Development Of A Test System To Replicate The Shock Profiles Through Small Arms Accessories

Nigel Linden
ReTest Equipment
40 Carriage Lane
Burnsville, MN 55306
(612)747-8378

ABSTRACT

Several vendors provide accessories that attach to small arms. These accessories generally involve optics and electronics that are subject to the harsh shock profile generated when the weapon is fired. In the past, these accessories were evaluated and developed through live firing in a range. This has been extremely costly and time-consuming, and the variability of live fire has made A-B comparisons difficult. This paper presents a novel test system and methodology that has been developed to reproduce a typical shock profile in these accessories. A shock-amplification fixture was developed that is mounted to a standard Electro-Dynamic Shaker. This fixture is able to shoot over 18,000 rounds per day, at minimal cost. The paper will compare data recorded on the range, with the same recordings on the test fixture.

INTRODUCTION

SOPMOD is a division within the Naval Surface Warfare Center in Crane Indiana. Concerned with weapons specifically for special operations, SOPMOD works with vendors to help them develop small arms accessories that are suitable for their applications. These accessories are small units that mount to the rails of combat rifles to enhance the soldiers aiming capability under various conditions.

The War on Terror has significantly changed the nature of the battlefield. Soldiers now fight the enemy at close quarters in an urban environment. To maintain a strategic advantage, our troops need to be able to remain invisible, while being able to sight the terrorists. This has spurred a significant increase in the level of technology that is bolted onto a weapon. Since these accessories involve delicate optics and electronics, they must be adequately ruggedized to withstand the harsh environment under battle.

SOPMOD subjects the accessories to a harsh battery of tests to ensure they will survive in battle, and not compromise the safety of the soldier. These tests range from temperature shock to structural shock.

Ironically, one of the most severe tests the accessories are subjected to is live fire on the host weapon. The ballistic shock that propagates through the rifle when the trigger is pulled is far more severe than any other shock the accessory sees. Traditionally, live firing is performed on a range, over several weeks, and involves around 30,000 rounds with a mix of semi-automatic and fully automatic shots. It takes 15 days to complete this test. When combined with labor hours, the rounds cost around $0.80ea to fire. The cost to live-fire test a single instance of an accessory is therefore $24,000. Since a sample size of one is rarely adequate, testing costs can be extremely high.

SOPMOD contracted with Bruel and Kjaer to develop a laboratory-based test to subject these accessories to an equivalent shock profile, under controlled conditions, and at a faster and less expensive rate than live-fire. They had already purchased a Tira shaker and control system that was to be used for this exercise.

Bruel and Kjaer contracted with ReTest to perform the test development. Since the test hardware already existed, the challenge was to develop a test that reproduced the field environment given the capabilities of the Electrodynamic Shaker.

After collecting data, it immediately became obvious that the armature of the shaker could not reproduce the measured g-levels. To solve the problem, a shock amplification fixture was designed that used the shaker to launch a hammer assembly into the rail-mounted accessory.

GUNS AND ACCESSORIES

Sets of accessories were used to develop the tests. These accessories represented a broad range of masses and mounting configurations to provide an envelope of the full gamut of possible configurations. These accessories were mounted on a range of guns, again to provide a broad range of shock profiles.

Figures 1 through 4 show the accessories tested. The ACOG is an optical scope, the PVS-17 is a night vision system, and the PEQ-2 and PEQ-5 are laser aiming devices.

FIGURE 1
ACOG

FIGURE 2
PVS-17A

FIGURE 3
PEQ-2

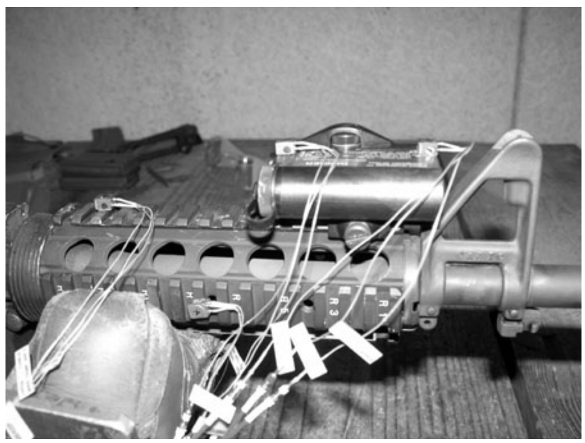

FIGURE 4
PEQ-5

These accessories were mounted on the following weapons for data collection:

- M4-A1 semi automatic with and without suppressor
- M4-A1 fully automatic with and without suppressor
- MK46 Machine Gun
- MK48 Machine Gun
- M249 Machine Gun
- M240B Machine Gun

DATA COLLECTION

Figure1 shows the location of tri axial accelerometers that were mounted to the top of the accessories. One mounted to the front, and one to the rear. This allowed measurement of the shock on all six degrees of freedom. Also two accelerometers were mounted to the rails, one to measure recoil, and one to measure radial acceleration. Data was collected on a B&K Pulse data acquisition system (Figure 5).

FIGURE 5
PULSE DATA COLLECTION SYSTEM

DATA SUMMARY

Table 1 shows a summary of the measured g levels for one accessory—the ACOG—on each weapon. The table shows the maximum positive and negative g's measured, and the range between the least severe shot and the most severe shot. This table provides an indication of the level of accelerations involved, and the deviation between shots, which was substantial. X is the acceleration in the recoil direction, Z is the acceleration in the radial direction. Transverse acceleration (Y) is ignored. As you can see, the acceleration magnitude can be up to 4,200g.

Values g/100																
	Top Front X				Top Front Z				Top Rear X				Top Rear Z			
	+ve		-ve		+ve		-ve		+ve		-ve		+ve		-ve	
	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high
MK46	5	11	4	9	2.5	6	3	6	4	11	5	10	2.5	5	2	5
M240B	5	11	4	9	3	6.5	3.5	8	6	12	6	20	3	4.5	3	7
M249	6	15	6	14	5	21	4	16	7	14	8	14	2.5	6	4	6
MK48	6	17	6	9	4	6	4.5	9	4	13	4	9	3	8	3	14
M4A1	20	36	24	42	8	16	8	16	8	17	9	20	4	12	6	9

TABLE 1
SUMMARY OF MEASURED ACCELERATIONS ON THE ACOG

EXISTING SHAKER CONFIGURATION

SOPMOD had purchased a shaker to perform this work. Table 2 shows the specifications for the system, Figure 6 shows the device itself. This system, as purchased, was to be used to reproduce the measured data.

Shaker	TV 5800/LS-330
Amplifier	A 52318
Rated Force	16kN (3.6Kip)
Frequency Range	DC-3kHz
Displacement	50.8mm (2in)
Velocity	2.5m/s (100in/s)
Acceleration	176g
Moving Mass	9.3kg (20lb)

All values are shock ratings

TABLE 2
SHAKER SPECIFICATIONS

FIGURE 6
TIRA 5880/LS-330 EDS

SHOCK AMPLIFIER DESIGN

It can be seen, by comparing the results in Table 1, with the specifications in Table 2, that the shaker itself is not capable of reproducing the accelerations measured on the weapon. To amplify the shock to the levels measured, a hammer-spring-mass assembly was designed. The original design can be seen in figure 7.

The design consists of a variable mass (called the hammer assembly) that rests on a set of springs. Weights can be added and removed from the hammer assembly, and different springs can be added and removed from the system to vary the stiffness. The hammer is Teflon coated to minimize energy loss through friction. In the original configuration, the receiver was bolted onto the top of the assembly.

After experimentation, a new fixture was designed to support the test article. This is shown in figure 8. The angle of the rail system with respect to the axis of the hammer and the adjustable hit area are intended to resolve the single-axis hammer hit into three degrees of motion: recoil, radial, and the “kick back” rotation. Figure 9 shows a photograph of the complete system. The rail is built into the fixture to allow specimens to be mounted directly.

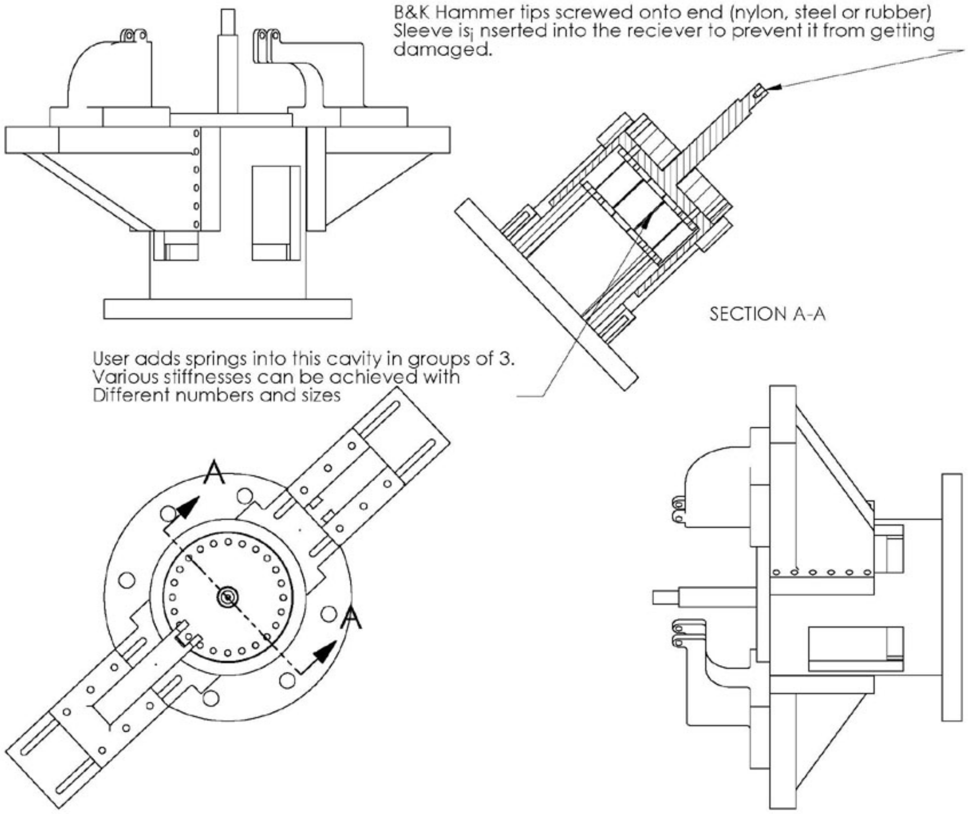

FIGURE 7
INITIAL SHOCK AMPLIFIER DESIGN

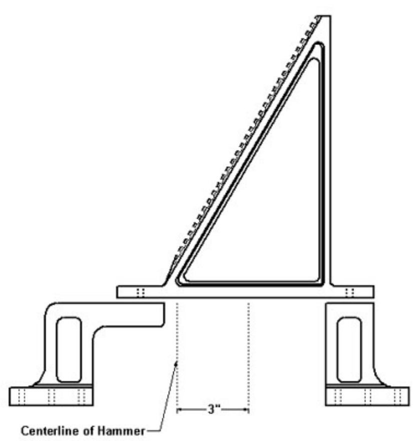

FIGURE 8
RAIL FIXTURE

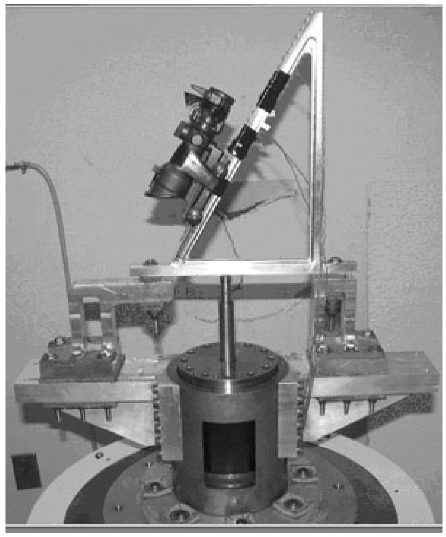

FIGURE 9
ACOG MOUNTED IN SYSTEM

SIMULATION

The armature of the shaker launches the hammer into the fixture assembly. The shock produced by the hammer is not directly controlled, only the profile used to launch it, which does provide some flexibility. The profile was shaped experimentally using a Vibration Research controller using Vibration View software. Classical shock profiling was used, and the shape of the shock is trapezoidal. The hammer tip for the simulations performed to date is steel.

The challenges in this simulation were not only to provide a shock pulse of the correct magnitude and shape, but also to reproduce a series of pulses 10ms apart to replicate automatic firing. It was impossible to create an infinite number of closely spaced pulses, because the maximum rate the system can run is around one pulse per second. However, it was possible to “double-hit” the specimen to replicate a pair of pulses. Any residual vibration in the test article that is still ringing as a result of the first hit will be amplified by the second hit, as they are in reality. However, there is not a steady-strain of pulses on the test system.

The simulator is able to shoot 18,000 to 20,000 shots per day, significantly reducing the time and cost of the test.

RESULTS

To limit the amount of data to a reasonable level, and remain within the size constraints of this paper, the results presented here will be for the ACOG simulation on the M4-A1 weapon using automatic fire. Similar results are available for all accessories and weapons tested.

Figure 10 shows five shots taken on the M4-A1. The plot is the acceleration in m/s/s of the top rear accelerometer in the Z (radial) direction. The purpose of this figure is to give an indication of the variability from shot to shot. This variability is evident not only in the magnitude of the accelerations, but in the frequency and time signatures also. Also note from this plot the pulse sequences. Two closely spaced pulses are followed by a significant time delay. The simulation focused on reproducing these two closely spaced pulses as accurately as possible, within the variability of the measured results.

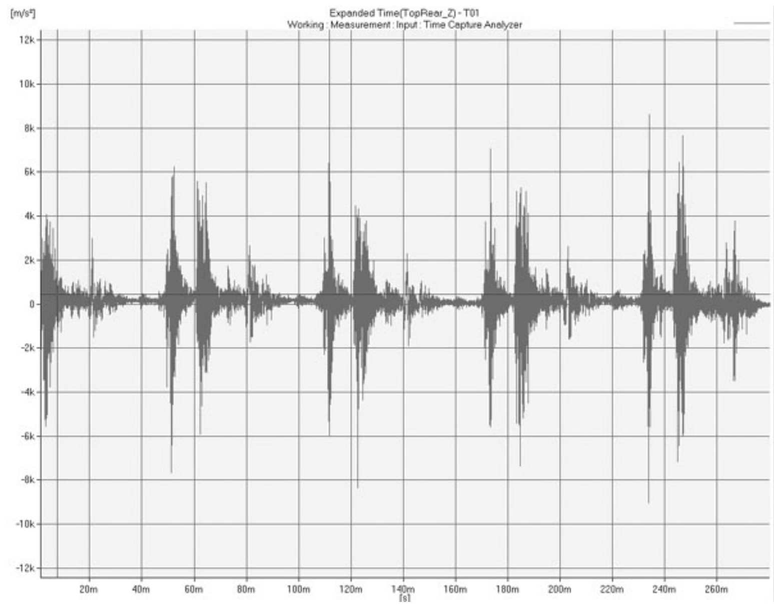

FIGURE 10
M4-A1-ACOG TOP REAR Z UNDER FULLY AUTOMATIC FIRE

Figures 11 through 16 compare pairs of pulses on the simulator vs. pairs measured on the weapon. Since the acceleration in the Y (lateral) direction is not controlled, and not a directly related to the firing event, it is not shown. The front X (recoil), front Z (radial) and rear Z directions shown fully define the controllable 3 degrees of freedom. Please note that the wide variability of firing on the weapon and simulator makes direct comparisons of single instances misleading.

Figures 17 through 22 show the Shock Response Spectra (SRS) for the same weapon/accessory combinations. Again there was significant variability from shot to shot.

DISCUSSION AND CONCLUSIONS

A shock amplification system has been shown to simulate live fire pulses on a broad range of accessories mounted to a broad range of weapons. With significant variability from shot to shot in the live fire case, it is difficult to draw conclusions regarding the integrity of the simulation. Confidence will continue to grow as field failures are replicated on the simulator.

A side benefit of developing the simulation is that it is now possible to perform HALT/HASS testing of accessories by increasing the shock amplitude to force failure.

The development of this simulation system will spawn new testing standards and techniques for the development of small arms accessories.

Once confidence is gained in the simulation, this system stands to save SOPMOD up to $100, 000 per accessory tested, with a simulation that can be closely monitored and controlled in the laboratory.

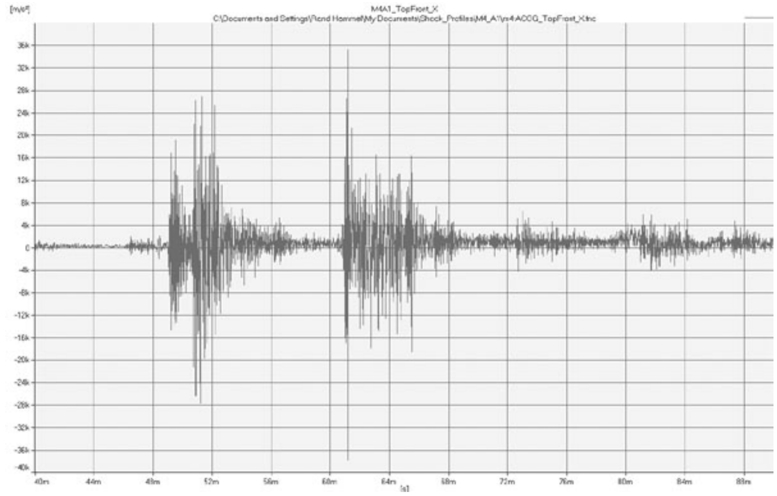

FIGURE 11
TOP FRONT X—WEAPON

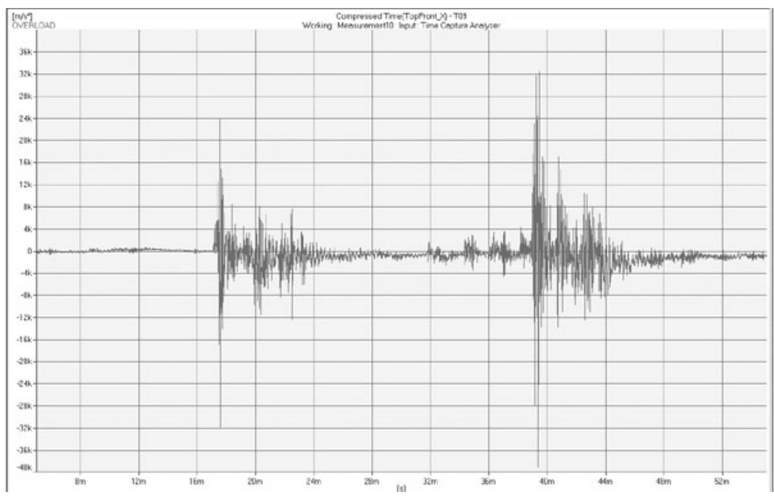

FIGURE 12
TOP FRONT X—SIMULATOR

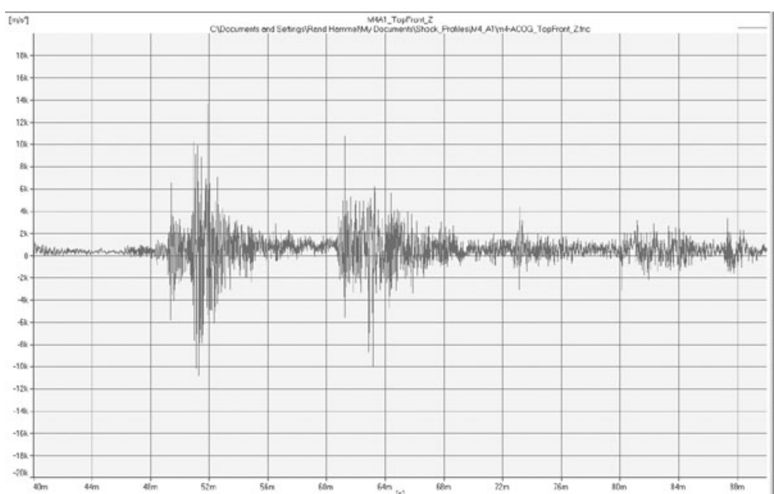

FIGURE 13
TOP FRONT Z—WEAPON

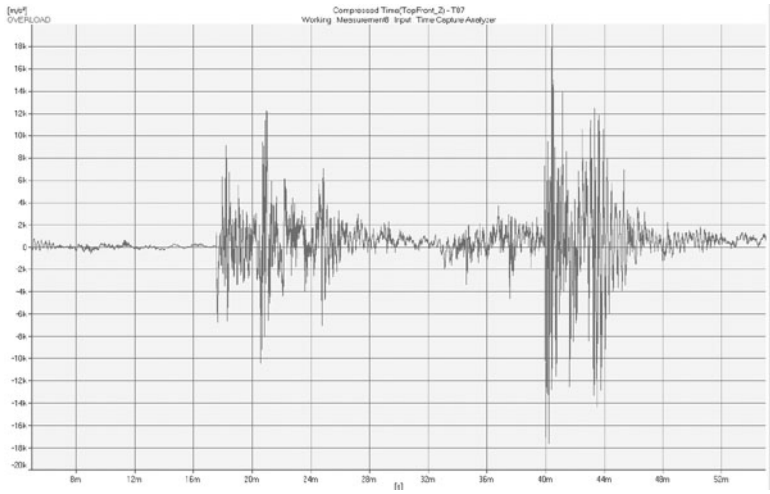

FIGURE 14
TOP FRONT Z—SIMULATOR

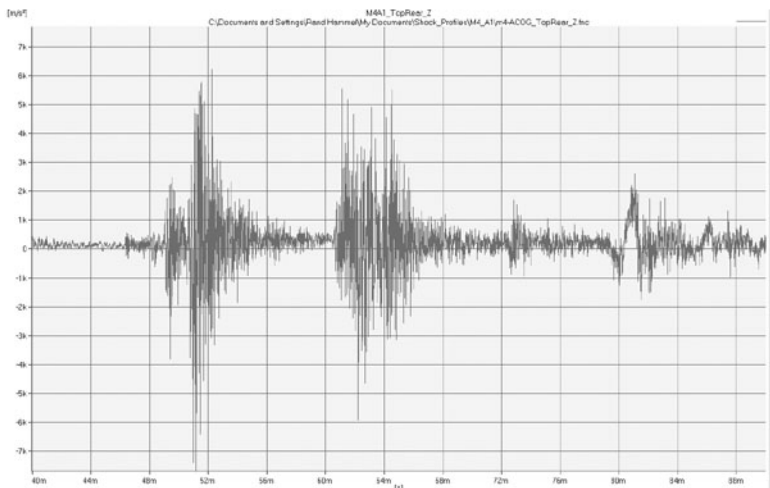

FIGURE 15
TOP REAR Z – WEAPON

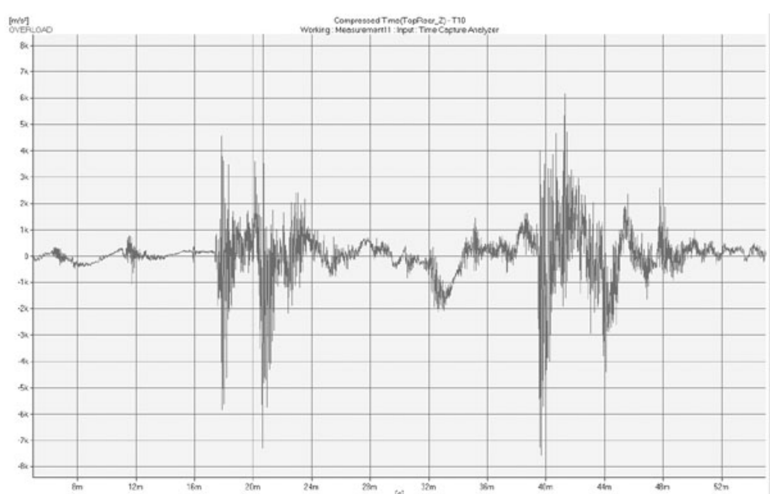

FIGURE 16
TOP REAR Z – SIMULATOR

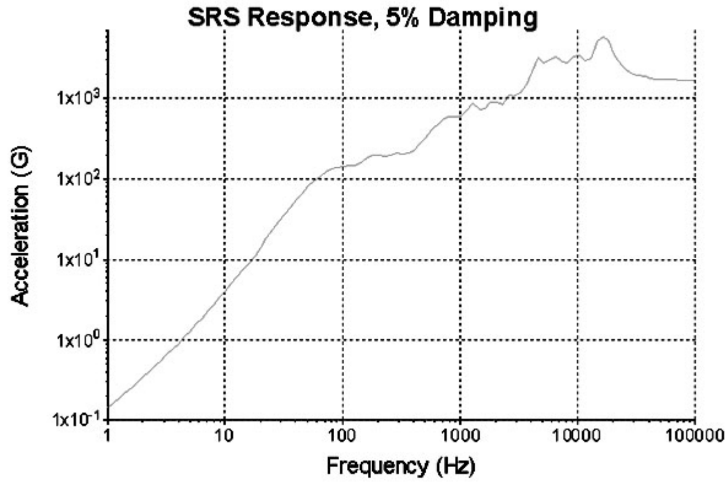

FIGURE 17
TOP FRONT X—WEAPON

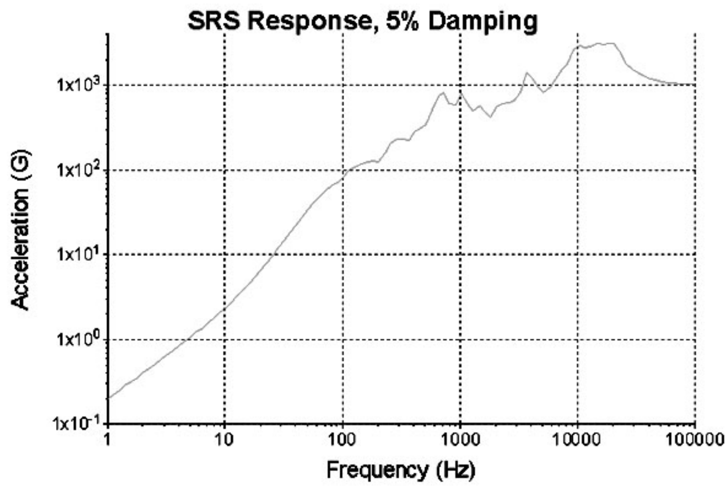

FIGURE 18
TOP FRONT X—SIMULATOR

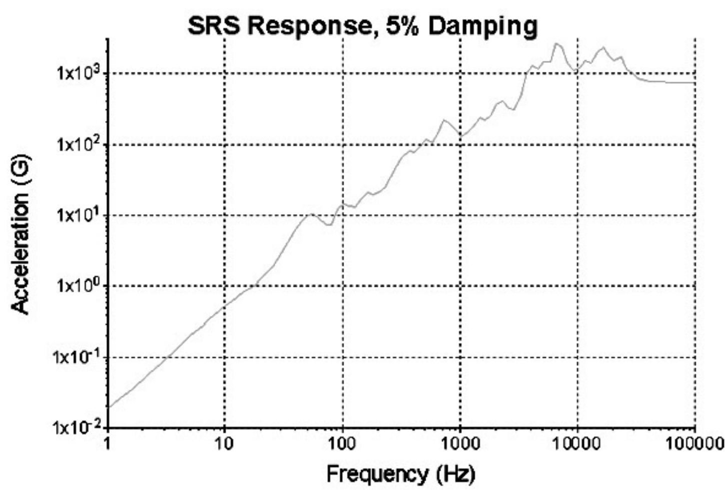

FIGURE 19
TOP FRONT Z—WEAPON

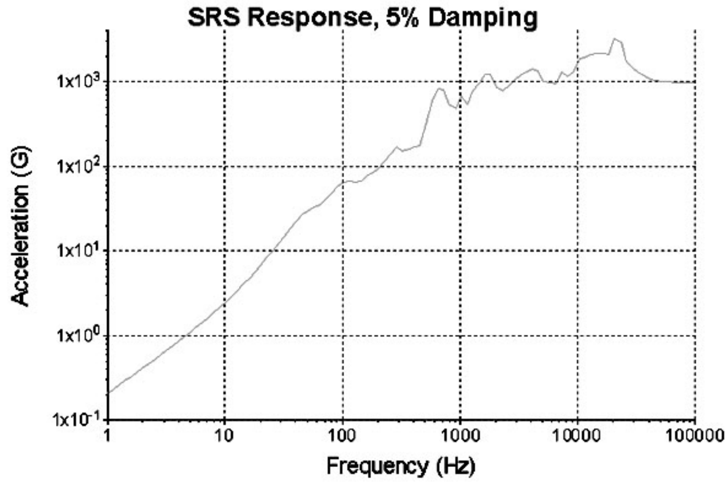

FIGURE 20
TOP FRONT Z—SIMULATOR

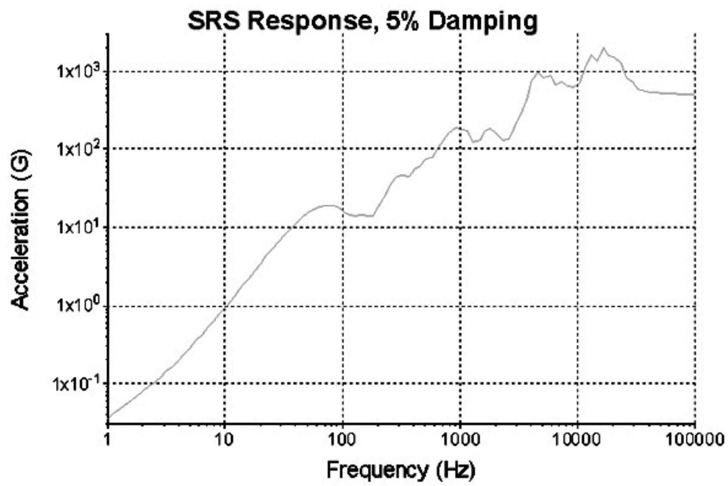

FIGURE 21
TOP REAR Z—WEAPON

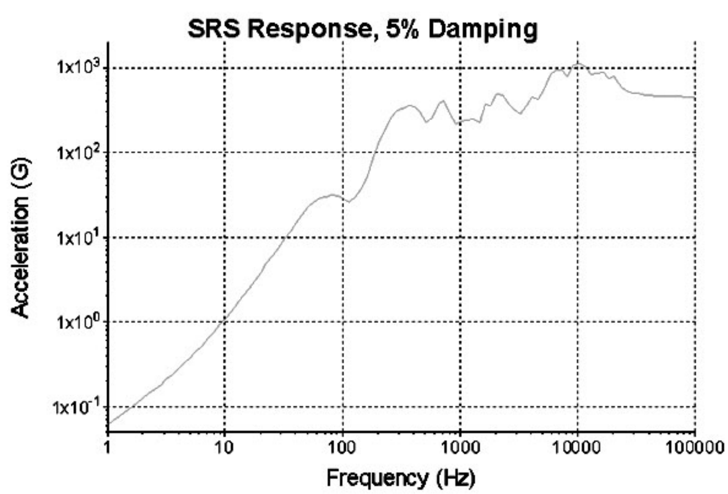

FIGURE 22
TOP REAR Z—SIMULATOR

REFERENCES

Himelblau, Piersol, et al., IES Recommended Practice 012.1: Handbook for Dynamic Data Acquisition and Analysis

Dave S. Steinberg, Vibration Analysis for Electronic Equipment

Clements, E.W., "Shipboard Shock and Navy Devices of its Simulation," NRL Report 7396, Naval Research Laboratory, July 12, 1972.

Cunniff, P.F., and O'Hara, G.J., "Damping and Recording Length Effects on Shock Spectra and Shock Design Values," 60th Shock and Vibration Symposium, Volume 3, November 14-16, 1989.

Piersol, A.G., "Pyroshock Data Acquisition and Analysis," 60th Shock and Vibration Symposium, Volume 1, November 14-16, 1989.

Thomson, W.T., "Theory of Vibration with Applications," 3rd Edition Englewood Cliffs, New Jersey, Prentice Hall, Inc. 1988

Hampton, Nathan, et al., Analytical Determination of Shock Response Spectra, for an Impulse- Loaded Proportionally Damped System

Doertenbach, N. “Highly Accelerated Life Testing—Testing With a Different Purpose,” Proceedings of the Technical Program, NEPCON West 2000, Vol. 2, pp. 765-773.

Morelli, M., “Effectiveness of HALT and HASS,” Proceedings of the Technical Program, NEPCON West 2000, Vol. 2, pp. 801-805.