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Firing Precision for Choreographed Displays

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For maximum effectiveness of tightly choreographed fireworks displays, it is important that shell bursts occur very near their intended times. Two main sources of variation combine to affect the overall precision of the shell bursts. First is the preciseness of the shell firings; second is the preciseness of the time fuse burning. Other than by purchasing high quality shells, a display company generally has little control over the precision provided by the shell's time fuse. However, the display company can do much to control the firing precision for those shells. For the most part accurate firings are only possible using electrical ignition. For the purposes of this article, it is assumed that a computer or other means of accurately applying the firing current to electric matches (e-matches) is being used. This leaves the question as to the degree of firing precision achieved using various methods of attaching e-matches to shells and is the subject of this article.

There are three common points of attachment for e-matches. These are illustrated in Figure 1. In terms of convenience, safety and effectiveness (firing time precision), each has its own set of advantages and disadvantages. While issues of safety and convenience are quite important considerations, they are beyond the scope of this article. In terms of firing precision, common knowledge has it that installation of the e-match directly into the lift charge (point 3 in Figure 1) provides the most precise timing; attachment at the end of the shell leader (point 1) provides the worst timing; and attachment to the shell leader just above the body of the shell (point 2) is somewhere in between in terms of effectiveness. However, the authors are unaware of any reported test of this common knowledge. Further, there are those that claim that the precision achieved using attachment point 2 is just as good as using point 3. Accordingly, (and because it made an interesting short project) a series of instrumented shell firings were conducted as a test of these two schools of thought.

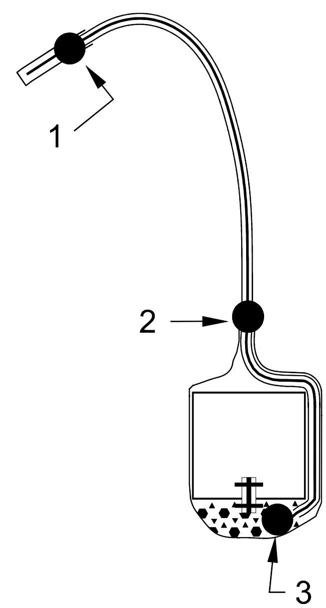

Figure 1. Illustration of the three common points of attachment of e-matches to aerial shells.

All tests were conducted using identical inert 3-inch (75-mm) spherical plastic aerial shells fired from mortars fitted with trip wires at their mouth. Firing times were measured using an instrument that provided the e-match firing current, and at the same instant started a precision timer, which stopped when the trip wire was broken. A series of eight tests were performed for each shell configuration, with the average and standard deviation of the firing times then calculated. To simulate actual field conditions, all test shells were assembled and fitted with e-matches, then placed in an environmental chamber [72 °F (22 °C) and 78% relative humidity] for three days.

In the first series of tests, e-matches were installed at the ends of 24-inch long shell leaders (point 1). Twenty-four tests were performed: eight with shell leaders made using a high quality quick match (from Precocious Pyrotechnics); eight with shell leaders taken from Horse brand shells; and two each with shell leaders taken from Yung Feng, Angel, Flower Basket, and Flying Dragon brand shells. The results are reported in the first three rows of Table 1. The firing times and their standard deviations for the third group of test firings are both rather excessive, due to the occurrence of two short duration hangfires (lasting approximately 2.5 and 1.2 seconds). In an attempt to give this method of e-match attachment the benefit of the doubt, the results were recalculated, this time omitting the two hangfire results. Finally, to approximate what would be expected in a typical display using a variety of different shell brands, all 24 (or 22) firings were considered as a single set, reported in Table 1 as "Combined".

Table 1. Firing Time Results for Various E-Match Attachment Points.

Test Conditions	No.[a]	F. Time[b] (sec.)	Std. Dev.[c] (sec.)
Precocious - long	8	0.26	0.15
Horse - long	8	0.32	0.12
Variety - long	8	0.76	0.76
	6[d]	0.41[d]	0.15[d]
Combined - long	24	0.45	0.49
	22[d]	0.32[d]	0.14[d]
Precocious - short	8	0.11	0.025
No Match® in lift	8	0.08	0.020
E-Match in lift	8	0.04	0.005

a) Number of individual test firings.

b) Firing time is the average of the eight elapsed times between applying current to the electric matches and the shells exiting from the mortars, rounded to the nearest 10 ms.

c) The one sigma standard deviations of the average firing times were determined using the n–1 method.

d) These data are for the same tests but do not include the two short duration hangfires that had occurred.

While the average firing times for the various groups differ somewhat, the precision for each individual group and the collection as a whole are not all that bad, if the two hangfires are not included. (Note that an average firing time of 0.32 second, with a precision of 0.14 second, means that about 70% of the firings will occur between 0.18 and 0.46 second, a range of approximately 0.3 second.) As a point of comparison, humans can fairly easily discern timing differences of 0.1 second, or about 1/3 that seen in these test firings. Accordingly, these tests produced a wider range than would be preferred, even if the time fuses and shell bursts had performed with absolute precision (no variation at all).

For the next group of eight test firings, again Precocious Pyrotechnics' quick match was used; however, this time the length of leader was only about four inches, just enough to reach to near the top of the shells. Another group of shells was fired using e-matches installed on the ends of B & C Products' 24-inch No Match® API shell leaders. (These were shock tube shell leaders.) Finally, there was a group of firings with the e-matches installed directly into the shell's lift charge. These additional results are included as the last three rows in Table 1.

These last three firing methods produced average firing times less than those using the full-length shell leaders. However, more importantly, the timing precision is greatly improved, with each method producing a firing-time precision better than would be perceived by spectators. Thus, although the precision achieved with e-matches installed directly in the lift charges was observed to be better than the short shell leaders (attachment point 2), the improvement would not be detectable by spectators.

In conclusion, it must be considered that this was a single brief series of tests. While the results are probably valid, it is possible that significantly different results would be found for other conditions and materials. Nonetheless, it would seem that both schools of thought about e-match attachment are generally correct. Attachment at the ends of long shell leaders produced the worst firing-time precision, but not terrible—providing actual hangfires were not considered. Installation of e-matches directly into lift charges produced the best precision (lowest standard deviation). However, the firing-time precision for short shell leaders was equally satisfactory, because it is better than could be detected by spectators. No Match® also performed well in these tests but only marginally better than the short quick match.

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