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Title:	LANL Test Engineering's Structural Dynamics Research and Development Efforts
Author(s):	Cramer, Ethan Savoy; Colford, Greta Pryor; Fickenwirth, Peter Hans; Flynn, Garrison Stevens; Harvey, Dustin Yewell; Haynes, Colin Michael; Morello, Andrew J.; Schultze, John Francis; Taylor, Stuart Glynn; Watts, Adam Christopher; Zimmerman, Sandra Jo
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Los Alamos NATIONAL LABORATORY

LANL Test Engineering's Structural Dynamics Research and Development Efforts

Ethan Cramer
Greta Colford
Peter Fickenwirth
Garrison Flynn
Dustin Harvey
Colin Haynes
Andy Morello
John Schultze
Stuart Taylor
Adam Watts
Sandra Zimmerman

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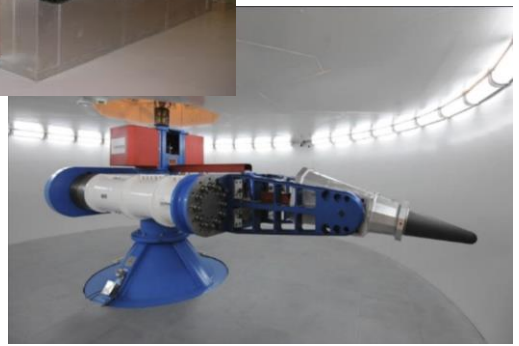
Test Engineering at Los Alamos National Laboratory (LANL)

- **LANL's priority roles are serving as a nuclear weapons design agency and a nuclear weapons production agency; addressing nuclear threats; and performing national security science, technology, and engineering**

- **LANL’s Test Engineering organization serves the national mission of maintaining a strategic nuclear deterrent by providing high-quality, empirical evidence through the execution and assessment of weapons system and component testing.**

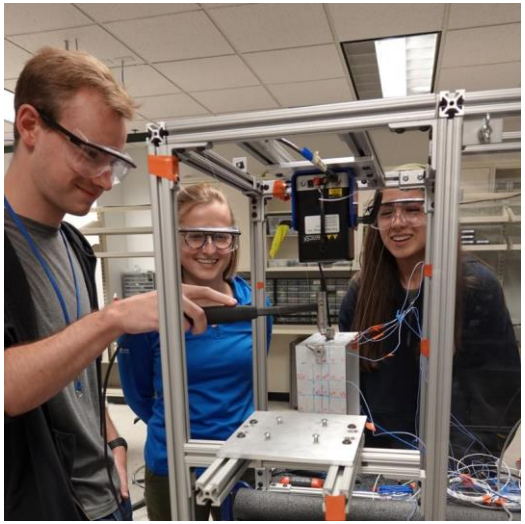
- **Shock and vibration environmental testing provides one key piece of evidence for evaluation and qualification of these systems and components in the service environments incurred during a lifetime in the stockpile.**



Test Engineering at Los Alamos National Laboratory (LANL)

- **LANL's Test Engineering group continuously pursues research and development in structural dynamics to improve shock and vibration testing capabilities, processes, and analysis techniques to increase the fidelity of service environment recreations in laboratory testing settings.**

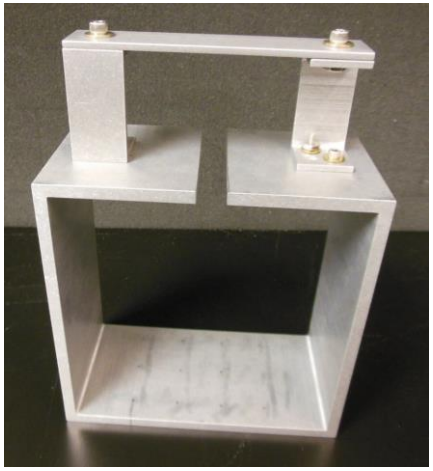
- **This talk will introduce traditional testing approaches and highlight recent R&D advancements in areas such as…**
  - Test planning methodologies
  - Environmental specification development
  - Multi-axis testing strategies
  - Data analysis tools
  - Test assessment methods



Traditional Shock and Vibration Testing

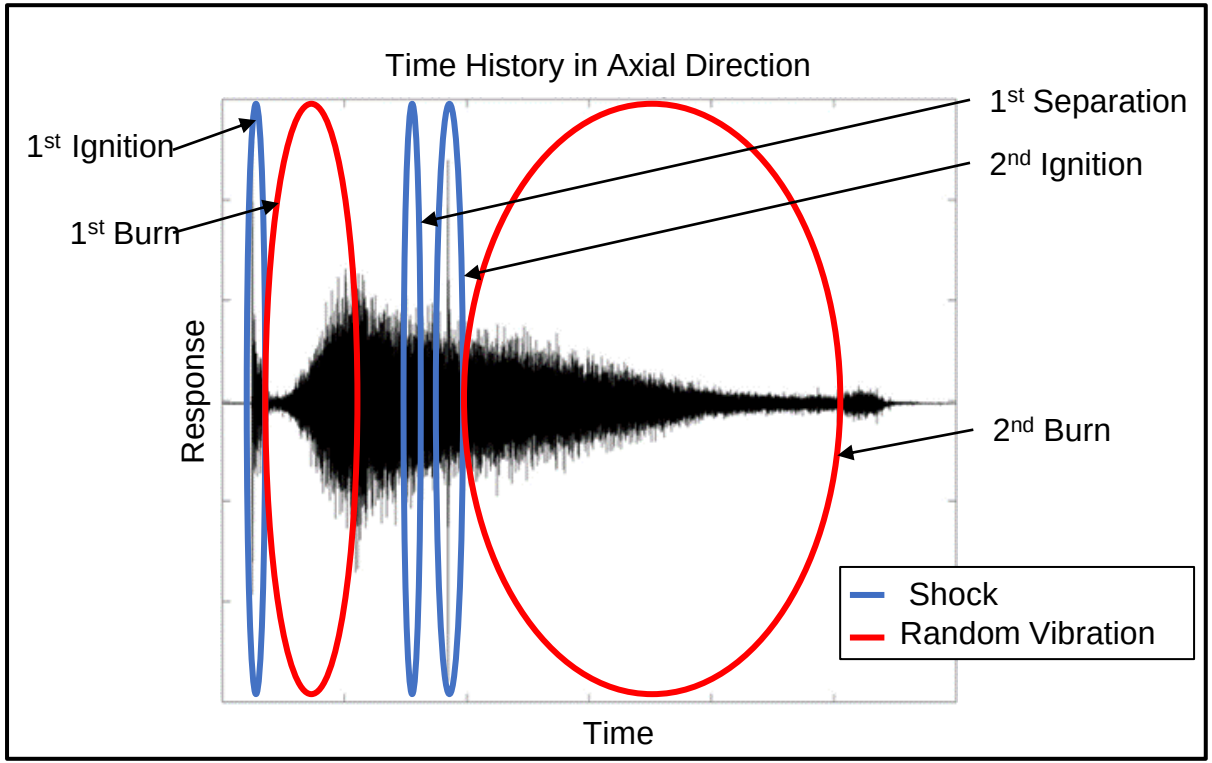
Field testing is performed to gather response data in service environments.

- **A research test article was flown in the HOTSHOT test series on a two-stage rocket to gather representative environmental data for R&D efforts.**



Field testing is performed to gather response data in service environments.

- **Decisions must be made regarding how to represent each segment of response and what conservative statistical treatments are appropriate to define a qualification level environmental specification.**

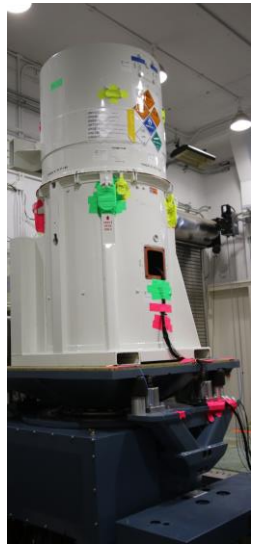


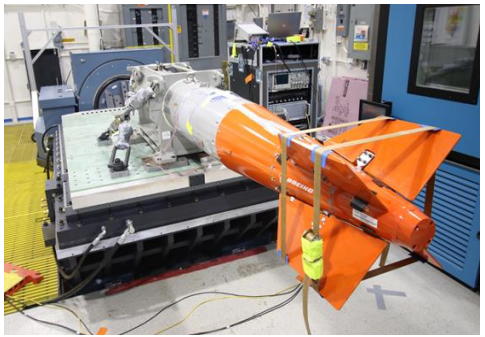
Electrodynamic shakers recreate shock and vibration service environments in a laboratory setting.

- **Derived environments are implemented using a shaker system with sufficient force, velocity, and stroke capabilities for the test article size and mass.**

- **Some shaker tests are performed with in-situ thermal conditioning to cold or hot environment extremes.**

- **Example Unholtz-Dickie Shakers**
  - S452 (6,000 lbf-g rating, 28”x28”)
  - T-2000 (16,000 lbf-g rating, 48”x48”)
  - T-4000 (44,000 lbf-g rating, 90”x60”)

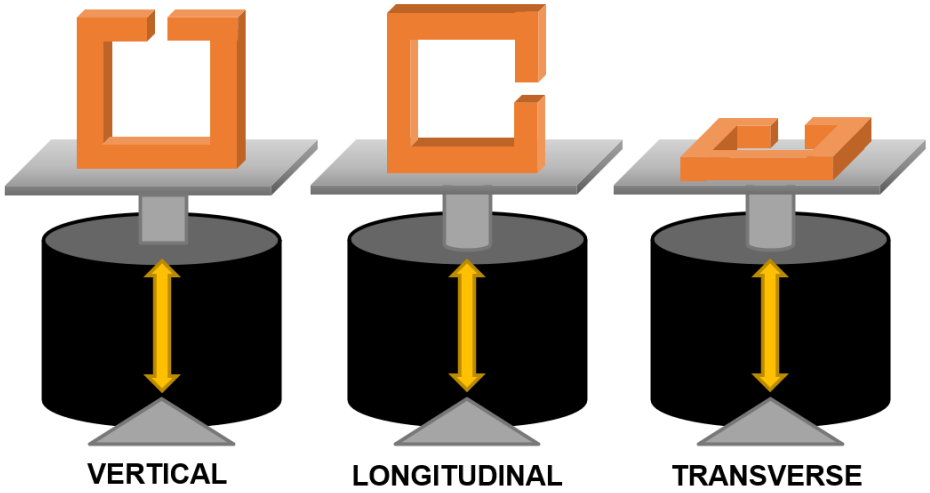




Random vibration and shaker shock tests are traditionally implemented as a series of three sequential, single-axis tests.

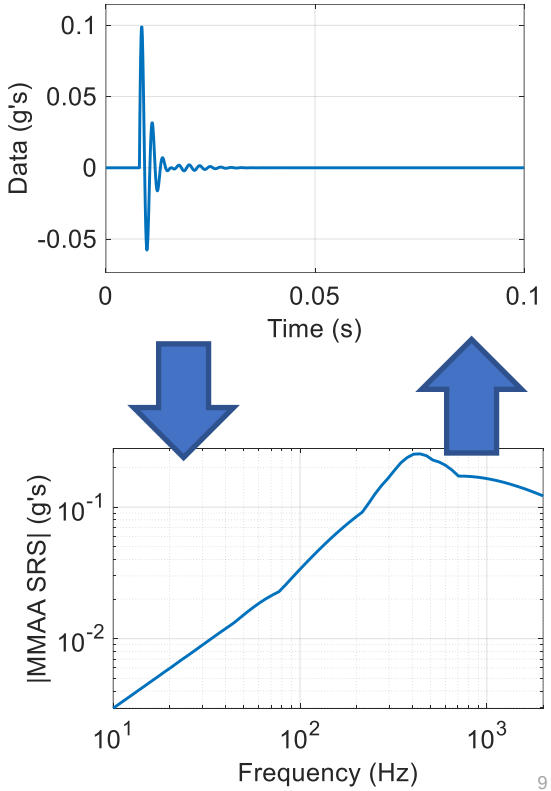
- For a 1-hour service lifetime in a given environment, the test article is excited for 1-hour in each of three axes for a cumulative test duration of 3 hours (plus three test setups).

- The sequential testing strategy assumes cross-axis responses orthogonal to the excitation direction are zero or negligible which is often not the case.



Shaker shock testing imposes a high amplitude transient pulse to reproduce a target Shock Response Spectrum (SRS).

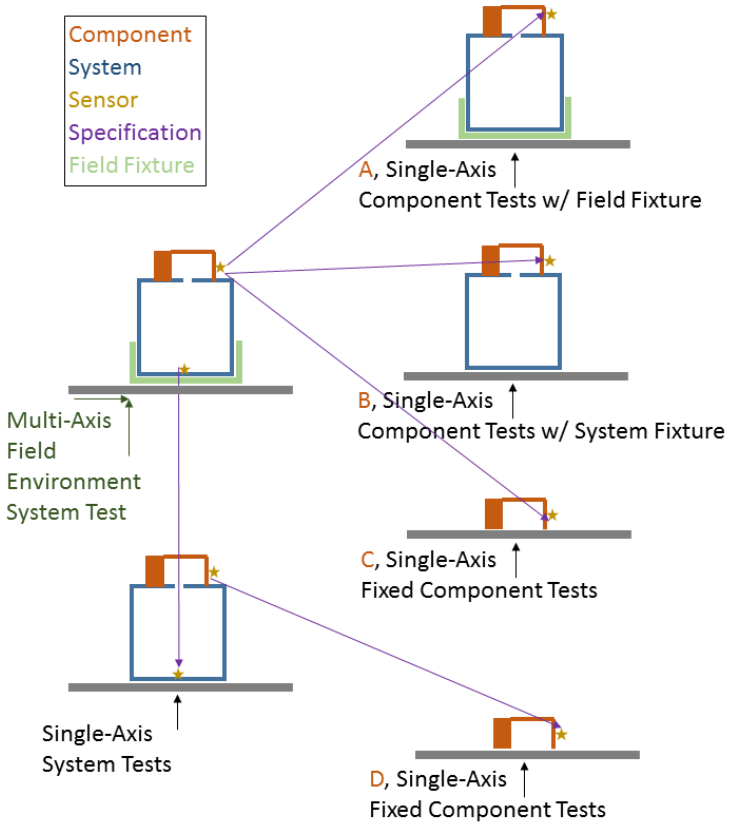
- **Shock test severity is specified and assessed in SRS space, but shakers and controllers implement a transient, time waveform excitation.**
- **The transform from SRS to time domain is non-unique, so a representative shock waveform must be synthesized to match target SRS.**
- **Decisions must be made by test designers and test engineers in how best to accurately recreate the service environment within a shaker's capabilities.**



Field test data is used to generate specifications for system-level and component-level tests which then feed further component-level tests.

- **Practical limitations restrict the amount of instrumentation deployed in any particular test. This means key components may or may not be instrumented in field tests.**

- **Decisions are made and tracked throughout a sequence of tests at various assembly levels to connect evidence required from component-level qualification tests back to measured service environments.**

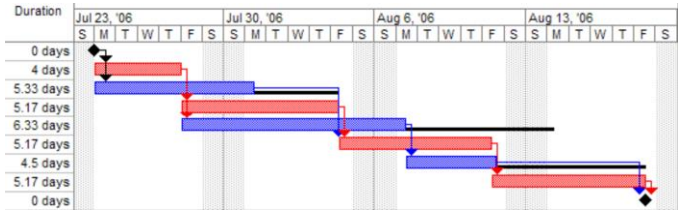


LANL Test Engineering's Structural Dynamics Research and Development Efforts

Test Planning Methodologies

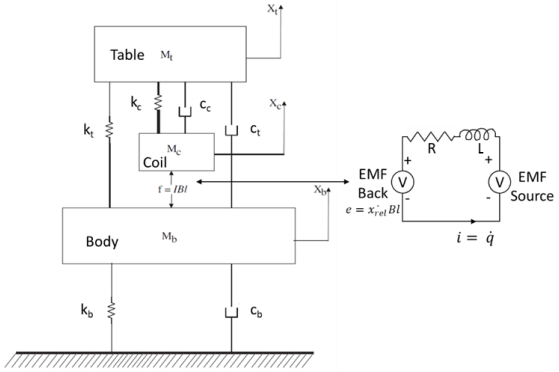
- **Shaker systems have limitations regarding force, velocity, and displacements that can be achieved for a given test article depending on its mass and the coupled dynamics of the shaker and test article.**
- **Many of our tests push these systems to their limits involving high severity environments and large, complex test articles.**
- **Shaker capability estimates for dynamic testing are challenging and necessary to optimize schedules of critical testing equipment and facilities.**

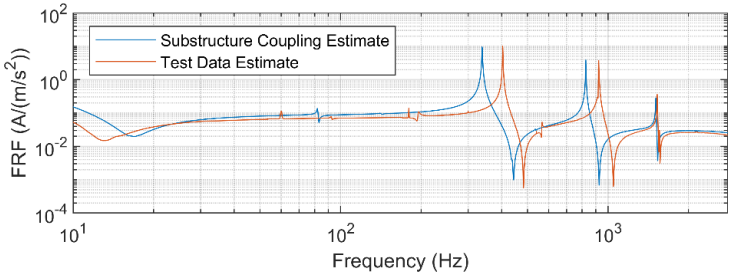
Problem: Assess the capability of each shaker system to implement specified target environments for a given test article design as early as possible in the test planning process.



Test Planning Methodologies

- **Developed electromechanical models of shaker and amplifier systems.**
- **Used dynamic substructuring to couple each shaker system model in turn to an experimental modal model of test article.**
- **Determined high-fidelity coupled shaker + test article dynamic model is necessary for effective test capability assessments.**



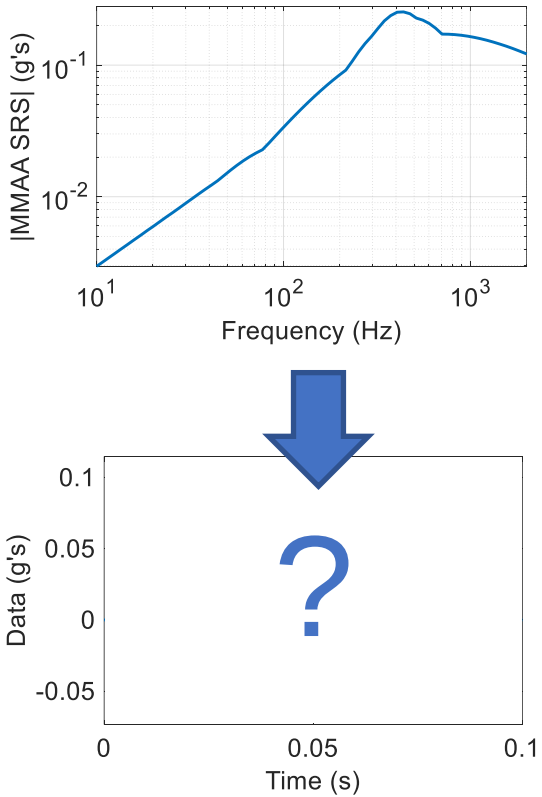


Publications:

Electrodynamic Shaker Capability Estimation through Experimental Dynamic Substructuring
Increasing Confidence in Vibration Testing Capabilities
Shaker Capability Estimation Through Experimental Dynamic Substructuring
Shaker-Amplifier System Characterization

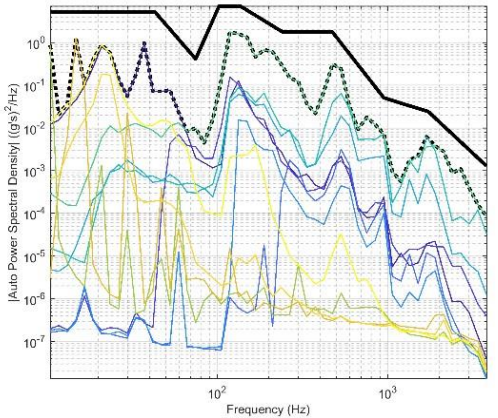
Test Planning Methodologies

- **For shaker shock tests, a time waveform must be synthesized to achieve the target Shock Response Spectrum (SRS).**
- **Traditional synthesis methods build waveforms from a constrained set of basis functions through a series of heuristics.**
- **Investigated global optimization based approaches with reduced basis function constraints to better match target SRS plus other time-domain characteristics of service shocks while respecting shaker system capability limits.**



Environmental Specification Development

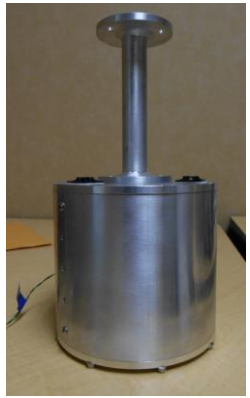
- **Environmental specification development efforts seek to conservatively and accurately capture key features of field test response that enable recreation on laboratory equipment.**
- **Field test datasets are rigorously assessed to ensure high data quality and correct metadata prior to use for specification development.**
- **Decisions must be made regarding appropriate signal processing and statistical treatments to distill populations of field test responses down into environmental specifications that represent worst-case environments with quantified levels of conservatism.**

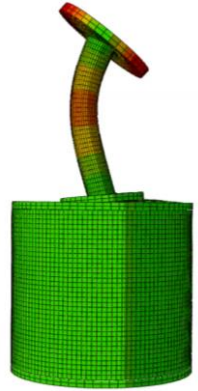


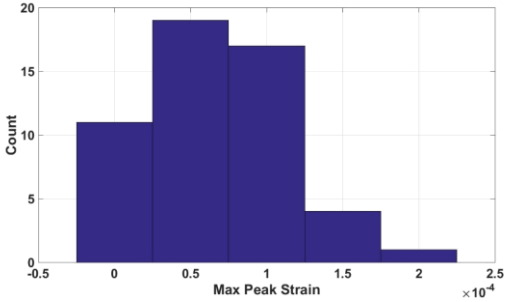
Environmental Specification Development

- **Performed a simulation study to assess potential response metrics of value for augmenting the SRS in shock test specifications to better represent service environment insults to components.**

- **For lightly-damped systems, identified narrow-band response energy and peak values around resonant frequencies as most likely candidates.**





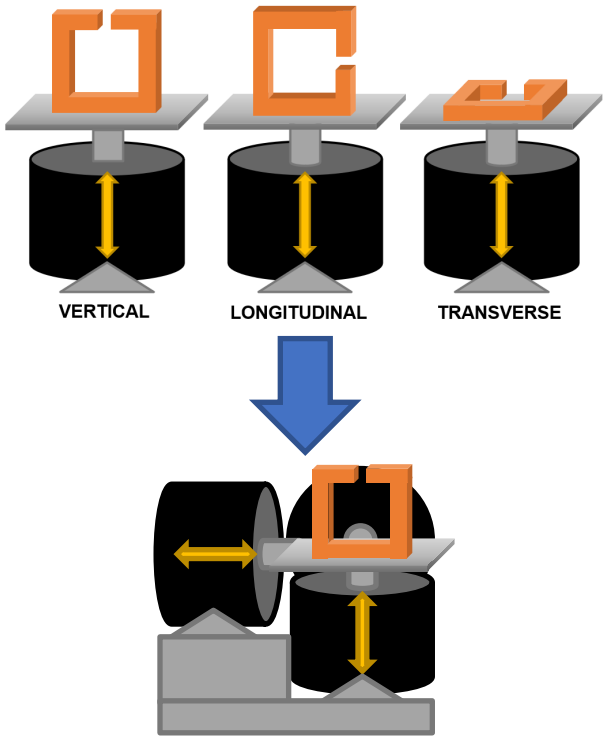


Publications: *Developing Conservative Mechanical Shock Specifications*
(Internal) Deriving and Updating Mechanical Environmental Specifications for System Qualification using the Echo Analysis Management Software
(Internal) Statistically Conservative Component Environmental Specifications from System-Level Test Data

Multi-Axis Testing Strategies

- **To eliminate the effect of cross-axis response and better recreate service environments, many efforts aim to move from 3 sequential tests to a single test where all axes respond as desired simultaneously.**

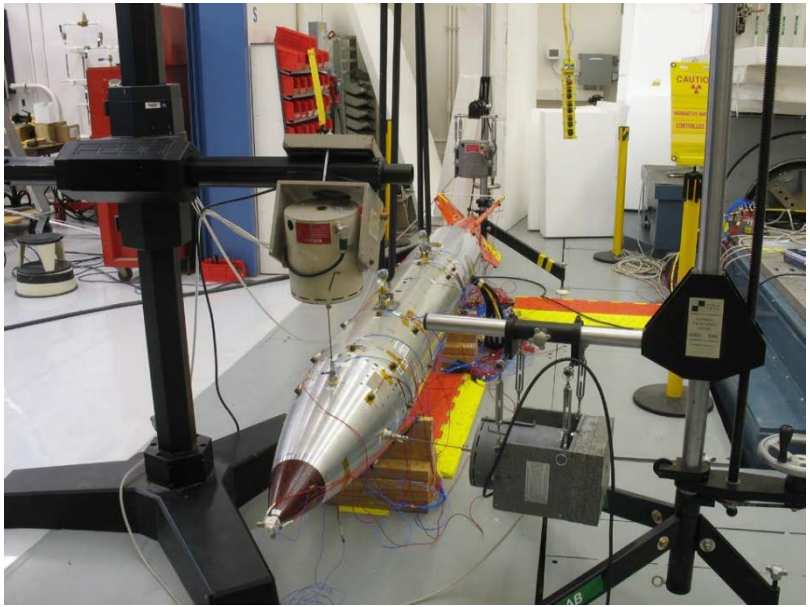
- **However, multi-axis excitation systems are costly and multi-axis control is a challenging problem.**



Multi-Axis Testing Strategies

- **R&D efforts are assessing multi-axis excitation test strategies involving multi-axis shaker system, suspended shakers attached directly to the test article, and combinations of the two.**

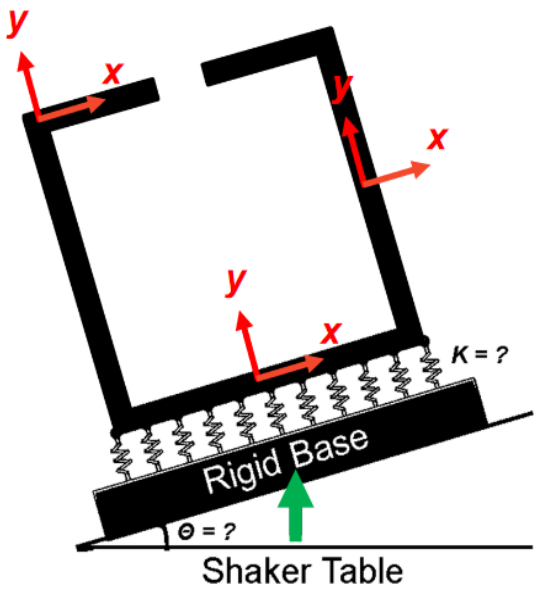
- **Maturation of these test strategies requires development of robust modeling efforts to support test design, design and implementation of effective multi-axis control strategies, and multi-axis environmental specification development which are all being pursued in parallel.**



Multi-Axis Testing Strategies

- **A related study demonstrated approximation of a multi-axis test using a single-axis shaker table and a test fixture structurally optimized to shape responses to match targets.**

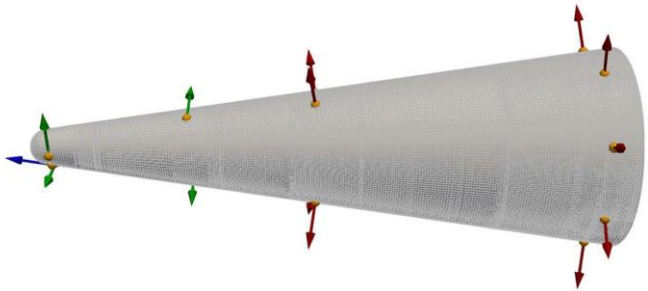
- **Study showed it's possible to incur only a small penalty in matching targets (1 dB average error increase across test article) with a single test avoiding cross-axis responses in sequential testing.**



Publications: *Rapid Approximate Multi-Axis Vibration Testing*

Data Analysis Tools

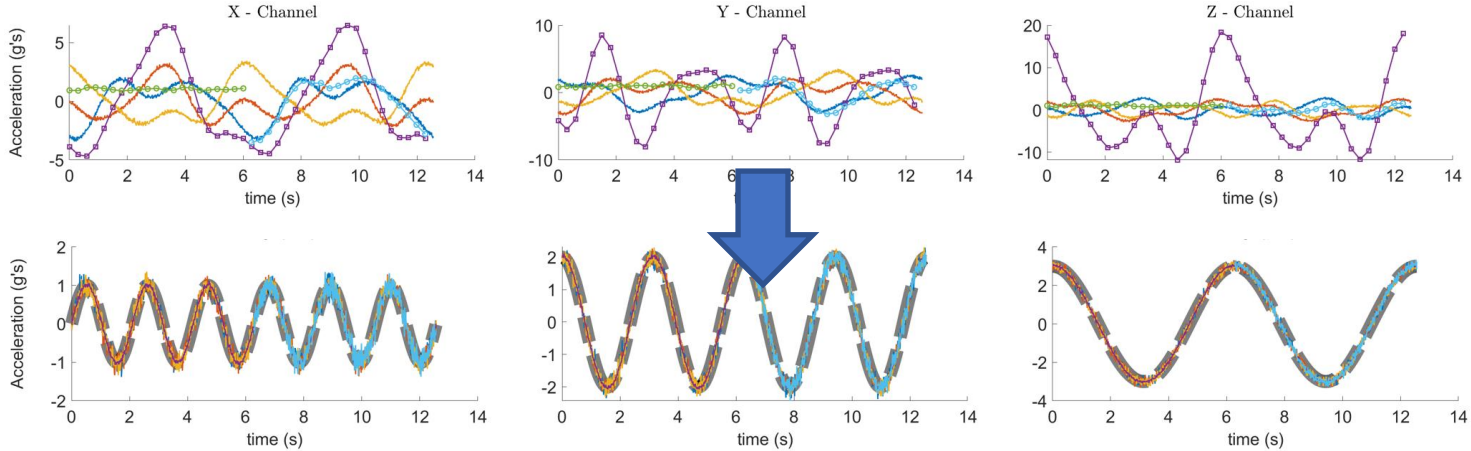
- **Directional sensors, such as triaxial accelerometers, cannot always be aligned with test article coordinate system during installation.**
- **Collected data is rotated in preprocessing to align to desired coordinate system.**
- **Need to detect and correct for errors in diagnostic installation and data acquisition such as swapping cables.**



Problem: Robustly automate the rotation of populations of experimentally collected tri-axial accelerometer data sets to a single global coordinate system.

Data Analysis Tools

- **Developed a Generalized Procrustes Analysis method to optimally orient a group of accelerometers on a body to a common coordinate system within a robust RANSAC optimization framework.**
  - Method is based on matching rigid body response of the test article at identified time points across all sensor locations.



Publications: *Robustly Automating the Accelerometer Rotation Process using Maximum Likelihood Estimation through a Random Sample Consensus Framework*

Data Analysis Tools

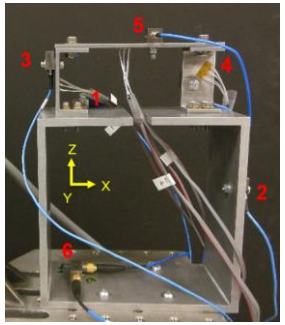
- **Echo provides an alternative to traditional scripted data analysis that helps analysts avoid mistakes, save time, and document results.**
- **Echo provides a comprehensive suite of tools for data wrangling, management, and analysis.**
- **Object-oriented approach to data analysis designed for robust and scalable execution of complex analysis workflows written in MATLAB.**

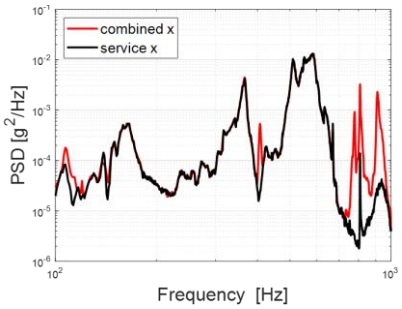
https://github.com/lanl/EchoDemo

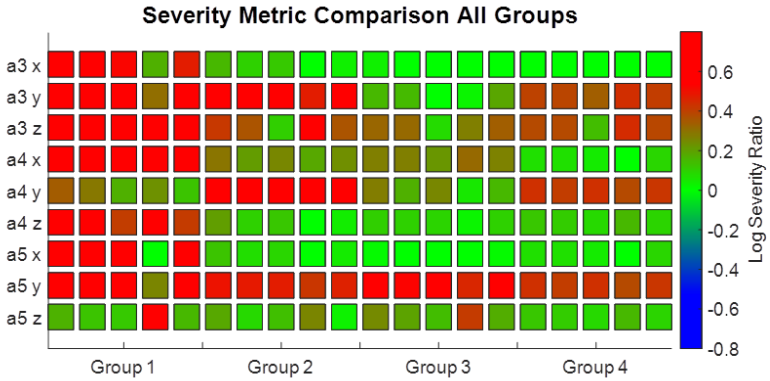
Publications: *Echo: Data and Analysis Management*
(Internal) Accuracy, Efficiency, and Transparency in Environmental Data Analysis

Test Assessment Methods

- **Need quantified test quality metrics with clear ties to failure modes of concern.**
- **Traditional metrics ignore the cross-axis responses incurred during sequential, single-axis testing.**
- **Applied a variety of possible metrics to measure the effect of different single-axis vibration test strategies on the estimated lifetime imposed on a system and its components.**
  - Determined under-testing is effectively non-existent for sequential, single-axis testing.







Test Strategies and Lifetime Metric Selections

Publications: *Accumulated Lifetimes in Single-Axis Vibration Testing*

Questions?