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# Study of the Effect of Ignition Stimulus on Aerial Shell Lift Performance

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***ABSTRACT***

*It had been speculated that the replacement of fierce burning quick match shell leaders with electric matches might have contributed to the production of a significant number of low breaking aerial shells experienced by a small fireworks display company. A preliminary study of the effect of ignition stimulus level did not supporting the theory that the weaker stimulus provided by electric matches (possibly in conjunction with Chinese lift powder) was the reason for the low breaking shells. However, that study was thought not to be sufficiently conclusive to completely settle the question. Accordingly, a more extensive series of tests were subsequently performed. For these tests, because of the lack of sufficient Chinese lift powder, Goex (USA) Black Powder was used. The result of these tests was that again no effect was observed for the flight times of the test aerial shells. The average flight times for groups of approximately 30 of the 75-mm (3-in.) test shells was 9.65 ± 0.13 seconds and 9.58 ± 0.17 seconds for shells using quick match and electric match firing, respectively.*

## Introduction

A few years ago, a small fireworks display company was experiencing what they thought to be an unusually large number of low breaking aerial shells (a few percent). These shells appeared to be breaking low because of being weakly propelled from their mortars. The shells were of Chinese manufacture but were of moderate to high quality (Jumping Jack, Thunderbird, and Sunny). The fierce-burning quick match on these shells had been removed and electric matches inserted into their lift charges. Obviously, one possible reason for the low breaking shells was a deficiency in their Black Powder lift charges (e.g., the amount or its quality). However, a few displays had been performed in which the shell leaders had not been removed, and on which the number of low breaking shells seemed to be significantly less. Accordingly, this lead to speculation about other possible causes for the low breaks when using electric matches. Foremost among the possibilities was the lower level of ignition stimulus thought to be provided by the electric matches in comparison with the strong jet of fire produced by the burning quick match shell leaders.

A preliminary study of the possible effect of ignition stimulus on lift powder performance was conducted previously.[1] First, the relative performance of the lift powders from the suspect shells was tested in an apparatus specially built for such testing.[2] These lift powders were found to produce muzzle velocities approximately two-thirds that of the same granulations of Goex[3] powders. Following this, a series of nine test shell firings were conducted, three using each of three levels of ignition stimulus: that produced by a hot wire igniter, that provided by an electric match (Daveyfire[4] SA-2000, A/N 28 B), and that from a shell leader taken from one of the suspect Chinese shells (Jumping Jack, Thunderbird, and Sunny). So that the test shells would be as near to identical as possible, inert spherical plastic shells were prepared, each measuring 67 mm (2.62 in.) in diameter, weighing 130 g, and each using the same amount and type of lift powder as used by the three manufacturers of the suspect Chinese shells. In that preliminary study, the flight times of the shells, peak mortar pressures, and pressure impulses produced dur-

ing firing were determined.[1] While no significant differences in lift performance as a function of ignition stimulus was observed, the number of test firings was not felt to be sufficient to be completely definitive. This current article is a report of a follow-on series of tests to further examine the effect of ignition stimulus on lift powder performance.

## Background

McLain has reported[5] that varying levels of ignition stimulus can produce differences in pyrotechnic output. To some extent, Shimizu[6] also documents the effect of varying the level of ignition stimulus. He reports that the velocity of propagation for flash powders can be substantially greater when initiated using a detonator (blasting cap) in comparison to that produced by thermal ignition. For example, Shimizu reported[6] that a potassium perchlorate, aluminum, and sulfur flash powder (in a ratio of 70:27:3, respectively) propagated at approximately 870 m/s when an electric igniter was used, as compared with a rate of 1420 m/s when initiated using a number 8 detonator.

In addition to McLain's and Shimizu's reports, the authors' found indirect evidence suggesting that the internal ballistics of aerial shells are quite sensitive to relatively minor changes in ignition stimulus. During laboratory measurements, it was found that surprisingly large variations in peak mortar pressure and muzzle velocity occur for apparently identical shell and lift powder configurations.[2,7,8] One possible explanation for this observation is that small differences, occurring in the earliest stages of lift charge burning, are responsible for relatively large differences in the propulsion of the aerial shells. Limited support for this theory can be seen in the lift pressure profile (lift pressure as a function of time) in a mortar as a shell is fired. For approximately half of the time between igniting the lift powder and the expulsion of the aerial shell, there is no significant pressure rise. (See Figure 1.) Presumably this apparently quiescent period is the time taken for the fire to spread through the grains of Black Powder before the burning becomes vigorous enough to cause a measurable rise in pressure. If that is the case, it is certainly possible that changing the manner of ignition of the lift powder could change the dynamics of the early fire spread and thus produce a significant difference in the propulsion of aerial shells. More support for this theory was found when it was discovered that lift performance can be significantly affected by relatively small changes in the point of ignition within the lift charge with all else being constant.[2]

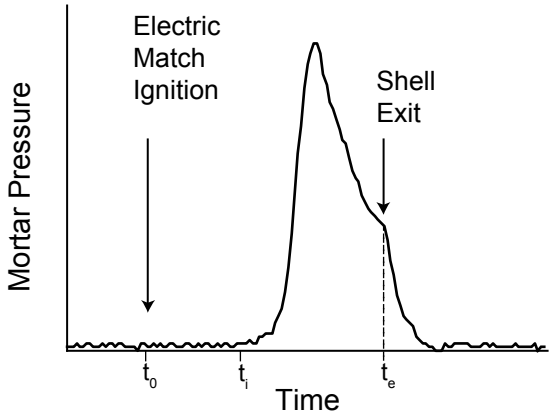


*Figure 1. A fairly typical mortar pressure profile\during the firing of an aerial shell.*

With the firing of an electric match, there is a sudden burst of fire, which is fairly limited in both amount and duration. With burning quick match, potentially a much more substantial and sustained jet of fire is produced. Thus it seemed reasonable to speculate that quick match, especially the quite vigorous burning quick match found on some Chinese shells, would provide a greater ignition stimulus for the lift charge than that provided by an electric match. Further, because the Chinese lift powders were found to be somewhat slow burning in comparison to domestically produced Black Powder, the Chinese powder might be expected to be more sensitive to differences in the level of ignition stimulus.

However, contrary to the above speculation, if a weak ignition stimulus was the cause of the low break problem, then why did the problem not occur in more of the Chinese shells being fired using an electric match? Further, why had other display companies, which also used electric matches installed directly into the lift charges, not been reporting similar problems? Despite these possible contrary indications, it seemed that the ignition stimulus hypothesis was

worth further consideration; not only because it might be related to the low break problem, but also because it might help to explain the large variations in lift performance observed experimentally during the firing of what seemed to be identical aerial shells. Accordingly, a brief study was undertaken to investigate the effect of various levels of ignition stimulus on lift powder performance.[1] In that preliminary study, no support was found for the weak ignition stimulus hypothesis. However, due to the brevity of that study, it was thought that the results were not sufficiently conclusive to completely settle the question. Accordingly, this follow-on study was conducted.

## Experimental

The test shells used in this study were all 75-mm (3-in.) inert spherical plastic shells with a diameter of 67-mm (2.62-in.) and weighing 90 g. The lift charges were each 14 g of Goex[3] 4FA Black Powder, ignited using either Daveyfire[4] SA2000 A/N 28 B electric matches or quick match from one of a collection of suppliers. In either case, the end of the igniter was placed in the approximate center of the lift charge. The test mortars were approximately 560-mm (22-in.) long HDPE with an ID of approximately 74-mm (2.93-in.). The test firings were conducted at an elevation of approximately 1400 m (4600 ft). For each test firing the effectiveness of lift charge performance was determined by measuring the time from firing the shell to its eventual return to the ground. This was used to determine the average maximum height reached by the shells.[9] The flight times were measured by two observers using stopwatches and recorded as the average of the two measurements.

A total of 64 test shells were fired. Of these 32 used electric matches; however, total flight times were successfully recorded on only 29 occasions. In addition, a total of 32 firings used quick match from a collection of manufacturers. The results from the test firings are reported in Table 1.

**Table 1. Results from Time of Flight Measurements.**

| Ignition Method | Average Time of Flight (s) | Std. Dev.[a] (s) | Std. Error[b] |
|---|---|---|---|
| Electric Match | 9.68 | 0.93 | 0.17 |
| Quick Match | 9.64 | 0.74 | 0.13 |

a) Standard deviation, determined using the $n - 1$ method.

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

## Conclusion

The time of flight results for both types of ignition stimulus were found to be statistically equal, and both correspond to a maximum shell height of approximately 110 m (370 ft). Thus, as in the preliminary study, the current tests provide no support for the theory that the low breaking shells were the result of a reduction in ignition stimulus because of the replacement of quick match with electric matches. However, in the current study only US produced Black Powder was used. Whereas it had been part of the initial speculation about the level of ignition stimulus affecting the lift charge performance, that perhaps the effect would be more noticeable when using Chinese Black Powder, which had been found to be less vigorous in its burning. Unfortunately, the authors did not have a sufficient supply of Chinese lift powder for use in the current study. However, even if the Chinese lift powder is more sensitive to varying levels of ignition stimulus than is the US powder, it is thought that some reduction in performance should still have been found in the current tests. Accordingly, it is concluded that a reduced level of ignition stimulus provided by electric matches, in comparison with that provided by fierce burning quick match, most probably was not the cause of the low breaking shells that originally prompted these tests.

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