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High Frequency Mechanical Pyroshock Simulations for Payload Systems*

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Sandia National Laboratories (SNL) designs mechanical systems with components that must survive high frequency shock environments including pyrotechnic shock. These environments have not been simulated very well in the past at the payload system level because of weight limitations of traditional pyroshock mechanical simulations using resonant beams and plates. A new concept utilizing tuned resonators attached to the payload system and driven with the impact of an airgun projectile allow these simulations to be performed in the laboratory with high precision and repeatability without the use of explosives. A tuned resonator has been designed and constructed for a particular payload system. Comparison of laboratory responses with measurements made at the component locations during actual pyrotechnic events show excellent agreement for a bandwidth of DC to 4 kHz. The bases of comparison are shock spectra. This simple concept applies the mechanical pyroshock simulation simultaneously to all components with the correct boundary conditions in the payload system and is a considerable improvement over previous experimental techniques and simulations.

INTRODUCTION

Sandia National Laboratories (SNL) designs mechanical systems with electronics that must survive high frequency events including pyrotechnic shock and hypersonic flight vibration. These environments have not been simulated very well at the payload system level. Recent advances in the control of multiple shakers in a reverberant acoustic field can allow the hypersonic flight vibration environments to be more accurately simulated [1]. The pyroshock environment has not been simulated very well in the past because of weight limitations of pyroshock mechanical simulations using resonant beams and plates. Since the size and weight of aerospace systems and their associated components are decreasing, the vulnerability of these systems to high frequency environments is increasing. A new concept utilizing tuned resonators attached to the payload system allow these simulations to be performed in the laboratory with high precision and repeatability without the use of explosives. The tuned resonators are driven into first bending mode resonance with the impact of an airgun projectile. The transmissibility of the pyroshock simulation into the payload's internal components has been measured and is presented below.

EXPERIMENTAL CONFIGURATION AND RESULTS

The resonant fixture that simulates the payload pyroshock event was designed with a technique developed previously [2]. Component responses measured in actual payload pyroshock events were examined and used to specify the natural frequency of the resonator and subsequently its dimensions.

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DISCLAIMER

The experimental configuration is shown in Figure 1. A projectile propelled from an airgun is used to excite the first bending mode in the resonant fixture. The resonant fixture response is coupled into the payload system through the release assembly at the rear of the payload. Figures 2-16 show comparison of laboratory responses with acceleration measurements during actual pyrotechnic events. Piezoresistive accelerometers were used to measure all acceleration responses. The bases of the comparisons presented in this paper are Shock Response Spectra (SRS). The SRS were computed with a Maxi-Max Absolute Acceleration (MMAA) algorithm with 5% critical damping ratio.

Figures 2-4 present the shock levels measured at the input to the payload system, identified as Location 1 in Figure 1. The input was measured at a point on the base of the resonant fixture close to the payload system attachment bolts. The inputs for the live pyrotechnic events were measured on the release assembly at the base of the payload system. The levels for the resonant fixture responses are an excellent match for the pyrotechnic shock events.

SRS comparisons are presented for five distinct component locations within the payload system, Locations 2-6 in Figure 1. In general, acceleration response magnitudes diminish with distance from the input and the number of joints as the shock moves forward in the payload system. Figures 5-10 present the SRS comparisons for forward and aft structural hard points within the payload system at Locations 2 and 3. Figures 11-16 present the SRS comparisons for three components at Locations 4-6. The SRS for component locations have lower magnitudes because the shock has passed through many bolted joints. The structural hard points have fewer joints between their location and the resonant fixture. Consequently, the hard point SRS have higher magnitudes.

The most significant result seen in these figures is the fact that the resonant fixture-induced SRS show excellent agreement with the pyrotechnically-induced SRS in both magnitude and frequency content for all locations. The figures also confirm the expected trends in response levels with location. The overall data quality is very good. However, some of the SRS are flat at low frequency. The worst low frequency problem is in Figure 8. The source of this problem is presumed to be drift in the differential voltage amplifier used with the piezoresistive accelerometers. The offsets are minor and not detrimental to the overall quality of the data because the magnitude of the offset is small relative to the overall peak amplitude of the measured response

UNCERTAINTY ANALYSIS

The uncertainty in these measurements and results are attributed to two sources: uncertainty in the sensors and the data acquisition system and uncertainty in the payload system assembly. The sensor and data acquisition uncertainty is monitored on a continual basis as required by the SNL Specification 9958003 [3]. These requirements include the performance of both the hardware (sensors, amplifiers, digitizers etc.) and the software IMPAX that controls the data acquisition system through a computer [3,4,5]. The 9958003 specification allows an accuracy of ±10% for amplitude, ±5% for duration, and ±8% for rise and fall time for any measured pulse greater than 50 μs in duration. The current data acquisition system and software meet these requirements within ±0.5%. Documentation of these results is maintained in the Mechanical Shock Laboratory. Consequently, the only uncertainty in these measurements is the uncertainty in the sensor calibration, ±5% [6] and the uncertainty in the torque wrench calibration, ±5%, that was used for payload assembly [6]. These two uncertainties are considered random, so they may be combined in an uncertainty analysis with a 95% confidence level as [7,8]:

$$w_T = \sqrt{w_s^2 + w_{t\&l}^2} \qquad (1)$$

where: w_T = total uncertainty,
w_s = sensor calibration uncertainty, and
$w_{t\&l}$ = torque wrench calibration uncertainty.

The value of the total uncertainty, w_T, is ±7% and is typical for the measurements made in the SNL Mechanical Shock Laboratory.

CONCLUSIONS

A mechanical simulation of a payload pyroshock event has been accomplished by a simple concept that applies the mechanical pyroshock simulation simultaneously to all components with the correct boundary conditions in the payload system. Comparison of laboratory responses with measurements made at the component locations during actual pyrotechnic events show excellent agreement for a bandwidth of DC to 4 kHz and reasonable agreement out to 10 kHz. This simulation is a considerable improvement over previous experimental techniques and simulations.

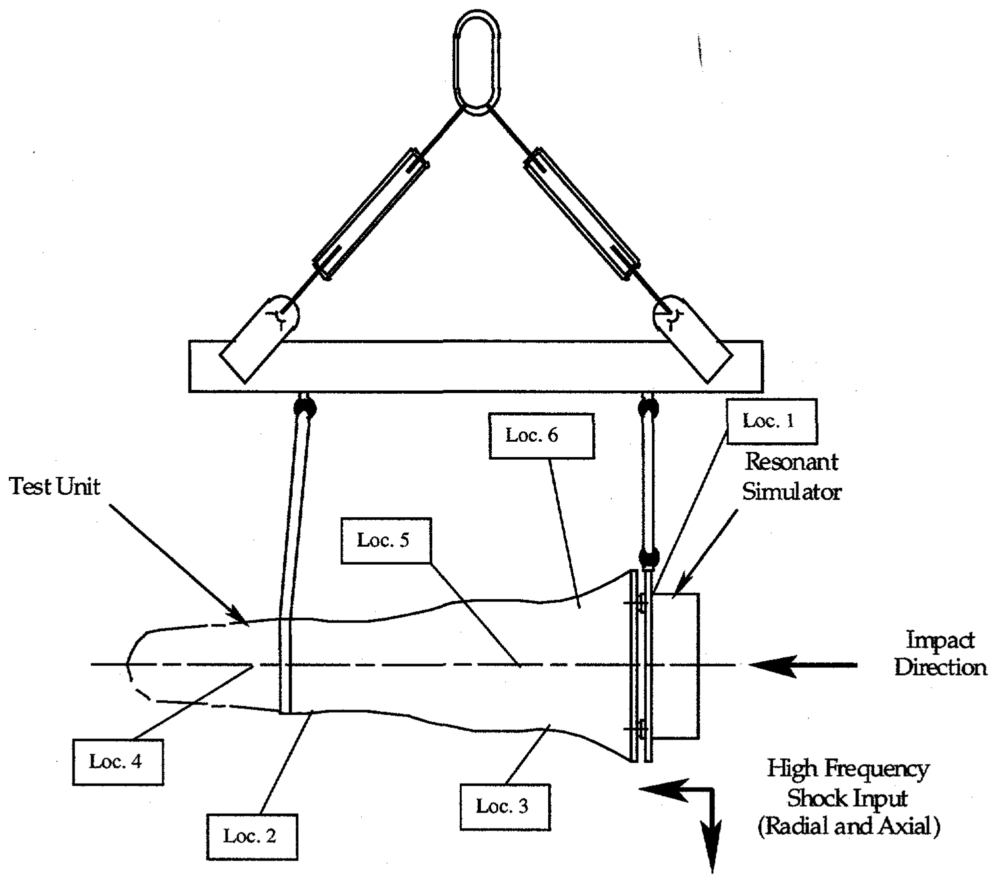

Figure 1: Mechanical Pyroshock Simulation Coupled at Release Bolts for Payload System.

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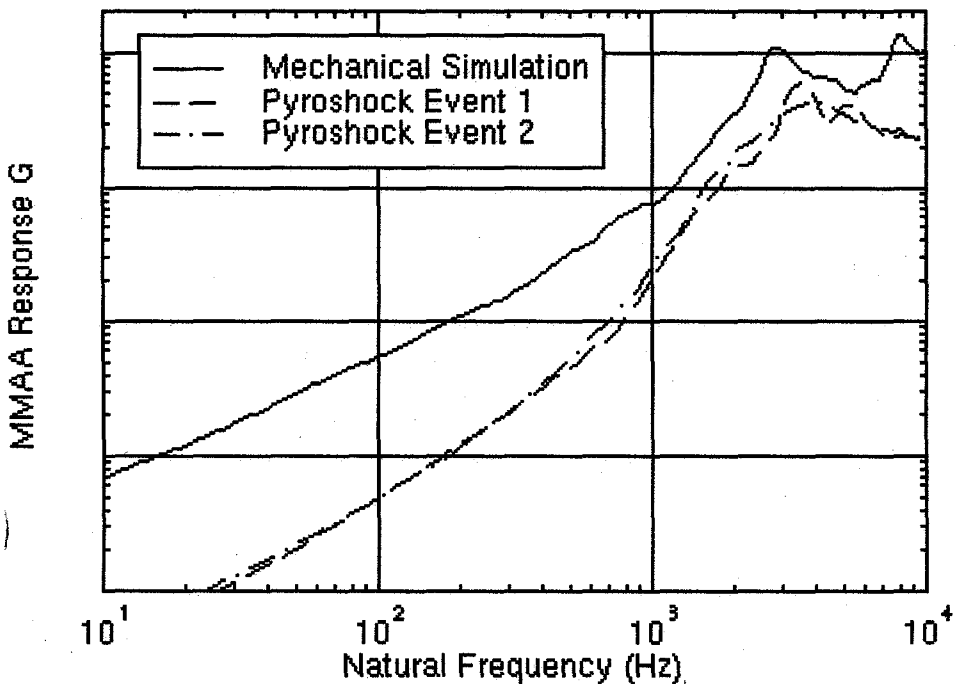

Figure 2: Axial Response Comparison of Mechanical Simulation and Two Pyroshock Events at Location 1 (MMAA SRS with 5% Damping).

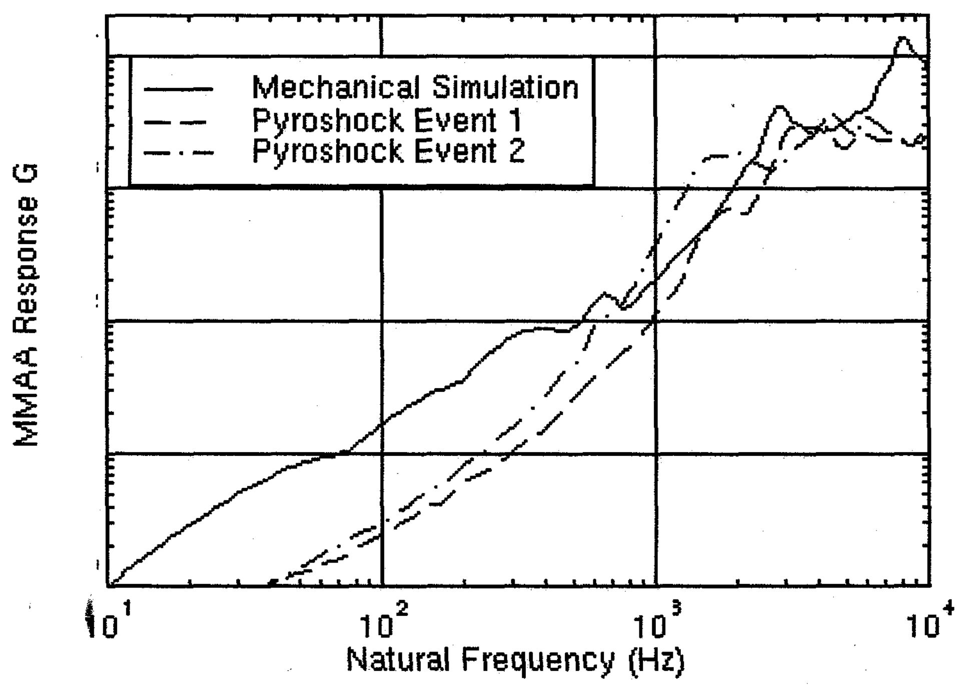

Figure 3: Lateral Response Y Comparison of Mechanical Simulation and Two Pyroshock Events at Location 1 (MMAA SRS with 5% Damping).

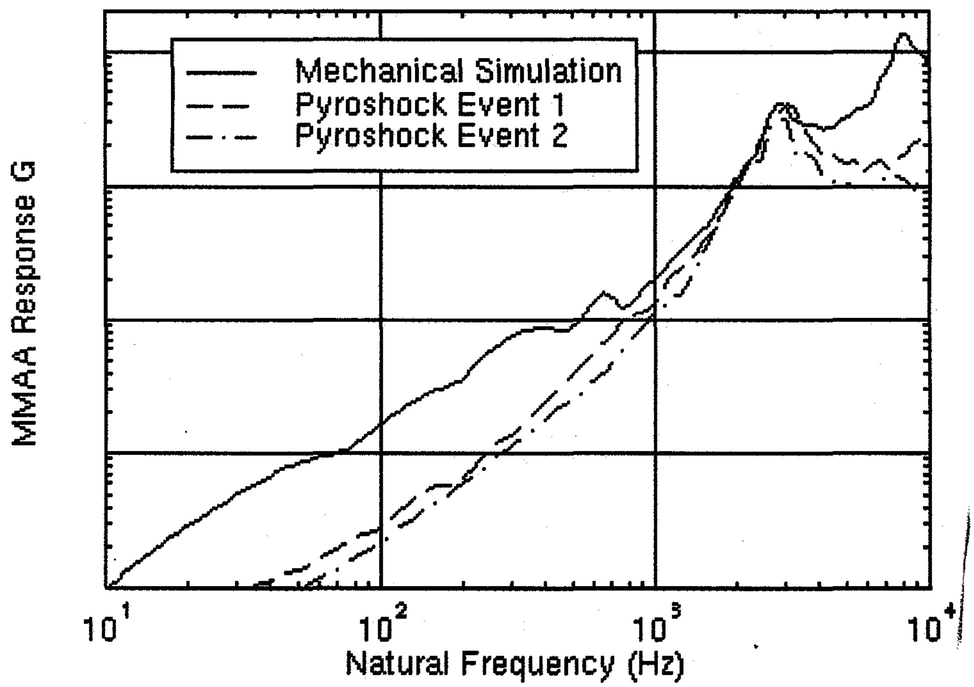

Figure 4: Lateral Response Z Comparison of Mechanical Simulation and Two Pyroshock Events at Location 1 (MMAA SRS with 5% Damping).

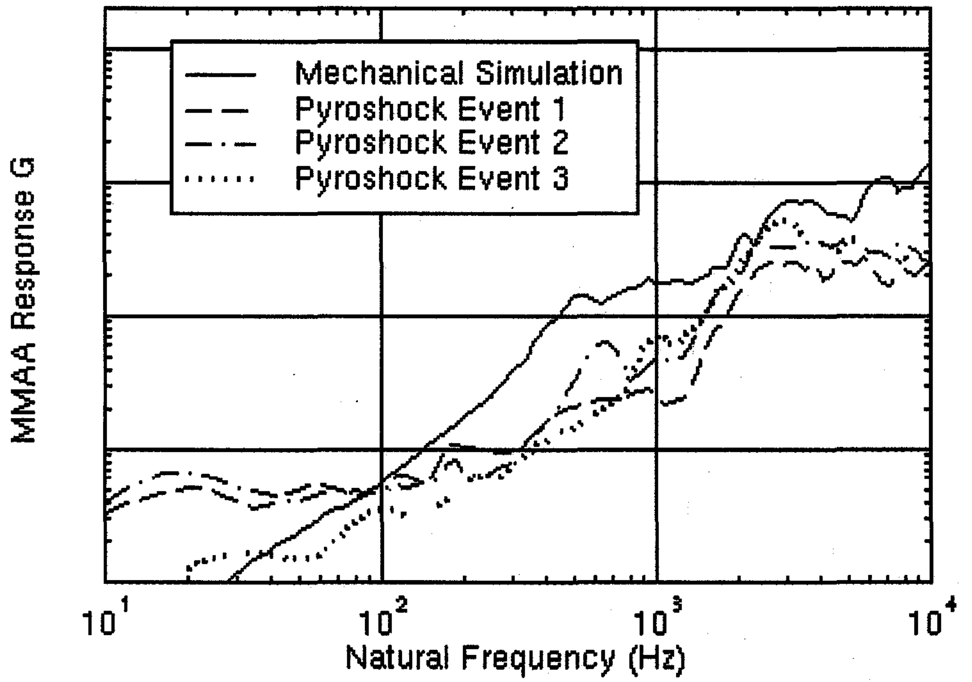

Figure 5: Axial Response Comparison of Mechanical Simulation and Three Pyroshock Events at Location 2 (MMAA SRS with 5% Damping).

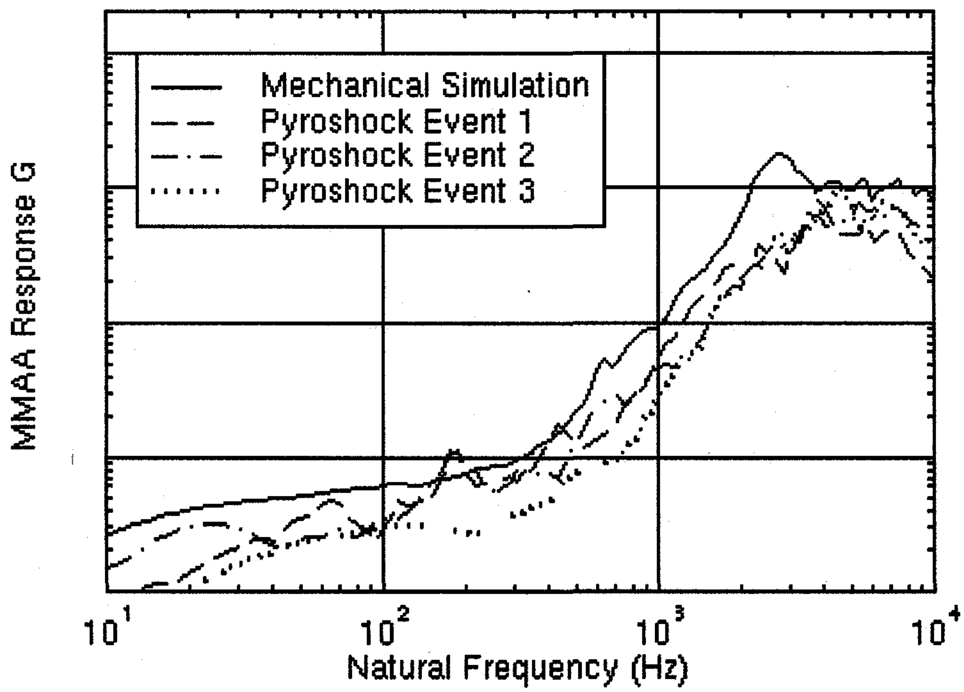

Figure 6: Lateral Response Y Comparison of Mechanical Simulation and Three Pyroshock Events at Location 2 (MMAA SRS with 5% Damping).

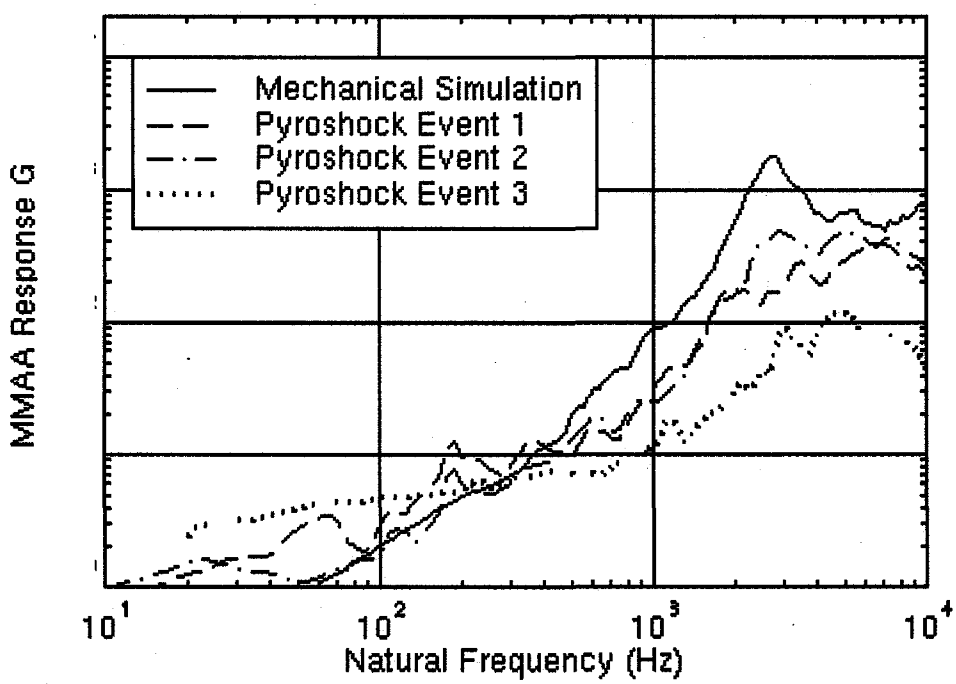

Figure 7: Lateral Response Z Comparison of Mechanical Simulation and Three Pyroshock Events at Location 2 (MMAA SRS with 5% Damping).

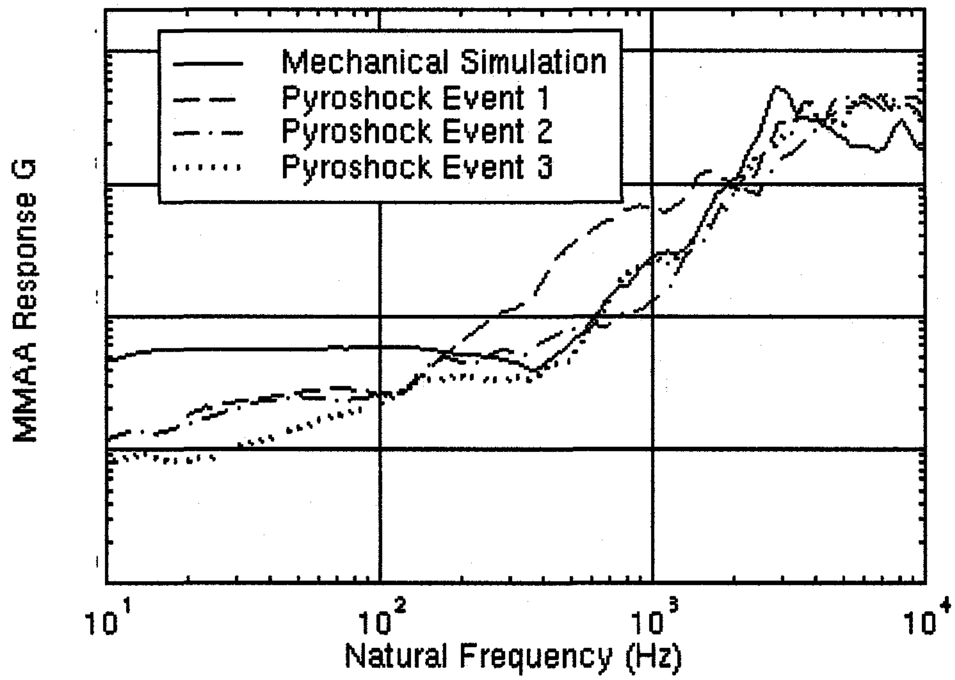

Figure 8: Axial Response Comparison of Mechanical Simulation and Three Pyroshock Events at Location 3 (MMAA SRS with 5% Damping).

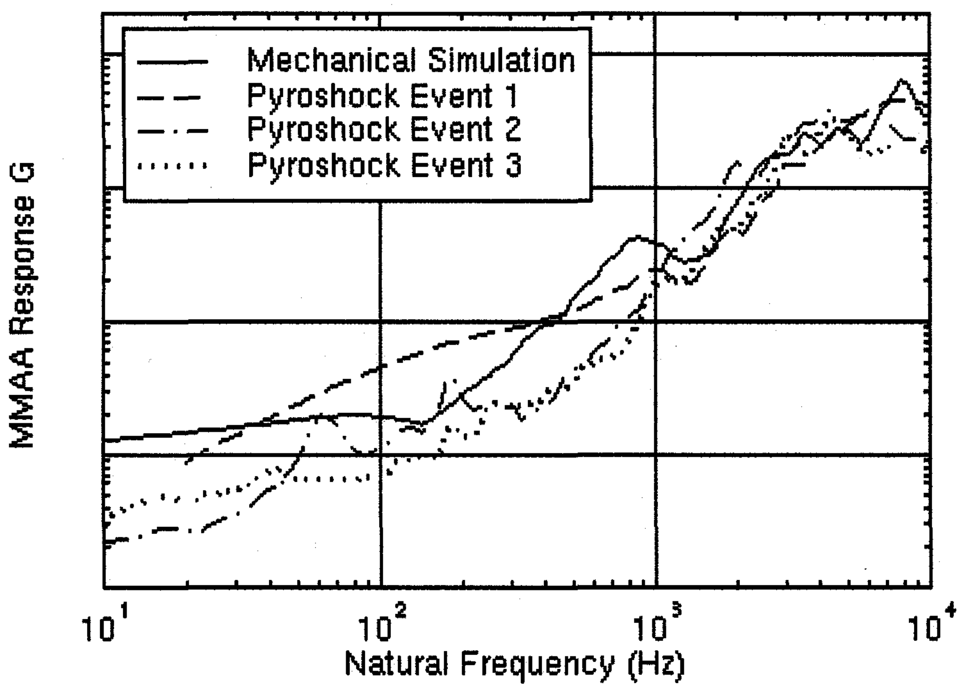

Figure 9: Lateral Response Y Comparison of Mechanical Simulation and Three Pyroshock Events at Location 3 (MMAA SRS with 5% Damping).

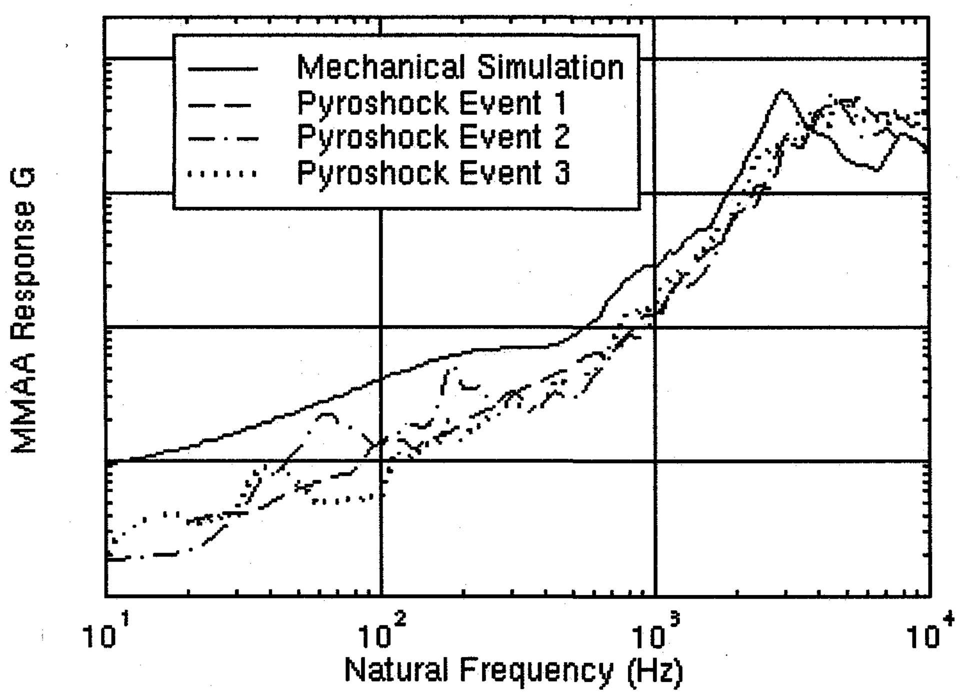

Figure 10: Lateral Response Z Comparison of Mechanical Simulation and Three Pyroshock Events at Location 3 (MMAA SRS with 5% Damping).

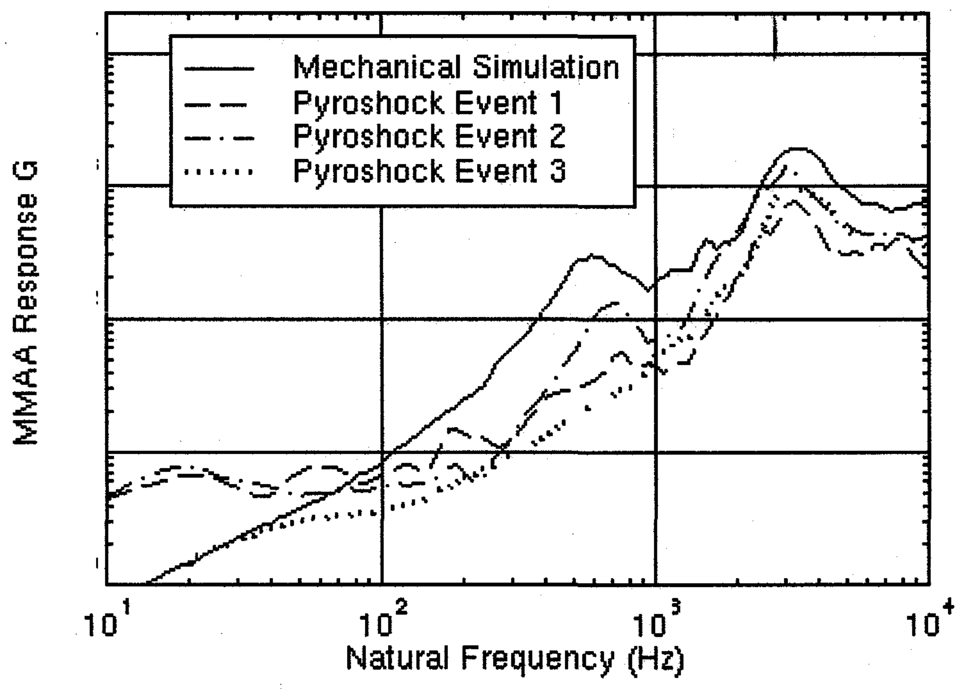

Figure 11: Axial Response Comparison of Mechanical Simulation and Three Pyroshock Events at Location 4 (MMAA SRS with 5% Damping).

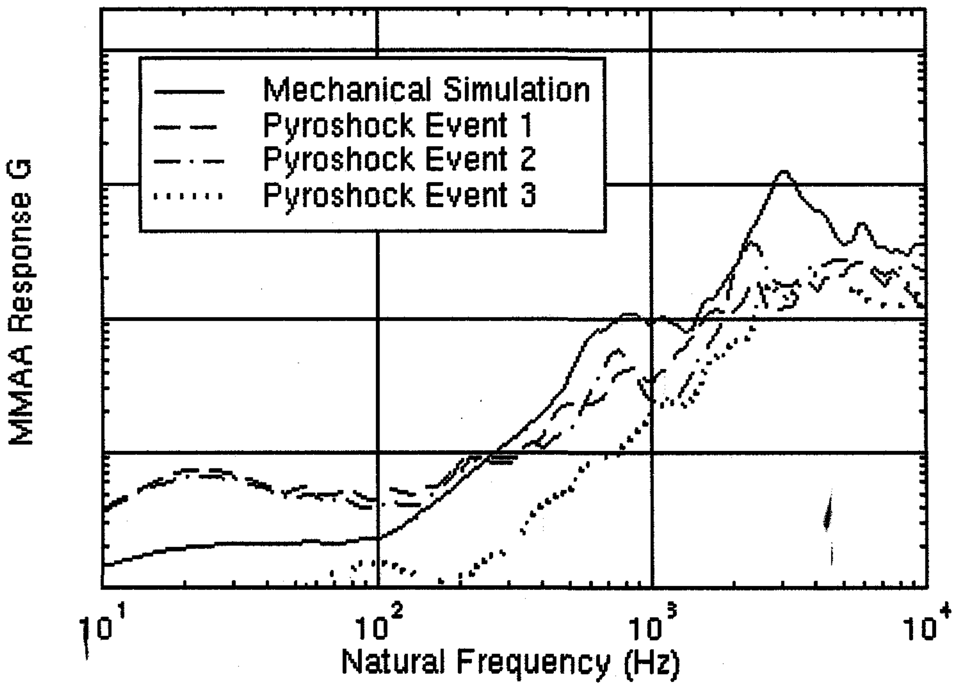

Figure 12: Lateral Response Y Comparison of Mechanical Simulation and Three Pyroshock Events at Location 4 (MMAA SRS with 5% Damping).

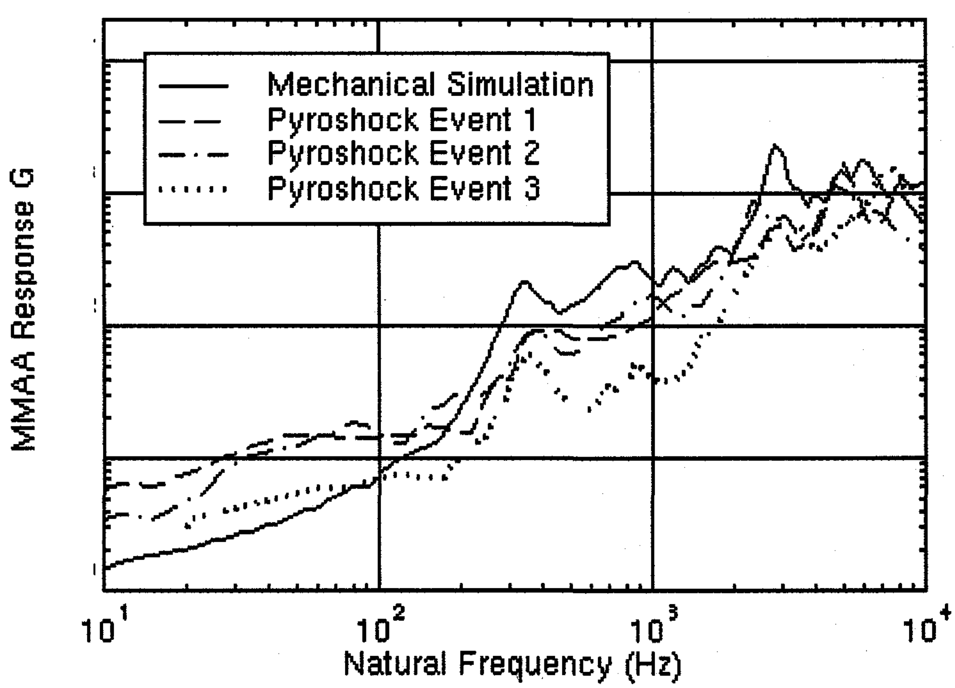

Figure 13: Axial Response Comparison of Mechanical Simulation and Three Pyroshock Events at Location 5 (MMAA SRS with 5% Damping).

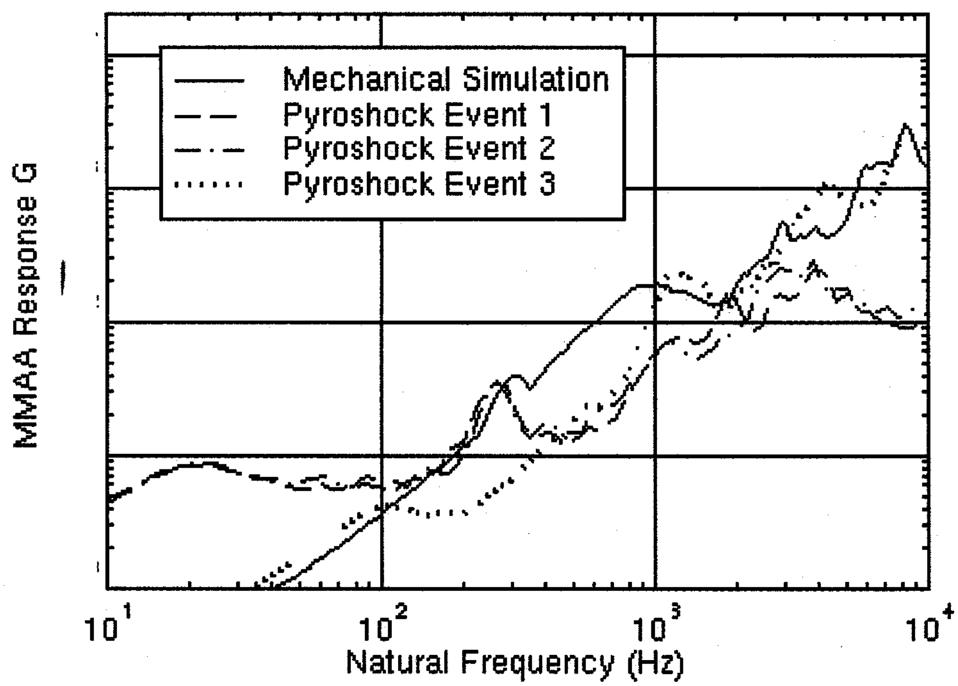

Figure 14: Axial Response Comparison of Mechanical Simulation and One Pyroshock Event at Location 6 (MMAA SRS with 5% Damping).

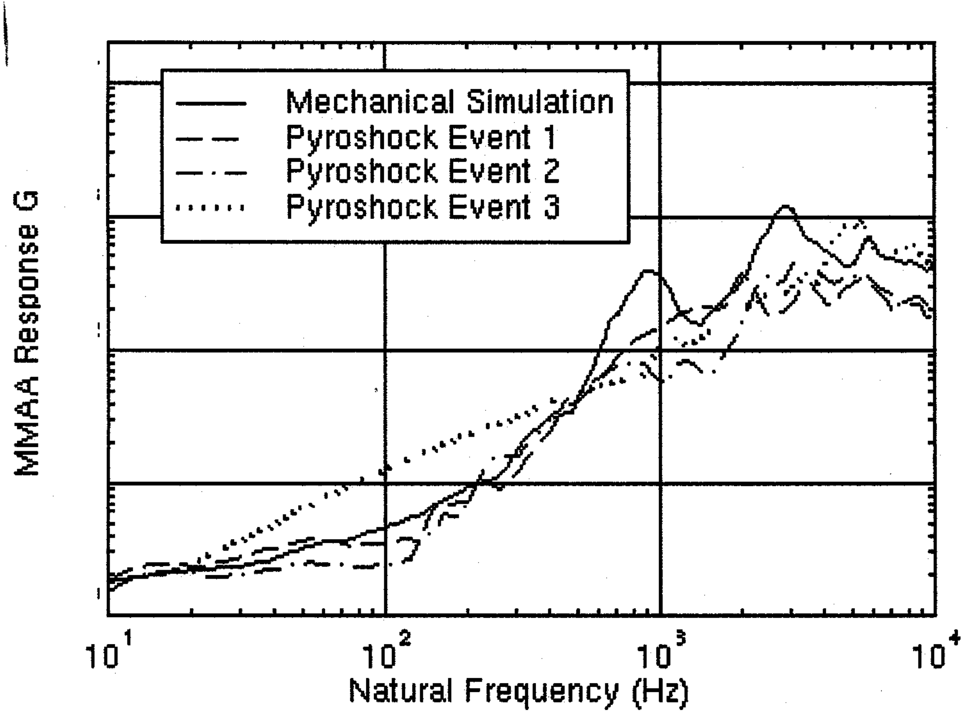

Figure 15: Lateral Response Y Comparison of Mechanical Simulation and One Pyroshock Event at Location 6 (MMAA SRS with 5% Damping).

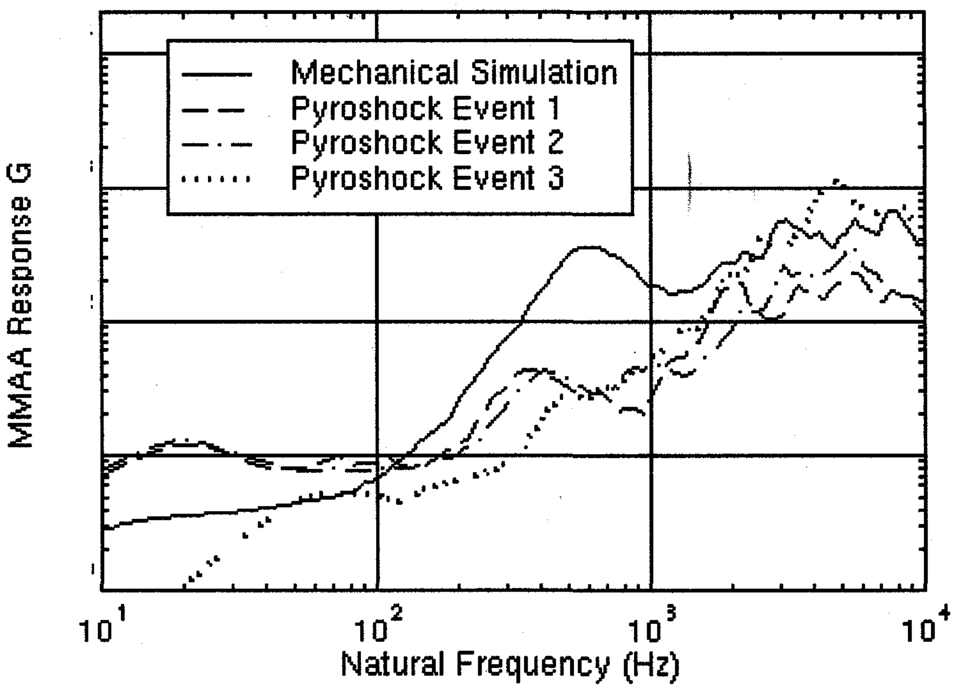

Figure 16: Lateral Response Z Comparison of Mechanical Simulation and One Pyroshock Event at Location 6 (MMAA SRS with 5% Damping).