SAND2018-12125C

A Method for Determining Impact Force for Single and Tri Axis Resonant Plate Shock Simulations

Brian A. Ferri, Ronald N. Hopkins

Analytical Structural Dynamics

Sandia National Laboratories[1], Albuquerque, NM 87185

ABSTRACT

In the past year, resonant plate tests designed to excite all three axes simultaneously have become increasingly popular at Sandia National Labs. Historically, only one axis was tested at a time, but unintended off axis responses were generated. In order to control the off-axis motion so that off-axis responses were created which satisfy appropriate test specifications, the test setup has to be iteratively modified so that the coupling between axes was desired. The iterative modifications were done with modeling and simulation. To model the resonant plate test, an accurate forcing function must be specified. For resonant plate shock experiments, the input force of the projectile impacting the plate is prohibitively difficult to measure in situ. To improve on current simulation results, a method to use contact forces from an explicit simulation as an input load was implemented. This work covers an overview and background of three axes resonant plate shock tests, their design, their value in experiments, and the difficulties faced in simulating them. The work also covers a summary of contact force implementation in an explicit dynamics code and how it is used to evaluate an input force for a three axes resonant plate simulation. The results from the work show 3D finite element projectile and impact block interactions as well as simulation shock response data compared to experimental shock response data.

Keywords: Resonant Plate, Shock Test, Multi-Axis Test, Shock Simulation, Input Force

INTRODUCTION

Three axis testing, meaning exciting three degrees of freedom of the system simultaneously, has become an area of research at Sandia National Laboratories for the past few years. It can reduce the number of test needed to qualify a part in a shock environment. Shock environments themselves are often multi-axis environments, so the specifications for components are usually derived as axis specific specifications, and are usually given as a Shock Response Spectrum (SRS). Accelerometers are used to track the time history of the acceleration during a shock test. The time data is transformed to the frequency domain via an SRS calculation and compared to the test specification. The quality of the test is computed as the average decibel (dB) error. For this work, the average dB error was calculated as the mean of the absolute difference between test data and simulation data in dBs. A shock test specification will have a ramp and a knee in the frequency domain. The knee is located at a frequency f_k, and an experiment will be designed such that a resonant fixture will have a peak resonance at f_k.

For structural dynamics work, force inputs to a system can be prohibitively difficult to measure in-situ. For example, the dynamics of a force gauge in the load path of a certain test setup can alter the input load even for low amplitude forces. For shock testing, it can be even more difficult. The test that is described in this work has a 12 lbs. steel projectile that impacts at 59 feet per second (fps). A calibrated strain gage would be the preferred measurement to compute the delivered impulse, however it is not possible to extract the delivered impulse due to the noise issues. Thus, a study into the exact temporal profile of the input load is needed to perform a structural analysis and to predict responses to the loading.

There are inverse methods for input force estimation that are used both at Sandia [1] and in industry [2]-[3]. These methods, while not applied to shock response typically still follow a similar methodology, which is to measure a dynamic quantity in the lab then rely on the known dynamics of the structure to back out the force via those dynamic relationships. This study follows a similar methodology in which an acceleration is measured, however, the force is found in a separate simulation that only considers the mass and momentum of the loading object. Thus, it is considered a forward problem, meaning that the

[1]Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

simulation begins with the inputs in order to calculate unknown results, as opposed to an inverse problem, which is the opposite.

Sierra Solid Mechanics [4] (Sierra SM) is a proprietary code at Sandia National Laboratories and is used in this work to simulate a projectile impacting a resonant fixture using an explicit solver algorithm. This method of analysis uses a frictionless contact surface interaction between the projectile and the resonant fixture. To reproduce this work, a similar finite element code with explicit capability would be sufficient. The contact force in Sierra SM is calculated at each time increment and written to an output file. The resulting contact force is then used as the input to a Sierra Structural Dynamics [5] (Sierra SD) simulation that is performed with Sierra SD's linear transient dynamic capability.

BACKGROUND

The primary input parameter to a computational shock simulation is the load function given as a temporal profile. Previous analysis used a load profile as shown in Figure 1.

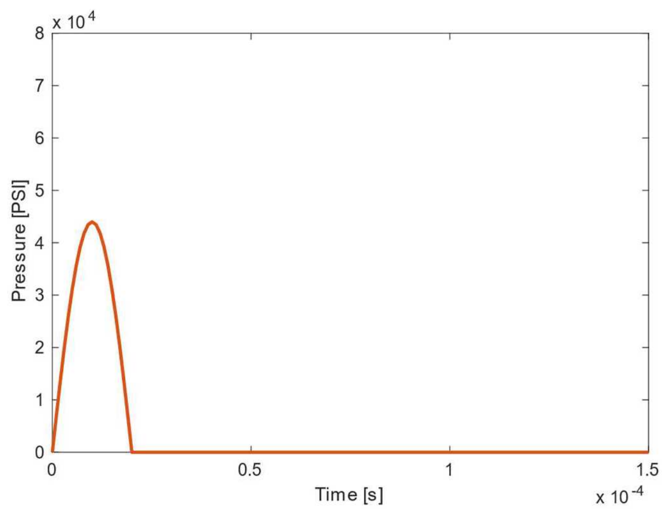

Figure 1: Input that was originally used in previous studies. The load profile has a peak amplitude of 44,000 PSI.

This load profile is a half sine impulse that was assumed given previous experience modeling lower amplitude dynamic force inputs as the true profile of the high amplitude shock test was unknown.

To determine the contact force exerted by the projectile on the resonant structure, the projectile was modeled with solid hex elements with a linear material model of steel. The projectile was given an initial velocity of 59fps (which was measured upon exit from the gas gun). This setup is shown as a diagram in Figure 2.

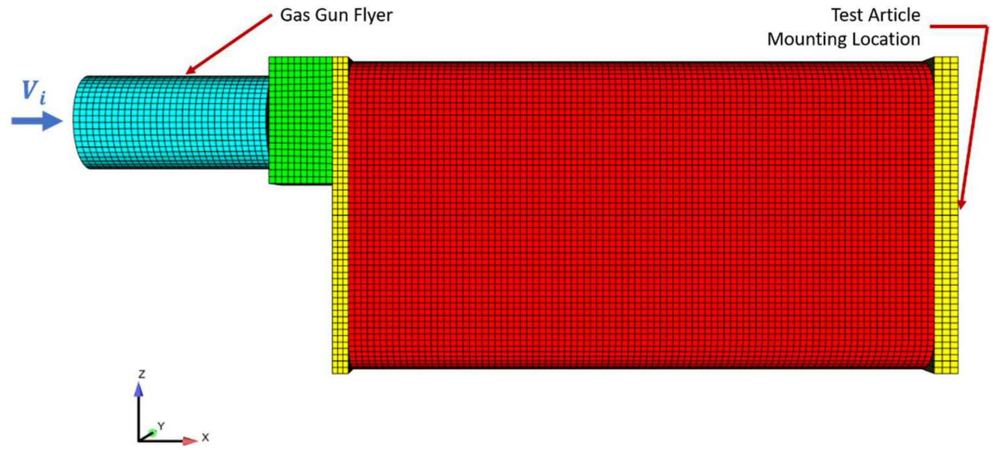

Figure 2: Simulation mesh of Projectile and Pedestal test configuration

As shown in Figure 2, the Projectile (shown in blue) is a steel cylinder that is 6 in long with a 3 in diameter and travels with a velocity V_i. The Impact Block (shown in green) is an aluminum block that is 4in by 2in by 2in. The Pedestal (shown in red) with plates (shown in yellow) on either end is constructed from steel. The test article is center mounted on the side opposite the impact block (shown on the right in this diagram). The projectile interfaces with an impacting block that is firmly attached to the resonant fixture. The interface between the projectile and the block is modelled as a frictionless contact interaction. This eliminates forces in the 'Y' and 'Z' directions, which would not be useful in prescribing a load in the 'X' direction. Figure 3 shows the isometric and front view of the resonant structure and impacting block.

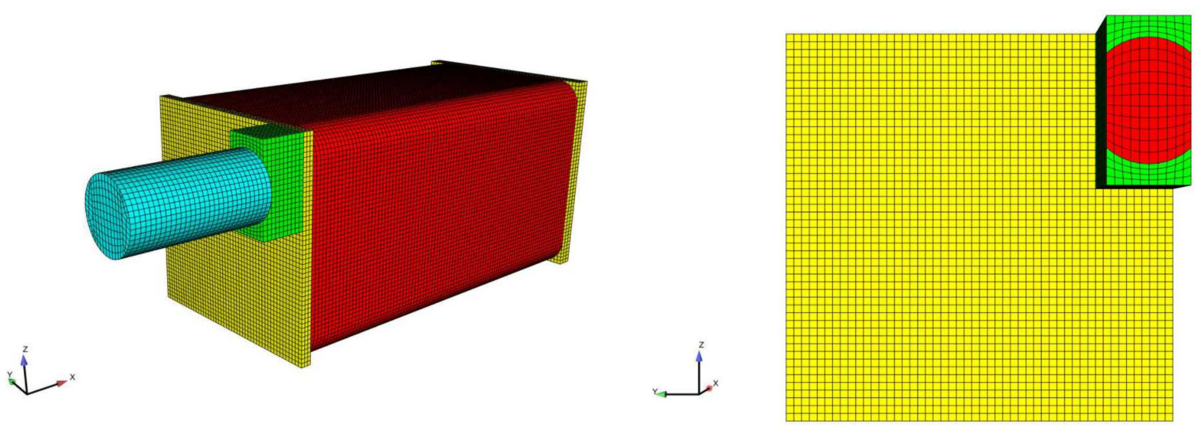

Figure 3: Isometric image of Projectile and pedestal setup (left). Front view of impact block with impacting area highlighted (right).

Since the load is not applied through the center of gravity, the force from the projectile, while not containing 'Y' or 'Z' components, will impart a moment about 'Y' and 'Z', which is the basis for the three axis excitation.

ANALYSIS

The results from the Sierra SM contact force extraction produce a load profile as shown in Figure 4.

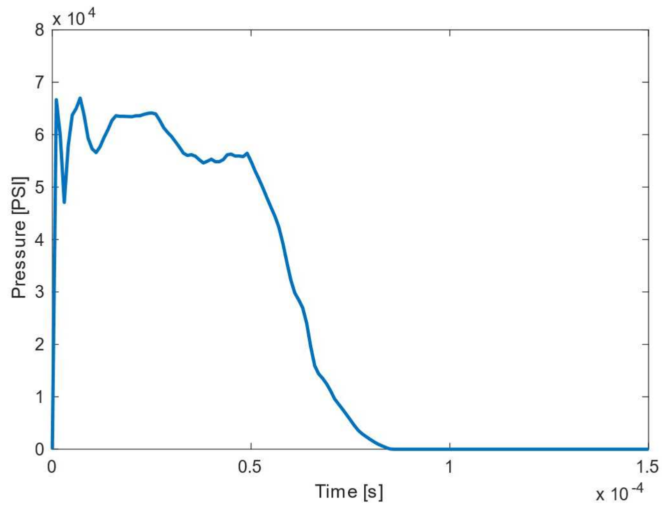

Figure 4: Input that found using Sierra SM frictionless contact. The load profile has a peak amplitude of 67,000 PSI.

When comparing the Sierra SM contact force results in Figure 4 to the original profile in Figure 1, the two largest discrepancies are the pulse length and pulse amplitude. Additionally, the rise time for the Sierra SM results is much steeper. This shortening of the loading time vastly increases the amount of high frequency response that will be in the system.

The SRS for the 'X' axis response for the original profile and the profile found from Sierra SM are shown for four separate locations shown in Figure 5.

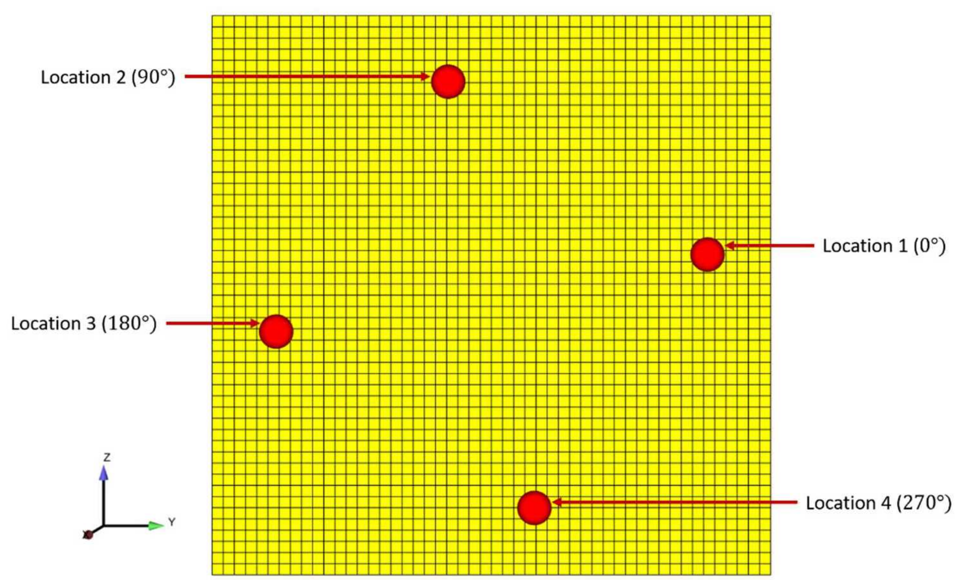

Figure 5: Diagram of four locations along with relative orientation angle in the 'Y-Z' plane

Because of the orientation of the locations about the 'Y-Z' plane, there are different expected responses at each location. The model and test results corresponding to the given 'X' axis specification is shown in Figure 6.

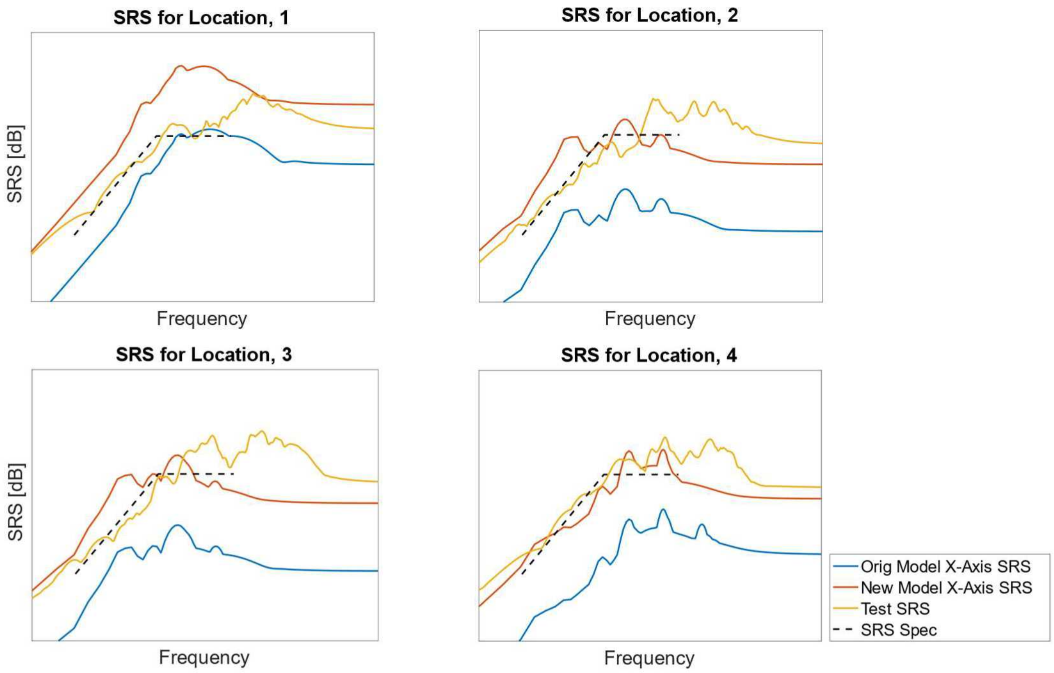

Figure 6: ‘X’ axis SRS response at four separate locations for the original model load profile and the new model load profile along with the SRS Spec for the ‘X’ direction.

As seen in Figure 6, the new model load profile has better agreement with the test data. The average dB error from the model to the test data goes from 14.19dB with the original model load profile to 7.07dB with the new model load profile over the frequency range of the SRS specification. This is a 475% improvement in the error.

Since this is a three axis test, the off-axes acceleration at the same 4 locations was captured simultaneously via a tri-axis accelerometer. The ‘Y’ and ‘Z’ response data is shown in Figure 7 and Figure 8 respectively.

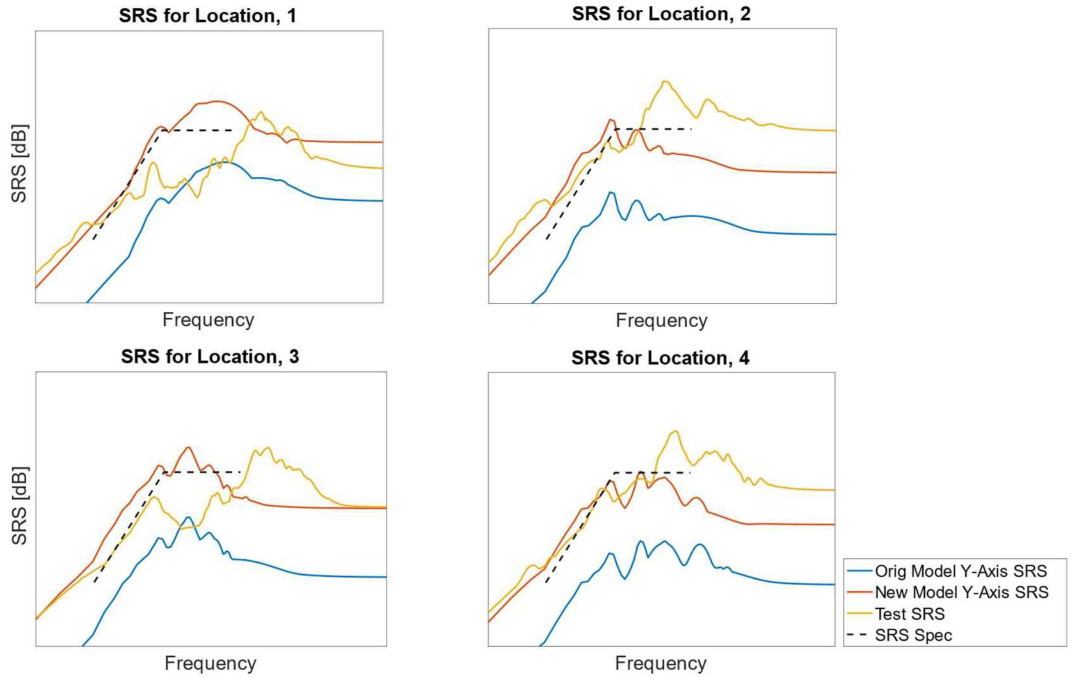

Figure 7: ‘Y’ axis SRS response at four separate locations for the original model load profile and the new model load profile along with the SRS Spec for the ‘Y’ direction.

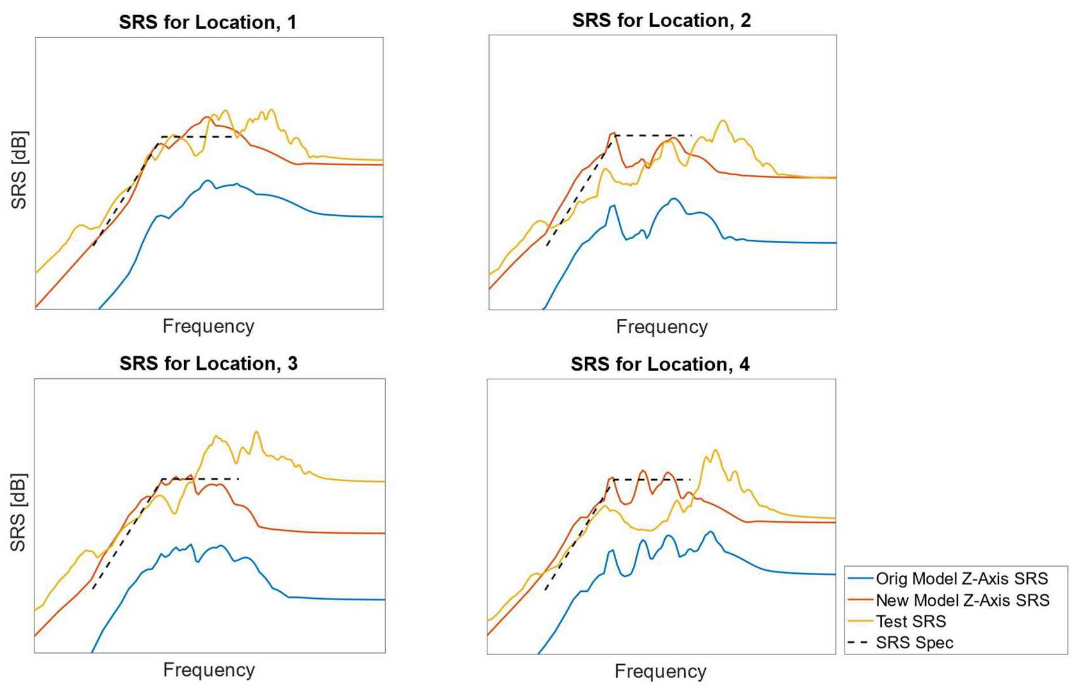

Figure 8: ‘Z’ axis SRS response at four separate locations for the original model load profile and the new model load profile along with the SRS Spec for the ‘Z’ direction.

As seen in Figure 7 and Figure 8, there is also noticeable improvement in the SRS from the original model load profile to the new model load profile including an average dB decrease in error of 14.23dB to 7.76dB for the ‘Y’ direction and 15.36dB to 4.58dB for the ‘Z’ direction. This is a 440% and 720% decrease in error respectively.

CONCLUSION

Assuming a linear model, the SRS results can be scaled for the original model load profile using a scale factor, and the results would have a closer match the test. The major drawback to this, however, is that the system must be assumed to be linear and that the SRS output must be known to determine the scale factor. For modelling performed prior to a test, there is no known response for the system to match the model via scaling or to find the force via traditional inverse methods. However, the load profile found using this method can be applied to new test articles given the same projectile and resonant structure configuration, making it possible to perform in a repeatable fashion. Further discrepancies of the model's response to the calculated load input can be attributed to uncertainties in other areas of the model.

Going forward, this method has proved useful in determining loading conditions for single and three axis testing. In the current work, there are efforts to add a 'programmer material' to the Sierra SM simulation to further enhance the fidelity of computing a delivered impulse for different test setups. Additionally, there are current efforts to introduce non-linear materials to the simulation environment, which show stiffening or softening given higher amplitude inputs. These types of non-linearities would remove the ability to effectively scale the output given previous approaches.

ACKNOWLEDGEMENTS

David Weigand – Project Leader and Technical Direction**;** Bill Bonahoom – Hardware Development and Test Engineer**;** Mikhail Mesh – Technical Consultant**;** Matt Spletzer – Resonant Fixture Test Engineer

REFERENCES

[1] Schoenherr, T. F., Calculating the Impact Force of Supersonic Hail Stones Using SWAT-TEEM, Conference Proceedings of The Society for Experimental Mechanics Series, Shock & Vibration, Aircraft/Aerospace, and Energy Harvesting, Vol 9, pp 67-79, 2015.

[2] Risaliti, E., Cornelis, B., Tamarozzi, T., Desmet, W., A State-Input Estimation Approach for Force Identification on an Automotive Suspension Component, Conference Proceedings of the Society for Experimental Mechanics Series, Model Validation and Uncertainty Quantification, Vol 3, pp 359-369, 2016.

[3] Klinkov, M., Fritzen, C. P., An Updated Comparison of The Force Reconstruction Methods, Key Engineering Materials, Damage Assessment of Structures, Vol VII, Pp 461-+, 2007.

[4] Sierra Solid Mechanics Development Team. Sierra Solid Mechanics - User's Notes. Technical Report SAND2018-2961, Sandia National Laboratories, April 2018.

[5] Sierra Structural Dynamics Development Team. Sierra Structural Dynamics - User's Notes. Technical Report SAND2018-2449, Sandia National Laboratories, March 2018.