SAND2016-4789C

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Characterization, verification, and validation process for the implementation of viscoelastic material models for structural dynamics random vibration analysis.

ASME V&V Symposium May 18-20, 2016

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Problem Description and Motivation

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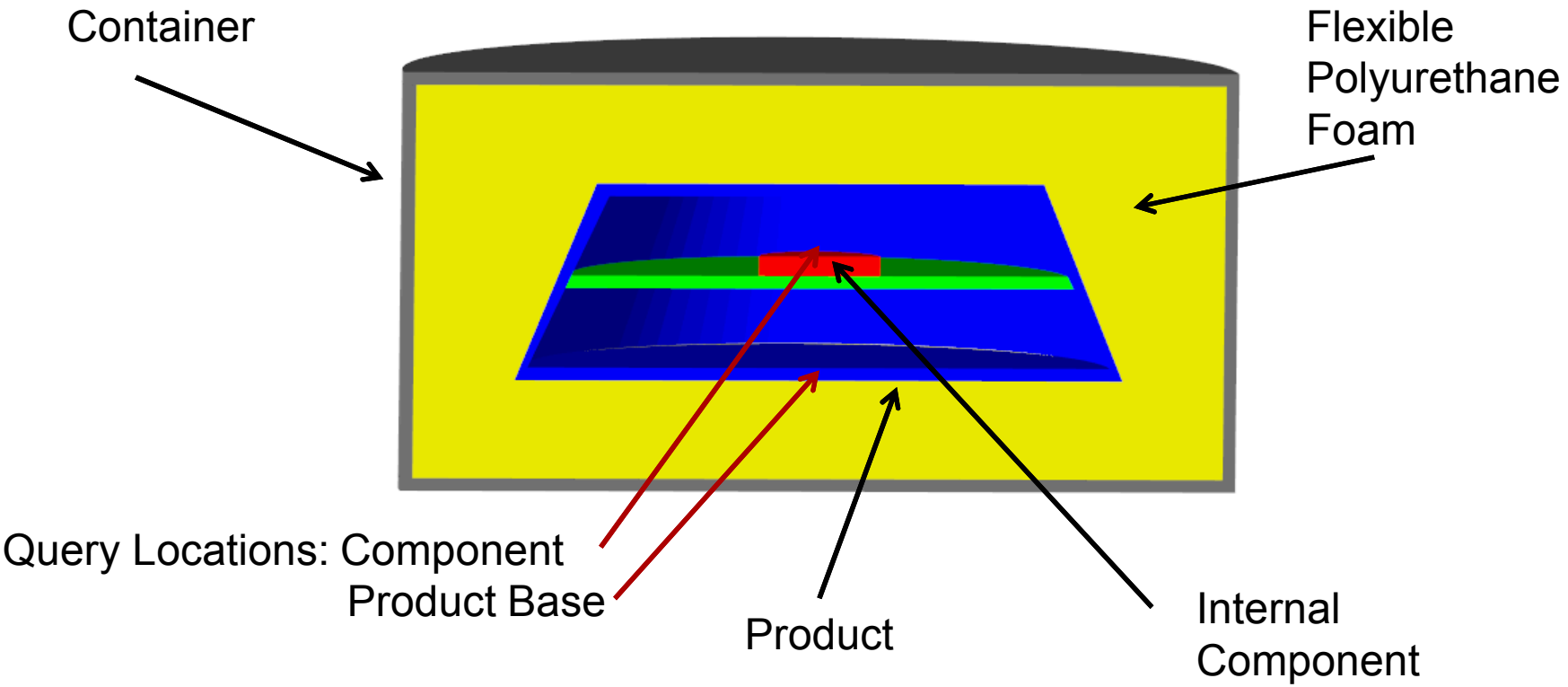
- A shipping container with polyurethane foam packaging material surrounding the product is subjected to random vibration loading.
  - Finite element modeling and physical testing may be used to asses excitation levels of the product.
- Efficient simulations of random vibrations typically consist of a modal analysis followed by random vibration loading via an Acceleration Spectral Density (ASD).
  - During the modal analysis, stiffness of the material is linearized and held constant. However:
    - **Physical testing indicates that the foam stiffness is frequency dependent.**
    - **Temperature changes may result in an order of magnitude difference in stiffness due to passing through a glass transition temperature**

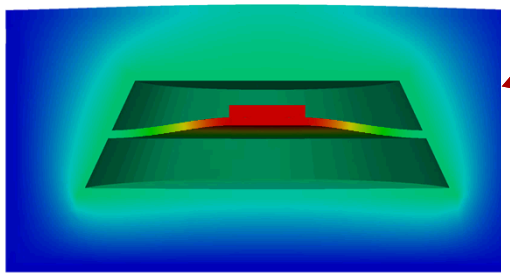
Example Random Vibration Simulation

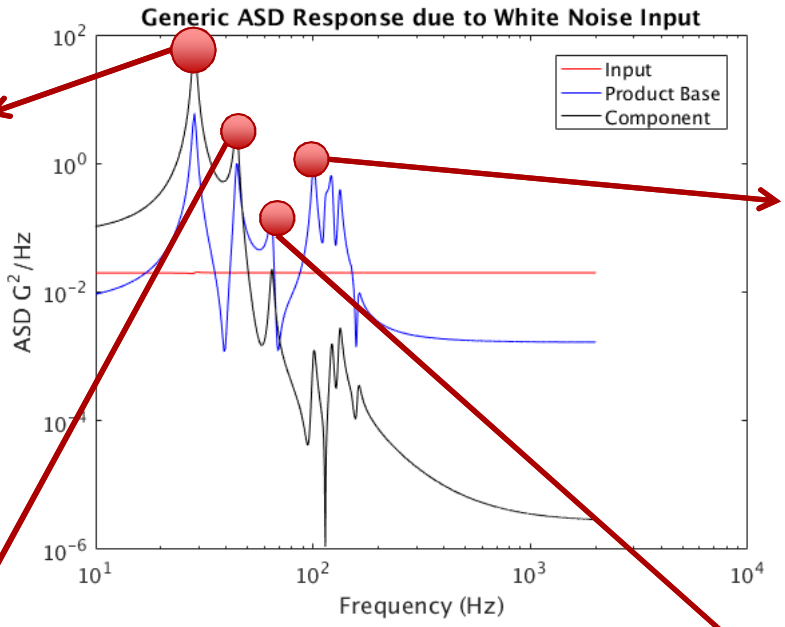
Simplified, Generic Container with Product



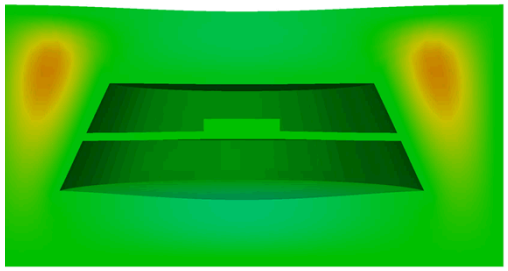
Resulting Acceleration Spectral Density

29 Hz

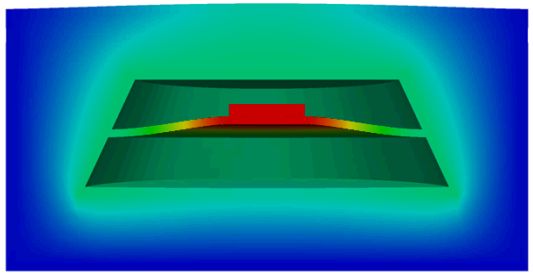




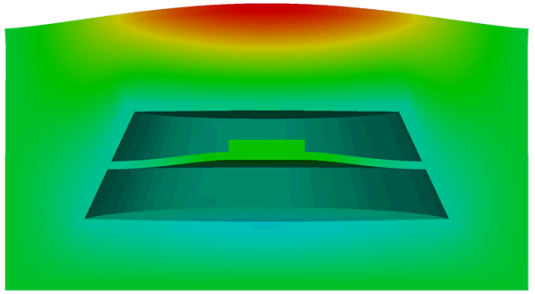
101 Hz



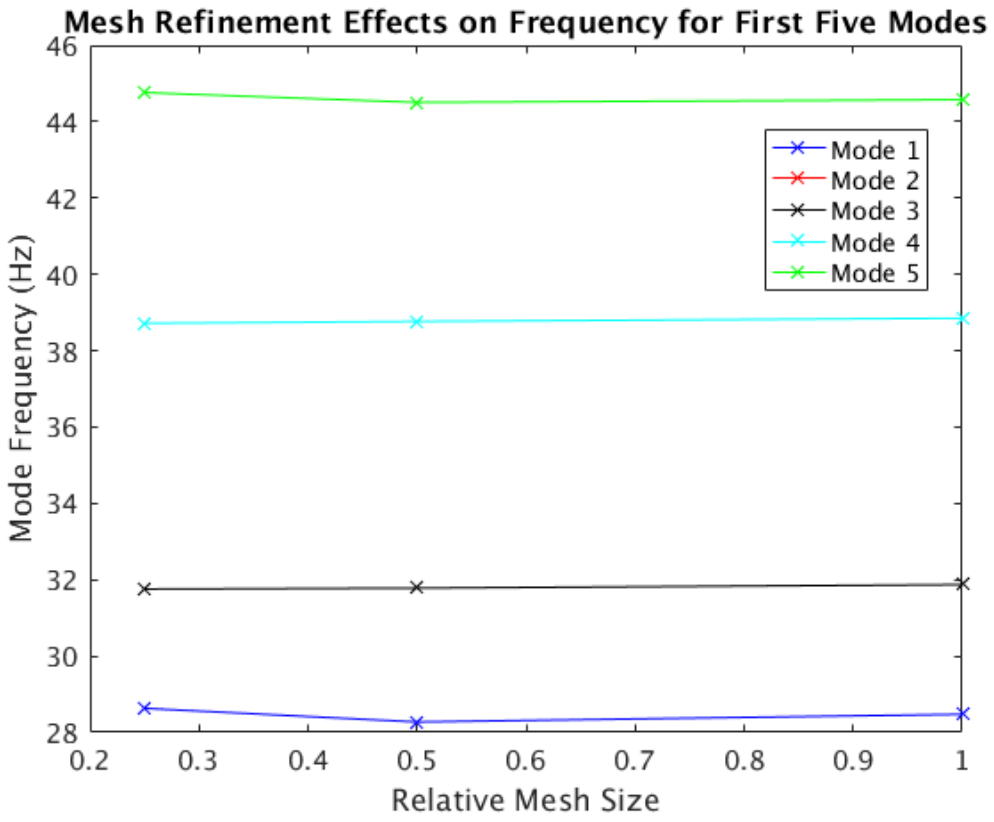
45 Hz

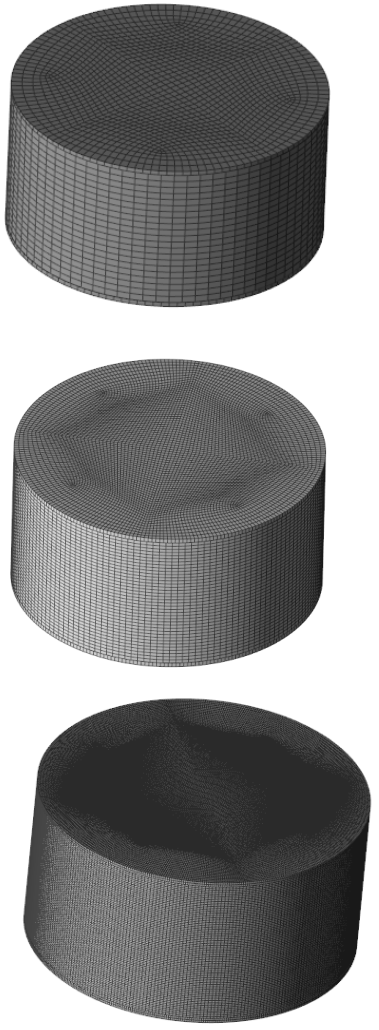


65 Hz



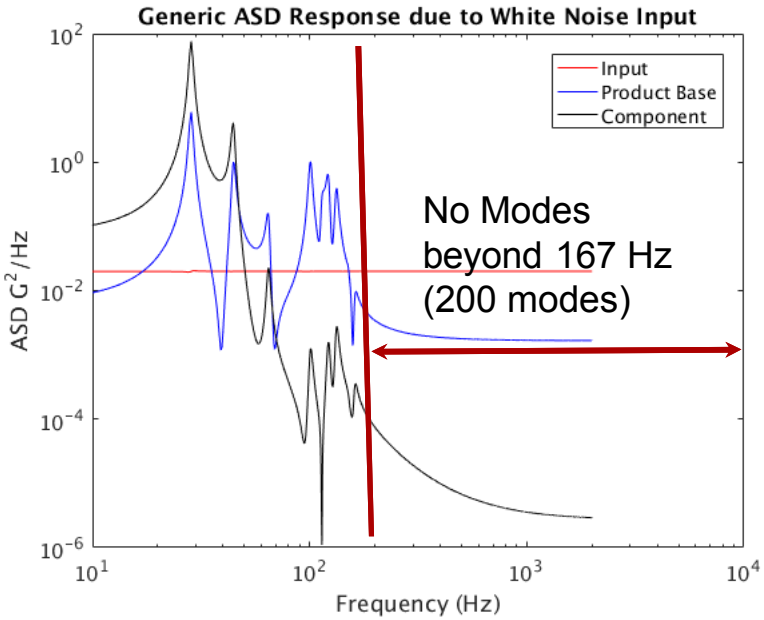
Spatial Mesh Refinement

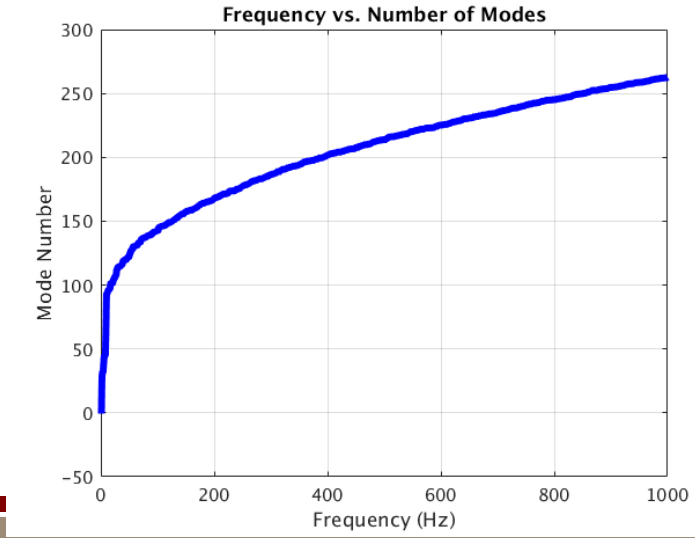




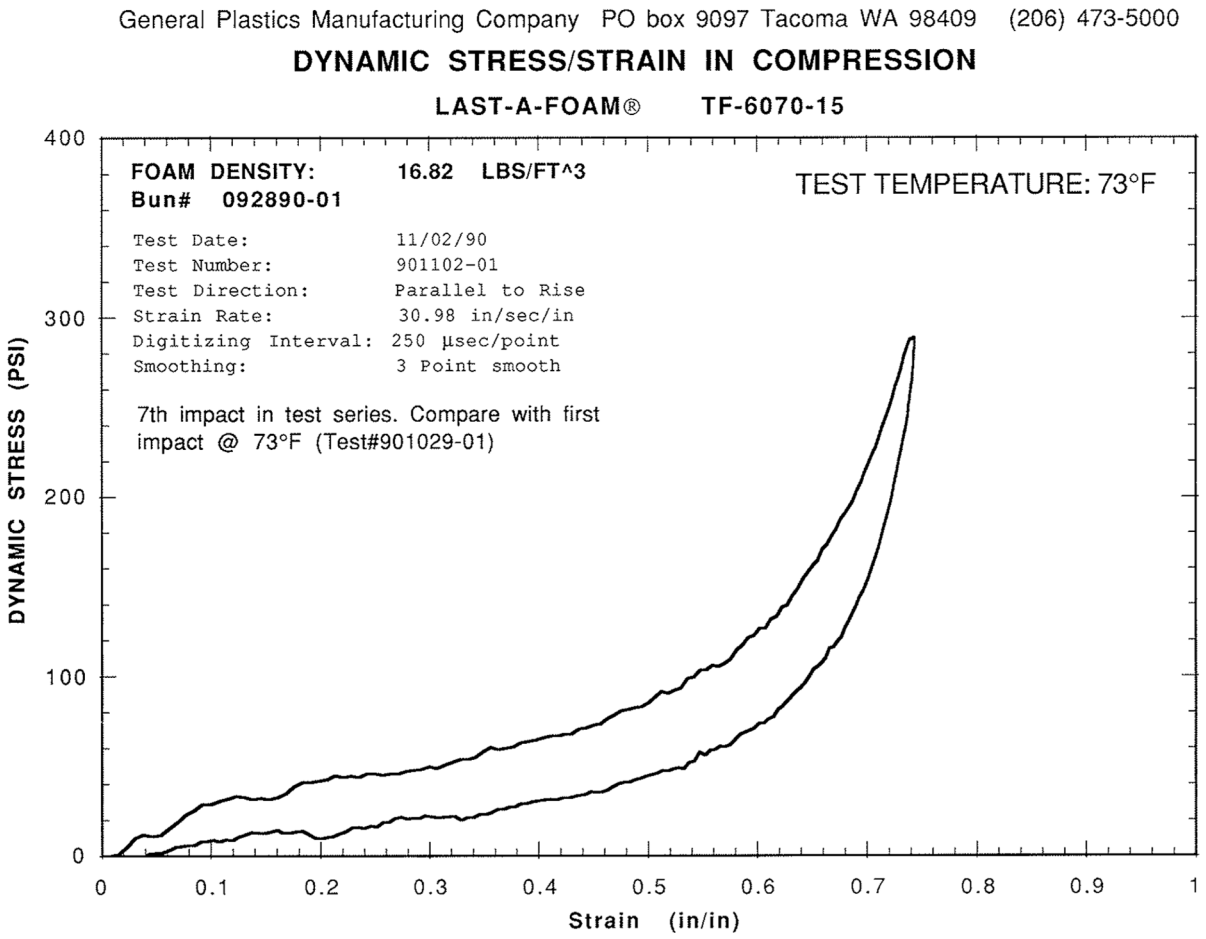
A few points …

- Achieving higher frequencies in a modal random vibration analysis becomes more computationally expensive and may reach a regime where progress is not made.
- Some of the simplifying assumptions are linear material properties and interfaces (e.g. tied/constrained)

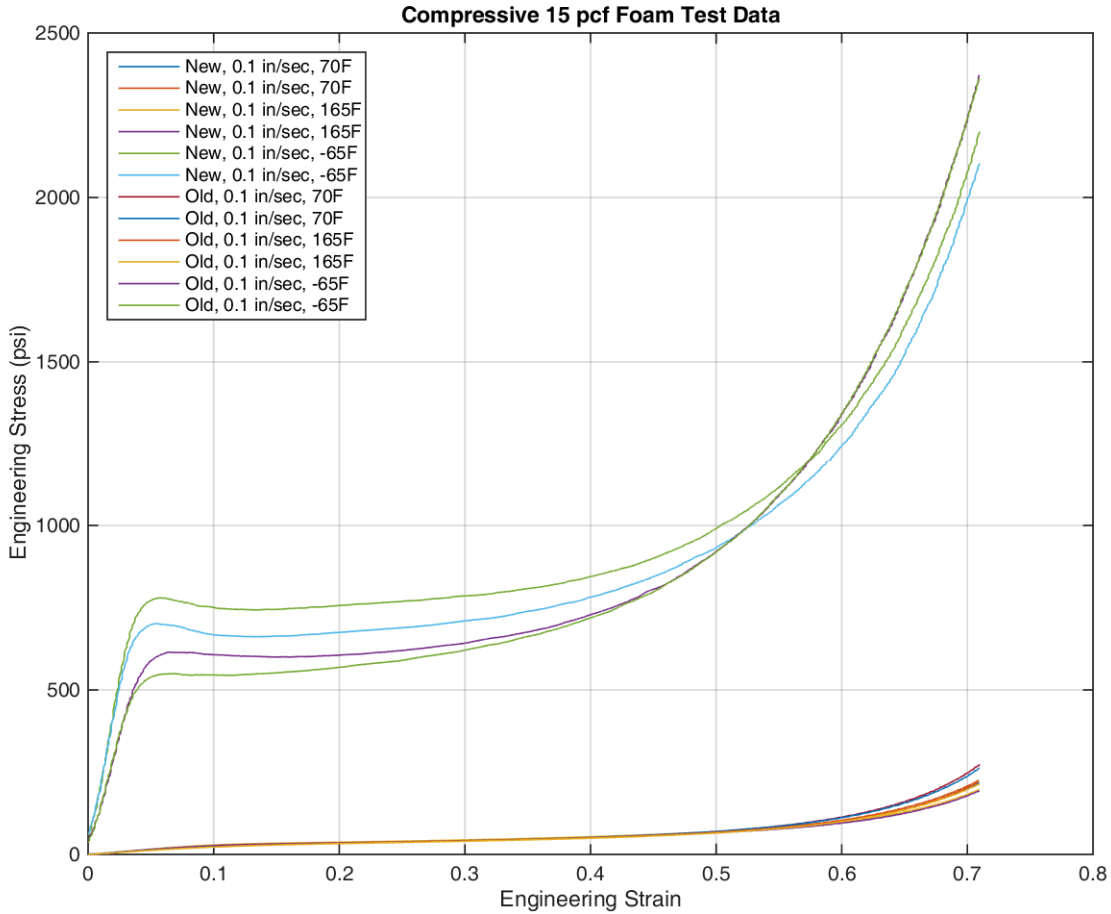




Flexible Polyurethane Foam Behavior

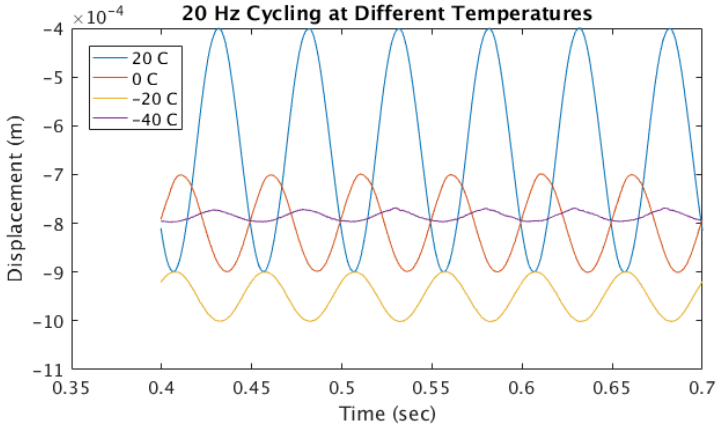


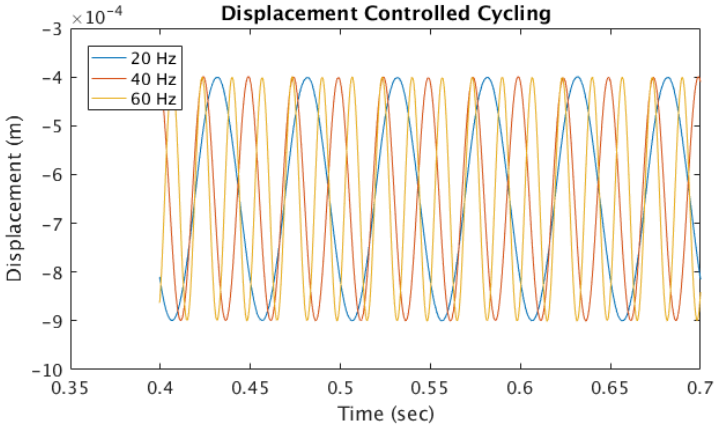
Flexible Polyurethane Foam Behavior

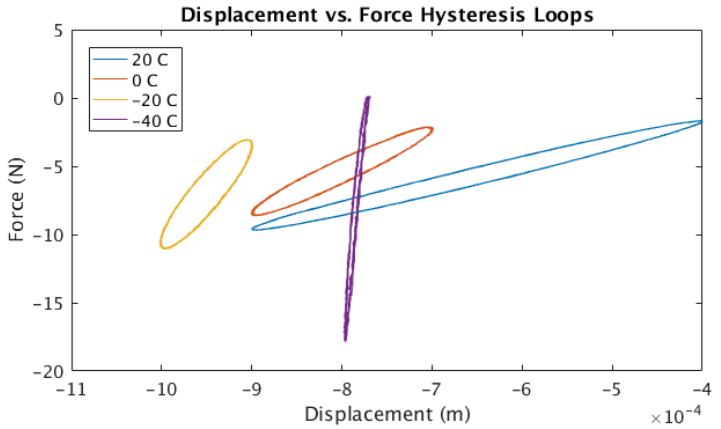


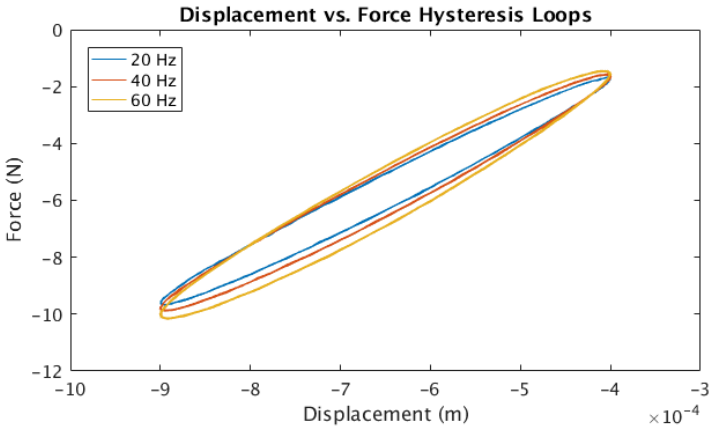
Test data provided by Brian Werner, Dept. 8343, Mechanic of Materials, Sandia National Laboratories

Flexible Polyurethane Foam Behavior









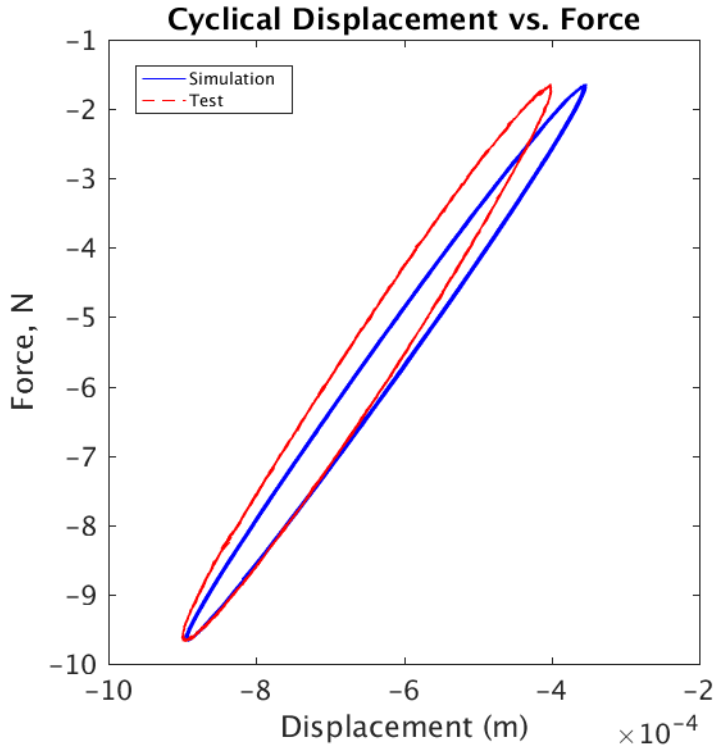
Test data provided by Wei-Yang Lu, Dept. 8343, Mechanic of Materials, Sandia National Laboratories

Material Modeling

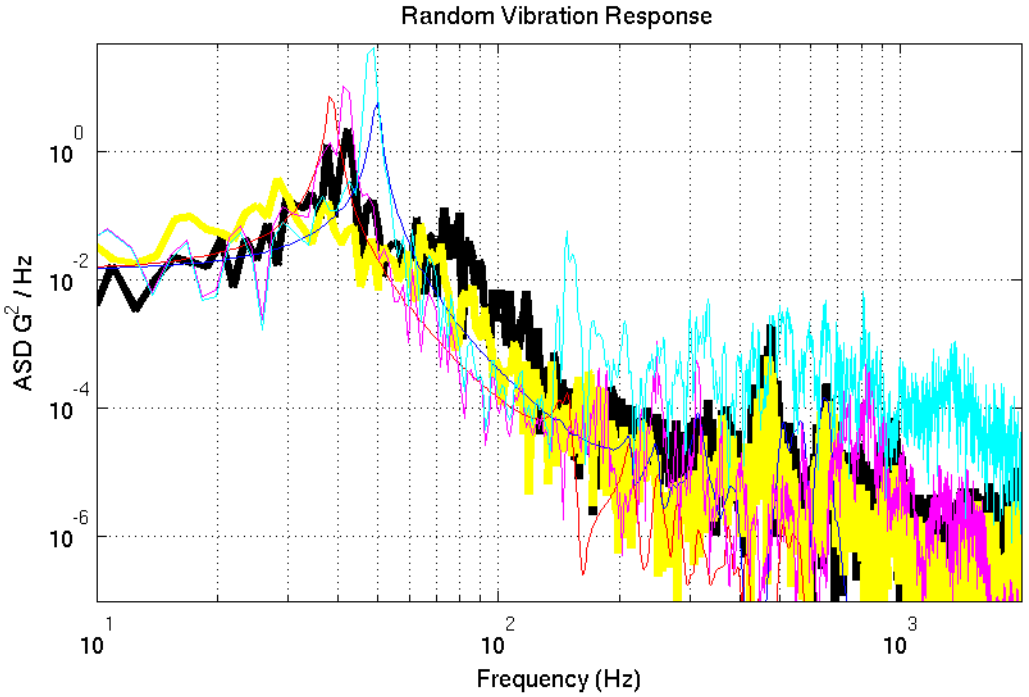
- Different approaches to capturing the age, temperature, and frequency dependency of the stiffness and damping of the foam.
  - Age: Use corresponding modulus and damping values.
  - Temperature: Assume steady state at selected temperature and use corresponding modulus and damping values.
  - Frequency dependency: More difficult, one approach is to run in a direct transient mode with a viscoelastic model.
    - Higher frequencies more practically obtainable in some cases, such as with the foam.
    - Incorporation of other nonlinear effects, such as contact at interfaces may be important depending on the application.
    - A main draw back is the computational cost involved with the direct transient simulations.

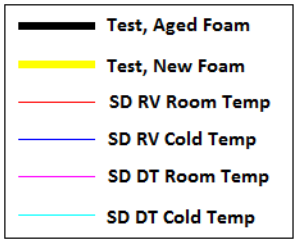
Viscoelastic Example Responses

- Material models characterized on one data set and then applied to another for validation.
- Overlaying the results show a wide range of variance, more work in process.
- One important note is the spread in test data and the possible difference in foam compositions.
  - Validation often reveals discrepancies not anticipated which can extend project/study time.

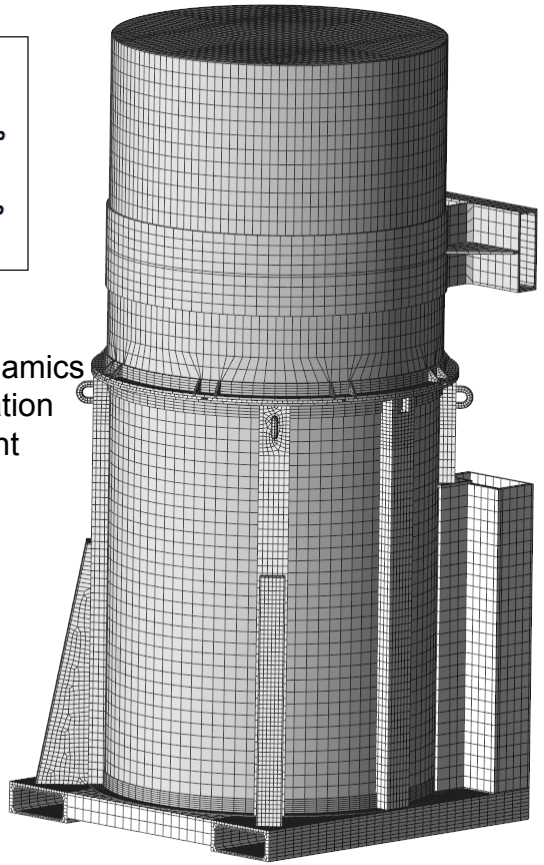


Test Data with Simulation Results





Note:
SD: Structural Dynamics
RV: Random Vibration
DT: Direct Transient



Summary

- The mechanical properties of flexible polyurethane foam vary with temperature, age, and frequency. These changes in stiffness and damping may effect the Acceleration Spectral Density (ASD) levels experienced by products within a shipping container.
- Incorporation of viscoelastic material models may provide improved simulation capability for random vibration environments.