Reduced-Order Nonlinear Structural Models

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Abstract:

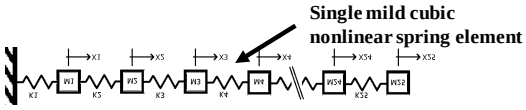
Commercial Space Transportation is currently configured around reusable launch and space vehicles to arrive at competitive pricing points for the transport services. As launch platforms carry the space vehicles to space on multiple missions, the structural integrity of the vehicles for subsequent missions must be determined. Acceptable safety margins must be established that are well understood as multiple missions are logged. A significant amount of structural response data must be collected in order to state confidence bounds on the computed safety margins. Test data suitable for safety margin assessment whether collected from ground tests, special flight tests, or during operational missions are expensive. Structural response data generated by simulation must be derived from validated simulations that include the proper physical parameters for extreme or limiting load conditions. Unfortunately, it is at the extremes that the nonlinearities are most pronounced.

The payoff of this research is many fold, the long term and most significant will be to help instill confidence in commercial space transport operations by producing sufficient data to establish reliable confidence statement on the safety margins of the transport and space vehicles.

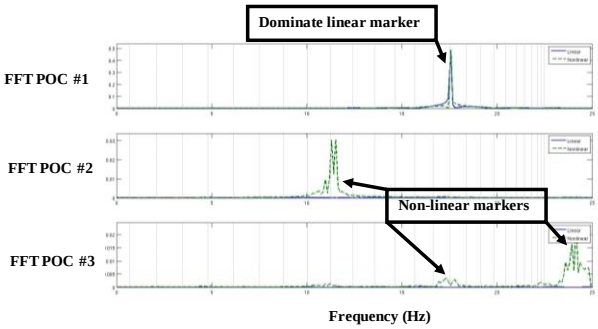
The Process:

To satisfy the overall objective of this research, a first step is to provide the capability of accurately predicting structural responses for full launch systems that have embedded non-linearities. While large finite element models of complete structural systems may be developed, exercising such models repeatedly with statistically significant parameter variations becomes daunting and expensive. Deriving high efficiently (reduced order) nonlinear models from both finite element models and directly from structural test data is the immediate goal of this research.

Unlike linear system response, where the total energy contained in a system can be assigned to specific spatial shapes which have harmonic time modulation at fixed frequencies, the energy in non-linear system responses moves into superharmonic and subharmonic of dominate frequencies which are no longer resonant frequencies. The particular response of a system is dependent on the energy state, as well as the magnitude of the excitation. Nonlinear responses can demonstrate stable periodic motion when forced by a periodic excitation, but such periodic response is not necessarily captured by unchanging basis functions. Other means of modeling non-linear responses using singular value decomposition (SVD)of transient responses has produced some promising results.



25 element model with single smooth cubic nonlinear element



Fourier Transform of Proper Orthogonal Coordinates (Time Modulation) showing evidence of non-linear responses

Completed Milestones:

- Assembled a seven-member peer review group comprised of members from the commercial launch companies, the FAA, NASA, university researchers and government laboratories.
- Formally collect and organize the body of data modeling structures exhibiting non-linear dynamic behavior. Review and categorize the literature into similar processes and/or approaches.
- Develop an experimental capability to excite and extract transfer functions from representative space structures.