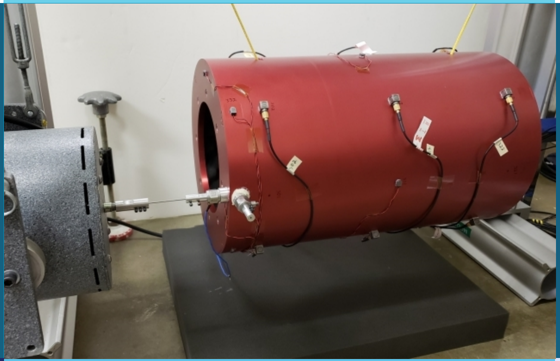
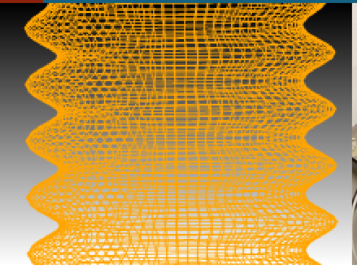
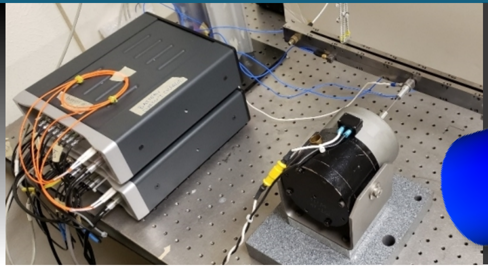
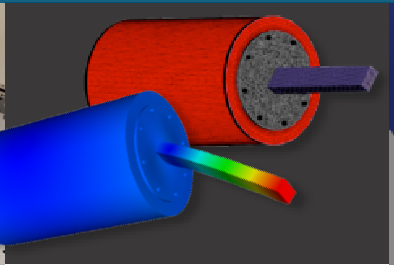
SAND2023-12219C

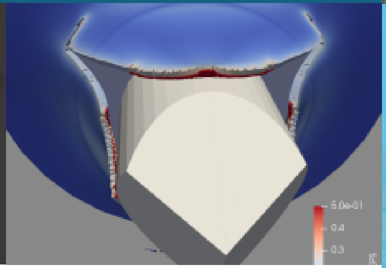
Model Validation of a Modular Foam Encapsulated Electronics Assembly With Controlled Preloads Via Additively Manufactured Silicone Lattices











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IMAC XLI, February 16, 2023 #14556

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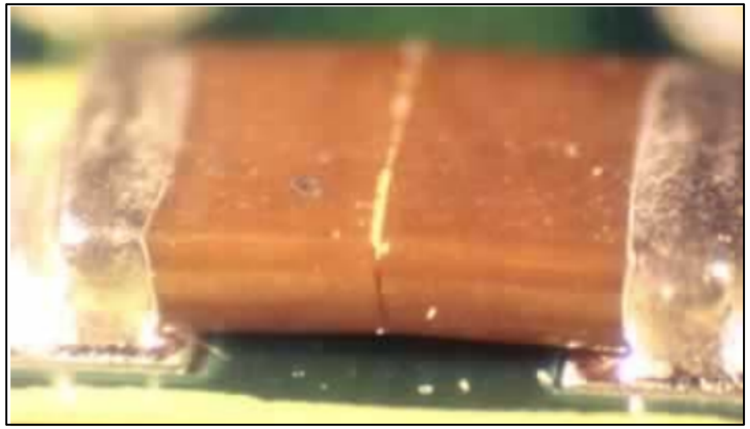
Presentation Overview

1. Background and Motivation
2. Experimental Methods
3. Material Modeling Strategy
4. Finite Element Modeling
5. Results
6. Conclusions and Future Work

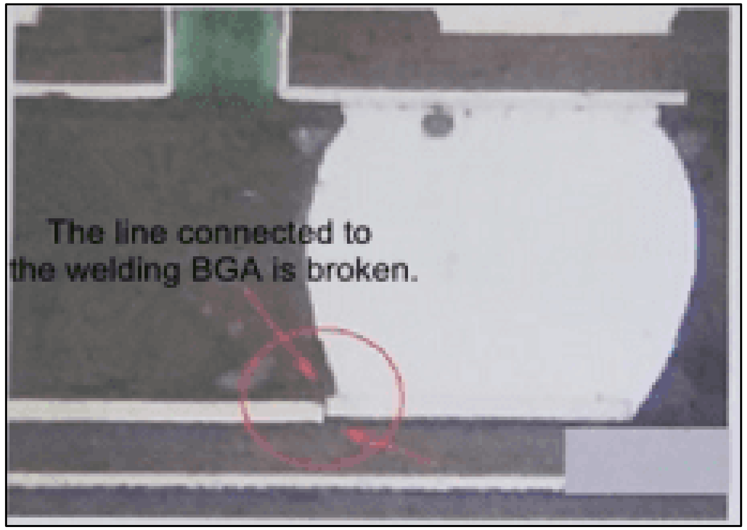
Background – vibrations of electronic assemblies

- Electronic assemblies can be exposed to harsh mechanical environmental conditions
  - Packaging is vital to ensure proper function under these conditions
- Failures resulting from demanding static (assembly) and dynamic (vibration or shock) environments include:
  - Cracking of circuit board base
  - Discontinuity of soldered connections
  - Permanent failure of strain-sensitive components (ceramic capacitors, ball grid arrays, etc.)

Modular Foam Approach: Use layers of compressed soft and rigid foams to protect the electronics by taking advantage of AM to control assembly stiffness



Broken Capacitor from Flexure [1]

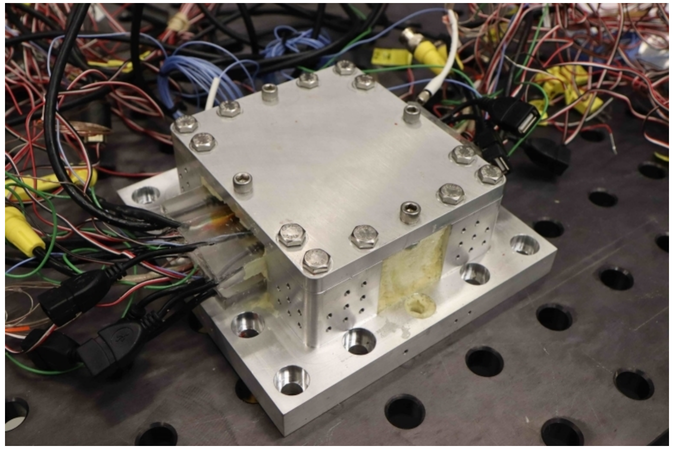


Severed Trace due to Vibrations [2]

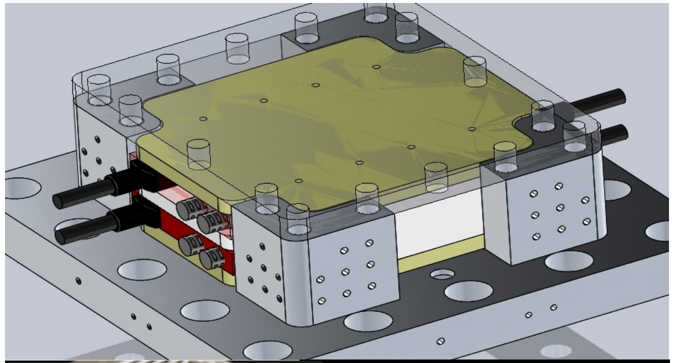
Introduction – Foam Encapsulation Approaches

	Traditional Potted Foam	Additive Manufacturing/ Modular Approach
Overall Cost		✓
Reusability		✓
Serviceability		✓
Environment Damping	✓	✓
Mechanical Support	✓	✓
Repeatability		✓

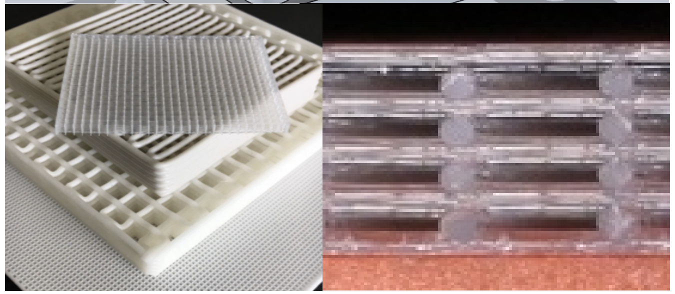
Potted Foam



Modular Foam

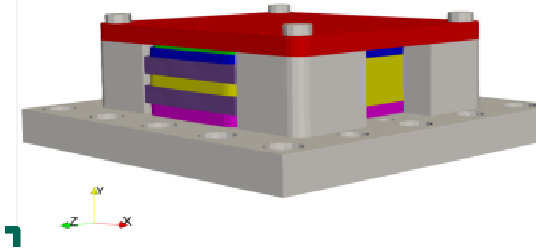


AM Lattice

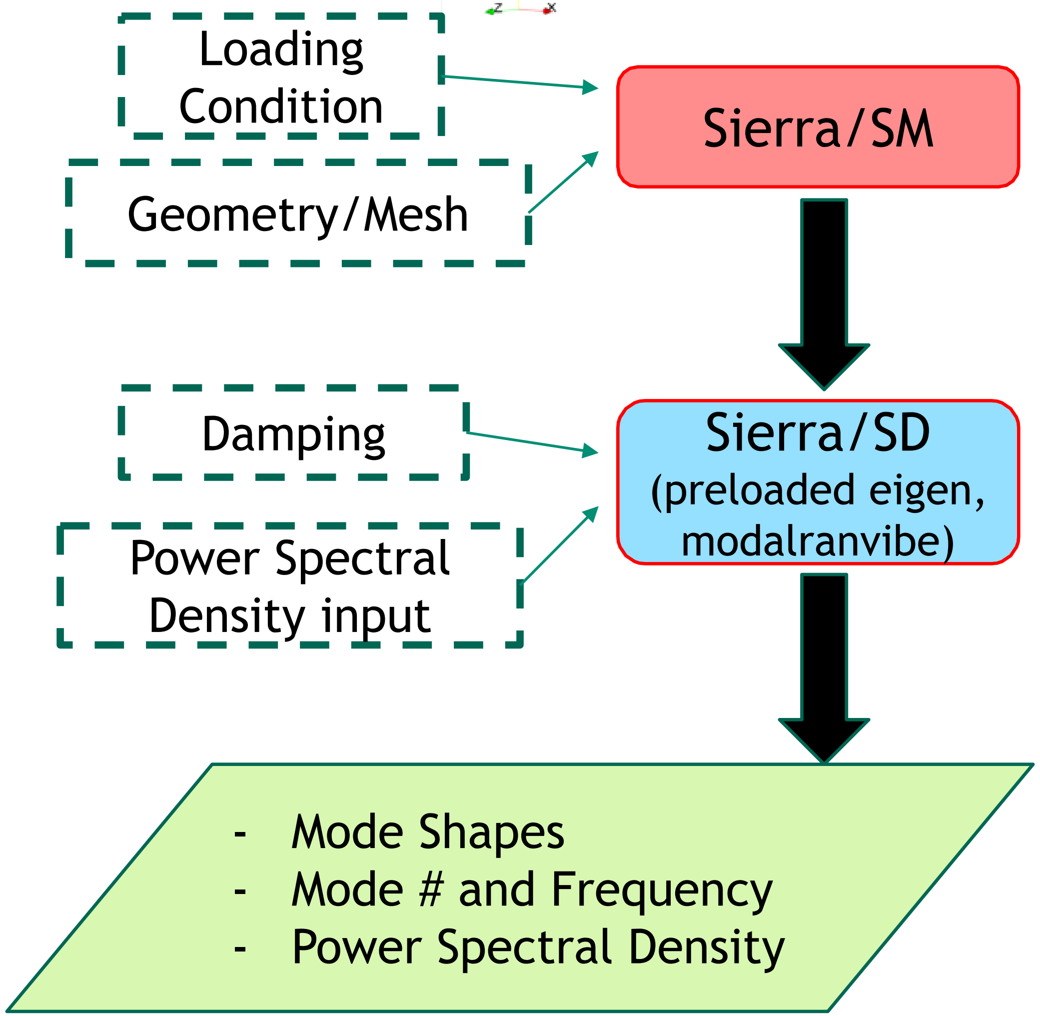


AM Modular approach offers advantages- need to develop modeling strategy

Objectives

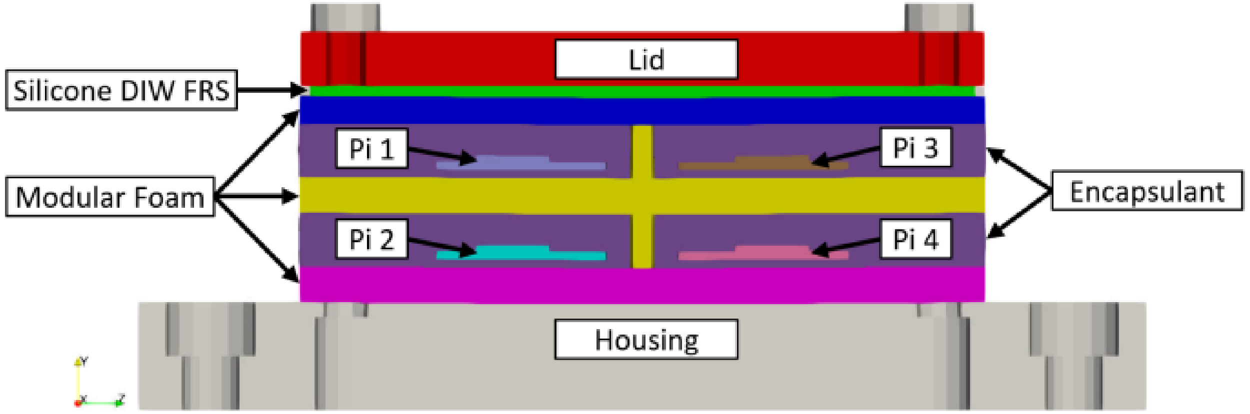


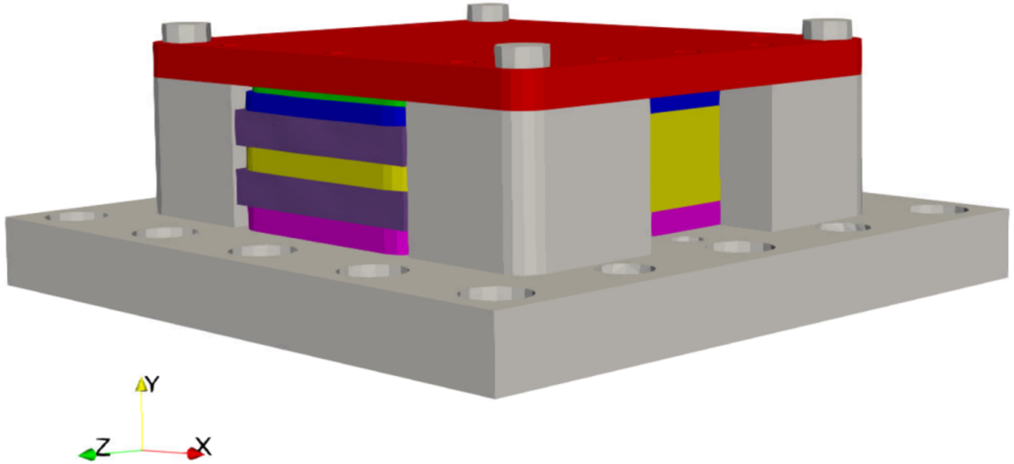
- Project Goals
  - Establish a computational model that validates modular foam experimental outcomes
  - Successfully preload the model in Sierra/Solid Mechanics and handoff the preloaded state for a modal and frequency response analysis in Sierra/Structural Dynamics
  - Investigate effects of various preloading conditions on the modal response



Geometry

- The assembly of interest is composed of:
  - An aluminum enclosure (housing and lid)
  - Direct Ink Write (DIW) AM Lattice
  - Foam layers
  - Electronics components encapsulated by the enclosure and foams
- The assembly is roughly 7 x 7 x 4 in (17.8 x 17.8 x 10.3 cm)

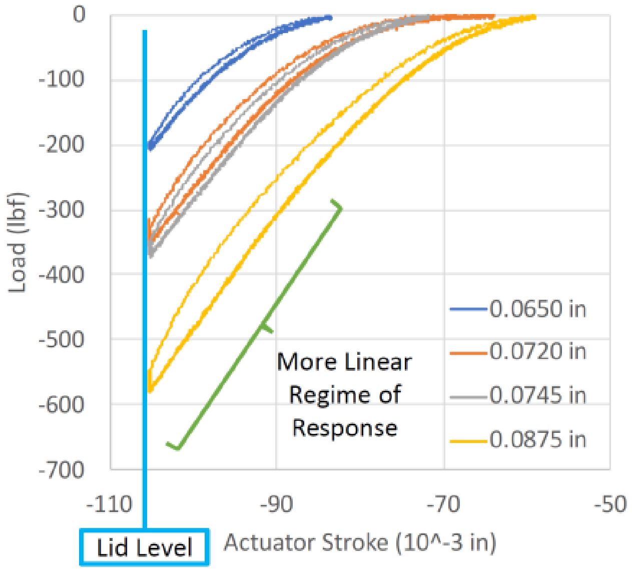




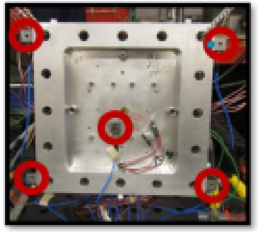
Experimental Methods

Tests used for model validation

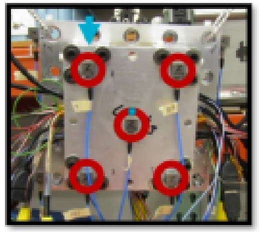
- **Load-Displacement Testing:**
  - Inform pre-compression levels for structural dynamics tests
- **Free-Free Modal Testing:**
  - Accelerometers fixed at key points
  - Experimentally measure mode frequencies and damping ratios
- **Fixed-Base Uniaxial Vibration Testing:**
  - Evaluate acceleration response of electronics
  - Unit-unit variability



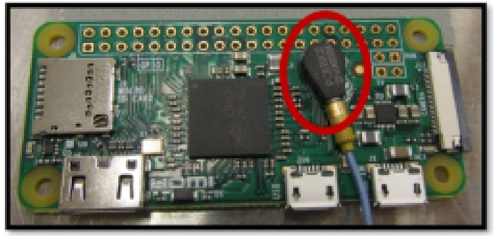
5 Accelerometers on the Bottom Plate

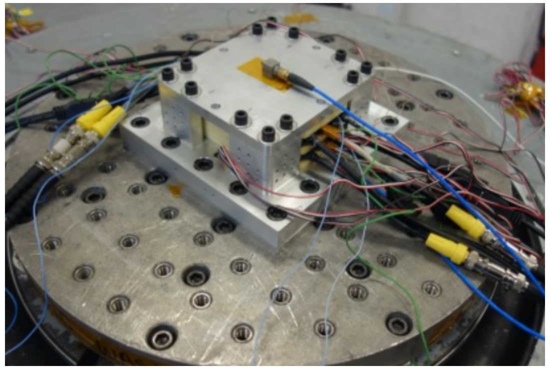


5 Accelerometers on the Top Plate



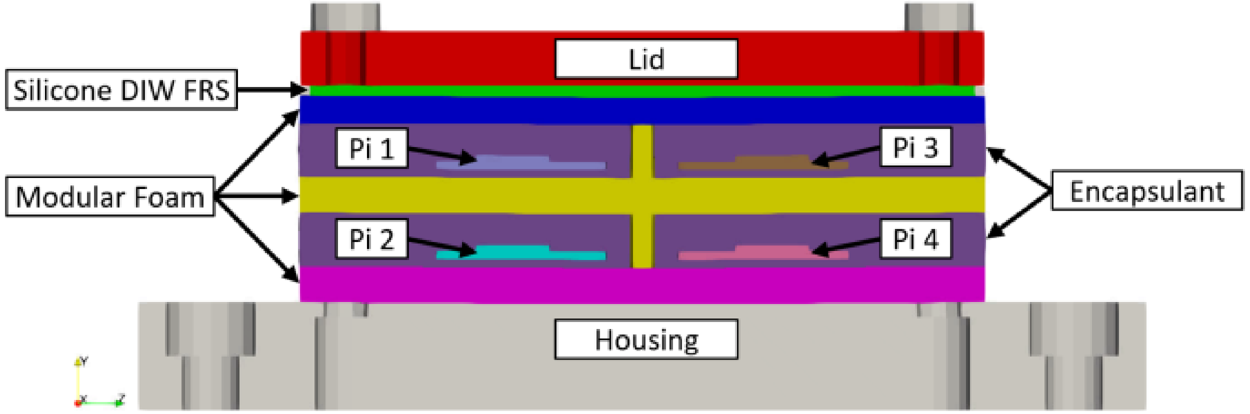
1 Accelerometer on the Raspberry Pi

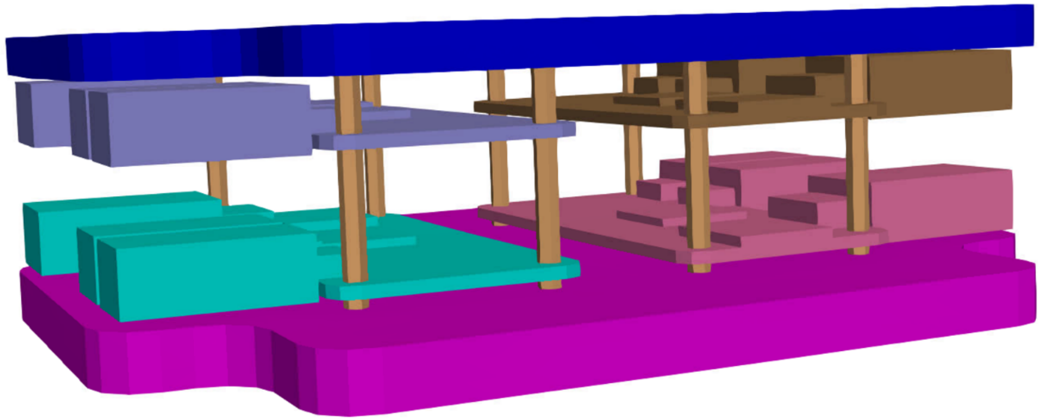




Material Modeling

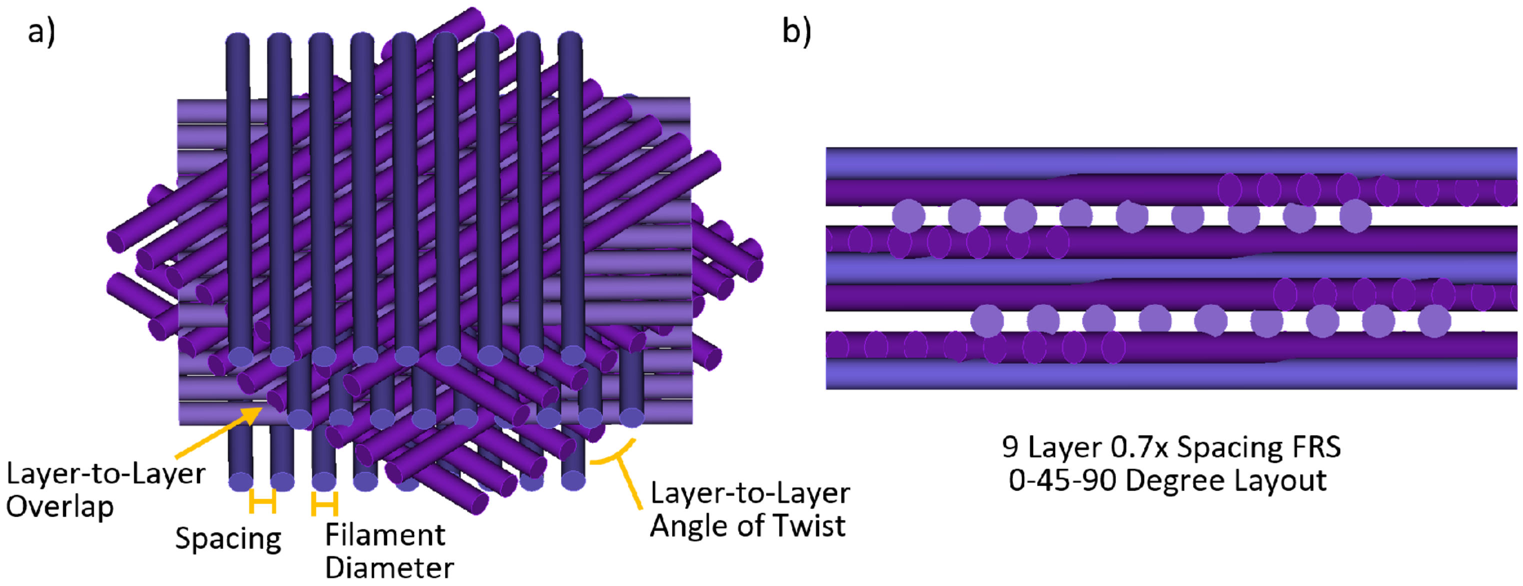
- **6061 Aluminum Lid and Housing:**
  - Linear elastic material
- **Raspberry Pi:**
  - Elastic-plastic material based on test
- **Bolts, pins, and fasteners:**
  - Linear elastic material
- **PMDI Modular Foam**:
  - Foam damage model for the solid mechanics simulation
  - Blatz-Ko model for structural dynamics simulation
- **Sylgard® 184 Encapsulant Foam:**
  - Gent model for solid mechanics
  - Neo-Hookean model for structural dynamics
- **Silicone DIW Foam Replacement Structure (FRS)**:
  - Hyperfoam model based on experimental data





Homogenization of the Silicone DIW Lattice

- **Homogenization based on:**
  - Uniaxial Compression tests of Direct Ink Write (DIW) lattices
  - Parameter Estimation to fit the stress-strain response to the Hyperfoam model
- **Advantages to homogenization:**
  - Reduce model complexity
  - Reduce computational costs
  - Simple to change material parameters
  - No need to create each variation of the lattice structure

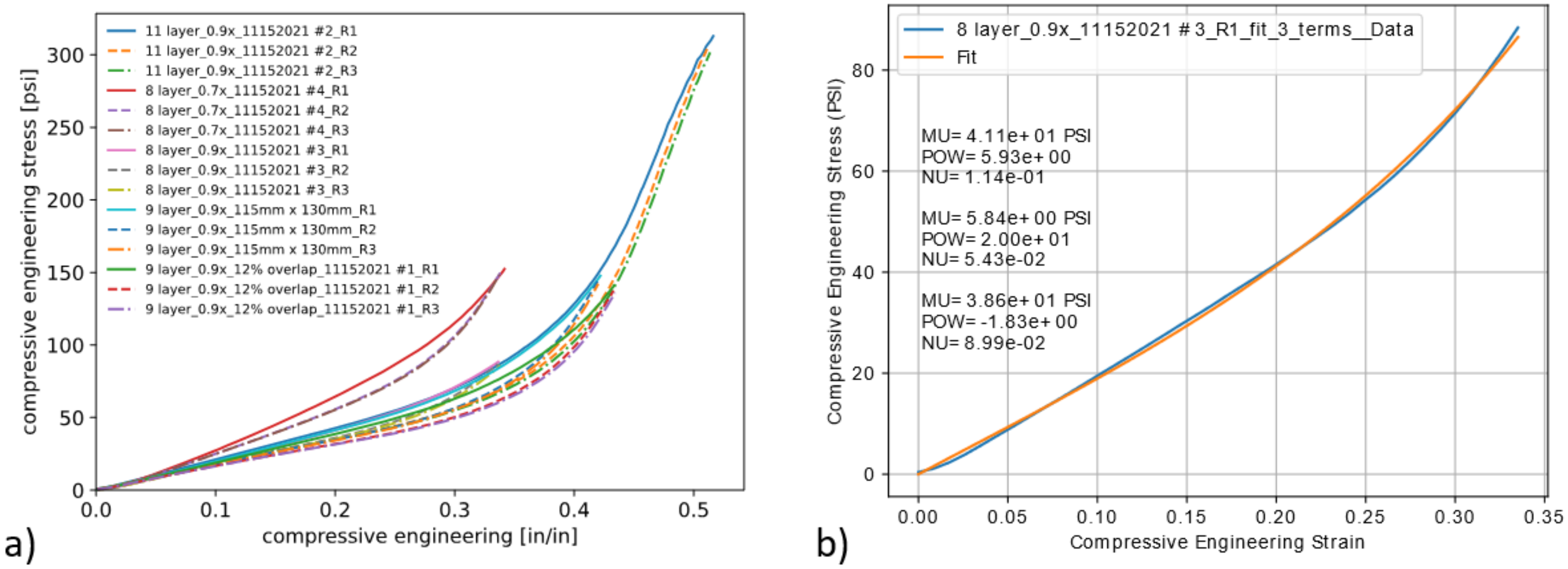


Modeling Additively Manufactured Soft Foams – Hyperfoam

Storaker (Hyperfoam) compressible hyperelastic model [3]

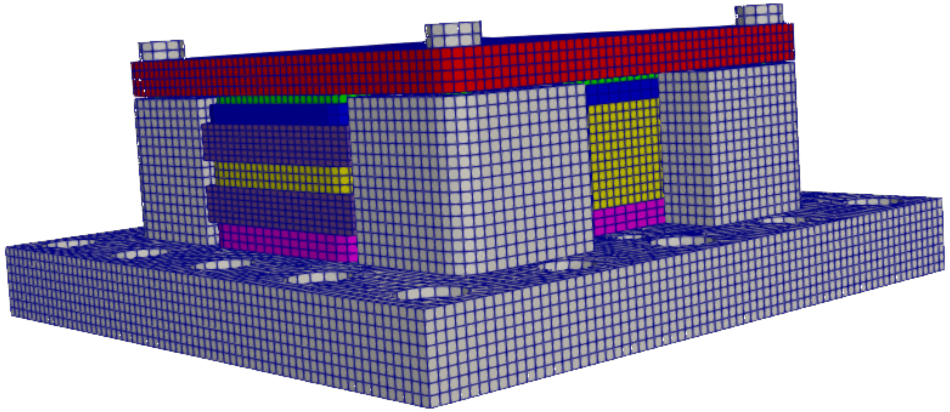
$$W(\lambda_1, \lambda_2, \lambda_3) = \Sigma_{i=1}^{N} \frac{2\mu_i}{\alpha_i^2}\left[\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3 + \frac{1}{\beta_i}\left(J^{-\alpha_i\beta_i} - 1\right)\right]$$

- Strain energy density dependent on principal stretch ratios (λ_k)
- Compressibility of each order: $\beta_i = \nu_i/(1 - 2\nu_i)$
- The order, N, determines how many parameters are needed
  - For each order, α_i, μ_i, and ν_i need to be estimated
  - If $N = 3$, a total of 9 parameters need to be estimated
  - If N =1, $\alpha_1 = -2$, $\mu_1 = \mu$, and $\nu_1 = 0.25$, the Blatz-Ko model is recovered



Methods – (mesh, elements, BC, Loadings)

- Quasistatic preload in Sierra/SM
- Handoff to Sierra/SD for dynamic analyses
- Mesh includes approx. 73,000 8-node Hexahedral elements (selective deviatoric)



SM Solution

- Fixed base in direction of loading
- Cosine ramp to prescribe lid displacement and compress assembly
- Artificial strain on bolts to close gap
- Temperature was fixed at 300 K

SD Solution

- Linearize preloaded state, material tangent update
- Free and fixed base for modal analysis
- Applied base acceleration for random vibration analysis

Finite Element Model Considerations

Solid Mechanics Simulations

- Computational Cost
  - Explicit time integration
  - Full model with no modifications, 12 hour sim
  - Addition of mass scaling of non critical components (base, lid)
  - After verification, sim time of 105 minutes
- Contact, Contact, Contact
  - A contact paradigm of general contact in the normal direction and friction model tangentially
  - Constraints had to be modified in order to fix contact issues
- The Handoff to SD
  - Concentrated mass at the end of rigid bar
  - Material model inconsistencies
  - Ensuring the proper state in the simulation is handed off

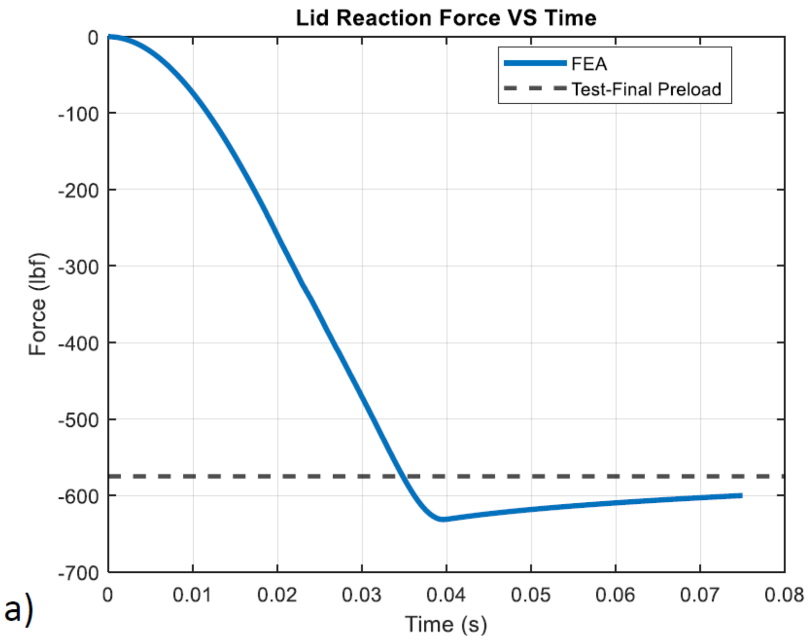
Structural Dynamics Simulations

- Cases and Parameters
  - Handoff
  - Eigenfrequencies and mode shapes computed up to 3000 Hz
  - Applied acceleration amplitude of 0.01 g^2/Hz modulated from 0 to 2000 Hz
  - Post processing
- Application of acceleration input
  - Concentrated mass at the end of rigid bar
  - Force applied to concentrated mass
  - Desired acceleration is applied to base
- Tuning
  - Global damping at 2%
  - First dominant mode damping at 5%
  - Second dominant mode damping at 3.25%

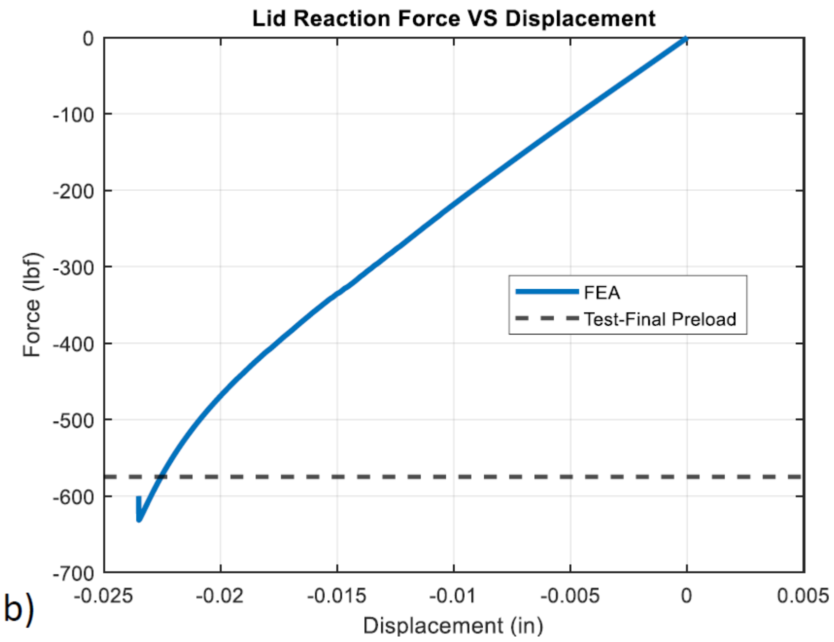
Results – Load-Displacement

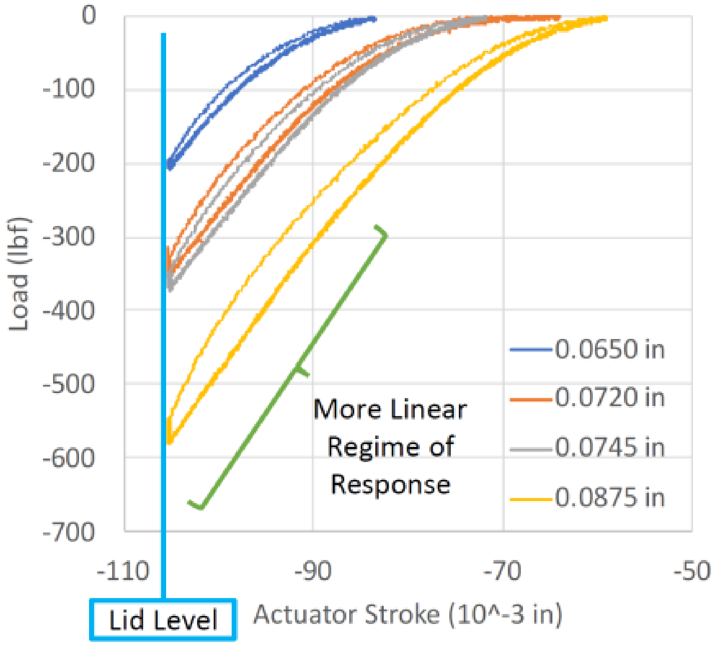
- **Results for 0.0875 in Lattice Structure:**
  - FEA result slightly over predicts the maximum load
  - FEA does not consider long-time relaxation
  - Results are filtered with a Butterworth filter

a)



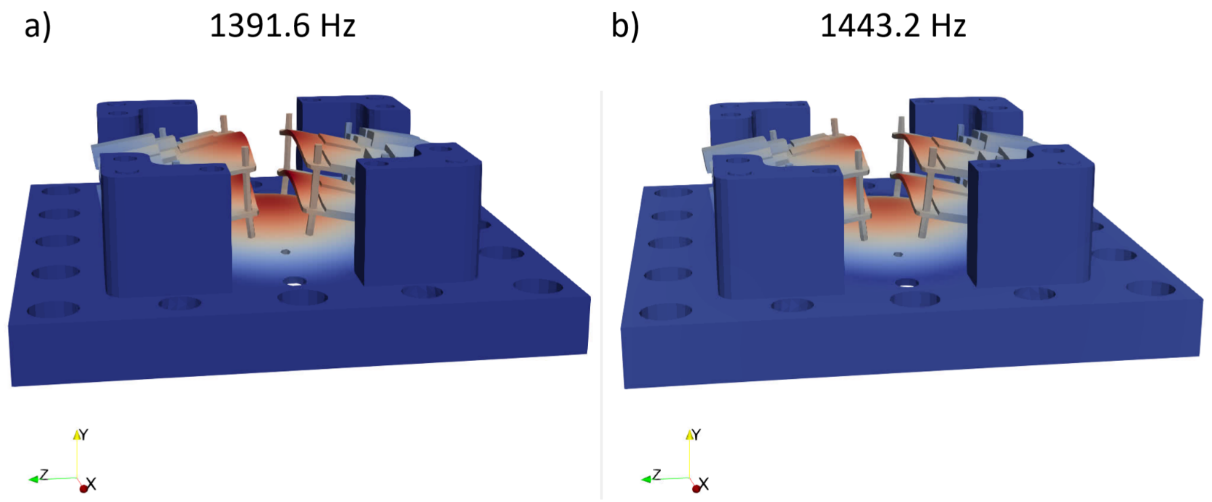
b)

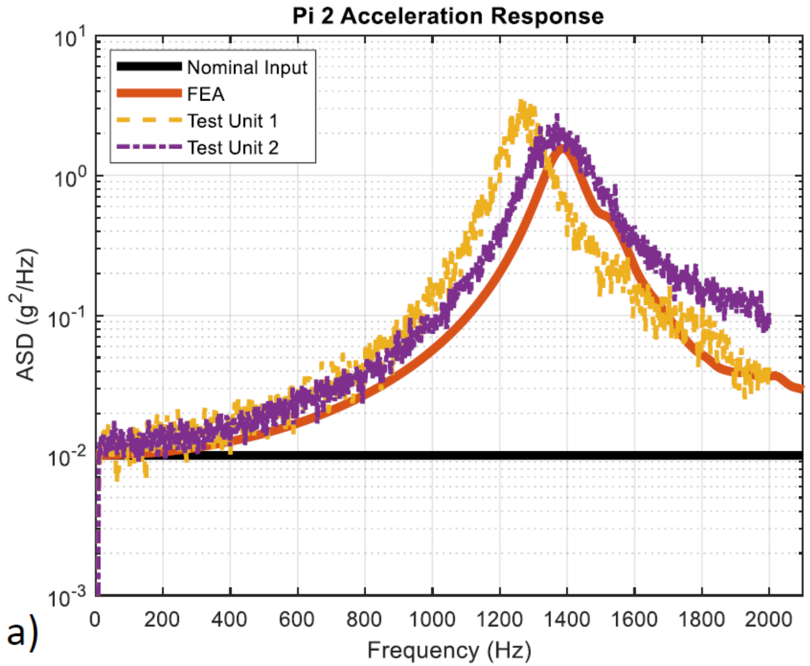


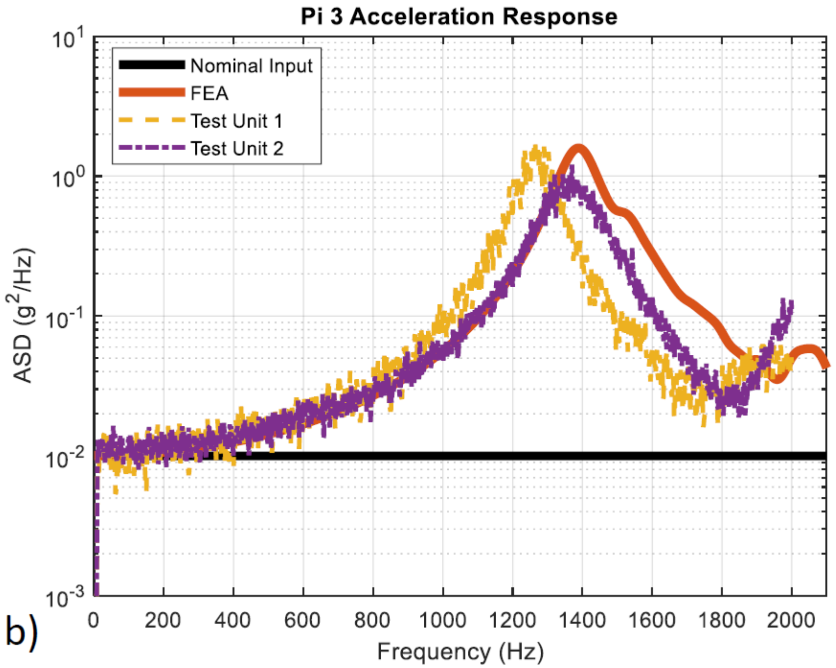


Results – Frequencies and Modes

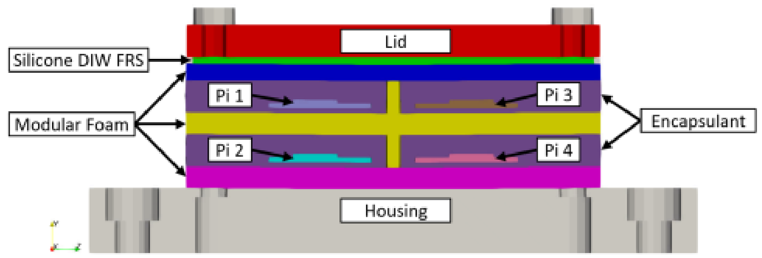
- **Results for 0.0875 in Lattice Structure:**
  - Free-Free and Fixed-Based simulations
  - Hyperelastic materials are linearized for the SD simulations
  - Acceleration Response at Raspberry Pi #2 and #3 are compared to experiments
  - Frequency range of interest: 0 Hz to 2,000 Hz





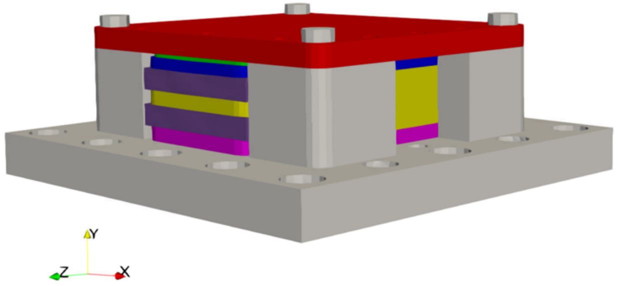


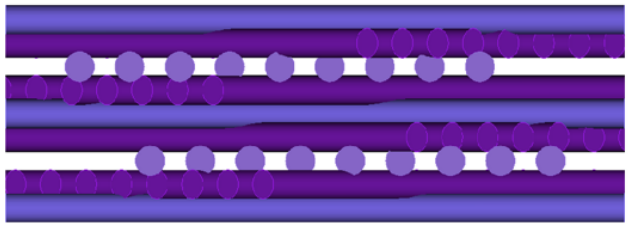
Unit	Free-Free Frequency (Hz)	Fixed-Base Frequency (Hz)
FE Model	1443	1392
Test Unit 1	1390	~1265
Test Unit 2	1526	~1370

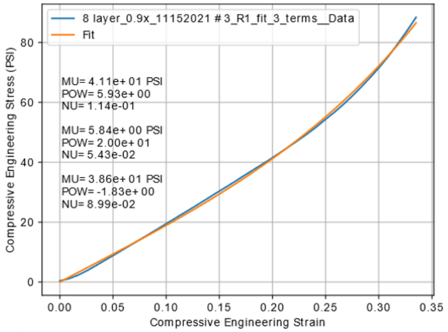


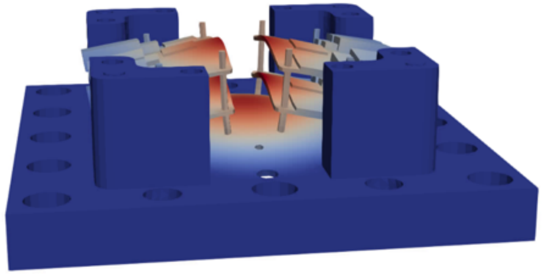
Conclusion

- Successful validation for an analysis involving an electronics assembly consisting of modular encapsulation and AM silicone foam lattice
  - Nonlinear Sierra/SM model showed comparable load-displacement behavior to testing
  - Successful handoff to a linearized Sierra/SD model
  - SD model shows modal and vibrations results that match well with experimental data
- Future work will explore various thicknesses and designs of the lattice structure
  - Investigate the effect of varying levels of preload on the static and dynamic responses of the assembly









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Acknowledgements

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Thanks! Questions?