Fireworks Shell Drift due to Shell-to-Bore Clearance

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ABSTRACT

For fireworks aerial shells, decreasing shell-to-bore clearance and increasing mortar length appear to have the effect of increasing the predictability of fireworks aerial shell trajectories, and thus dud aerial shell impact points. Some geometrical considerations are given to the influence of mortar length and shell-to-bore clearance on apparent aerial shell drift.

Keywords: fireworks aerial shell drift, mortar length, shell clearance

Introduction

There are many potential mechanisms to explain fireworks aerial shell drift. However, in the readily available literature pertaining to shell drift, very little has been said on the effects of mortar length and shell-to-bore clearance (bore windage).[1–6] While this is not surprising considering the wide variations between different shells and mortars, large shell clearances can significantly increase the error in calculations and observations of exterior ballistics.

Background

The rifled artillery piece came into general use during the US Civil War (1861–1865), and the earlier smoothbore brass and iron artillery, though still in service, was being phased out. Mortars of that era were classed as artillery and continued to be unrifled (i.e., smoothbore).

Most material on smoothbore artillery is no longer in print, but Gibbons' *Artillerists Manual*[7] is helpful in its identification of bore balloting. Balloting is the effect caused by an iron shell 'bouncing' side to side in a softer brass barrel, causing dents or "ballots" to be formed in the barrel, somewhat similar to the surface of a washboard. Repeated firing enlarged these ballots to the point where the gun's retirement from service would become necessary. The advent of the iron gun barrel, when fired with an iron shell, reduced the barrel balloting, but the term was retained to indicate the effects of excessive shell clearance that led to wild inaccuracy. Steps were taken to improve shell casting techniques, and the resulting shells were 'ring gauged' to prove size and sphericity.[7]

Experiments and Procedure

In the author's experience with some thousands of shells fired from civil war pattern mortars using solid lead ball projectiles from 2-3/4 to 5 inches in diameter, and bowling balls of 8-inch diameter, many ballistic effects were noted. Among these was the effect of bore windage causing an off-axis launch and producing apparent shell drift. These tests were performed on a nearly weekly basis from 1972 until 1980, under generally good conditions: elevation 300 feet above sea level, mild temperatures, low winds, and at ranges from 100 to 200 yards. Targets were premarked circles, 10 to 20 feet in diameter. Azimuth alignment was accomplished using fixed iron sights, and elevation was measured using a gunner's quadrant, accurate and reproducible to 1/2 degree. (This is obviously not conducive to producing the best accuracy.) After each shot, the barrel of the mortar was searched to remove debris, wet swabbed to remove powder fouling, and dried. Firing intervals were held to 5 minutes minimum. Most test firing was done by E Battery, 4th US Artillery, Civil War Skirmish Association.

The mortars used in the above tests were civil war pattern mortars made from seamless steel tube with a wall thickness equal to the bore diameter, and were proof tested with vastly increased powder and projectile loads.

Acceptable accuracy (i.e., projectiles hitting within the pre-marked circles) was found to occur only when shell clearance was reduced to within one percent of the bore diameter. No sabot or other alignment aid was used. Many experiments were made with projectiles of different shapes, densities, sizes, etc. and the minimum shell drift was accounted for using an ordinary (and simple) trigonometric relationship. This relationship is illustrated in the following example.

Two lengths of mortars are compared

Short tube: Length = 12 in. (4 calibers)
Inside diameter = 3 in.

Long tube: Length = 40 in. (13.3 calibers)
Inside diameter = 3 in.

Projectile: Shape = Spherical
Diameter = 2.5 in.

Figure 1 shows the shell in initial contact with the side of the mortar tube, probably a typical situation for a fireworks (or any other) shell. This results in an approximately 1/2-inch shell-to-mortar clearance opposite the contact point. If the shell is fired and does not contact the barrel (mortar wall) before exiting, probably an unlikely event, there is an initial angle, θ, through which it has freedom of movement. For this scenario (no balloting), θ is the maximum angle of launch that is uncontrolled by the axis of the bore of the mortar.

For the case of the short mortar, 12 inches in length, with a 1/2-inch shell-to-bore clearance,

$$\tan\theta = \frac{0.5}{12} = 0.0417 \qquad \text{and}$$

$$\theta = 2.4°$$

Accordingly, due to shell clearance in the short mortar, the launch may be anywhere from 0 to 2.4° away from the bore axis, and in any direction about the axis.

For the long mortar, 40-inches in length and 1/2-inch shell clearance,

$$\tan\theta = \frac{0.5}{40} = 0.0125 \qquad \text{and}$$

$$\theta = 0.7°$$

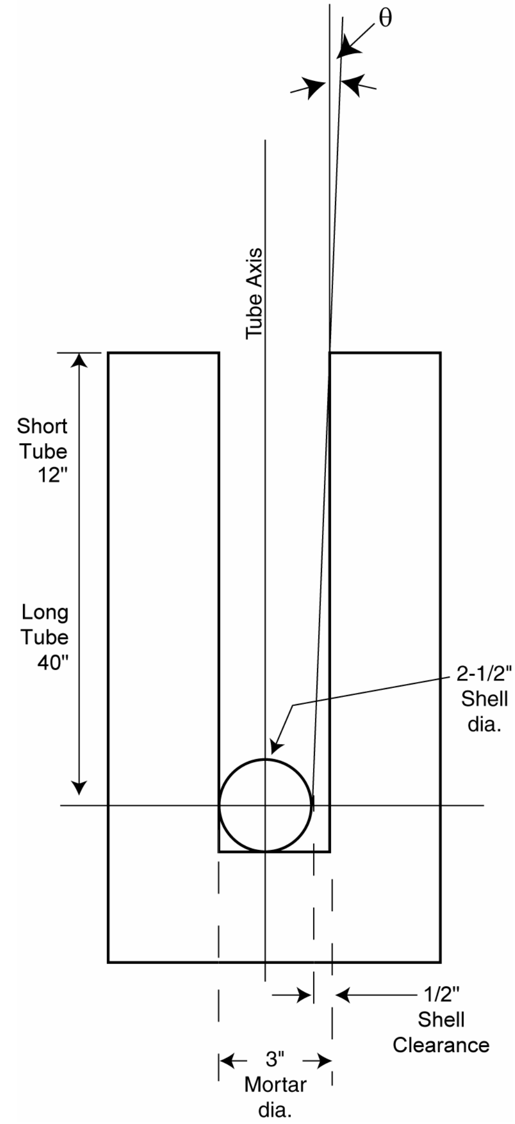

Figure 1. Sketch of the maximum projectile deviation that can occur without balloting during firing, where θ *indicates the deviation from the bore axis.*

Accordingly, for the long mortar, the off axis launch angle is significantly reduced—held to no more than 0.7° from the bore axis.

To calculate the potential results for fireworks aerial shells, an external ballistics computer model[8] was used. For this calculation, trajectory deviations of 2.4 and 0.7° were used for an aerial shell projected to a height of 300 feet from an otherwise vertical mortar in the absence of wind or other trajectory altering forces. This implies a trajectory uncertainty at its zenith of approximately 22 and 6 feet, for the short and long mortar examples, respectively. If these aerial shells fail to burst (i.e., are duds), they would be expected to fall to the ground at a distance of 40 and 12 feet, respectively, from that predicted based solely on mortar angle.

As the maximum height of the shell or bore clearance increases, so will the maximum shell deviation at its zenith and upon its impact with the ground. Again, note that the above calculation is only for the scenario where the shell does not touch the side of the mortar (ballot) as it traverses the length of the mortar tube. However, if the shell does touch, the geometrical effects of bore clearance increase drastically, as shown in Figure 2.

For a shell contacting the tube wall at the halfway point of the 12 inch mortar,

$$\tan\theta = \frac{0.5}{6} = 0.0833 \qquad \text{and}$$

$$\theta = 4.8°$$

Accordingly, in this case, the result is a maximum deflection of 4.8° from the mortar axis, twice the deviation found previously when the shell did not contact the mortar wall upon exiting. In this case for an aerial shell projected to 300 feet elevation, the deviation can be approximately 44 feet at its zenith and 80 feet if it falls back to the ground. Thus, there exists a "cone of uncertainty" in the trajectory of the shell before it leaves the mortar that may amount to a significant percentage of the separation distance from spectators.

In this brief article, a number of subjects were not addressed. These include the effects of any rotational forces caused by the contact of the shell with the bore, the effects of the center of gravity not being coincident with the geometric center of the shell, the effects of surface protrusions or surface texture of the shell and mortar, and whether or not the shell or mortar is plastically or elastically deformed due to setback forces.

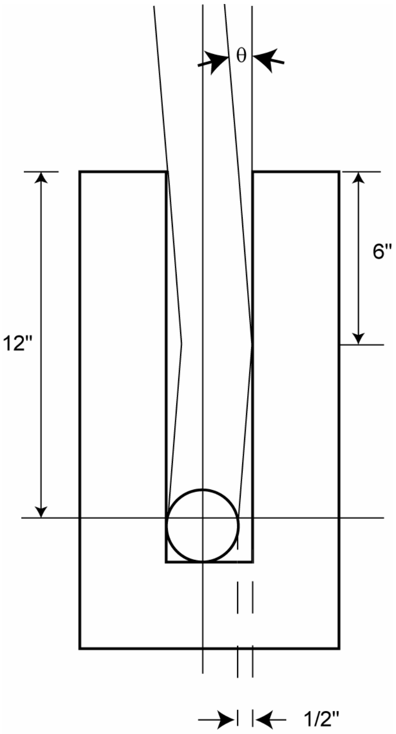

Figure 2. Sketch of projectile deviation that can occur if the projectile contacts the wall of the mortar tube at the half-way point, with θ indicating the angle of deviation from bore axis.

Conclusions

For any given amount of bore balloting, increasing mortar length to the longest convenient length will reduce the launch trajectory uncertainty resulting from shell-to-bore clearance. Similarly, for any given mortar length, keeping the shell clearance as low as possible will reduce the launch trajectory uncertainty.

Testing is planned to further study shell clearance effects. Three mortars are being constructed to fire inert fireworks shells. Results of this additional work will be reported upon its completion.

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