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Electrical Firing of Musically Choreographed Aerial Fireworks Displays

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1.0 Introduction

There are a number of reasons why one might be reluctant to consider abandoning traditional show firing methods in favor of performing electrically fired shows, especially those choreographed to a musical program. One reason is the perceived high cost of performing such shows. Other reasons might be a lack of detailed knowledge about performing such displays or the lack of a full appreciation of the benefits to be gained. It is the purpose of this paper to present detailed information concerning the staging of electrically fired aerial displays choreographed to music. However, in the process we hope to show how high initial costs can be offset in a relatively short time by increased profit. Also we hope it will become clearer that there are other benefits to be gained.

This paper is divided into two major sections. The first discusses electrical firing methods, not from a theoretical orientation, but rather by addressing the practical application of theory. (Note that a comprehensive and well written discussion of theoretical aspects of electric matches, wiring and firing controllers has been authored by Sam Bases.[1] The second section addresses details of musically choreographed display design and performance.

This paper will discuss the methods used by the authors for shows priced between $1,000 and $20,000. This approach was chosen in part to limit the length of this paper, but mostly because it is only these methods about which the authors have had extensive experience. Certainly it is not intended to imply that these methods are the only approach or even the best approach. However it should at least serve to demonstrate all the important aspects of electrically fired shows choreographed to music. For readers who have not yet begun performing such displays, hopefully, this paper will serve as a starting point from which their methods can be developed. For readers already performing such displays, this paper may present some alternate ideas that may be of some use.

2.0 Electrical Firing, Applied

2.1 Basic Requirements

The basic requirements of any method for electrical firing, in order of importance, are safety, reliability, and ease of set-up and firing. A full discussion of these requirements is most appropriate; however, they will only be mentioned at this time. The discussion of these requirements is distributed throughout the paper as this method for electrically firing displays is presented.

2.2 Dense-Pack Mortar Trailers

A key concept in this electrical firing method involves the use of “dense-pack” mortar trailers. An example of one of these trailers is shown in Photos 1 and 2. This particular trailer has a bed six by 16 feet, a loaded weight of 7500 pounds, and contains 117 3-inch, 70 4-inch, 32 5-inch, and 21 6-inch paper mortars (note that plastic mortars could have been used). In addition 11 steel mortars, ranging from 7 to 12 inches in diameter, can be placed in a special rack in the front of the trailer. The trailers have the wiring for electrical firing built in, such that final preparation for firing is to simply plug-in the entire trailer. All electrical firing control wiring is in metal conduit to protect the wiring from damage and to shield the wiring from RF transmissions. The mortars are “aimed” by parking the trailer with the tongue pointing away from the fall-out zone, and then using the hydraulic tongue jacks to properly angle the mortars as illustrated in Photo 1. To eliminate any chance of unintentional trailer movement, its wheels and frame are blocked in position (not shown). If for reasons of safety the mortars need to be re-aimed, all 251 mortars can be completely repositioned in only a few minutes by removing the trailer blocks, releasing the tongue jacks, pull-

Photo 1. Side view of large "Dense-Pack" mortar trailer raised into possible firing position.

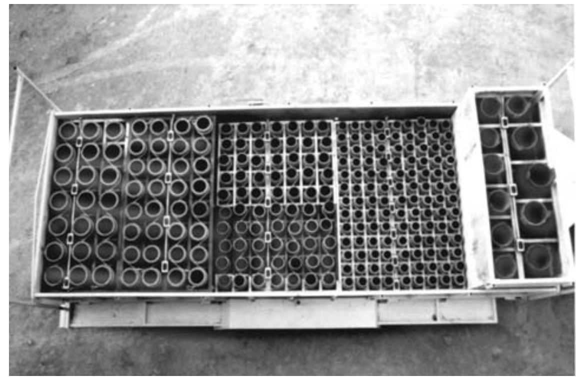

Photo 2. Overhead view of large "Dense-Pack" mortar trailer.

ing the tongue to one side or the other, then hydraulically raising the tongue again and re-blocking.

The mortars are held in place by a grid-like frame-work made of square tubular steel that loosely surrounds each mortar at its base, mid-point, and near the top. To prevent any chance of a mortar rebounding from its proper position after firing, a piece of elastic cord is woven back and forth between the mortars of each row. (This has the added benefit of slightly cocking the mortars back and forth which helps to disperse the shells in the air.) Because of the close packing of mortars and the lack of complete protection of one mortar from the next, large salutes are normally not fired from the trailers (the use of multiple smaller salutes is discussed below). Thus far, on those few occasions when star shells have exploded and destroyed the paper mortar in which they were loaded, there has never been serious damage to the surrounding mortars and no damage whatever to the rack frame. Further, in terms of safety, it is hard to imagine that it is possible to damage another mortar or the steel frame seriously enough to represent a public safety problem. Even if an adjacent mortar were seriously damaged without the knowledge of the operator, it will still be aimed properly. It is quite possible, if an unfired shell is in the mortar, that it will jam in the mortar and flower-pot when fired, or, if it leaves the mortar, it may have insufficient altitude. However, if normal safety distance requirements have been observed and a properly sized fallout area has been provided, there should be no risk to the public or operator. (Of course the most appropriate action to take if there is any suspicion of possible mortar damage is to interrupt the display to inspect the mortars.)

In addition to safety considerations discussed above, there are two others worth mentioning. Once shells are loaded into mortars, fused and individually covered as described below, the possibility of a careless smoker or stray sparks during a show causing a disastrous mass ignition of shells is eliminated. In addition, since all shells are secured in individual mortars in a small, easily policed area, the likelihood of the theft of shells is greatly reduced.

There are a few other features of this trailer that are worth mentioning. First are the carrying racks on top, which can be used for transporting poles and other set-piece materials to the site, or more importantly, with the aid of three 2 × 4's and two tarps, they can be used to provide a sheltered work place protected from sun and rain. Note that it is only the center support that must be removed from the trailer during the firing. Also shown is a pole with a mercury vapor light on top. This is stored under the trailer until after the show, at which time it and others are easily erected to provide a well-lighted work area during clean-up. On the sides of the trailer is a foot wide platform, for standing on while loading mortars. Electrical firing cables are long, heavy and expensive. The use of sturdy garden hose reels facilitates easy lay out and retrieval of cable and at the same time minimizes damage from twisting, knotting or kinking. (Note that during a show, cable on any reel where burning fall-out is possible should be protected by covering or should be removed to a safe place.) Finally there is a metal storage box in front of the trailer, which is useful for transporting and/or protecting trailer blocks, tarps, electrical cords, and other equipment.

Smaller, similarly-constructed trailers are also used (see Photo 3). This trailer has a bed roughly four by six feet and, loaded, weighs 1000 pounds. Its capacity is 32 3 or 4-inch paper mortars plus 20 sets of smaller mortars. For protection of the small mortar sets from accidental damage and sparks (unintentional ignition), each set is placed inside a large diameter plastic tube. The tubes are 8-inch ID with 3/8-inch walls, are slightly longer than the mortar sets, and have a 1½-inch thick wooden plug in the bottom (see Photo 4). To exclude sparks and burning debris from above, each plastic tube is covered with an 8-inch diameter cardboard disc taped over its open end. Typically the small mortar sets will be either four 2½-inch mortars, six 2-inch shell mortars, four 2-inch salute mortars, or twenty 1-inch salute mortars. (The effective use of large numbers of smaller shells and salutes is discussed in Section 3.2 of this paper.) These small trailers can be used singly for very small shows or for modest finales. One or more can be used in conjunction with larger trailers to provide multiple shooting sites. It is also possible to have larger trailers supporting two to four of these small racks. When more than one rack is used on a single trailer, it is possible to spread aerial effects more widely in the sky if the individual racks can be angled (tipped slightly) to opposite sides.

Photo 3. View of small "Dense-Pack" mortar trailer.

Only 1 and 2-inch salutes are routinely fired from dense-pack trailers. When this is done the mortars are protected from each other using small steel frameworks which are placed inside the 8-inch plastic tubes mentioned above (see Photo 4). Of the relatively few 3-inch salutes used, most are fired from paper tubes staked separately above ground alongside the trailers. On those rare occasions when a 3-inch salute is fired from a trailer, it is arranged for it to be surrounded by empty and/or already-fired mortars. Four-inch, or larger, salutes are not used.

Photo 4. View of small one and two inch mortar frames and heavy walled plastic tube used to protect adjacent mortar when firing small salutes.

It is suggested that only single-break shells be used in shows fired from dense-pack trailers. There are two reasons for this. The first is related to safety. Single-break shells put less strain on the paper (or plastic) mortars and are less likely to do serious damage to the firing mortar and adjacent mortars in the event of a flowerpot or shell detonation. However, more importantly, in the event of any of the possible shell malfunction modes, multi-break shells offer greater risk to public safety than do single-break shells. They also tend to generate more burning fallout because of their heavier construction. The second reason for not using multi-break shells is economic. Multi-break shells in comparison with multiply fired single-break shells cost more and generally offer the audience little by way of added entertainment. When hand firing, multi-break shells do offer the advantage of allowing more breaks to be put into the air in a given amount of time. With electrical firing, it is easy to put up any number of shells in a given time. Further, multiply fired single-break shells can reproduce virtually any effect created by multi-break shells (and many they cannot). When the cost of a multi-break shell is compared with an equivalent number of single-break shells, the multi-break shell usually costs 10 to 20% more and their break sizes are often smaller. However, there is one situation in which multi-break shells are useful. That is when the shells are fired slowly and the audience is close enough and astute enough to see that it is a single shell breaking again and again. Even under these conditions, it is only effective to use a few of these shells during a show, and this can be done with steel mortars outside of the trailers.

By way of demonstrating the effectiveness of dense-pack mortar trailers, consider the following. Over a recent July Fourth season, using these trailers and the methods further described below, four displays were performed in four days, and were performed by the two authors essentially without assistance. These displays consisted of more than 5000 aerial effects and were geographically separated by as much as 250 miles (and several mountain passes).

2.3 Chain Firing

As may be seen from careful examination of Photo 2, the electrical wiring and connection terminals only run down the center of each rack section. This is shown more clearly in Figure 1, which is a sketch of the 5-inch mortar rack. Note that while there are eight mortars grouped around one set of electrical firing contacts, there is provision for firing only four electric matches. Of course it is possible to use multiple electric matches attached to one pair of terminals, which would fire shells simultaneously. There are times when this is desired but more often some delay between firing is desired. Further, in the case of the 3-inch mortar rack, there are only two firing connection points for every nine mortars. Only occasionally is it desirable to simultaneously fire four or five shells, even in shows approaching $20,000.

Obviously the system could have been designed with one set of firing contacts for each mortar. However this approach was not chosen for several reasons. The first two, and not very important reasons, are economic. The trailer under discussion has 251 mortars but employs only 87

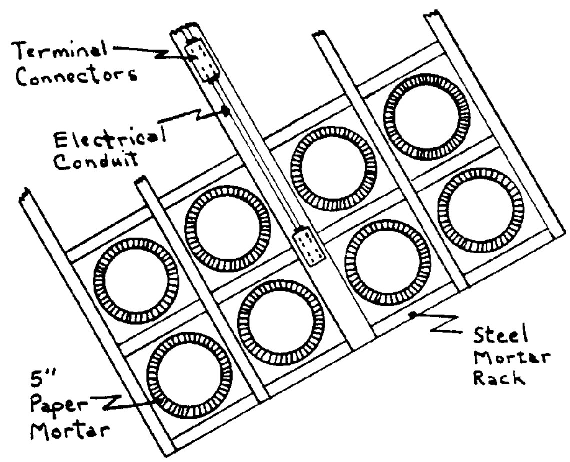

Figure 1. Overhead sketch of a portion of the five-inch dense-pack mortar rack, showing arrangement of mortars and electrical firing contact points.

firing circuits. This reduces the cost and complexity of the trailer wiring, cables, and firing control system. Further, only one-third the number of electric matches need be used. These points were considered but are certainly not the main reason for using this arrangement. The fusing method, to be described below, offers the significant advantage that during a show the operator has an average of three times longer between electrical firings. As a result of having more time, it is less likely that firing errors will occur; there is more time for the operator to observe where fallout is occurring and if people have encroached into unsafe areas; there is more time to critically evaluate the performance (the authors occasionally record such observations on tape during the course of firing a show); sometimes there is even enough time to relax for a moment and enjoy the show!

The method of firing to be described is referred to as "chain firing". While the method is quite effective, it is only practical when electrically firing mortars which are securely positioned and are in close proximity to one another. To facilitate chain firing, each mortar must have two small (slightly greater than ¼-inch) holes approximately one inch down from the top and separated by about 90 degrees of angle (see Figure 2). The first shell in the chain is fired using a "match header" (shown in detail in Figure 3), attached to its shell leader.

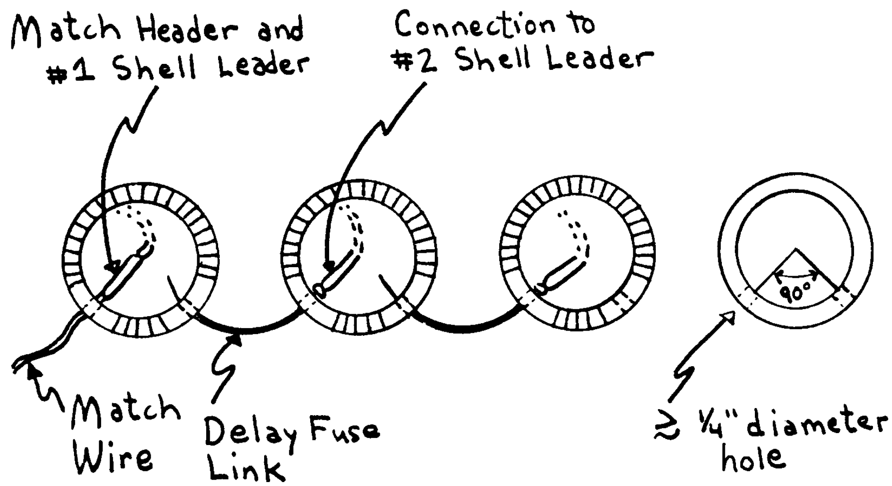

Figure 2. Overhead sketch of mortars chain-fused together, showing match header and delay fuse links. (Note: Heavy rubber bands are used to secure the fuse links but are not shown. See Photo 6.)

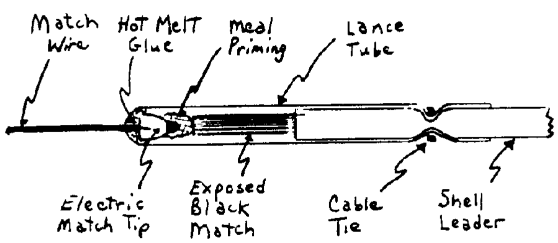

Figure 3. Cut-away sketch of match header attached to shell leader ready for firing.

Match headers are used for a number of safety, reliability and economic reasons. REGARDING SAFETY: electric matches are both impact and friction sensitive[2] and serious accidents have been reported to have resulted from their use. There is concern that an electric match imbedded in the lift or placed relatively unprotected inside a shell leader could ignite if a large shell were dropped on a hard surface or if the electric matched leader were pinched between two shells. There is also concern that an unprotected electric match inserted into a shell leader could ignite if jerked out during rough transport or during loading into mortars. Match headers are somewhat protected by the lance tube used. Also, if pulled free from a shell leader, the electric match will not be rubbed against the black match. REGARDING RELIABILITY: surprisingly, on two occasions it has been observed by the authors that unprimed electric matches that were placed in contact with the black match inside the shell leaders failed to ignite the black match when the electric match ignited. When chain firing, if the electric match fails to launch the shell, not only will that shell be absent from the show, so will all the other shells in the chain. Match headers contain a heavily primed electric match which produces more fire upon ignition. REGARDING ECONOMICS: when assembled from its basic components using personnel paid $4.50/hour, match headers cost no more than bare electric matches with the same length lead wire. (When 1000 match headers were recently assembled the total cost was approximately $500.)

The first step in assembling match headers is to attach electrical leads to purchased match tips (Note: bare match tips cost about $300/1000). After cutting two conductor (22-gauge solid) ribbon cable to the desired length, its ends are stripped of insulation. With ribbon wire (and only a little practice) both wires can be stripped at the same time using a standard side cutting pliers. The end to be connected to firing control points can be stripped to any convenient length and then the two conductors of the ribbon wire can be separated for a short distance to facilitate attachment to firing control points at the time of use. The end to be attached to the match tips is only stripped of about ½-inch of insulation and the two conductors should not be separated in any way. The normal separation between the two wires is ideal for attachment to the bare match tips (see Figure 4). In fact, with the proper wire, after the match tip is slid between the two wires, there is sufficient friction to hold the match tip in place while it is soldered to the wires. The soldering operation is accomplished using a 40 watt pencil soldering iron and thin rosin core solder (22-gauge). Note that it is fairly easy to ignite an electric match tip by holding the soldering iron on the match tip too long. However, except for demonstration of this potential problem to an employee the authors never had an ignition of a match tip while soldering. Nevertheless, no more than 100 tips at a time are allowed in the immediate work area and there are no other pyrotechnic materials or other combustibles in the general area when soldering.

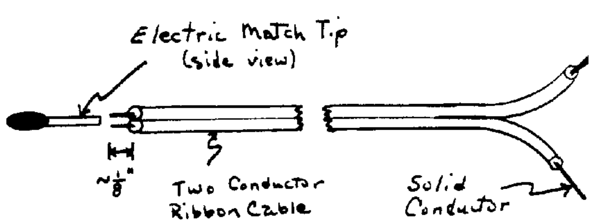

Figure 4. Sketch of two-conductor ribbon cable prepared for soldering to electric match tip.

At this time, it is appropriate to shunt the leads of the electric match (match tip soldered to the leads) by simply twisting the stripped wire ends together. Such shunting is effective in reducing the possibility of unintentional ignitions and is required by law in some states. (Regarding safety, it has been reported[3] on at least one occasion that the act of separating the leg wires on an electric match is suspected to have resulted in electric match ignition.)

Next the completed electric matches are coated with prime so that additional fire is produced when they are ignited. The prime mix is handmade meal powder in nitrocellulose lacquer. Approximately 25 electric matches at a time are dipped about 3/8-inch into the prime and then hung as a group to dry. When nearly dried, any electric matches that have stuck together can still be easily separated. During the drying time, the lance tubes can be prepared. In order to accommodate the electric match wire, each lance tube is slid over a 1/8-inch rod to partially open its spun-closed end. In the final operation the electric matches are slipped into the lance tubes and a small amount of hot melt glue is injected into the mostly spun-closed end of the lance tube. This makes it almost impossible for the electric match to be pulled through the end of the lance tube, unless enough force is used to destroy the tube.

If necessary, the operation of attaching a match header to a shell leader can be carried out well in advance of the date of the show. However, even with the modest protection offered by the lance tube, it is very important to protect electric matched shells from impact and rough treatment, and the shunting of the electric match wires must be maintained.

Attachment of match header to shell leader is accomplished by exposing about three inches of black match at the end of the leader, doubling the black match back on itself by folding, twisting the paper cover at the end of the leader tight against the black match core to minimize its diameter, and sliding the black match and leader into the match header until the black match contacts the primed electric match. Finally the leader is securely held in position using a small cable tie (0.1 by 4-inch tie, which costs about $15/1000) and a standard tensioning tool. The reason for folding the black match back on itself is to increase the surface area at its end and to expose a fresh (heavily coated) surface of the match. When properly assembled, the match header will be securely attached to the leader; it should be possible (but definitely not recommended) to lift up to a 6-inch oriental shell by the electric match wires. Photo 5 shows a completed match header attached to a piece of shell leader; also shown are cable ties and tensioning tool.

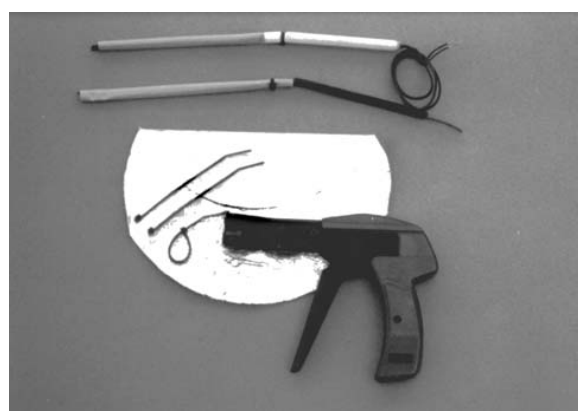

Photo 5. "Chain Fusing" components. Shown are: match headers attached to a piece of shell leader; delay fuse link attached to a piece of shell leader; aluminum foil / fiberglass mortar cap, folded to show both its sides; small cable ties and a tensioning tool.