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Paintball Accuracy Measurements

by James Garner and Mark Bundy

ARL-MR-674 September 2007

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14. ABSTRACT
As low intensity conflicts become more prevalent worldwide, nonlethal solutions are often appropriate responses to such circumstances and can help to prevent escalation of the event to a lethal level. The ability to disperse angry crowds often hinges on calming or isolating a few individuals. The following report details the general performance of selected paintball brands with regard to range and accuracy. In addition, simple methods of increasing the performance are considered and examined for potential near-term usage.

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1. Introduction

The ability to disperse angry crowds often hinges on calming or isolating a few individuals. Such leaders are especially emboldened when they believe their chances of capture or identification by authorities are minimal. Technologies that offer the ability to mark an individual for immediate or post incident apprehension are valuable. Marking projectiles with improved accuracy and extended ranges fit neatly into filling this need as they allow adequate standoff distances to operate from and adequate targeting of individuals.

Paintballs are a readily available example of a marking technology in widespread use. While the shape of the paintballs (spherical) offers advantages from a production and loading aspect, the shape is far from optimal aerodynamically. Subsequently, paintballs display poor accuracy relative to a standard bullet. Efforts to characterize the projectile's effective range and accuracy were undertaken to understand what is reasonable to expect performance-wise from paintballs and what differences there are, if any, between some popular brands. Alternate methods of firing to enable greater range and broader operational capabilities were also examined. Projectiles fabricated and tested under the effort were created with minimal production costs in mind and it is assumed that a production facility could easily reproduce our modifications.

2. Test Projectiles

In order to assess some common commercially available designs, standard 0.68-in. diameter paintballs were fired, for dispersion and velocity. Some of their physical characteristics are noted in table 1. Figure 1 shows the paintballs tested at the 30-m side range of the Aerodynamics Experimental Facility. The distance of 30 m is often quoted as the maximum range of accuracy for recreational users. The FN303 "Impact" paintball is used by law enforcement and does not fall under the recreational projectile category, though it is considered here as a possible future direction for paintball/nonlethal projectile design.

Table 1. Paintball brands and their associated thickness variations.

Manufacture/Brand	Diameter (in.)	Weight (g)	Wall Thickness (in.)
Nelson/Nelsplat	~0.68	2.9	0.005–0.014
PMI/Super Swirl	~0.68	3.1	0.005–0.014
Nylon	~0.68	2.3	solid
Empire/Ramp	~0.68	3.1	0.005–0.017

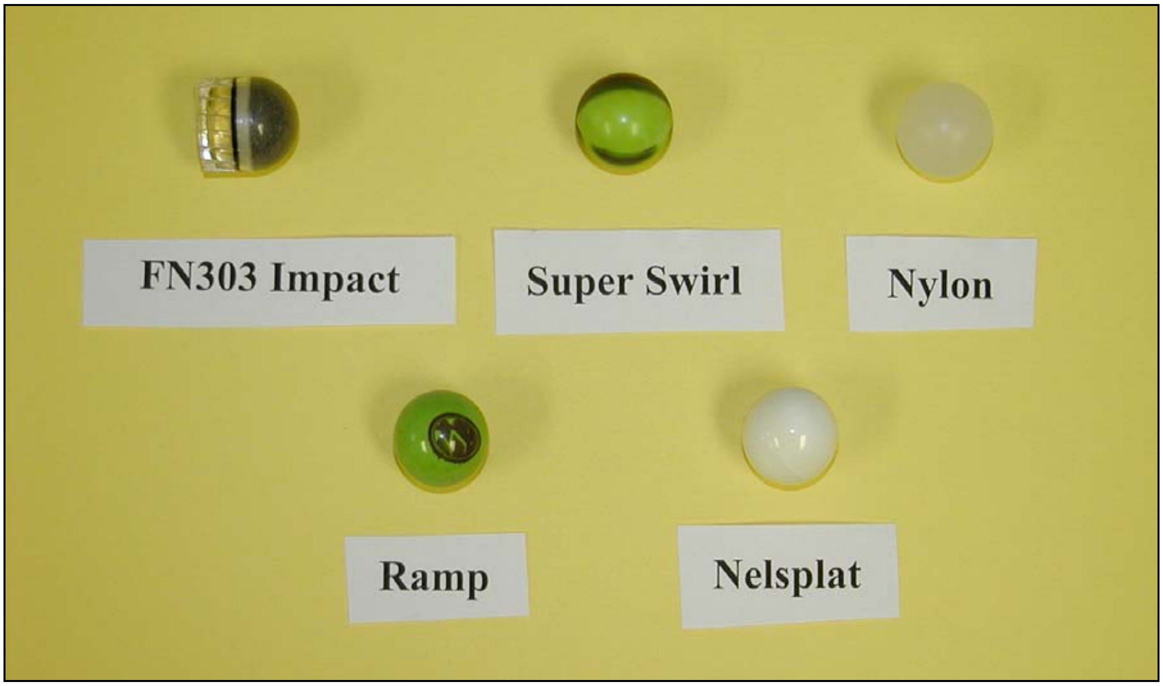

Figure 1. Selected commercial nonlethal projectiles.

Paintballs have a high degree of variability in their shape and composition. Such asymmetries are detrimental to accuracy. The external shape is often not a perfect sphere and can vary due to its storage orientation. Balls can be flat on a side or dimpled due to contact with hard surfaces. Frequently the fabrication of the paintball is done by melding two hemispheres together. Unfortunately ball diameters can vary due to imperfect melding. Aging (drying out) of the paintballs can also produce ball skins that are tougher or more brittle. Exposing the seam (where the two halves are joined) to the pressure blast could quite conceivably result in the ball breaking in-bore. The FN303 projectiles are different in their geometry and meld a frangible hemisphere to a plastic base. For the FN303, the launch pressure impinges on the plastic base, not on a projectile seam that might be susceptible to breakage. They are, therefore, able to withstand the high launch pressures better. These require loading in a preferential orientation and they use a special ammunition clip and gun combination.

Table 1 lists the physical characteristics for the paintballs tested. Four varieties of projectiles were chosen to get an albeit small spectrum of some performance differences that might be expected from one brand to another. The solid nylon balls are not really a sensible projectile as they do not act as a marking tool. They also exhibited the poorest accuracy. Only 4 of 10 fired hit the 4 by 4 ft target at 30 m. Their egregious accuracy owes to the fact that they launch with a measure of “blow-by,” and generally seal very poorly. Their solid composition does not let them deform to create a seal with the barrel. Their greatest attribute is that they are cheap.

3. Baseline Experimentation and Evaluation

The Aerodynamics Experimental Facility at Aberdeen Proving Ground, MD, is an enclosed facility (not subject to cross winds) and has in its group of three ranges a 30-m range. A 4 by 4 ft target was positioned at the 30-m location with the center of the target optically sighted. Figure 2 shows the gun setup used for the firings. The gun fixture was weighted to eliminate barrel and mount motion as a factor in the weapon performance. The guns used in the firings were a Tippman carbine and a Tippman 98. These employed a CO_2 canister pressurized at 800 psi. The FN303 projectiles were fired from a handheld gun that was not conducive to the firing setup used for the other firings.

Figure 2. Firing setup for paintball testing.

Firings consisted of 10 round groups of a variety of paintballs. The impacts are shown in figures 3, 4, and 5.

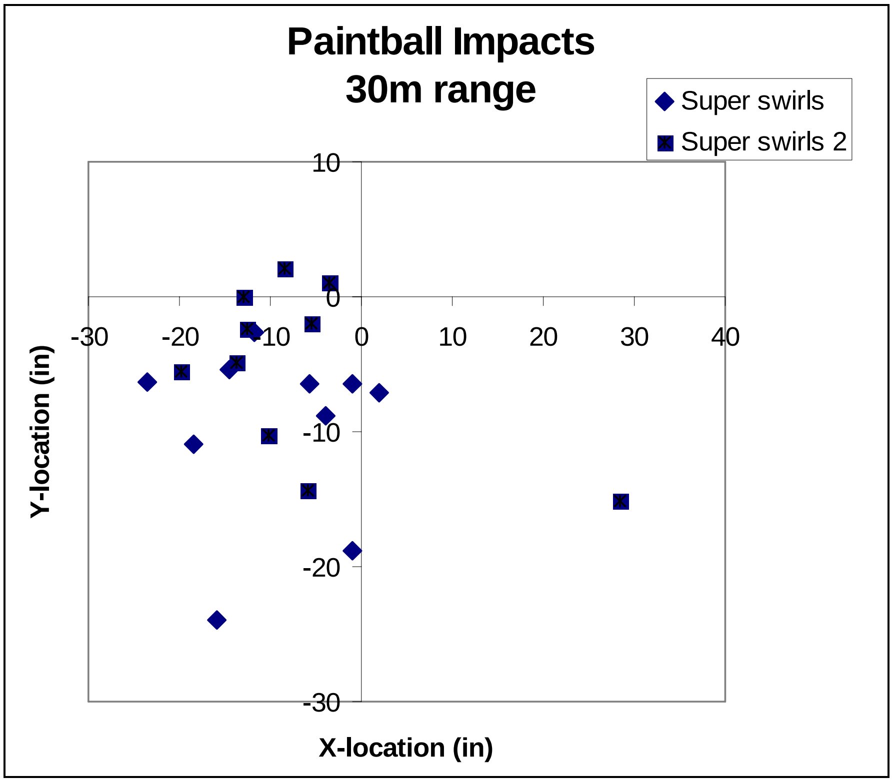

Figure 3. Impacts for Super Swirl brand paintballs fired from a Tippman carbine gun.

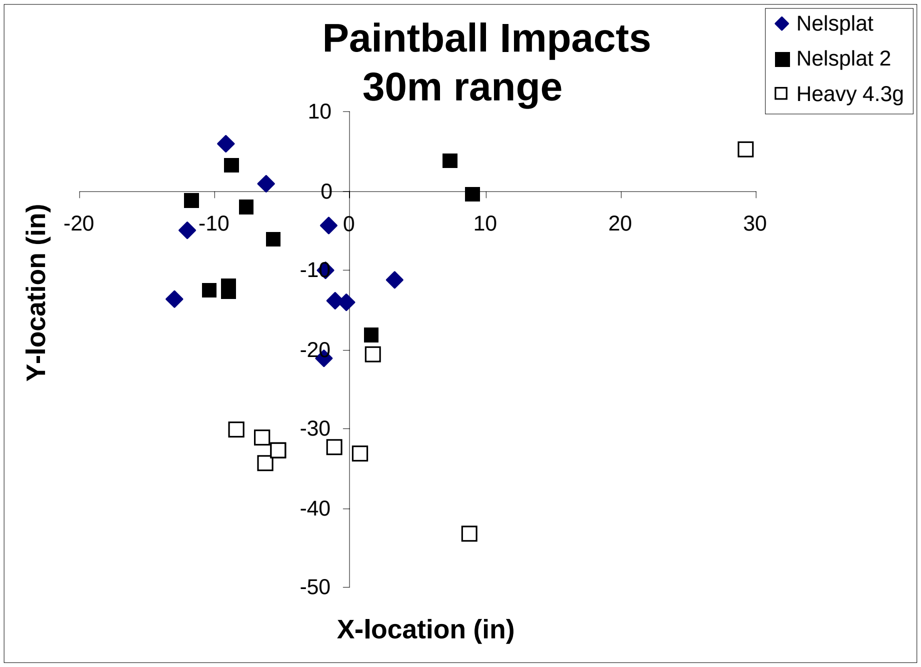

Figure 4. Impacts for Nelsplat brand paintballs and 4.3 g weighted paintballs fired from a Tippman carbine gun.

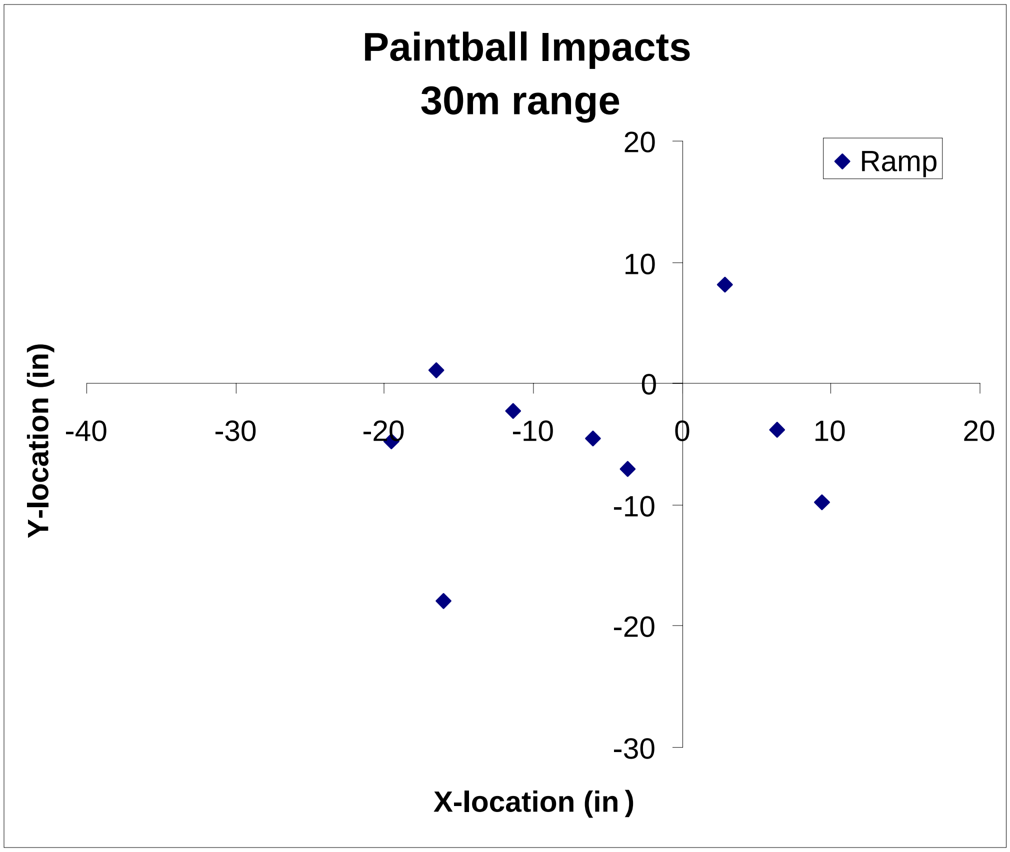

Figure 5. Impacts for Ramp brand paintballs fired from a Tippman carbine gun.

Figures 3, 4, and 5 give a good general sense of how consistently the rounds behaved though it's hard to tell the whole story from the graphs. The Nelsplat paintballs seemed to shoot a little more consistently, as noted in table 2. The standard deviations are the measure of consistency and are the basis of the judgments rendered. The horizontal and vertical standard deviations are denoted by σx and σy, respectively. The σvel is listed as velocity variations have an effect on projectile gravity drop and generally increase dispersion. An interesting result is the behavior of the heavy paintballs. These paintballs were injected by the U.S. Army Research Laboratory (ARL) with aluminum oxide powder to increase the density of the fill material. This infusion boosted the weight from 2.9 to 4.3 g. What is unusual is that the initial eight firings, noted as Heavy, displayed a markedly low standard deviation.

The final two firings deviated greatly. It is believed that either an in-bore condition (residue from a previous paintball skin) or simply an unusual shape or physical nonhomogeneity may have caused the deviations. While a statistician may be offended by an analysis that ignores the final two shots, common sense indicates that something changed. Only 9 symbols are visible in figure 4 for the heavy firings as two firings impacted the same spot. Figure 5 (impacts of the Ramp paintball) shows only 9 impacts as the one of the firings missed the target and the missed round was not included in the analysis.

Table 2. Impact standard deviations for various paintball brands.

Paintball Brand	σx (in.)	σy (in.)	σvel (ft/s)
Nelsplat	8.0	7.4	3.5
Super Swirl	10.8	6.4	3.5
Nelsplat-heavy	11.2	13.0	6.3
Heavy	3.7	4.3	6.5
Ramp	11.3	7.6	NA
FN303	3.0	4.4	1.9

The trade-off for firing heavier projectiles is a drop in velocity. The average velocity of the 4.3 g paintball was 68.29 m/s vs. 106 m/s with the 2.9 g variety.

A comparison can be offered for the FN303 nonlethal round seen in profile in figure 1. It nominally weighs 8.6 g and is launched at ~83.8 m/s. It uses a high pressure (3,000 psi) cylinder as the reservoir pressure for the projectile. The plastic boattail and added weight, along with its small variation in launch velocity, seem to create a more consistent impact. The FN303 values given in table 2 are the result of several FN303 firings in which small changes in nose fill material were made. These changes changed the weight slightly but they are broadly considered to be equivalent for this study.

4. Modified Operational Usage

A trajectory analysis was run to determine what ranges are realizable for paintball usage. The answer is dependent on how the gun is employed. Launch velocity is obviously an important aspect in determining trajectory and range. The standard recreational launch velocity limit to assure nonlethality is 300 ft/s. This velocity equates to a maximum of 12J and is well below the internationally recognized lethality limit of 75J. Experimentally, it was found that velocities of 350 ft/s were obtainable without modifying hardware or breaking the paintball in bore during firing. Given this it was considered permissible to use a launch velocity of 350 ft/s to get a maximum trajectory. For small arms, a direct (flat-fire) trajectory is typically how the gun is used. Analytically a 2.9 g paintball fired at 350 ft/s from a shooter's height of 1.37 m will travel 39 m in about 0.7 s and impact the ground.[1]

[1]Weinacht, P.; Cooper, G.; Newill, J. *Analytical Prediction of High Velocity Direct Fire Munitions*; ARL-TR-3567; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2005.

One method of extending range is to input a gun elevation angle. Very large elevation angles (greater than 45°) dramatically increase flight times, and launch conditions, such as spin, and crosswinds have a significant effect over these time periods. Simple analytical predictions though are generally still valid for small angles (10° or less)[2] and for these reasons only small elevation angles were considered. A 10°-gun elevation angle results in a 78-m range using a constant drag coefficient as in the flat-fire case. For many common geometries, constant drag coefficient assumptions are valid for subsonic flow to Mach 0.6. Accuracy and dispersion tests for line-of-sight, elevated firings are nonexistent, or very rare, to present knowledge, as line-of-sight, flat-fire is the normal operative mode for paintball guns. Elevated firings almost always mean non-line-of-sight firings in Army thinking. Since the paintball firings would still be line-of-sight but elevated, the concept is a little different than the standard range and accuracy characterization. Figure 6 shows the resultant trajectories for a spectrum of small elevation angles. The range is essentially doubled for a 10° elevation vs. a flat fire launch. If this method of fire were considered practical, an inclinometer would have to be installed to allow the user to gage the elevation prior to firing.

[2]JC's Paintball, Bel Air, MD. Personal communication, May 2007.

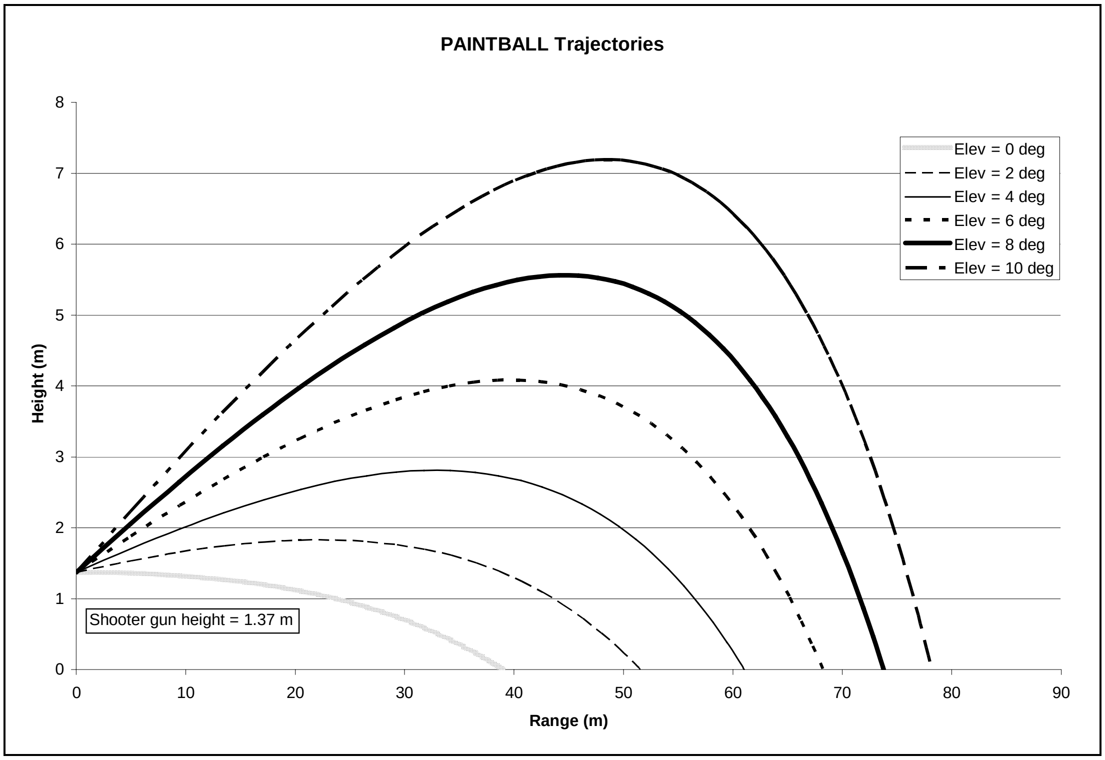

Figure 6. Range variations for small launch elevation angles.

NOTE: Trajectory data was provided by Firing table and Ballistics Division, U.S. Armament Research Development and Engineering Center via the GTRAJ computer program. The program theory is based on a U.S. Army Ballistics Research Laboratory (BRL) report.[3]

While range is typically what is examined for projectile performance, an equally important attribute for paintballs may be velocity at range. Since the paintball must break on impact it will need sufficient velocity to do so. Figure 7 shows the velocity variation at select distances for various paintball weights. A 75-m range assumes firing at elevation and the 150-m target range would require a combination of a lower elevation for the target and an elevated firing. A 45-grain (2.9 g) projectile has roughly 17 m/s velocity remaining at 75 m. This residual velocity is at the threshold where the paintballs marginally break on impact. Reducing the breakage velocity to 7 m/s equates to adding another 20 m of effective range (from analytical estimates). Of course, a decreased velocity equates to an even less lethal impact.

[3]Lieske, R.F.; Reiter, M.L *Equations of Motion for a Modified Point Mass Trajectory*; BRL report no. 1314; U.S. Army Ballistics Research Laboratory: Aberdeen Proving Ground, MD, March 1966.

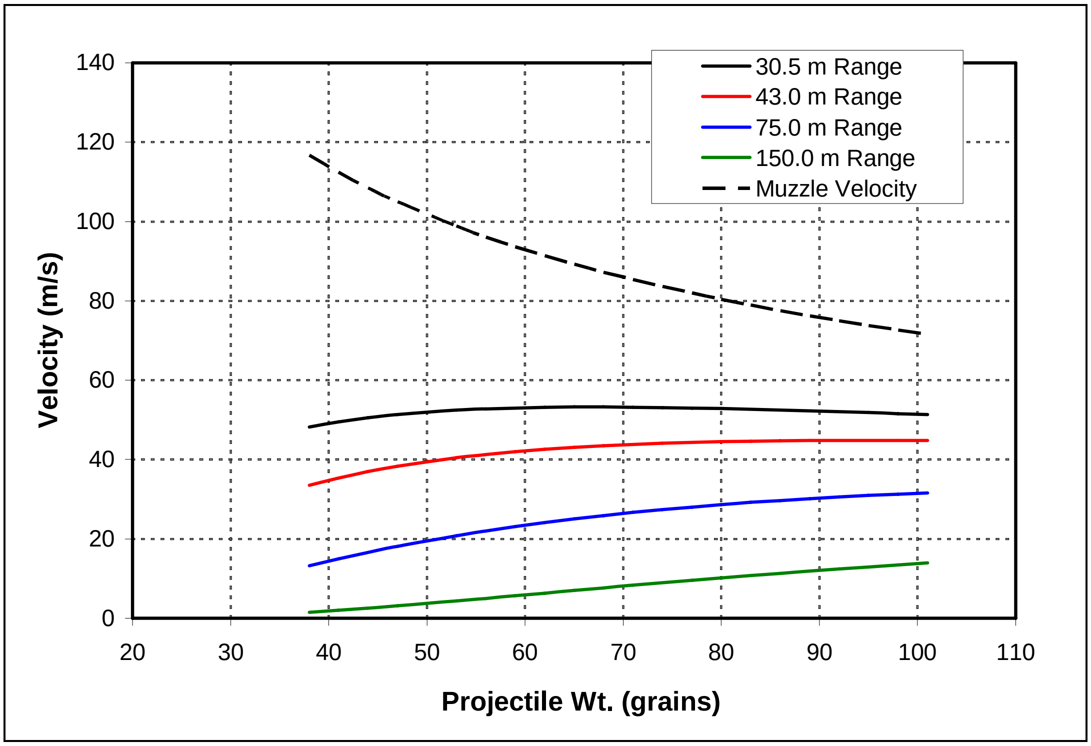

Figure 7. Velocity variations vs. projectile weight.

A concept to facilitate paintball breakage at range is to introduce a flaw in the projectile shell at muzzle exit. One method of creating a flaw might be to create a slit in the paintball via a razor mounted on a muzzle device. The slit should be small enough that it will be aerodynamically irrelevant but substantial enough to reduce the velocity required for breakage. The challenge is that since paintball shells are already thin, a slit might penetrate the skin and release the marking paint.

A number of other challenges were encountered in trying to determine the level at which paintballs break. Experimentally the gun pressure propelling the paintball required regulation to create a slow enough launch to result in impacts that did not break the paintball. Impacting a plywood target required velocities of 12.2–15.2 m/s for the balls to break. Modulating the gun pressure at these levels (~70–100 psi) via a regulator was very difficult. A manual launch (thrown by hand) was tried and resulted in a few rounds in the 40 ft/s range that did not break and one round at 18.3 m/s that did break. This correlated with the anecdotal breakage threshold level of 15.2 m/s.

The impact surface was also at issue. It was reasoned that a typical target might have a surface toughness more like rubber than plywood. Given this a pad of ½-in. rubber (similar to a computer mouse pad), was thought to be a more representative target surface. Impact velocities of roughly 19.8 m/s against a ½-in. rubber target consistently left the paintballs unbroken and allowed use of the Tippman gun and launch pressures of 110 psi. The slitting device was then attached and adjusted to create various depth cuts in the paintballs and produced the results shown in table 3. With the slit device set to produce a 0.050 in. depth slit, all of the shots fired on the same target at 19.8 m/s broke. The muzzle slit device did induce the paintball to break while not detrimentally affecting the launch velocity and was successful from that standpoint. More firings using the device are necessary to assure that accuracy at range is not degraded. The paintballs were also fired at 76.2 m/s to examine the effect of the slitting device at high velocities. Slitting depths above 0.050 in seemed to severely affect the launch such that a spray was produced and the paintball did not maintain its spherical configuration.

Table 3. Paintball structural integrity at velocities impacting a ½-in. rubber pad.

Paintball Condition (in.)	**Impact Velocity (19.8 m/s)**	**Impact Velocity (76.2 m/s)**
Standard	Intact	Not tested
Shallow slit (0.020)	Intact	Broke
Deeper slit (0.050)	Broke	Spray
Deepest slit (0.100)	Spray	Spray

An attempt was made to quantify the effect of the spray produced from the paintball when the deepest slitting was used. Firings were conducted such that the paintball was split into halves and two impacts were seen on the target board. Unfortunately the amount of spray produced, though visible, was insignificant and was unable to mark a target as a spray at 7.62 m. One explanation for this occurrence is that much of the residual fill remains in the halves of the split paintball and only a fraction is atomized. Larger fills and perhaps slitting devices that quarter the paintball may be able to produce more spray and enable their use in close proximity (5–10 m) conflict situations.

5. Conclusions

A number of factors influence paintball accuracy, trajectory, and effectiveness. Sealing the gas behind the projectile to prevent blow-by is essential to obtain accuracy. Solid (nylon) spheres are not conducive to maintaining good obturation. Projectiles that do not seal well, either due to asymmetries from projectile aging or production anomalies, will be challenged to hit their targets. Heavier rounds seem to be more accurate, though their launch velocities are reduced. Generally, the commercial rounds were similar in their accuracy performance. Small elevation changes can have noticeable effects on the projectile range and are worth considering especially if a rapid fire option is available to the user. If the projectile is required to break on target, then a scheme to enhance projectile breakage is valuable and should be incorporated.

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