An earlier draft appeared in *Journal of Pyrotechnics*, No. 3, 1996.

Aerial Shell Drift Effects: (A) The Effect of Long Mortars

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(B) The Effect of Capsule-Shaped Shells

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ABSTRACT

Aerial shell drift is defined as the difference between the ballistically predicted trajectory of a shell and its actual trajectory. It had been speculated that longer length mortars and capsule-shaped shells might experience significantly different drift than normal length mortars and spherical shells. While longer mortars propelled 6-inch (155-mm) aerial shells to greater heights, the average shell drift was unaffected. Further, it was found that 6-inch (155-mm) capsule-shaped shells probably drifted slightly more than spherical shells.

Key Words: aerial shell drift, mortar length, shell shape.

Introduction

Knowing the initial conditions (mortar tilt and azimuth, wind speed and direction, and shell parameters), the flight path of aerial shells can be calculated using ballistics models.[1] While such calculations are fairly good at predicting the average path taken by a large number of identical shells, they are rather poor at predicting the actual path of an individual aerial shell. In large measure this is because of additional aerodynamic forces acting on the shells along their trajectory that are difficult or impossible to characterize prior to firing a shell. One example is the magnus force resulting from the shell tumbling along its path.[2] This force can not be determined without first knowing the rate and orientation of tumbling. Because this information is generally unknowable before a shell is fired, the resulting magnus force and drift cannot be predicted. (For a dud aerial shell, shell drift is defined as the difference between the ballistically predicted and actual points of fall of the aerial shell.)

Aerial shell drift was originally studied for to help determine the adequacy of spectator separation distances during fireworks displays. Based on initial tests, the average drift distance for dud spherical aerial shells was established to be approximately 32 feet per inch of shell size (0.38 m/mm).[2] If there are conditions that produce significantly different average drift distances, that could be justification for suggesting different spectator separation distances for those conditions.

During various discussions of the initial reports of shell drift, it was speculated that mortar length might affect the results. For example, using longer mortars might result in increased average aerial shell drift, because the shell would have a higher initial velocity. A greater shell velocity will result in a greater magnus force and because the flight time will be greater, there will be more time for the force to act on the shell. On the other hand, a longer mortar might result in reduced average shell drift, because the longer mortar might allow less divergence of the shell as it exits the mortar (a consequence of the shell being smaller than the mortar ID). This possibility is supported by some observations that the use of long mortars facilitates the precise placement of shell bursts during choreographed displays. Assuming this is true, reduced shell drift may be part of the explanation.

Some results discussed in reference 2 for an unusual shell shape (a cylinder with one concave and one convex end) apparently had a drift distance less than that for spheres. Accordingly, it seemed possible that capsule-shaped shells (roughly a cylinder with two convex ends) might also have a drift distance less than spheres. The two brief studies reported in this article were conducted to determine whether either mortar length or the modified shell shape significantly affected drift distance of dud shells.

(A) The Effect of Long Mortars

Nine pairs of identical aerial shells were fired to determine whether there was an effect of mortar length on shell drift. The shell pairs were nominally 6-inch (155-mm) Sunny International shells. The lift charges were temporarily removed from the shells and water was injected into the time fuses to prevent them from burning. The mortars used were 6.08-inch (154-mm) internal diameter steel pipe with internal lengths of 29 and 65 inches (0.75 and 1.65 m). Both mortars were placed vertically in a field at approximately 600 feet (180 m) above sea level.

For these tests, essentially calm wind conditions would have been preferred. However, the tests were conducted as part of another project that had a serious time constraint that resulted in having to perform the tests on a day when surface winds averaged 25 mph (40 km/h). The test protocol followed for these tests was the same as used in all previous tests, which approximately corrects for the effects of wind (and minor mortar orientation errors), and is described in reference 2. In essence, the shells are fired into the air, and their points of fall determined in a coordinate system with the mortars at a known location. (In this case, the mortars were located at North 0 and East –200 feet). A new coordinate system is established at the point of average displacement (center of gravity) of the collection of points of fall from the mortar. Then shell drift is measured within this new coordinate system. The shift of the coordinate system is believed to approximately correct for wind effects and mortar positioning errors (in the case of these measurements, care was taken to assure that the mortars were vertical to within less than 0.5 degree). In these tests, to minimize the effect of any changes in wind speed or direction between the firing of shells from the long and normal length mortars, each pair of shells were fired within seconds of each other. The data from these tests are presented in Tables 1a and 1b, and in Figure 1. Also shown in Figure 1 are the average displacements of the points of fall of the shells from the long and normal length mortars, and the average drift distances about these average displacements.

As expected, the average time of flight for the shells from the long mortar are greater (by 2.5 seconds), indicating that these shells were propelled to a greater height before falling back to earth. This allowed the wind to act for a longer time on those shells, causing their average point of fall to be shifted further down wind. That the average displacements of the two sets of points of fall do not lie on the same line from the mortars, must be partly due to statistical effects, but may also be due in part to different wind direction as a function of altitude.

Table 1a. Data from Normal Length Mortar Shell Drift Tests.

Shell Number	Time of Flight (s)	Point of Fall (Orig. Coord. Sys.)		Point of Fall (Shifted Coord. Sys.)		Drift Distance (ft)
		North (ft)	East (ft)	North (ft)	East (ft)	
1	12.2	5	–43	167	–69	181
2	14.3	–225	189	–63	163	175
3	(a)	–339	75	–177	49	184
4	13.7	–66	262	96	236	255
5	12.1	–78	100	84	74	112
6	(a)	–104	–104	58	–130	142
7	14.5	–241	15	–78	–11	79
8	(a)	–208	–229	–46	–255	259
9	(a)	–207	–29	–45	–55	71
Average	13.4	–162	26	≅ 0	≅ 0	162
Std. Dev.	1.1					68

(a) Time of flight not determined, usually because sight of shell was lost.

For conversion to SI units, 1 foot = 0.30 m.

Table 1b. Data from Long Mortar Shell Drift Tests.

Shell Number	Time of Flight (s)	Point of Fall (Orig. Coord. Sys.)		Point of Fall (Shifted Coord. Sys.)		Drift Distance (ft)
		North (ft)	East (ft)	North (ft)	East (ft)	
1	16.1	76	92	166	–74	182
2	15.6	–80	31	10	–135	135
3	17.9	44	–12	134	–178	223
4	15.4	–156	321	–66	155	168
5	14.7	–267	162	–177	–4	177
6	(b)	(b)	(b)	(b)	(b)	(b)
7	15.9	6	235	96	69	118
8	(a)	–114	192	–24	26	35
9	(a)	–225	309	–135	143	197
Average	15.9	–90	166	≅ 0	≅ 0	154
Std. Dev.	1.1					58

(a) Time of flight not determined, usually because sight of shell was lost.

(b) This shell burst in the air, because one of its time fuses functioned even after having been wetted.

For conversion to SI units, 1 foot = 0.30 m.

The average shell drifts for the paired sets of shells were found to be 162 feet (49 m) and 154 feet (47 m) for the normal and long mortars, respectively. The one-sigma standard errors are ±23 feet (7.0 m) and ±19 feet (5.8 m). Thus the two drift distances are the same, to within the limits of statistical certainty.

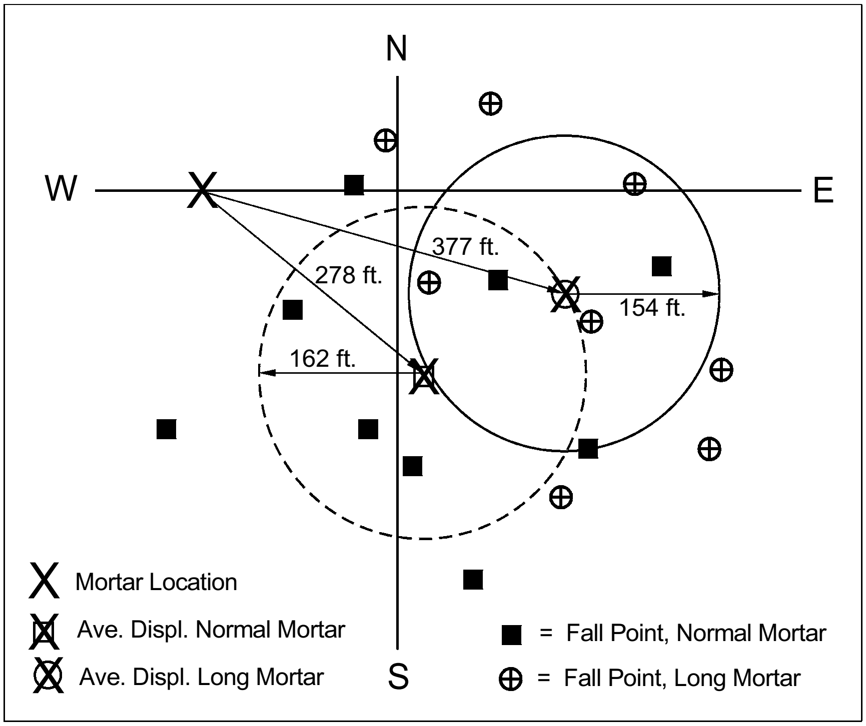

Figure 1. The location of the points of fall for the shells fired from long and normal length mortars.

(B) The Effect of Capsule-Shaped Shells

Ten 6-inch (155-mm) capsule-shaped aerial shells were fired to determine whether this shell configuration resulted in shell drifts that were noticeably different from typical spherical shells of the same size. A cross sectional view of a capsule-shaped shell casing is illustrated in Figure 2. The shells had a maximum diameter of 5.88 inches (149 mm), a length of 7.31 inches (186 mm), and were filled to a weight of 2.5 pounds (mass of 1.13 kg) using a mixture of dry dog food and small pebbles. The shells were fired from a steel mortar with an internal diameter of 6.05 inches (154 mm) and a length of 29 inches (0.75 m). The mortar was positioned vertically. In each case, the propelling charge was 1.75 ounce (50 g) of 4FA Black Powder. This is about one ounce (28 g) less than typical for a 6-inch (155-mm) spherical shell, and was done in an attempt to correct for the fact that these shells fit more tightly in the mortar. They were about ¼ inch (6 mm) larger in diameter than typical spherical shells. (The success of this adjustment can be judged by comparing the average flight times reported in Tables 1a and 2, which are virtually identical.)

These tests were conducted at an elevation of approximately 4600 feet (1400 m) above sea level and with a surface wind of less than 2 mph (3.2 km/h). Again, the standard test protocol was used.[2] The test results are presented

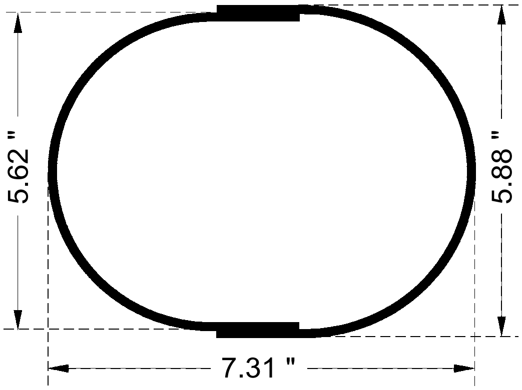

Figure 2. Illustration of a capsule-shaped aerial shell casing.

Table 2. Data from Capsule-Shaped Shell Tests.

Shell Number	Time of Flight (s)	Point of Fall (Orig. Coord. Sys.) North (ft)	Point of Fall (Orig. Coord. Sys.) East (ft)	Point of Fall (Shifted Coord. Sys.) North (ft)	Point of Fall (Shifted Coord. Sys.) East (ft)	Drift Distance (ft)
1	12.3	–13	–240	31	–189	192
2	13.4	–229	61	–185	112	216
3	13.3	–241	–66	–197	–15	197
4	13.6	–147	–237	–102	–186	213
5	13.4	287	–10	331	41	334
6	13.3	202	–220	246	–169	299
7	14.5	–114	–90	–70	–39	80
8	14.6	–167	299	–123	350	371
9	13.9	87	212	131	263	294
10	12.3	–106	–219	–62	–168	179
Average	13.5	–44	–51	≅ 0	≅ 0	237
Std. Dev.	0.7					82

For conversion to SI units, 1 foot = 0.30 m.

in Table 2.

The average drift distance for the 6-inch (155-mm) capsule-shaped, pulp-molded shells was 237 feet (72 m) with a 1-sigma standard error of ±26 feet (7.9 m). Past measurements of 6-inch (155-mm) shells under similar conditions gave a drift distance of 145 feet with a 1-sigma standard error of 31 feet (9.5 m). Based on a linear fit to drift data for various sized shells, a drift distance of approximately 192 feet (59 m) would be expected.[2] Accordingly, it seems that the capsule-shaped shells do not drift less than spherical shells, and it is likely they drift somewhat more.

Conclusion

Based on these brief studies, it seems clear that mortar length does not have a major effect on spherical aerial shell drift. Further, it seems clear that capsule-shaped shells do not drift significantly less than spherical shells and probably drift slightly more. Accordingly, for either case, there seems to be no reason to consider modified spectator separation distances at fireworks displays.

References

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