



Free Fall Experimental Data for Non-lethal Artillery Projectile Parts

by James M. Garner, Michael Maher, and Michael A. Minnicino

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1. Introduction

U.S. military forces increasingly find themselves in situations compatible with the use of non-lethal weapons. Extending the range and spheres of influence for the projectiles delivered by these weapons is considered essential as an option in future conflict scenarios. With this in mind, the U.S. Army Research Laboratory (ARL), Maryland, and the U.S. Army Armament Research Development and Engineering Center (ARDEC), Picatinny Arsenal, New Jersey, have joined in an effort to produce a non-lethal artillery projectile. With support from Los Alamos National Laboratory, New Mexico, and the Edgewood Chemical Biological Center, Maryland, ARDEC has accepted the challenge of selecting and tailoring the payload and expulsion issues while ARL will focus on its traditional area of expertise in ballistics and will develop technologies for a non-lethal carrier of the selected payload. The goal of this effort is to project non-lethal payloads to ranges similar to those of standard artillery.

Extending the range of non-lethal projectiles poses several technological challenges. From the start, the projectile must withstand the high acceleration environment required to achieve extended ranges. High density, high strength metals are particularly well suited to withstand these environments. Unfortunately, these metals carry lethal energies at range even at relatively low velocities. As such, lightweight, high strength materials that quickly dissipate their energy at the target are mandated. This dictates the use of highly specialized composite technology. The composites must not only meet the structural requirements of launch but must fragment to part sizes and geometries with non-lethal characteristics. Tailoring the frangibility¹ of the projectile to achieve this goal is crucial. Aeroballistic challenges in stabilizing the projectile and selecting the fuze to achieve the reliability and non-lethality specifications require the examination and development of creative solutions. The round is currently designed to be fin stabilized and uses a standard fuze.

A subset of this effort is to assure that once the projectile bursts and delivers its payload, the fragments of the projectile that fall to the ground are non-lethal. To accomplish this, a frangible case was developed for the projectile body, which is ballistically similar to the M864 artillery round. Upon bursting/expulsion of the projectile, predetermined part shapes of a specific size and weight will result. Ideally, the aerodynamics and weights of these part shapes will constrain them to be non-lethal. It is believed that the resulting lightweight parts will reach their steady state velocities quickly and that the free fall terminal velocity will result. This was considered a baseline for evaluating the shapes, since the parts are guaranteed to have at least this amount of energy (that energy obtained in free fall) upon impact. To this end, a drop test was conducted to quantify this condition.

¹Frangibility in the non-lethal community normally describes a part that can be broken easily or in a predetermined manner.

2. Test Setup and Methodology

The test had to address many factors to produce good data. A variety of shapes that could be formed by the frangible case technology was considered and tested. The attributes in common for the specimens were that they were all 28 inches long and made from fiberglass-epoxy resin. The weights of the parts varied from 516 g to 199 g and resulted from the number of plies used in their fabrication. This produced different part thicknesses. The part twist (from base to nose) varied from straight (0 degrees) to 10 degrees. To augment the ability of the radar return from the motion of these parts, an aluminum foil skin was applied to the exterior. Figure 1a shows a finite element representation of how the parts might look when assembled as a projectile body and a fabricated part (figure 1b).

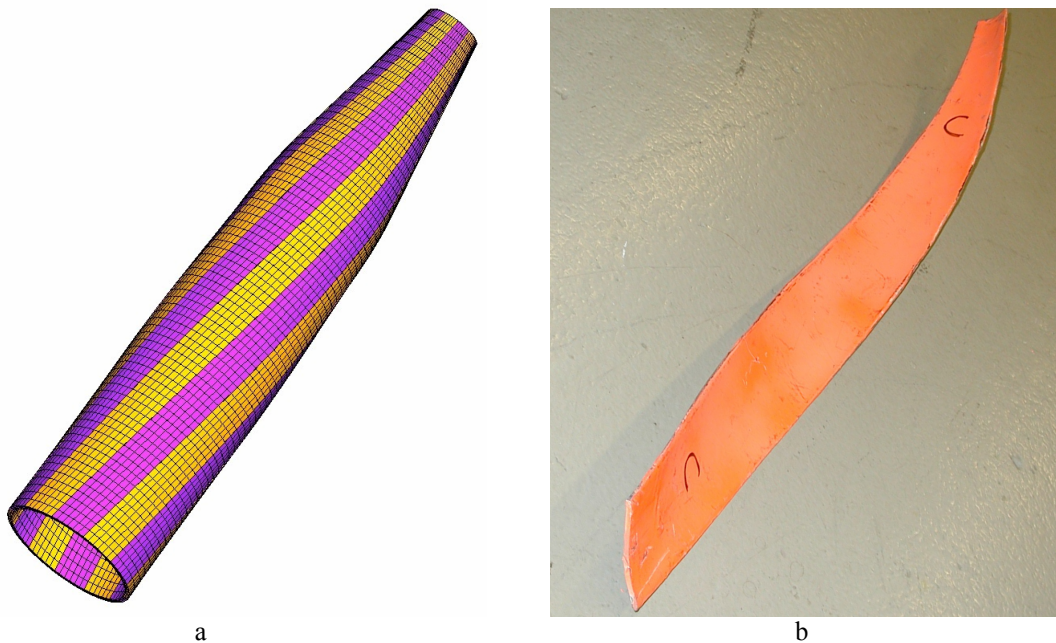


Figure 1. A finite element representation (a) and fabricated part for a frangible artillery round body (b).

The test execution also required several details to be addressed. The drops were done at 500 and 1000 feet. Parts were painted orange to aid in their after-test recovery. Drops at altitudes greater than these did not usually result in recovery of the parts, as determined from pre-tests. While sufficient altitude is required for the part to be outside the range of effect of the rotor downwash², earlier tests had estimated this distance to be only 200 to 300 feet. Figure 2 shows the Bell UH-1 helicopter, pilot, and radar setup as used in the test.

²Downwash is an air stream directed downward (as by a helicopter rotor).



Figure 2. The downward-looking Weibel radar head configuration.

A 7-watt Weibel radar was configured to attach to the helicopter in order to track the velocity of the non-lethal parts. The radar beam width is fixed, and slight adjustments were required by the operator to track the parts and acquire a clear return signal. All parts dropped were successfully tracked, and the radar returns produced a clear signal. There were a number of concerns about vibration effects on the radar system as well as other electronic interference, but none of these impeded the acquisition of good data. Normally, the radar is positioned on the ground, looking upward at the part. In this case, it was thought that the radar return signals from the helicopter would overwhelm the signal from the falling part and that no part velocity data would be acquired. Therefore, the solution was to put the radar on the helicopter, looking downward. Errors attributable to the vertical motion of the helicopter were small (<2 m/s) as the pilot was able to hover in a stable manner. Power conditioning consisted of a universal power supply connected to the helicopter inverter. This stabilized the power and eliminated voltage surges.

3. Experimental Results and Analysis

The intent of the testing was to determine the terminal velocity of the parts and to compare the kinetic energy to the 75-J threshold accepted as the lethality limit. As always, testing is complicated by nuisance factors. One of these was the previously mentioned downwash effect of the helicopter blades on the part velocity. This is a significant factor, and one possibility to mitigate the effect was to “fling” the part clear of the downwash region upon release. This option was rejected since it required the experimenter to lean farther out of the helicopter, and the release conditions could vary widely. More importantly, the ability to track the part would be compromised because of the limited beam width of the Weibel head. The parts were simply released next to the Weibel radar head and tracked as long as possible. The thinking was that the downwash effect would be negligible after a distance and the part would move to a terminal velocity. In some sense, this situation is closer to reality in that the actual artillery round (and the parts that dissociate upon expulsion) will have a forward velocity and expulsion velocity components. These additional components are substantial, but the burst height of ~1 km will allow the parts to slow significantly. We can obtain the estimated terminal velocity by first equating the drag force to the gravitational force (mg) in equation 1:

$$mg = \frac{1}{2}\rho V^2 S C_d \quad (1)$$

and solving for velocity (V),

$$V = \sqrt{2mg/\rho S C_d} \quad (2)$$

The measured variations from this solution occur because the part’s presented area (S) varies wildly as the part tumbles in free fall, and the subsonic drag coefficient is assumed to be 1.0. The predicted terminal velocity for the parts varies from 6 to 13 m/s. The prediction assumes that the orientation of the part is such that the greatest surface area is presented. A more accurate estimate might be to determine an average “S,” given the other orientations possible and their frequency of occurrence during free fall. Table 1 shows the final measured velocity of the parts (when dropped from 500 feet and 1000 feet) as compared to their predicted velocity.

A typical velocity trace is shown in figure 3. The rapid velocity increase is attributable to the combination of the downwash from the rotor and gravity. The free fall time in a vacuum (no drag, just gravity) would be 7.8 seconds. The time shown here does not reflect the full time of fall since it is only as long as the radar tracks the piece. A full trajectory time of flight was achieved for part “K” which took 20 seconds to reach the ground. A varying drag is significantly affecting the time of fall.

Other complications on the empirical end of this comparison include the fitting of the data and the fact that some of the rounds were tracked longer than others and thus, probably came closer

to their steady state velocities. It is notable that some of the 500-foot drop velocity measurements indicate that the part is going slower than after the part dropped 1000 feet. If you assume that the part quickly (within 500 feet) reaches terminal velocity, these velocity differences are attributable to the part orientation and drag, but it is also indicative of the fact that the downwash from the helicopter rotor is a secondary effect at distances greater than 1000 feet since the velocities are about the same. What is perhaps most valuable is the trend that the part velocities are tending toward a 10- to 15-m/s velocity range. The kinetic energy for this part velocity indicates that these parts are non-lethal (using the 75-J lethality criterion).

Table 1. Part attributes and test results

Part Designation	Mass (g)	Predicted Velocity (m/s)	1000-ft Drop Measured Velocity (m/s)	500-ft Drop Measured Velocity (m/s)	Energy (J)
A	478.2	11.8	9.2	12.0	34
B	230.4	8.2	9.0	6.6	9
C	237.7	8.3	8.3	N/A	8
D	412.9	11.0	14.2	11.9	42
E	233.7	8.3	10.0	7.4	12
F	516.3	12.3	N/A	10.6	29
G	212.0	13.7	9.8	N/A	10
H	238.6	14.5	16.9	11.5	34
I	199.2	13.2	8.2	12.8	16
J	226.5	14.1	12.4	13.2	19
K	~230	14.2	13.5	14.1	23

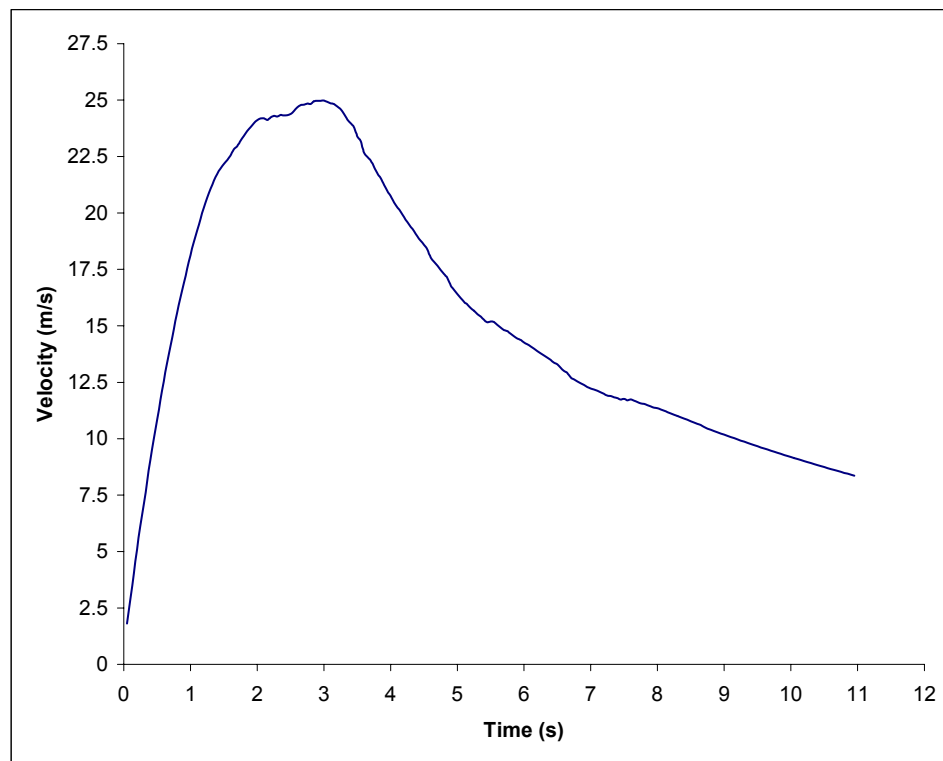


Figure 3. Velocity history for a composite section when dropped from 1000 feet.

The larger surface area pieces (A through F) tended to have the lower velocities, and their flight modes were typically a rapid rotation about their long axis—much like the behavior of confetti. This flight mode drastically slowed the part’s descent. Some of the thinner parts (G through K) rotated about their center of gravity—more like a helicopter blade. While this effect decelerated the part, the smaller surface area for the thinner sections made the “hovering” effect less pronounced than the flights of the broader parts. Some thin parts flew in a similar manner as the broad parts and rotated rapidly about their long axis. The flight modes (flutter-rotation) were not completely consistent for our tests, but all the resultant velocities were acceptable from a non-lethality standpoint.

There were a few disappointments in the test results. Some of the not available (N/A) results were attributable to the part flying outside the tracking beam of the radar. This condition really could not be predicted since it heavily depends on the initial release conditions and the part geometry as well as any short-term weather condition (such as a wind gust). The radar returns for most of the parts were quite good and exceptional for part “K.” Ironically, this was the sole part that was not recovered despite its orange coloration. Generally, the aluminum tape helped provide a clear return radar signal. As noted before, drops from higher altitudes would likely result in the loss of the part at APG where there is much vegetation. If the same test were performed at Yuma Proving Ground, Arizona, perhaps the drop height could be increased to more closely mimic the conditions associated with the expulsion sequence planned for the prototype round, and the part could be expected to be recovered. More on-the-ground observers could also aid in future part recovery efforts now that it has been shown the parts are non-lethal.

4. Summary

Several conclusions can be taken from this drop test:

1. The kinetic energy level of the parts in free fall from 500 and 1000 ft is non-lethal.
2. Larger area lighter parts tend to have the least energy upon impact.
3. Velocities are reasonably close, whether dropped from 1000 or 500 feet, so helicopter downwash does not appear to be a substantial velocity contributor after roughly 500 feet of trajectory.
4. Radar tracking of freely falling parts from a helicopter can provide excellent data.

Appendix A. Additional Part Attributes

Table A-1. Additional composite part attributes

Part Designation	Mass (g)	Twist (deg)	Length (cm)	Width (cm)
A	478.2	None	71	7.5
B	230.4	None	71	7.5
C	237.7	10	71	7.5
D	412.9	10	71	7.5
E	233.7	5	71	7.5
F	516.3	5	71	7.5
G	212.0	None	71	2.5
H	238.6	None	71	2.5
I	199.2	5	71	2.5
J	226.5	10	71	2.5
K	~230	10	71	2.5

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Appendix B. Symbols

m	mass of part
g	gravitational constant ($\sim 9.81\text{m/s}^2$)
C_d	drag coefficient
S	reference area
V	downward velocity of the part
ρ	air density (standard sea level conditions assumed)

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