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# Electrical Firing of Musically Choreographed Aerial Fireworks Displays

K. L. and B. J. Kosanke

## 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

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

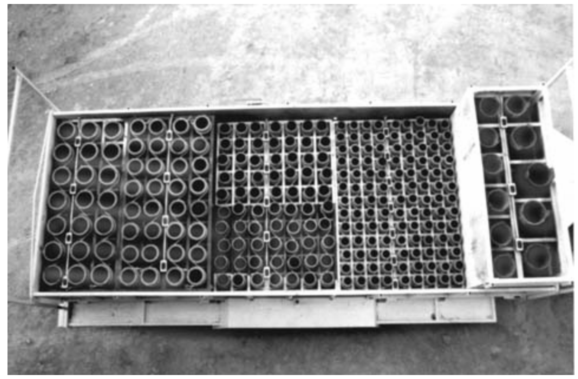

*Photo 2. Overhead view of large "Dense-Pack" mortar trailer.*

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, pulling 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

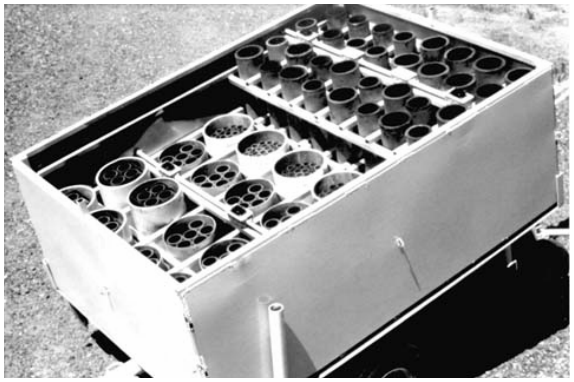

*Photo 3. View of small "Dense-Pack" mortar trailer.*

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.

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.

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

*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.*

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 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!

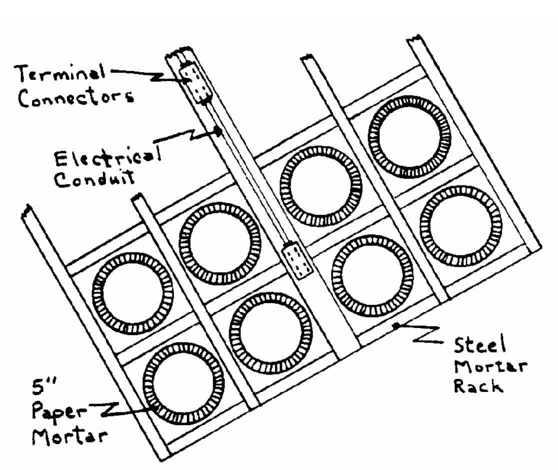


*Figure 1. Overhead sketch of a portion of the five-inch dense-pack mortar rack, showing arrangement of mortars and electrical firing contact points.*

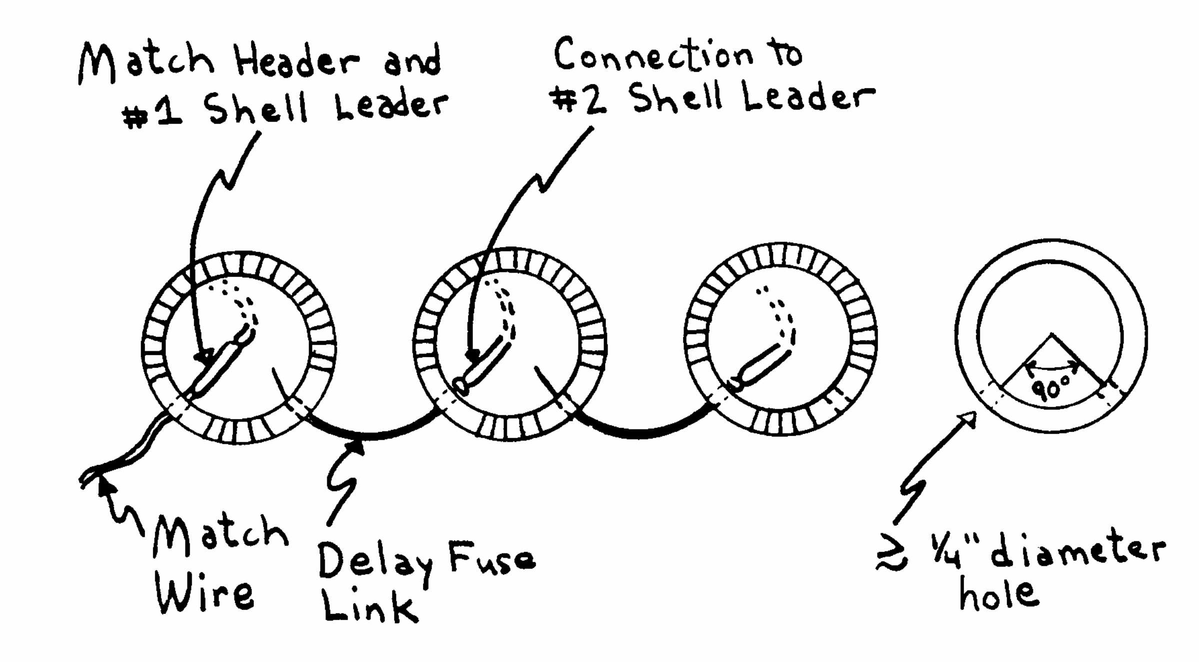


*Figure 2. Overhead sketch of mortars chain-fused together, showing match header and delay fuse links. (Note: Heavy rubber bands are used to secure the fuse links but are not shown. See Photo 6.)*

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.

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

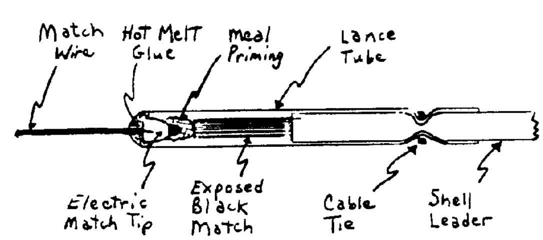


*Figure 3. Cut-away sketch of match header attached to shell leader ready for firing.*

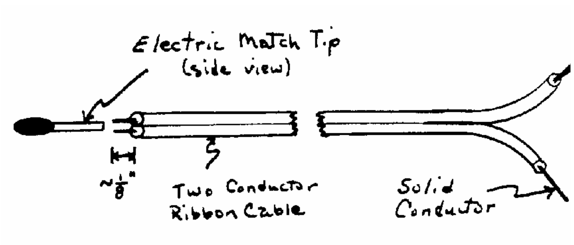


*Figure 4. Sketch of two-conductor ribbon cable prepared for soldering to electric match tip.*

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.

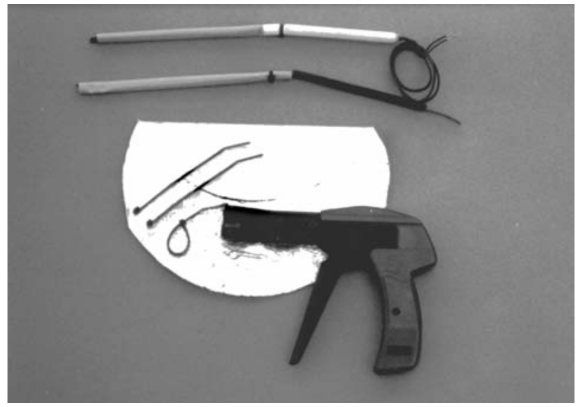

*Photo 5. "Chain Fusing" components. Shown are: match headers attached to a piece of shell leader; delay fuse link attached to a piece of shell leader; aluminum foil / fiberglass mortar cap, folded to show both its sides; small cable ties and a tensioning tool.*

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.

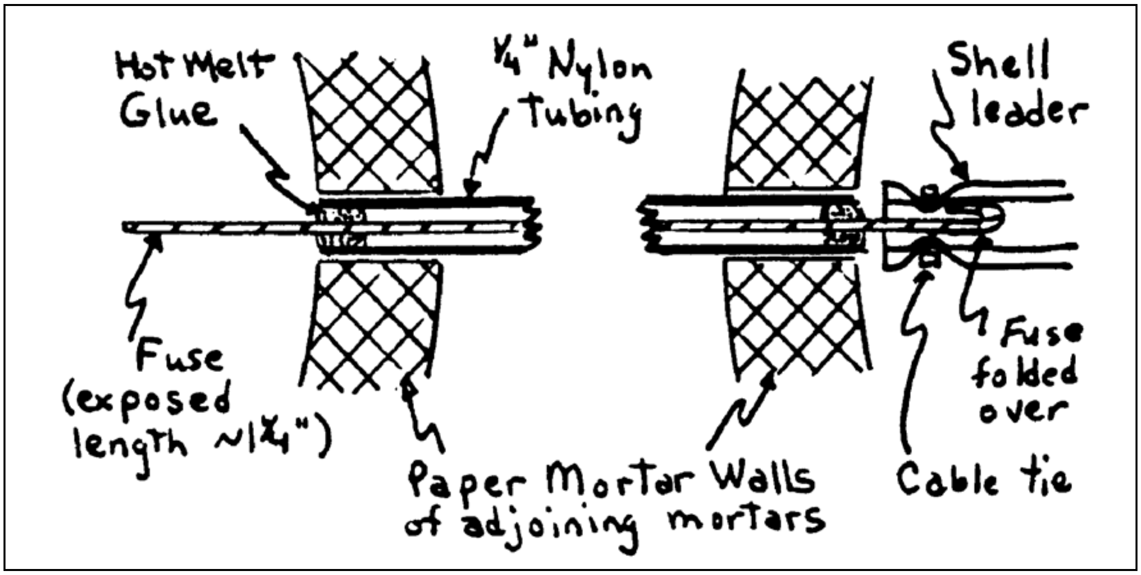


*Figure 5. Cut-away sketch of delay fuse link attached to shell leader.*

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.

When ready for use, the prepared shell is loaded into its mortar. The match header wires are brought out through one of the mortar's ¼-inch holes (preferred) or just over the top and connected to the appropriate firing control contacts.

The second and all succeeding shells in the chain are fired using "delay fuse links". In essence these are segments of reliable, easily ignited, and rapidly burning fuse that have been inserted into a protective jacket. The types of fuse well suited for use, in decreasing order of burn rate, are: thermite based Ensign Bickford quarry cord (approximately 18 inches per second), brown Imperial Chemical Industries (ICI) igniter cord (approximately 8 inches per second), white CXA thermalite (approximately 2.2 inches per second), green CXA thermalite (approximately 1.2 inches per second), green Imperial Chemical Industries igniter cord (approximately 0.9 inches per second), and red CXA thermalite (approximately 0.6 inches per second). The protective jacket used in making delay fuse links is ¼-inch (OD) polyethylene or nylon tubing (cost is about $3.00/100 feet).

Delay fuse links are made by first cutting pieces of the protective tubing to the proper length, see Table 1 and Figure 5. Note that for each delay fuse type it is the length of the protective tubing and not the total length of the fuse that determines delay time. This is a result of how the delay fuse links are used (discussed

**Table 1. Delay Fuse Link Specifications.**

| Delay (Sec.) | Fuse Type/Length (inches) | | | | Relative Quantity | |
|---|---|---|---|---|---|---|
| | Short | | Long | | Short | Long |
| .25 | Th | 4.0 | — | — | 8 | — |
| .37 | — | — | Th | 6.0 | — | 4 |
| .50 | Br | 4.0 | Th | 8.0 | 4 | 2 |
| .75 | — | — | Br | 6.0 | — | 6 |
| 1 | — | — | Br | 8.0 | — | 6 |
| 2 | W | 4.0 | — | — | 2 | — |
| 3 | — | — | W | 6.25 | — | 2 |
| 4 | G | 4.50 | W | 8.50 | 2 | 2 |
| 5 | G | 5.75 | W | 10.75 | 2 | 1 |
| 6 | — | — | G | 6.75 | — | 4 |
| 7 | R | 3.75 | G | 8.25 | 4 | 2 |
| 8 | R | 4.25 | G | 9.50 | 8 | 2 |
| 9 | R | 4.75 | G | 10.75 | 8 | 2 |
| 10 | R | 5.25 | G | 12.0 | 4 | 1 |
| 11 | R | 5.75 | — | — | 4 | — |
| 12 | — | — | R | 6.5 | — | 2 |
| 13 | — | — | R | 7.0 | — | 1 |
| 14 | — | — | R | 7.5 | — | 1 |

Length: length of fuse contained within the ¼" tubing (i.e., length equals length of tubing).

Symbols used in table:

Th: Ensign Bickford Thermite-based Quarry Cord.
Br: ICI Fast (brown) Igniter Cord.
W: CXA Fuse Fast (white) Igniter Cord.
G: CXA Fuse Medium (green) Igniter Cord.
R: CXA Fuse Slow (red) Igniter Cord.

below). Next, lengths of fuse approximately two inches longer than the tubing are cut and slid into the tubing, with nearly equal amounts of fuse exposed on each end. Finally small amounts of hot melt glue are injected into each end of the tube to immobilize the fuse. It is important to exercise caution in the assembly of these fuse links. Both the operation of cutting the fuse and the operation of hot-melt gluing the fuse have been reported to have resulted in unintentional ignition.[4] For these reasons, no more than one roll (100 feet) of fuse is allowed in the immediate work area and no other pyrotechnic compositions or combustibles are allowed in the general area while cutting or gluing delay fuse links. In addition, the person carrying out these operations must be specifically trained how to react in the event of an accident.

Because of the various spacing between different sized mortars, it is useful to have available both long and short fuse links that produce the same time delay. In those cases where it is practical, Table 1 includes specifications for both long and short versions of fuse links. Links shorter than 3½ inches are virtually unusable and those longer than about ten inches tend to be cumbersome. Also included in Table 1 are relative quantities of variously-timed fuse links used in a more or less typical display (Note: the cost of delay fuse links, including labor, averages less than $25.00/100). (See Photo 5 for a completed delay fuse link attached to a piece of shell leader. Note however, that shell leaders are not attached to delay fuse links until after the shell is loaded into its mortar and the fuse link installed in the wall of the mortar, discussed below.)

Delay fuse links are used by securing one end into one of the small (slightly greater than ¼-inch) holes in the top of the preceding mortar. The other end is secured into a hole in the mortar to be fired. For reasons to become clear below, it is important that the fuse link be held so that the protective tube jacketing the fuse is positioned approximately flush with the inside surface of the mortar. Though it is desirable to have the fuse link fit snugly into the holes, it is not acceptable to rely on friction to hold it properly in place. To assure maintenance of proper position, a large (size 73 or 84) rubber band is used on each end of the link. The rubber bands are quickly installed as follows: as the first end of the fuse link is inserted into the first mortar, it is passed through the center of the rubber band; next pull upward slightly on the rubber band and twist the rubber band half way around (180 degree rotation of end not held by fuse link); next slip the end of the loose rubber band over/around the top of the mortar; the operation is completed by repeating the process for the other end of the fuse link as it is inserted into the next mortar. Photo 6 illustrates the process. The use of rubber bands to secure delay fuse links has been quite successful. The authors have never had a fuse link loosen during a show. On one recent occasion after trailering 250 miles with fuse links pre-loaded, firing the display and returning home, no links came loose. (Note: the operation of pre-loading the variously timed fuse links for the 251 mortar trailer requires about 1½ hours for two people.)

After installing the fuse link between mortars, the shell to be fired by the link should be temporarily loaded into a nearby empty mortar, but not the one where the shell fusing will take place. The shell is loaded into a mortar so that in the unlikely event of accidental ignition during attachment to the delay link, the shell will fire harmlessly into the air and not remain in the work area and cause injury or ignite other shells., The shell is loaded into a mortar other than the one where it is to be fused because the fusing operation requires placing one's fingers over and slightly into the mortar with the fuse link. In the unlikely event of accidental ignition, the shell will fire harmlessly out of the other mortar and not the one where fingers are at risk.

The shell leader should be cut off just short of exposed black match so that the black match is cut flush with the end of the leader. Attachment is made by bending back a short length (approximately ¼-inch) of fuse at the end of the link, inserting the bent over end of fuse into the shell leader, and securing the coupling with a small cable tie. (See Figure 5.) Some care should be taken to assure that the delay fuse is in contact with the black match in the leader. The fuse end was bent over to facilitate insertion into the shell leader, to generate added fire at that point, and most importantly to reduce the possibility of the fuse link pulling out of the leader. In order to achieve the intended timing, the fuse in the delay link should have been inserted as far as possible into the shell leader. Remember, the delay times were determined by the burn time of the fuse while inside the protective tubing. When the operation of attaching shell leader to delay fuse link has been completed, re-load the shell into its intended mortar. With a little care, the shell will easily fit past the point of attachment with the delay fuse link.

Thus, as you have probably already concluded, a delay fuse link functions by its fuse taking ignition from escaping lift gases of the first shell, continuing to burn inside the protective tubing, and then passing fire to the leader of the next shell. This process is repeated for each shell in the chain.

The final operation in preparing the trailer is to place a protective cover over the mouth of

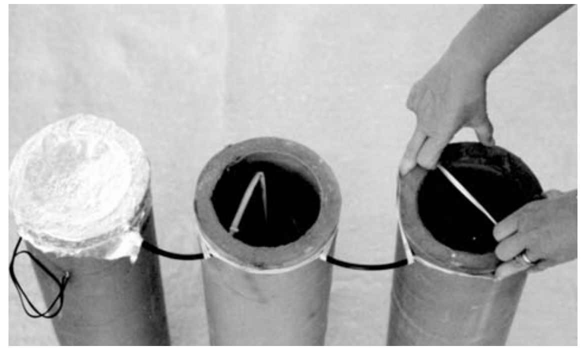

*Photo 6. Chain fusing method in various stages of the fusing operation.*

each mortar. For this, roughly-cut circles of a special material are formed over the tops of the mortars and held in place with heavy rubber bands (see Photo 6). The special material is Fiberglas cloth that has aluminum foil bonded to it and is highly fire resistant and mostly waterproof (also see Photo 5). This is the same material used by the US Forest Service for small tarps used to protect forest fire fighters in the event they are overrun by fire. When a shell fires, the escaping gases blow the cover clear of the ascending shell. After a show nearly all of the covers (most with rubber bands still attached) will be found in the immediate area and should be retrieved for reuse. Though our use of these covers is also relatively new, it seems that their average service life is at least six shows. These covers are used for two reasons (the importance of the second will become clearer in the next section of this paper). Prepared in the manner described, the dense-pack trailers ready for firing are essentially water-proof and are fallout fire-proof. It is difficult to imagine almost any combination of rain, sparks or burning stars that would necessarily force an interruption of the performance. (Note: the operation of shell loading for the 251-mortar trailer requires about three hours for two people.)

By way of demonstrating the reliability of chain firing, consider the following. Although the authors have used this exact method of chain firing for only their last six shows, there have been only two failures attributable to the methods presented here.

## 2.4 Parasitic Firework Effects

For the purpose of this paper, "parasitic firework effects" are small shells, mine stars and other components that derive their lift energy from other "host" shells. The sizes of parasitic shells usually range from 1¾-inch (festival balls) to 3-inch shells. The quantity and size of mine stars are scaled according to the size of the host shell. Components oftentimes are merely firecrackers, jumping jacks or small bees. (Obviously, when the audience cannot view the mortar area, it is ineffective to use mine and small component effects.) In order to most effectively draw lift energy from other shells, the parasitic effects must be loaded on top of the host shell. When this is the case and the total weight of the parasitic devices is modest in comparison with the weight of the host shell, the host shell's altitude is not detectably reduced, and the parasitic devices reach ample height. There are a number of reasons why a modest weight of parasitic effects should be expected to be propelled without noticeably affecting the altitude of the host shell. One reason, especially true for spherical shells, is that to some extent parasitic effects are propelled by wasted high velocity lift gases escaping from around the host shell. Another reason is that the greater inertial mass of the combined host shell and parasitic effects means that (without adding more lift powder) higher lift pressures will be manifested throughout the time the host shell is in the mortar. In addition, the higher lift pressure, resulting from the greater inertial mass, acts to speed up the burn rate of the lift powder[5] which results in a further increase of lift pressure throughout the period when the host shell is in the mortar and the lift powder is still burning. The effect of higher lift pressure translates into modestly greater carrying capacities for host shells without the use of more lift powder. In some respects this is the same effect that allows a 3-inch cylindrical shell weighing 100% more than a 3-inch spherical shell to be lifted to the same altitude using only 30% more lift powder. It is not intended to imply that parasitic effects can be added without diminishing the height of the host shell. However, when only a modest weight of parasitic effects are added, the height of the host shell is reduced less than might be expected, and the slight reduction in altitude is insufficient to necessitate the addition of more lift powder.

**Table 2. Parasitic Weights and Relative Points for Host Shells.**

| Host Shell (Single Break) | | | Parasitic Effect |
|---|---|---|---|
| Size (in.) | Approx. Weight (lb) | Point Rating | Typical Total Weight (oz) |
| 3 | .5 | 1 | 3 |
| 4 | 1.0 | 2 | 5 |
| 5 | 2.0 | 3 | 8 |
| 6 | 3.5 | 4 | 10 |
| 7 | 5.0 | 6 | 13 |
| 8 | 8.0 | 8 | 16 |
| 10 | 12.0 | 11 | 22 |
| 12 | 18.0 | 14 | 28 |

Table 2 includes typical weights of host shells and parasitic firework effects. Acceptable relative weights for parasitic effects range from as much as 1/3 for a 3-inch shell down to 1/10 for a 12-inch shell. In part these varying relative weights correspond to the carrying capacity of the host shell. (Note that because of its low ratio of mass to projected area, a 3-inch shell requires a disproportionately larger lift charge to reach proper altitude. Accordingly, a 3-inch host shell has the greatest relative carrying capacity for parasitic effects.) However, for the most part the varying relative weights for parasitic effects are the result of aesthetic considerations. When a 3-inch shell is properly augmented with parasitic effects, those effects usually weigh about three ounces. For an 8-inch shell, optimum results can be achieved with about 16 ounces of effects.

In order to maximize the artistic effect, parasitic effects must be properly timed and sized with respect to the host shell. In general, the lowest altitude and smallest effects should occur first, followed by higher and larger effects leading to the break of the host shell, which should be impressively greater than that which preceded it. To illustrate this, consider one possible 6-inch "shell set" (host shell plus parasitic effects). On firing, the shell set produces a massive blue-willow mine effect extending about 150 feet in the air; this is followed shortly by a flurry of eight small purple (festival ball) breaks at about 250 feet, followed by the massive break of a 6-inch bright red to silver comet chrysanthemum shell at about 600 feet. The synergistic effect of the combination of effects produces a result that is far more aesthetically pleasing than might be expected (particularly when the very modest added cost for the parasitic effects are considered).

There are three reasons for giving the use of parasitic effects serious consideration. The first reason, given above, is aesthetics. Though often seriously under-utilized in displays, mines and ascending effects are attractive in their own right. They also offer variety and utilize an otherwise unused portion of the sky. If nothing else, their use heightens the audience's appreciation of aerial shells by moving the action around in the sky and limiting the boredom which can result during an aerial-shells-only display. Another aesthetic payoff comes in the length of time the effect lasts; the use of a shell set such as the one described above produces a display that lasts about twice as long as would be produced by the large shell alone. Essentially every sponsor of a show wants it to look like one costing two or three times more. For most smaller shows, what is wanted is multiple effects and rapid firing. This would be easy to accomplish if it were not that the show still needs to last sufficiently long. In large measure, the use of parasitic effects affordably achieves the sponsor's aesthetic requirements. However, the most important aesthetic reason for using parasitic effects is that their use increases the perceived beauty of the host shell. As an analogy, consider an example from the cinema, a horror movie. How much impact would the violence of the movie have if it were not for the music setting up the audience by telling them something terrible is about to happen? How much impact would there be if the audience were not first set up by knowing that something was out there somewhere, preparing to do some terrible thing to an unsuspecting person? To a large extent the horror is psychological; horror is mostly the anticipation of violence and not the violent act itself. Without first setting up the audience, the violent act would probably only seem revolting. In a similar way, when host aerial shells are properly set up using parasitic effects, the audience's anticipation of unfolding beauty results in the perception of the host shell as significantly more beautiful than if fired alone. It is difficult to imagine how effective this can be without actually seeing it.

The second reason to consider using parasitic firework effects is increased profit. One obvious benefit from using this approach is that significantly more fireworks can be put up from the same number of mortars. The dense-pack trailer shown in Photos 1 and 2 will fire a conventional show which would normally be priced at about $4200 (excluding insurance and choreography). However, when parasitic effects are added, a fair value for the display is about $5600. In part, the higher price for the display results from the additional fireworks included. However, because the parasitic effects add so much to the favorable impression of the audience and yet cost relatively little, it is acceptable to increase the gross profit on them. (The increased profit can be rationalized as necessary to off-set the fairly high initial costs of firing electrically from dense-pack trailers.) The authors normally work with a gross profit of about 100%, but for parasitic firework effects the gross profit is 200%, and in spite of this, the feedback from sponsors has been very favorable. It's a great day when you can increase your profit and still have delighted sponsors wanting to shake your hand for the great job you did for them!

The third reason for considering the use of parasitic effects is that their use allows a significant reduction in the variety of shells that must be kept in inventory. Consider the following shell sets: blue-willow mine followed by silver glitter parasitic shells followed by large red peony; purple-gold glitter mine followed by green meteor shells followed by large red peony; green-silver comet mine followed by short-delay small artillery shells followed by large red peony. In each case the host shell was a red peony; however, even if these shell sets were fired one after the other, they would be perceived by the audience as presenting great variety. By using different combinations of only five types of mine stars (taken two types at a time), five types of parasitic shells and five types of host shells, it is possible to assemble five hundred different shell sets. Obviously not all of the 500 different shell sets will be artistically effective or usable but very many will. Thus the use of parasitic effects allows a significant reduction in the number of different types of shells needed in inventory.

Parasitic effects are prepared in advance by loading the mine stars and small shells or components into small (two mil thick) plastic bags and sealing them with PVC tape. A few of the possible assemblages of parasitic effects are shown in Table 3. Large quantities of these pre-bagged items can be stored until needed, during final loading before a show. Also given in the table is a point rating for each of the different assemblages. These are used as an easy way of determining which and how many of each of the assemblages can be loaded on top of any given size host shell. Note that Table 2 includes a point rating for typical host shells; any number and any combination of assemblages can be used as parasitic effects providing their cumulative point total does not exceed the rating for the host shell. For example, for a 5-inch host shell, six festival balls, or two festival balls plus one 2½-inch shell, or one 3-inch shell are all acceptable as parasitic effects.

It is important that parasitic effects be well primed to insure ignition by the escaping lift gases from the host shell. Probably the most reliable priming method is one that concludes with pressing the primed item into grain powder while the prime is still wet. This provides many angular points on the primed surface insuring easy ignition. Small shells are usually primed by dipping the whole area of their fuse into a prime mix (usually handmade meal in nitrocellulose), then pressing the primed area into 3 or 4 Fg commercial grain powder. Packs of firecrackers or jumping jacks are primed by running a bead of prime from a catsup-like squeeze bottle down the spine of each pack, then pressing into grain powder. Small components are usually primed by dipping batches of several hundred at a time into the prime mix, then tumbling the items in handmade meal. Mine stars need only be primed as they would be for use in shells. Priming is important in all cases, but especially when parasitic effects are loaded on top of canister shells, where it may be less likely than with spherical shells that each of the items will be well exposed to the lift gases. When parasitic items without a mine effect are used with canister shells, it is desirable to add a small charge of Black Powder to the plastic bag containing the effect. This will help to insure proper ignition of the effects by more completely filling the bag with fire when the host shell is launched.

**Table 3. Points for Some Possible Parasitic Effects.**

| Points | Description[(a)] |
|---|---|
| 1 | 2 Festival Balls plus 1 ounce of mine stars |
| 1 | 4 packs (approximately 70) Firecrackers or Jumping Jacks plus 1 ounce of mine stars |
| 2 | 1 – 2½” Shell (may include 1 ounce of mine stars) |
| 2 | 3–1” x I½” Flash Salutes |
| 3 | 1 – 2½” Shell plus 3 ounces of mine stars |
| 3 | 1 – 3” Shell (may include 1 ounce of mine stars) |
| 3 | 1 – 2” x 2” Crossette Comet |
| 3 | 6 ounces of 1” x 1” Comets |
| 4 | 1 – 3” Shell plus 3 ounces of mine stars |

Note — all items are heavily primed.

Parasitic effects are loaded into mortars by simply dropping the filled plastic bags into the mortar after the host shell has been loaded. It is inappropriate and unnecessary to remove the contents from the bags. (This is inappropriate because loose components or stars might jam between the host shell and the mortar wall; unnecessary because the plastic bag will melt away almost instantly when the host shell is fired.)

One word of caution, there is always the possibility that sparks from the firing of one shell will fall into other mortars and unintentionally ignite parasitic effects in those mortars. However, this is prevented by the use of the protective covers mentioned in Section 2.3 above, which provide very effective protection from sparks and even small burning stars.

Certainly the use of parasitic effects in conventionally fired shows is possible (consider ascending flowers and attached comets). However, their use is ideally suited to electrical and chain firing of pre-loaded mortars.

### 2.5 Trailer Pre-Loading

It is fairly obvious that as much work as possible should be completed in advance of the day of the show. In a well designed electrically fired show, whether performed to music or not, the shells and their firing sequence are carefully planned to achieve specific purposes. That is to say, not only are shells selected in advance but also their order of firing, the times between firings, and even which mortar will be used for each firing are predetermined. Accordingly, the shells to be used can and should be marked and pre-packaged in some logical way, well in advance of the show, ready for loading when the time comes. Because the timing of each firing is also known, all necessary delay fuse links should be selected and installed in advance in the proper mortars. In this paper, a display prepared in advance to this state is referred to as "partially pre-loaded". Essentially every show should be at least partially pre-loaded.

Consider the dense-pack trailers used for these performances again for a moment. It is relatively easy for these trailers to meet Department of Transportation requirements for transporting special fireworks. Thus it would be possible on the day of the show to load the display remote from the shooting site and transport it to the site only a few hours before the start of the performance. This would have a number of advantages: security, availability of tools and materials, and personal comfort, to name a few. If the trailers have properly-secured metal tops and are painted with epoxy paint, they would qualify as mobile Type IV magazines. If this were the case, the complete display could be preloaded and stored for days or weeks until being transported to the site on the day of the show. (Arriving at the site in this way is probably safer than with shells loaded in mass in boxes.) In this paper, trailers prepared to this state are referred to as "fully pre-loaded".

Obviously, by arriving on site with partially or fully pre-loaded trailers, a great deal of set up time can be saved; correspondingly, the size of the crew can be reduced. This can have a significant impact on profitability. It is not so much that work is saved, but rather that it can be scheduled in advance at YOUR convenience. When the work is performed in advance, workers can be assigned to perform these tasks during periods when they might not otherwise be fully utilized. This corresponds to greater productivity. The more work done in advance, the more shows that can be staged by the same number of workers. More shows mean more opportunity for profit. When a crew is on the road preparing for a show, you are probably providing food and lodging. So if you can send a smaller crew for less time, this means lower expenses. Occasionally shows are lost when problems with local authorities surface on the day of the show or when the weather is inclement. If it only takes an hour on site to set up, even a last minute resolution of problems or a break in the weather may allow a successful performance. (Shows lost at the last minute are costly.)

### 2.6 Firing Control Equipment

As mentioned above in Section 1.0, a theoretical discussion of the construction of electrical firing control equipment has been published elsewhere. The articles by Bases[1] should allow most readers with some background in electronics or science to design and construct their own. If the reader does not have such a background, it is likely he can find someone who does. Also there are several sources from which equipment can be purchased. The purpose of this section will be only to express some preferences of the authors and to mention some peripherally related subjects.

Much of the firing control equipment in use fires each item by toggling a switch (assuming the circuits are already armed). This requires some degree of concentration to be certain that the operator's finger(s) are on the right switch(es), and, when in a hurry, it is easy to get the wrong switch. Also, it is difficult to relax between firings when the operator has to keep in mind the number of the next circuit to be fired or has to continuously hold his finger against the next switch so as to be ready to fire it when the time comes. It is thought preferable to have one set of switches used only to arm one or more circuits in advance of firing and a second switch used each time for the actual firing. (For safety reasons, it is preferred that the second switch actually be two switches in series.)

Compatibility between cables, controllers and trailers (or racks) is important. It is preferable to have all cables, controllers and trailers be interchangeable. Arriving at a distant site with the right controller but the wrong cable is at least a problem and possibly a disaster.

Redundancy in design is also desirable. Having two small firing controllers instead of one large one offers more flexibility (allowing use of two firing sites or two simultaneous shows in different towns). However, more importantly, if one controller fails, is damaged or stolen, you will still have one to fire the show, even if it means having to repeatedly plug and unplug different cables into the controller.

Electric generators are frequently used on-site to power lights and music systems, etc. However, unless properly earth-grounded using a rod driven into the ground, they should not be used to power firing control equipment. It is possible for ungrounded generators to build up large static charges. Thus unless care is taken when using a generator, it is possible that a static discharge will accidentally fire some electric matches wired into the display. While ungrounded generators may be used to charge internal batteries in firing control equipment before a show, they should not be connected to the firing equipment during the show.

When firing a show electrically, a low level of light is necessary for the operators to follow the script and operate equipment. The use of any number of light sources is possible; however, the use of part or all of a string of Christmas tree lights can provide low level lighting over a wide area and does not detract from the show.

When firing a conventional show it is often difficult for the operator to be in communication with safety people and others helping to control the show. This might be the result of the operator participating in the firing or just because of the noise and commotion in the area of the mortars. When electrically firing, it is normal to set up the firing control equipment at least 100 feet from the dense-pack trailers, where there is considerably less noise and commotion. After a number of trials of various types of communication equipment, it was concluded that CB transceivers are a good compromise between cost and performance. Because of the limited power of legal CB equipment, it is felt there is no danger of accidentally firing electric matches. Normally a five-watt base station is used at the firing control site and one-watt portable transceivers (walkie-talkies) are used by persons stationed remote from the firing site. Because the antennas on the portable units are cumbersome and possibly even dangerous at night, the transceivers are normally operated with only the thickest one or two antenna sections extended. This results in a reliable communication range of ¼ to ½ mile. (Note that because of the low power of these units they are not harmed by operating with antenna detuned by not being fully extended.) By watching for sales, a base station plus four portable units should cost less than $200. As is true for any communication system, where it is possible that critically important messages may need to be sent, some form of backup is appropriate. Probably the cheapest and still very effective backup is the use of flashlights. When aimed in your direction they can be seen for quite a distance and a pre-arranged flashing signal from any safety person can quickly shut down a display until the potential problem is investigated.

When performing an electrically fired display, particularly one choreographed to music, the sponsor is expecting, and usually willing, to pay for a more professional performance than the typical hand-fired show. There may also be a moderate amount of equipment necessary, such as firing controllers, digital clock timers, sound equipment, communication equipment, and operational lighting. Accordingly, it is appropriate to set up some type of control center from which to operate. This could be nothing more than a table set in the open near the shooting site. This, however, offers little protection for the equipment and operator from wind, rain, dust and errant fireworks; requires a fair amount of set-up time without providing the operating team with a very effective control center; and certainly does not give a sponsor much confidence in the professionalism of the display company. Another possibility is the use of some form of mobile control center, specifically in the form of one of the vehicles used to transport the trailers. Photo 7 is of such a control center in the bed of a pickup truck. Note that the top of the unit is on tracks which allows

*Photo 7. Mobile firing control center in bed of pick-up truck.*

it to be slid forward giving the operators an unobstructed view of the sky and a nearly 360-degree, and slightly elevated, view of the grounds. In addition to the desk for equipment and to work from, there is also a sound equipment rack and a large storage cabinet with a cot on top. Over the front bumper there is an AC generator for large power requirements and built into the engine compartment is an inverter for backup power. Such a control center offers protection of the crew and equipment from weather and dust, and can be set up in minutes. When not being used for a display, all equipment can be removed and the truck used conventionally.

## 3.0 Musical Choreography

There are essentially three ways in which music can be used to augment a fireworks display. These are differentiated by the degree to which fireworks and music are synchronized. On the one extreme, in what might be called "accompaniment music" shows, the music is used only as background. The fireworks display is designed just as any traditional show and there is not a serious attempt to synchronize the fireworks and musical programs. In this case it is nice to have the musical background, but it adds relatively little to the dramatic impact of the show. At the other extreme, in what might be called "micro-sync" shows, each shell break is precisely timed to break on specific musical cues and there are not two separate programs (fireworks and music) but just one. This can have a powerful impact on the audience. However, the necessity to account for differing time fuse delays and still achieve synchronization to fractions of a second for rapidly-fired shells makes computerized firing almost a necessity. The third and most common way to use music to augment a fireworks display requires synchronization to about one second. For the most part, the difference between these displays (which might be called "macro-sync" displays) and micro-sync displays is only in the precision of the synchronization. Each individual shell is selected and utilized to fit the musical program. The only difference in shell selection may be a tendency to employ multiple smaller shells in place of large shells. This helps mask the fact that synchronization of music and fireworks is not precise.

It is only the macro-sync technique that will be discussed in this paper. However, most of what is presented is applicable to micro-sync displays as well and much even applies to accompaniment shows.

### 3.1 Music Selection

Selection of the musical program for the show is not just important, it is critically important. In a properly designed show, proper selection is probably more important than the quality of the fireworks in producing a positive audience reaction. In part, this may be true because audiences are not as offended by poor quality fireworks as are skilled fireworkers. Probably, however, it is because music is a more powerful creator of mood and emotion than are fireworks. Considering its critical importance, one should plan to spend many hours selecting and preparing the music. The musical program should be good enough that if played alone, without fireworks many in the audience would stay just to hear the music and would enjoy the concert.

In terms of audience response, the difference between a good musically-choreographed display and an equally good conventional show is in the height of emotion evoked. To some extent, with a properly designed musical display, it is possible to "wear out" the audience by taking them on an emotional roller coaster ride. In accomplishing this it is the music that is most effective in determining emotional response. Obviously, emotional response is maximized

**Table 4. Examples of Effective Music Taken from Movie Sound Tracks.**

| Movie | Song Title | Emotion |
|---|---|---|
| Brain Storm | Michael's Gift to Karen | Pensive followed by jubilant |
| Patton | Winter March | Building sense of forceful resolution |
| Patton | Patton March | Prideful militarism |
| Cosmos | Vangelis' Heaven and Hell– Part 1 | Ethereal beauty and wonderment |
| Cosmos | Pachelbel's Canon à 3 or a Ground in D | Optimistic fulfillment and satisfaction |
| Cosmos | Vangelis' Entendus to les Chiens Aboyer | Reverent joy |
| Other Side of the Mountain - Part 2 | Indian Children's School | Loneliness – sadness |
| Other Side of the Mountain - Part 2 | Love Theme | Joy and fulfillment |

when both the music and fireworks are working toward the same end. However, if the moods evoked by the music and fireworks are in opposition, it is the music that will prevail. As an example, consider the same salute barrage fired to the final strains of the "Stars and Stripes Forever" and then again to a portion of Mussorgsky's "A Night on Bald Mountain". In the first case the emotional response will be one of prideful patriotic exuberance, in the latter, the response will be one of ominous trepidation. In the first instance the audience will be standing tall (physically), in the latter they will be detectably recoiling, with heads pulled down slightly between their shoulders. The same slowly fired sequence of large spherical shells will create a feeling of beauty and wonderment when viewed to "Abraham's Theme" from Chariots of Fire, yet will produce a sense of profound sadness when viewed to Barber's "Adagio for Strings" with a voice over of the news broadcast of President Kennedy's funeral procession.

Since it is an emotional response that is intended to be produced, motion picture sound tracks are an obvious place to look for effective music; musical sound tracks are added to films to elevate the emotional response of the audience; they are intended to add dramatic impact. Even when these sound tracks draw their musical theme from the classics, they are re-orchestrated. Usually this means condensing around a single theme and heightening its emotional content. As an example, compare the introductory fanfare for Richard Strauss' "Also Sprach Zarathustra" as played on the classical album versus the rendition from the movie "2001 — A Space Odyssey". It is the same music, but very different in emotional impact. Just a slight change in timing and the drama of the fanfare is significantly magnified. Generally during a musically choreographed display, it is desirable to change mood, or at least intensity of mood, every two to four minutes (i.e., between each piece of music). This is another reason to look at movie sound tracks, even for classical themes. The classical piece will generally play for five to 20 minutes, and it is difficult to extract the portions needed. The re-orchestrated version for a movie will invariably shorten the musical theme to a more manageable (useful) length. Table 4 presents a few examples of useful music from movie sound tracks.

Obviously, music can be an effective creator of emotion; however, this is particularly true when the music triggers pre-formed mental images in the listener. Properly staged, the playing of the National Anthem will put a lump in the throats of most of the audience. In this case, while the music is stirring in its own right, it is the mental association with patriotic nationalism that greatly magnifies the emotional response produced. When selecting music for its ability to evoke mental images, it is essential to consider the make-up of the audience. In Georgia, the playing of "Dixie" will put the audience on their feet cheering, like "Yankee Doodle Dandy" never will! Table 5 presents some examples of music producing strong mental images (not all of which produce strong emotion).

Most popular (or popularized) music has some sort of lead-in or introductory passage and often some sort of run-out at its end. This is useful in that it provides a smooth transition

**Table 5. Examples of Music That Is Effective in Creating Mental Images.**

| Song | Mental Image or Response |
|---|---|
| National Anthem | Patriotic nationalism – my country right or wrong |
| Marine's Hymn | Militaristic arrogance – potential enemies beware |
| Dixie | Pride in southern heritage |
| Battle Hymn of the Republic | Religious patriotism – God is on our side |
| Auld Lang Syne | New Year's remembrances |
| "The Storm", 4th movement of Beethoven's 6th | Furious storm building then passing |
| Olympic Fanfare | Athletic achievement |
| Stravinsky's "The Rite of Spring" | Ominous, foreboding, intimidating |
| Handel's "Messiah" | Spiritual upwelling |

between pieces with differing moods. Generally, no fireworks are shot during these times. The pause in fireworks during the lead-in serves to build the anticipation of the audience; the pause during the run-out gives the audience a moment to relax and contemplate what they have just experienced. The only problem with lead-ins and run-outs is when they are too long; 10 to 15 seconds is great, but 30 seconds begins to be excessive. Another benefit to these short pauses in the fireworks portion of the show is a partial resetting of the audience s visual perspective. When fireworks are fired more or less continuously, it requires greater and greater expenditures for larger and/or more fancy fireworks to hold the level of the spectators' interest. Pauses of even 15 to 30 seconds during a display allow the use of slightly fewer or smaller effects without diminishing audience appreciation of the fireworks. However, during a conventional show, pauses of 15 to 30 seconds generally make the audience impatient and thus have a negative impact that seriously offsets any gain from resetting visual perspective. During a musically choreographed display, the same pauses in the fireworks (but not in the music) can add to the entertainment value of the display.

It was mentioned above that the mood, or at least the intensity of the mood, should generally change in a major way between each piece of music. This is true, but it is often desirable to also have at least minor changes of some sort within each piece occur every 30 to 45 seconds. These changes help carry an audience along in building or sustaining emotion. One aspect of Sousa's "Stars and Stripes Forever" that helps create its rousing exuberance is the contrast between its rousing and delicately quiet passages. In addition, if the fireworks program follows the music, major changes in the fireworks will only occur when there are changes in the music. If this only happens between pieces of music every two to four minutes, the audience will generally lose interest. One of the few exceptions is for relatively slow firing of large shells when attempting to create a sense of beauty and wonderment. In this case, two to four minutes is the preferred time interval to allow the mood to develop.

The selection of vocal versus instrumental music is of little importance. Each has its strong points. Vocal music can be better in creating mental images whereas instrumental music can be better in creating moods. Similarly, classical, traditional and pop music can each be used effectively. In any case, music should be selected for specific purposes; if the selection accomplishes the purpose, it does not matter what type it is. However, most audiences are diverse, thus a wide variety of music is usually appropriate.

Once the basic selection of songs for a display has been made, one should not consider the task of music selection complete. In most cases there are several, occasionally even hundreds, of renditions of the same song, and they are not all equally suitable for use in a display. Even if one is not very discriminating, many simply will not be acceptable. Remember, the selection of music is critically important to the performance. The difference between mediocre and excellent quality firework items will have less effect on the audience than mediocre versus excellent music. It is important to keep looking until really effective renditions are located.

Although not explicitly stated above, part of the music selection process must be a determination of the sequence in which the music will be played. For the typical display, moderate mood and style changes are appropriate between each piece of music. It is usually inappropriate to put all the rousing or all the classical music selections together as one part of the display.

However, it should be understood that simultaneous radical changes of both mood and style are also undesirable. This makes the show seem disjointed and will not maximize favorable reactions to the display. One example of how to smooth a transition between musical selections can be demonstrated with Neil Diamond's "America". The piece has a classical instrument style lead-in changing to an up-beat pop vocal style. This piece serves well as a bridge after a classical selection. Another way to smooth a transition is to use two pieces of music, significantly different in style and mood, but featuring the same instrumental group, for example, a selection by a Mariachi band followed by a classical trumpet concerto or a pop selection with a brassy sound. When a show is designed such that there are threads of continuity between the pieces of music, the display seems more like a single cohesive performance and the audience's reaction will be more favorable.

The final task in selecting music for a display is the preparation of a high quality audio tape of the various pieces of music. Generally a four second pause between each piece is appropriate. Also, at the start of the tape it is useful to record information describing the tape (e.g., "1986 Labor Day Show for Hillsboro Downs Race Track") and a count down to help queue the tape when used at the display.

### 3.2 Guides to Choreography

In essence, there is really only one rule for effective fireworks with music choreography: The mood created by the music must be the same as that created by the fireworks. In that case, the degree of emotion experienced by the audience will be maximized. When the moods are in conflict, the result is rather bland. Whether the response is instinctive or learned, most people have little difficulty identifying the mood of music: rousing versus tranquil, exuberant versus ominous, etc. However, in practice, the ability to sense or predict the mood produced by fireworks is not nearly so well developed, even among firework people. Accordingly, most of this portion of the paper will be devoted to that subject.

**Table 6. Pleasing, Mood Up-lifting Changes.**

| Characteristic | Change |
|---|---|
| Light Intensity (shells or stars) | Dim to bright |
| Size (shells only) | Small to large |
| Altitude (shells only) | Low to high |
| Tail (shells or stars) | No tail to comet |
| Color Spectrum (shells or stars) | Cool to warm |

In fireworks, there are some effects that are particularly pleasing and create a mood-uplifting sense.[6] Generally these result from changes in light intensity, size, or color; Table 6 summarizes these. For light intensity, it is dim-to-bright that results in a pleasing reaction. This is true for both stars and for shells, i.e., an uplifting mood can be created by a dim-to-bright intensity change for stars in a single shell, and also by firing a pair of shells, the first with low light output followed very shortly by one with high output. In terms of size, it is small to large that produces a pleasing response. Two shells, the first small and the second large, fired with one-half to one second in between will produce a positive reaction. Similarly, but to a much lesser extent, low altitude versus high altitude effects will also accomplish this. With respect to stars, the analog to a change in size is the presence or absence of a tail; here, a change from a simple color to a comet effect produces a pleasing sense. Finally, in terms of color, a cool-to-warm color sequence produces the uplifting response. Cool-to-warm spectral colors start with blue and run through green, yellow, and orange to red, the warmest. In terms of color warmth, the non-spectral color white is very cool and the non-spectral color purple is roughly equivalent to green. By and large, the positive emotion created is magnified when several of the rules of Table 6 are followed at the same time. Imagine a 3-inch dim white peony followed very shortly by a 6-inch bright red chrysanthemum breaking above.

To some extent, an ominous and foreboding response can be produced by breaking the rules in Table 6. For stars in individual shells this is not

**Table 7. Fireworks Used to Evoke Emotional Responses.**

| Response | Fireworks Used |
|---|---|
| Excitement | Rapid random firing of variously-sized shells, both cylindrical and spherical shells, using a variety of colors and effects. If salutes are used, they should be randomly mixed in, or fired in sustained volleys at peaks in the excitement and at its conclusion. |
| Jubilation | Rapid random firing of similarly sized shells, using only a few colors or effects at a time with all shells either cylindrical or spherical. Colors, effects and types of shells should be changed infrequently or gradually. Shell and star combinations should follow rules of Table 6. Ascending comet effects are particularly effective. |
| Foreboding | Slow random firing of shell and star combinations that break as many of Table 6 rules as possible, using cylindrical (asymmetrical-breaking) shells. If salutes are used, they should be large. Parasitic effects should be avoided. |
| Wondrous Beauty | Slow mostly steady firing of shell and star combinations that follow as many of Table 6 rules as possible, using large spherical (symmetrically-breaking) shells. Generally allow each shell to complete its performance before the next is presented. Parasitic effects are particularly effective. |
| Somber | Slow mostly steady firing of shell and star combinations that frequently break Table 6 rules, using mostly spherical shells. The use of parasitic effects must be avoided. |
| Prideful/Patriotic | Flights of cylindrical shells (all the same within each flight) with some flights being salute barrages. |

easily accomplished unless one makes their own shells. Commercial manufacturers almost invariably follow the rules given above in order to produce a pleasing response. To evoke a negative emotional response in the audience, using purchased shells (not made to specification), usually the only possibility of breaking Table 6 rules is to play one shell against another.

In matching fireworks to music, the colors used, the size of breaks, the symmetry of breaks, the timing and combination of breaks are all important considerations in creating mood and building emotion. Table 7 is a guide outlining some of the ways fireworks can be used to evoke emotional response. However, in using Table 7, be aware that the art of using fireworks for this purpose is still relatively primitive and the content of the table was developed from observations and trials extending only over a few years. The ideas expressed there do work, but others not considered here may work as well or better.

In Table 7 and elsewhere in this paper, shells are occasionally described as being fired randomly. Obviously, in an electrically fired display, nothing happens randomly. What is meant is that the firing should appear to be somewhat random to the audience. The intervals between firings should not be exactly the same. When these time separations are all the same, the display will appear mechanical as opposed to spontaneous (which is preferred).

In Table 7, the degree of jubilation and excitement created by the fireworks depends mostly on their rate of fire. The higher the rate of fire is, the more the sense of excitement and/or jubilation. The degree of wonderment and beauty created depends mostly on the size of the shells. The larger the spread of the shells is, the greater the sense of wonderment and beauty. Finally, the sense of fullness (heaviness) versus airiness (lightness) created depends on the warmth of star color. The warmer the color is the greater the sense of fullness.

Generally, as a display progresses, larger and larger shells are employed. However, in using Table 7, frequently smaller shells and flights of shells are recommended. The appropriate number of small shells to use is that number which nearly equals the dollar value of the larger shells that they are being substituted for. As an aside, multiple smaller shells are usually more impressive than a single large shell costing the same amount. Consider two 3-inch shells replacing

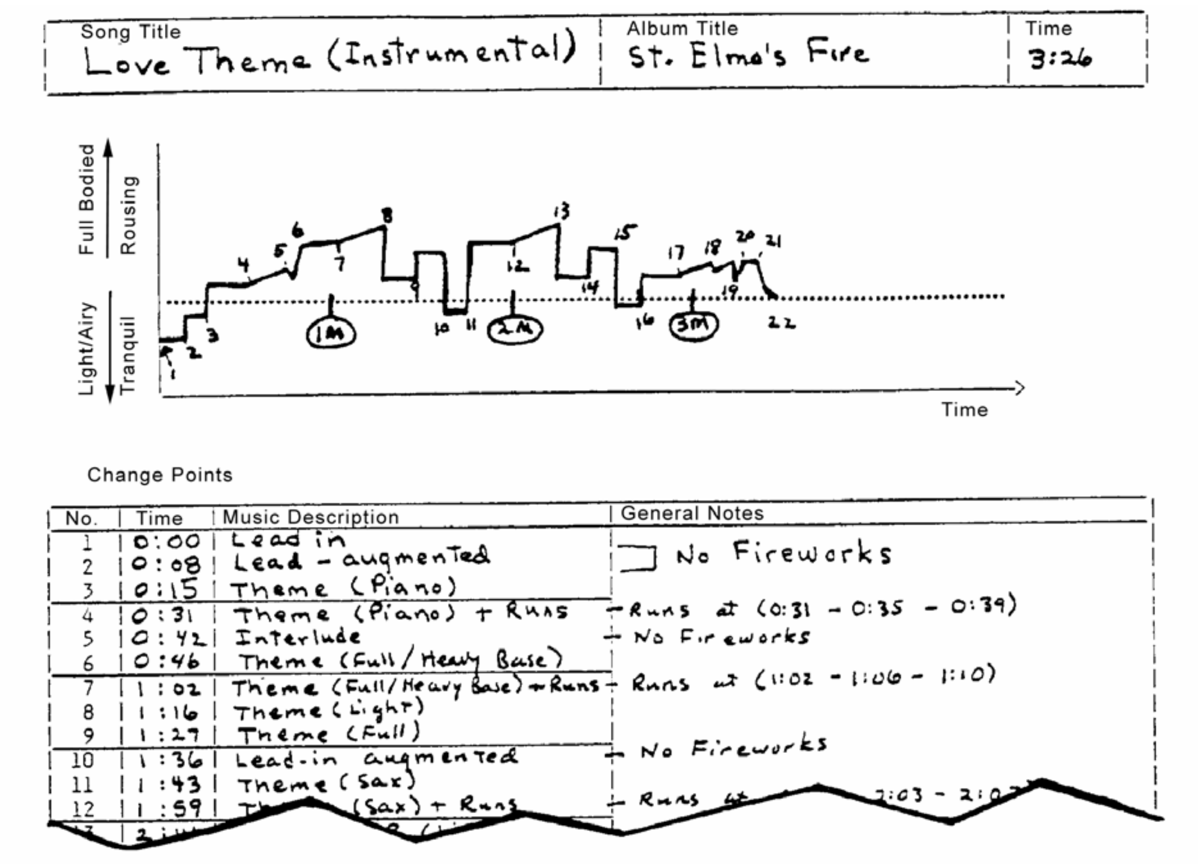


*Figure 6. Example of a complete Music Charting Form.*

one 4-inch shell or four 4-inch shells replacing a 6-inch shell. (Obviously all shells are assumed to be of equal quality.) However, as a minimum, increased variety can be introduced into displays by substituting multiples of smaller shells for single large shells.

Another guide in matching fireworks to music, independent of the mood of the music, is to consider the sound or feel of the music. Light, airy, higher-pitched music is most effectively matched with cool colors and strobe effects. Heavy, full and lower-pitched music is effectively combined with warm colors and comet effects.

In a musically-choreographed macro-sync display there are not very many uses for large singly-fired salutes. Large salutes can be fired randomly mixed with many rapidly-fired color shells to create a mood of excitement. They can also be used in groups to generate a sense of trepidation. To the contrary, there are many times when volleys of numerous small salutes can be used. In particular, they are very effective when used to punctuate high points and the conclusion of segments intended to produce a sense of excitement, jubilation or prideful patriotism.

### 3.3 Mechanics of Display Design

Having selected the music for a display while keeping in mind, in a general way, the guidance given above for choreography, the next step is to design the show in detail. This requires several steps, the first of which is to chart each piece of music. It is important to know each piece in detail, including how long each passage of the music plays; how each passage contrasts with other passages in terms of its musical feel (tranquility versus rousing, or lightness versus fullness), and some general ideas of how each passage might be expressed in fireworks. In one way or another it is necessary to chart each piece of music. If this is done somewhat formally, this has the advantage of documenting the information for use again in future shows.

However, more importantly, as the time for the display approaches, for reasons of nervousness or possible better ideas for the show, it is frequently necessary to re-examine the charted information. If the information was poorly recorded, time will often be wasted by having to re-chart many of the musical selections.

Figure 6 is an example of a completed music charting form as used by the authors. The form has three parts: one to identify the source of the music, one to chart the music graphically, and one to record times and descriptions of the various passages. In the graph, time from the start of the music is displayed along the horizontal axis, and the feel of the music is displayed using the vertical axis. Rough indicators for the feel of the music are its sense of lightness, airiness, or tranquility versus a sense of heaviness, fullness, or rousingness. Obviously these qualities are subjective and difficult to quantify. However, this not really a problem as it is only the approximate feel of each passage and how that compares with adjacent passages that is important. Exactly how tranquil or rousing each passage is, is relatively unimportant, compared with knowing whether the passage is tranquil as opposed to rousing and whether it has more or less of that quality in comparison with the preceding and subsequent passages. Also, while the length of each passage is quite important, it is a waste of effort to attempt to record precise times on the graph. The graph is useful only for visualizing the approximate lengths of the various passages. The detailed time information necessary for display design is recorded in the third part of the form.

The music charted in Figure 6 is the "Love Theme" from the movie St. Elmo's Fire. This was chosen because it was quite popular (at the time of writing this paper) and might thus be familiar to the reader (or it should be relatively easy for the reader to obtain a recording). This is important if the reader is having difficulty grasping how the charting is done. Then it will be helpful to recall the music or to listen to the actual music while studying Figure 6. The music begins with a lead-in passage lasting eight seconds before being augmented with another instrumental voice. This augmentation adds to the sense of fullness and appears on the graph as a stepwise increment in that direction (shown as number 2 in the graph in Figure 6). At 15 seconds into the music the main theme of the piece is played featuring the piano, which is again charted as an increase in the fullness of the sound (number 3). At 31 seconds the piano theme continues with a series of three musical runs; the start of each is separated by four seconds. This contributes to a modest building of a sense of spiritual fulfillment and is indicated as a slight ramp-up on the chart (number 4). At 42 seconds there is a brief interlude leading to a repeat of the main theme at 46 seconds. The interlude before the repeat of the theme is shown as a dip followed by a rapid rise on the chart (number 5); the manner in which this is charted is unimportant. It is only intended to show when and how long the interlude lasted. In this case it is shown as a rapid ramp up because the repeated main theme following the interlude has added to it a hard driving bass component. This gives the repeated theme a considerably increased sense of fullness, which needed to be charted in a higher position on the graph (number 6). Had the interlude led to a passage lighter than the piano theme, the interlude would have been charted as a ramp downward. The process of charting continues in a similar manner to the end of the music.

In the lower portion of the charting form, times (to the nearest second) and brief descriptions of passages are recorded along with other notes which may be useful later in designing the display, e.g., the timing of the musical runs is recorded. Note that those times when no fireworks will be shot are also indicated in this area, e.g., during the lead-in.

Having completed charting the music for the display, the next task is to design the fireworks part of the program. In doing this, use the charted music information and the choreographic guidelines presented in Section 3.2. For example, when expressing excitement or jubilation, the rate at which shells are fired should generally follow the levels graphed on the charting form. Similarly, when expressing wonderment and beauty, the warmth of star color should generally follow the graphed levels. However, it would be a mistake not to also consider what the music "says" to you; close your eyes while listening to the music and let your imagination express itself. Hopefully you have already done this in a general way during the process of selecting the music; now detail must

| PROGRAM QUEUE LOG | | SHOW: G.J. Chamber of Commerce | | DATE: 1986 |
|---|---|---|---|---|
| Tape No. | Circuit No. | Time | Effect | Notes |
| — Love Theme: St. Elmo's Fire 3.26 | | | | |
| | — | 0:00 | Music Start | No Fireworks |
| | R 12 | 0:15 | 6 – 4" Silver Sets | Random (Ave. 3 sec.) |
| | G 41 | 0:31 | 3x3 – 3" Silver Sets | Flights at 0 + 4 + 4 Sec. |
| | — | 0:42 | Interlude | No Fireworks |
| | R 22 | 0:46 | 6 – 4" Red Sets | Random (Ave. 3 sec.) |
| | G 42 | 1:02 | 3x3 – 3" Red Sets | Flights at 0+4+4 sec |
| | R 11 | 1:16 | 4 – 4" Blue + Silver Sets | Random (Ave. 3 sec.) |
| | R 12 | 1:27 | 4 – 4" Blue + Green Sets | Random (Ave. 2 sec.) |
| | — | 1:36 | Interlude | No Fireworks |
| | R 32 | 1:43 | 6 – 4" Red + Silver Sets | Random (Ave. 3 sec.) |
| | G 43 | 1:59 | 3x3 – 3" [illegible] Sets | F[illegible] 0+4+4 Sec. [illegible] 2 Sec.) |

*Figure 7. Example of a completed Program Cue Log.*

must be added. When the display design is fairly well in mind, it must be transferred to paper. This is done using some sort of "Program Cue Log", like the example shown in Figure 7. At this time only the three columns on the right are completed. First, the times from the music charting form are entered. Next a description of the fireworks effect for each segment of music is added. In Figure 7, shells are described as "sets". This is a shell of the size listed plus parasitic effects like those described in Table 3. Further, when Figure 7 lists "3 x 3" as the number of shells, this is meant to be three groups of three shell sets. In the final column of Figure 7 to be completed at this time, fusing instructions or other notes may be recorded. For example, at 15 seconds a series of six 4-inch silver shell sets will be fired to appear somewhat random with an average of three seconds between each firing. It is important to record this firing (delay fusing) information because the effect created will be different for random appearing firing, equally spaced firing, firing as a flight, or simultaneous firing.

By comparing the descriptions of the fireworks being used in Figure 7 with the descriptions of the music given in Figure 6, some idea of how Section 3.2 guidelines are implemented may be gained. For example, when the main theme is first introduced at 15 seconds and then repeated with more fullness at 46 seconds, star color changed from cool to warm. Each time musical runs were added to the main theme (e.g., at 31 and 62 seconds) this was mimicked by the fireworks through the use of smaller shell flights.

The next step in display design is the assignment of each shell to a specific mortar. The process that will be discussed here will be for dense-pack mortar trailers using delay fuse links, but in many ways it is analogous to what would be done for mortars positioned more traditionally. In any event, one cannot wait until the day of the show to physically lay out the arrangement of mortars and wiring; the process just takes too long and mistakes can be costly in terms of both time and personal energy. It is appropriate to map out mortars and wiring well in advance of the show. Figure 8 is a stylized map of the 4-inch mortar rack in the dense-pack trailer shown in Photos 1 and 2. The map has been filled out to record fusing and shell loading instructions. In the example above, the first shell series for the St. Elmo's Fire Love Theme is a series of six 4-inch silver shell sets fired in a manner appearing somewhat random with an average time interval of about three seconds. On the map, this is recorded in the upper left hand area.

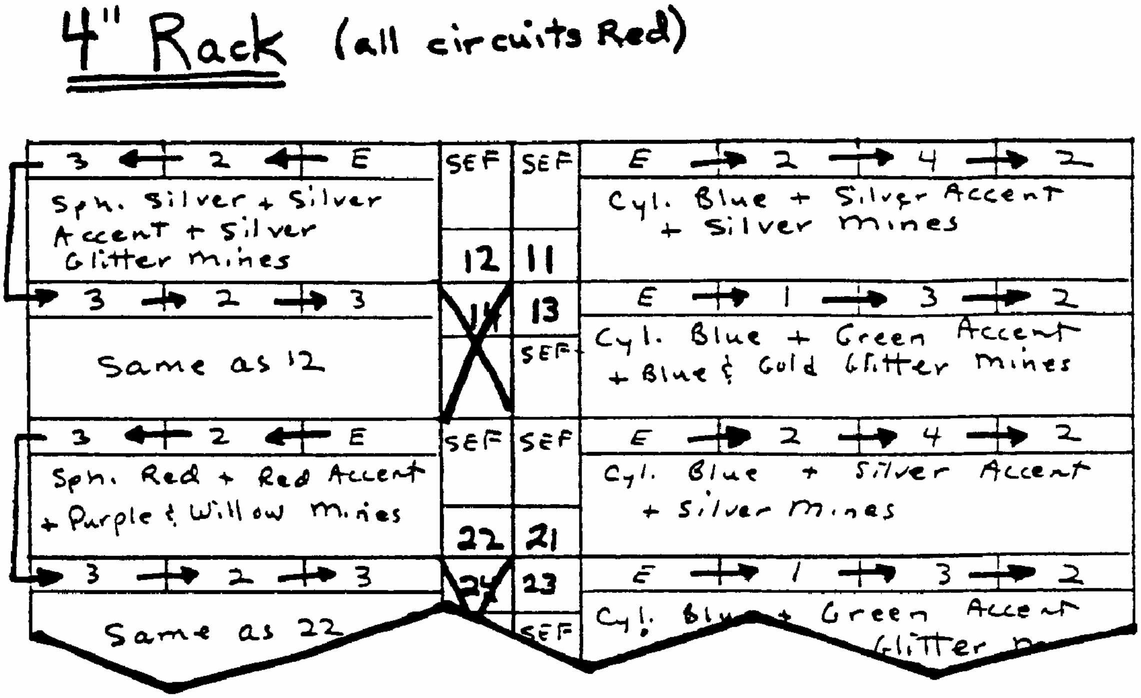


*Figure 8. Example of a Trailer Loading Map for the four-inch mortar section of the large "Dense-Pack" mortar trailer.*

The 4-inch rack has its electrical firing contact points running down the middle of the rack with three mortar positions to the left and four mortar positions to the right of each set of contact points. In Figure 8, the series of electrical contact points is shown as the vertical band of boxes running from top to bottom about half way across the map. Contact points are grouped in sets of four; in Figure 8 the numbers 11, 12, 13 and 14 correspond to the first set of contact points. The first series of shells for St. Elmo's Fire is fired by circuit number 12. Above the small box for contact points number 12 is another slightly larger box that can be used for recording some brief notes; here the letters "SEF" have been written to denote that this is one of the circuits that will be fired during the music from St. Elmo's Fire. To the left of these two small boxes is the area used to record fusing and shell information for the first three mortars.

Fusing information is noted in the three small rectangular boxes. The "E" in the rightmost of these boxes, next to the electrical contact point for circuit number 12, indicates that the first mortar is to be fired electrically. The arrow pointing left indicates that the first mortar is used as the ignition source to chain fire the next mortar. The "2" in the second box indicates that the time delay of the fuse link for the second shell is two seconds. Similarly the next arrow pointing to the "3" indicates that the second shell is to be the ignition source for a three second delay link to the third shell.

The design of the display calls for the firing of six 4-inch shells. The remaining chain of three shells could be fired electrically; however, it is easier and cheaper, and firing errors are less likely if the last three shell firings are just made a continuation of the first chain of three. In Figure 8 this is shown as an arrow down the edge of the rack map to a second set of three small rectangular boxes, with additional arrows indicating continued chaining and numbers indicating delay times for the delay links. Because both sets of three mortars to the left of the electrical firing points 12 and 14 have been fired using a single electrical ignition, initiated by circuit number 12, the second circuit, number 14, is crossed out, indicating that it will not be used.

The show design calls for the firing of the first six shells to occur with three second average random firing. This was accomplished by the use of delay fuse links of slightly different delay times that roughly average three seconds.

In the larger rectangular areas, below the series of small boxes for fusing instructions, descriptions of the shells and parasitic effects are listed. In the case above, all six shells and effects are identical and only a single description need be used. Accordingly, for the above example, spherical silver display shells with silver parasitic accent shells and silver glitter mines are identified. If each shell set were to be different, separate descriptions for the shells would have been written below each of the small boxes used for fusing instructions.

At this point an additional piece of information needs to be entered on the Program Cue Log, Figure 7. That is the circuit number for firing the first shell series. In this case it is circuit 12 (the "R" in Figure 7 is a special designation peculiar to the authors' electrical firing controller).

The process of selecting, charting, choreographing and mapping is continued for each piece of music until the display design is complete. In actual practice, it is often effective to start at the two ends of a show and work toward the middle. The reason for this is that one usually has a good idea of what percent of the show budget must be spent on the finale for it to be effective; also one usually knows at what pace the show should begin. Then the process is only to fill in the middle in some logically consistent way without running out of money.

As a final comment concerning show design, it is appropriate to remember that usually, for various reasons, not all spectators will be able to hear the musical program. It is appropriate to consider these spectators too when designing the display. For the most part this just means that long periods of dark sky and prolonged repetition should usually be avoided even if that fits well with the musical program.

### 3.4 Mechanics of Pre-Production

Having completed the detailed design of the display including the layout of the mortars and wiring, the next step is to prepare to take the show on the road. Remembering that there is always too much to do at the last minute, as much work as possible should be done in advance. There are three areas in which advance work can be done: mortar preparation, shell set preparation, and general preparation.

Mortars should be cleaned, inspected and loaded into the trailers, and all required delay fuse links should be installed as early as convenient. It is appropriate to have on hand an abundant supply of variously-timed delay fuse links. The authors use a large case for storage of pre-made fuse links. The case is fitted with a large number of bins into which delay links are loaded. Thus a large number of delay links, organized by their delay times, can be kept ready for use in the chain-fusing operation. Using two people to read fusing instructions from the mortar rack map, select the proper fuse link and install it, results in speedy installation (more than 150 per hour) with essentially zero errors.

Again using the mortar rack map, the shells for the show can be readied. It is effective to prepare, as groups, shell sets just as they will be used in the display. Thus, from the example above, one such group would be six 4-inch silver spherical shells with their plastic bags of silver accent shells and silver glitter mines. As shells are withdrawn from inventory, any that will be fired electrically can have match headers attached to their leaders provided the electric matches are shunted and care is taken to protect them from rough treatment. Those shells that will be chain fired should have their leaders trimmed to remove the exposed black match (or other delay materials normal for shells intended to be manually fired). When a shell set series has been assembled and readied, it can be loaded into a large plastic bag marked to indicate the set of mortars into which they will be loaded. This is usually accomplished by marking the bag with the appropriate electrical firing circuit number. (Even when all the shells in a group are not identical, usually they are not individually marked. Rather, the group of shells is loaded at the shooting site according to the descriptions on the rack map.) Several bags of shell sets are then loaded into a box marked to indicate the contents. The marking should be clear and easy to interpret, as there will not be time to re-sort things on the day of the display.

Another preparation that can be made in advance is to complete a checklist of those many items that will need to be taken to the display. This is more important than it might seem; musically-choreographed shows fired electrically are considerably more complex and require considerably more equipment (primary and backup) than conventionally-fired displays. The general type of items that should be considered for the checklist include: safety equipment, such as fire extinguishers, warning signs and ear protection; electrical firing equipment, such as cables, hand tools and testers; musical program equipment, such as the program tape, backup tape and reproduction equipment; fireworks, checked item by item from a complete program inventory; program equipment, such as the completed program cue log and stop watch; crowd control equipment, such as flashlights, radios and barriers; personal comfort items, such as sun screen and salt tablets; general display equipment, such as racks, lumber and tools; business items, such as the display contract, permits and proof of insurance. The list of needed equipment can grow to be very long and the probability of forgetting one or more important items is too great not to use a checklist. In addition to just preparing a checklist, as much as practical, the equipment should start to be accumulated several days in advance, ready for final loading.

Other general preparation tasks include making travel preparations such as vehicle inspection and any needed repair, and making lodging arrangements. Also arrangements for support services such as security and clean-up should be finalized.

### 3.5 Music Reproduction

In Section 3.1, the importance of effective music selection was emphasized. However, even the greatest selection of music will add little emotional impact if its reproduction is of poor quality. The sound needs to be loud enough to be easily heard during the show over the noise of the crowd and over most of the fireworks. The sound needs to be full-bodied, with good bass response (50–200 Hz) and reasonable high frequency response (2k–10k Hz). The importance for amply loud and high-fidelity sound cannot be overstated. If this cannot be accomplished, don't even bother trying to put on a musically-choreographed display, it simply will not be worth the time and expense!

There are two basic ways to handle music reproduction: broadcast over a radio station or use high-fidelity PA systems. To large extent, which way is best is determined by site and type of display. If the audience is widely dispersed, e.g., across an entire metropolitan area, a radio broadcast is the only possibility. This has the advantage of requiring less equipment on the part of the display operator and is fairly easy to arrange. Depending on the size and popularity of the display, most radio stations will at least seriously consider doing such a broadcast. Probably the greatest disadvantage is the problem of publicity; if spectators don't know that there will be a musical accompaniment, remember to be near or bring a radio, and know what station to tune to, they will be left out. Another problem can be arranging to get the audio signal to the station. Obviously the easiest is to give the radio station a copy of the music program tape. However, this results in a loss of control over its playback. This may not be critical but requires at least some sort of two-way communication link with the radio station. There is always the potential for the display to be delayed or interrupted by an equipment failure or safety problem. Should this occur, coordination with the station to interrupt, delay or restart the musical program is essential. It is simply unacceptable to allow one to be put into the position of having to choose between overlooking an unsafe condition and aborting the musical portion of the show, because one cannot communicate with the radio station. An alternative to giving the station the program tape is to use one's own playback equipment and send an audio feed to the station. This is not trivial but can be arranged particularly if the station is doing a remote broadcast from the shooting site and can accept the audio signal. In that case, only a long audio cable is needed.

If the audience is confined to one or two relatively small areas (such as a grandstand), it is effective to use high fidelity sound reproduction equipment positioned just for the benefit of the audience. Nearly any high power amplifier(s) will be sufficient, as essentially all modern equipment has good frequency response. The problem with the amplifier will be to get sufficient power output. To be heard effectively and have sufficient bass response, music reproduction requires considerably more power than normal voice PA systems. To be heard equally well, high quality (not loud) music requires five to ten times the audio power needed for voice. Power requirements for even a small crowd will be several hundred watts; larger crowds may require several thousand watts of power. Speakers are another problem. As not only do they have to be able to handle the large power, they need good frequency response. Normal PA speakers, that may be available at the site, are simply inadequate. They almost never have acceptable low frequency response. Unless speaker response extends well below 100 Hz, the music will sound thin and will not be very effective. To make the musical program as effective as possible, an equalizer can be used to balance and temper the frequency response of the system for the acoustics of the site. As a minimum, if an audio spectrum analyzer cannot be used, several parts of the program should be previewed with the listener positioned where the crowd will be and the frequency equalizer adjusted for a pleasing sound.

If high fidelity PA equipment is used to broadcast the music, the listener has no control of the sound level. Those with control generally will not be in the audience and will have difficulty in setting the proper level. Guesses made during the day, at what level will be effective, will probably miss the mark at least to some extent. For the display to be really effective, the sound level must be nearly as loud as comfort will allow. To complicate things, in the loud environment of the display, the audience's tolerance (desire) for loud sounds will increase as the display proceeds. Accordingly it is desirable to station someone in the audience with a two-way radio to give instructions for setting the audio level during the display. (Note that this same person can also perform a safety watch for debris falling into the crowd or for shells breaking over the audience.)

### 3.6 Show Performances

There are significant differences between set-up and performance of electrically fired displays and hand-fired shows. However, beyond what was presented in Section 2 of this paper that discussion is beyond the scope of this article. (See reference 1 for such a discussion.) The addition of a musically choreographed program to an electrically fired display does not change the setup, electrical wiring, mortar distance to spectators, etc. One difference may be the need for AC power on site for tape playback equipment. If a high output audio system is used, the power requirements may be considerable (4 to 5 kW).

It is very useful to have two people firing the musically programmed display, one to throw the switches and one to read the program and stop watch or tape counter. The use of chain fusing and parasitic effects significantly reduces the number of electrical firings and does make it possible for a single person to control a show, but this is clearly not desirable. With only one person, any small problem will be magnified and could seriously diminish the effectiveness or safety of the display.

If the display crew has control of the tape playback equipment, the tape counter on the tape deck can be used to indicate firing times during the display. The Program Cue Log (Figure 7) should then have the appropriate tape counter numbers entered into the leftmost column. If the display crew does not have control of the tape playback equipment, or if they prefer not to use the tape counter for program cues, some form of stop watch or digital timer can be used.

During the display it is necessary to be able to receive input (by radio) from safety people stationed to monitor the fallout and crowd areas. It is necessary for the person doing the firing and the person reading the script to hear each other clearly. It is important to be able to hear the musical program particularly if it becomes necessary to improvise or adjust because of some technical problem. All these important communications taking place in the high noise environment of a display may present problems. One solution is to use an intercom system like that used in helicopters, with headphones and microphones for the two operators and additional inputs for the communications radio and the music program. In Section 2.3, it was mentioned that it is occasionally desired to record one's comments and observations during the show performance. With this type of intercom system it is relatively easy to include an output signal for a tape recorder. If this is done, there will be a complete record of the show and all comments and observations. This also includes all reports from safety monitors, which may be helpful if ever there is an accident.

## 4.0 Conclusion

By way of conclusion, it is perhaps worth restating that the added expense of hardware needed to fire musical aerial displays electrically from trailers can be offset by the increased profit in a relatively short time.

Some specific examples are:

- Such displays require a considerably smaller work force on the day of the show. This results in a savings in salary and per diem expenses per show and also allows more shows to be staged with the same size work force.
- The use of personnel during marginally-productive periods well in advance of shows can represent a savings of labor costs.
- The use of parasitic effects gives the sponsor a more effective show and reduces the number of mortars needed, both of which translate into more profit.
- Shooter and spectator safety are increased in these shows. Even with full insurance coverage, accidents are very costly.
- The use of chain firing can improve a show by reducing errors caused by having to rapidly fire effects. It also saves electric matches and allows the use of less cable and firing control equipment with fewer circuits, all of which can translate into savings.
- Sponsors now increasingly expect and are willing to pay for truly effective and professionally-performed displays. (Note that this may also be an effective way for small operators to compete with a larger company's ship-shows.)
- There are a number of tax advantages (ACRS depreciation, investment credits and Section 179 expensed equipment) that can significantly reduce the effective costs of the equipment.

Considering all aspects, the authors estimate that the cost of equipment will be recaptured after about six displays.

## 5.0 Acknowledgments

As is so often true, most of the ideas presented in this paper are borrowed from others, and relatively few are original. Unfortunately, there is uncertainty regarding who contributed which ideas over the years. With a general apology, however, some of those who have contributed personally or through their writing to the development of the methods presented in this paper are Takeo Shimizu, Ken Nixon, Robert Winokur, Sam Bases, Tom DeWille, and Bill Ofca.

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Finally, the authors wish to acknowledge the efforts of the staff of PYROTECHNICA especially those of its publisher Robert Cardwell.

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