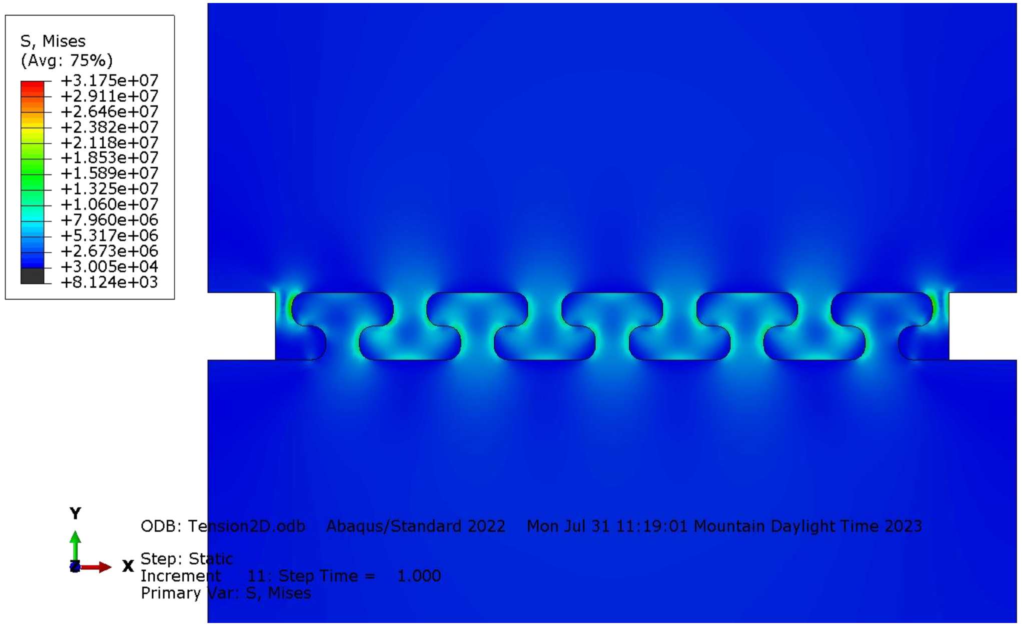
Quasi-Static Tension – 3D

- Attempted to quickly test the validity of the 2D models by running a 3D test to compare
- Stress profiles are similar, but values are slightly off
- 2D model interprets design to be as thick as the block, which is not true

3D Model

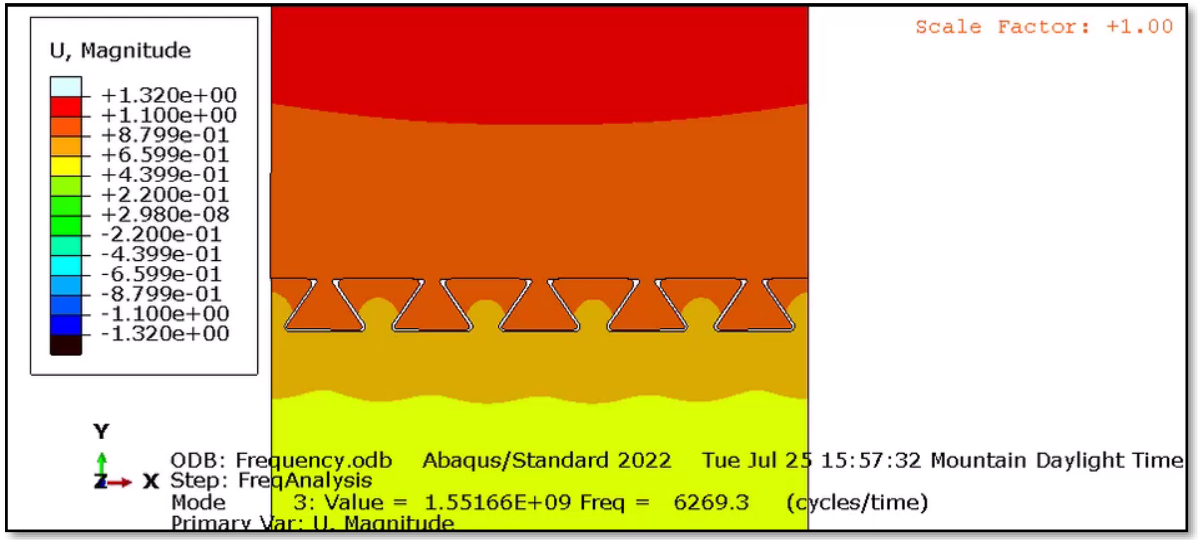


2D Model



S.S. Modal Dynamics – 2D

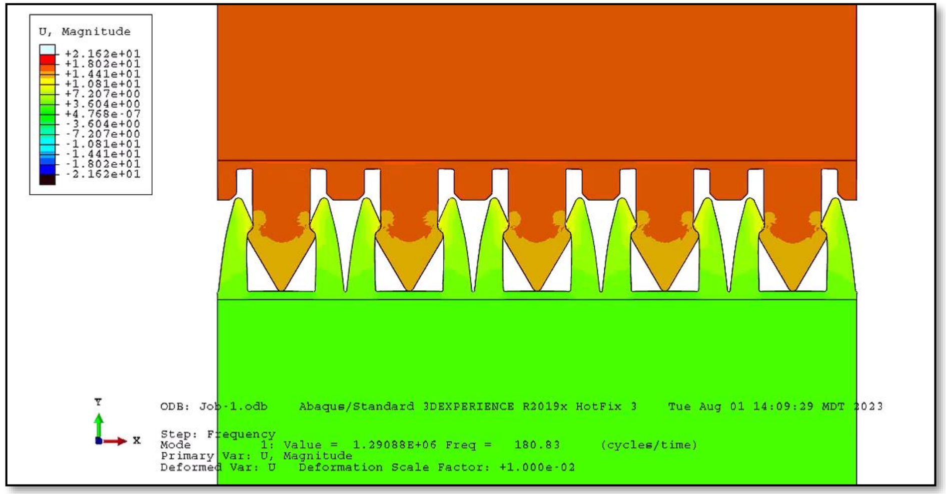
- Performed frequency analysis
  - Interested in mode with vertical displacement
  - Experimented with different configurations: 1x1 unit cell, 5x1 array
- Performed steady-state dynamic analysis on original shape
- Introduced 25 mm mass blocks to model to reduce rigidity of structure

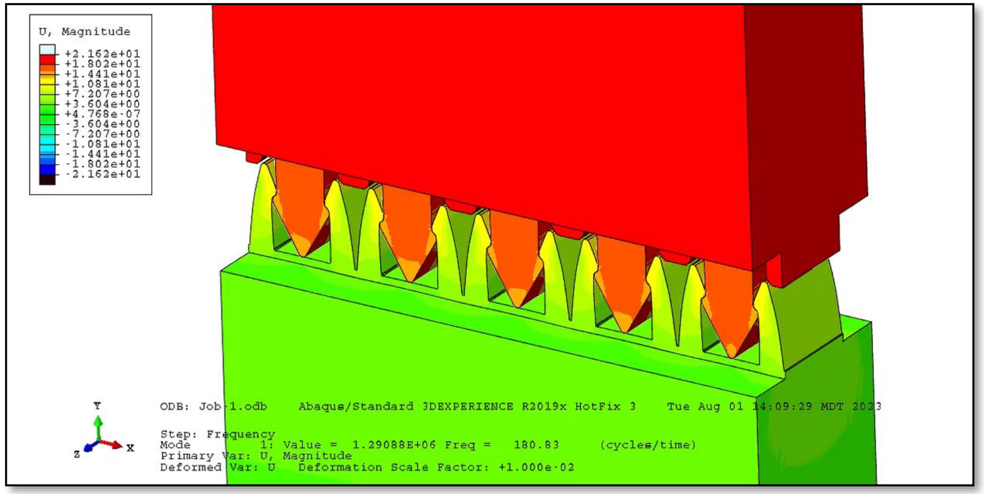


5x1 array of V-slot with natural frequency of 6269.3 Hz

S.S. Modal Dynamics

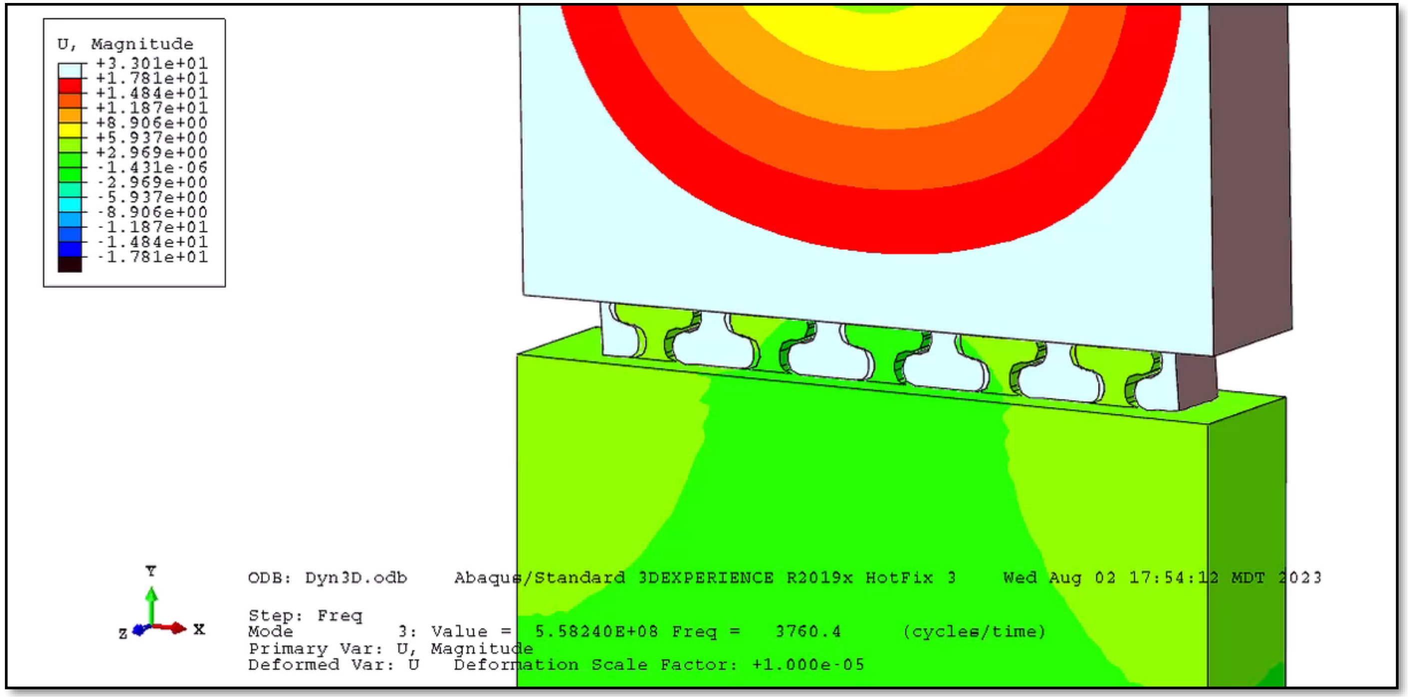
Frequencies of Mode of Interest (Hz)			
	T-Slot	V-Slot	Split Arrowhead
2D	6795	6269.3	229.12
3D	6674	-	180.83





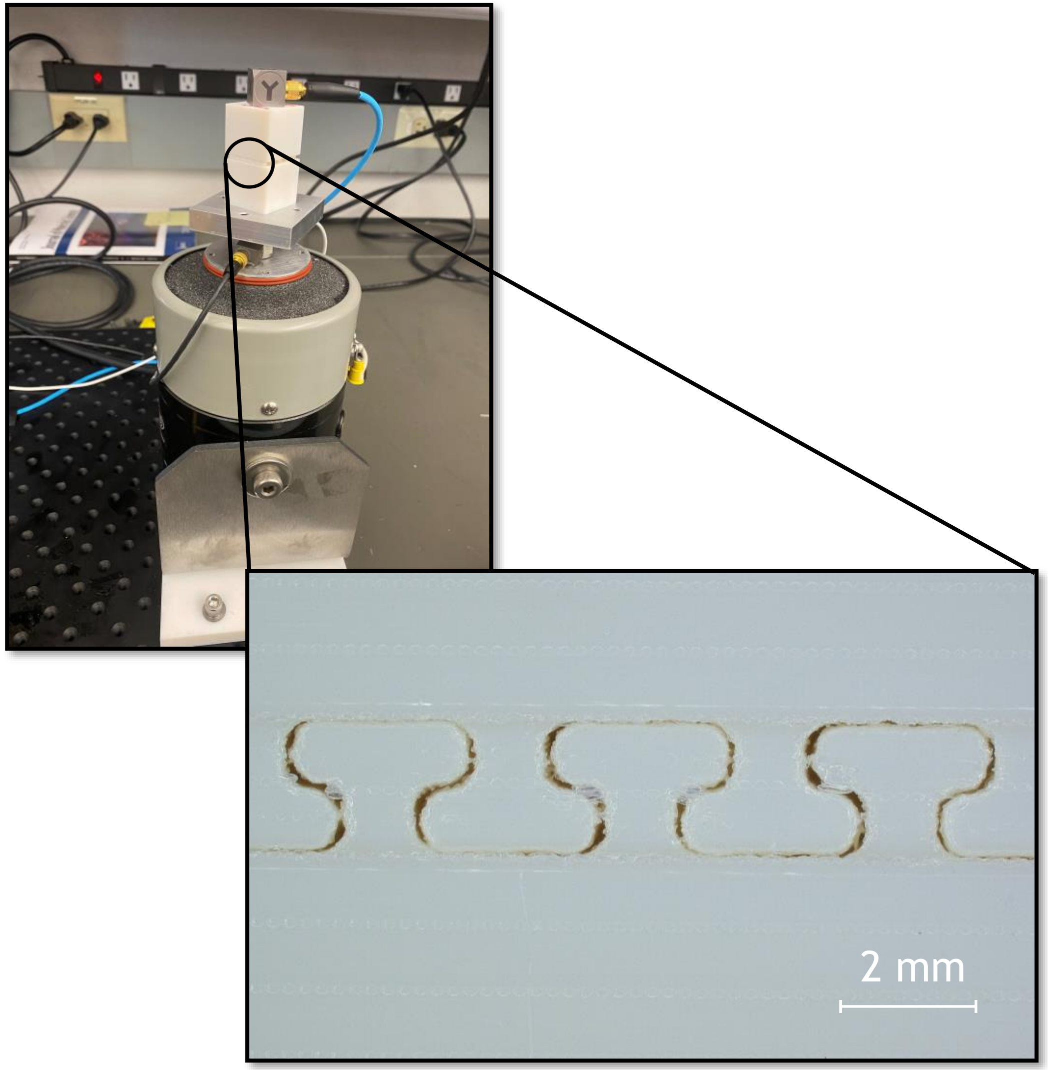
S.S. Modal Dynamics – 3D

- Introduced new configuration: 5x5 array
  - 5x5 array produced similar frequencies to 5x1 array → only use 5x1 array for simulations, less computationally expensive
- Generated plots for optimized shape for comparison with experimental data

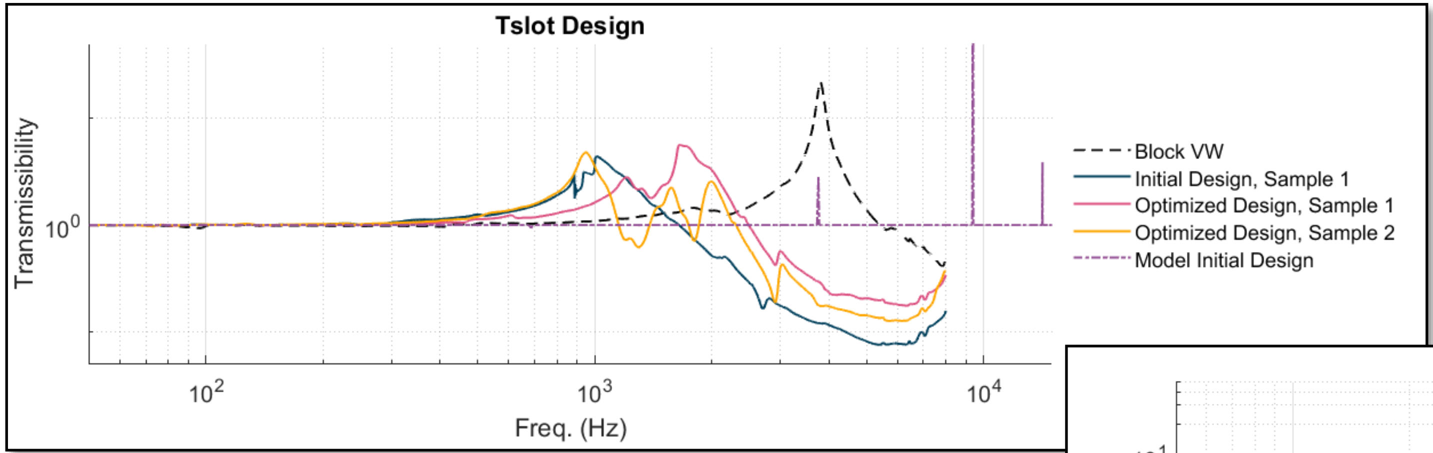


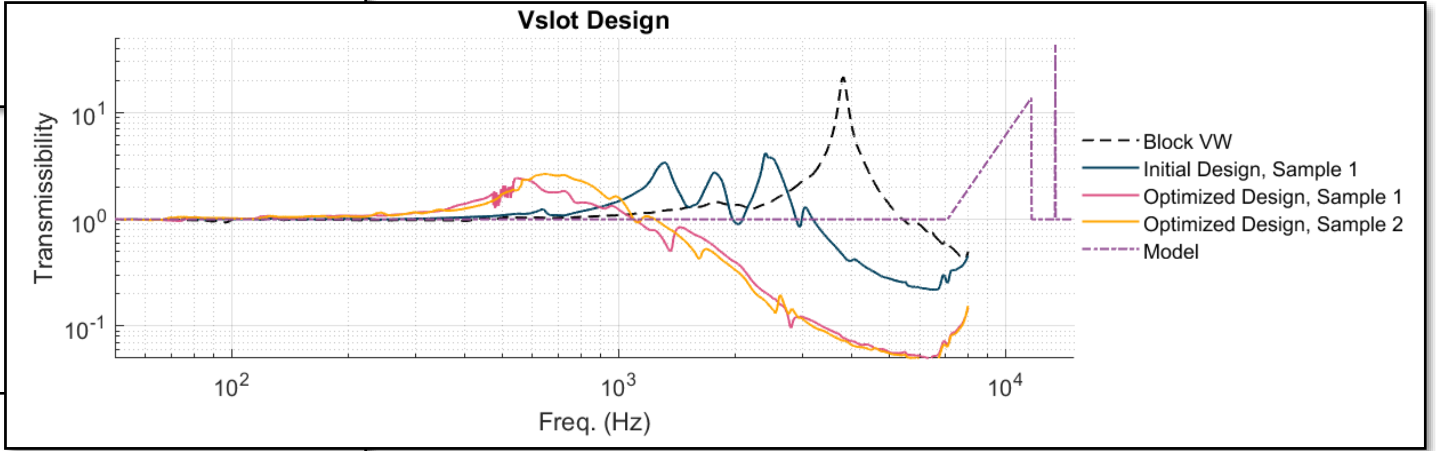
S.S. Modal Dynamics – Experimental Setup

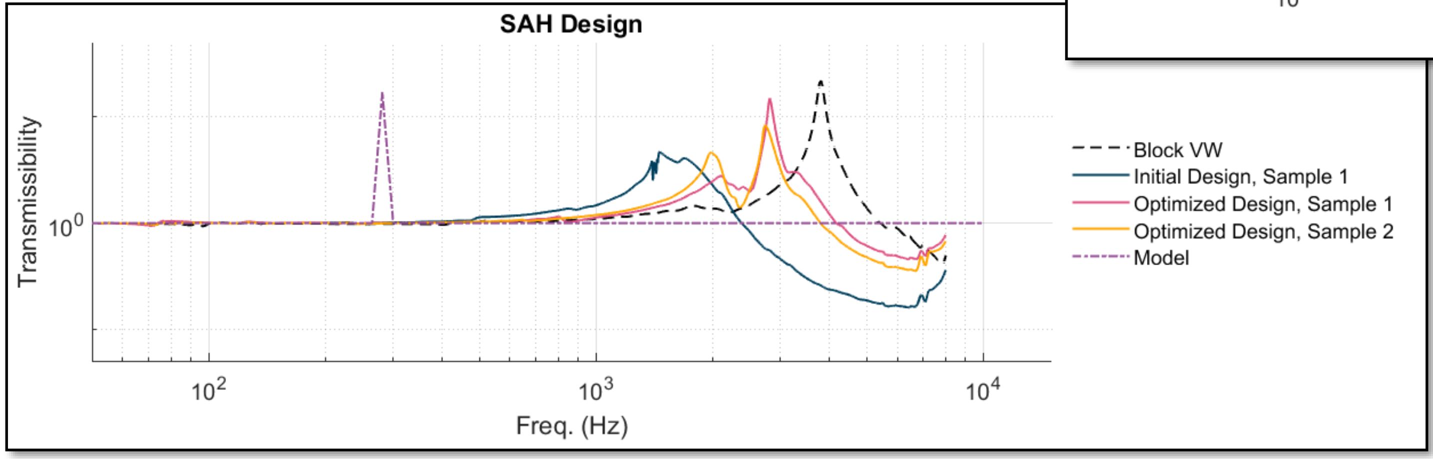
- Triaxial accelerometer, sample, and shaker are mounted on top of each other respectively
- Printed designs in 5x5 array
- Printed 1 original design and 2 optimized designs
  - Ran 3 sine sweeps from 50 – 8000 Hz for each sample
  - Repeatable runs



S.S. Modal Dynamics – Experimental Results

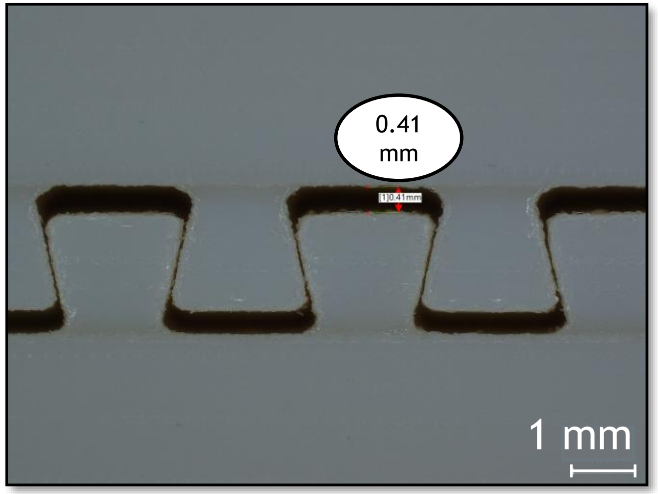




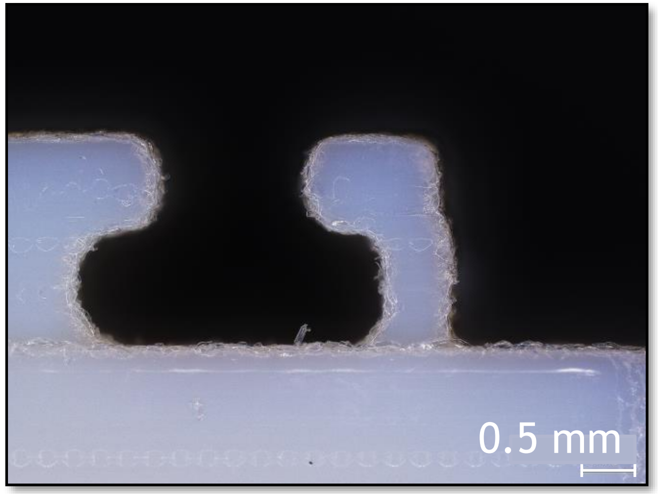


Discrepancies Between Printed Parts and FEA

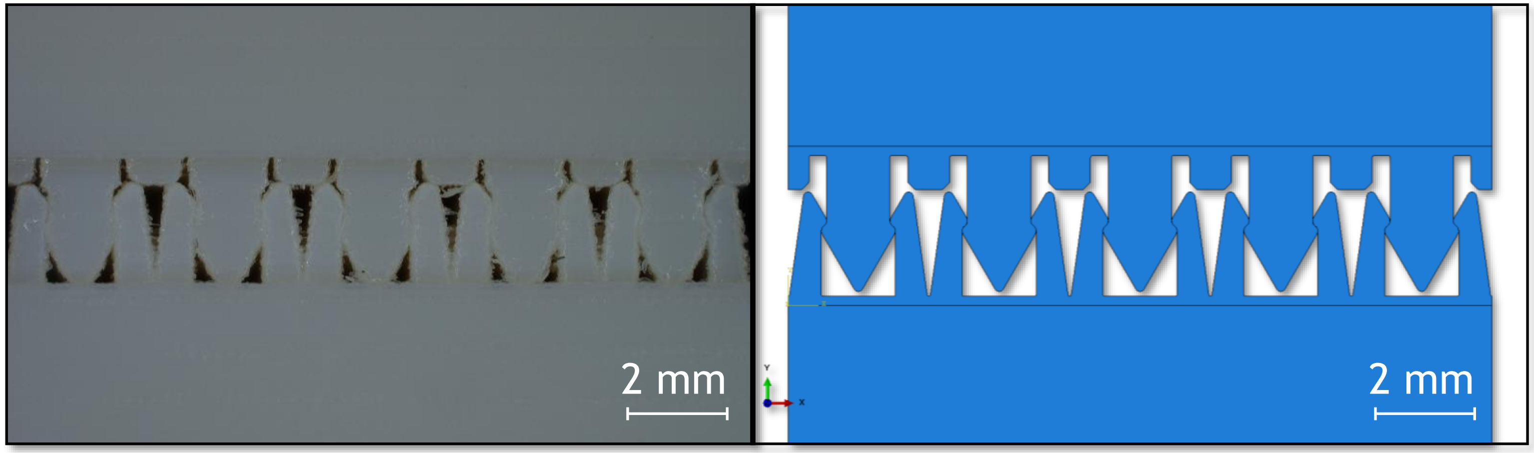
- CAD models and FEA models did not have exact same measurements
- Boundary conditions and edge geometry have a large effect on the dynamics of the sample
- Contact Properties
- V-slots
  - Tolerances affected accuracy of transmissibility plots



Large gaps appeared between some of the parts



On the edges of the model, there are significant deformations that occur



On average, each dimension in our Abaqus model was larger than the printed model

Conclusion

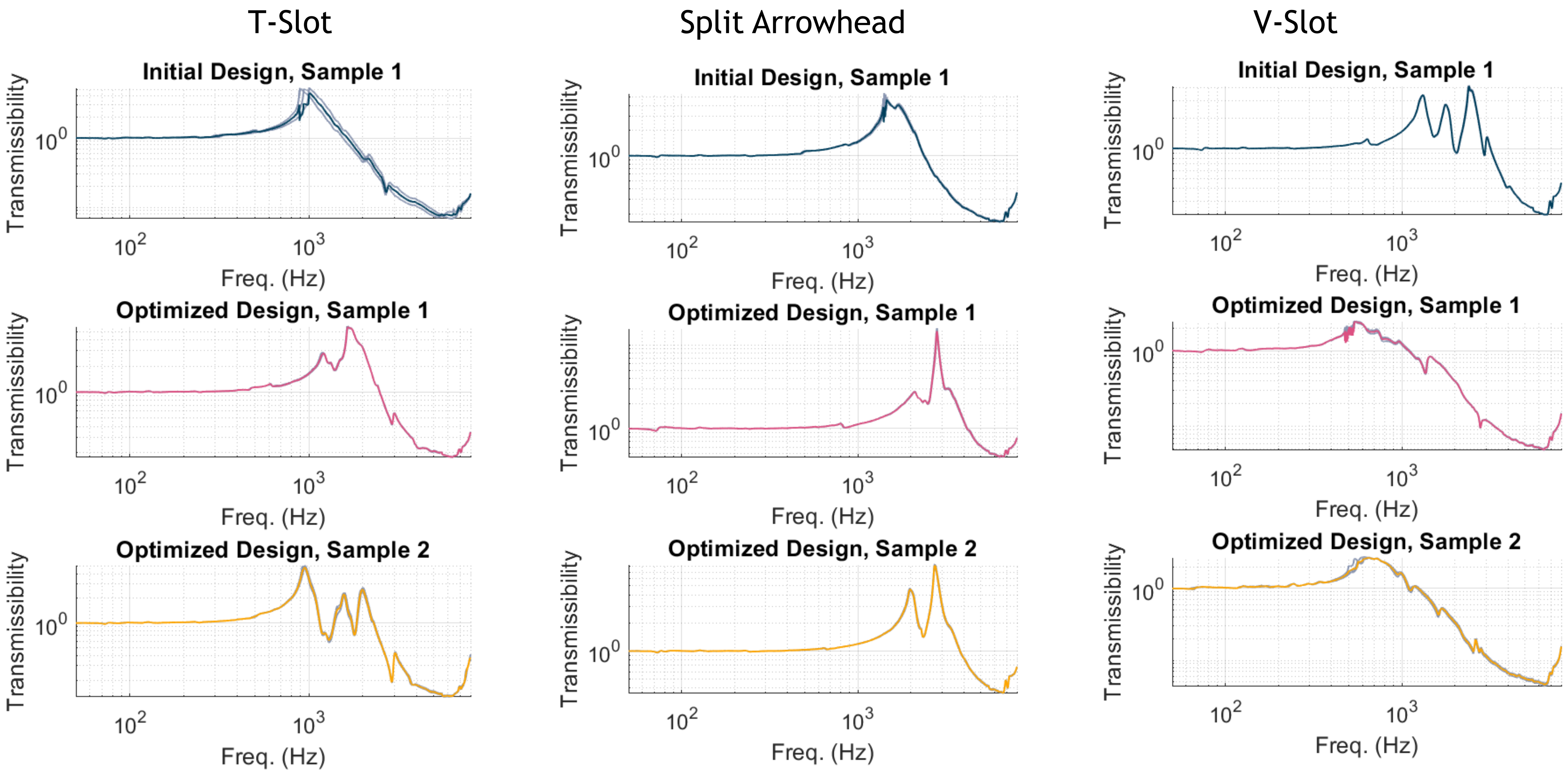
- Cells parameterized for tension had varying effects on the frequency response
- Our FEA models do not accurately predict the frequency response
- For the sliding T-slot and Split Arrowhead, the 5x1 vs. 5x5 frequency analysis is virtually identical

Future Work

- Test model strength in shear
- Explore different optimization schemes
  - Enforce more constraints that prevent the cells from disengaging
  - Use an optimization function dependent on yield stress and failure instead of maximum Von Mises stress
- Optimize shape to increase natural frequencies
- Model more accurate FEA model
  - Change contact properties
  - Better accommodate for gap between parts
  - Create more realistic boundary conditions
  - Recreate FEA model to match geometric parameters of printed part

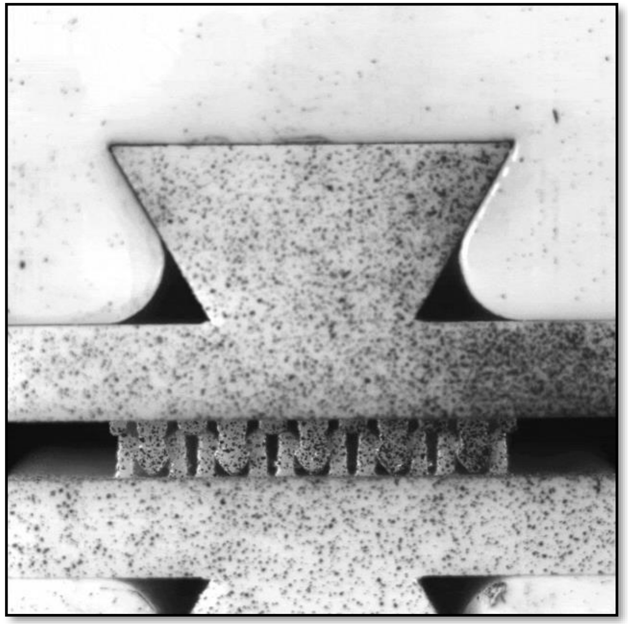
EXTRA SLIDES

S.S. Modal Dynamics – Experimental Results

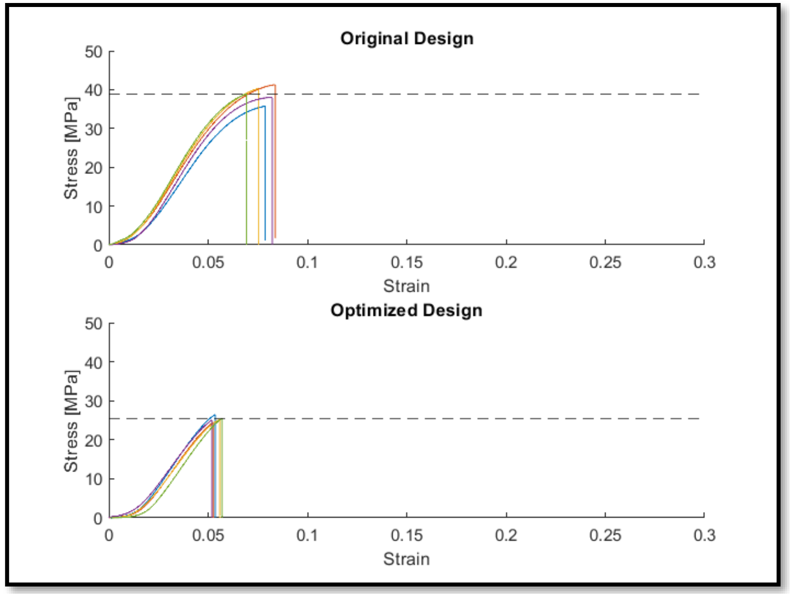


Quasi-Static Tension – Experimental

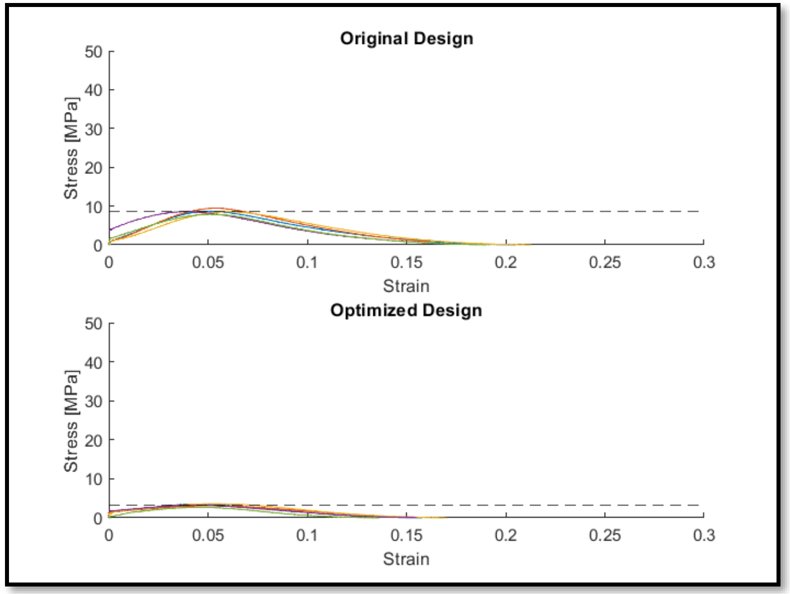
- Some designs fracture, some disengage
  - Optimizing the design can create sufficient compliance in the parts for disengagement
- Not optimizing for strength at failure



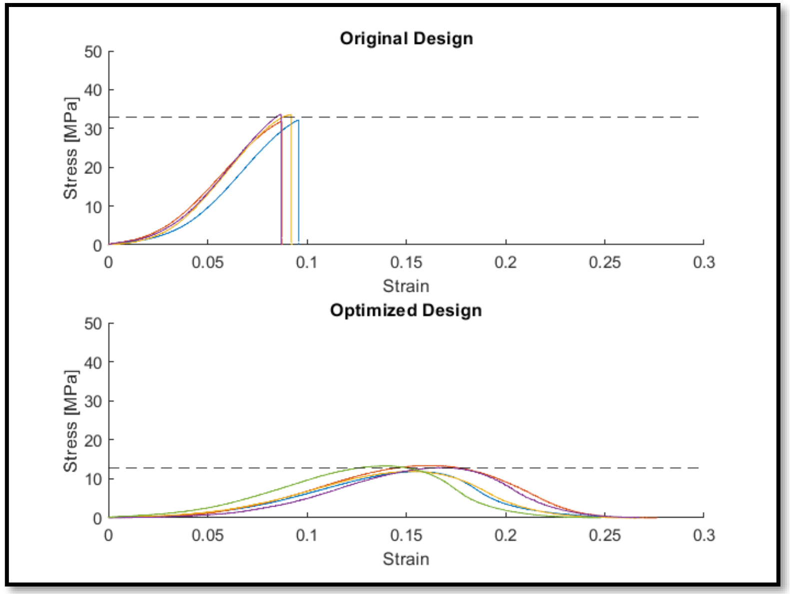
T-Slot



Arrowhead



V-Slot



References

1. Bolmin, O., Young, B., Leathe, N., Noell, P. J., & Boyce, B. L. (2023). Interlocking metasurfaces. Journal of Materials Science, 58(1), 411-419.
2. Young, B., Bolmin, O., Boyce, B., & Noell, P. (2023). Synergistic strengthening in interlocking metasurfaces. Materials & Design, 227, 111798.