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A Soft Recovery System Coupled With Advanced Diagnostics

by James M. Garner, Bernard J. Guidos, Robert A. Phillabaum, Peter C. Muller, and Eric Scheper

ARL-TR-3957 October 2006

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James M. Garner, Bernard J. Guidos, Robert A. Phillabaum, and Peter C. Muller
Weapons and Materials Research Directorate, ARL

Eric Scheper
U.S. Army Armaments Research, Development, and Engineering Center

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
October 2006	Final	January 2005 to September 2006

4. TITLE AND SUBTITLE
A Soft Recovery System Coupled With Advanced Diagnostics

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
James M. Garner, Bernard J. Guidos, Robert A. Phillabaum, Peter C. Muller (all of ARL), Eric Scheper (ARDEC)

5d. PROJECT NUMBER
AH80

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
Weapons and Materials Research Directorate
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-3957

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Testing to quantify the performance of a soft recovery system was conducted at the U.S. Army Research Laboratory's Transonic Experimental Facility. An on-board recorder (OBR) was inserted into 10 of the 14 rounds fired. Recovery of the OBR equated to recovering the projectile. This necessitated a soft recovery system for the 120-mm projectile. This report details the hardware and methodology used to create a soft recovery and notes about the results of testing.

15. SUBJECT TERMS
catcher box; large caliber; PENCURV; penetration model; projectile recovery; recovery box; soft recovery; XM1068; XM1069

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					James M. Garner
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** (*Include area code*)
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR	25	410-278-6557

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

The authors would like to thank the U.S. Army Research Development and Engineering Center at Picatinny Arsenal, New Jersey, for providing support, timely funding, and guidance. We also recognize the contributions of Messrs. Stewart Gilman, Jesse Sunderland, and Ryan Johnson of the LOS-BLOS multipurpose munitions team. We further recognize ATK (formerly Alliant TechSystems), specifically Pat Sansing, for supplying projectile hardware and for sharing the on-board recorder data and technical support. Thanks are offered to the U.S. Army Research Laboratory's Transonic Experimental Facility for the thorough and timely execution of the firings. Their accommodation of the firings was critical in allowing the test to occur.

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1. Introduction

Soft recovery of test projectiles is becoming important to evaluate new projectile designs. The development of the XM1069 (full bore) and XM1068 (saboted) line-of-sight multipurpose (LOS-MP) candidate rounds required just such testing. Several of these rounds were equipped with an on-board recorder (OBR) to enable us to understand the projectile's acceleration history. Since the OBRs were not equipped to telemeter the data, this essentially demanded a soft recovery system or method less damaging than that resulting from shooting into a sandpile (the present standard). Additionally, the volatile memory in the OBR mandated that the rounds be recovered within 20 minutes. The projectile designs tested are shown in figure 1. This report details the hardware and methodology used to create a soft recovery and reviews the data obtained from the OBRs for the two rounds.

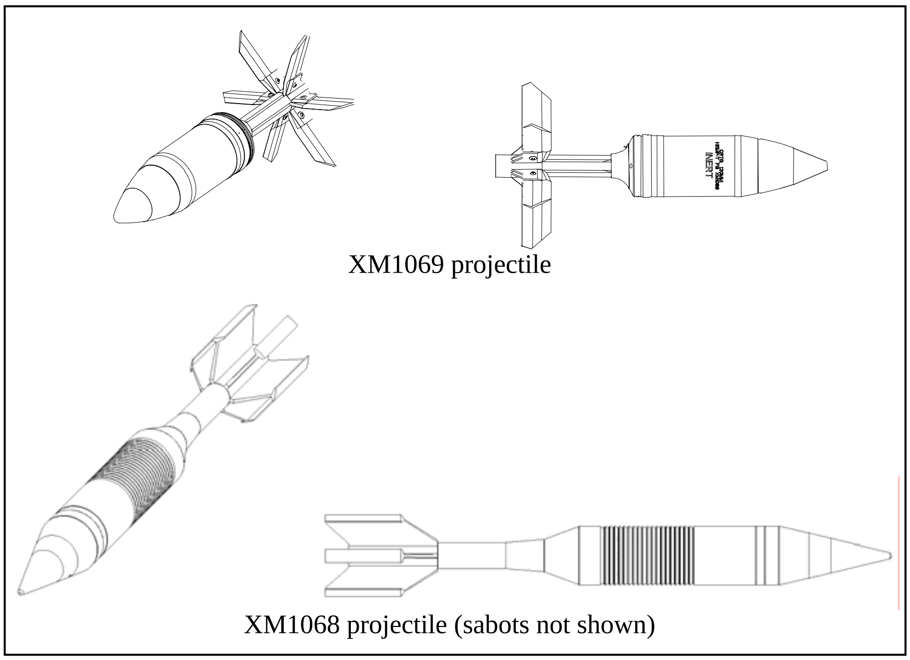

Figure 1. Sketches of the candidate XM1069 and XM1068 120-mm LOS-MP projectiles.

2. Catcher Box Setup and Parameters

The problem is, how can a 16-kg projectile with 3 MJ of kinetic energy (the XM1069) be stopped in a reasonable distance (less than 9 m) with the use of readily available materials, without damaging the projectile? A series of semi-enclosed catcher boxes with adjustable filler materials was offered as a possible solution. The design used a series of four boxes with armor-sided floor, walls, and roof. A sacrificial plywood retaining sheet was used in the front and back to hold the filler. The plywood face and rear sheets also served as witness panels to help focus the search for the projectile in a specific area. Differing penetration characteristics of future test projectiles suggested a modular nature for the soft recovery system so that multiple boxes and their fill material could be varied. The spacing between these boxes balanced the need for access to the box to recover the projectile, versus the spacing required to minimize the chance of the projectile escaping via an errant trajectory. Figure 2 shows a post-firing photograph of a target and the first catcher box, as well as some of the diagnostics employed to record the impact of the projectile into the concrete target. The resultant penetration depths for the XM1068 and XM1069 did not vary widely and the number of boxes and fill remained the same throughout the test.

Figure 2. A post-firing photograph of the first catcher box after the concrete target.

A bound, 8-inch-thick concrete slab was the initial target of choice from which deceleration levels were desired. Later shots used a simulated bunker wall as the target and noted the corresponding decelerations. Figure 3 shows a more complete schematic of the catcher box design without the roof plate. Previous efforts at the (former) Ballistics Research Laboratory used water as a deceleration medium (*1*). The water spray system of the past was designed for a 155-mm projectile recovery and allowed a projectile trajectory of only a few feet. Sand has also traditionally been used as the standard stopper material, but it was often very damaging to the projectile and produced instances when the round exited the sand with great energy. Alternate material choices were required.

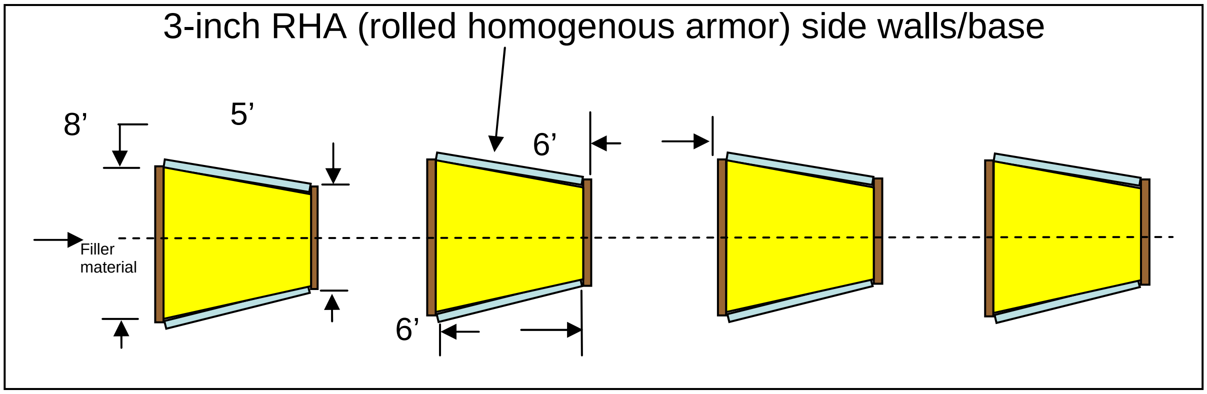

Figure 3. A schematic of the full catcher box system.

An extremely simplified understanding of penetration mechanics is that penetration is based, to a first order, on target density. Given this, the following deceleration (filler) materials were considered: water, sawdust, hay, and mulch. Water is a choice that requires a liner to seal the system. Filling a catcher box with water between each firing was considered problematic and time consuming. Bailed hay was not readily available but appeared to be an attractive alternative, although hay alone would not be adequate. Mulch (defined here as a mixture of ground wood and soil) was eventually selected for trial since it was available, inexpensive, and easily loadable into the catcher boxes. The recovery method tested during the LOS-MP firings was a graded density system, in that it used mulch and sand. The least dense stopper materials are penetrated first and slow the round so that the denser materials, impacted later, impart less of a shock to the projectile. Table 1 lists the densities for the various stopper materials considered.

Table 1. Densities of selected media.

Media	**Density (lb/ft^3)**
Sand	85.58
Mulch	24.73
Sawdust	7.59
Hay	1.67

First order, zero-yaw approximations via PENCURV[1]+ (*2*) indicated that 20+ feet (three boxes and part of a fourth) of sand would stop the projectile. Of course, several conditions can cause stopping distance estimates to vary widely. The yaw angle of the projectile upon impact and during penetration, the dynamic shape of the projectile, and the non-homogeneity of the fill material are but a few variables that can substantially affect the stopping length estimates. PENCURV+ assumes rigid body penetration. In all the experiments, the projectile bodies deformed and lost penetration efficiency. PENCURV+ does not predict projectile deformation

[1]PENCURV is not an acronym.

but it does allow input for pitch and yaw and reduces the penetrator efficiency for yawed rounds. Unfortunately, no yaw data or velocity data were obtained between the recovery boxes in the array. In order to match the experimental results, the strength (penetration resistance) of the mulch was adjusted. Figures 4 through 8 illustrate these results. The ability to match the penetration results indicates that estimates of the number of boxes and fill material can be made for other firings. This is important since testing of rounds that require recovery is ongoing. PENCURV+ modeling is presently the sole computational indicator for fill material and expected penetration depths.

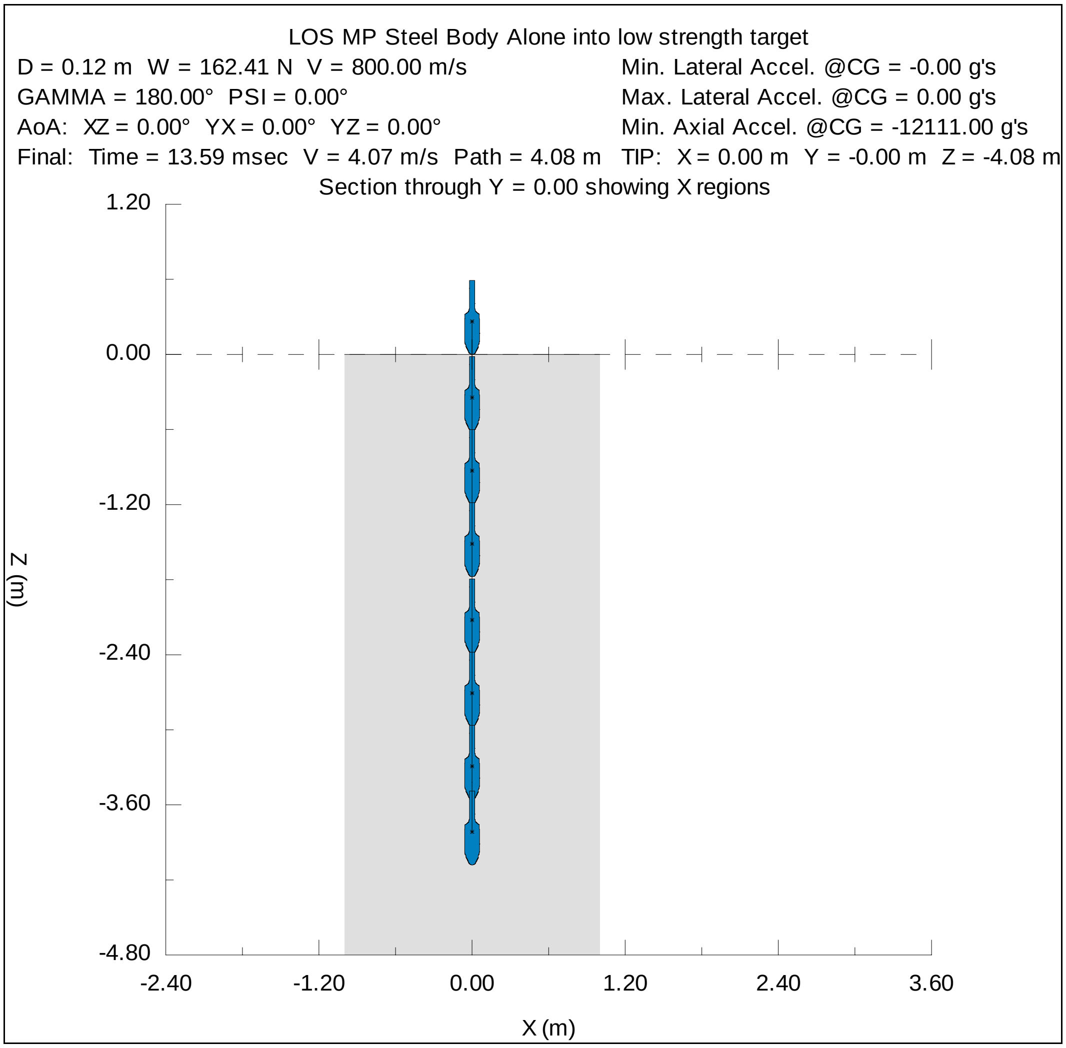

Figure 4. PENCURV+ result of XM1069 penetrating continuous mulch media.

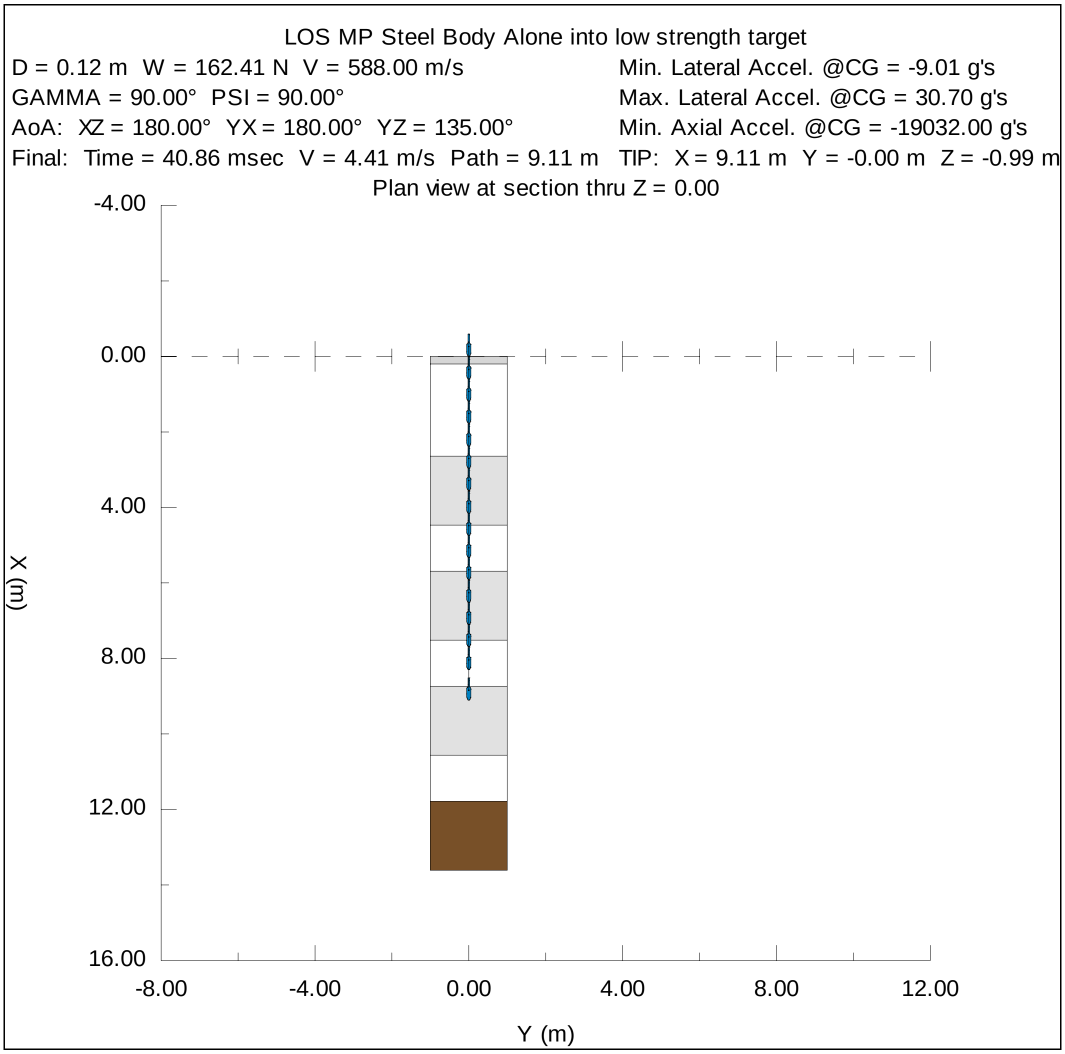

Figure 5. PENCURV+ result from XM1069 impact with 203.2-mm concrete wall.

The results from the mulch fill arrangement were generally good from the standpoint of round recovery, as noted in the test record in table 2. The projectile recovery time varied from picking up the round between the second and third boxes (no digging or searching required) to loss of the round. There is still substantial improvement to be made though. Ideally, the round would be recovered just after it exited the fourth catcher box (so that the most gradual deceleration could be created), but the time required to optimize such a system and replace all the various media in their required amounts was not considered worthwhile in support of LOS-MP testing. Additional recovery testing can help fine tune the process and improve the experimental results and the modeling.

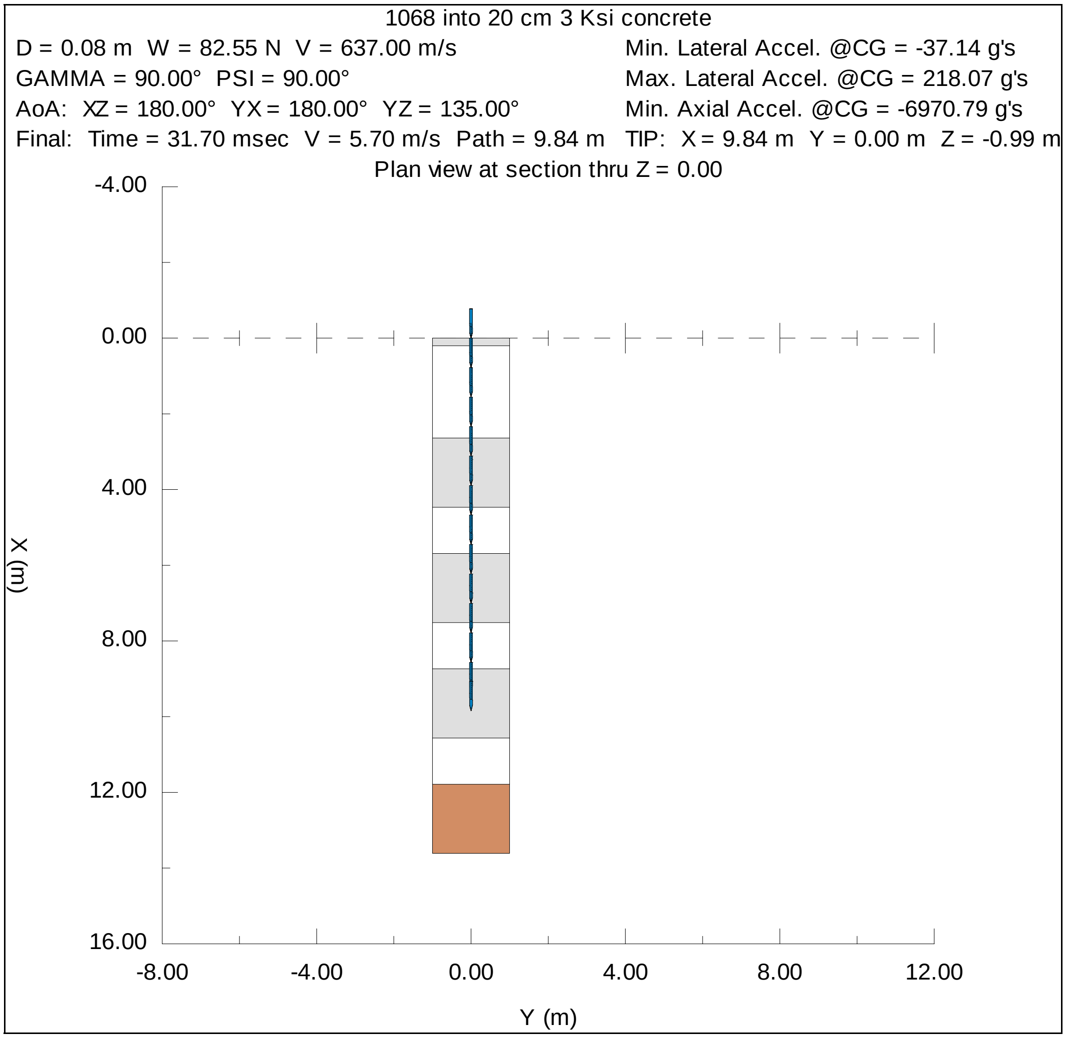

Figure 6. PENCURV+ result from XM1068 impact with 203.2-mm concrete wall.

Figures 9 and 10 show the projectile before and after recovery. The damage shown in figure 10 (no fins and paint stripped) is believed to be largely the result of the interaction with the concrete target. The nose was removed so we could access the OBR in the figure. Rounds fired into mulch alone and recovered display little or no projectile degradation.

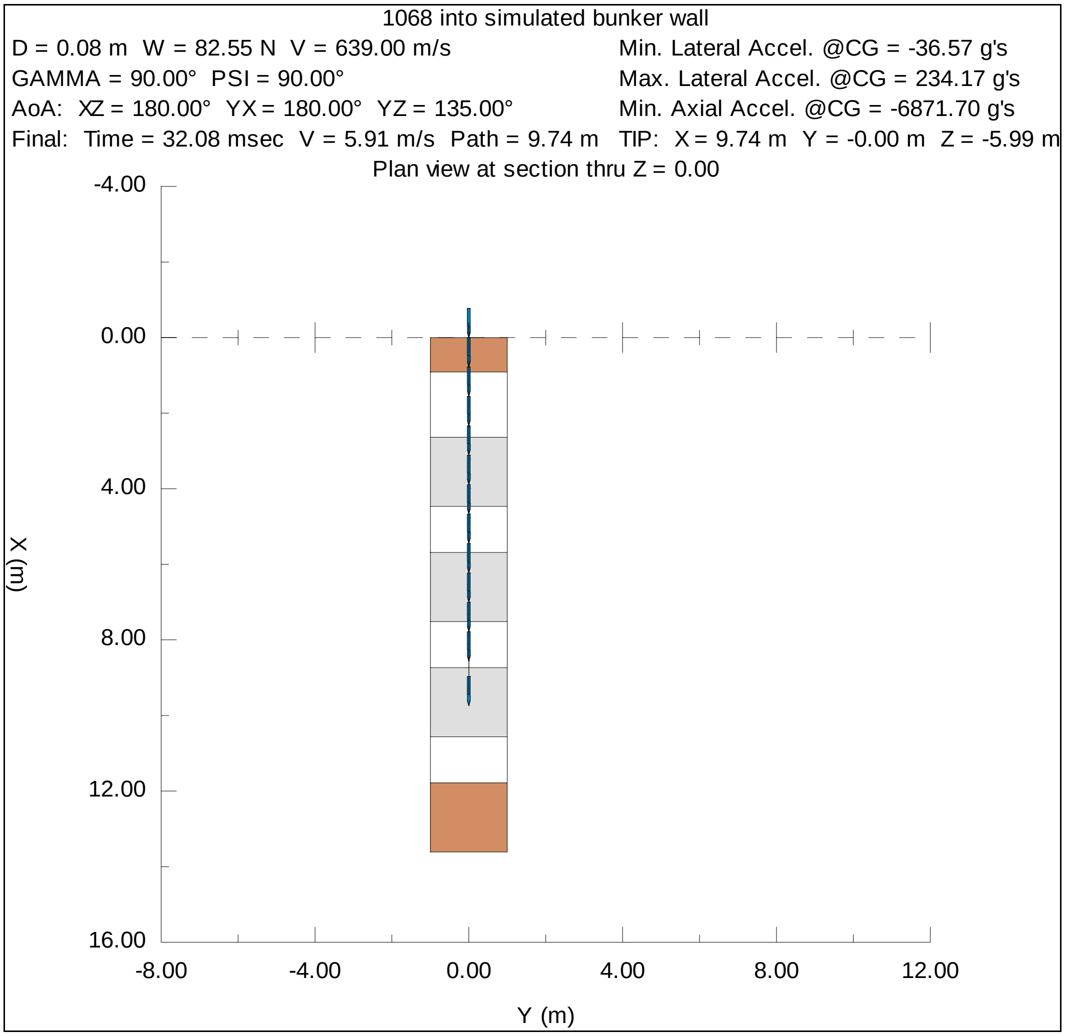

Figure 7. XM1068 through bunker wall into recovery array.

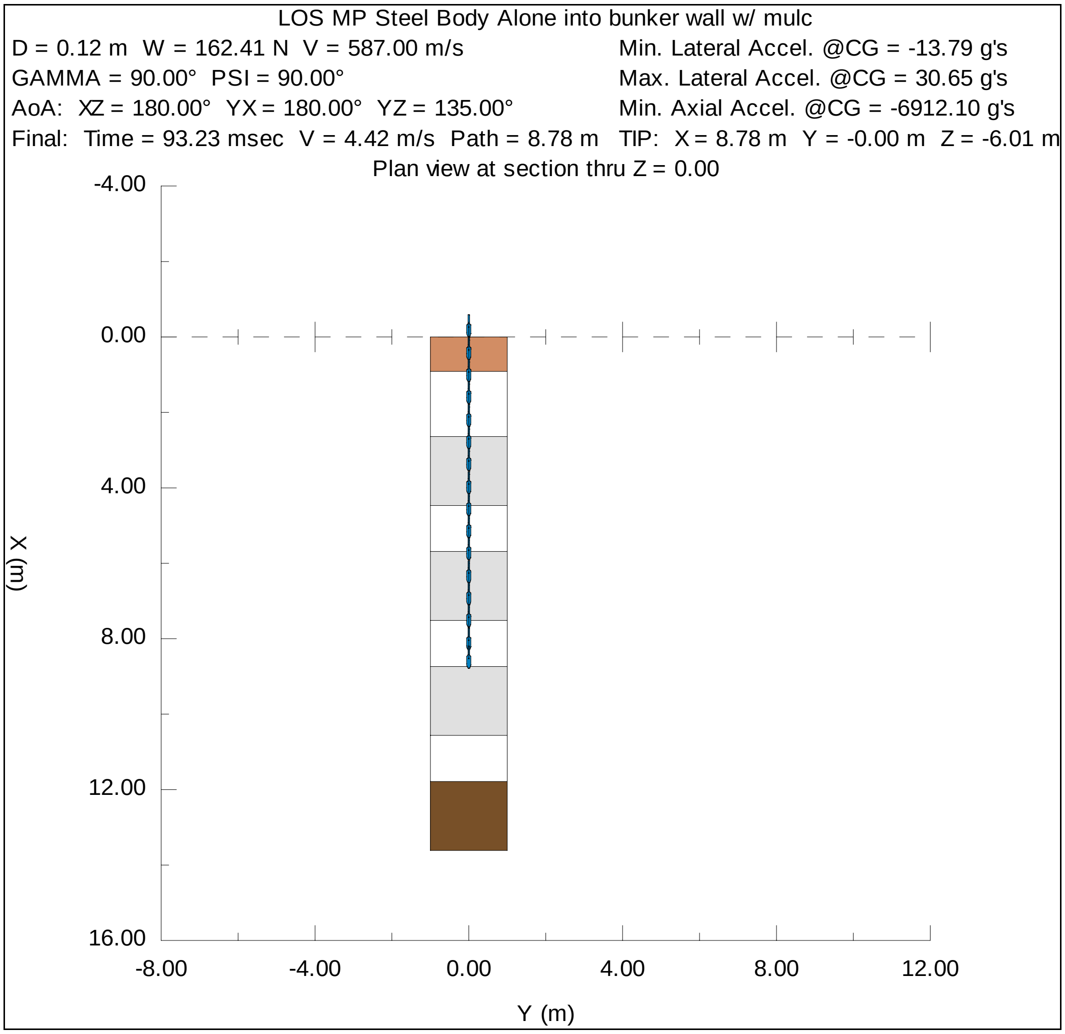

Figure 8. XM1069 through bunker wall into recovery array.

Table 2. Firing history for OBR rounds.

Round No.	Projectile	Round Recovered	Round Location	Muzzle Velocity (m/s)	OBR Function
ARDEC 36298	XM1069	fragments	between boxes 2 and 3	N/A	destroyed
ARDEC 36299	XM1069	yes	skipped out of box 2 rear	N/A	unusable data
ATK 36300	XM1068	yes	mid box 2	630	good data
ATK 36301	XM1068	yes	just into box 3	642	data are clipped
ATK 36302	XM1068	no	N/A	650	N/A
ATK 36303	XM1068	yes	mid box 3	639	data are clipped
ATK 36304	XM1068	fragments	N/A	656	destroyed
ATK 36305	XM1069	yes	skipped out of box 2 high	584	batteries destroyed
ATK 36306	XM1069	yes	between boxes 2 and 3	587	perfectly functioning
ARDEC 36307	XM1069	yes	mid box 3	589	OBR not functioning

Figure 9. Pre-assembly photograph of the XM1069 with cartridge case adapter.

Figure 10. Recovered XM1069 through bunker wall into recovery array.

3.   Experimental Results and Analysis

The data retrieved from the OBRs told much about the projectile flight. Unfortunately, only some of the rounds produced usable OBR data. Firings in which the round struck the steel side walls generally resulted in nonfunctional OBRs. Apparently, the combination of the impact shock and the high frequency resonance is enough to render the circuitry nonfunctional. Figure 4 shows the catcher box arrangement for shot 36306. Not shown in figure 11 is the fourth catcher box (filled with sand), since it never was penetrated by any of the firings and is omitted for simplicity. The results from the recovered ARL OBR are shown in figure 12. The black traces are the raw data and the red line inside the black markings is the filtered signal. Fortunately, this round was not damaged severely and its OBR functioned ideally after recovery.

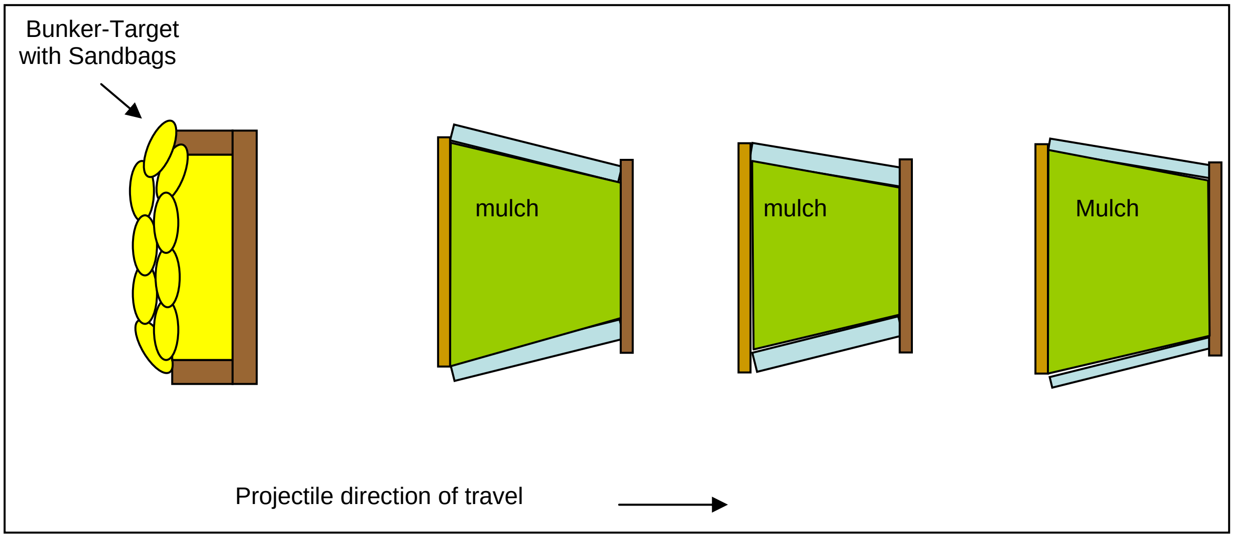

Figure 11. Target-catcher box setup, shot 36306.

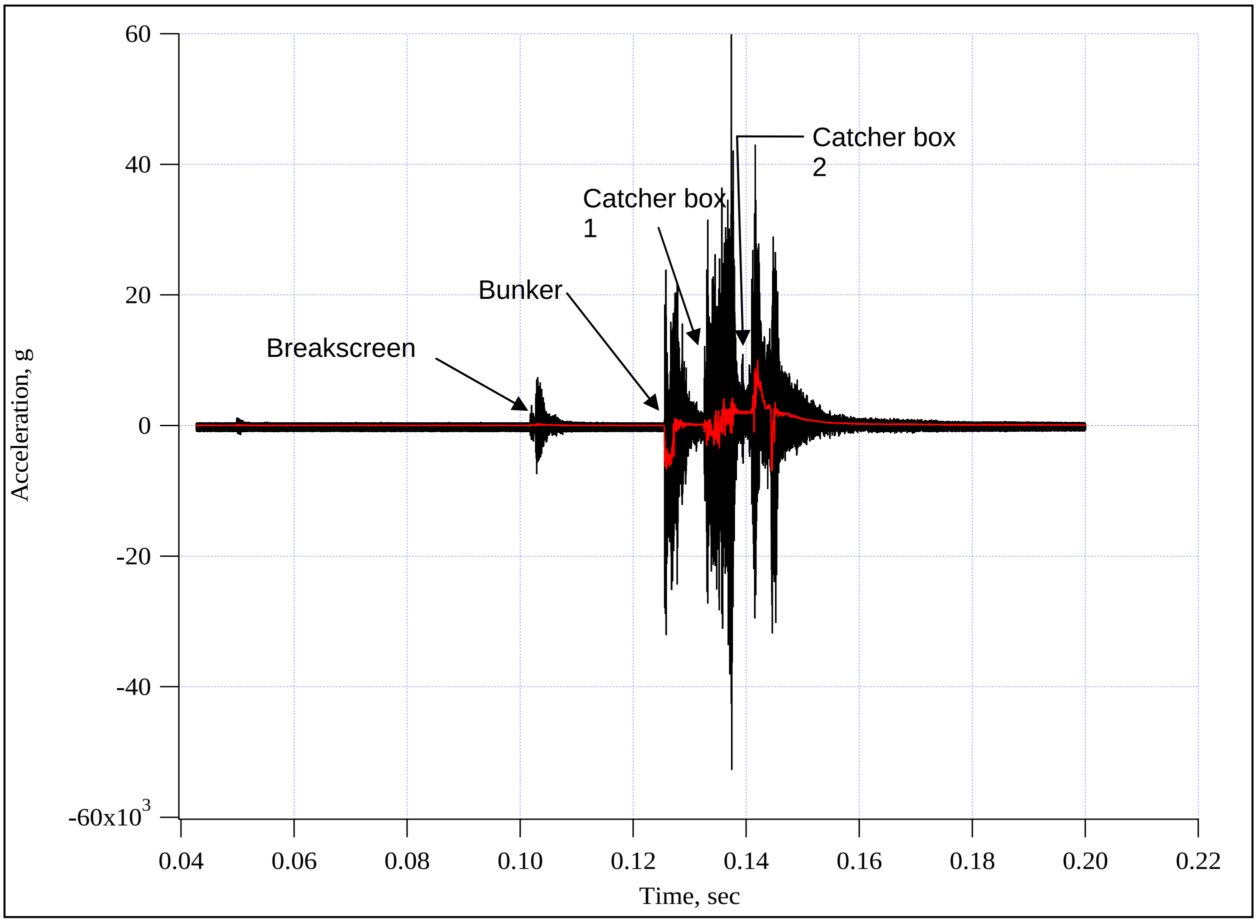

Figure 12. OBR response for shot 36306.

The initial impact that the round makes is with a chipboard sheet (not shown in figure 11) used as a trigger for the cameras. Deceleration registers as a negative signal because of the accelerometer orientation. This impact has a brief effect on the OBR but results in little deceleration of the projectile. A more pronounced effect is seen when the projectile encounters the sandbags (simulated bunker wall face). Figures 13 and 14 show a magnified version of the bunker wall face and catcher box impact traces, returned from the OBR. The duration of the pulse is predictably longer and shows a prolonged downward dip and flat lines upon exiting the bunker target. The next trace spike correlates to the impact into the first catcher box. Although it is tempting to estimate a velocity because we know the distance between the bunker and catcher box, it is uncertain time-wise as to exactly when the projectile exits, and this makes a precise velocity prediction challenging. Since this particular firing only impacted the mulch-filled catcher boxes, a comparison to the deceleration performance of the spectrum of media densities could not be created.

As the projectile exits the first catcher box, it appears to have a flat line (filtered signal shown in red in figure 5) at a non-zero value. The acceleration level should be essentially zero with the projectile in free flight as it exits the first box.   The probable cause of the non-zero acceleration level is the rotational energy (tumbling) of the projectile as it interacts with the mulch in the first catcher box. This projectile acceleration level is described by an $r \times \omega^2$ with r being the distance to the center of rotation from the accelerometer and ω the rotational velocity of the projectile body as it tumbles in the filler material. Rotational forces and rates arise from the interaction of the yawed projectile with non-homogeneous filler (mulch). This is an artifact of the filler composition (some pieces of ground wood are larger than others and oriented differently) and potential voids that result from the filling of the boxes. The transition to free flight represents a large density change and can magnify yaw rates.

The large acceleration spike as it enters the second catcher box is positive and is counter-intuitive to the projectile decelerating. In real terms, this positive value probably indicates that the projectile has impacted the second box base first, and accordingly, the acceleration-deceleration directions have been reversed relative to their initial orientations.

Markers of known acceleration magnitude or timing in the data traces are very valuable in assessing the data returns. The deceleration sequence is somewhat chaotic, and glancing impacts with the catcher box side wall are a possibility and will produce spikes in the recordings. A large downward spike is seen toward the end of the trace. This reveals that the projectile likely impacted a solid object. It is speculated that this could be the impact with the pavement after the round exited the second catcher box.

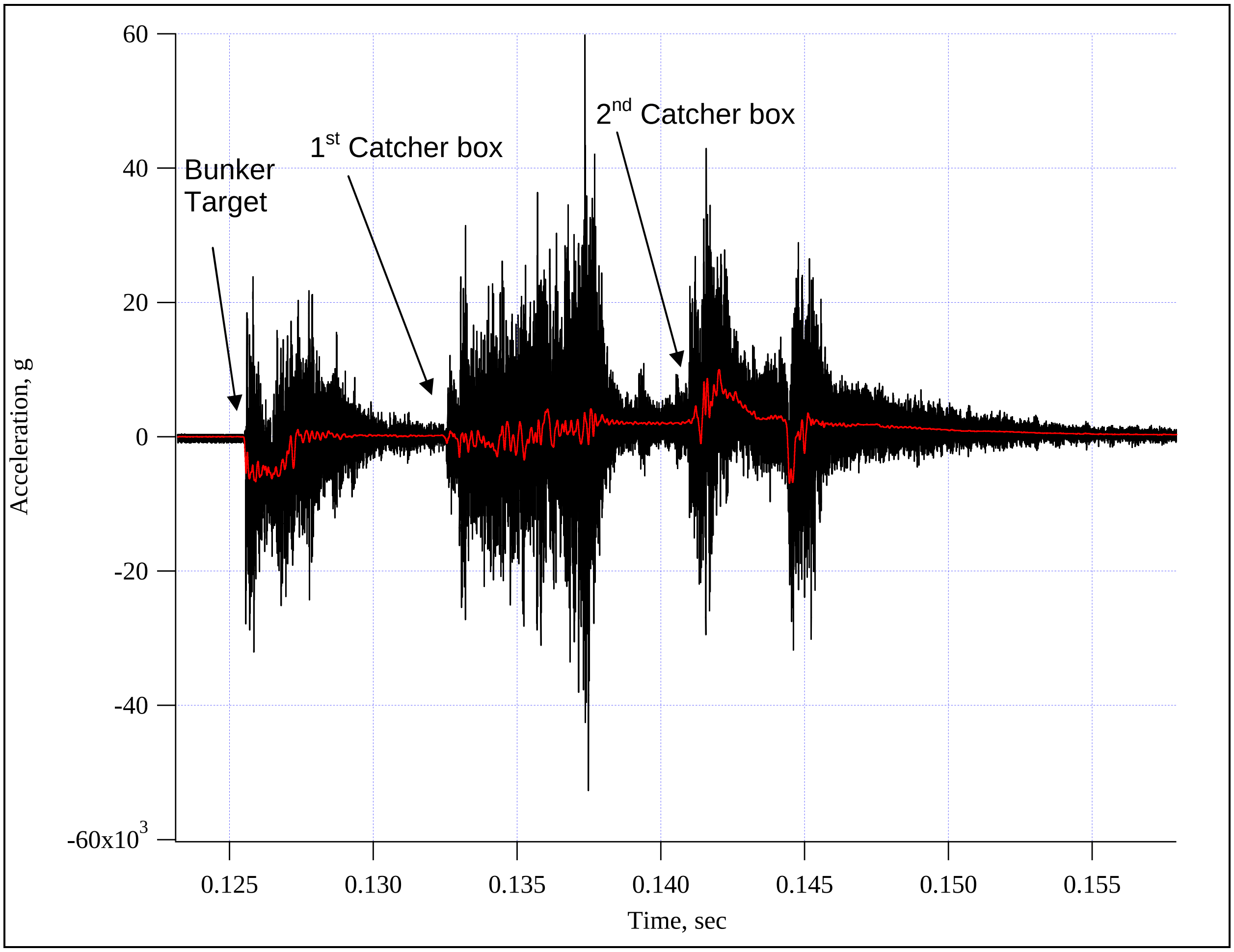

Figure 13. Magnified trace view of OBR response for shot 36306.

Figure 14 shows a filtered OBR response from the XM1068 projectile. The projectile was equipped with ATK OBRs. Some filtering has been used to extract the very high frequency responses that are not useful in analysis. Some of the data structures recorded for the XM1068 are very similar to those of the XM1069. The initial dip at the beginning of the trace corresponds to the set-back load experienced at launch. There appears to be an acceleration offset of 5000 g's in the recording from the ATK accelerometer. This is deduced since 5000 g's are registered before the shot and after the projectile exits the gun. Acceleration levels should be zero pre-shot and a very small negative value after bore exit. The origin of the smaller spike at 0.19 s is not obvious. It could represent a low velocity impact into the mulch-filled third catcher box followed by a collision with the steel roof.

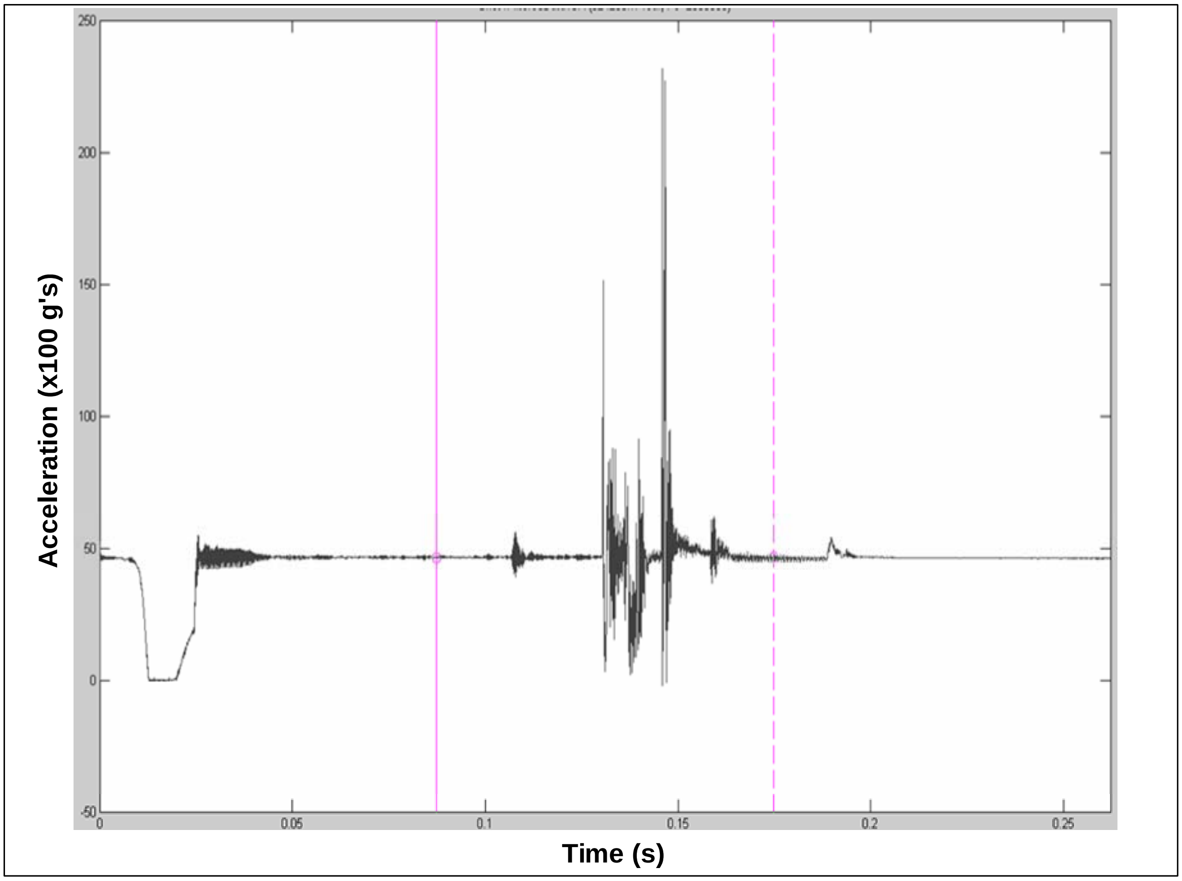

Figure 14. OBR response from the recovered XM1068 projectile.

Table 3 offers a comparison between the values from PENCURV+ and the OBR readings from the recovered projectiles. The data from the OBRs have high frequency characteristics, as seen in the preceeding figures. An exact peak deceleration is therefore difficult to state with certainty. Multiple reviews of the data produced the peaks listed in the OBR column. Although the deceleration levels do not match precisely, they give estimates of the deceleration that can be expected with a particular projectile configuration and mulch filler. This is useful for projectile design and post-shot analysis of recovered parts, as well as providing insight for future recovery efforts.

Table 3. Decelerations for the XM1068 and XM1069 projectiles after bunker wall impact.

Projectile	**PENCURV+Maximum Acceleration**	**Recorded OBR Acceleration**	**Muzzle Velocity (m/s)**
XM1068	7000 g’s	4000, -5000 g’s	639
XM1069	6900 g’s	~5000 g’s	584

Some general observations are worth noting for future efforts. The recovery rate using mulch is better than historically experienced with sand, and it is believed this is because of a softer deceleration. The use of deceleration materials other than sand is quite practical, and a greater spectrum of filler materials is desired for testing. The use of hay as a precursor to mulch or sawdust-filled boxes followed by a sand-filled box may be an effective recovery suite. The velocities tested were a little more than half the tactical muzzle velocity. Higher velocities present a greater challenge to soft catch, and softer interstitial materials may have to be employed to mitigate steel side wall impacts.

4. Conclusions

Soft recovery systems combined with advanced diagnostics can offer useful insights to the projectile acceleration history. This in turn can aid in the design of projectiles to accomplish intended objectives and increase their reliability.

Anything that creates yaw is detrimental to catching the projectile. Yaw tends to direct the projectile to the side so that it impacts the steel side wall and is damaged. If the yaw and corresponding diversion of the trajectory are unfortunate enough to happen near the rear of the catcher box, the round may miss the subsequent catcher box entirely and not be recovered at all. Larger length-to-diameter (l/d) rounds are better candidates to catch, since they are generally more resistant to yaw changes. The disadvantage of larger l/d rounds is that they tend to penetrate farther, and more deceleration material or greater density material is generally required.

Unfortunately, low yaw penetrations cannot be assured. More rugged OBRs are required since side wall impacts are destined to occur. Hardening the OBRs to shock and cushioning the walls if possible should greatly improve the percentage of rounds recovered with functioning OBRs. The data that the recovered rounds produce are generally consistent across their populations and give basis to the belief that the measurements represent real phenomena and the data are valid. Any known acceleration markers (such as the acceleration upon set-back at launch) should be recorded in the traces, if possible, since they are helpful in determining timing, gain responses and offsets (i.e., deceleration registers as a negative signal in the ARL OBR). An amount of extended vibration (ringing) exists in all the recordings, and it is desired that future generations of OBRs damp this to a minimum so that the signal will require less filtering and be more easily understood.

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2. Adley, M.D.; Berger, R.P.; Cargile, J.D.; Boswell, D.D. *Methodology and User's Guide for PENCURV+, Version 1.0*; Technical Report TR-03-2; U.S. Army Engineering Research and Development Center, Geotechnical and Structures Laboratory: Vicksburg, MS, 2003.

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