An earlier version appeared in *Fireworks Business*, No. 249, 2004.

The Effect of Intentionally-Caused Fire Leaks into 3-inch Display Firework Aerial Star Shells

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This article is the second report on a series of tests to more definitively establish the difference between the causes of so-called *flowerpots* and *muzzle breaks*. A previous article[1] reported on a similar study using 2-1/4 inch (57-mm) plastic aerial shells (formerly classed as consumer fireworks). The current article extends the earlier work by considering relatively high quality, although small, display firework shells. To conserve space and avoid needless repetition, some of the background and supporting information presented in the earlier article will not be repeated in the present article.

The current study, as in the previous study, concludes that quite large fire leak holes are needed to cause the shells to explode while still within the mortar upon their firing. This is significant because it was previously demonstrated that the nature of the break charge substantially affects the size of the hole needed to cause shells to explode within the mortar as they are fired.[1] For example, the presence of a relatively small fire leak hole is sufficient to cause a salute to explode while still well within its firing mortar. This is in contrast with the 2-1/4 inch (57-mm) plastic aerial shells tested previously, which had little if any break powder, and the fire leak hole results for those shells were not considered to necessarily apply to higher quality more powerfully breaking aerial star shells. The display shells in the current study had ample high quality break powder and were reasonably powerfully breaking. (Although testing using larger caliber display aerial shells has not yet been completed, it is appears that rather large fire leak holes are also necessary to cause those larger caliber shells to explode while still inside their mortars as they are being fired.) Thus, as was concluded in past studies of the probable causes of flowerpots and muzzle breaks of star shells,[2] small cracks and holes in those shells have the potential to cause muzzle breaks; however, much more substantial fire leaks (up to and including total casing failures) are required to produce in-mortar shell explosions. (Note that a discussion of the causes of malfunctions described as flowerpots is complicated somewhat by the observation that some muzzle-breaking shells actually give the visual appearance of what would generally be described as flowerpots.[3]

Test Procedure

In the current tests, the shells were 3-inch (75-mm) Thunderbird brand "Color Peony-Gold" product number TBA-105. The shells were approximately 2.68 inches (68 mm) in diameter and of typical paper construction with two time fuses. On average, the shells had a total mass of approximately 4.8 ounces (130 grams), and with approximately 1.3 ounces (36 grams) of lift powder. The shells contained approximately 2.5 ounces (70 grams) of stars that were approximately .032-inch (7.6 mm) in diameter, and approximately 0.64 ounces (18 grams) was rice hull break powder.

To prepare the test shells for firing, their paper lift bag covering and the plastic bag of lift, with the shell leader attached, were removed. A fire leak hole was made in the immediate area of the time fuses of each test shell, using a remotely operated mechanically driven awl. Awl diameters ranged from 0.040 inch (1.0 mm) to 0.23 inch (5.8 mm). Because the shell casings were paper, following removal of the awl, the diameter of the hole remaining open was slightly less than the diameter of the awl. The actual diameters of the fire leak holes were determined by inserting drill stems of various diameters into the hole until the largest one that fit effortlessly was found. The diameter of the fire leak holes ranged from 0.035 inch (0.89 mm) to 0.20 inch (5.1 mm). The shell leaders were removed from the bags of lift powder and replaced with electric matches (Daveyfire AN/28 B). The lift charges were then secured to the bottom of the shells us-

Table 1. Results From Fire Leak Testing of 3-inch (75-mm) Display Fireworks Aerial Shells.[6]

Fire Leak Hole(a)		Shell Burst Height (ft.)			High Speed Video	Mortar Pressure Gauge
Diameter (in.)	Area (x 10^3) (in.^{2})	Average(a,b)	Standard Deviation(a,c)	Standard Error(d,e)		
0.035	0.96	7.3 (0)	1.0	0.5	Yes	No
0.055	2.4	9.0 (0)	2.5	1.	No	No
0.074	4.3	3.5 (0)	0.9	0.4	Yes	No
0.086	5.8	4.1 (0)	1.5	0.7	No	No
0.11	9.4	3.0 (0)	1.8	0.8	Yes	Yes
0.16	20.	2.4 (0)	1.1	0.5	Yes	Yes
0.20	31.	0.76 (3)	0.9	0.9	Yes	Yes

a) Values reported to two significant figures.

b) The number in parenthesis is the number of shells bursting within the mortar. In calculating the average burst height, a shell burst occurring within the mortar was arbitrarily assigned a burst height of –0.5 foot.

c) The standard deviation was computed using the so-called $n - 1$ method.

d) The standard error of the mean is equal to the standard deviation divided by the square root of the number of measurements being averaged (i.e., in this case the number of measurements was 5).

e) Values reported to one significant figure.

ing a small amount of tape. For each fire leak hole size, five test shells were prepared and fired.

The test mortars were high density polyethylene (HDPE), 22.5 inches (570 mm) long above the mortar plug and 2.93 inches (74.4 mm) inside diameter. For some tests, the mortar was fitted with a piezoelectric pressure gauge. This was done because monitoring the mortar pressure profile as a shell fires provides confirmation as to whether the shell exploded within the mortar as opposed to a few feet above the mortar. (See reference 3 for a demonstration of the spike in mortar pressure when a shell explodes before it has exited the mortar.)

In all cases the testing was documented by video taping using conventional video equipment. However, during the course of the testing, the use of a high frame-rate video system was acquired.[4] This aided in the ability to accurately determine the height above the mortar at which the shell bursts had occurred. However, when shell burst occurred very close to the muzzle of the mortar (within the muzzle flash of a firing mortar), the high speed video provided confirmation as to whether the shell burst occurred just inside or just outside the mortar. This is because of differences in the pattern of the stars produced, which are only discernable using the high frame-rate video system. (See reference 3 for a demonstration of the differing star patters for shell bursts occurring well-outside, just-outside and inside the mortar.)

Burst Height Results

The results of the testing are summarized in Table 1 and Figure 1. As in the previous study, there is a large amount of variability in the burst height data, which is thought to be a reflection of the large variability so often seen in pyro-

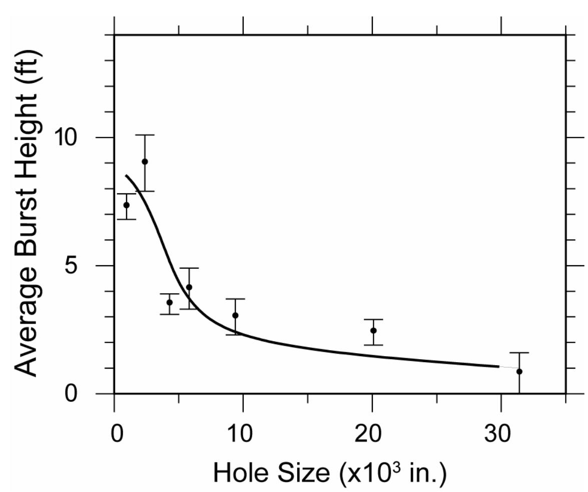

Figure 1. Graph of average burst height as a function of fire leak hole area. (The error bars are the one sigma (1 σ) standard errors reported in Table 1.)[5,6]

technic ignition and propagation. For this reason the location and shape of the average burst height trend line in Figure 1 is relatively uncertain. Had this needed to be determined with greater accuracy, many more test aerial shells (than the five for each size fire leak hole) would have needed to be test fired.

The general shape of the average burst height curve is similar to that found previously for the 2-1/4 inch (57-mm) plastic aerial shells. Both start at roughly 10 feet (3 m) for the smallest fire leak holes (approximately 0.04-inch diameter), then fall to lower burst heights for larger size holes, with shells bursting within their mortars when the fire leak hole diameter reaches approximately 0.2-inch (5 mm) in diameter. However, the approximate hole size where there appears to be a substantial drop in average burst height occurs at approximately 0.06-inch (1.5 mm) for 3-inch (75-mm) display shells whereas a similar drop did not occur until significantly larger fire leak holes (approximately 0.15-inch [3.8-mm]) for the 2-1/4 inch (57-mm) plastic shells. Based on the substantially different types and amounts of break powder for the two types of shells, and the previous testing using various types of break charge, a difference such as this could be expected.

These display aerial shells had more lift charge than thought to be typical of other manufacturers. However, this is not expected to have produced substantially anomalous results. With more lift charge, the mortar pressures were greater than the average of previous measurements. (Peak mortar pressures in this case averaged approximately 110 psi (759 kPa) whereas previous measurements of a variety of shell types produced an average of only approximately 40 psi [276 kPa].). The higher pressure must cause more burning lift gas to pass through a given diameter fire leak hole, which will result in reduced time for the shell to explode. (This effect was demonstrated in the testing reported below.) However, at the same time, the greater mortar pressures will also cause the shells to exit the mortar in less time (also shown below). The result of the shell explosion times and mortar exit times both being reduced must tend to balance each other and should tend to leave the burst height versus fire leak hole diameter data somewhat unaffected.

Measurement of Shell Burst and Mortar Exit Times

To help gain a better general understanding of the flowerpot versus muzzle break processes, measurements were also made of the average time required for a test shell to exit its mortar after having its lift charge ignited and the average time required for a test shell to explode after having its contents ignited. The same methods that have been used successfully in the past[1,2] were employed in these measurements and will not be described again in this article.

The average of five measurements of shell exit time was 0.027 second. This compares with an average of 0.043 second measured previously for a variety of 3-inch (75-mm) display shells.[2] Considering that the current test shells have a greater amount of lift powder than typical, this reduction of approximately 35% in average exit time seems reasonable.

The average of five measurements of shell burst time was 0.065 second. This compares with 0.043 second measured previously for a variety of 3-inch (75-mm) display shells.[2] While this is greater than the average found previously for other shells, it is within the range of those earlier measurements.

In an attempt to quantify the effect of an increased amount of fire leaking into an aerial shell because of the greater than typical mortar pressure found for these test shells, some additional measurements of shell burst time were made. In these tests two electric matches were sealed into the shells at points across from one another in the shell casing, rather than using the single electric match as in previous tests. When this was done, the average shell burst time decreased from 0.065 to 0.042 second, approximately 30% less than when a single electric match was used.

Conclusion

The most significant piece of information gained from this study is that a fire leak hole nearly the same diameter as a typical time fuse must be present to cause the shell to explode while still inside the mortar. Further, based on the mortar pressure profile data, even those shells in this study that did explode inside the mortar did so quite near the top of the mortar.

Accordingly, the results of this study support and help quantify the conclusions presented in reference 2, that relatively small fire leaks must produce muzzle breaks in display aerial star shells, and that flowerpots are the result of very much more substantial fire leaks, up to and including the complete failure of shell casings due to the inertial forces produced by the very great acceleration of aerial shells as they are being fired (accelerations that can exceed 1000 times that of gravity[5]).

To further investigate and document the causes of muzzle breaks and flowerpots, similar studies using larger caliber shells have begun and will be reported when they are completed.

Acknowledgment

The authors are grateful to Larry Weinman (Schneier / Weinman Consultants) for commenting on an earlier draft of this article.

References and notes

1) K. L. and B. J. Kosanke, "The Effect of Intentionally Caused Fire Leaks into 2-1/4 Inch Plastic Firework Aerial Shells", *Fireworks Business*, No. 241, 2004; also in *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 and 2004)*, Journal of Pyrotechnics, 2006.

2) K. L. and B. J. Kosanke, "Hypothesis Explaining Muzzle Breaks", *Proceedings of the Second International Symposium on Fireworks*, 1994; also in *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 3 (1993 and 1994)*, Journal of Pyrotechnics, 1996.

3) K. L. and B. J. Kosanke, "Muzzle Breaks That Appear as Flowerpots", *Fireworks Business*, No. 247, 2004; also in *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 and 2004)*, Journal of Pyrotechnics, 2006.

4) The high speed video camera system was provided by SpeedVision Technologies, Inc. San Diego, CA, USA (858-450-7107).

5) K. L. and B. J. Kosanke, "Peak Shell Accelerations", *American Fireworks News*, No. 217, 1999; also in *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 5 (1998 through 2000)*, Journal of Pyrotechnics, 2002.

6) For Si Unit Conversions: 1 inch = 25.4 mm; 1 foot = 0.305 m; 1 psi = 6.9 kPa.