Nonlinearity of Joints in Structural Dynamics of Weapons Systems

Daniel Brown
AWE

Dan Segalman
Sandia National Laboratories†

† Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

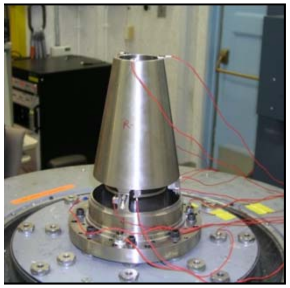
WHY THIS IS IMPORTANT

- Joints are a (the) major source of variability and nonlinearity in our structures.
- Linear models are incorrect. Calibration in one experiment yields predictions that do not match other experiments.
- Propagation of parameter uncertainty with the wrong model form is nonsense.
- Tuning linear models to small-amplitude tests yields over-conservative models. Affordable designs are scrapped.
- Even though linear models are usually conservative - this is not always the case!

What we can do?

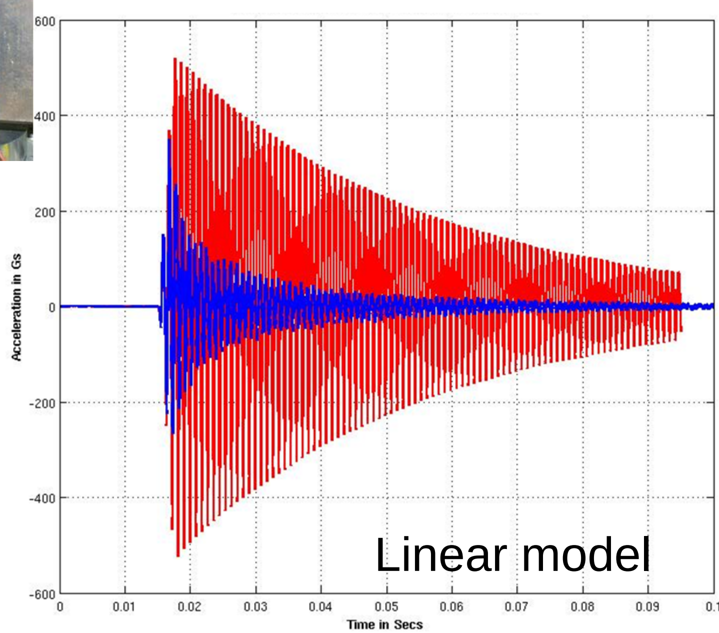
	Single Homogeneous Structure	Simple Assembly Level	Complicated Assembly Level
Natural Frequencies	✓	✓	✓
Mode Shapes	✓	✓	✓
Identify problem Frequencies	✓	✓	Depending on complexity
Amplitude	✓	✗	✗
Cumulative effects	Depending on problem	✗	✗

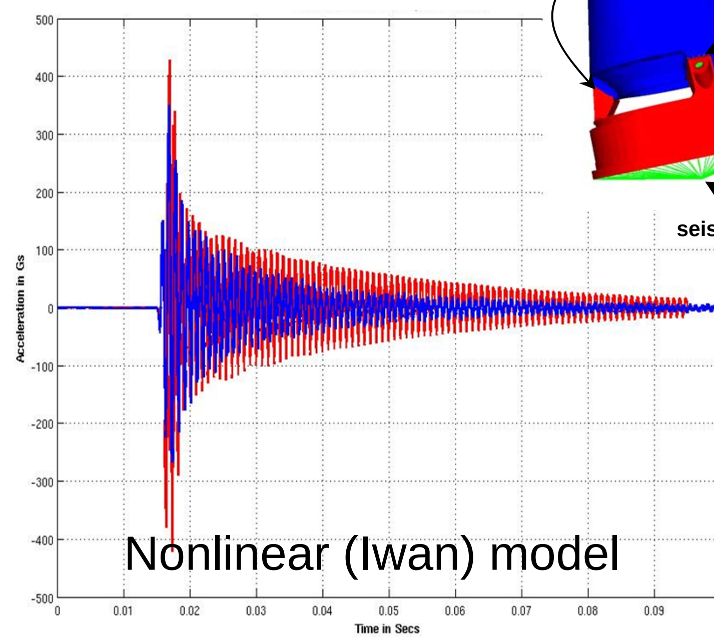
Even Simplest Systems are a Challenge

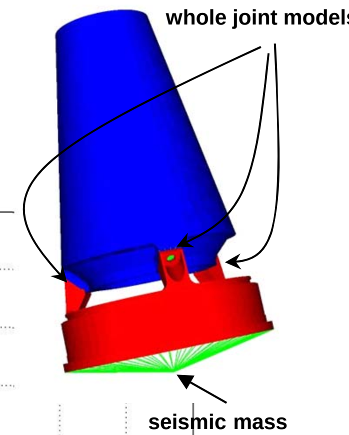


- Macro-slip and effective vibration isolation during blast
- High damping during sustained excitation

Acceleration predictions at forward mount joints:
Ti-SS mock 3-leg with shaker dynamics







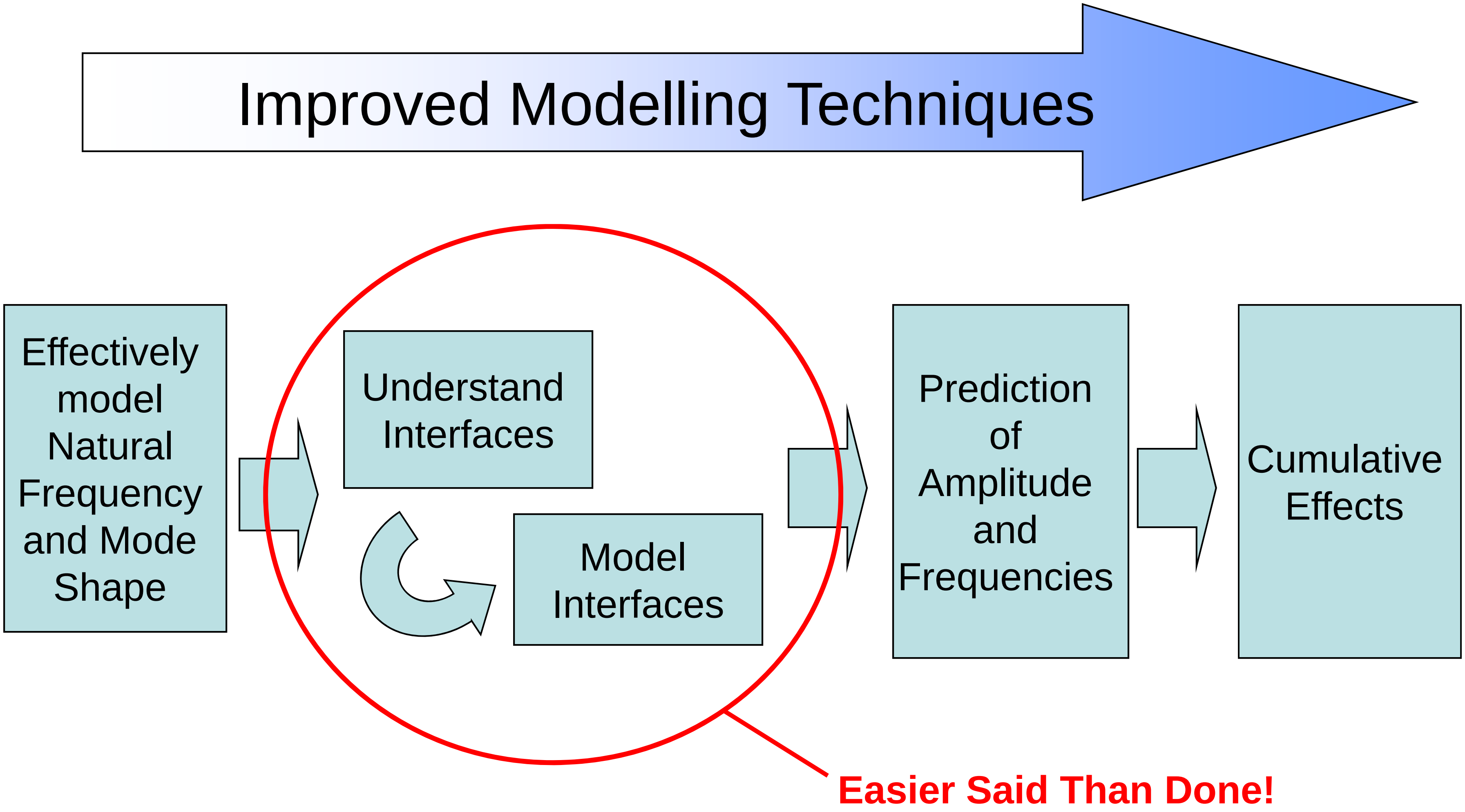
Experiment

Model

We can model individual joints (crudely) and insert them into a system model

Sandia National Laboratories

What Next for Such Interfaces?

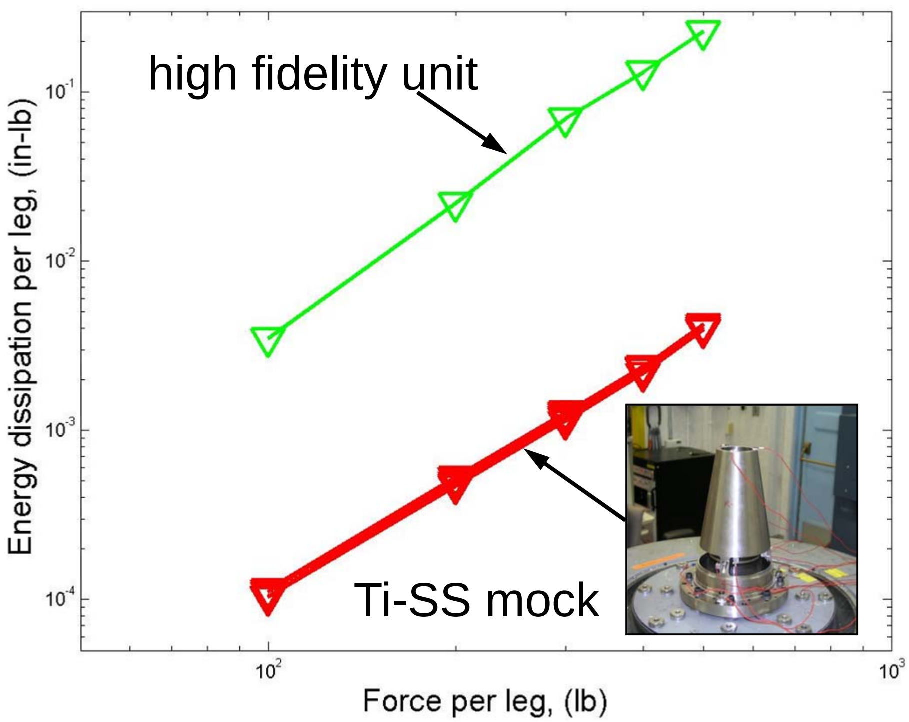


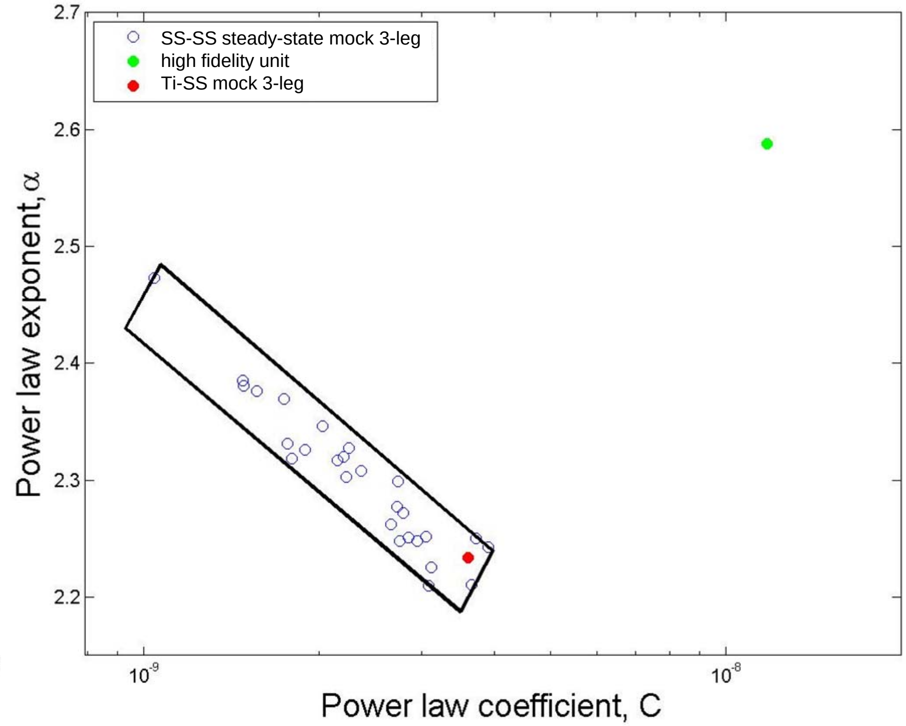
Sandia National Laboratories

The Problem is Larger than Just an Occasional Lap Joint

Sandia National Laboratories

Even Whole Subsystems May Behave in Joint-Like Manner





- The dissipation of the high-fidelity unit is very joint-like in nature.
- That dissipation is much more than can be explained by the forward mount joints alone.

Weapons systems contain a plethora of interfaces; How can we account for them in aggregate?

$$M\ddot{u} + C\dot{u} + Ku = F_X(t) + F_J(t, \{x_k^j\})$$

where F_J is force vector for joints and $\{x_k^j\}$ are state variables for joint j

Postulate $F_J = M\Phi\left\{\mathcal{G}_j\left(\alpha_j(\tau), \tau = -\infty, t\right)\right\}$

where α_j are modal coordinates

For modal BPII, $$\mathcal{G} = \int_0^\infty \mathrm{diag}\left(\left\{\rho_k(\phi)\right\}\right)\beta(t,\phi)d\phi$$

where

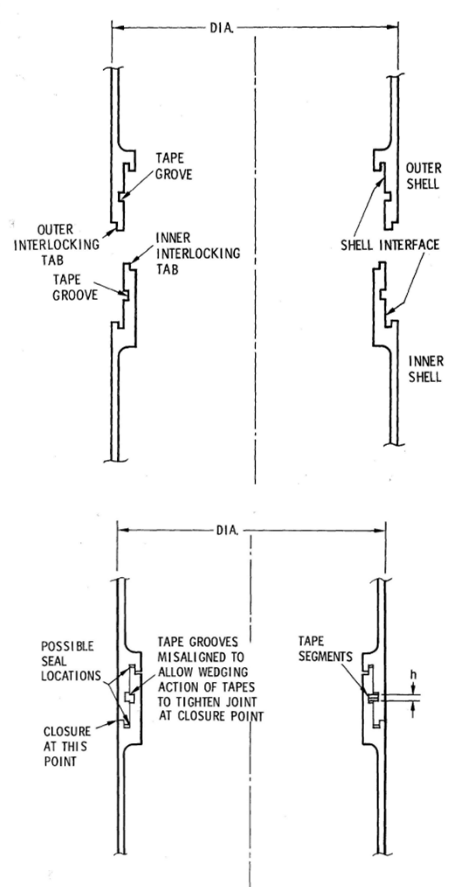
$$\dot{\beta}_k(t,\phi) = \begin{cases} \dot{\alpha} & \text{where } \dot{\alpha}(\alpha_k - \beta_k) > 0 \text{ and } |\alpha_k - \beta_k| = \phi \\ 0 & \text{otherwise} \end{cases}$$

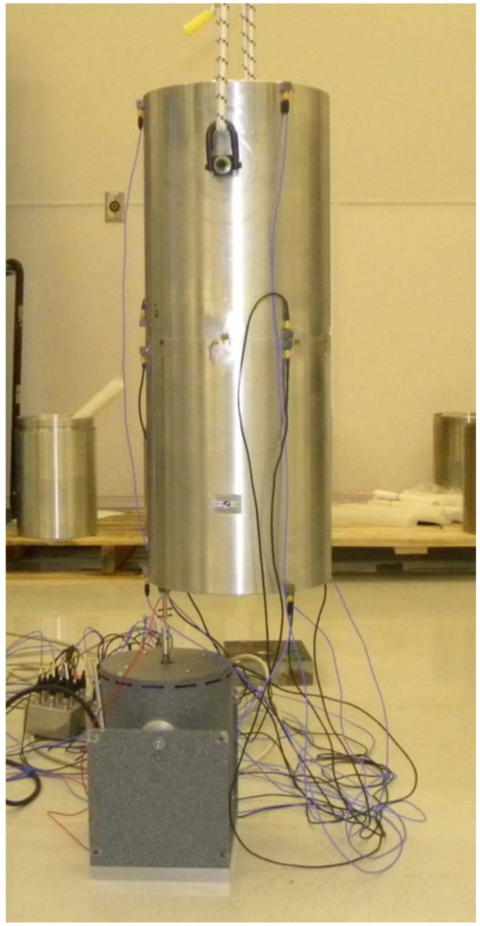
Sandia National Laboratories

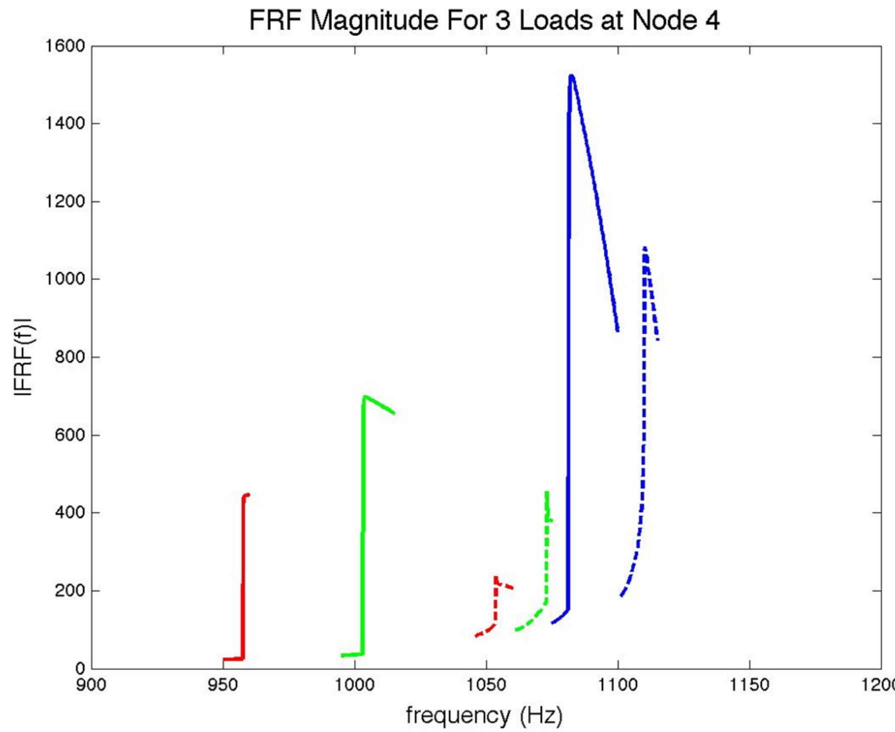
How could we possibly determine the parameters for our nonlinear modal operators?

- Decompose the response in modal components
  Look to empirical mode decomposition.
- Fit modal parameters in same way that joint parameters were fit.

Other Sorts of Nonlinear Joint: Consider Tape Joints





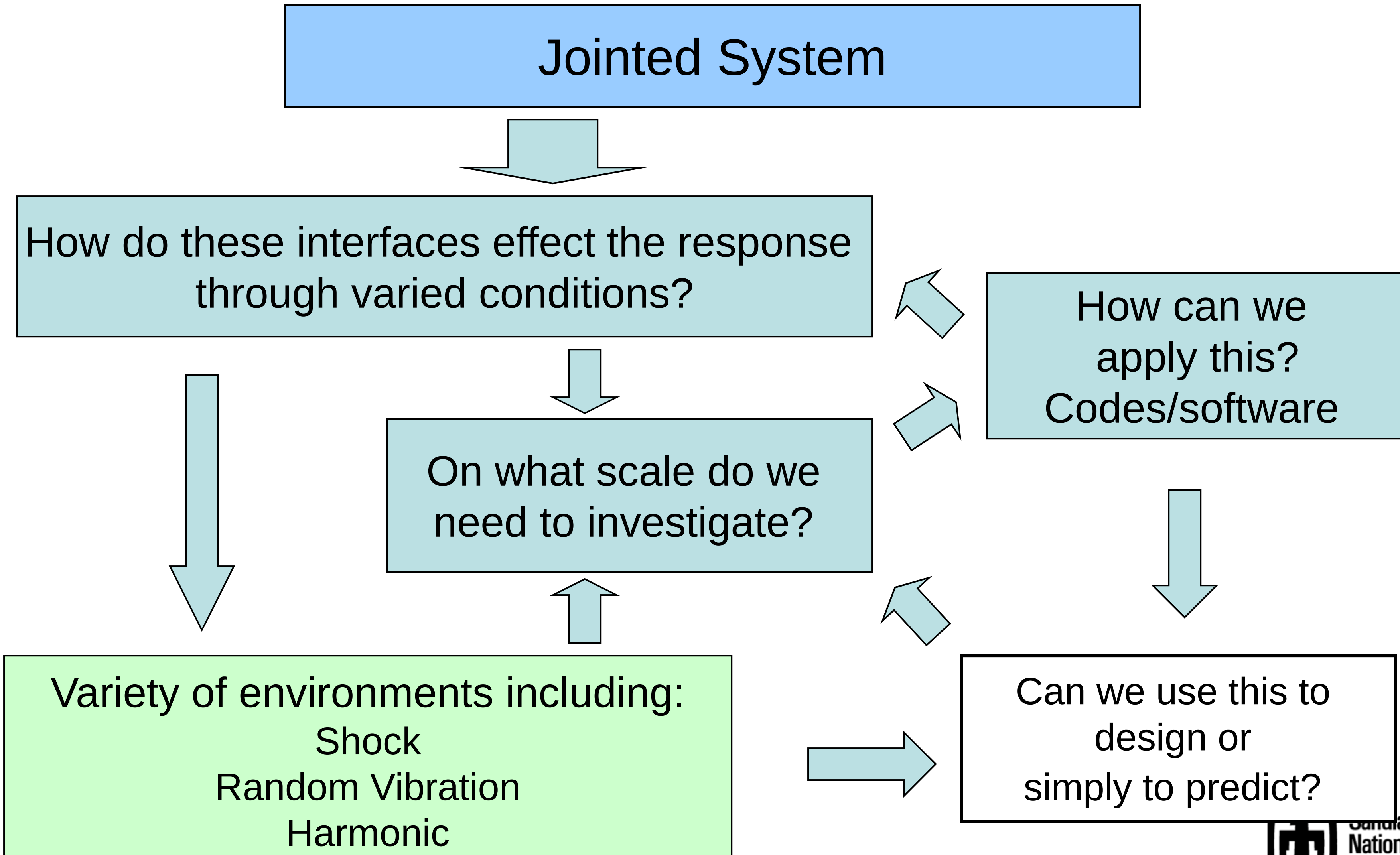


- Multiple FRF show system is very nonlinear
- Shows classic features of softening system

Response is more like that of a Duffing oscillator than that of a linear system

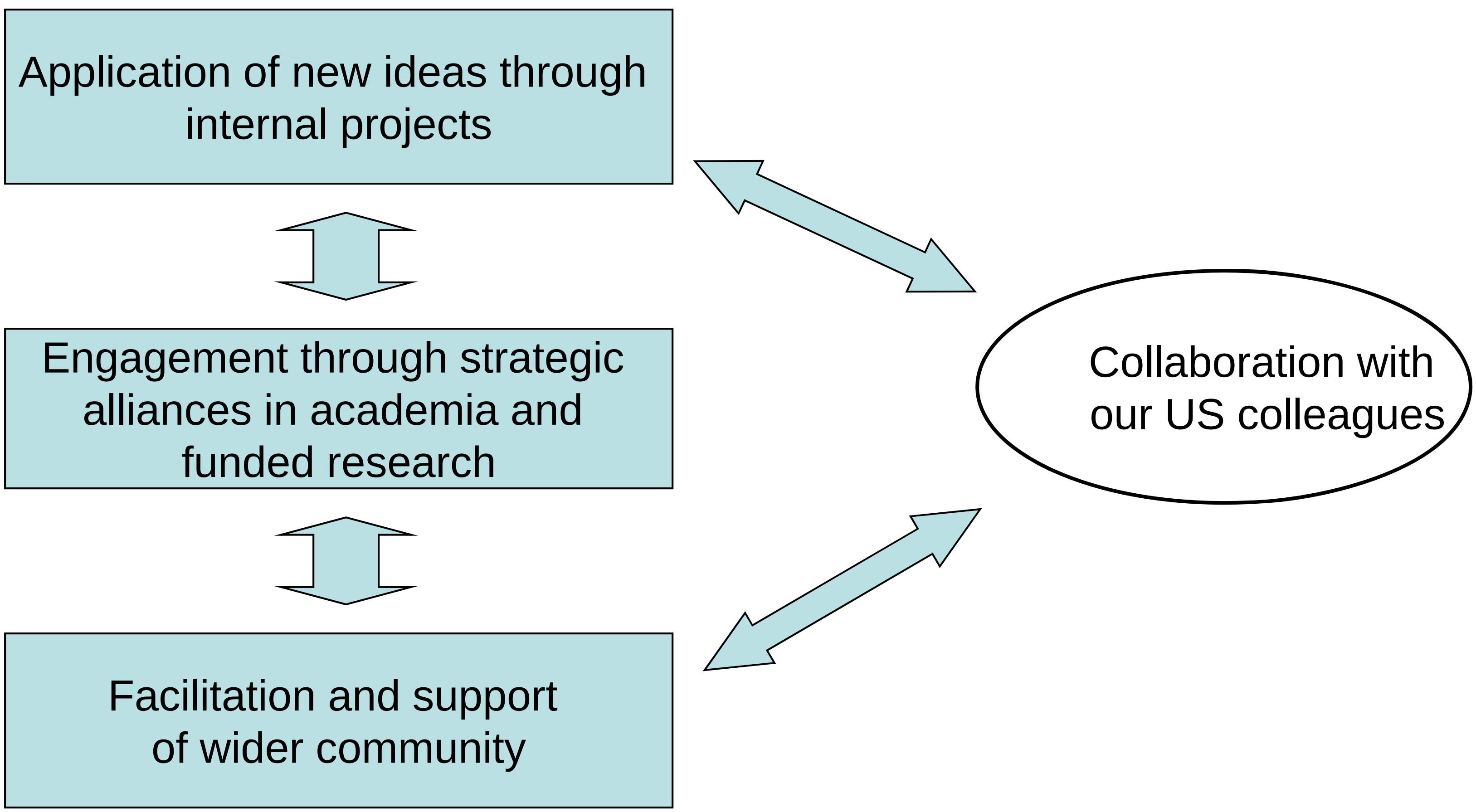
Sandia National Laboratories

Assessing Where We Stand



How to Move Forward?

- We do not have the resources to commit to significant and sustained in house research…



Sandia National Laboratories

BACKUP

Sandia National Laboratories