Nonlinearity of Joints in Structural Dynamics of Weapons Systems

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AWE

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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?

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<th>Single Homogeneous Structure</th>
<th>Simple Assembly Level</th>
<th>Complicated Assembly Level</th>
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<td>Identify problem Frequencies</td>
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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

We can model individual joints (crudely) and insert them into a system model
What Next for Such Interfaces?

Improved Modelling Techniques

Effectively model Natural Frequency and Mode Shape

Understand Interfaces

Model Interfaces

Prediction of Amplitude and Frequencies

Cumulative Effects

Easier Said Than Done!
The Problem is Larger than Just an Occasional Lap Joint
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?

\[ M\dddot{u} + C\dddot{u} + Ku = F_X(t) + F_J(t, \{x^j_k\}) \]

where \( F_J \) is force vector for joints and \( \{x^j_k\} \) are state variables for joint \( j \)

Postulate \( F_J = M \Phi \left\{ G_j \left( \alpha_j(\tau), \tau = -\infty, t \right) \right\} \)

where \( \alpha_j \) are modal coordinates

For modal BPII,

\[ \mathcal{G} = \int_0^\infty \text{diag} \left( \{ \rho_k(\phi) \} \right) \beta(t, \phi) \, d\phi \]

where

\[ \dot{\beta}_k(t, \phi) = \begin{cases} \dot{\alpha} & \text{where } \dot{\alpha}(\alpha_k - \beta_k) > 0 \text{ and } |\alpha_k - \beta_k| = \phi \\ 0 & \text{otherwise} \end{cases} \]
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
Assessing Where We Stand

Jointed System

How do these interfaces effect the response through varied conditions?

On what scale do we need to investigate?

Variety of environments including:
- Shock
- Random Vibration
- Harmonic

How can we apply this?
Codes/software

Can we use this to design or simply to predict?
How to Move Forward?

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

  Application of new ideas through internal projects

  Engagement through strategic alliances in academia and funded research

  Facilitation and support of wider community

  Collaboration with our US colleagues
BACKUP