Hybrid Time- and Frequency-Domain Methods for Simulation of Dynamic Environments with the Goal of Understanding the Statistics and Uncertainty of the Result

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Much of the challenge of mechanical design of structures, ground vehicles, and spacecraft lies in the use of measured data from previous events to define a new vehicle or structure that will perform successfully in that environment. Historically, the direct use of hours of acceleration measurements to perform analysis of a new design has not been feasible. In the 1960s, a breakthrough in methods for this type of design analysis came in the concept of random analysis, defined by Steven Crandall of MIT, through which many hours of data of a road surface, turbulence for an airplane, or vibration from a rocket motor burn could be condensed into a concise definition of the environment based on the statistical variations documented as a random process. Decades before random analysis, however, other frequency-domain methods were developed. In particular, shock response analysis and Fourier analysis made it possible to understand massive amounts of acceleration measurements by forming a shock response spectrum or a frequency response function that could be used with the appropriate analysis methods to design a structure. Today, the standard methods in commercially available software for dynamic analysis are tied to these specific types of frequency-domain analyses, which make vast amounts of measured data manageable but also result in the loss of the statistics of the results. The limitations of these methods become clearest when the real environment includes multiple types of dynamics environments. For example, measured dynamic environments for a helicopter or a liquid rocket engine include not only specific sine tones with well-defined deterministic amplitudes and frequencies but also random excitation that is known only statistically. The combined result from these specific frequency-domain analyses is neither statistical nor deterministic and suffers from the loss of stress tensor understanding as well.

This presentation explores a revised approach that maintains the advantage of the various types of frequency-domain analyses in condensing and understanding the environmental measurements but utilizes the time domain to perform the analysis. In this way, the statistics as well as the full stress tensor can be maintained for better understanding of the material response to the dynamic environment. But even more importantly, the statistics of the result can be maintained and uncertainty propagated such that the design evaluation gives not just a margin of safety but a probability of success. The future challenge in design of structures for extreme dynamic environments is not to predict the worst possible case but to shape the design to reach a selected probability of achieving the desired performance.