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Study of the Effect of Leg Wire Attachment on the Burst Height of Aerial Shells

K. L. Kosanke
PyroLabs, Inc., 1775 Blair Road, Whitewater, CO, USA

and

B. J. Kosanke
Journal of Pyrotechnics, Inc., 1775 Blair Road, Whitewater, CO, USA

ABSTRACT

In many electrically discharged fireworks displays, it is a common practice to securely attach the electric match leg wires to both the aerial shell and to the firing mortar or mortar rack. When this is the case, it is necessary for the aerial shell to sever the attachment to the mortar or rack upon the firing of the shell. Usually this is accomplished by severing (tearing) the leg wires themselves. In this process, some of the kinetic energy of the shell is consumed, resulting in a reduction in the burst height that would otherwise have been achieved. This reduction in burst height will be greatest for those shells possessing the least kinetic energy (i.e., the smallest and lightest of the aerial shells). While experience has shown that the amount of reduction in burst height apparently does not present a significant safety hazard, the question remains as to how much reduction actually results. In a brief study of this question, it was concluded that for even the smallest and lightest aerial shells commonly used in displays (75 mm with a mass of 90 g) the reduction in burst height is on the order of 12%, and this decreases to about 1% for mid-sized aerial shells (150 mm with a mass of 1.1 kg).

Introduction

After loading fireworks aerial shells into their mortars for firing electrically, it is a common practice to firmly secure the electric match leg wires to the rack or mortar (a process often called *short wiring*). One purpose of this is to prevent the leg wires attached to one shell, from dislodging the leg wires attached to other shells, when the first aerial shell is fired. Further, to achieve a high degree of aerial shell burst time precision,[1] electric matches are often installed either into the quick match at a point close to where it enters the lift charge or directly into the lift charge itself. When this is done, it is common for the electric match leg wires to be securely attached to the aerial shell itself.

In those instances where solid leg wire attachments have been made to both the rack and the shell, it is necessary for the aerial shell to break the leg wire tether upon firing. Often this is accomplished by a breaking (tearing) of the leg wires themselves, a process that must reduce the shell's upward velocity and thus the height achieved by the aerial shell.

From time to time, pyrotechnists have pondered the extent of that burst height reduction. Obviously, the effect will be the greatest for small spherical shells that have lower amounts of kinetic energy. However, even for the smallest commonly fired spherical aerial shells (75 mm or 3 in.), common experience has shown that the reduction in height is not so great that it represents a substantial safety risk from low breaking shells. Nonetheless, the question remains as to the amount of reduction that occurs. Toward satisfying such curiosity, a brief study was conducted to determine the reduction in the height achieved by small caliber (75-mm or 3-in.) aerial shells that had to sever their electric match leg wires upon exiting the mortar after firing.

Table 1. Results from Time of Flight Measurements for Test Aerial Shells.

Leg Wire Attachment Method	Average Time of Flight (s)	Std. Dev.[(a)] (s)	Std. Error[(b)] (s)	Muzzle Velocity[(c,d)] m/s (ft/s)	Approx. Height Reached[(d)]		
					1400 m (4600 ft)[(e)] m (ft)	300 m 1000 ft[(e)] m (ft)	3 sec.[(f)] m (ft)
Wires Free	10.09	0.58	0.16	84.5 (277)	122.6 (402)	113.4 (372)	107.6 (353)
Wires Break[(g)]	9.38	0.65	0.17	72.6 (238)	106.4 (349)	98.8 (324)	95.1 (312)
Difference	0.71	—	—	11.9 (39)	16.2 (53)	14.6 (48)	12.5 (41)

a) The standard deviation was determined using the $n - 1$ method.

b) The standard error was reported as the standard deviation divided by the square root of the number of measurements.

c) The muzzle velocity was calculated to be that needed to produce the observed flight time for the test shells fired at 1400 m (4600 ft) above sea level, which is the elevation of the test facility being used.

d) More significant figures are being carried than might be justifiable. While it is thought that the relative accuracy of these data is fairly good (probably to within a percent or two), the absolute accuracy is not as good (perhaps no better than about 10 percent).

e) The approximate shell height attainable at the elevation above sea level indicated, assuming shell does not burst prior to that.

f) The approximate shell height attained after 3 seconds of flight at 300 m (1000 ft) above sea level.

g) The attachment of the leg wires was sufficiently strong to cause them to tear, as was confirmed by inspection after each firing.

Experimental

Typically, even for just one size aerial shell, there is a considerable range in shell characteristics (lift charge type and amount, shell diameter and mass, etc.). As a result, upon their firing, shells possess a considerable range of kinetic energy. The test shells used in this study had characteristics chosen to be representative of 75-mm (3-in.) aerial shells producing only relatively modest kinetic energy (such that they would be more greatly affected by having to sever their leg wire attachments).

The test shells used in this study were all 75-mm (3-in.) inert spherical plastic shells with an actual diameter of 66 mm (2.62 in.) and weighing 90 g (3.2 ounces). Each lift charge contained 14 g (0.5 ounce) of Goex[2] 4FA Black Powder and was ignited using a Daveyfire[3] SA2000 A/N 28 B electric match inserted into the approximate center of the lift charge.

For one collection of 16 aerial shells, the electric match leg wires were firmly attached to the body of the shell; for a second collection of 16 shells, the leg wires were not attached to the shell. In both cases, the other ends of the electric match leg wires were firmly attached to the mortar rack. (The attachments to shell and rack were sufficiently strong to cause the leg wires to tear upon firing the shell, as was confirmed by inspection after each firing.) For each test, the total flight time, from firing the shell to its eventual return to the ground, was measured by two observers using stopwatches and was recorded as the average of the two measurements. However, of these 32 firings, only 29 flight times were properly recorded (14 with leg wires free of the shells and 15 with wires attached to the shells). The averaged results from the test firings are reported in the first four columns of Table 1.

Results

After incorporating the parameters of the tests into an aerial shell ballistics model,[4] the computer model was used to convert the measured average flight times into the shell muzzle velocities that would be needed to produce those flight times. The computer model also produced maximum shell heights expected to be reached by those shells. (Note that the general accuracy of the computer model had previously been verified by comparisons between its predictions and actual test shell firings.) These muzzle velocities

Table 2. Expected Reduction in Burst Height for Typical Aerial Shells.

Spherical Aerial Shell	Muzzle Velocity m/s (ft/s)	Shell Weight kg (lb)	Shell Diameter mm (in)	Burst Height Reduction (%)
75 mm (3 in.), Modest Energy$^{(a)}$	84 (277)	0.09 (0.2)	67 (2.62)	12
75 mm (3 in.), Typical	92 (300)	0.14 (0.3)	67 (2.65)	7
100 mm (4 in.), Typical	92 (300)	0.36 (0.8)	91 (3.60)	3
125 mm (5-in.), Typical	92 (300)	0.68 (1.5)	117 (4.60)	2
150 mm (6 in.), Typical	92 (300)	1.14 (2.5)	141 (5.55)	1

(a) See Table 1.

and maximum shell heights are presented in columns five and six of Table 1.

When the two sets of data were compared, the model predicted a reduction of approximately 11.9 m/s (39 ft/s) in the muzzle velocity for those shells that had to break their electric match leg wires. Further, this corresponded to a reduction of approximately 16.2 m (53 ft) in the maximum height reached by those test shells that had to break their electric match leg wires. In this case, the firmly attached shells were predicted to have reached only approximately 106.4 m (349 ft) on average, as compared with the shells that flew freely to have reached approximately 122.6 m (402 ft).

It must be considered that this testing took place in western Colorado at an elevation of approximately 1400 m (4600 ft) above sea level. Accordingly, the computer ballistics model was used to convert the shell height predictions to their corresponding values for an elevation of 300 m (1000 ft) above sea level (assumed to be a reasonable average for most display sites). This reduced the calculated maximum heights to approximately 98.8 and 113.4 m (312 and 353 ft) for the shells with attached and unattached leg wires, respectively.

Finally, it must be considered that typical 75-mm (3-in.) fireworks aerial shells burst approximately three seconds after their firing, which is typically before the shells will have reached their maximum achievable height. Accordingly, by consulting the time record of the ballistics model, it was determined that on average the shell height upon bursting will be 95.1 and 107.6 m (324 and 372 ft), respectively for shells (fired at 300 m above sea level) with attached and unattached leg wires, respectively. This corresponds to an approximate 12 percent reduction in burst height for these (modest kinetic energy) 75-mm (3-in.) aerial shells that must break their electric match leg wires upon being fired from their mortars.

If it can be assumed that the results reported above are reasonably correct and that the energy consumed by more massive aerial shells breaking free is the same as for the test shells, then some additional inferences can be drawn. The first four columns of Table 2 present the salient parameters for "typical" 75-mm (3-in.) to 150-mm (6-in.) aerial shells. Reported measurements of aerial shell muzzle velocities typically range from approximately 75 to 110 m/s (250 to 350 ft/s), mostly independent of shell size. Accordingly, for this study, muzzle velocities of 92 m/s (300 ft/s) are assumed for the variously-sized shells. Shell weights and diameters are those the authors have used in previous studies; they are based on a series of measurements of a wide range of display shells made in the mid 1980s, and the values are assumed to still be typical of shells produced today. Using these input parameters, the ballistics modeling code was used to predict the heights of the typical attached and unattached aerial shells. The burst height reductions are presented in the last column of Table 2 and are rounded to the nearest percent.

Conclusion

The ballistics model used in these calculations has been tested and found to accurately reproduce the results of field trials. However, to obtain the greatest accuracy in its calculations, one must adjust for actual air density at the time of the shell firings and also fine tune the drag coefficients of the shells. This was not done for the calculations in this article. Accordingly, while the relative accuracy of the calculations should be quite good, the absolute accuracy may be considerably less. For example, when calculating the difference between pairs of predicted shell heights differing only because of a small change in muzzle velocity, the results are probably accurate to within a meter; whereas, when considering any one predicted shell height alone, the results may be no more accurate than perhaps ten meters. Considering the wide range of actual shell parameters and firing conditions, the uncertainties the in the shell heights reported in Table 2 must be small by comparison.

The reduction of burst height, for modest kinetic energy 75-mm (3-in.) spherical aerial shells when they must break free of their leg wire attachment (≈12%), is only minimally significant. The reduction for normal energy 75-mm (3-in.) shells (≈7%) is mostly insignificant, and that of larger shells (≤3%) is completely insignificant. Accordingly, the results reported in this article are consistent with the empirical observation that the reduction in aerial shell burst height, as a result of shells having to break free of their leg wire attachment, does not represent a safety problem for typical 75-mm (3-in.) and larger aerial shells.

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