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Title: Vibrational Properties of Additively Manufactured Materials Closeout

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Intended for: Discussion of vibration with NASA engineers.

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Vibrational Properties of Additively Manufactured Materials Closeout

Background

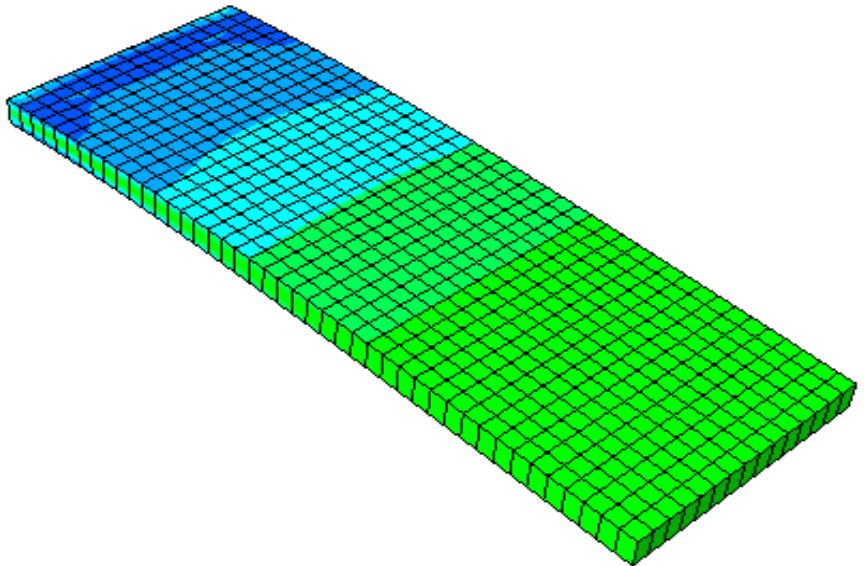
- AM parts: complex, rapidly prototyped, unreliable?
- Resonance caused by vibration during launch can damage sensitive components
- The vibrational properties of AM parts are not well understood

Experiment

- Use the dynamics lab to test AM and conventional cantilever beams

Troy Pacheco ISR-5

Scale Factor: -0.90

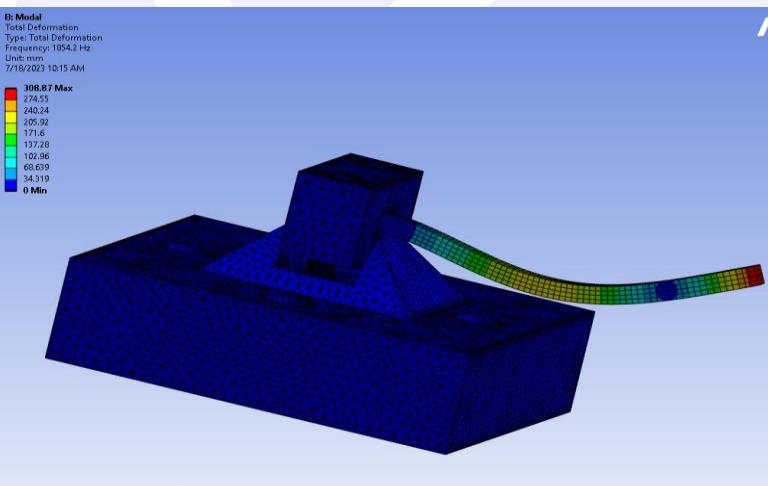
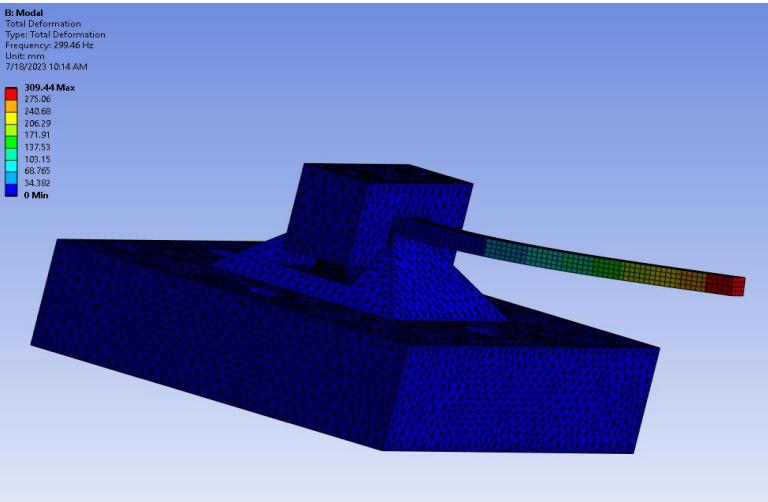


Design and Modeling

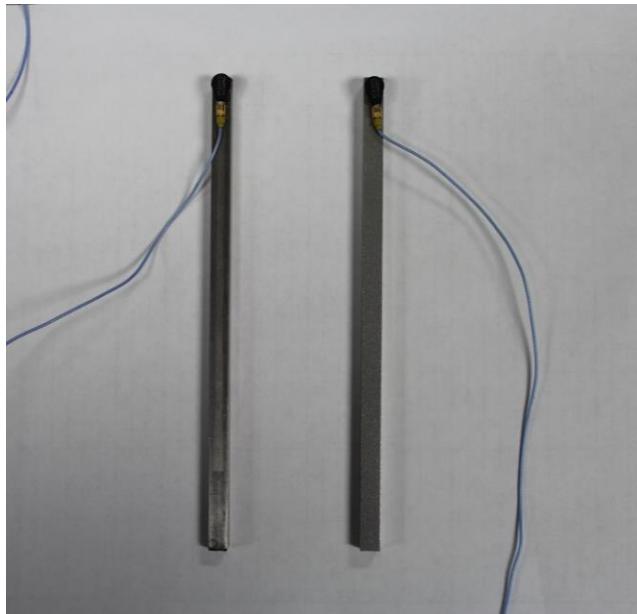
Use an aluminum base and clamp to hold either an Additively Manufactured (AM) or Stainless Steel (SS) cantilever beam as it is tested on the vibe table

AM Density – 0.280 lb/in³
SS Density – 0.282 lb/in³

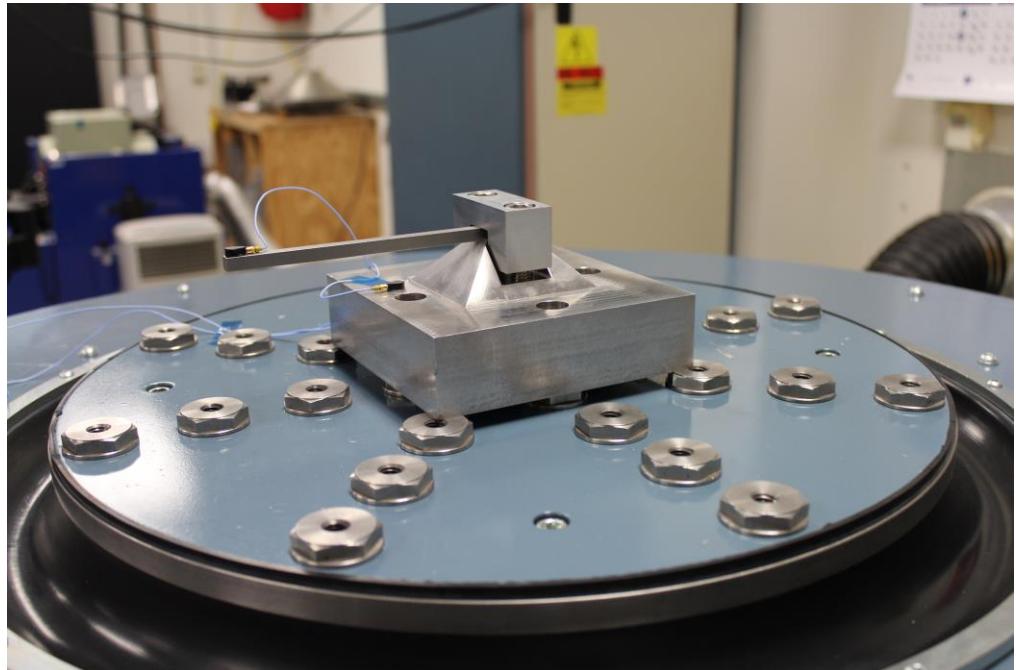
Mode 1: 290 Hz
Mode 2: 1850 Hz



Experimental Setup



Single axis accelerometers
attached using super glue



The experimental setup mounted on the z
axis of the shaker table. All mounts were
torqued to 35ft-lbs

Vibration Levels

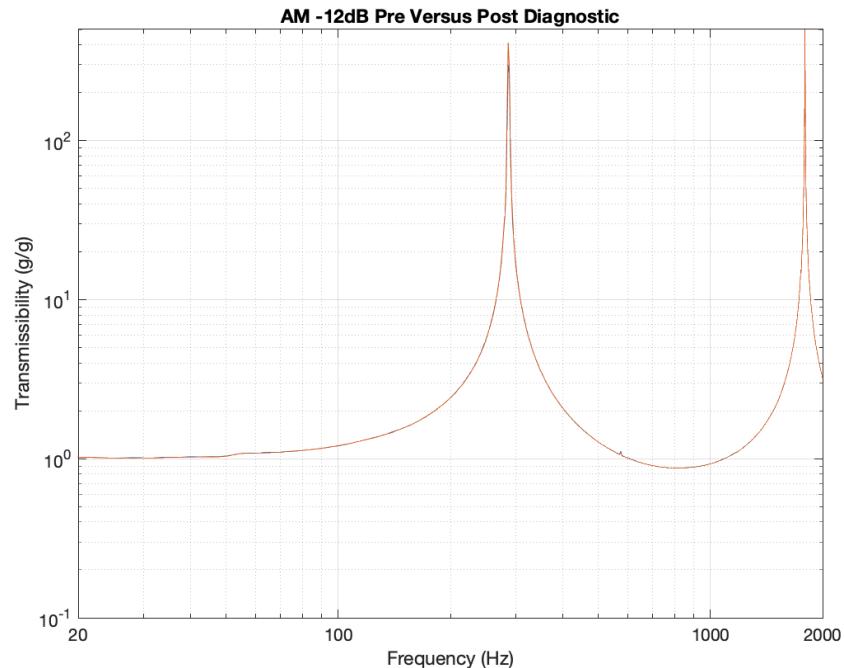
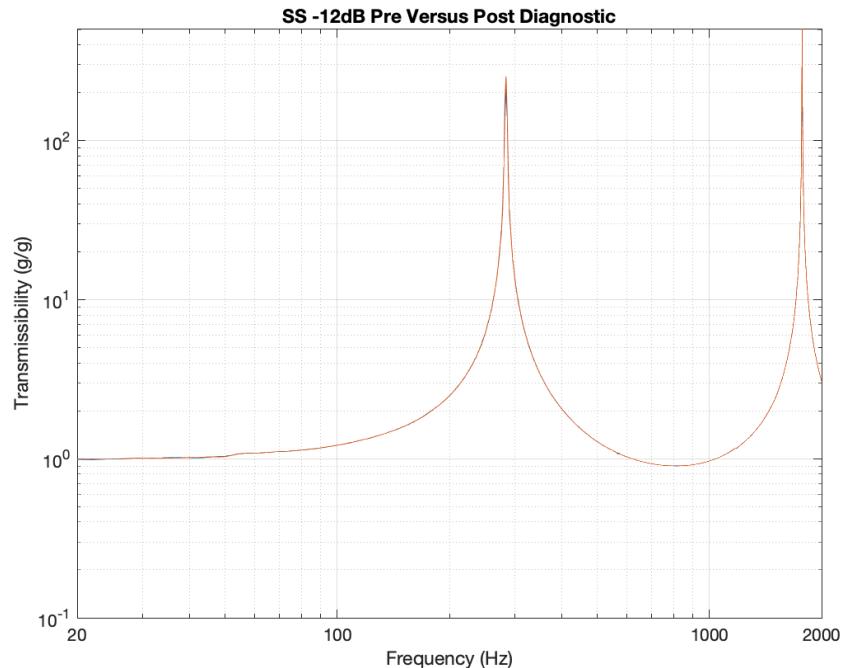
Random Vibration

- $0.02\text{g}^2/\text{Hz}$ from 20-200Hz
- 6.293 gRMS

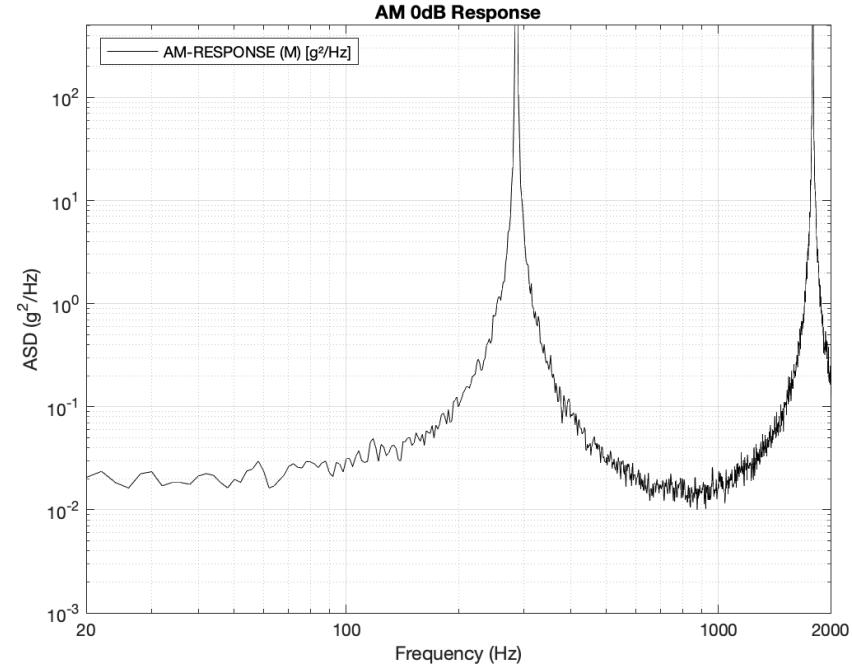
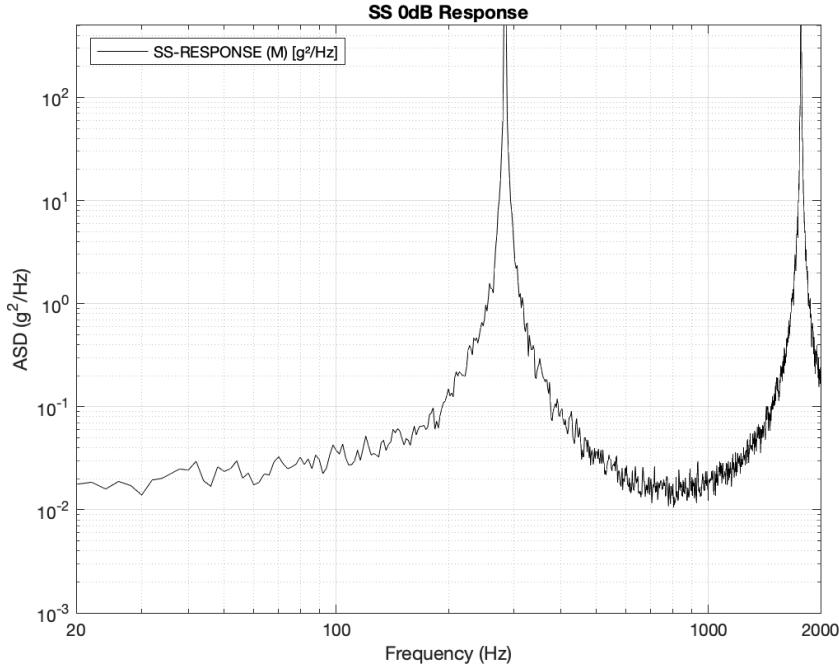
Sine

- 0.5g from 20-2000Hz

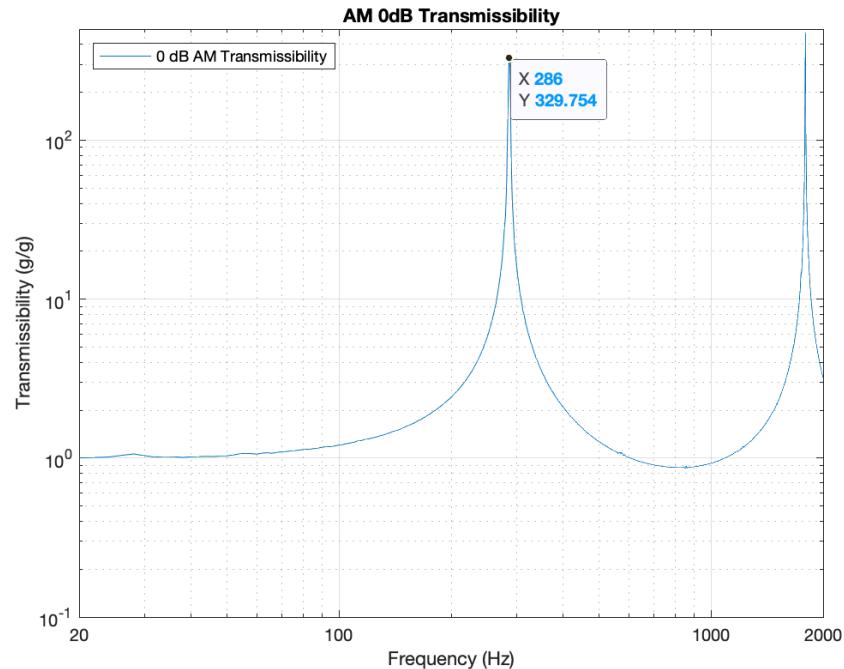
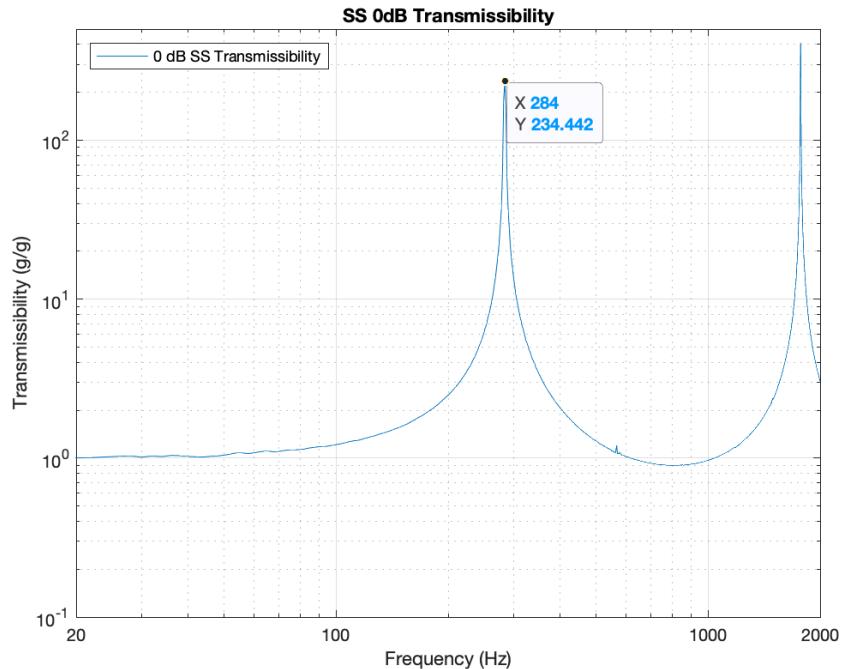
Pre vs Post Transmissibility Comparison



Random Vibration Results, Input $0.02\text{g}^2/\text{Hz}$ 6.293 gRMS



Transfer Functions



Frequency Calculation

In addition to the modal analysis from the model, the theoretical modes were calculated using:

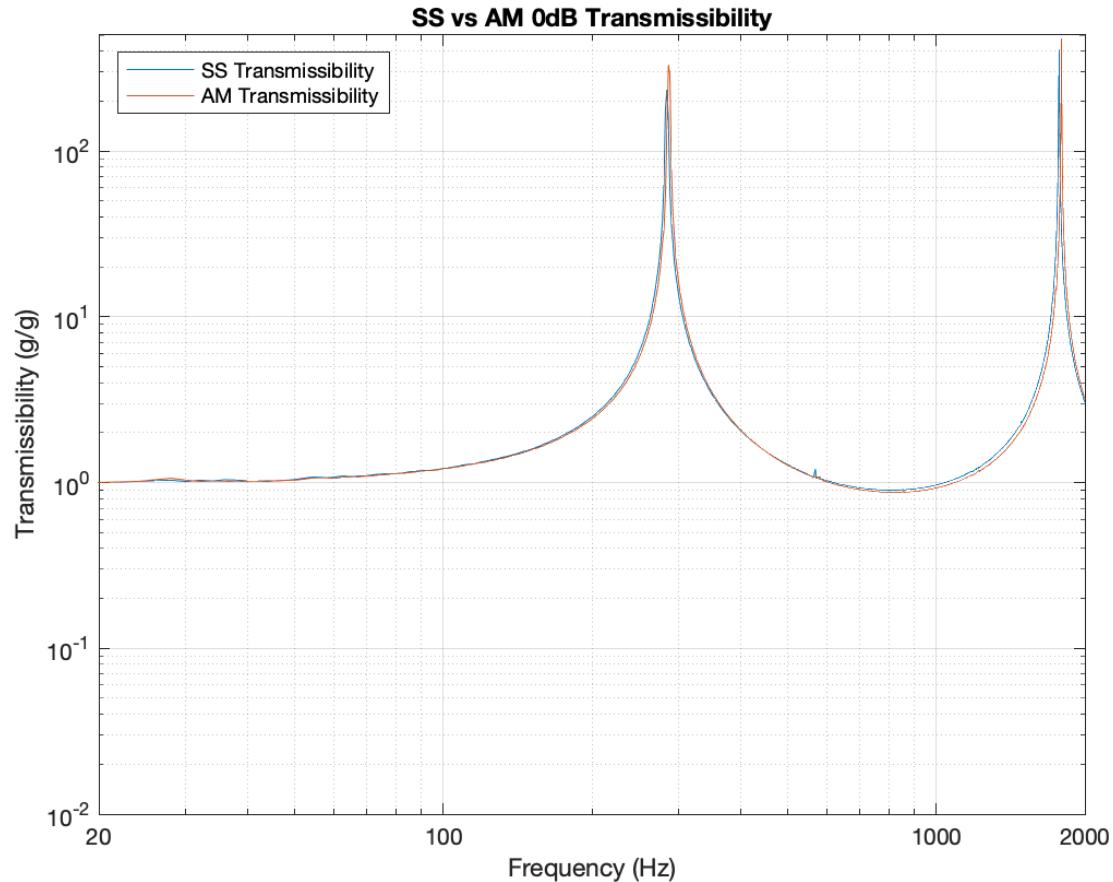
$$f_n = \frac{K_n}{2\pi} \sqrt{\frac{EIg}{wl^4}}$$

From Young, W. C., Budynas, R. G.(2002). Roark's Formula's for Stress and Strain, 7th edition. McGraw Hill, Chapter 16, pp767-768.

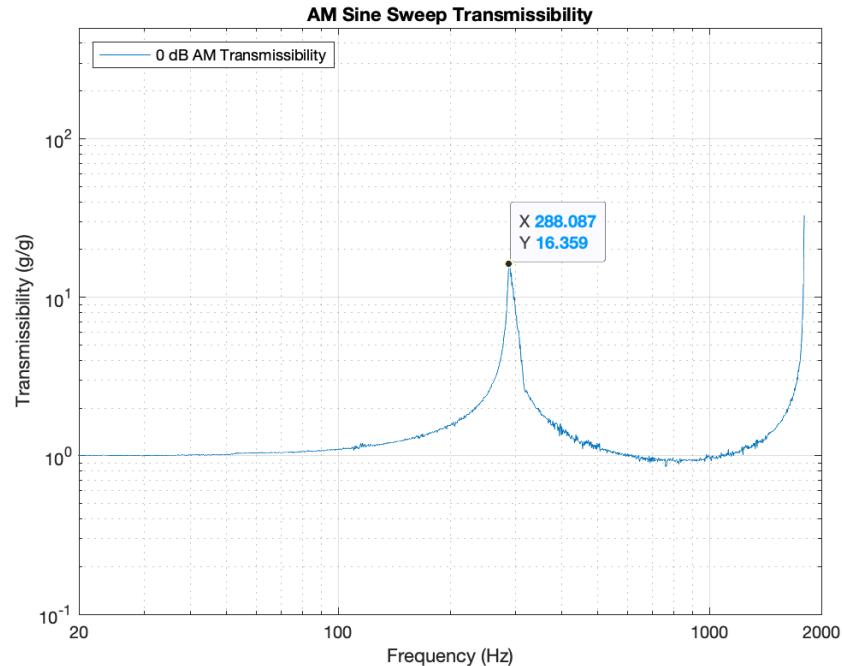
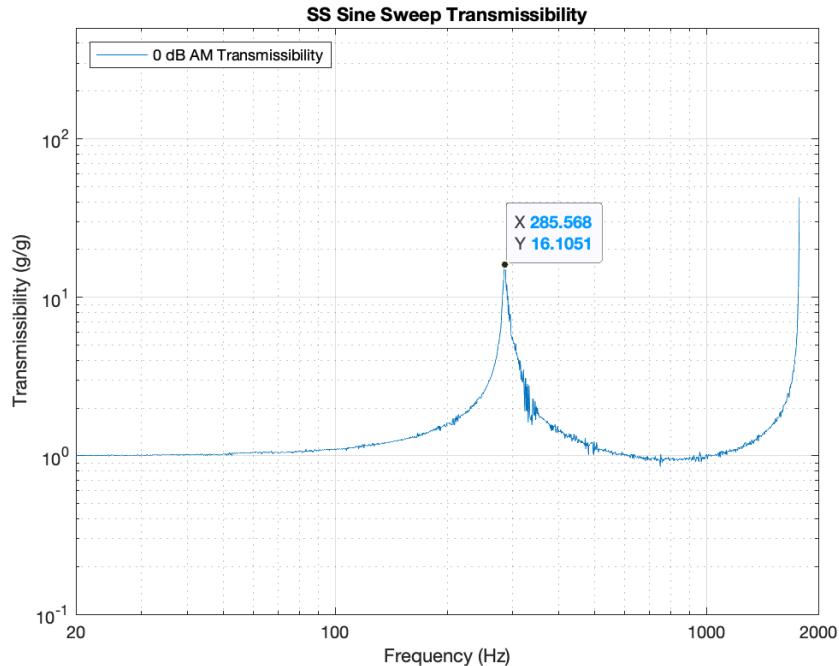
Where f_n is the natural frequency, E is the elastic modulus, I is the moment of inertia, g is the gravitational constant, w is the uniform load (weight per unit length), l is the length, and K_n is a constant for each mode with $K_1=3.52$, $K_2=22.0$

Comparison

	Theoretical	Model	SS	AM
1	312	299	284	286
2	1950	1850	1772	1792



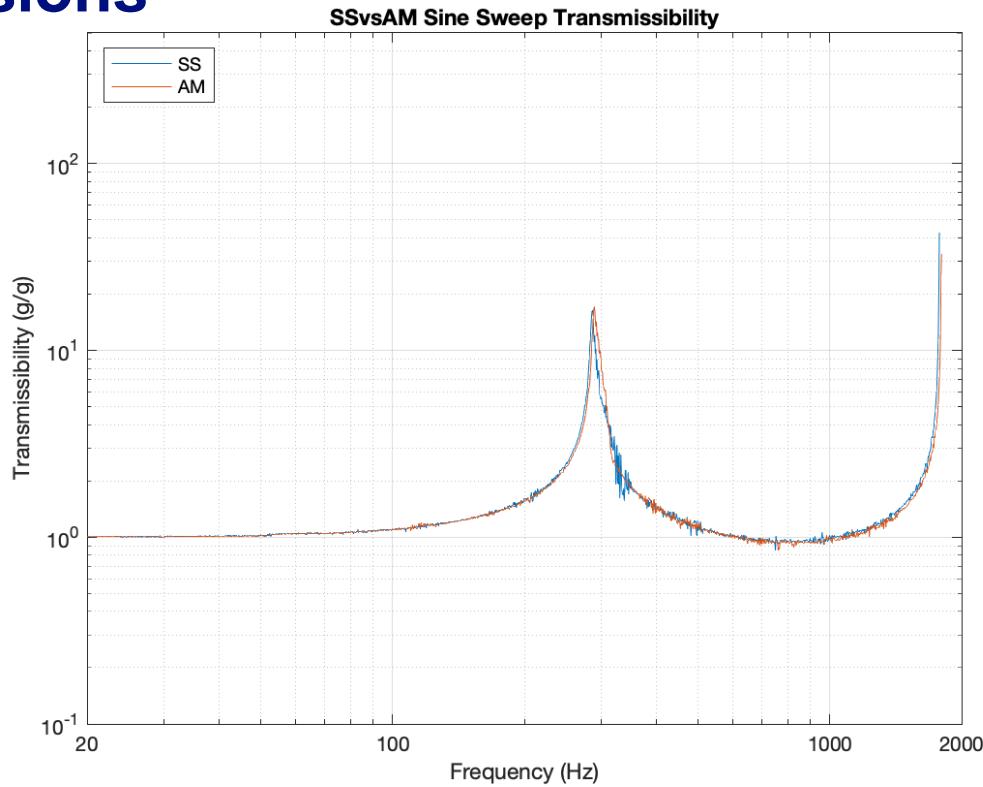
Sine Sweep, 0.5g from 20-2000Hz



Comparison and Conclusions

The results of the Sine Sweep are also nearly identical for both the SS and AM test bars.

We can be confident that our models are accurate for vibrational testing of AM parts in the future



Future Research

- After discussions with the advanced manufacturing division, we determined that the effects of the AM process might not become evident until higher frequencies.
- The shaker table in ISR cannot test above 2000Hz, but the shock beam can.
- The next phase of research would be to repeat the experiment using the shock beam up to 10,000Hz.

Works Cited

- [1] J. J. Lewandowski and M. Seifi, "Metal Additive Manufacturing: A Review of Mechanical Properties," *Annual Review of Materials Research*, vol. 46, pp. 151-186, 2016.
- [2] M. Albakri, L. Sturm, C. B. Williams and P. Tarazaga, "NON-DESTRUCTIVE EVALUATION OF ADDITIVELY MANUFACTURED PARTS VIA IMPEDANCE-BASED MONITORING," in *International Solid Freeform Fabrication Symposium*, 2015.
- [3] E. R. Fotsing, A. Dubourg, A. Ross and J. Mardjono, "Acoustic properties of periodic micro-structures obtained by additive manufacturing," *Applied Acoustics*, vol. 148, pp. 322-331, 2019.
- [4] D. Russel, "Vic Sparrow's Acoustics and Vibration Animations," Pennsylvania State University, 17 May 2018. [Online]. Available: <https://www.acs.psu.edu/drussell/Demos/Sparrow/Sparrow.html>. [Accessed 12 March 2023].