IN-BORE ACCELERATION MEASUREMENTS OF AN ELECTROMAGNETIC GUN LAUNCHER

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ABSTRACT

The US Army Research Laboratory has been involved in the design and implementation of electromagnetic gun technology for the past several years. One of the primary factors of this research is an accurate assessment of in-bore structural loads on the launch projectiles. This assessment is essential for the design of mass-efficient launch packages for electromagnetic guns. If not properly accounted for, projectile failure can result. In order to better understand the magnitude of the in-bore loads, a data-recorder was integrated with an armature and on-board payload that included tri-directional accelerometers and magnetic field sensors. Several packages were launched from an electromagnetic railgun located at Aberdeen Proving Ground, MD. Substantial effort was placed on soft-catching the rounds in order to facilitate data recovery. Analysis of the recovered data provided acceleration and magnetic field data acquired during the launch event.

KEYWORDS

Electromagnetic Gun, On-Board Recorder, Tri-directional Accelerometers, In-bore Data

INTRODUCTION

Electromagnetic (EM) Gun research has been an ongoing effort at the US Army Research Laboratory in APG, MD for the past several years. During this time, a significant amount of time and effort has been concentrated on the development of EM pulsed power, launcher design and materials and EM armatures and projectiles. The Propulsion Science Branch (PSB) of the Weapons and Materials Research Directorate of ARL has been a major contributor to this ongoing research. An Electromagnetic Railgun has been built at the ARL EM Experimental Facility in APG and is being used by the PSB to test different iterations of EM projectiles and armatures. One part of this testing is to determine the characteristics of the in-bore structural loads on the test projectiles. In order to better understand these in-bore loads, the PSB initiated a joint effort with the Advanced Munitions Concepts Branch (AMCB) to instrument a test projectile with an on-board recorder and sensors which could measure these loads. The test plan was to fire these projectiles using the EM railgun, recover the projectiles using a soft-catch recovery system and download and analyze the data from the on-board recorder. AMCB was well suited for this task since they have been providing in-flight diagnostics for a wide variety of programs and projectiles for many years. This paper will cover the design and implementation of an instrumented EM projectile which provided in-bore acceleration measurements of the EM Railgun. An overview of the projectile, sensors, electronics, test set-up and flight measurements will also be included.

FLIGHT PROJECTILE

The first step in this project was the development of a flight projectile for use in the EM gun. The projectile design used for these tests is shown in figures 1 and 2. The projectile had dimensions of 11.53cm in length and 3.81cm in diameter. Both inert, or dummy, rounds and instrumented rounds were fabricated. The dummy rounds were made of solid aluminum and would be used as preliminary shots to verify the test set-up. The instrumented rounds were also made of aluminum with a solid nose section and hollowed out body which would hold the electronics package. Each round had a weight of around 250 grams and included nylon bands which would insulate the projectile from the rails. An EM armature was used in each test to push the projectile down the tube and would become detached once the projectile exited the gun.

Figure 1: Test Projectile

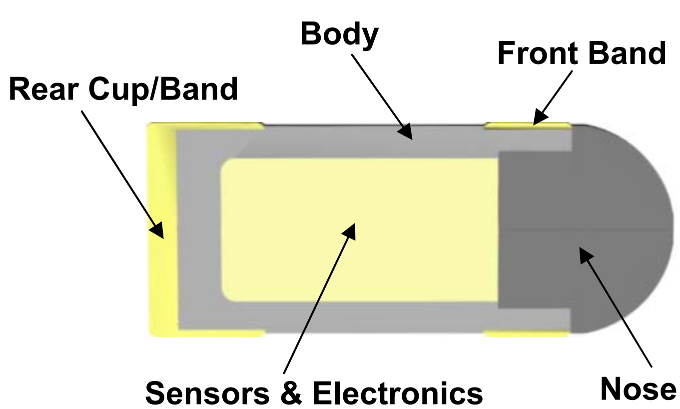
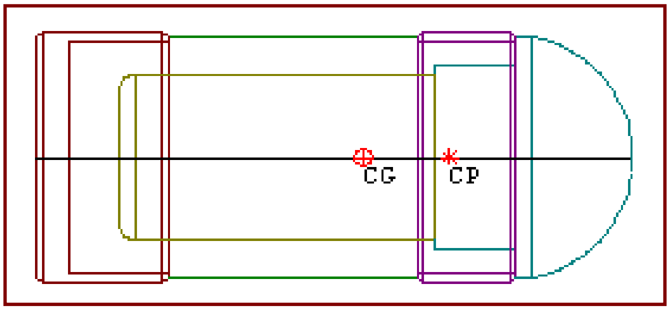


Figure 2: Cross-section of Projectile

Since a soft recovery system was being used to catch each projectile, the projectile design was focused more on impact survivability rather then flight stability. However, aerodynamic predictions were still conducted using an empirically based aerodynamic predictive code called PRODAS. The stability analysis for the final projectile design is shown in figure 3.



Muzzle Velocity	**300.0 m/sec**	**Mass**	**209.4 gms**
Air Density	**1.22500 kg/m^3**	**Air Temperature**	**15.0 C**
Muzzle Spin Rate	**375. CPS**	**Muzzle Exit Twist**	**21.0 cal/rev**
CP from Nose	**3.33 cm**	**CP from Nose**	**0.90 Calibers**
CG from Nose	**4.63 cm**	**CG from Nose**	**1.26 Calibers**
Mach Number	**0.88**	**Gyro Stab Factor**	**6.71**
Ballistic Coeff	**0.165**	**Cd at Muzzle**	**0.460**
Deceleration	**429.81 m/s/1000m**	**Muzzle Jump Factor**	**0.120 mils/rad/sec**

Figure 3: Predicted Static Stability of Projectile

SENSORS AND ELECTRONICS

The electronics instrumentation package used for this project was based on a previous design concept created by AMCB for use on a 25mm projectile. The inertial sensor suite section of the electronics consisted of a 17.5mm diameter board which incorporated a total of eleven sensors. These sensors included three axis of magnetic field measurement, two axis of angular rate, three axis of low-G acceleration and three axis of high-G acceleration. In the case of the EM gun projectile, the critical sensor data was the axial high-G setback acceleration. The accelerometers used were Endevco model 7270A 20,000G piezoresistive accelerometers. The 7270A is a single axis sensor so three of them were used. The accelerometers were positioned within the projectile in order to obtain both axial and radial in-bore setback acceleration data.

The on-board recorder was designed by engineers at the Georgia Tech Research Institute (GTRI) as part of a joint ARL/GTRI 25mm projectile program. It was originally designed to take eleven channels of data, but was modified for use on the EM gun projectile. In this case, only the three channels of high-G acceleration were recorded. This allowed the recorder to sample at a much higher rate while still maintaining a 12-bit resolution. The complete electronics stack is shown in figure 4.

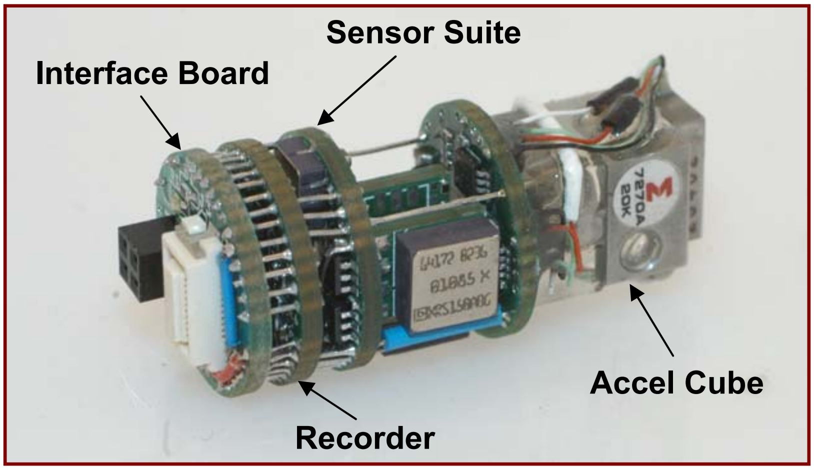


Figure 4: Electronics Stack

Once the electronics were assembled, they were integrated into the EM projectile. This was done by first inserting the stack into a plastic sleeve which would hold the boards in place and assure the correct orientation of the sensors. The batteries were then attached to the stack and placed in the lower section of the plastic sleeve. The electronics were then encapsulated using a potting compound to help increase the survivability of the stack. The entire sleeve was then inserted into the projectile and a final encapsulation was done. Communication between the internal recorder and external equipment was done through connectors on the top side of the interface board. Figures 5, 6 and 7 show an overview of the assembly process.

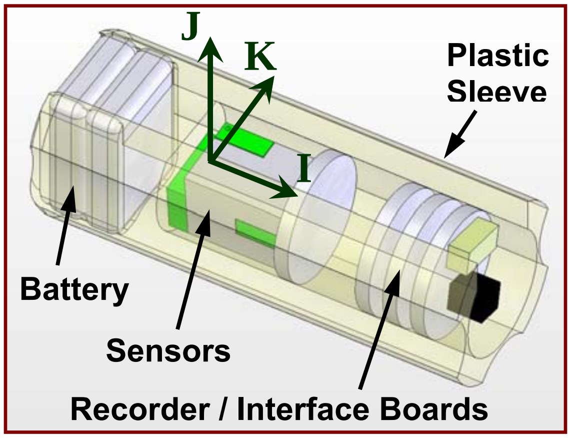


Figure 5: Electronics Module Concept

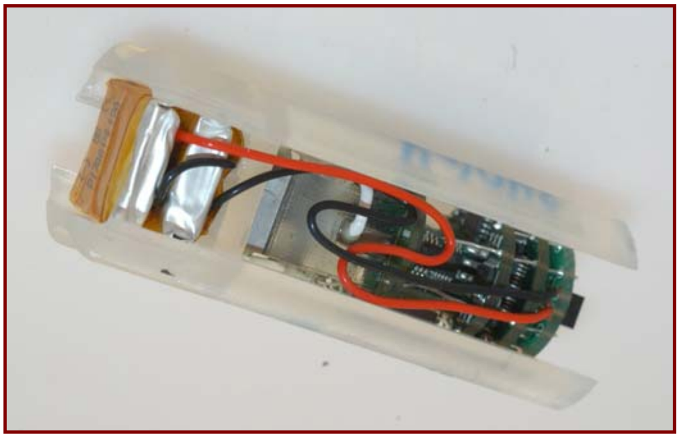


Figure 6: Actual Electronics Module

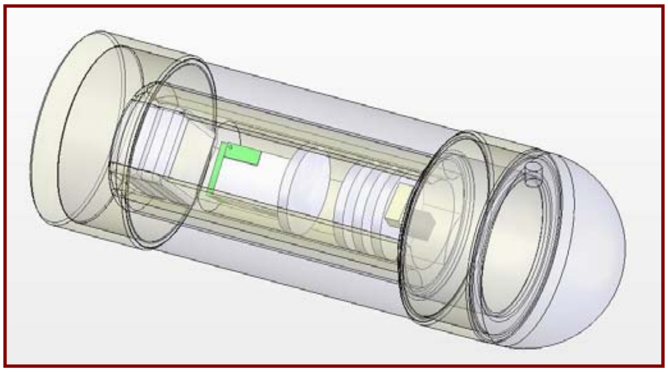


Figure 7: Electronics Module Inserted into Projectile

TEST SETUP AND PRELIMINARY TEST SHOTS

All testing was conducted using the EM railgun located at the ARL EM Experimental Facility. A soft-catch recovery system, shown in figure 8, was used to capture each round that was fired.

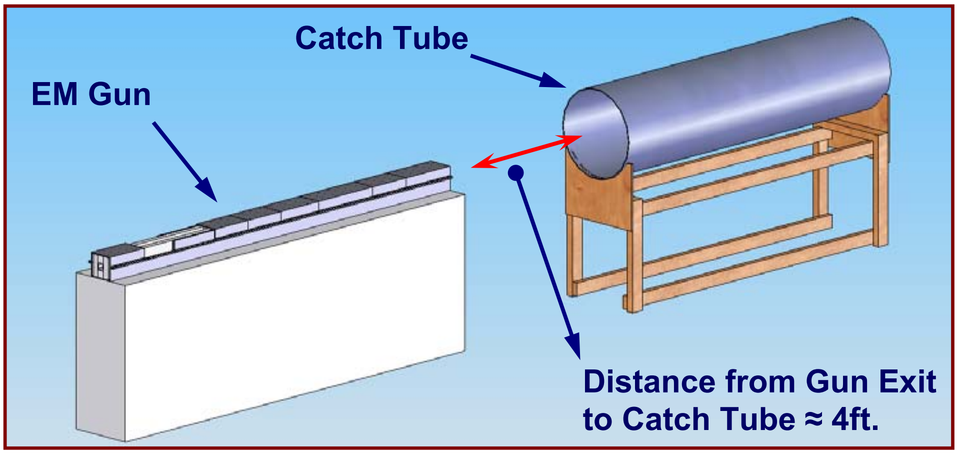


Figure 8: Experimental Test Setup

Dummy rounds, which were identical in shape and size to the instrumented rounds, were used to verify that the test setup would work as expected. A major concern was whether or not the soft-catch recovery system would indeed successfully capture the rounds since this had never been tried before. The first two projectiles fired, shown in figures 10 and 11, were successfully caught and recovered, but were severely damaged during the process. In order to avoid damage to subsequent rounds, the catch tube configuration was modified in-between each of the tests until an optimum setup was found. A third dummy round was fired and successfully recovered with no apparent damage as shown in figure 12.

Figure 9: Dummy Projectile

Figure 10: Dummy Projectile #1

Figure 11: Dummy Projectile #2

Figure 12: Projectile #3 Successfully Recovered

INSTRUMENTED TEST ROUND SHOTS

After the first successful recovery of a dummy projectile, the first instrumented round, unit #1, was fired. Unfortunately, the round was damaged during the shot, figure 13, and no data was recovered. In order to determine the exact cause of failure, an X-ray analysis of unit #1 was conducted, figure 14, and then the electronics module was extracted, figures 15 and 16. It was determined that the reason for failure was due to damage to the batteries located in the back end of the projectile. Additional testing showed that while the batteries were no longer functional, the electronics and sensors were still working properly. This was very encouraging considering the amount of damage present on the round.

Figure 13: Unit #1 After Recovery
Back End of Projectile Damaged

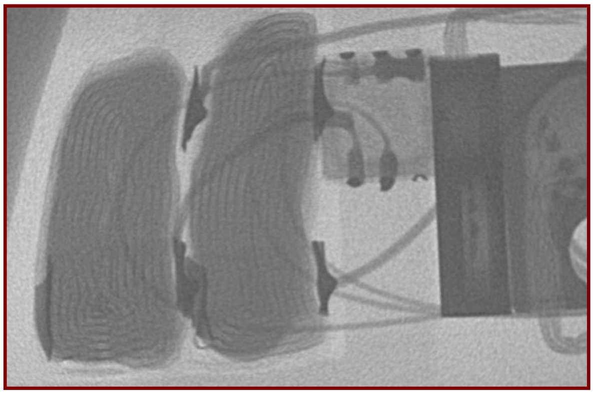
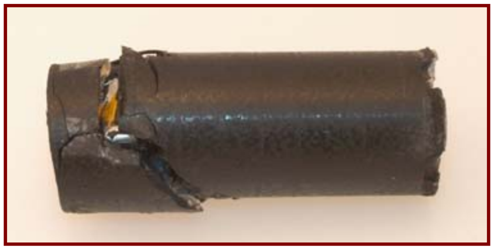


Figure 14: X-ray of Unit #1
Shows Damage to Batteries



Figures 15 and 16: Unit #1 Electronics Module After Extraction
Back End of Module (location of batteries) Badly Damaged

After further consideration, it was concluded that the damage to the round was not caused by the recovery system, but rather by the armature hitting into the back of the projectile once in the catch tube. It was initially believed to be an isolated incident and firing of the instrumented projectiles continued. Unit #3 was the next projectile fired and was successfully recovered with no damage to the projectile. Data was successfully downloaded from the unit and is examined in the next section. However, after firing unit #3 a second time, the unit was damaged and the data was lost due to a failure of the batteries. Photos shown in figures 17 and 18 prove that the damage was once again caused by the armature impacting the back of the projectile once inside the catch tube. While this was initially thought to be an isolated incident, these results showed that further modifications to the recovery system were necessary.

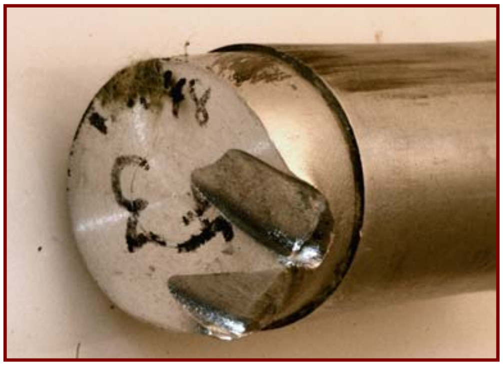
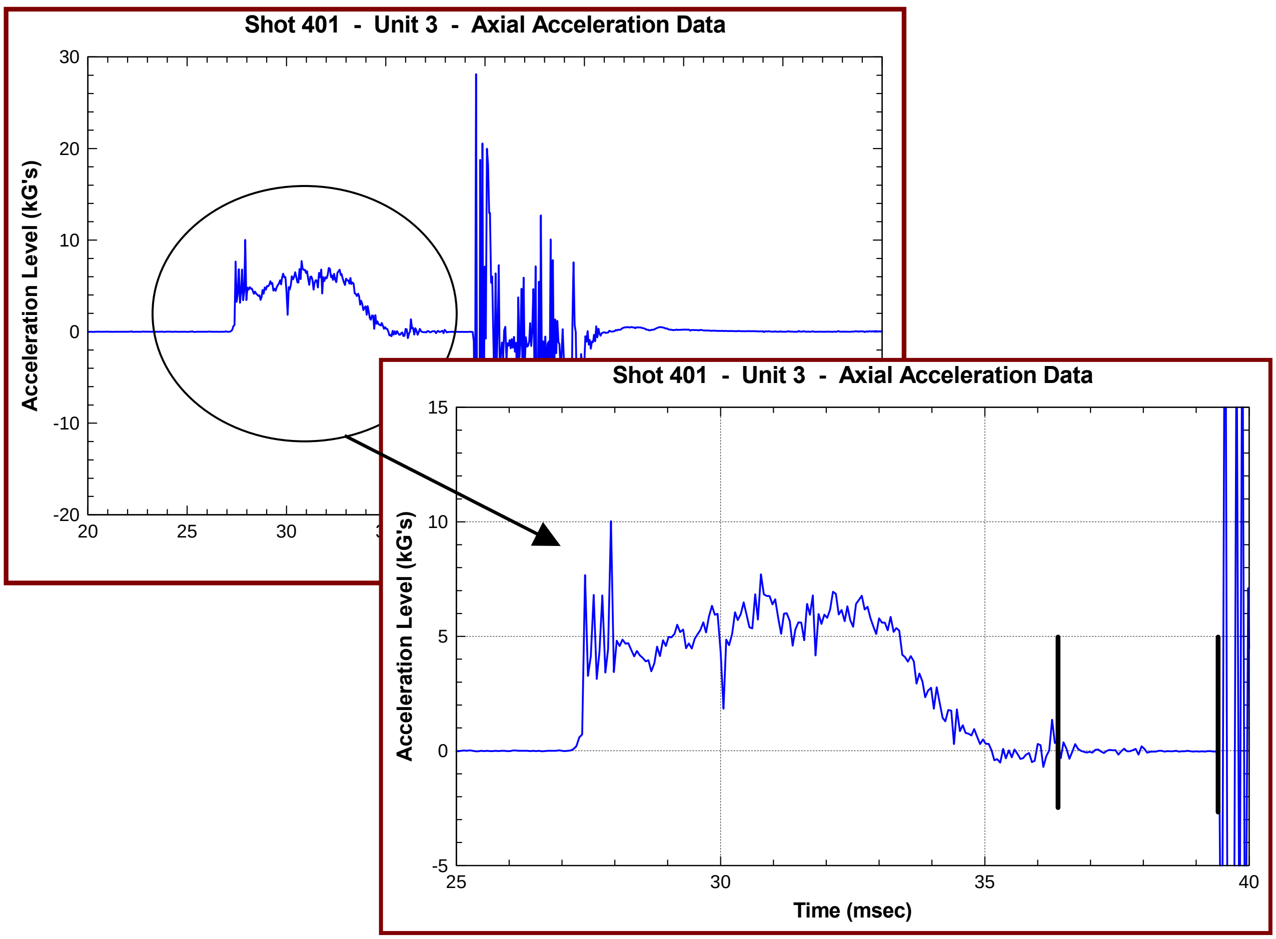


Figure 17: Unit #3 After Second Shot

Figure 18: Unit #3 with Recovered Armature
Damage Apparently Caused By Armature Impact into Projectile

FLIGHT TEST RESULTS

Although unit #3 was damaged during it's second shot, data was successfully recovered from the unit the first time it was fired, figures 19 thru 23. The recovered data provided axial and radial in-bore accelerations. Velocity and position could also be calculated from the acceleration data.



Figures 19 and 20: Axial Acceleration Data from Unit #3 Shot #1

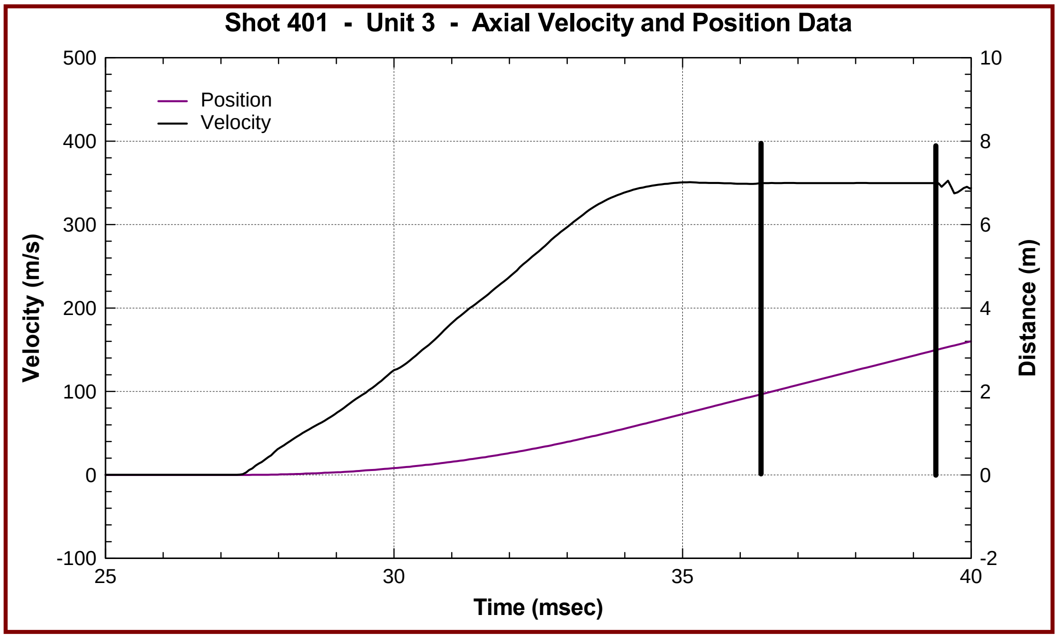
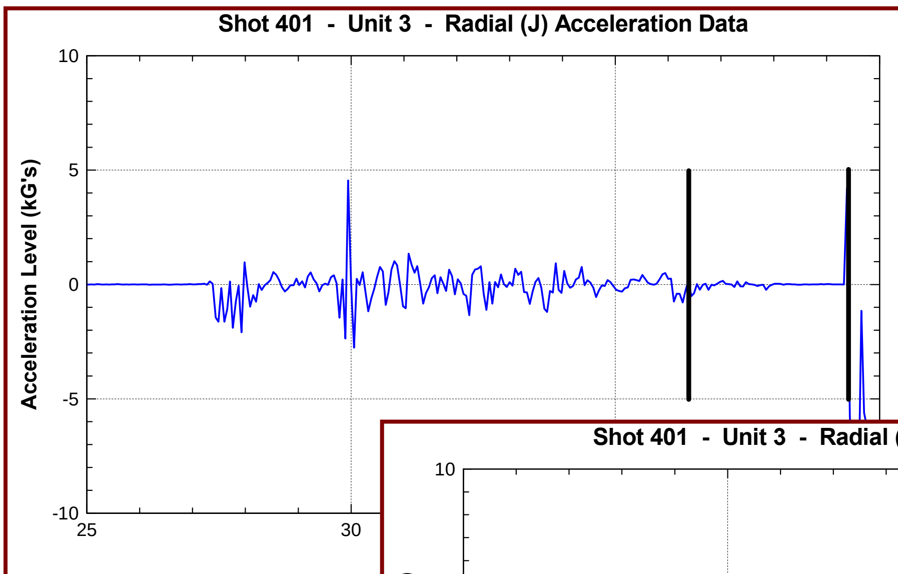
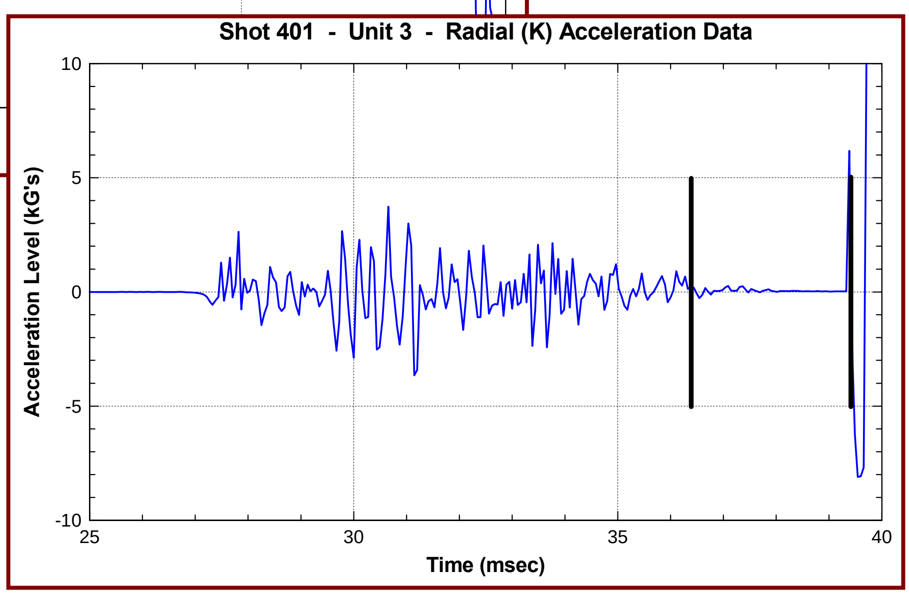


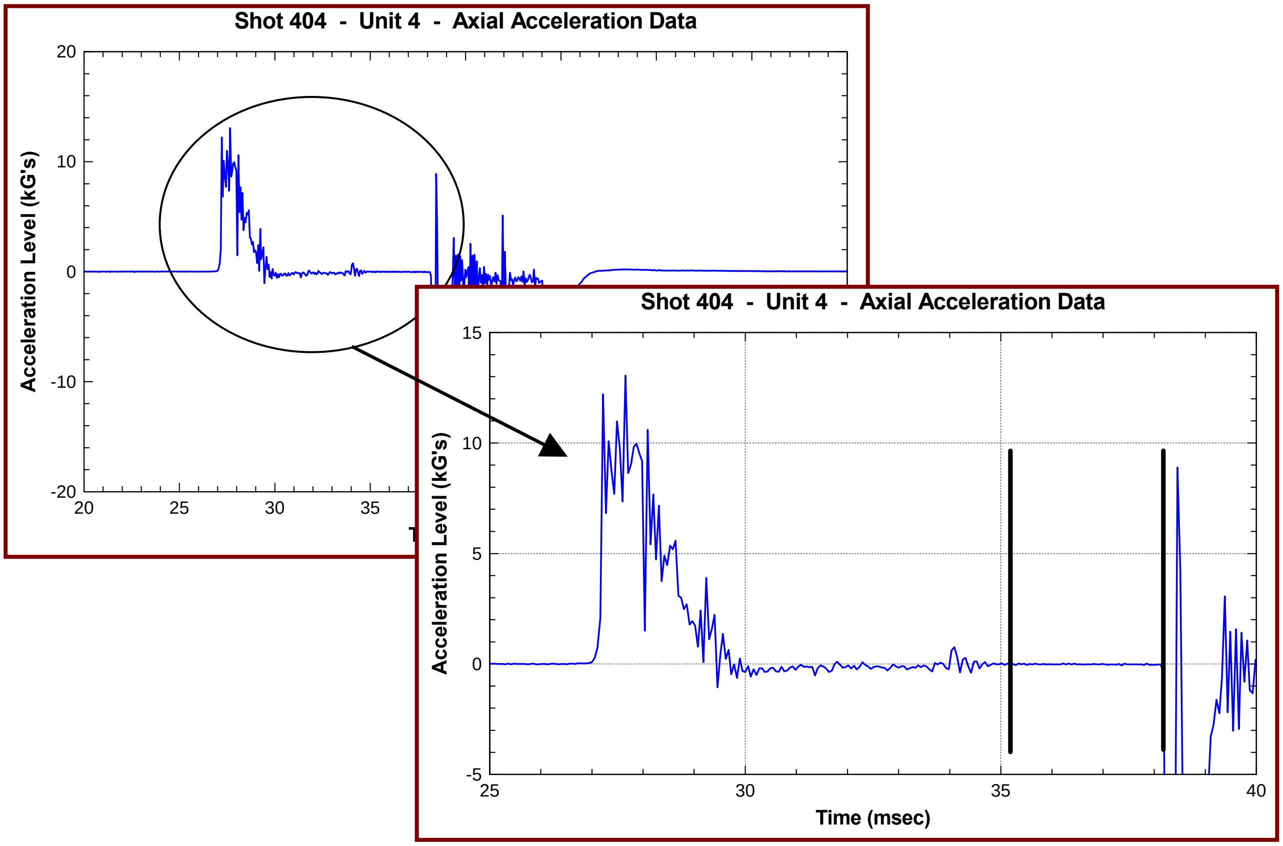
Figure 21: Axial Velocity and Position Data from Unit #3 Shot #1





Figures 22 and 23: Radial Acceleration Data from Unit #3 Shot #1

The final instrumented projectile fired was unit #4. Unit #4 was successfully fired and recovered two times, providing good data after each test. The unit was still completely functional after testing was completed. Resultant data from these tests are shown in figures 24 thru 29.



Figures 24 and 25: Axial Acceleration Data from Unit #4 Shot #1

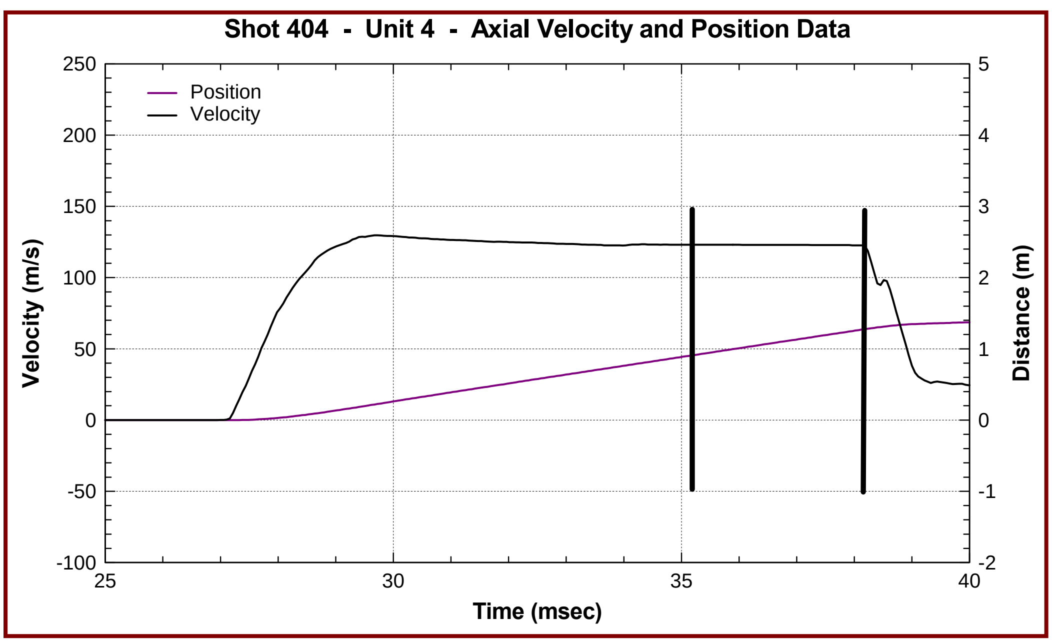
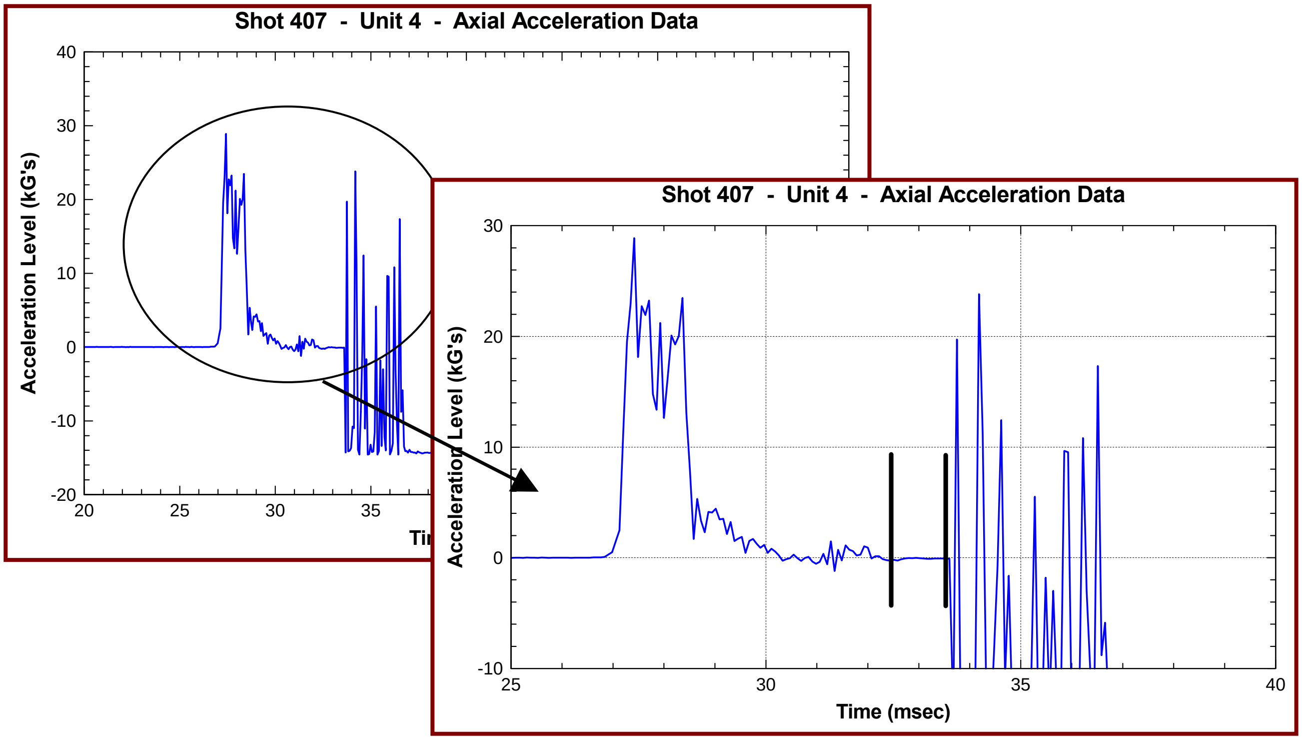


Figure 26: Axial Velocity and Position Data from Unit #4 Shot #1



Figures 27 and 28: Axial Acceleration Data from Unit #4 Shot #2

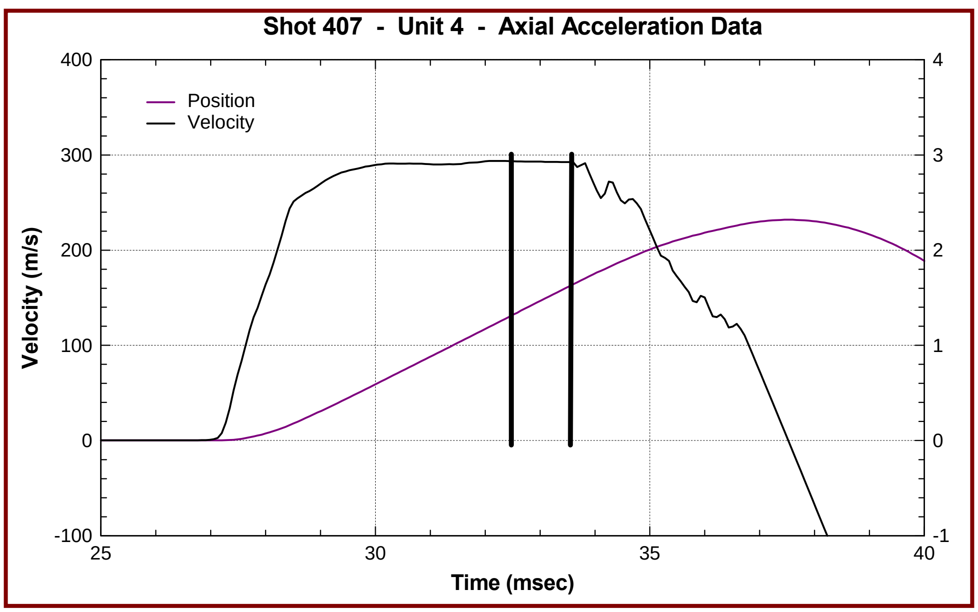


Figure 29: Axial Velocity and Position Data from Unit #4 Shot #2

CONCLUSIONS

In-bore acceleration data was successfully captured and retrieved from multiple EM railgun projectiles. The on-board electronics survived the EM pulse and high-G launch and recovery. Issues with the recovery system were resolved as testing progressed. Overall, an effective system for measuring in-bore accelerations of an EM gun was achieved and demonstrated.