British Pyrotechnists Association

Lecture Notes for BPA Firework Firers Course and Examination Level 1 and Level 2

Original by
K. L. and B. J. Kosanke
with additional input from
T Smith, J. Steinberg, R. Winokur and L. Weinman

Published by

The British Pyrotechnists Association
and
Journal of Pyrotechnics, Inc.

BRITISH PYROTECHNISTS ASSOCIATION FIREWORK FIRERS COURSE

This guide for display operators has been prepared by the British Pyrotechnists Association (BPA) as the core material for the BPA's Firework Firers Courses.

This guide is not intended to be used as a technical manual by those in experienced in the management of firework displays.

The BPA Firers Course and Examination IS NOT a licence to purchase or use category 4 fireworks. BPA members have agreed to sell category 4 fireworks only to those

- With adequate licenced storage (NOT registered)
- Holding 365-day insurance
- Who operate as a company (but including sole-traders, partnerships and limited companies)
- Who can demonstrate competence (by way, usually, of this course) in the materials they wish to purchase

These class notes are intended for use in a two day training course for level 1 and a two day training course for level 2 on the practical and safety aspects of performing fireworks displays. In addition to the lectures, the training includes numerous video and live demonstrations, as well as student exercises. Even if the current training is scheduled for less than a full week, for the sake of completeness, the full set of notes has been provided. However, in that case, some of the lectures included in the notes will have been eliminated along with some demonstrations and exercises.

Each page of the notes contains the same information as the presentations used in the lectures. At the beginning of each section, the outline for the material that follows has been reproduced.

An attempt has been made to have these notes be reasonably consistent with various international regulations and codes of practice. Toward that end, generally the word "must" has been used when something is generally a requirement, or it is something about which the authors feel rather strongly. The word "should" generally has been used for things that are important but are not specifically required. Generally the word "may" has been used for things that are sometimes good practice, are of less overall importance, or are unproven at present.

Contents

SECTION 1 - INTRODUCTORY ELEMENTS OF HAZARD MANAGEMENT FOR FIREWORK DISPLAYS:

Accidents, law suits and regulation

Definitions:

- Hazard
- Risk
- Safe

Hazard management:

- Recognition of hazards
- Evaluation of risks
- Control of risks

Display operator defined and their responsibilities

ACCIDENTS, LAW SUITS AND REGULATION

Fireworks are not unreasonably dangerous when they are properly used.

A recent study found that people are at least 3 to 5 times more likely to be killed or seriously injured driving round trip to view a fireworks display than they are to be killed or seriously injured from the fireworks at the display. Most fireworks accidents are the result of carelessness, misuse or failure to follow regulations and workplace guidelines.

Each year people (spectators and crew members) are needlessly injured (or possibly killed) because of failures to recognize and take seriously the potential danger of fireworks.

Lawsuits and regulation are the natural result of accidents that produce injuries. This is a chain of events.

Accident → Injury → Litigation → Legislation

The only practical point to break this chain is to limit accidents, especially those involving injuries.

HAZARD AND RISK DEFINED

These two terms are often confused with each other, however their meaning is distinct and clear:-

The <u>hazard</u> of an event is the potential consequences of an event—however infrequently that event may occur. The consequence of an event is its intrinsic potential for harm to persons or property.

Synonyms for hazard include:

- Consequence
- Danger (a poor term and one with overly negative connotations)

The <u>risk</u> arising from an event considers both the intrinsic hazard of the identified event and the frequency with which that event tends to occur.

Synonyms for frequency include:

- Likelihood
- Probability

"SAFE" DEFINED

A typical dictionary definition of "safe" is ***"Anything involving no risk of mishap, error, etc."***

By this (poor) definition of safe, nothing mankind does is safe because there is always some "risk of mishap" in literally every possible activity.

- Crossing the street. → Being hit by a car.
- Eating food. → Choking or food poisoning.
- Reading a book. → Getting a paper cut.

The definition of "safe" from hazard management:

"Something is safe when the attendant risks are below an acceptable level." *[W.W. Lawrence]*

This definition recognizes the fact that nothing one does is completely free of the possibility of injury and that something is considered safe when the risk (probability and/or consequence) is sufficiently small. This is the definition used in these notes.

FIREWORKS HAZARD MANAGEMENT

The three basic elements of all hazard management programs are:

RECOGNITION (OF POTENTIAL HAZARDS):

Understanding how fireworks function and occasionally malfunction.

EVALUATION (OF THE RISKS POSED BY THOSE HAZARDS):

Combining estimates of the probability of a problem occurring and the severity of the resulting consequences for various possible fireworks malfunctions, equipment failures, crew errors, and spectator problems.

CONTROL (MINIMIZATION OF THE RISKS):

The actions undertaken to reduce the risk by reducing the probability of an accident occurring, the consequences of a fireworks accident or both.

1) RECOGNITION OF FIREWORKS HAZARDS

Fireworks present a level of hazard greater than many workers in the trade realize. For example:

- ♦ Fireworks salutes often have an air blast equivalency in excess of 50% of their weight in TNT.
- ♦ Large aerial shells often leave the mortar travelling more than 200 m.p.h. (320 km/h); this is nearly the energy produced by a small automobile travelling at 20 m.p.h. (32 km/h).
- ♦ Firework stars may burn at temperatures greater than 3600 ºF (2000 ºC).
- ♦ Dud shells can fall to the earth travelling about 125 m.p.h. (200 km/h). This is sufficient that even a relatively small aerial shell can cause death if a person is struck.
- ♦ Large aerial shells can explode with an air blast pressure significantly greater than that produced by a military hand grenade; they can produce an intense fire ball and may generate potentially life threatening fragments.

2) EVALUATION OF RISK

Risk assessment has two components that involve determining or estimating:

The probability of a mishap occurring, and the severity of the consequences if the mishap does occur.

A minor risk has a low probability or a minimal consequence.

For example, consider the following potential activities:

Activity	Consequence	Probability	Risk
Jumping off tall buildings to see if you can fly	Crash landing (Severe)	Very High	(≈100%) Unacceptable
Swimming in the sea	Being eaten by sharks (Severe)	Very Low	(≈0%) Acceptable
Flipping a coin to decide what TV program to watch	The other program is better (Inconsequential)	High	(50%) Acceptable

Note: the BPA has adopted a more sophicated scheme for risk assessment which will be discussed later in the book.

Risks are least when both the consequences are minor and the probability of occurrence is low, conversely a high risk operation may be one where the consequences OR probability is high, and VERY high risk operations are when the consequence and probability are both high.

The BPA has adopted a more sophisticated risk analysis regime, details of which are available in later sections.

3) EXAMPLES OF FIREWORKS RISK CONTROL

To reduce the probability of an accident occurring:

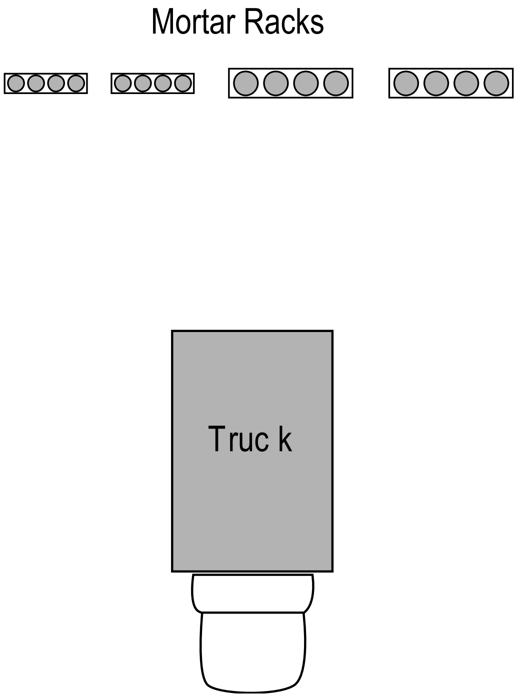
- Inspect all aerial shells for damage and do not use any suspect shells.
- Keep electric igniters shunted when possible and their safety shrouds in place.
- Protect aerial shells and other fireworks from damage due to moisture.

To reduce the consequences of an accident:

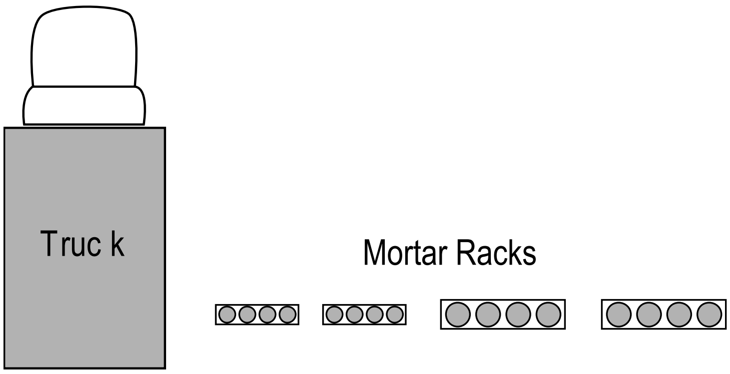
- Keep unnecessary personnel out of the fireworks firing area.
- Sandbag or barricade the fireworks mortars when manually firing aerial shells.
- Separate the storage areas for fireworks from areas where fireworks are being prepared.

Often risks can be minimized using methods that require little or no additional effort or expense.

Sometimes a little thought will provide a safety improvement with no added work. It is common to position the truck carrying the fireworks as shown to the right. If there is an accidental ignition of an aerial shell in the mortar area when the back of the truck is open, there is a good chance that the contents of the truck will be ignited producing a much greater accident.



With the following orientation of the truck, that type of accidental ignition of the contents of the truck is effectively eliminated, without having to carry the aerial shells farther on average.



ROLES

Through out this book we use the following conventions:

Firer - Assistants onsite under the supervision of the Senior Firer. These would normally be Level 1 Firers.

Senior Firer - Responsible for managing the display, including site layout, liaising with organising and managing of assistants. These would normally be Level 2 Firers.

Display Manager - Designated person in the Company who is responsible for all displays organised by that Company and is likely to be the person who carries out site visits, RA and liaises with the Client prior to the display date.

Display Company - Fireworks Company organising the professional fired display.

Client - Person or Company paying for the services of the Display Company

Event Organiser - Person or Company actually managing the event prior to and on the display date. This may or may not be the same as the Client.

Enforcer - Any Government or other Authority that may be involved in the organising and supervision of the display and responsible for insuring legal compliance by the Event Organiser and the Display Company.

DISPLAY COMPANY'S RESPONSIBILITIES

Senior Firer: The person with overall responsibility for safety, and the setting up, firing and derigging of an outdoor fireworks display.

The operator's responsibility:

With regard to the Public:

- ♦ No single failure of fireworks or equipment can be allowed to injure a member of the public.
- ♦ With regard to the Crew:
- ♦ Training: Tell them the correct way and WHY.
- ♦ Crew Size: Do not have too many or too few.

With regard to the Display Company and Client:

- ♦ First and Foremost: A Safe Show.
- ♦ Second: A Great Performance.

Operator Participation:

- ♦ Before and after the display — Oversee and check on the proper completion of all work.
- ♦ During the display — Monitor safety and crew performance and take all needed corrective measures.

SECTION 2 - BASIC AERIAL SHELL COMPONENTS AND THEIR MANNER OF FUNCTIONING:

Firework aerial shell shapes and sizes:

- Spherical
- Cylindrical

Basic aerial shell components

Manner of aerial shell functioning (manual firing)

Shell leader (fuse):

- Black match
- Quick match

Lift charge (propelling charge)

Fireworks time delay fuse (delay fuse) and priming

Stars (pellets of pyrotechnic composition)

Shell inserts (small pyrotechnic components)

Shell burst charge (break charge)

Shell labels

AERIAL SHELL SHAPES AND SIZES

Aerial shells are the most commonly used type of display fireworks. There are 2 basic styles of aerial shell construction:

- Spherical Aerial Shells (for instance Japanese or oriental-style shells). Spherical shells typically produce star patterns that are spheric ally symmetric.
- Cylindrical Aerial Shells (for instance Italian style shells). Cylindrical shells typically produce less symmetric star patterns.

Aerial shells range in size from less than 2 inches (50 mm) to more than 12 inches (300 mm). However, most shells used in displays are between 2.5 and 6 inches (65 and 150 mm).

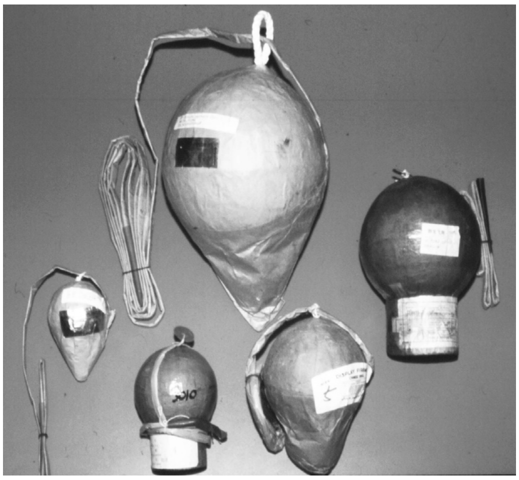
Aerial shells are measured in terms of the internal diameter of the tube (fireworks mortar) from which they are designed to be fired.

Because of the need for clearance between the aerial shell and mortar, actual shell diameters are less than their nominally stated size. For example, most 3-inch (75-mm) shells are about 2.7 inches (66 mm) in diameter.

Aerial shells must be constructed to fit properly in the mortar such that they will be propelled to the proper height before functioning.

TWO TYPES OF AERIAL SHELLS

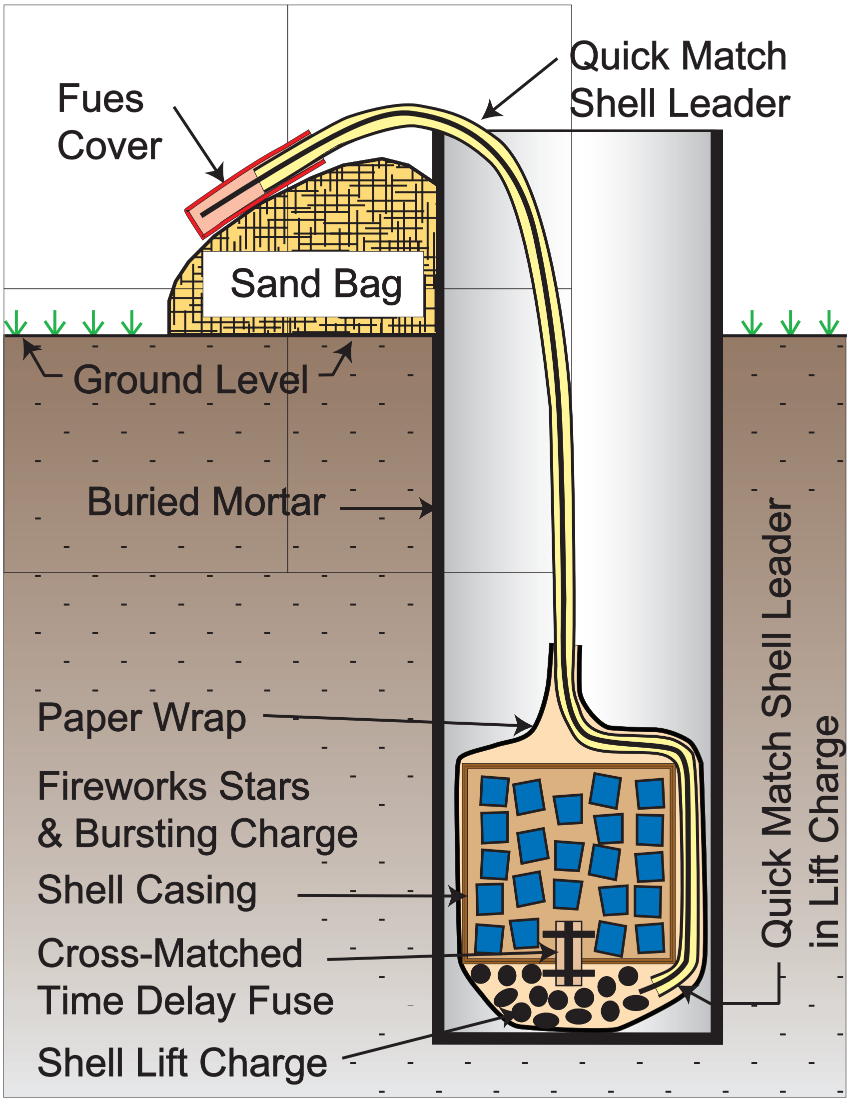
Spherical Aerial Shells



Cylindrical Aerial Shells

BASIC CYLINDRICAL AERIAL SHELL COMPONENTS

Illustration of the basic components of a cylindrical aerial shell in its mortar. (To be discussed later.)



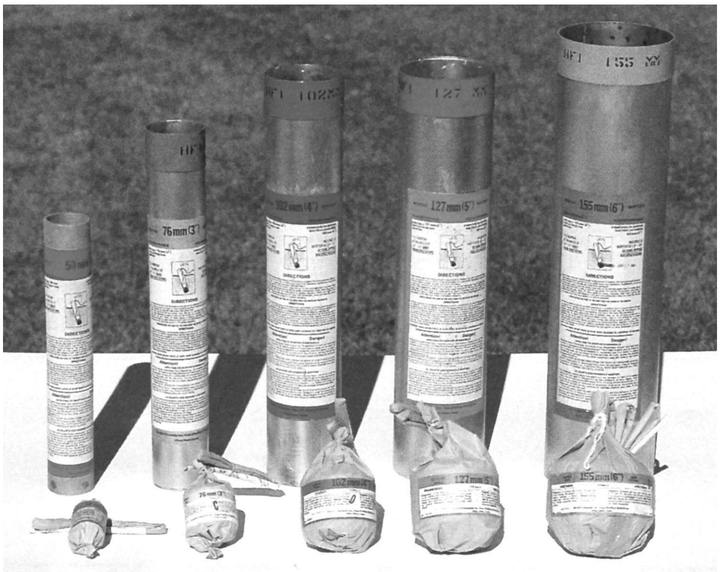
MANNER OF AERIAL SHELL FUNCTIONING - (MANUAL FIRING)

An aerial shell is a ballistic projectile fired from a tube (a mortar). The sequence of events is:

- Fuse cover, which protects the exposed black match, is removed (not shown). The black match or other delay element is ignited and provides a delay.
- When burning reaches the start of the quick match portion of the shell leader, it burns quickly, in about 0.3 second.
- When the burning shell leader fuse reaches the Black Powder lift charge, it is ignited.
- The burning lift charge produces combustion gases that are partially confined within the mortar. The burning gas pressure that is produced propels the shell upward and ignites the shell's time fuse.
- The aerial shell, having exited the mortar, travels skyward (coasting upward) while the time delay fuse continues to burn.
- Eventually, the time delay fuse burns through to ignite the burst charge and stars in the shell. This burning produces an increasingly high pressure inside the shell. When the internal pressure exceeds the strength of the shell casing, it bursts to expel the burning stars in a display of light effects.

FIREWORK MORTARS

Although not physically part of an aerial shell, the firework mortar is essential to properly fire the shell into the air. The fit between the aerial shell and mortar determines how much of the burning lift gas will escape. Thus, a proper fit is necessary for the shell to be propelled to a safe height.

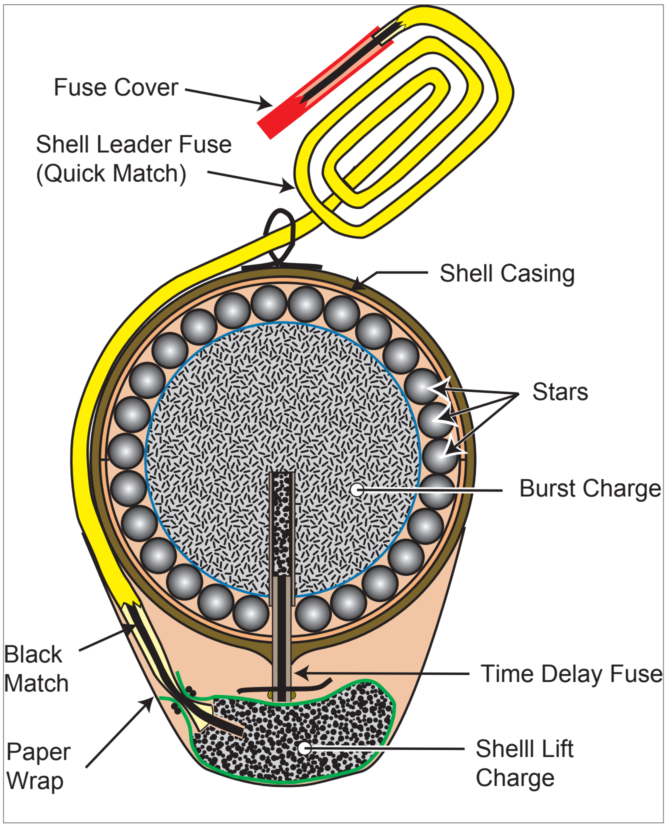


[CERL – Fireworks Manual]

The fit of an aerial shell in a mortar should be "close but freely sliding". Accordingly, each different size aerial shell requires a different size firework mortar.

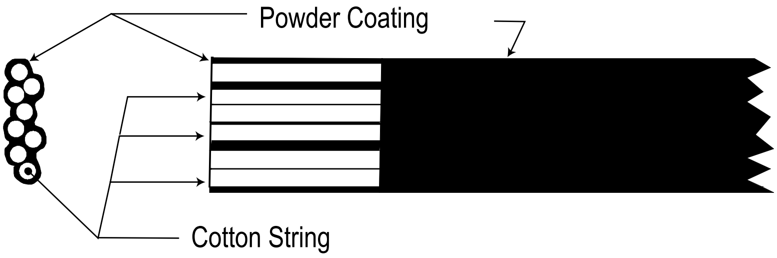
BASIC SPHERICAL AERIAL SHELL COMPONENTS

Illustration of the basic components of a spherical aerial shell.

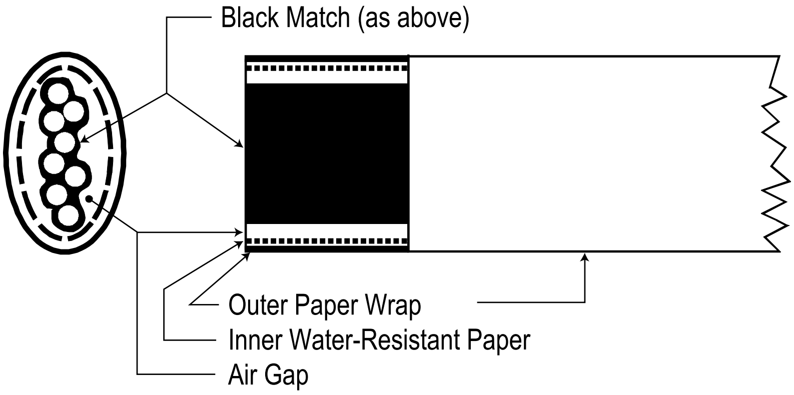


BLACK MATCH AND QUICK MATCH

Black match is made by coating a slurry of Black Powder on cotton strings, to produce a fuse about 1/8" x 1/4" (3 x 6 mm) in cross section. Black match burns at a rate of about 1 inch/second (25 mm/s).

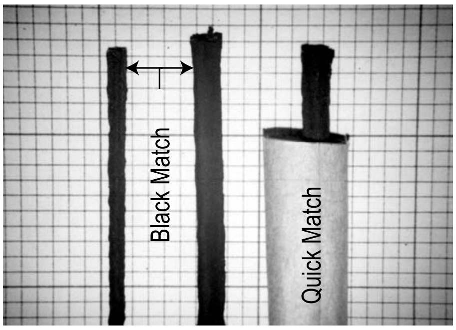


Quick match is made by simply wrapping black match with a loose paper covering. Quick match burns at a rate of about 15 feet/second (5 m/s); approximately 200 times faster than black match.

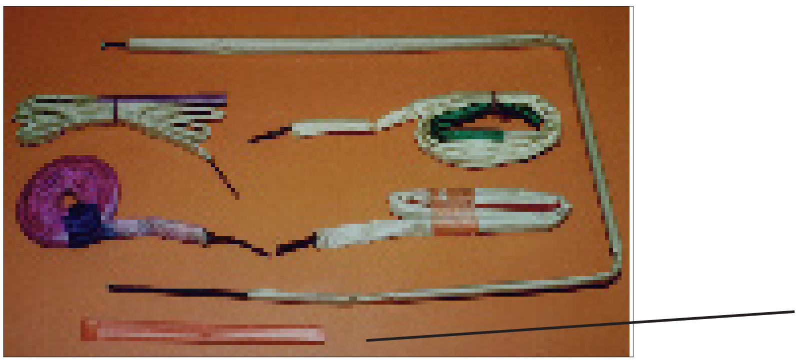


BLACK MATCH, QUICK MATCH AND SHELL LEADERS

Examples of two thicknesses of black match and one example of quick match. [0.1 inch (2.5 mm) per division]

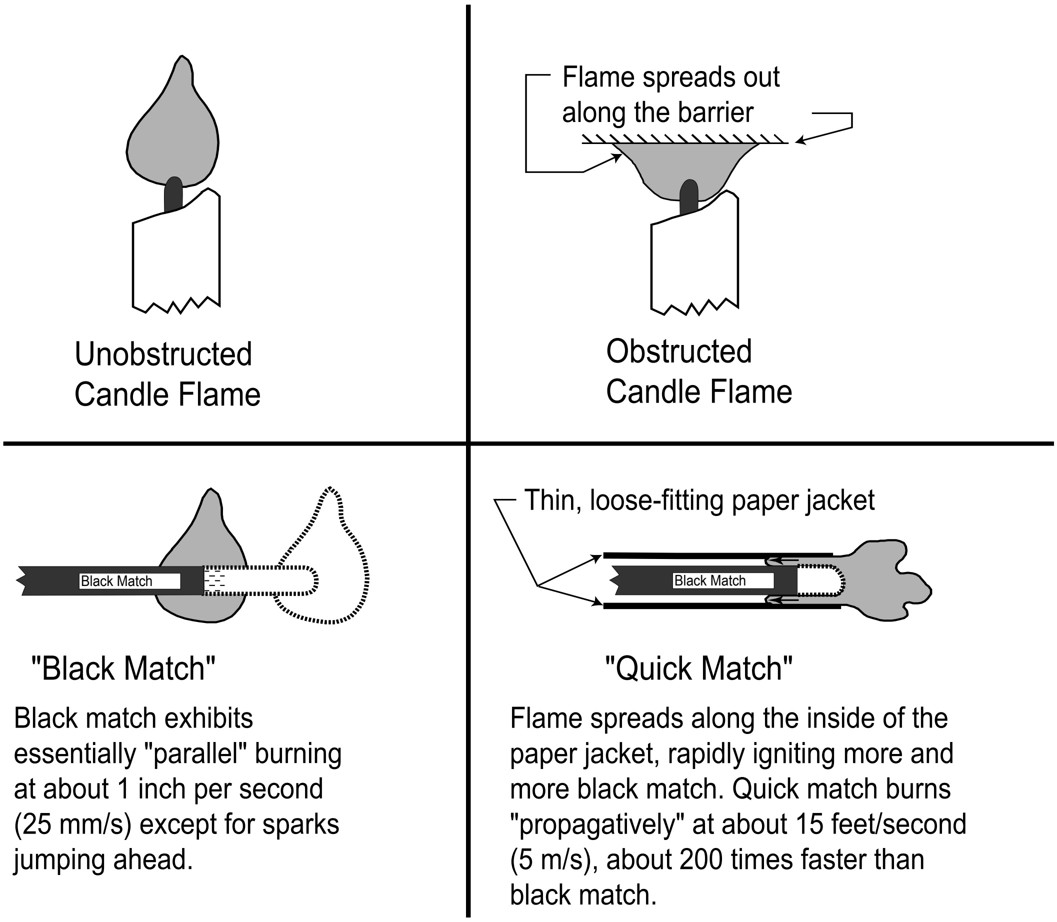


Various examples of shell leaders.



MECHANISM OF QUICK MATCH BURNING

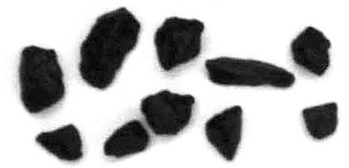
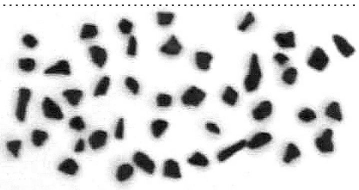
The rapid burning of quick match can be explained using the analogy of a candle flame [T. Shimizu]. Black match burns much like an unobstructed candle flame. Quick match burns much faster because its flame spreads along the paper wrap (like an obstructed candle flame) progressively igniting more and more powder.



FIREWORKS LIFT CHARGE

The propellant for aerial shells is essentially always granular Black Powder (gun powder) made of an intimate mixture of 75% potassium nitrate, 15% charcoal and 10% sulphur. This is often referred to as “lift powder” or simply as “lift”.

❷ *Generally, finer granulations are used for smaller fireworks aerial shells and coarser granulations are used for larger aerial shells. Also, spherical shells tend to use finer granulations compared to the same size cylindrical shells.*

Grade	Appearance	Typical Use
2FA		Cylindrical shells 3-inch and larger
4FA		Cylindrical <3” Spherical ≥ 3”
5FA		Spherical shells smaller than 3-inches

Some Black Powder granulations commonly used are:

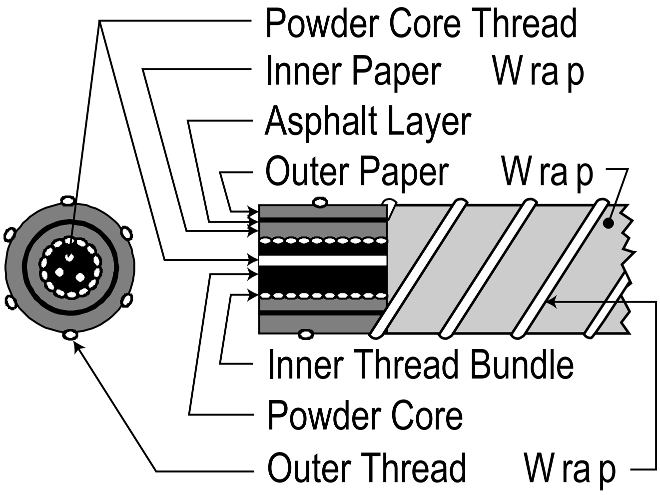
	US	Smaller Than		US	Larger Than	
Grade	Mesh	inch	mm	Mesh	inch	mm
2FA	4	0.19	4.8	12	0.066	1.7
3FA	10	0.079	2.0	16	0.047	1.2
4FA	12	0.066	1.7	20	0.033	0.85
5FA	20	0.033	0.85	50	0.012	0.30
7FA	40	0.016	0.42	100	0.006	0.15
Meal D	40	0.016	0.42	No Limit on fineness		
Meal XF	140	0.004	0.11	No Limit on fineness		
Cannon	6	0.13	3.4	12	0.066	1.7
Fg	12	0.066	1.7	16	0.047	1.2
2Fg	16	0.047	1.2	30	0.023	0.60
3Fg	20	0.033	0.85	50	0.012	0.30
4Fg	40	0.016	0.42	100	0.006	0.15

At least 85% of the powder will fall between the two particle size limits.

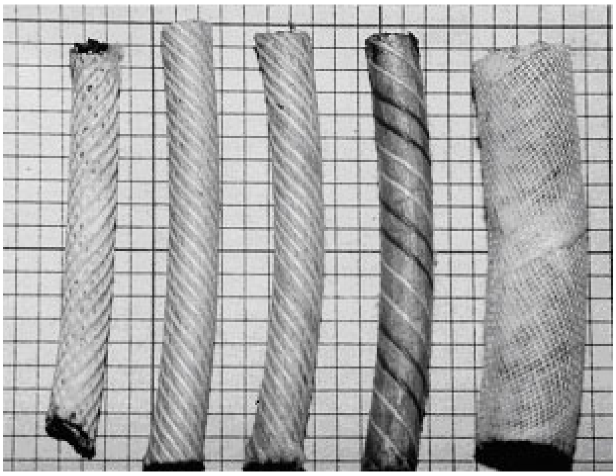
Black Powder is often coated with graphite, in part for improved moisture resistance, but mostly to make it free flowing and less dusty.

TIME DELAY FUSE

❷ *Fireworks time delay fuse is an internally burning fuse, generally about 1/4 inch (6 mm) in diameter. It has an ample powder core and burns about 1/3 inch/sec (8 mm/s). Time delay fuse is somewhat water resistant.*

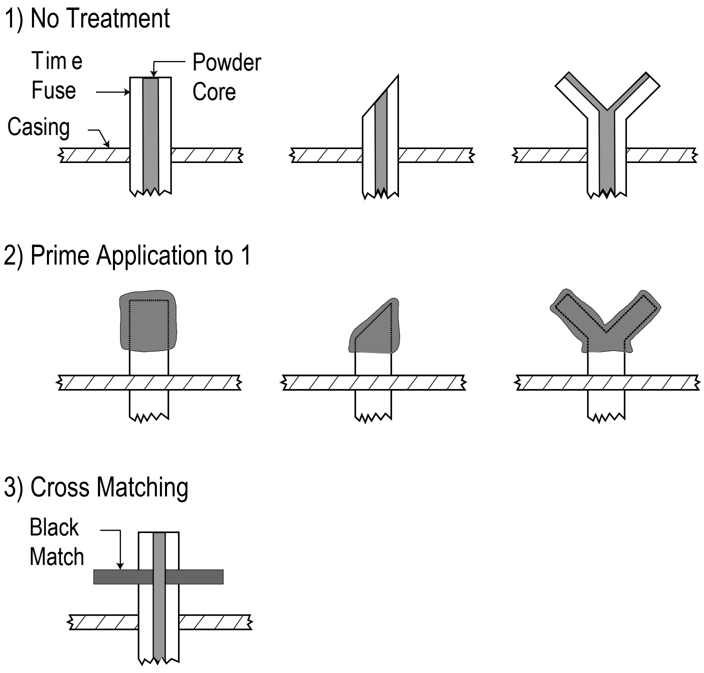


Examples of various types of fireworks time delay fuses. [0.1 inch (2.5 mm) per division]



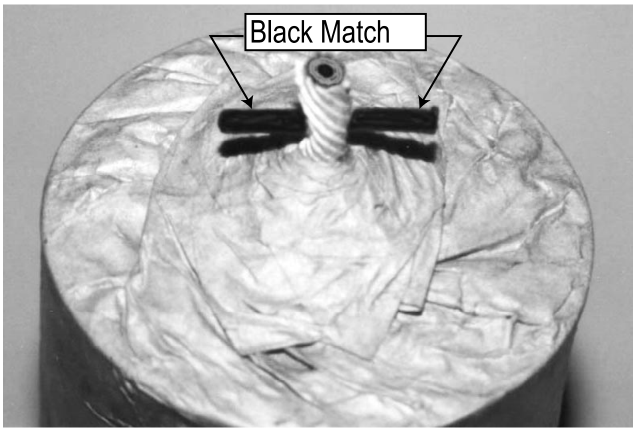
TIME DELAY FUSE IGNITION

❷ *To increase the probability of time delay fuse ignition as an aerial shell fires from its mortar, some method of "priming" is generally used. The outer end of the cut fuse (as in 1) may be coated with prime (as in 2), or a piece of black match may be inserted into a hole punched through the time delay fuse (as in 3).*

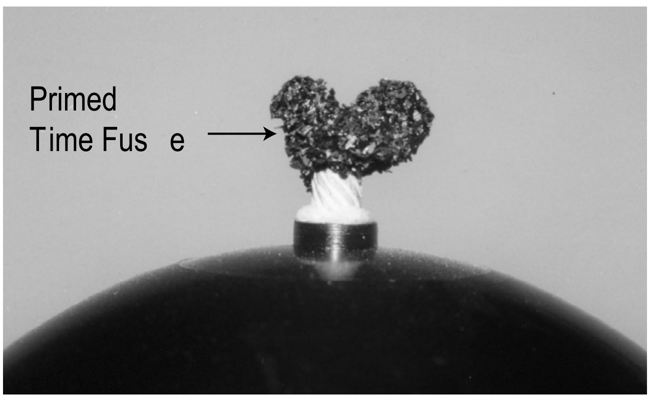


PRIMING TECHNIQUES

❷ *In "cross matching", a small hole is punched through the time delay fuse and a piece of black match is inserted.*



An example of a time delay fuse that has been coated with prime composition (fine Black Powder mixed with a binder) that was then dipped into granulated Black Powder to further increase the likelihood of ignition.



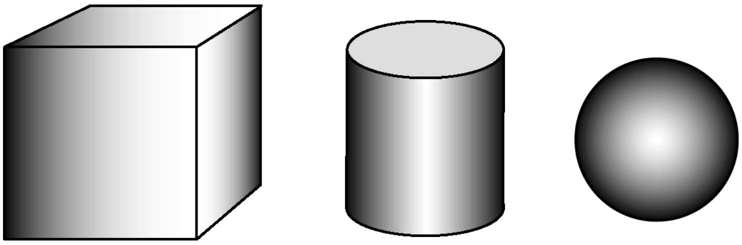
FIREWORKS STARS

❷ *Fireworks stars are pellets of pyrotechnic composition that burn to produce the visual display in the sky. Depending on the method of manufacture, the pellets may be spherical, cylindrical or cubic. They can produce coloured light, a trail of sparks, or both.*

The size and chemical composition of stars determines how long the stars will burn.

STAR SHAPES

❷ *Fireworks stars are made in a variety of shapes. Cut stars are manually produced using a technique much like dicing in cooking. Cut stars are most often approximately cubic in shape.*

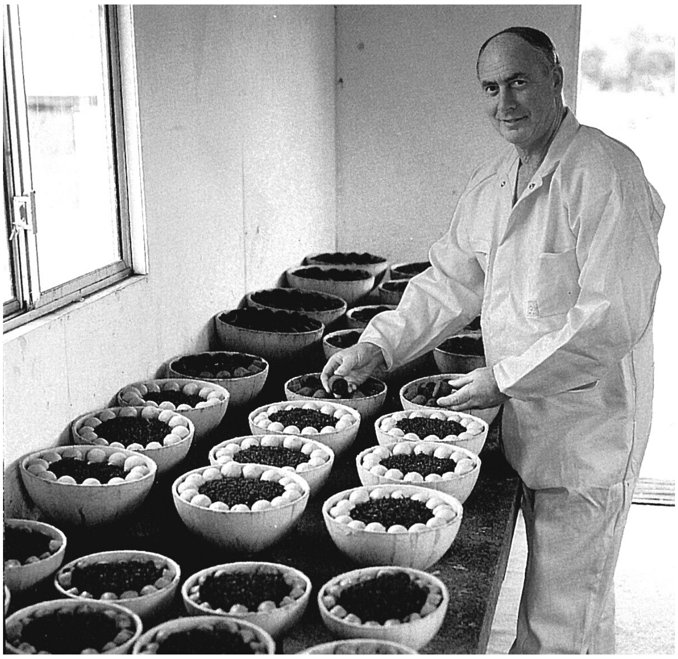


Pressed stars may be produced manually or mechanically where the star composition is compacted into a cylindrical form to produce a cylindrically shaped star.

Rolled stars are made in a rotating drum in which successive layers of star composition are built up (something like the layers of an onion). Rolled stars are nearly spherical in shape.

Stars are almost always coated with a Black Powder prime to help insure their ignition.

[Photos courtesy of Howard and Son]



SHELL INSERTS (COMPONENTS)

In addition to (or in place of) stars, aerial shells may contain shell inserts.

- Shell inserts are individual small firework devices such as:
- Small salutes (also called shots, reports or crackers).
- Small aerial shells.
- Whistles.
- Saxons (small spinning fireworks producing a trail of sparks).
- Hummers (small spinning fireworks producing a humming sound and possibly a trail of sparks).

Aerial shells containing inserts are commonly called “component shells” and the inserts may be called “components”.

SHELL BURSTING CHARGE

The explosive charge that bursts an aerial shell is referred to as the “bursting charge” or “break charge”. Most often, it is made by coating a pyrotechnic composition on rice husks (then called “rice husk powder”). The coating can simply be handmade Black Powder but may be a more energetic composition made using potassium chlorate or potassium perchlorate and charcoal. In cylindrical aerial shells, the break charge can be commercial or handmade granular Black Powder.

Example of rice husk powder. [0.1 inch (2.5 mm) per division]

The break charge may be placed in the centre of a pattern of stars or may simply be mixed in randomly with the stars.

SPHERICAL AERIAL SHELL

This is a cut-away model of a spherical aerial shell. The model demonstrates the typical appearance and placement of the components of a spherical aerial shell.

EXAMPLES OF AERIAL SHELL LABELS

The following illustrates typical shell labels

OTHER SHELL TYPES

See later for other types of Shells

- Peanut
- Multibreak cylinder
- Repeater
- Aquatic
- Tailed shell
- Shells with appendages

SECTION 3 - AERIAL SHELL MALFUNCTIONS, THEIR CAUSES AND SAFETY CONSIDERATIONS:

Aerial shell ignition problems:

- “Premature ignition”
- Delayed ignition – “Hangfire”
- Ignition failure – “Misfire”

Aerial shell functioning problems:

- Explosion within the mortar
- Mild explosion – “Flowerpot”
- Powerful explosion – “Shell Detonation”
- Explosion just above the mortar – “Muzzle Break”
- Delayed explosion – “Low or Ground Break”
- Failure to explode – “Dud Shell” or “Blind Shell” or “Black Shell”
- Burning debris reaches ground
- Shell components fall to ground unignited

Measures to protect the public and the crew from malfunctions

Aerial shell inspection items

PROPER FUNCTIONING VS MALFUNCTIONS

See the flow chart below for the aerial shell firing sequence, showing proper functioning (centre shaded column) and possible malfunctions (unshaded columns to either side).

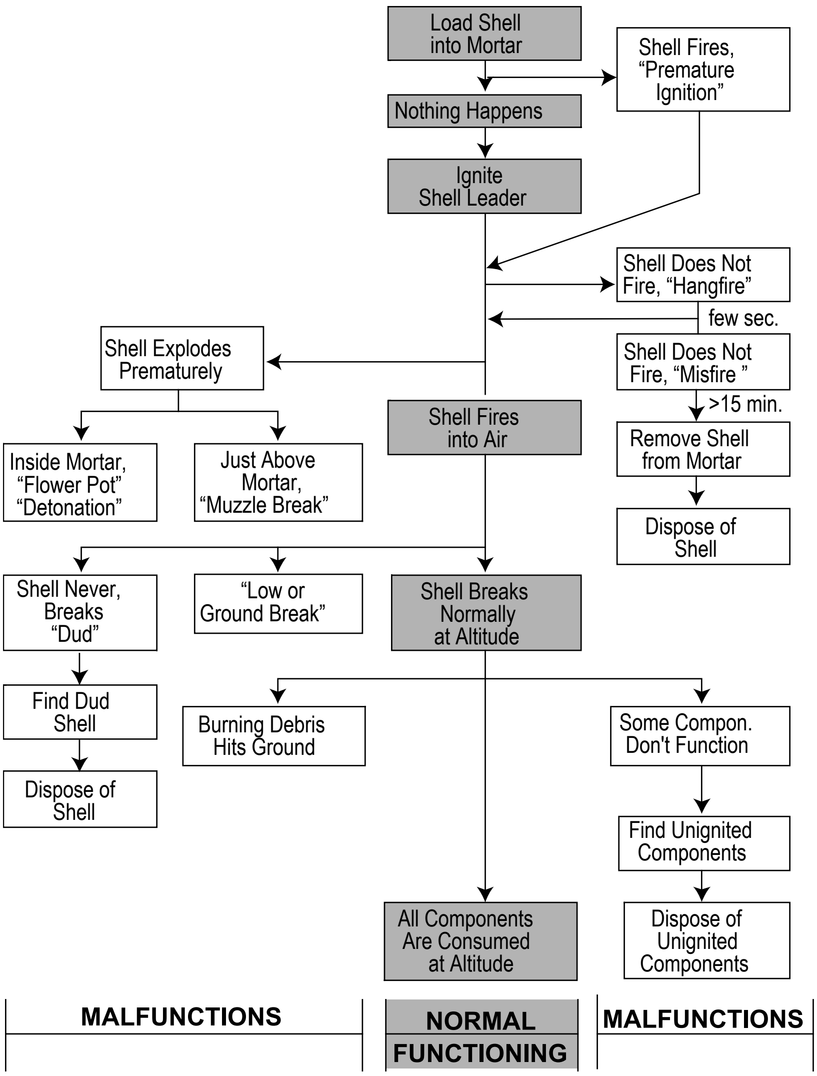
For these notes, a malfunction is defined as hazardous performance, other than intended.

Some malfunctions can be caused by mishandling the aerial shells, and some existing problems can be identified by careful inspection at the display site.

Format for malfunction discussions:

- ♦ Description (definition) of the particular malfunction — for the purpose of discussion.
- ♦ "Cause" of the malfunction — primary cause(s), emphasizing those things under the control of the display operator or that can possibly be detected by inspection by the display crew.
- ♦ "Prevention" of the malfunction — emphasizing those actions that can be taken by the display crew, rather than by the manufacturer.
- ♦ "If it happens" — what can be done to help minimize the consequences in the event of this malfunction.

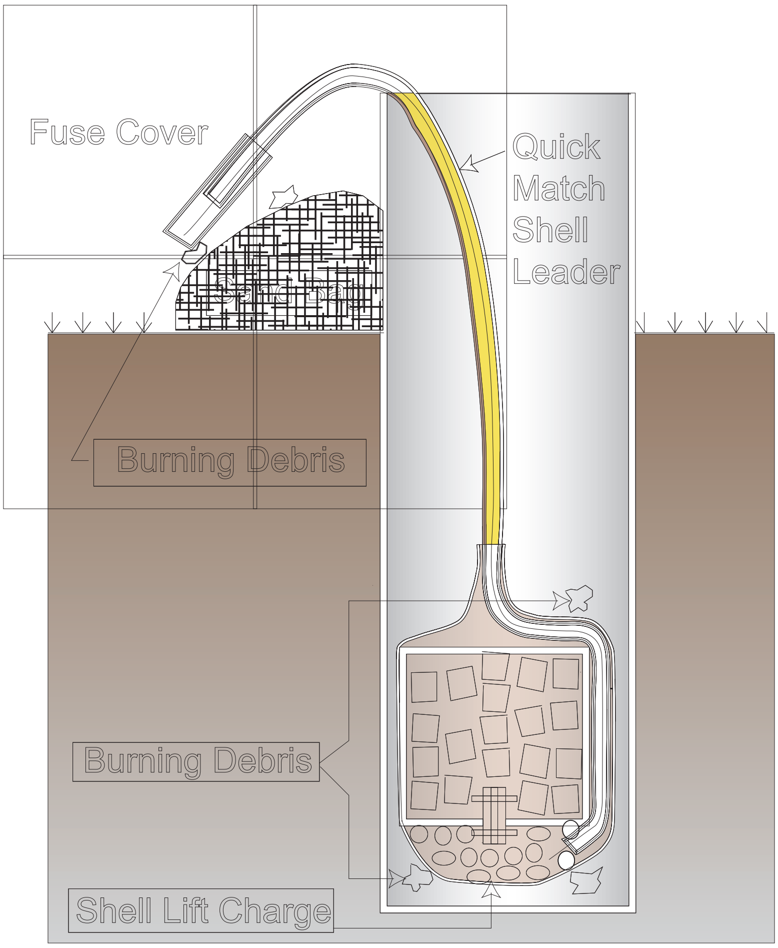
AERIAL SHELL FAILURE FLOWCHART FOR MANUAL FIRING



•

PREMATURE IGNITION

Premature Ignition. An aerial shell fires from mortar before it is intentionally ignited.



❷

- *Cause: Burning debris in the mortar or on the ground near the shell leader, or sparks otherwise contacting exposed pyrotechnic composition.*
- *Prevention: Eliminate burning debris and any exposed pyrotechnic composition.*
- *If it happens: NEVER have any body parts over a loaded mortar ! ! !*

HANGFIRE

Hangfire. An unusually long delay (more than a few seconds) between lighting the shell leader and the aerial shell firing from the mortar.

❷

- *Cause: Shell leader (fuse) damaged or damp.*
- *Prevention: Careful inspection of aerial shells (especially the fuse) before the display and protection of the shells from moisture may reduce the probability.*
- *If it happens: Wait several seconds before approaching to properly mark the mortar; be aware that the aerial shell may fire at any time. Also verbally warn the crew not to reload the mortar.*

MISFIRE

Misfire. The shell leader is ignited, but the aerial shell never fires from the mortar.

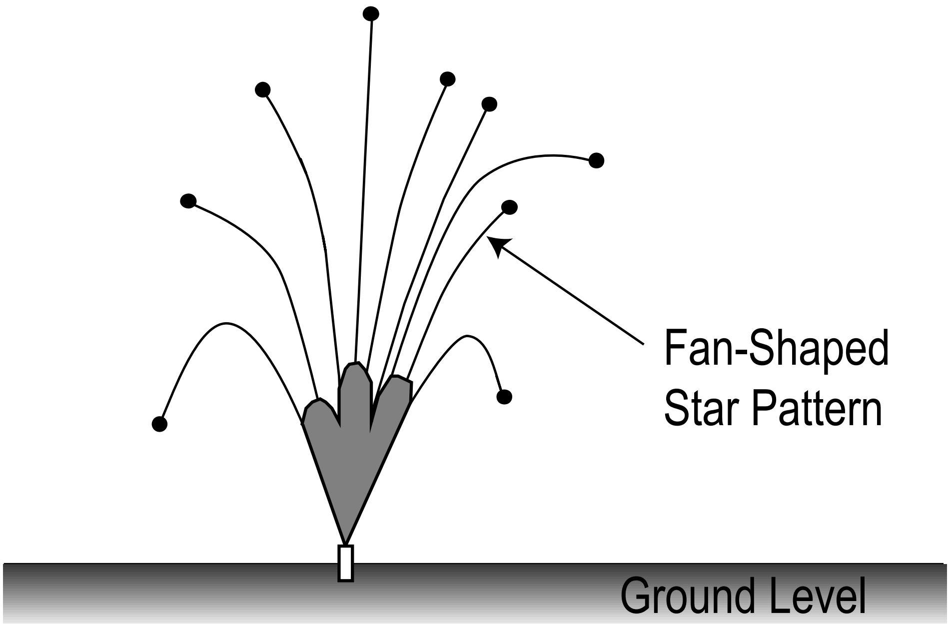
❷

- *Cause: Shell leader (fuse) damaged or damp.*
- *Prevention: Careful inspection of aerial shells (especially the fuse) before the display and protection of the shells from moisture may reduce the probability.*
- *If it happens: Wait several seconds before approaching to properly mark the mortar; be aware that the aerial shell may fire at any time. Also verbally warn the crew not to reload the mortar. After the display, clear the shell from the mortar. (Discussed in Post-Display Procedures)*

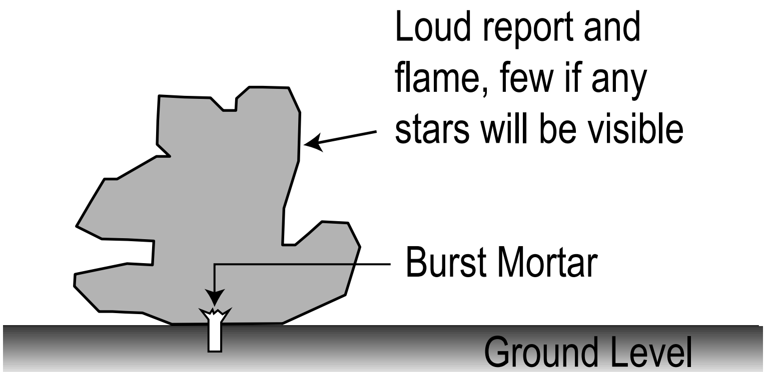
SHELL FLOWERPOT

Flowerpot. An aerial shell explodes inside the mortar, which usually remains intact.

❷ *Appearance:*



- *Cause: A major fire leak into the aerial shell. Possibly because of a substantial failure of the shell casing or upside down.*
- *Prevention: In extreme cases, inspection may reveal damage to the shell casing.*
- *If it happens: Protect aerial shells in suitable containers and shells being loaded from sparks and burning debris (thus avoiding larger problems), wear proper clothing and personal protection equipment.*



➋ *Note that some muzzle breaks may present much the same visual appearance as a mine.*

SHELL "DETONATION"

Shell "Detonation". An aerial star shell explodes violently while still inside the mortar, which is often destroyed. [Note, this is almost certainly not a true high explosive detonation, but all or most of the shell's contents are consumed almost instantly.]

➋

- *Cause: A major fire leak into a star shell. Possibly because of a substantial failure in the shell casing or upside down. (Why does this not result in just being a flowerpot? This is not well established; perhaps the stars are unusually pressure sensitive.)*
- *Prevention: In extreme cases, aerial shell inspection may reveal damage to the shell casing.*
- *If it happens: There is no time to react. Have well buried or barricaded mortars, have personnel in a "protective position" (crouched down and facing away from the mortar) and have personal protection equipment being worn. Inspect for damage to other equipment and fireworks before continuing.*

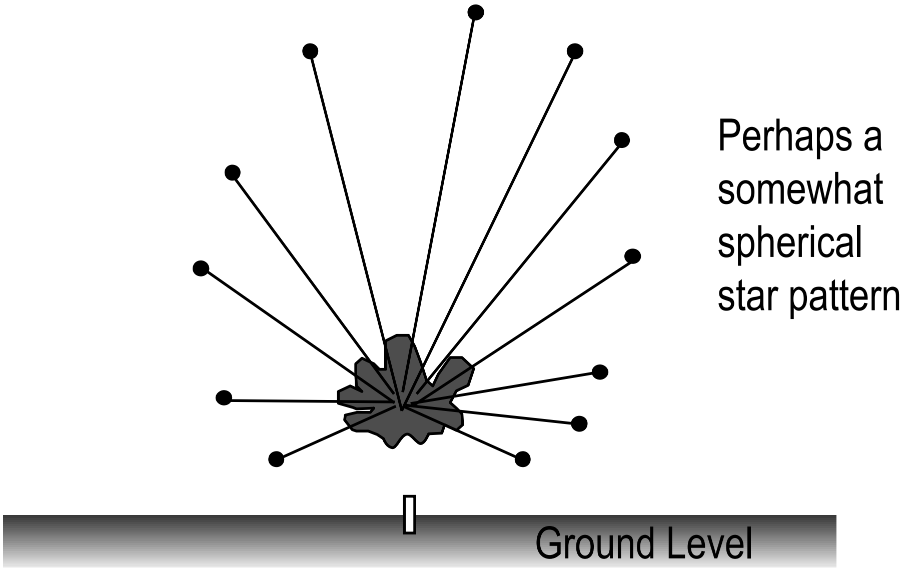
SHELL "DETONATION" EXAMPLES

A large hole blown in the ground and mortars are displaced because of a shell "detonation".

Large steel mortar shredded by a shell "detonation".

MUZZLE BREAK

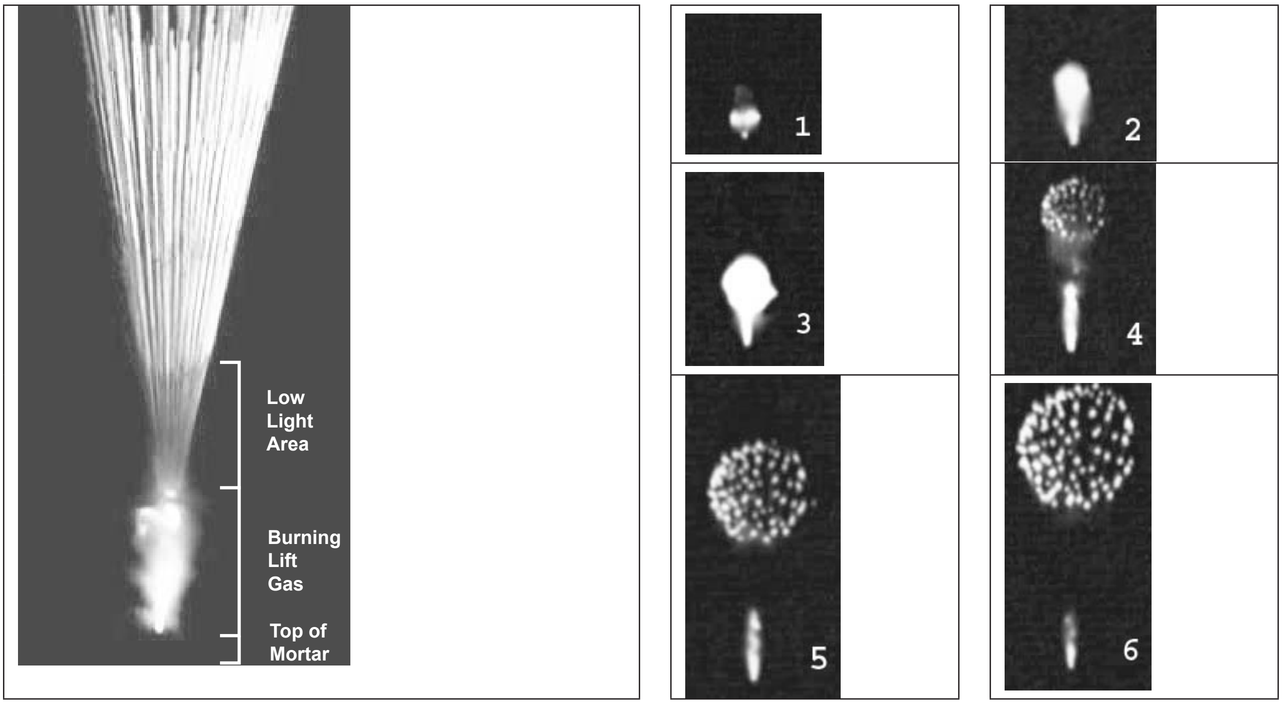
Muzzle Break. An aerial shell explodes just after leaving the mortar.



❷

- *Cause: A relatively minor fire leak into the aerial shell or an internal ignition due to friction because of the movement of stars inside the shell. This seems to be more common with shells larger than 6 inch (150 mm).*
- *Prevention: None known. The point where the minor fire leak most likely occurs is around the time delay fuses.*
- *If it happens: There is no time to react. Have any unloaded fireworks well protected, have personnel in a "protective position" (crouched down and facing away from the mortar) and wear personal protection equipment.*

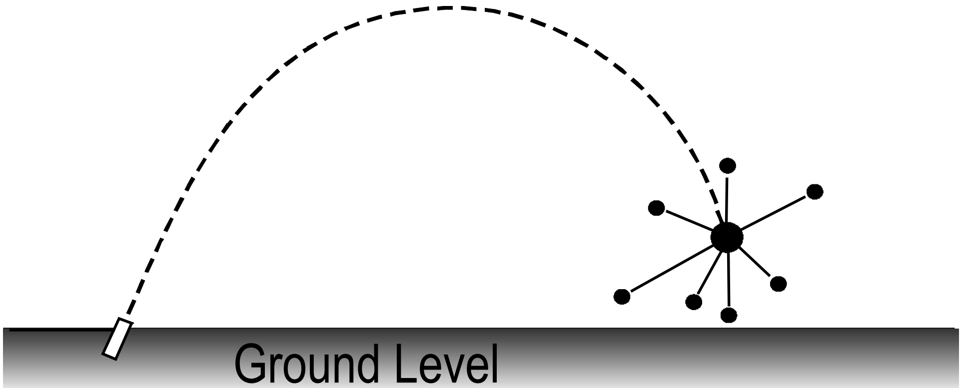
When a muzzle breaking shell is travelling upward at a high speed, compared with the radial spread of the stars, it creates the visual appearance of a flower pot.



❷ *Two views of the same event. Left, as it would be "seen" by an observer. Right, a rapid series of images taken with a fast shutter speed. The aerial shell burst can be seen to occur in the third photo; then the stars form a normal spherical pattern.*

LOW (OR GROUND) BREAK

Low or Ground Break. The aerial shell fires normally, but bursts near or on the ground.

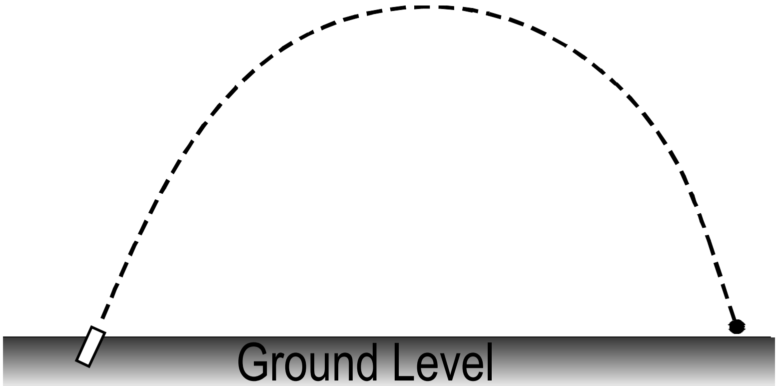


❷

- *Causes: The shell was fired from an over-sized mortar, or the Lift powder was lost or was quite damp, or a mortar with a leaking or blown-out plug was used, or the shell was not fully lowered into the mortar.*
- *Prevention: Take care in loading aerial shells in or if reloading. Inspect aerial shell for leaking lift powder and signs of dampness. Inspect mortar for a solidly attached plug, and clean mortar (but only when necessary).*
- *If it happens: When possible, have mortars angled away from the crew and spectators, use a display site that is sufficiently large, have no combustibles in the fallout area, and keep unfired fireworks protected from sparks and burning debris.*

DUD SHELL (BLIND)

Dud. The aerial shell fires normally, but never bursts and falls to ground as a "live" (unexploded) shell.



❷

- *Cause: Damp time fuse, damaged time delay fuse or insufficient prime on fuse.*
- *Prevention: Careful aerial shell inspection may indicate current dampness or past water damage.*
- *If it happens: When possible, have mortars angled away from the crew and spectators, use a display site that is sufficiently large. Locate and remove the dud shell after the display, and properly dispose of the dud shell.*

Note that dud shells (especially large calibre aerial shells) may ignite when they impact the ground. However, they will generally have been sufficiently damaged by the impact that they will mostly produce a fire ball effect, rather than a powerful explosion that disperses the stars to a great distance.

BURNING FALLOUT

The aerial shell breaks at altitude, but some burning materials fall to the ground.

❷

- *Cause: Stars or components are damp or over-size; non-pyrotechnic materials in the aerial shell are ignited when the shell bursts.*
- *Prevention: Careful aerial shell inspection for current dampness or past water damage may reveal a problem.*
- *If it happens: When possible, have mortars angled away from the crew and spectators, use a display site that is sufficiently large, have no combustibles in the fallout area.*

DUD COMPONENTS

Some shell components fail to ignite or burn and fall to the ground as "live" items.

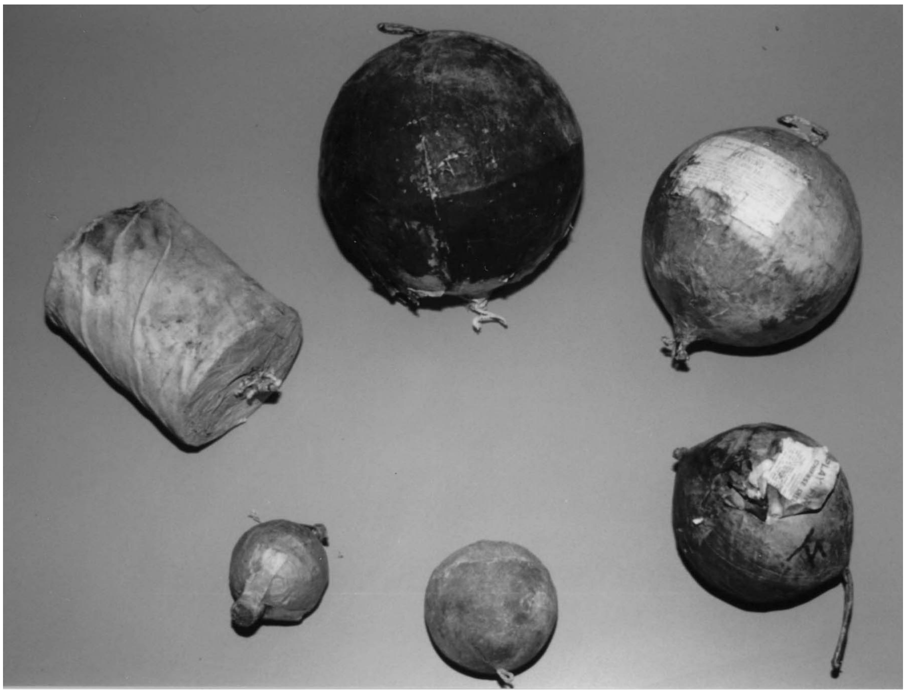
❷

- *Cause: Stars or components are damp, are poorly primed, or the aerial shell break is too powerful for the stars or components to remain ignited.*
- *Prevention: Careful aerial shell inspection for dampness or water damage may reveal a problem.*

- *If it happens: When possible, have mortars angled away from the crew and spectators, use a display site that is sufficiently large. Retrieve unignited components after the display and properly dispose of them.*

DUD SHELL AND COMPONENT EXAMPLES

Dud aerial shells:



Dud components and unburned stars:

MEASURES TO PROTECT THE PUBLIC AND CREW IN CASE OF AERIAL SHELL MALFUNCTIONS

Prioritised list:

- PROVIDE ADEQUATE SPECTATOR SEPARATION DISTANCE (during the display).
- LOCATE AND REMOVE DUDS (after the display).
- Inspect the aerial shells at the display site well before the display. (See next several pages.)
- Provide the crew with proper training and personal protective equipment.
- Use mortar racks, that will not be disrupted by a malfunction.
- Use proper mortar burial and/or barricading as applicable.
- Maintain crowd control (generally not responsibility of the display crew).
- Protect fireworks from adverse weather and sparks.

Taking the first two steps will eliminate the vast majority of injuries to the public.

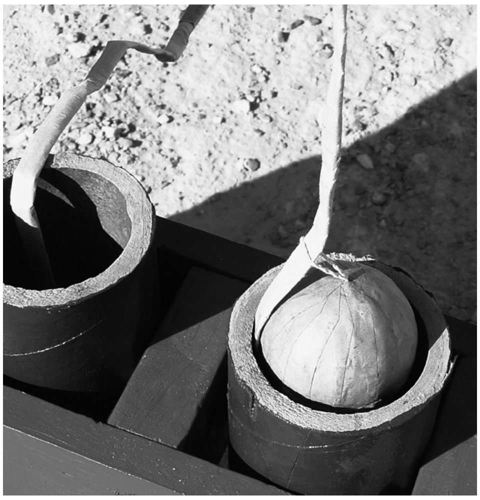
Over the past 25 years there have been great improvements in the performance of aerial fireworks. However, the display crew must never assume that malfunctions will not occur.

AERIAL SHELL INSPECTION

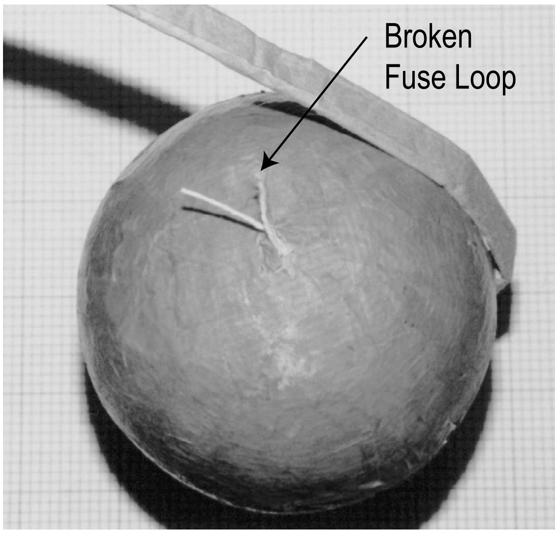
No leaking lifting charge. (Loose powder in a box of aerial shells may indicate that a shell(s) is losing its lift powder.)

Feel for the presence of lift powder on all shells.

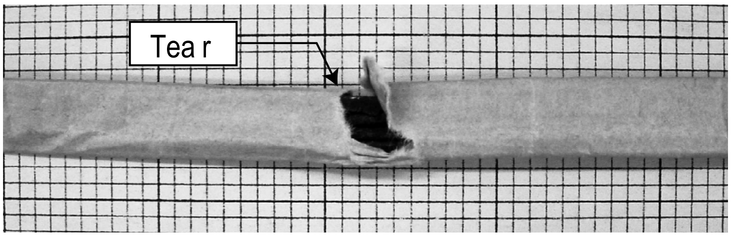
The proper fit of shells in mortars (close but freely sliding).



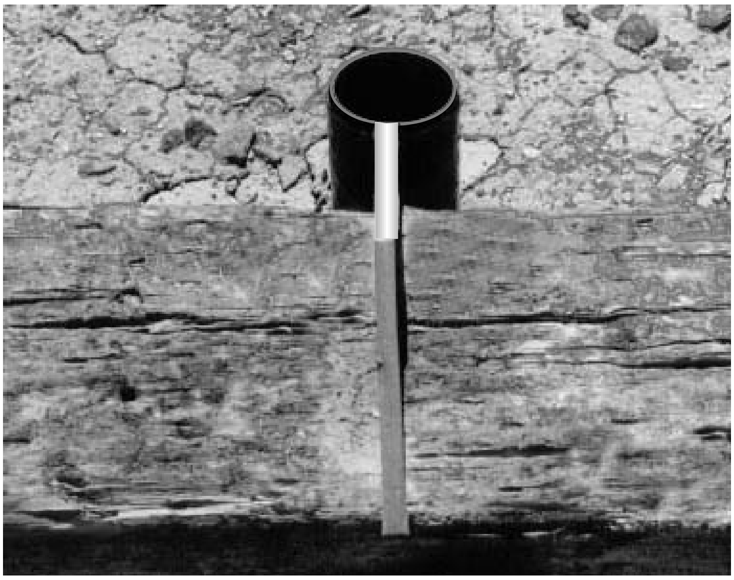
Leader fuse must be secured to the top of the shell. The shell below needs to be repaired.



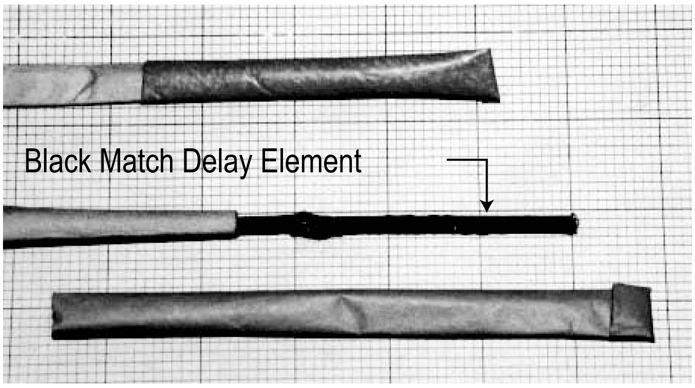
No tears or other damage in shell leader (fuse). The leader should be repaired. [0.1 inch (2.5 mm per division]



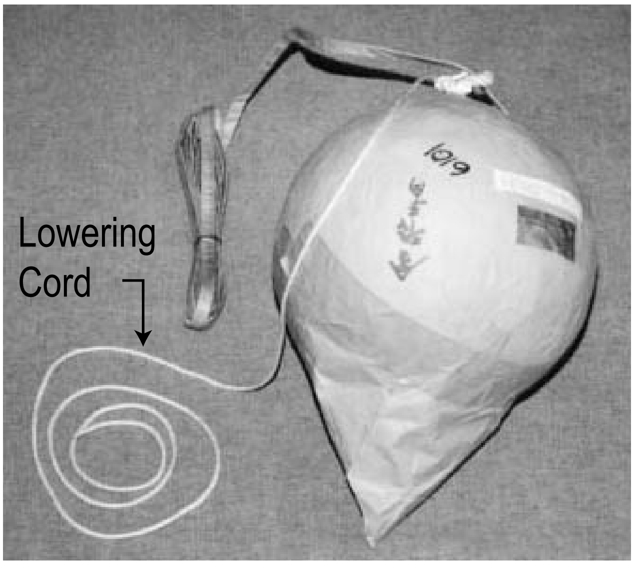
Leader is long enough (mortar length + approx. 6 inches).



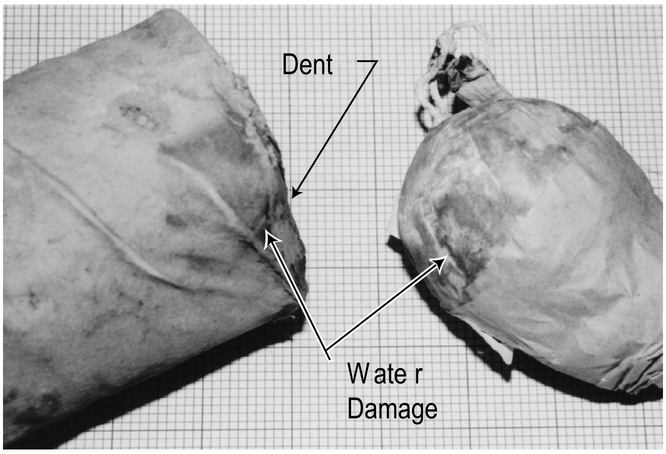
The black match delay element is long enough (usually 3 to 4 inches or 75 to 100 mm), and the fuse cover is present and in place. [0.1 inch (2.5 mm per division]



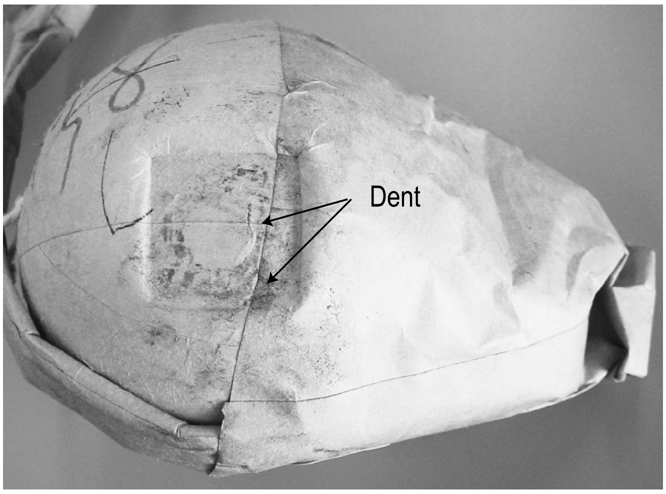
A strong lowering cord is present on large aerial shells above 8”.



No evidence of water damage or of aerial shell having been wet. [0.1 inch (2.5 mm per division)]



No dented, broken or cracked aerial shell casings.



SECTION 4 - ALTERNATE FIREWORKS AERIAL SHELL COMPONENTS AND CONSTRUCTION:

❷ *Please note that this chapter is all level 2*

Aerial shell fusing:

- Top vs. bottom fusing
- Redundant fuses
- Spolette fuses

Aerial shell types:

- Multi-break shells
- Component shells
- Salutes / Reports / Maroons

Spherical aerial shell star and burst charge configurations

Cylindrical aerial shell burst configurations

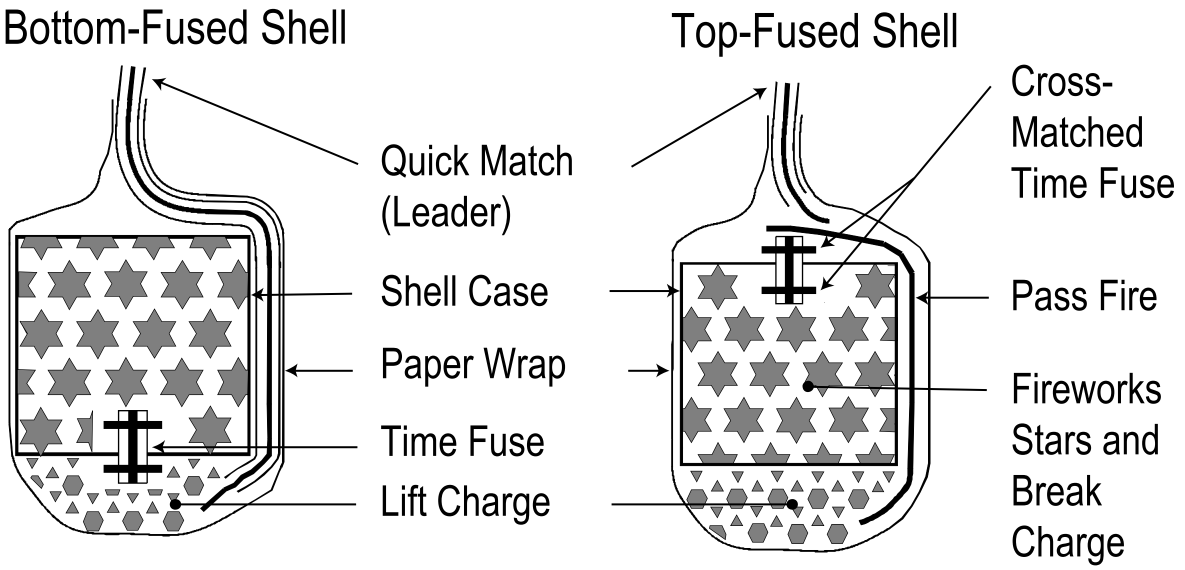
Star types:

- Colour change stars
- Comet and strobe stars

Electric igniters and connectors

TOP-FUSED AERIAL SHELLS

❷ *Top-fused aerial shells have their time delay fuse installed on top of the shell (as oriented when in the mortar). A "passfire" fuse is used to carry fire down to the lift charge. The passfire fuse may be quick match or a strand of black match, which burns like quick match because of fire paths along side it.*

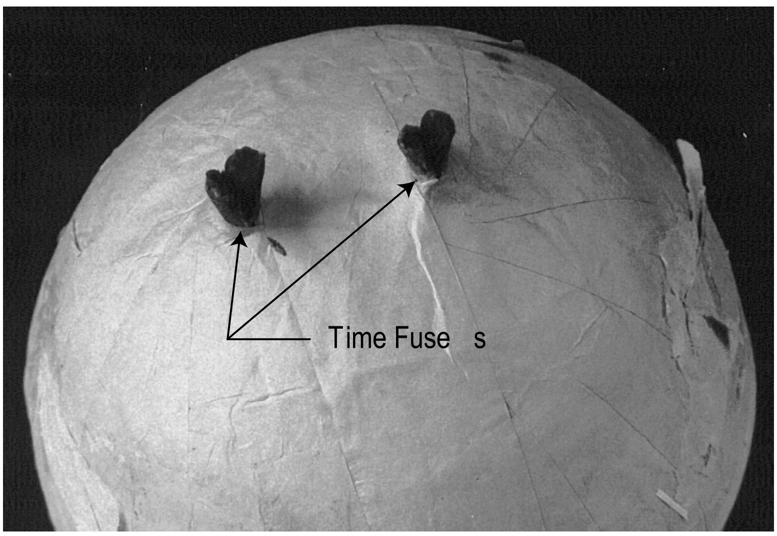


Top-fused aerial shells are less likely to experience fire leaks around the time delay fuse. Top fusing is most often used on cylindrical shells that are large or multi-break. With top-fused aerial shells, there is the possibility of the time delay fuse igniting but not the lift charge. This will cause the shell to explode at the bottom of the mortar after a few seconds delay.

REDUNDANT TIME FUSES

❷ *The time delay fuse on an aerial shell occasionally fails to initially ignite, fails to burn continuously through its length, or fails to successfully transfer fire to the contents of the shell. When that happens on an aerial shell with a single time fuse, the shell will fail to explode and will fall to the ground as a dud (or possibly ignite on impact).*

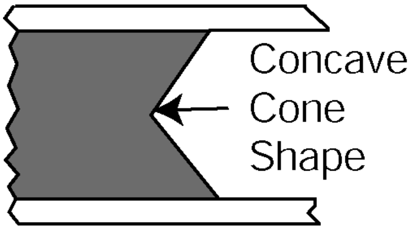
Time fuses are generally cross-matched or primed to reduce the chance of their ignition failure. It has become common to use a second (or even third) time delay fuse on aerial shells, to greatly reduce the number of time delay fuse failures (duds) that occur.



SPOLETTE FUSES

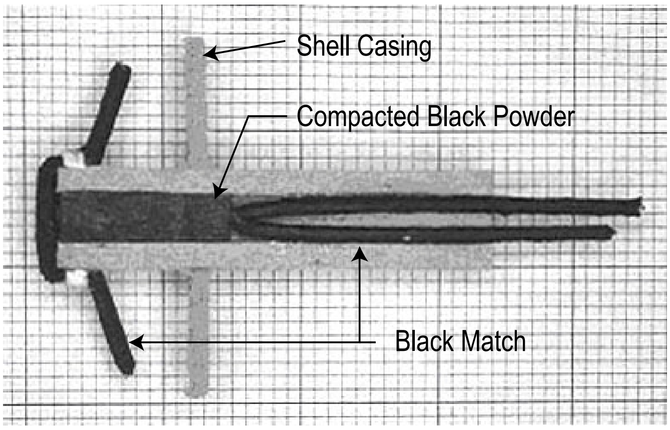
❷ *A spolette is a handmade fuse in which commercial Black Powder or handmade rough powder is tightly compacted in a strong tube with a relatively small internal diameter, typically about 3/8 inch (9 mm).*

Spolettes are preferred when the burn time must be short (such as for multi-break shells) or when precise timing is needed. When spolettes are properly made, they are highly reliable. When they have black match across one end and multiple pieces inserted in the open end of the tube, their ignition and the internal ignition of the aerial shell is nearly assured (especially if the inside end of the powder column has a concave cone shape).

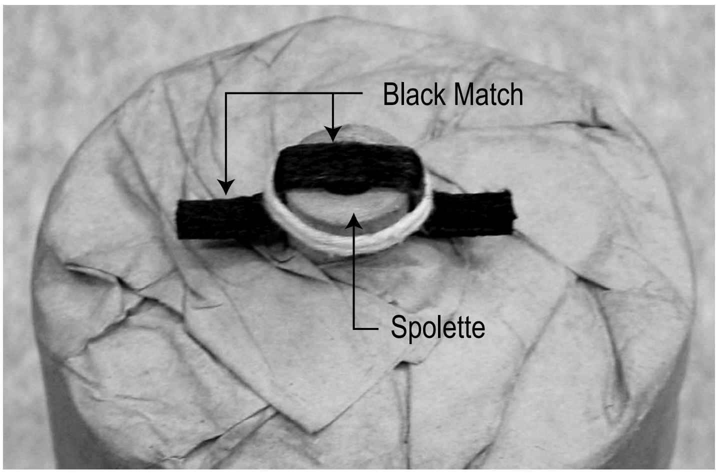


Spolettes are almost always used in a top-fused configuration, and usually only on large calibre and multi-break cylindrical aerial shells. Spolettes may also be called "Roman Fuses" or "Rammed Fuses".

Cut away view of a spolette. [0.1 inch (2.5 mm per division]

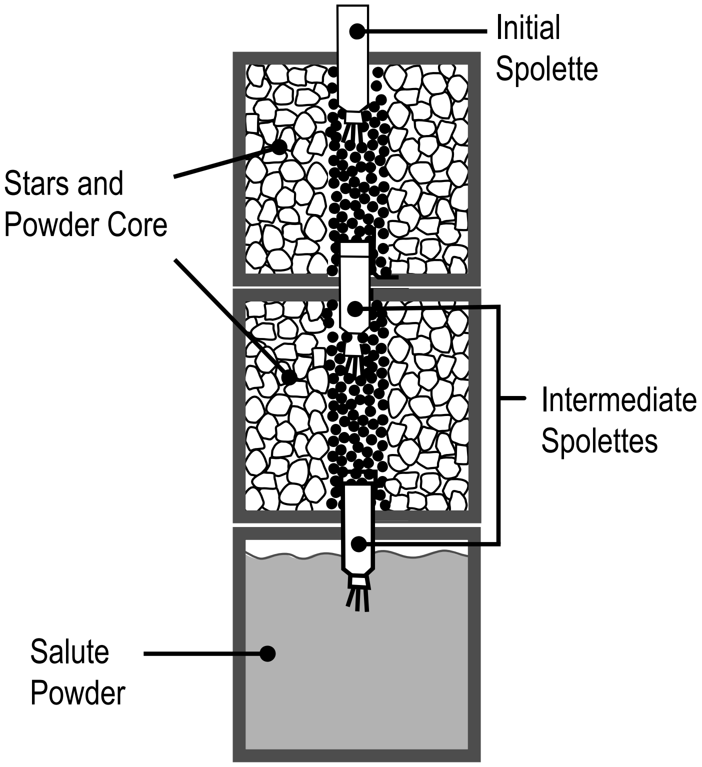


A spolette shown in a top-fused configuration.



MULTI-BREAK SHELLS

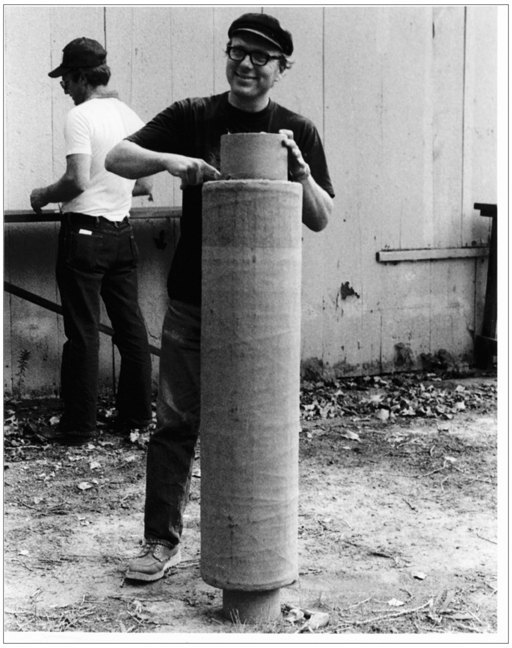
❷ *In essence, a multi-break shell is a stacked collection of individual shells, typically with each break igniting the delay element for the next break.*



With multi-break shells, all the possible aerial shell malfunctions are either more likely to occur or the consequences are more serious if a malfunction does occur, for example:

- ♦ *They generally contain a greater quantity of pyrotechnic material than single-break shells.*
- ♦ *There is a chance that one or more of the breaks will explode close to the ground or will fall to the ground as a dud.*

Multi-break shells can range to very large sizes.



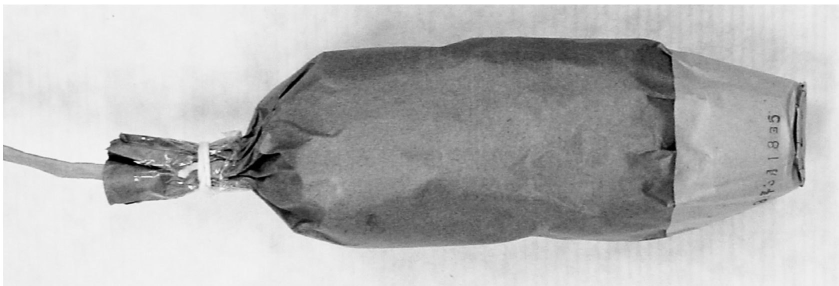
This is a photo of a 12-inch (300-mm), 3-break shell.

The firing of multi-break shells often requires the use of special mortars (ones with extra strength and length).

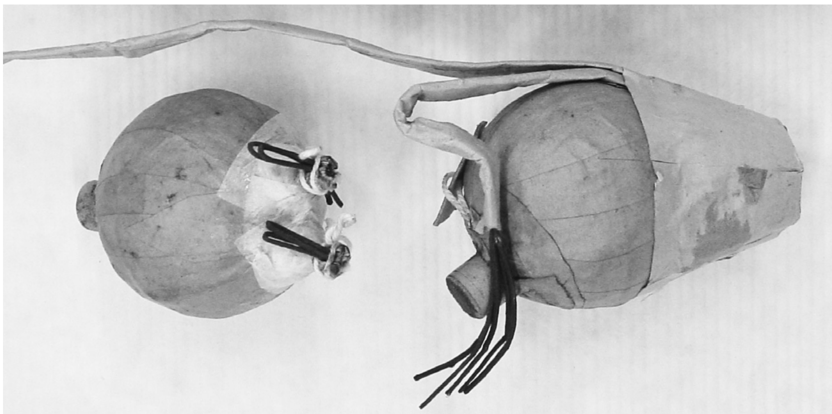
Recently spherical, multi-break shells have begun to be used. These aerial shells are sometimes called "Peanut" or "Double-Bubble" shells. They are two single-break aerial shells simply connected by a support ring between them.

The time fuses for both aerial shells are typically ignited at the same time, and they burn independently.
An example of the construction of a "peanut" spherical shell

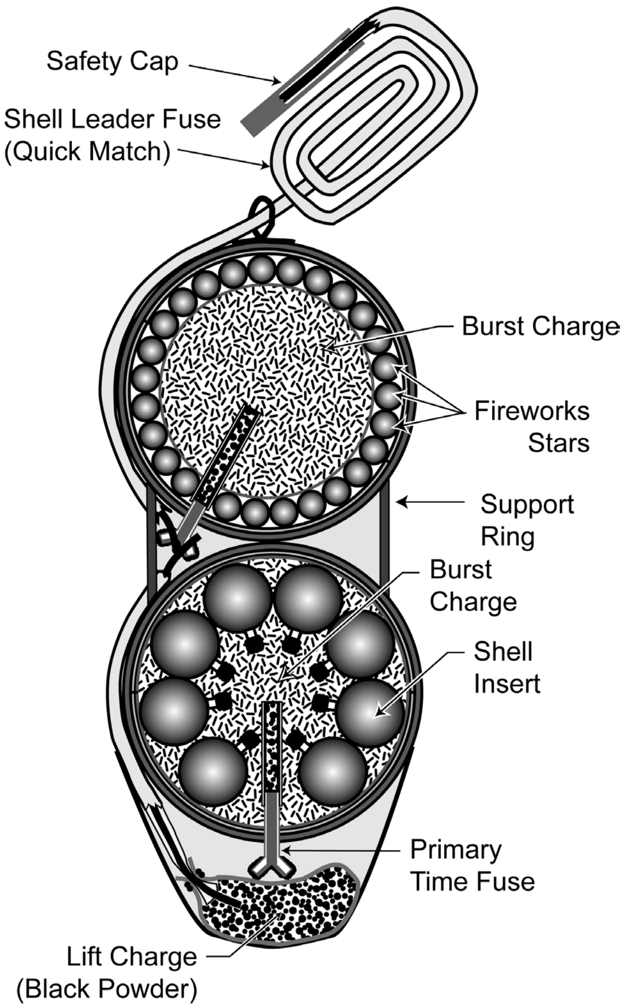
A 3-inch, 2-break spherical aerial shell.

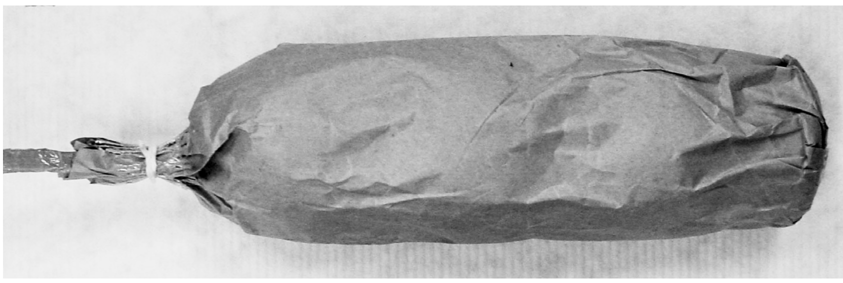


Note: This is actually just 2 aerial shells in the same outer wrapping, without a support collar between the two shells, and there is no solid connection of the fusing to the upper shell.

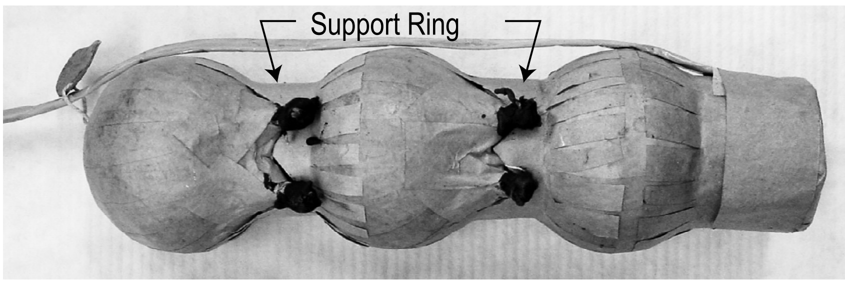


A 3-inch, 2-break spherical aerial shell.

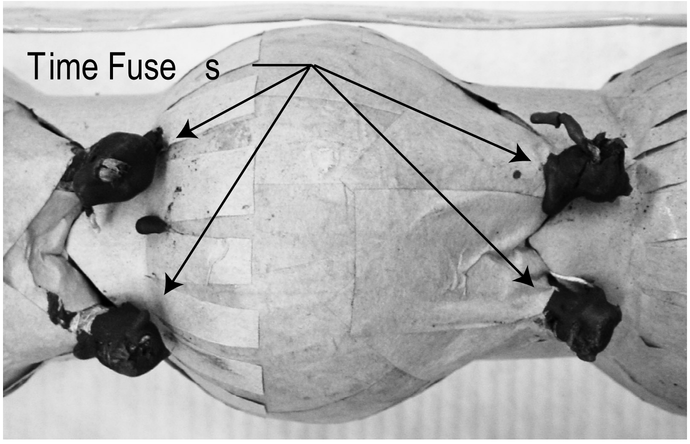




Note the use of support rings between the aerial shells in this triple peanut shell.

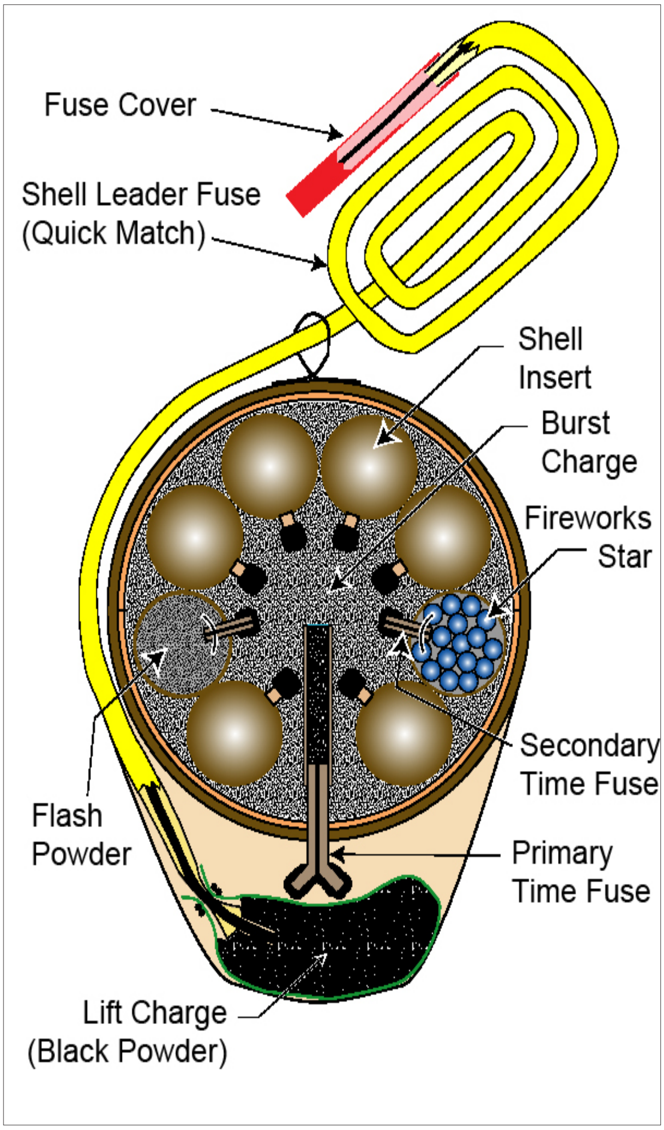


Note that only the escaping fire from the lift gas accomplishes the ignition of the top two aerial shells.



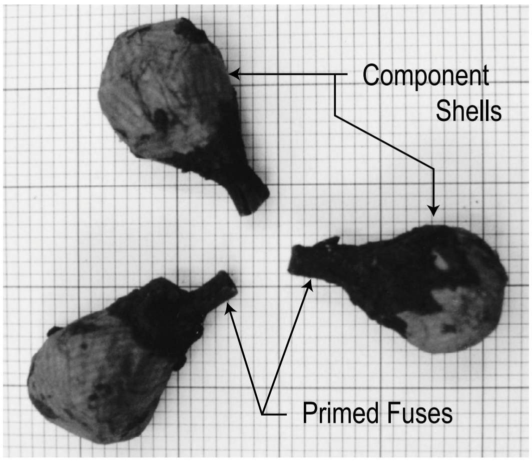
COMPONENT SHELLS

❷ *Component shells have multiple internally-fused devices or aerial shells that are ignited as the outer shell burst is burning. (Component shells may contain stars in addition to components.) The shells and their components may be cylindrical or spherical in shape.)*



If all the components contained in the shell are shells themselves, the shell will be called a "shell of shells".

The components in aerial shells can have a wide variety of appearances. Often they are cylindrical, but roundish shapes are also common, particularly when the components are used in spherical shells. [0.1 inch (2.5 mm per division]

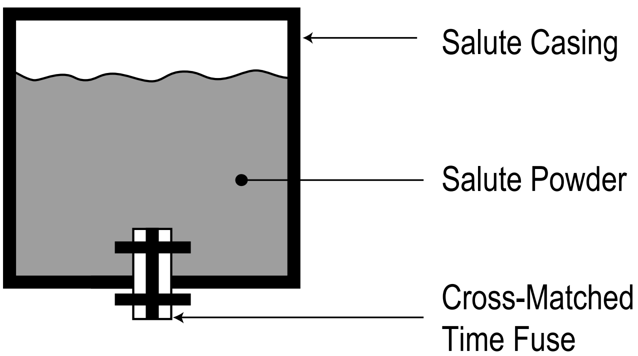


Dud components may be small, but can be powerful enough to cause serious injuries if found and ignited. It is important that dud components be located and disposed of after a display. It will often be difficult to determine whether the components have functioned. Often it is necessary to inspect them carefully.

Shell components may also called "inserts".

SALUTES (ALSO REPORTS OR MAROONS)

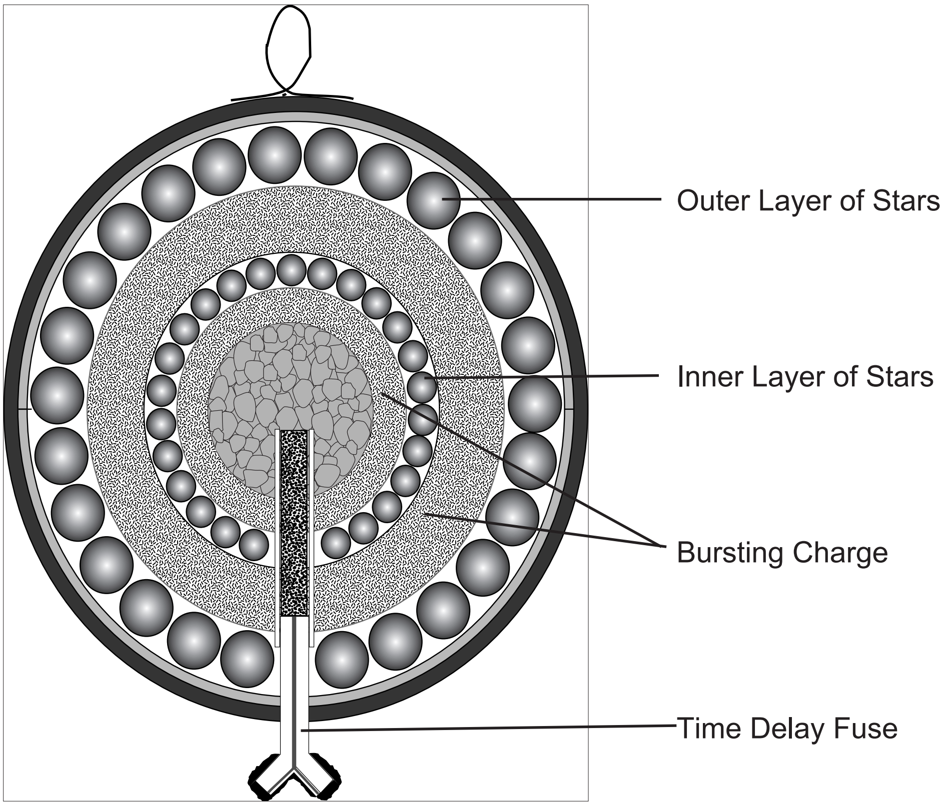
➋ *Salutes contain salute powder and produce a loud report when they explode. The salute powder will generally be a flash powder, in which case a bright flash of light is also produced. Salute powder may contain granular titanium to produce an added white spark effect.*



STAR AND BURSTING CHARGE CONFIGURATIONS

❷ *When fireworks stars and the breaking charge are randomly mixed inside an aerial shell, a random pattern of stars will be formed when the shell bursts. When the fireworks stars are carefully positioned around a central bursting charge, the pattern of stars produced when the shell bursts will be similar to that of the stars inside the shell. The most common pattern of stars is a hollow spherical pattern produced by spherical shells with their stars lining the entire wall of the shell casing with the burst charge in the centre (as shown above).*

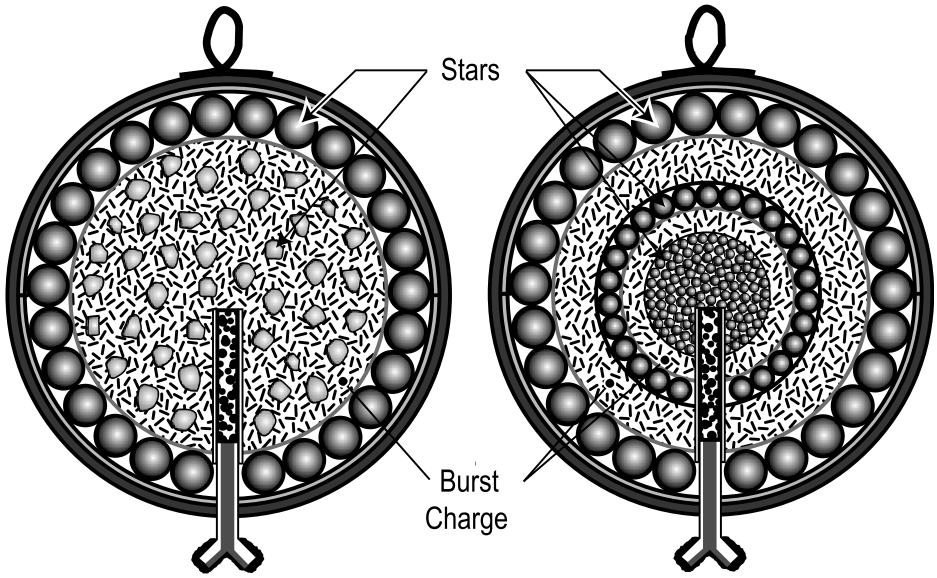
A common variation to the single hollow spherical pattern are those with inner star petals. These shells burst to appear as a hollow spherical star pattern inside a larger outer hollow spherical star pattern. (This is more common with large calibre shells.)



DOUBLE PETAL

❷ *These aerial shells are made by including smaller spherical collections of stars inside the aerial shell. The stars used to make the inner petal are usually smaller in size such that they will complete their burning shortly before the outer petal.*

Another variation to the hollow spherical pattern is one with a number of randomly placed stars mixed with the burst charge inside the outer layer of stars. This produces a random central collection of stars, sometimes called “pistils”.

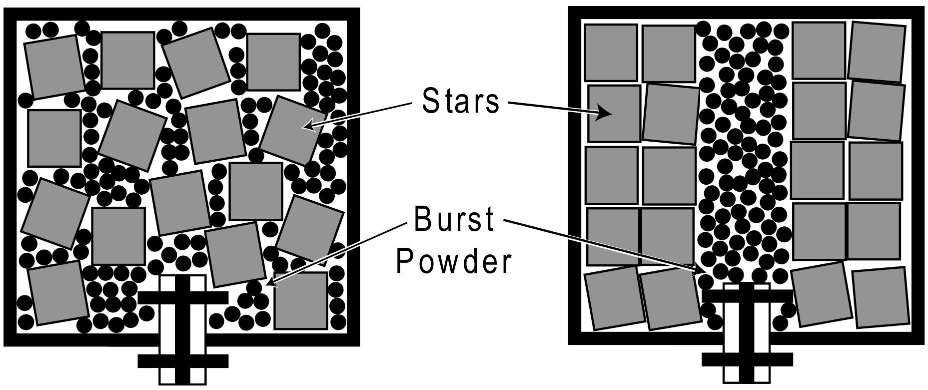


Single Petal with Pistils   Double Petal with Heart

A dense collection of stars appearing at the centre of the spherical pattern(s) of stars is generally called a "heart". This effect is produced by packing the centre of the aerial shell with a large number of small stars.

CYLINDRICAL AERIAL SHELL BURST CONFIGURATIONS

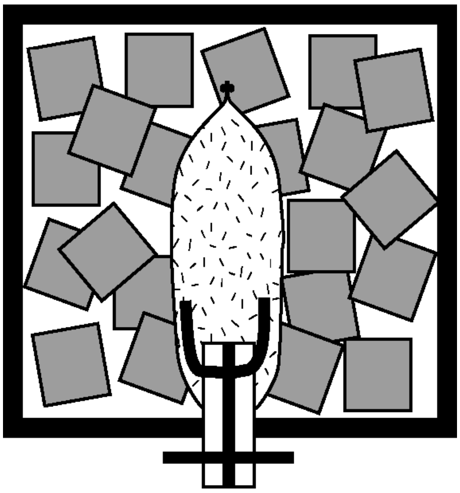
❷ *Cylindrical aerial shells also have varied configurations and types of burst charges. Often cylindrical aerial shells use a central core filled with granulated rough powder (handmade Black Powder). (See diagram on the right.) Such shells produce a somewhat symmetric spread of burning stars.*



As an alternative, the burst charge may be distributed approximately uniformly throughout the interior of the aerial shell. (See diagram on the left.) Such shells tend to produce a random spread of stars.

The burst charge may also be commercial Black Powder (gun powder), loose whistle composition or a combination of different powders.

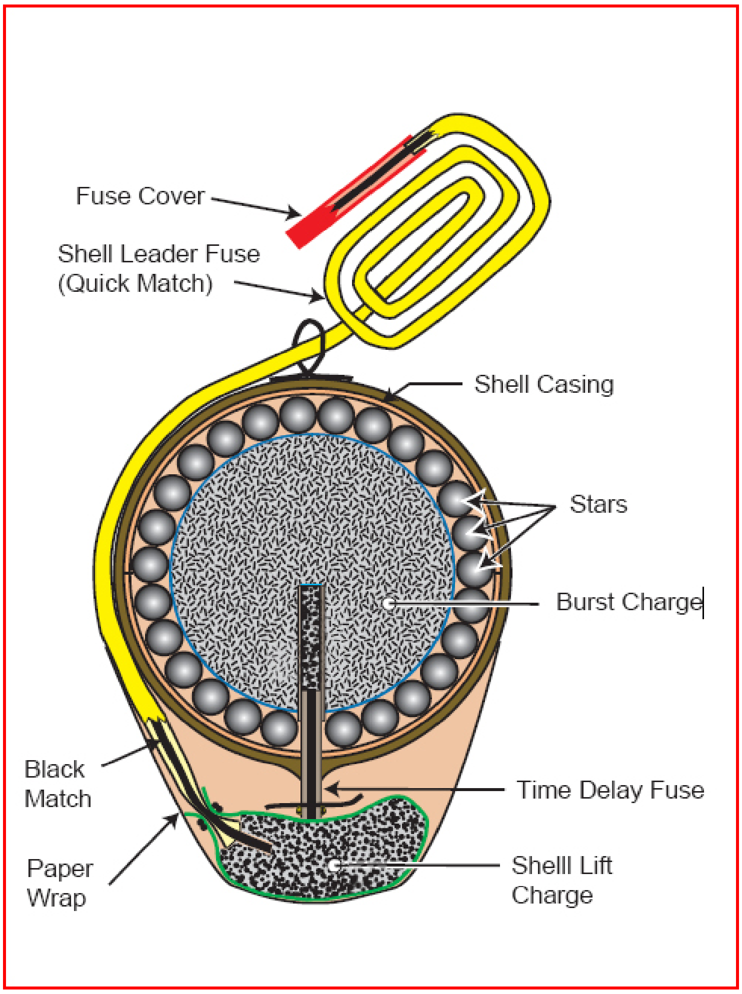
A small centrally located charge of a more powerfully exploding composition contained within a thin-walled paper or plastic tube (often called a flash or burst bag) can also be used to burst an aerial shell.

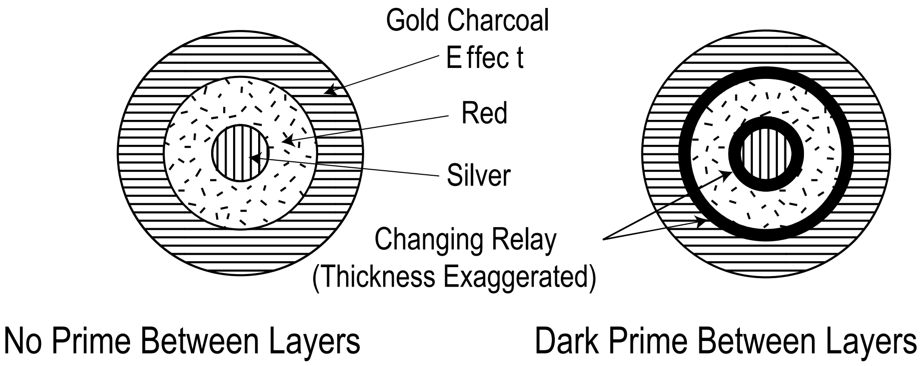


The flash bag composition may be a weak (slower burning) flash powder or uncompacted whistle composition.

STAR TYPES – COLOUR CHANGING STARS

❷ Colour-changing stars are commonly used in large spherical aerial shells. These stars are made using a layering process in which different chemical compositions are applied in sequence to form the complete star.

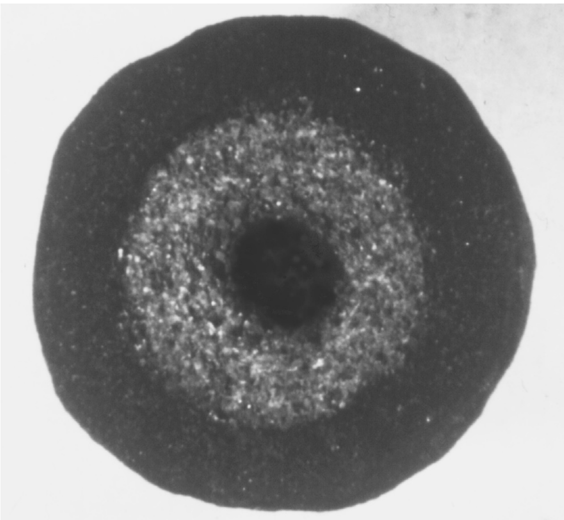




In exhibition quality shells, the colour-changing stars will use a "dark prime" or "changing relay" to aid in the appearance of a perfectly timed colour change.

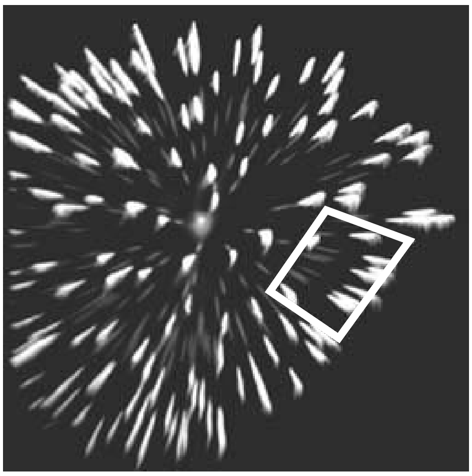
When the first (or only) star effect is one that produces a trail of sparks, the spherical aerial shell is generally referred to as a "Chrysanthemum". If the first star effect is a colour without a trail of sparks, the shell is generally referred to as a "Peony". When the outer prime layer is especially thick and produces orange sparks, the shell description usually includes the term "Reddish Gamboge".

Example of a cross section of a colour-changing star.



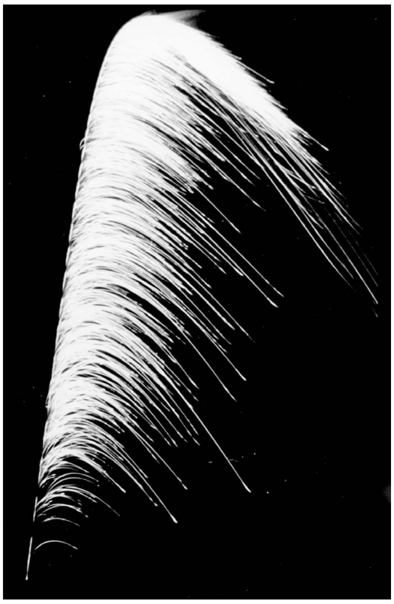
[Photo courtesy of R. Winokur]

Appearance of burning colour-changing stars using changing relay. Note dark areas between the effects.



STAR TYPES – COMET AND STROBE STARS

❷ *Comet stars produce a long-lasting trail of sparks as they burn. The colours of the sparks range from dim orange (made using charcoal), through yellow (made using ferrotitanium alloy), to bright white (made using aluminium or titanium metal), depending on the spark producing materials used.*



A strobe star is a colour star that produces a series of bright flashes of light separated by periods of darkness. The flash rate may vary from approximately one to ten flashes per second.

SECTION 5 - TYPICAL AERIAL SHELL PERFORMANCE:

❷ *Please note that this chapter is all level 2*

Typical aerial shell and mortar parameters

Aerial shell firing time sequence

Internal mortar pressures

Mortar recoil forces

Aerial shell muzzle velocity

Aerial shell burst height

Effect of mortar length

Aerial shell burst delay times

Aerial shell burst spread (effect diameter)

Explosive and thermal output

Effect of mortar tilt angle (trajectory)

Aerial shell drift distance

Aerial shell float time in water

TYPICAL AERIAL SHELL AND MORTAR PARAMETERS

❷ *Typical spherical aerial shells:*

Shell Size (in.)	Shell Diam. (in.)	Shell Weight (lb.)	Lift Powder Type	Lift Weight (oz)	Dead Volume (cu. in.)	Mortar Length (in.)
3	2.7	0.3	4–5 FA	0.5	12	20
4	3.7	0.8	4–5 FA	1.0	24	24
5	4.7	1.5	4 FA	1.7	46	30
6	5.6	2.5	4 FA	2.7	72	36
8	7.6	5.5	4 FA	5.5	150	42
10	9.5	11.	4 FA	10.	290	48
12	11.5	18.	4 FA	17.	520	54

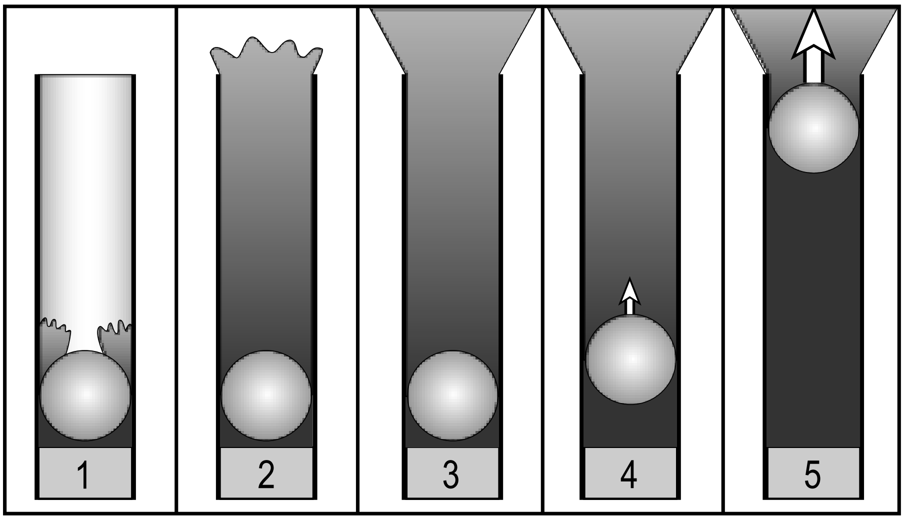
For SI units: 1 in. = 25 mm; 1 oz = 28 g; 1 lb = .45 kg; 1 cu. in. = 1.6 × 104 mm3

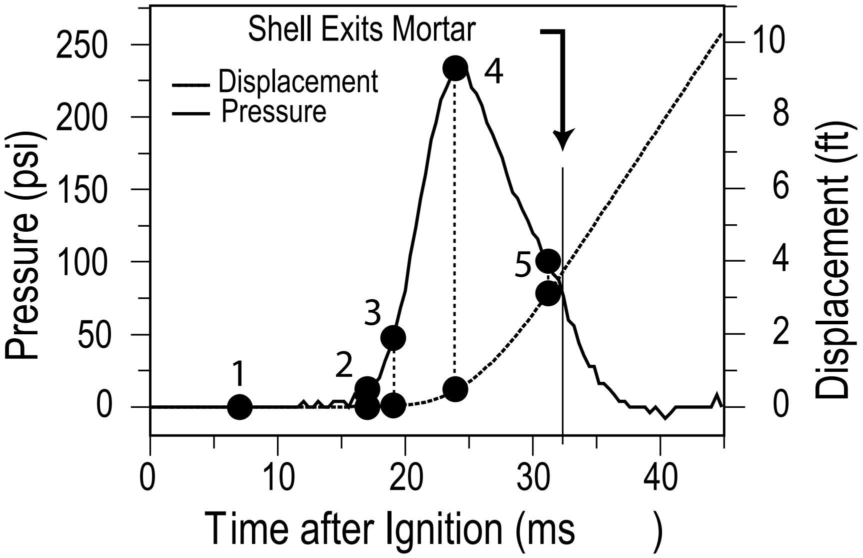
Typical cylindrical aerial shells:

Shell Size (in.)	Shell Diam. (in.)	Shell Weight (lb.)	Lift Powder Type	Lift Weight (oz)	Dead Volume (cu. in.)	Mortar Length (in.)
3	2.7	0.4	2–3 FA	1.0	9	20
4	3.7	1.0	2–3 FA	1.9	20	24
5	4.7	2.0	2 FA	3.0	35	30
6	5.6	4.0	2 FA	4.5	57	36
8	7.6	10.	2 FA	9.0	121	42
10	9.5	20.	2 FA	16.	234	48
12	11.5	36.	2 FA	26.	394	54

AERIAL SHELL FIRING TIME SEQUENCE

❷ *The general shape of typical mortar pressure profiles and the overall times for aerial shells to exit the mortar are mostly independent of shell size.*





The graph is for an 8-inch (200-mm) spherical shell. The numbers in the graph correspond to those in the illustrations and on the next page.

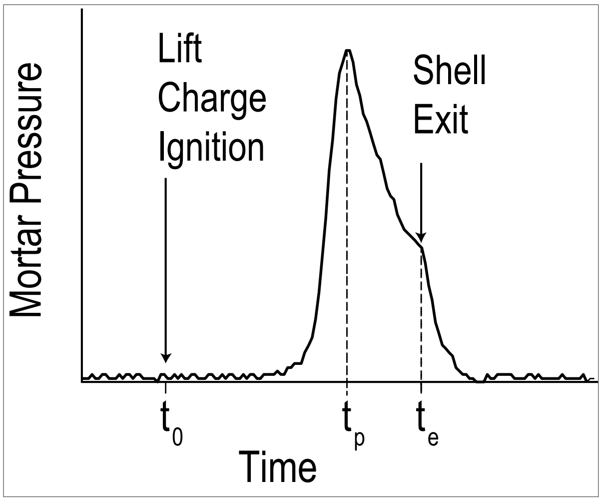
In this case, it required approximately:

1. *0.007 second after the start of ignition of the lift charge for flame to spread through the lift charge and to reach slightly past the top of the shell.*
2. *Another 0.010 second for the flame to be seen to start exiting the top of the mortar.*
3. *Another 0.002 second for the pressure to rise to a point where the upward lift force on the aerial shell equals the downward force due to gravity.*
4. *Another 0.005 second for the pressure to reach its maximum and for the aerial shell to rise approximately 12% of the distance up the mortar.*
5. *Another 0.007 second for the shell to nearly reach the top of the mortar (during that same time the mortar pressure has already dropped significantly).*
6. *Another 0.002 second for the aerial shell to actually exit the mortar. (This is not shown on previous page.)*

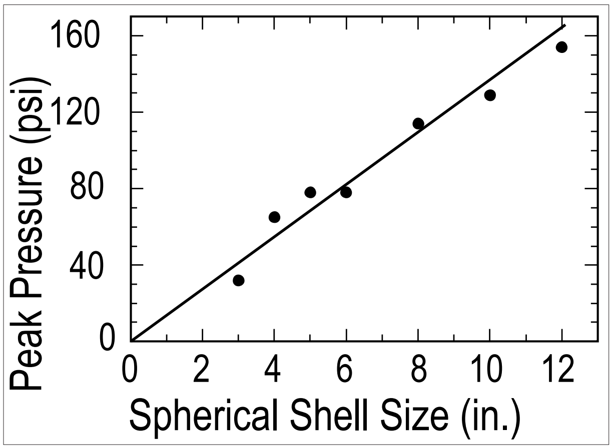
The total elapsed time for this aerial shell to exit the mortar was approximately 0.033 second. Typical aerial shell exit times range from 0.03 to 0.06 second.

INTERNAL MORTAR PRESSURES

❷ *The graph below is somewhat typical of mortar pressure profiles (internal pressure as a function of time during the firing of an aerial shell).*



The graph below is of typical peak mortar pressures for spherical aerial shells as a function of their size (averages for 136 measurements).



On average, peak mortar pressure is approximately 14 psi (100 kPa) for every inch (25 mm) of spherical aerial shell size.

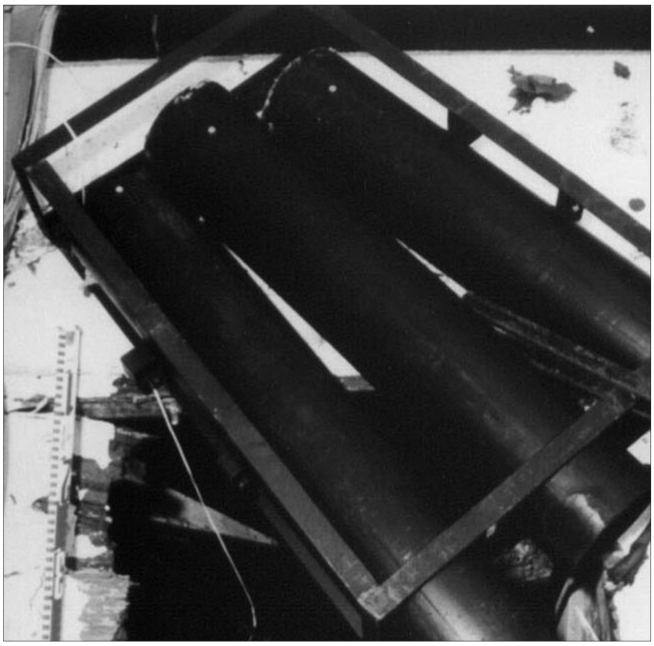
A limited number of measurements suggest that cylindrical aerial shells produce roughly twice the peak pressure of spherical shells of the same size.

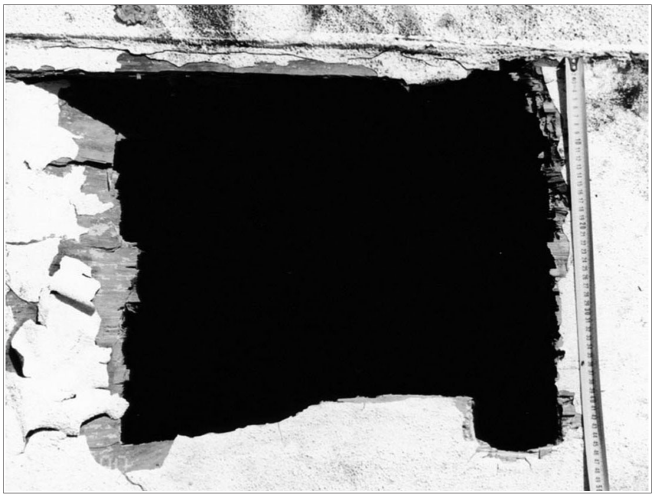
MORTAR RECOIL FORCES

❷ *When aerial shells are fired from mortars, the mortar will recoil as a result.*

If the mortar is positioned on a support structure, it is important that the structure has sufficient strength to withstand the recoil force produced.

Photos of a wooden barge deck that failed to accommodate the recoil forces produced.





The recoil force produced approximately equals the pressure inside the mortar times the inside cross-sectional area of the mortar. Accordingly, the magnitude of the recoil force as a function of time has the same general shape as the mortar pressure profile.

Approximate peak mortar recoil forces when firing typical spherical aerial shells.

Mortar Size [ID] (in.)	Peak Recoil Force (lbf)[a]	Average Recoil Force (lbf) [b]	Recoil Impulse (lbf·s) [c]
3.0	290	130	3.3
4.0	700	320	7.9
5.0	1,400	630	16
6.0	2,300	1000	26
8.0	5,300	2400	60
10.0	11,000	5000	120
12.0	18,000	8000	200

For SI units: 1 in. = 25 mm; 1 lbf = 4.45 N; 1 lbf·s = 4.45 N·s

a) Recoil forces are great but last for only a very short time (0.015 to 0.030 second) and peak force only persists for a few thousandths of a second.

b) The average recoil force over the duration of the pressure pulse is about 45% of the peak value.

c) Recoil impulse is the integral of recoil force over the time during which it persists.

IMPORTANT: Recoil forces may be at least twice as great as typical values listed in the table!

AERIAL SHELL MUZZLE VELOCITY

❷ At the moment of peak mortar pressure, typical spherical aerial shells will be accelerating between 800 and 1600 times the acceleration due to gravity.

As a typical spherical aerial shell leaves the mortar, it will have attained a speed of approximately 300 ft/s (100 m/s), which is approximately 200 mph (360 km/hr). The photo shows an apparatus for measuring aerial shell muzzle velocity.

The reason that large calibre aerial shells travel to greater heights is not because they start out travelling faster. It is because their greater mass allows them to better resist the aerodynamic drag forces acting on them.

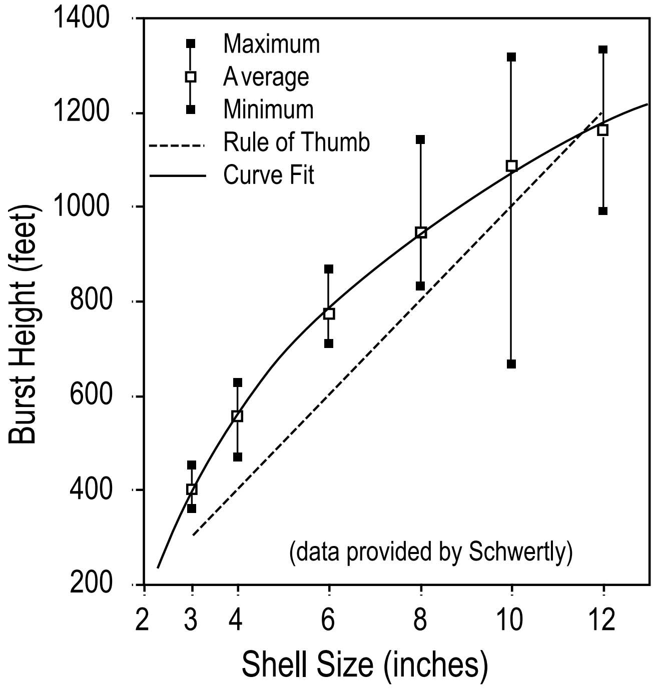
If an aerial shell falls to the ground as a dud after reaching its full height, it will reach a speed of approximately 120 ft/s (40 m/s) or 80 mph (140 km/h) for large shells and approx. 90 ft/s (27 m/s) or 60 mph (100 km/h) for small aerial shells.

AERIAL SHELL BURST HEIGHT

❷ A useful "rule of thumb" to predict the burst height of spherical aerial shells is that they reach 100 feet (33 m) of height per inch (25 mm) of shell size.

However, for mid-sized aerial shells, this tends to under estimate typical shell burst heights by about 150 feet (50 m).

Burst height measurement results for a collection of 40 shells from a variety of manufacturers fired at approximately 1000 feet (300 m) above sea level:



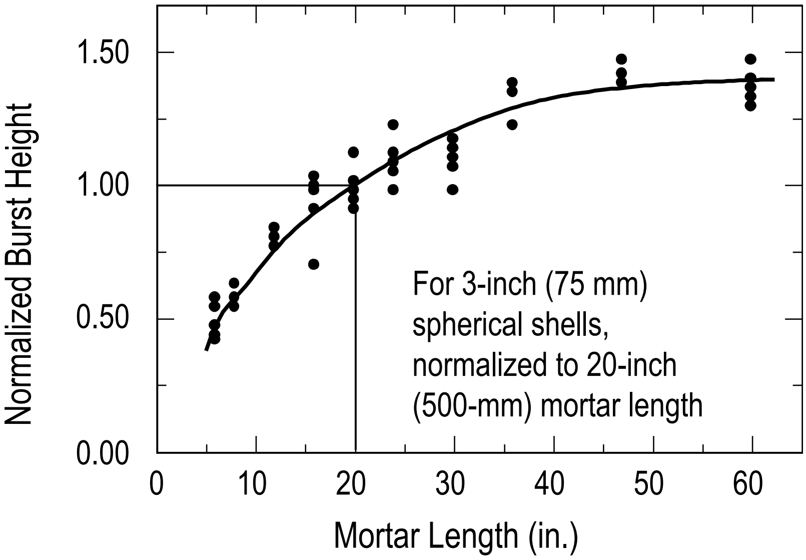
Many factors affect the burst height of individual aerial shells:

- *Delay fuse timing (type and length)*
- *Lift powder effectiveness (amount, granulation and quality)*
- *Lift powder moisture content and ambient temperature*
- *Mortar length and tilt angle*
- *Clearance between shell and mortar-wall*
- *Dead volume below the aerial shell*
- *Shell weight (mass)*
- *Shell shape*

The degree to which the above factors affect an aerial shell are often complex and almost all are beyond the scope of these notes.

EFFECT OF MORTAR LENGTH

❷ *As mortars are made longer, aerial shells fired from them reach higher altitudes. This is a result of greater muzzle velocities reached by the shells before they exit the mortar.*



The effectiveness of additional mortar length decreases as mortars get progressively longer.

Generally, small calibre mortars (< 8 inch or 200 mm) are made at least 5 times as long as their internal diameter. Larger mortars (≥ 8 inch or ≥ 200 mm) are usually only at least 4 times as long as their internal diameter.

AERIAL SHELL BURST DELAY TIMES

❷ *The average time interval between firing an aerial shell and when it breaks is a function of shell size. Approximate average burst delay times for spherical aerial shells are:*

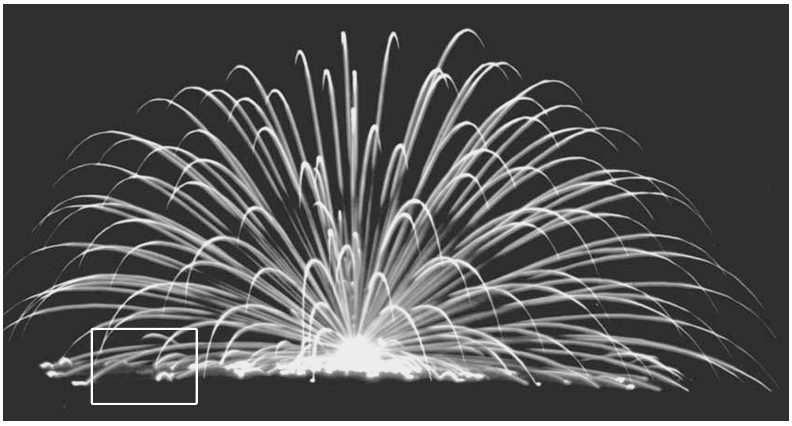
Shell Size		Approx. Delay Time (s)
(in.)	(mm)	
2.5	62	2.5
3	75	3
4	100	3.5
5	125	4
6	150	5
8	200	6
10	250	6.5
12	300	7

In designing a fireworks display to be synchronized to music, it will generally be necessary to know the precise delay times for each type of shell to be used. Then, by knowing how much in advance to fire the shells, it is possible to have the shells burst on cue to fit the music.

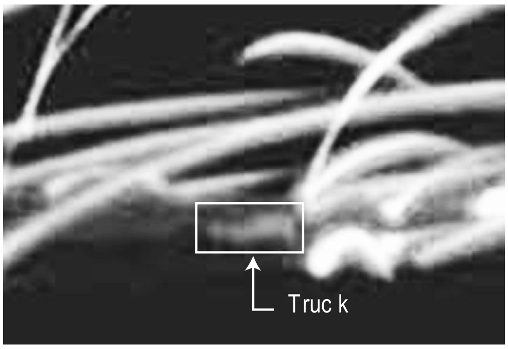
The typical time taken for an aerial shell to explode, after its contents are ignited, depends on many factors including the shell's size. This time ranges from approximately 0.04 second for a 3-inch (75-mm) shell to roughly 0.10 second for a 12-inch (300-mm) shell.

SPREAD FOR A LARGE AERIAL SHELL

❷ *Photo of the 800-foot (240-m) burst spread for a high quality 8-inch (200-mm) spherical aerial shell.*



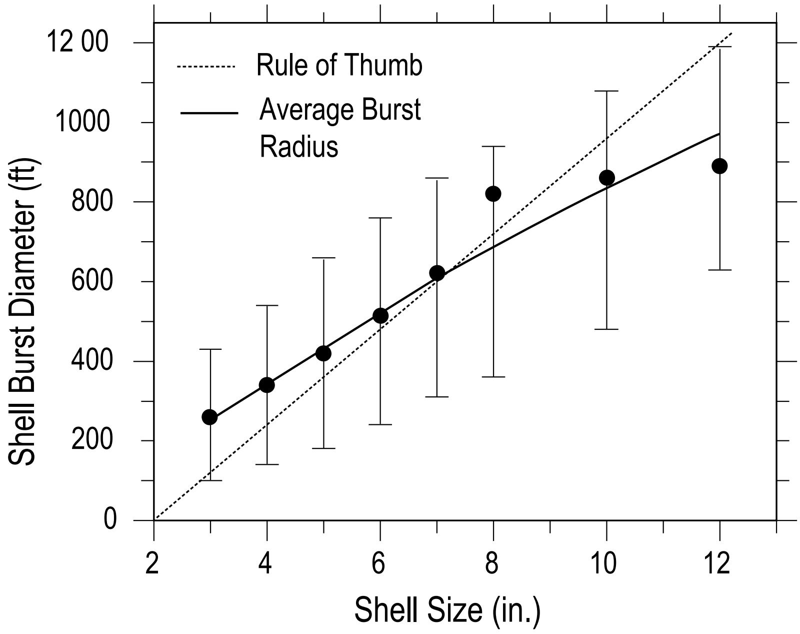
Expanded view of a small portion of the above aerial shell burst. Note the box drawn around an 18-foot long, 1-ton pick-up truck with a large cargo box.



AERIAL SHELL BURST SPREADS

❷ *Large aerial shells generally burst with greater force than do small shells. Also, because their stars are more massive, large shells typically have a wider spread.*

The measured burst radii of approximately 280 relatively high quality spherical aerial shells [T. Shimizu], including some additional results, are graphed below.



A somewhat reasonable rule-of-thumb is that aerial shells burst with a diameter of roughly 100 feet per shell inch or 1m per mm of shell.

Presenting the star spread results as a table:

Spherical Shell Size		Typical Spread of Stars (diameter)	
(in.)	(mm)	(ft)	(m)
3	75	260	79
4	100	340	103
5	125	420	143
6	150	510	155
8	200	820	248
10	250	860	260
12	300	890	270

(Most raw data provided by T. Shimizu.)

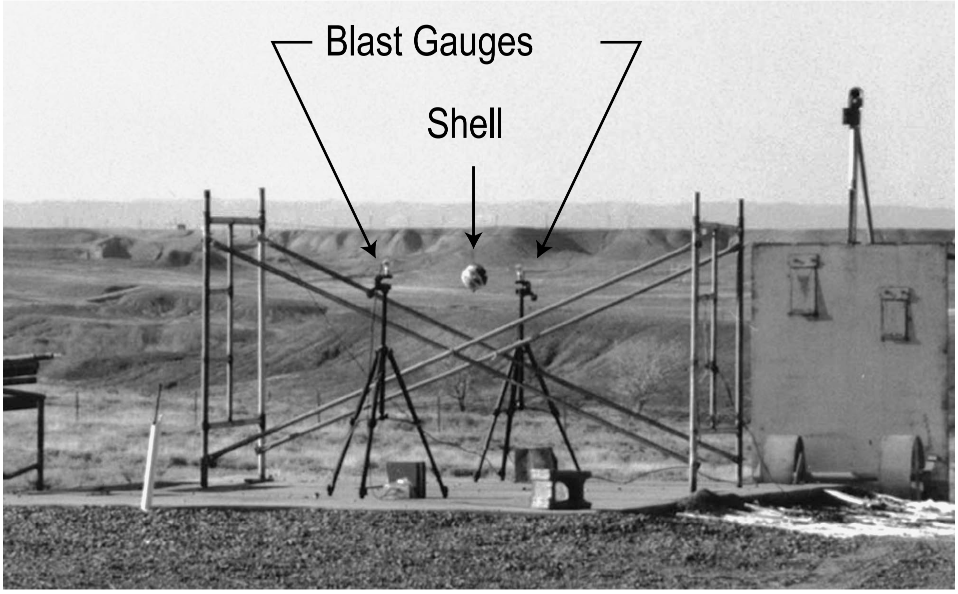
Note that these 8-inch (200-mm) spherical aerial shells were found to spread significantly wider than might be expected for their size. Accordingly these shells can be particularly cost effective.

Note that these 12-inch (300-mm) spherical aerial shells were found to spread significantly less than might be expected for their size.

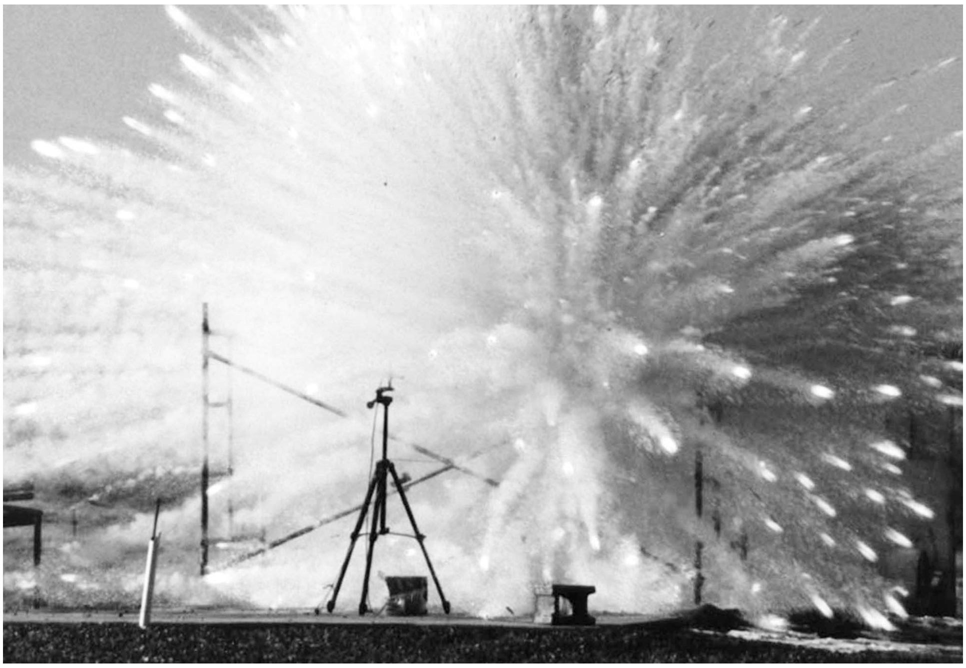
Cylindrical aerial shells typically have star spreads that are substantially less than spherical aerial shells.

MEASUREMENT OF EXPLOSIVE OUTPUT FROM FIREWORKS

❷ *Suspended aerial shell with free-field blast gauges.*



Exploding aerial shell.



EXPLOSIVE AND THERMAL OUTPUT FROM INDIVIDUAL FIREWORKS

❷ *Free field salute blast pressures (measured at 4 ft. or 1.2 m):*

Salute Shell Size		Peak Pressure	
in.	mm	psi	kPa
1	25	4	27
3	75	7	48
4	100	10	70

[The threshold for ear drum rupture is approximately 3 psi (21 kPa)].

The flame temperatures produced by exploding fireworks salutes typically exceed 3000 ºC (6000 ºF).

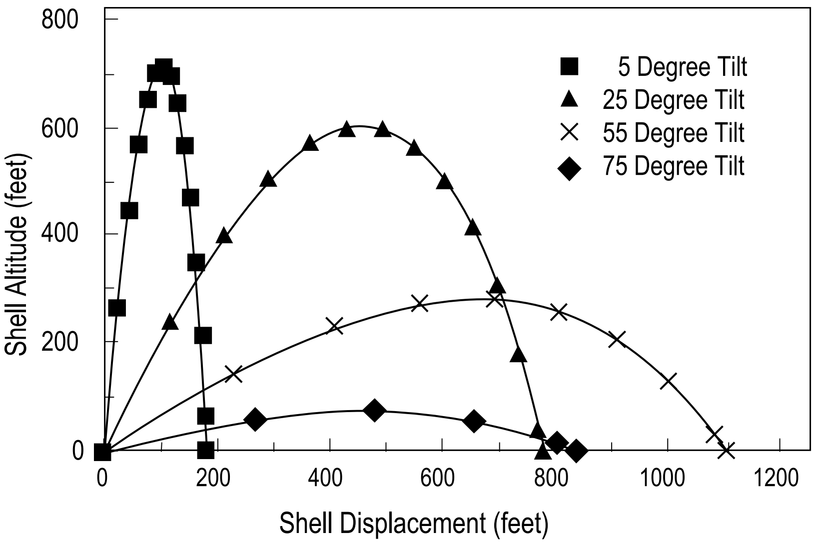
Star shell blast pressures (measured at 4 ft. or 1.2 m):

Star Shell Size		Peak Pressure		Maximum Star Spread Distance	
in.	mm	psi	kPa	ft	m
5	150	1.3	9	380	115
8	200	6	41	470	142
10	250	13	90	510	155

The temperatures produced by burning fireworks stars often exceed 2000 °C (4000 °F).

"DUD" AERIAL SHELL TRAJECTORY

❷ *The graph below illustrates the calculated trajectory of typical 6-inch (150-mm) dud spherical aerial shells fired from variously tilted mortars. Each point (symbol) along the trajectory is the predicted location of the shell at one-second intervals after firing.*



Although not shown above, the down-range distance for a 45º mortar tilt is somewhat less than that for a 55º mortar tilt, which typically produces the approximate greatest down-range distance. Typically these aerial shells would have burst after approximately 5 seconds into their flight. In the absence of wind, the amount of down range displacement of typical dud shell landing points for various tilt angles are:

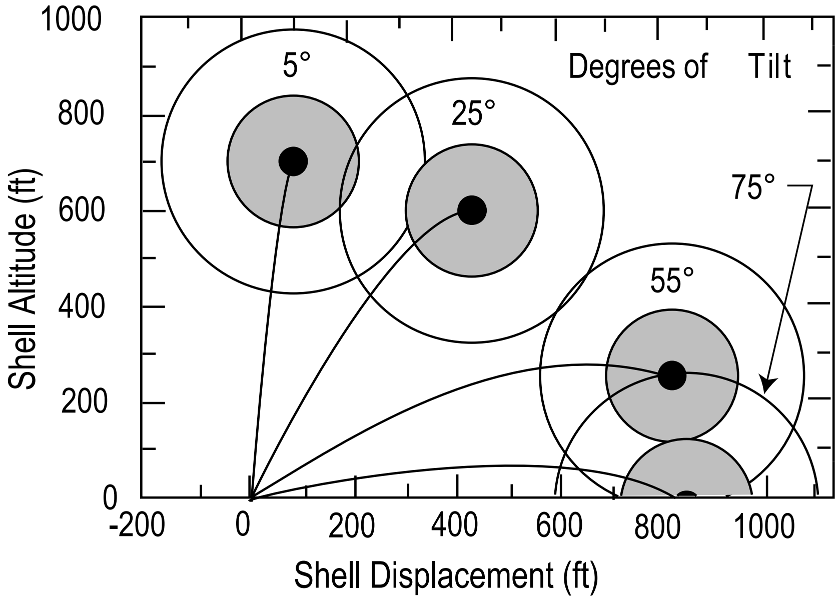
Tilt Angle (deg.)	Down Range Dud Displacements by Shell Size					
	3 in.	75 mm	6 in.	150 mm	12 in.	300 mm
	ft.	m	ft.	m	ft.	m
0	0	0	0	0	0	0
2	42	13	74	23	127	39
5	103	31	184	56	314	96
10	201	61	359	109	611	186
15	291	89	520	159	885	270
20	372	113	664	202	1130	345

(Note these results are calculated for spherical shells under fairly typical conditions.)

When the mortars have been offset 1/3 the distance from the centre of the display site toward the main spectator area, in the absence of wind, a mortar tilt angle of approximately 8 degrees from vertical will cause the average dud shell point-of-fall to be 1/3 the distance beyond the centre of the display site.

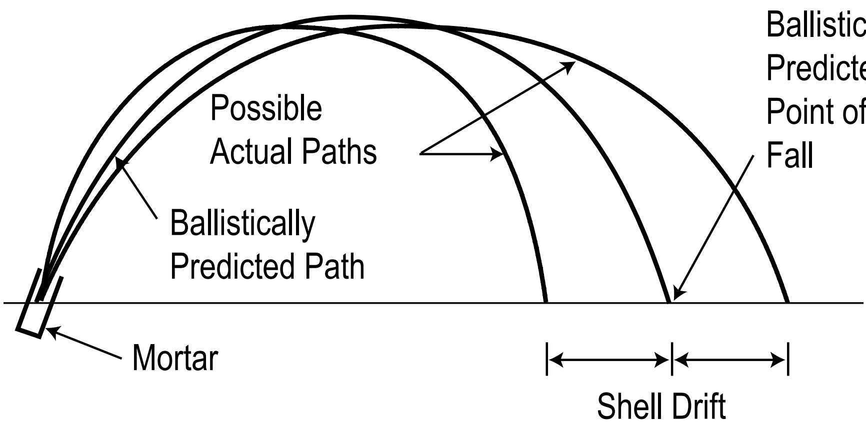
When an aerial shell fires from a tipped mortar and explodes after the normal fuse burn time. There may be the potential for people to be injured.

In the figure below, for typical 6-inch (150-mm) spherical aerial shells, in each case, the small black circle is the zone of greatest danger. The shaded and unshaded circles represent zones progressively of less danger.



AERIAL SHELL DRIFT

❷ *Because of bore balloting and aerodynamic forces acting on aerial shells, they do not follow their precise ballistically predicted path.*



Aerial shell drift is defined as the deviation from a shell's ideal (ballistically predicted) path; drift distance is the difference between the predicted and actual point-of-fall for dud shells.

Average aerial shell drift distances are:

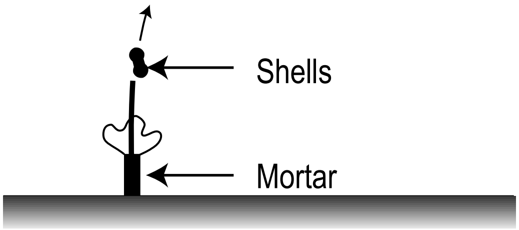
Shell Type	Average Drift Distance	
Spherical	32 ft/shell in.	10 m/shell 25-mm
Cylindrical	20 ft/shell in.	6 m/shell 25-mm

IMPORTANT NOTE: Aerial shells will sometimes drift 2 or 3 times these averages!

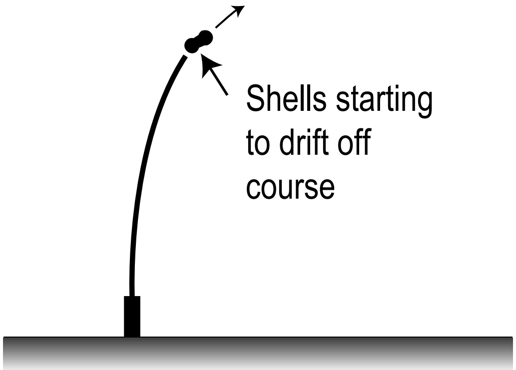
DRIFT DISTANCE FOR MULTI-BREAK SHELLS

❷ *The drift distance for multi-break shells can be greater than for single-break aerial shells. Consider the following possible sequence of events:*

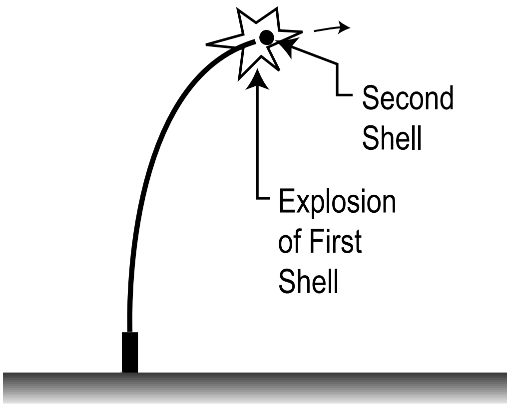
A double-break spherical aerial shell has just fired from the mortar.



The normal factors affecting the pair of aerial shells have resulted in some degree of shell drift. (These normal factors include bore balloting, Magnus forces, and wind effects.)



The first aerial shell has just exploded and that applies an added force on the second shell. Depending on the orientation of the shells when the explosion occurs, the second shell can be pushed further off course.



Second shell continues to drift further off course.

SECTION 6 - OTHER FIREWORKS TYPES:

Low-level aerial fireworks:

- ♦ Mines
- ♦ Single shot candles (Shot Tudes) and Comets
- ♦ Roman candles
- ♦ Cakes and multi-shots

Rockets

Helicopters (Saucers)

Wheels

Fountains, gerbs, and waterfalls

Lancework

- ♦ Quick match fusing
- ♦ Tape Match fusing

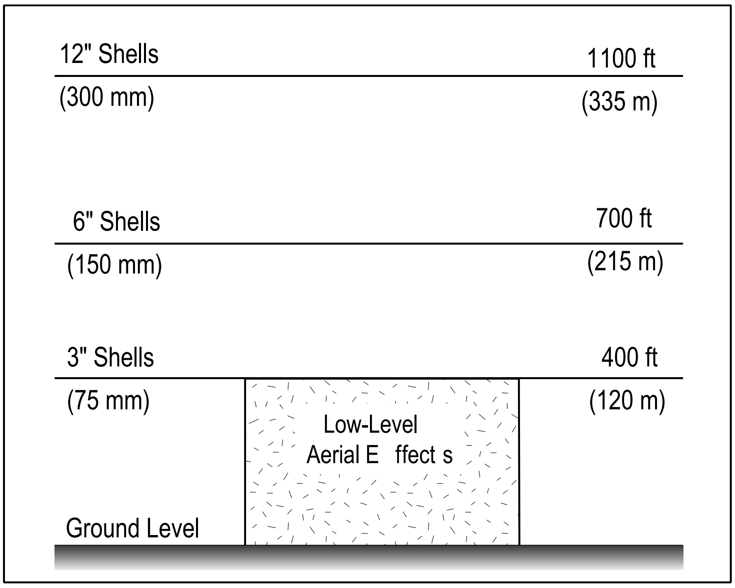
Fire rope

LOW-LEVEL AERIAL FIREWORKS

Low-level aerial fireworks generally consist of mines, Single shot candles, Roman candles and cakes or multi-shot devices. Also included may be small aerial shells (< 2.5 inches or < 62 mm).

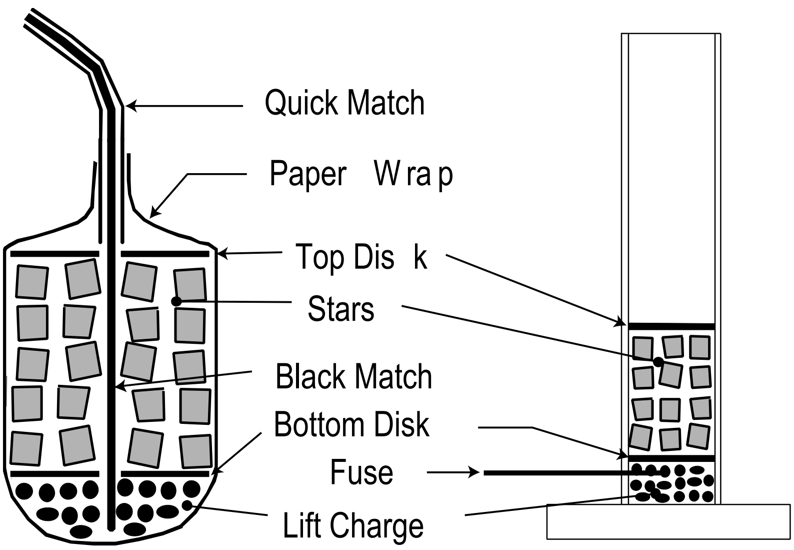
Mines, Single shot candles and most Roman candles begin their display at ground level. Thus, when spectators can view this area of the sky, these items can be quite effective because they fill a portion of the sky that is mostly left blank during the display.

Low-level aerial fireworks generally do not reach heights exceeding 400 feet (120 m).



FIREWORK MINE EFFECT

A firework mine produces a rising effect in which the materials are ignited in the mortar and are propelled upward, giving much the same appearance as the aerial shell malfunction called a flowerpot. There are two types of mines, so called “bag mines” and pre-loaded mines (in which the components of the mine are loaded into the mortar from which it will be fired).



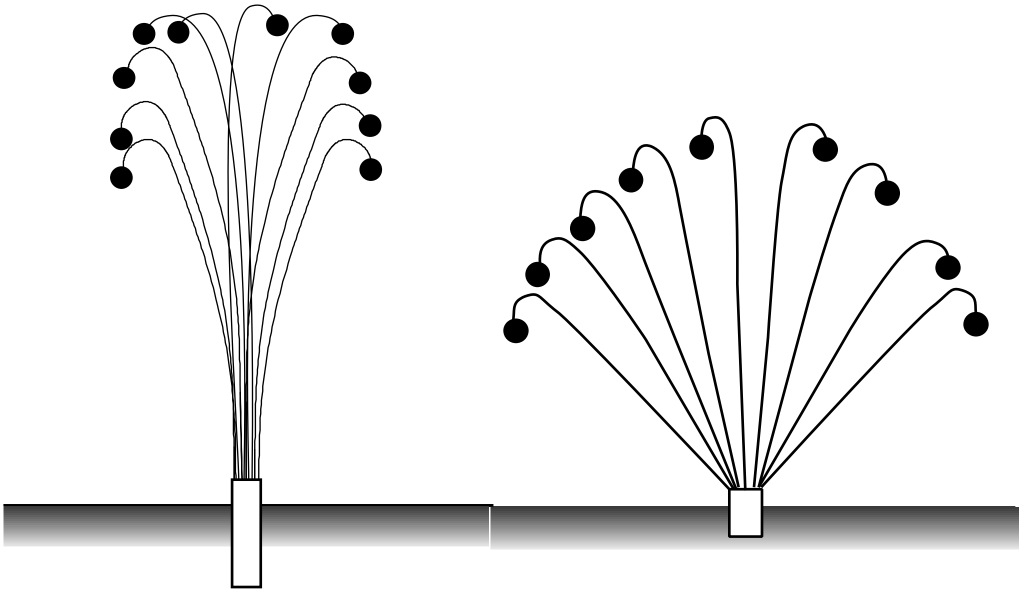
Larger mines are generally supplied to be loaded into mortars (shown on the left above). Many small mines (less than 2.5 inches or 50 mm) are supplied already loaded into their firing mortar (shown on right above).

Mines may contain stars, component devices (e.g., small shells and whistles), or both.

APPEARANCE OF A FIREWORK MINE

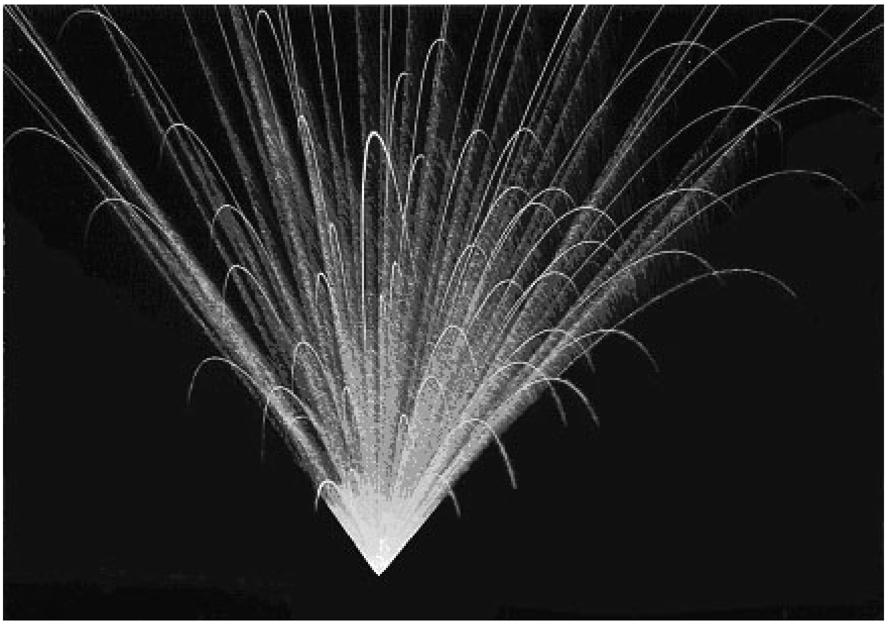
The appearance of a star mine depends on many factors including the length of the firing mortar.

The mine appears relatively tall and narrow when fired from a long mortar. It is tall because of the added propulsion the stars receive while still inside the mortar. It is narrow because the longer mortar tends to restrict the divergence of the exiting stars.

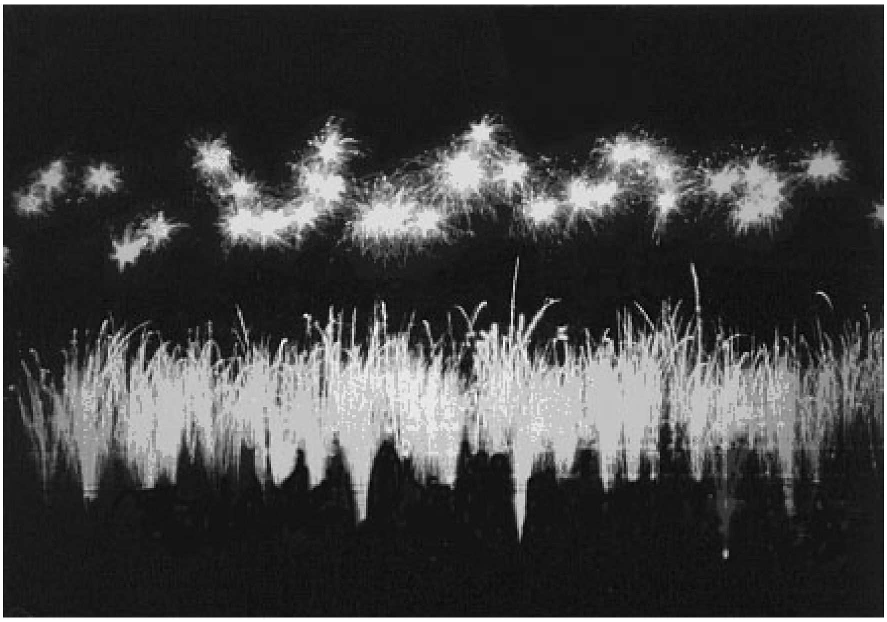


The same mine will appear shorter and broader when it is fired from a relatively short mortar, which provides less propulsion and allows greater divergence.

Appearance of a single star mine (viewed close-up).



Appearance of a star mine "front" that contains small component shells that burst above the display of burning mine stars (viewed from a distance).



MINE CHARACTERISTICS

Mine to be loaded into mortars look much like a cylindical aerial shell.

Large mines are loaded and fired from mortars, using the same procedure as for aerial shells. Mine have a potential for fallout of burning debris near the mortar much as aerial shell flowerpot malfunctions. Thus, it is important to guard against accidental ignition of fireworks in the immediate area where mines will be fired.

The most common sizes for display firework mines are 3 and 4 inch (75 and 100 mm). However, both larger and smaller sizes are used. Most commonly, mines consist only of stars, but they can also contain component devices, such as whistles, small salutes, small shells, etc.

Mines will not be propelled to the same height, as will aerial shells of the same size. This is because the relatively low mass of the individual projectiles causes them to slow more quickly due to aerodynamic drag forces.

MINE MALFUNCTIONS

Mine suffer many of the same malfunctions as aerial shells:

Burning fallout: (Similar to an aerial shell flowerpot.) A well made mine shell will produce relatively little fallout. However, burning fallout can be a problem and care should be taken to assure that other fireworks are not accidentally ignited as a result.

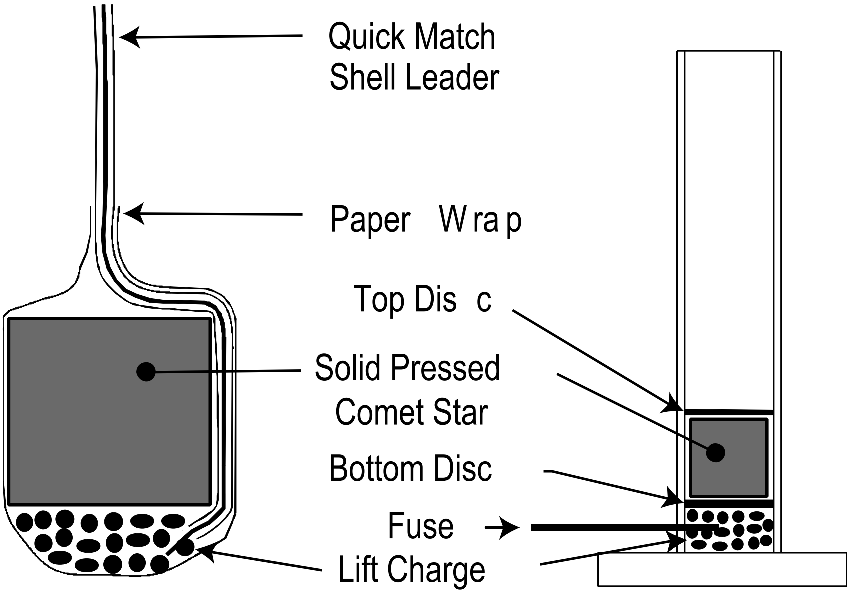
Hangfire or Misfire: (A delay in the firing or a non-firing of the device after ignition of the shell leader fuse.) This is caused and handled just as with an aerial shell.

“Detonations”: (A violent explosion within the mortar with the potential to destroy the mortar.) The cause is not completely known; however, while still relatively rare, the frequency of occurrence seems to be greater for mines than for aerial shells. Thus it is appropriate to consider burying and/or barricading the mortar when manually firing. This is especially appropriate for metal mortars.

Dud components: When the mine contains component devices, there is always the possibility that some will fail to ignite and will become duds. These dud components must be found and removed after the display.

COMET EFFECTS AND SINGLE SHOT DEVICES

A comet produces a rising effect in which a single large pellet of composition is ignited in the mortar and propelled upward. The burning comet generally leaves a trail of rising sparks, giving much the same appearance as an astronomical comet in the sky.

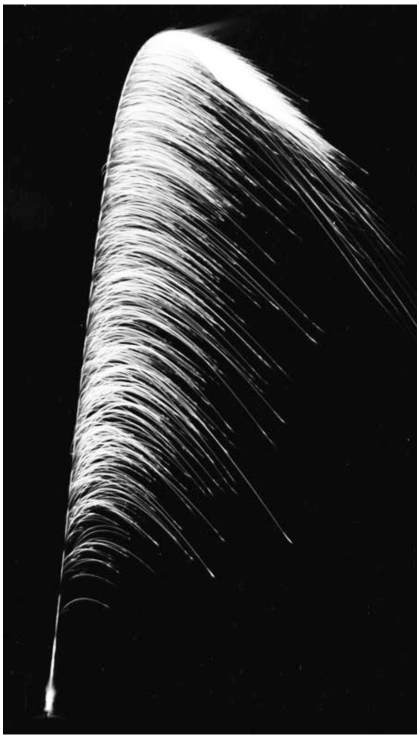


Larger calibre comets are generally supplied as (as shown on the left). These look like an aerial shell but feel somewhat heavier because of their solid construction.

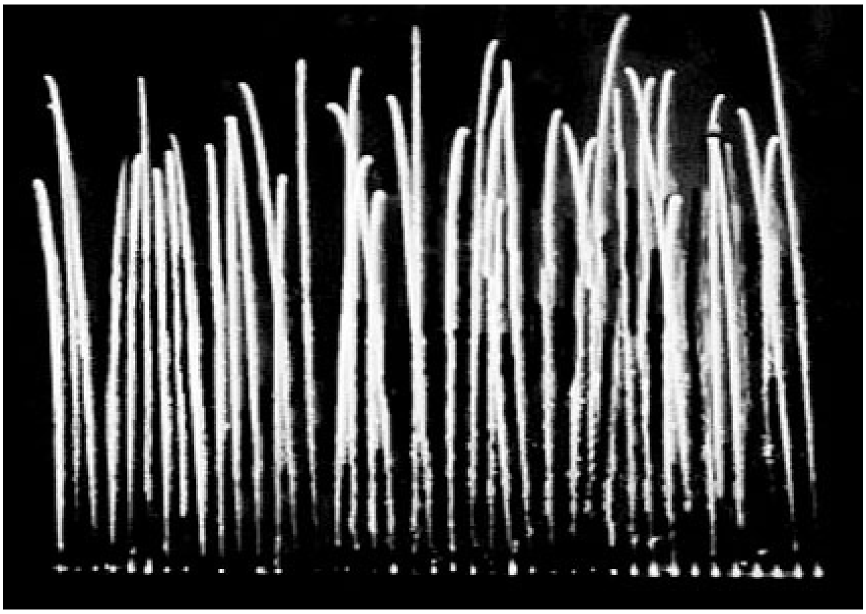
Most small comets (< 2.5 inches or <50 mm) are supplied as a unit called and classified in the UK as shot tubes. In essence these fireworks are already loaded into their firing mortar (as shown on the right).

APPEARANCE OF A FIREWORK COMET

Appearance of a single comet (viewed close-up).



Appearance of comet front (viewed from a distance).



COMET AND SHOT TUBE CHARACTERISTICS

Large calibre comet are loaded and fired from mortars using the same procedure as for aerial shells. However, their greater mass will put a greater stress on the mortar and mortar plug when they are fired. Large comets may have burn times of six or more seconds. Because of the long burn time, if such a comet is weakly propelled, there is a chance that it will fall to the ground while still burning.

The most common sizes for display firework comet shells are 2 and 3 inch (50 and 75 mm). However, both smaller and larger sizes are used. Smaller comets generally are not made for individual firing but are typically fired in groups described as “comet batteries”.

Most comets leave a trail of sparks, but some only produce a moving point of coloured light.

A comet will often be propelled to a greater height than an aerial shell of the same size. This is because of the relatively high mass of the comet, which does not cause it to slow down as quickly from aerodynamic drag forces.

COMET AND SHOT TUBE MALFUNCTIONS

Comet suffer some of the same malfunctions as do aerial shells.

Burning Fallout. A well-made comet will stay intact as it is fired and will rise to a great height. However, it is possible that one or more small pieces will break-off when the comet is fired and those burning pieces may fall to the ground. This is more likely if the comet is handled roughly or manufactured so poorly that it readily cracks or breaks apart.

Hangfire or Misfire. (A delay in firing or a non-firing of the device after ignition of the shell leader fuse.) This is caused and handled just as with an aerial shell.

“Detonations”. Some recently encountered comet formulations have proven to be capable of producing very powerful in-mortar explosions.

Mortar Failures. Comets are quite heavy for their size. They also tend to have less space below them (dead volume) after being loaded into mortars. For both of these reasons, higher peak mortar pressures are produced when a comet is fired as compared with aerial shells of the same size. This can cause a weak mortar (e.g., a paper mortar) or its plug to fail and the comet to not reach its full height.

SHOT TUBES

Shot tubes are similar in appearance and function to pre-loaded comets. However, they may contain several stars or other units and function in a similar manner to a pre-loaded mine.

Shot tubes are the basic building blocks of multi-shot "cakes" and are included here because of the fact that classification of cakes in the UK is dependant on the classification of the shot tubes which they contain.

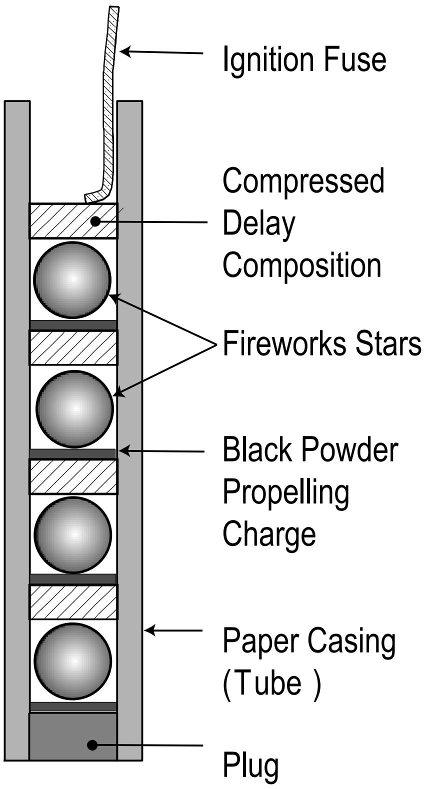
ROMAN CANDLES

Roman candles propel a series of projectiles into the air typically with a few seconds delay between firings. The projectiles will usually be firework stars (coloured or tailed) or they can be small firework devices (e.g., bombettes, whistles, reports, etc.).

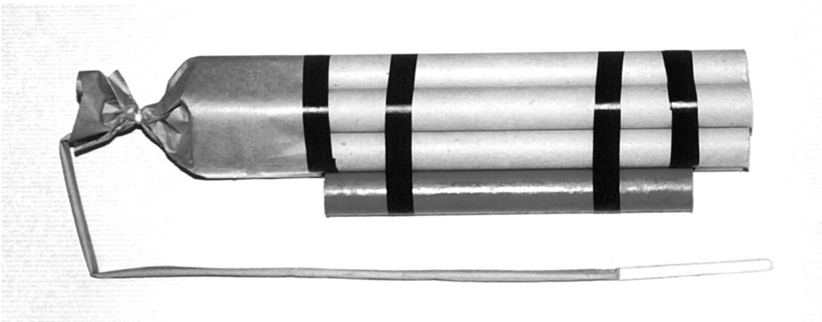
The delay between firing is sometimes provided by a slow burning pyrotechnic composition. The propelling charge is loose granular Black Powder. When Roman candles are fired in bundles or groups, they are referred to as "Roman candle batteries".

ROMAN CANDLE EXAMPLES (COMET TYPE)

A collection of individual display Roman candles and consumer Roman candles is shown below.



A group of Roman candles fused together to fire simultaneously, forming a candle battery. (There is a short tube attached to the bundle to aid in securing the candle battery to a stake in the ground.)

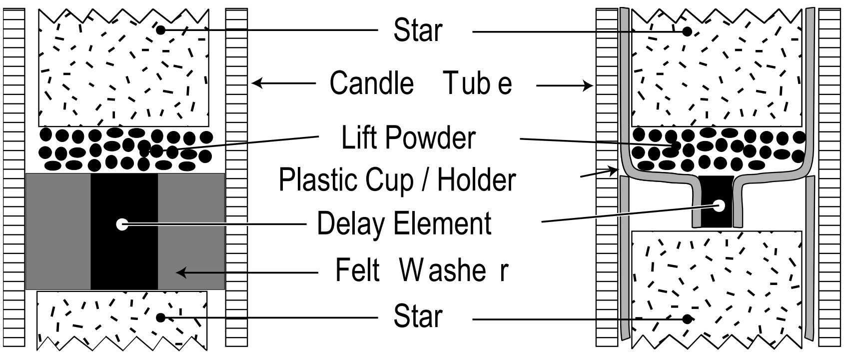


ROMAN CANDLE DELAY ELEMENTS

Traditional Roman candles used slow-burning “candle composition”, which was a type of handmade Black Powder with added charcoal, as the delay between shots.

Today, in small and relatively inexpensive Roman candles, it is common to find one or two fuses running along the inside wall of the tube and inert filler (e.g., loose clay, sawdust, or a mixture) providing the separation between shots.

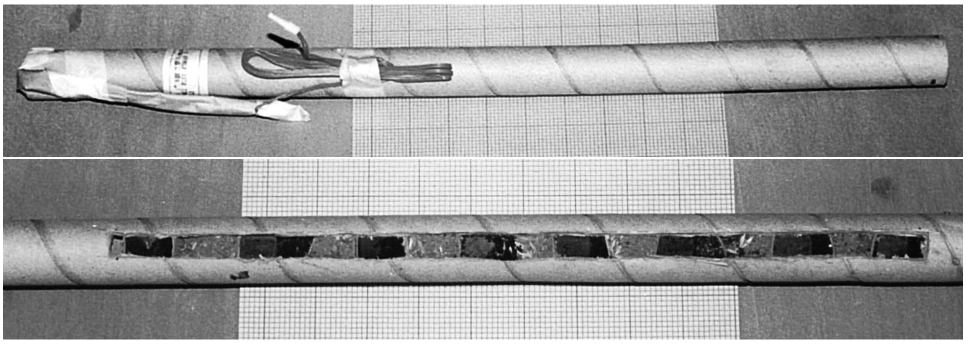
High quality display Roman candles have relatively precise firing delays. They commonly use pressed delay elements or short lengths of time delay fuse held tightly between the shots, either in felt washers or in special plastic holders.



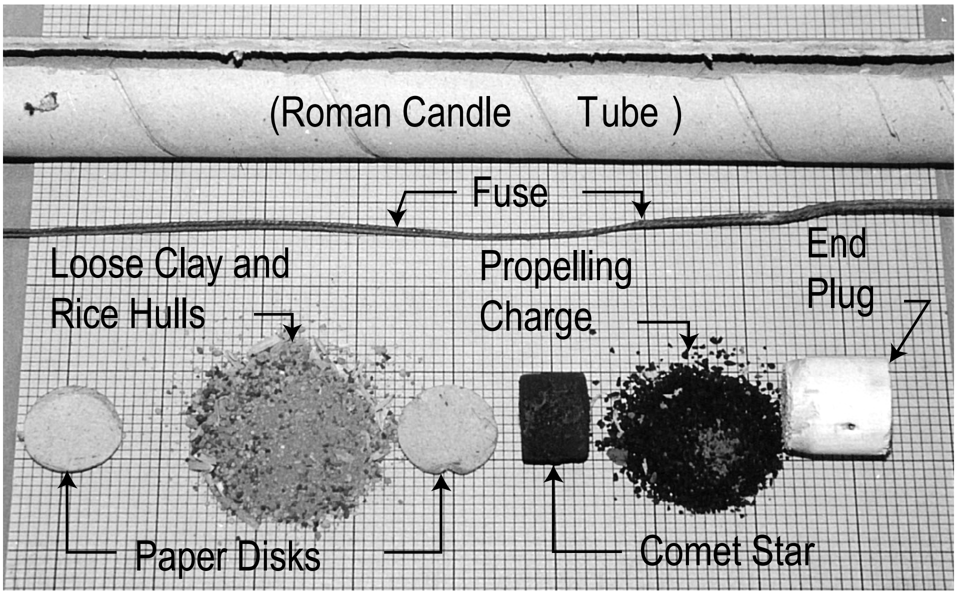
Note that the felt washer shown in the diagram above (left) often forms the greatest part of the debris produce from firing Roman candles.

DISPLAY ROMAN CANDLE DISSECTION

This Roman candle uses two lengths of visco fuse to provide the delay between shots (not visible in upper photos).

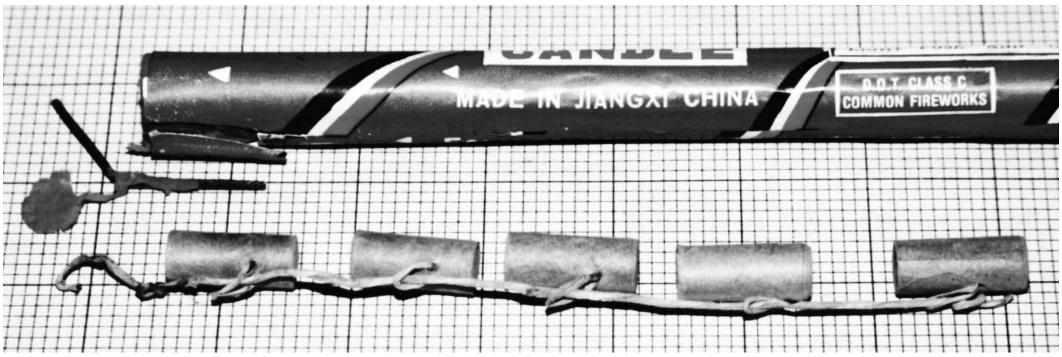


The spacing between shots consists of a pair of chipboard paper discs with a loose mix of clay and rice husks (or husks) between the discs. [0.1 inch (2.5 mm) per division]

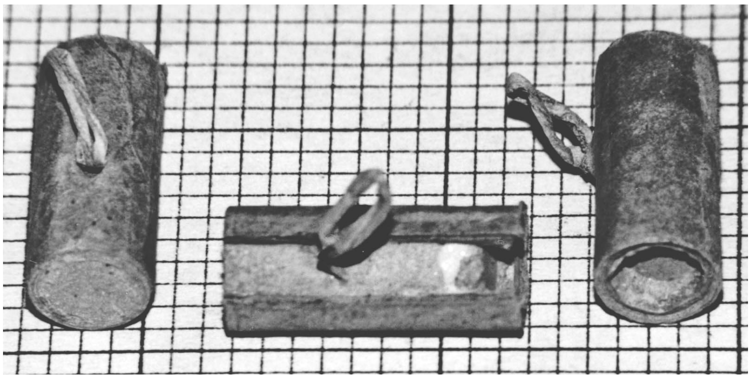


COMPONENT ROMAN CANDLE

This consumer firework Roman candle uses a tissue paper fuse (“Chinese fuse”) as the delay element. There is no expelling charge for the self-propelled devices and there is no filler between. [0.1 inch (2.5 mm) per division]

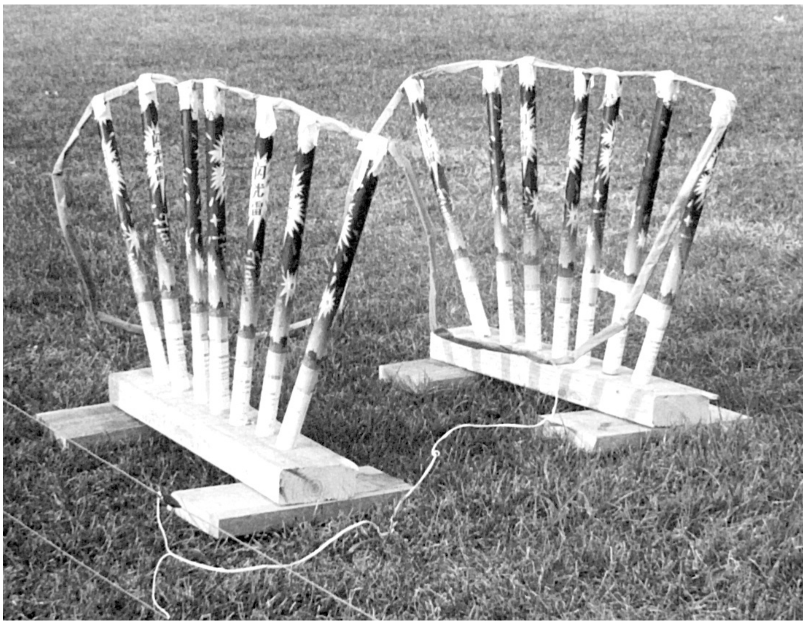


These Roman candle projectiles are small spin stabilized rockets that produce a humming sound as they emit a coloured flame.

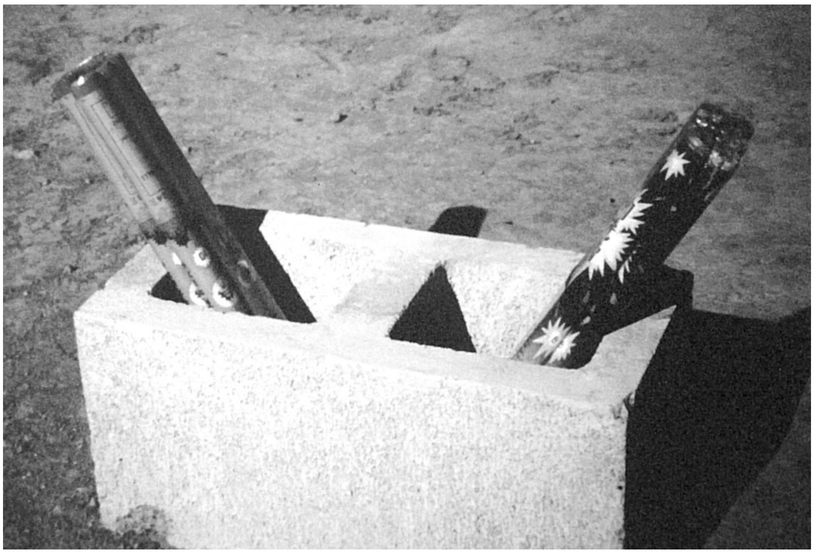


ROMAN CANDLE BATTERY EXAMPLES

A Roman candle battery made using consumer Roman candles to make a fanned-out display.



A pair of Roman candle batteries mounted to produce a V-shaped display. (This is not an acceptable method to use because they are not properly secured into position).



ROMAN CANDLE CHARACTERISTICS

A Roman candle is a chain-fused item. That is to say, a series of projectile firings occur after a single ignition.

Extra care should be taken in mounting and barricading Roman candles so they do not become misaligned and send burning material in dangerous directions.

The most common sizes of Roman candles range from 3/8-inch (9-mm) to 2-inch (50-mm) internal tube diameter. However, both larger and smaller sizes can occasionally be found.

Typically, the number of Roman candle projectiles (firings) ranges from 5 to 10 and the height of Roman candle projectiles ranges from about 50 feet (15 m) to well over 250 feet (75 m).

ROMAN CANDLE MALFUNCTIONS

Many Roman candle malfunctions may pose a safety problems:

- Incomplete firing, with some of the shots remaining unfired.
- Multiple near simultaneous firings.
- Delayed firings; longer than normal delay intervals.

Some Roman candle malfunctions can pose significant safety problems:

- Weak firings can allow burning projectiles to fall to the ground where they could ignite combustibles or other fireworks.
- Tube blowout could cause a Roman candle battery to come apart or dislodge from its support, with some Roman candle projectiles then firing in dangerous directions.
- Some recent Roman candle star formulations have produced powerful in-tube explosions similar to aerial shell “detonations”.

CAKES AND MULTI-SHOTS

Cakes and multi-shots are composed of a number of individual small tubes (shot tubes) that are chain fused near their bottom and propel a series of effects into the air.

Extra care should be taken in mounting and bracing cakes so they do not become misaligned and send burning material in dangerous directions.

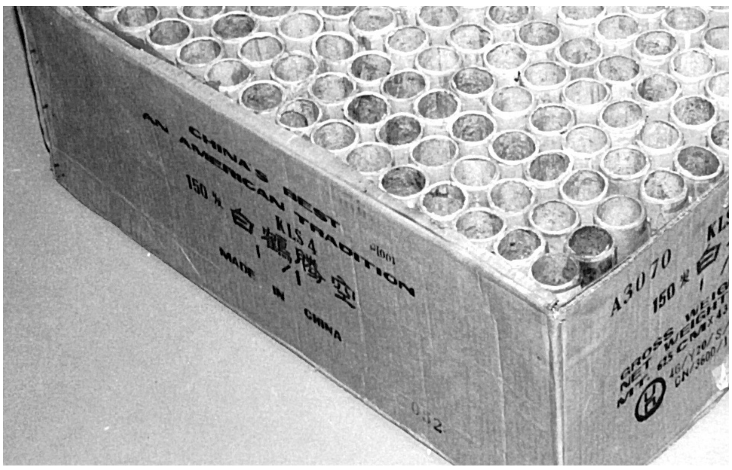
Characteristics:

- The number of tubes typically ranges from about 19 to 600 but can have many more.
- The internal diameter of the individual tubes typically ranges from about 3/8 inch (9 mm) to 1 1/4 inch (30 mm) but can be as large as 3 or 4 inches (75 or 100 mm) in boxed finales.
- The projectiles can be firework stars (coloured or tailed), bombettes, whistles, reports, etc.
- The interval between firings can range from a small fraction of a second to several seconds.
- Malfunctions are much the same as those of Roman candles.

FIREWORK CAKES (MULTI-SHOT) EXAMPLES

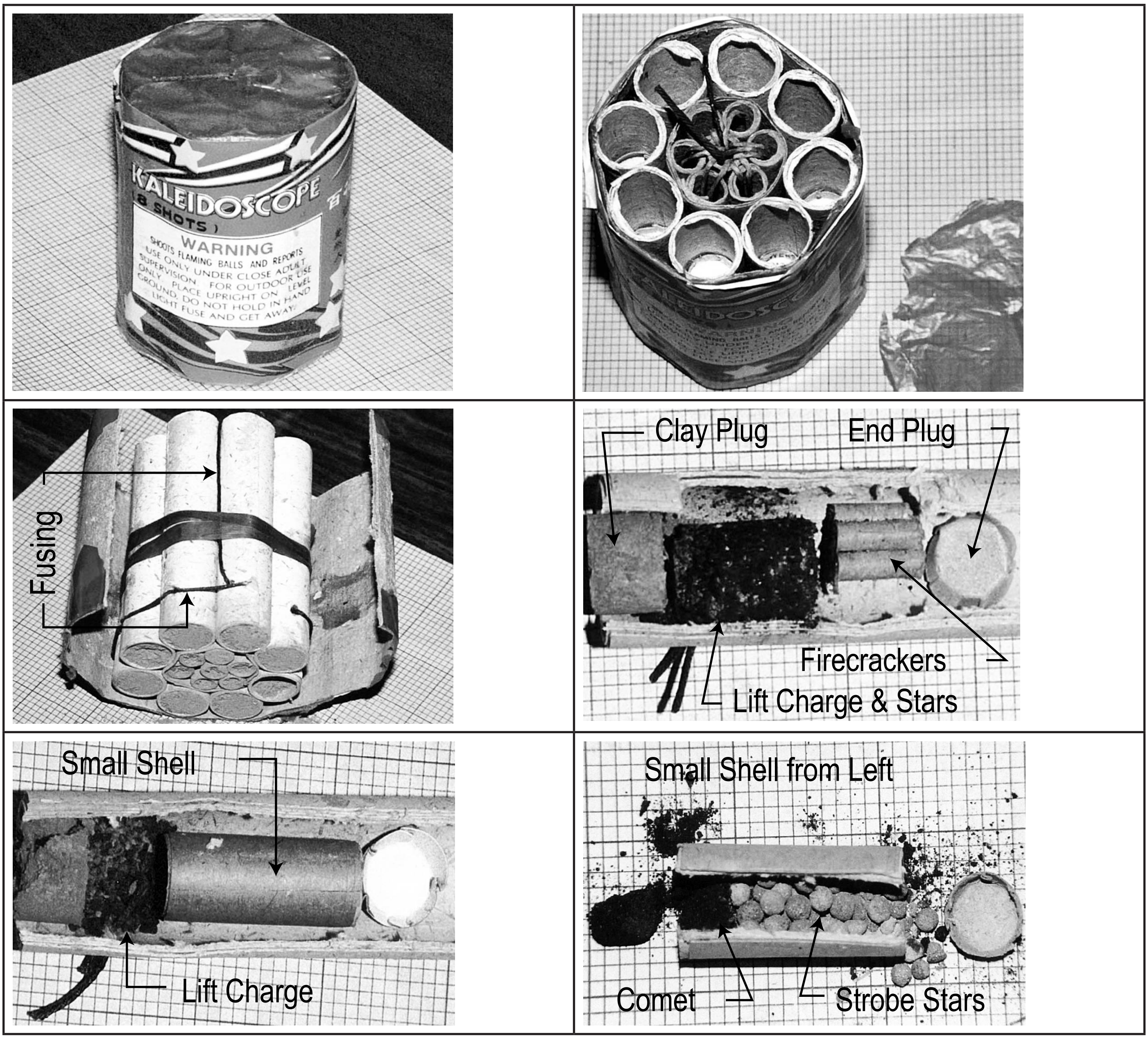
Examples of some of the smaller types and sizes of cakes (multi-shots) that are available.

Display boxes containing approximately 1-inch (25mm) diameter items (100-150 shots).



DISSECTION OF A SMALL CAKE FIREWORK

❷ *The following series of photographs were taken at various stages during the dissection of a small firework cake item. The item contained several different effects.*



[0.1 inch (2.5 mm) per division]

ROCKETS

A rocket combines a somewhat typical firework aerial shell (rocket heading) with a rocket motor for propulsion. Generally, the rocket produces a trail of sparks on its upward flight and then produces a display from the rocket heading.

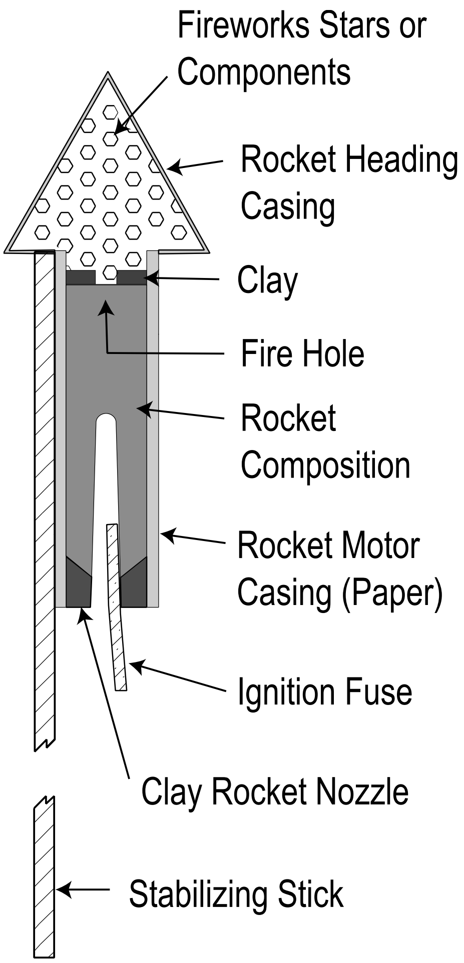
Rockets have three major disadvantages:

1) They are capable of travelling a great and unpredictable distance horizontally from their point of launch.

2) Track into wind

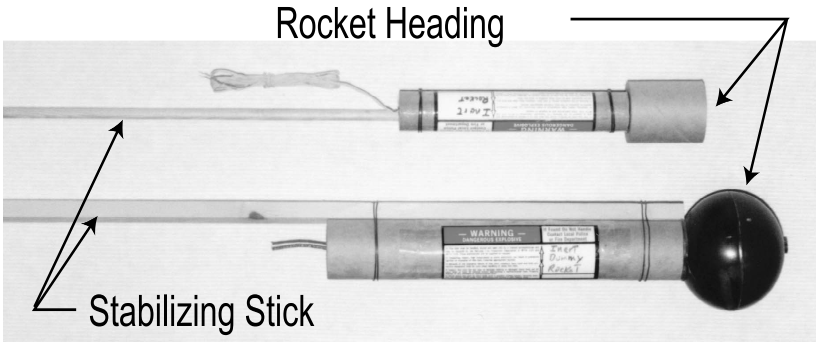
3) Upon completion of their flight, a significant amount of debris falls to earth.

Disadvantages 2 and 3 are major potential safety hazards and are the reasons why rockets are almost never used in public displays.

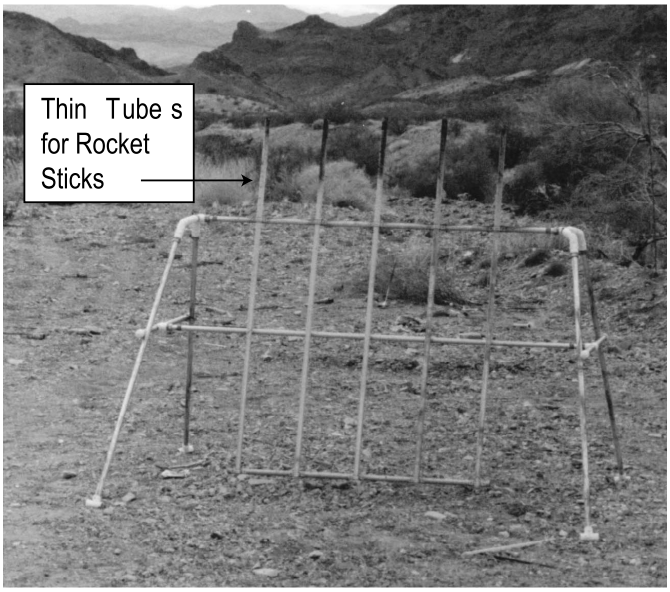


DISPLAY ROCKET EXAMPLES

Examples of display firework rockets.



An example of the type of equipment used to help aim and guide firework rockets during the initial portion of their flight. The rockets' stabilizing sticks are inserted into the thin metal tubes before firing.



ROCKET CHARACTERISTICS

Rockets have rocket motors that typically range in size from about 1/8-inch (3-mm) ID and 2-inches (50-mm) long to about 1/2-inch (13-mm) ID and 5-inches (125-mm) long. These rockets propel themselves to heights from 100 feet (30 m) to more than 300 feet (100 m) and typically carry.

Display firework rockets have rocket motors that range in size from about 3/4-inch (20-mm) ID and 7-inches (175-mm) long to about 1-1/4-inches (32-mm) ID and 15-inches (375-mm) long.

These rockets can reach heights of 1000 feet (300 m) or more and can carry typically 0.45 kg as payload of stars or other effects to produce a display.

Most display rockets use a long thin stick as the means of stabilizing their flight. Before launching, these stabilizing sticks are generally inserted into thin tubes or other apparatus to aim and help guide the rockets as they are fired. Because of safety concerns regarding debris and the imprecise timing, firework rockets are rarely used in public displays.

ROCKET MALFUNCTIONS

Nearly all rocket malfunctions pose a threat to safety.

- If a rocket veers off course or is deflected off course, it may travel a great distance in a dangerous direction before functioning; thus posing a fire or explosion hazard far from its point of launch.
- If a rocket motor explodes shortly after ignition, the head will generally explode at the same time or shortly thereafter. This may shower the ground with burning materials.
- If a rocket is a dud (does not explode), the spent rocket and live heading may fall to the ground, possibly a very great distance from where it was fired.

Even if a rocket functions properly, it may still pose a safety hazard.

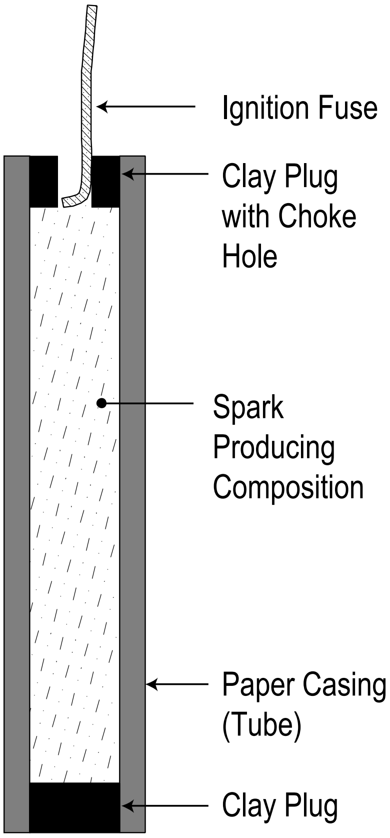
- Rockets track into wind (because the stick is deflected down wind and hence the rocket head is angled up wind) and thus may extend the fall out area considerably. Furthermore rockets fired directly into wind will tend to go more vertically upwards and achieve a greater altitude where as rockets fired directly down wind will tend to achieve a lower altitude but greater range. Consequently the greatest care must be taken when using rockets of any type to ensure that the fall out area is adequate.
- The spent rocket casing and attached stick may fall to the ground (somewhat like an arrow) a very great distance from where it was fired.

SET PIECES

FOUNTAINS, GERBS AND WATERFALLS

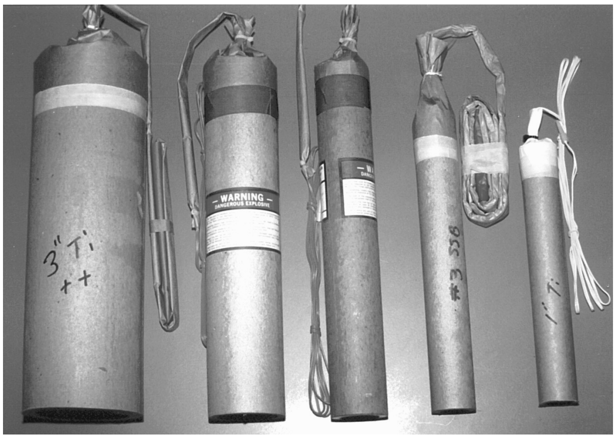
Fountains and gerbs are mostly the same thing. A fountain or gerb is made by packing a strong tube with a spark producing pyrotechnic composition. To make its spray of sparks extend farther, the tube is generally partially closed with a clay plug (choke).

Waterfalls are made by suspending a number of gerb-like devices upside-down from a wire above the ground to produce a wall of sparks falling downward. Unlike gerbs, waterfalls typically have open-ended tubes (without chokes). In order for all the tubes to ignite at nearly the same time, they are usually chain fused using quick match.

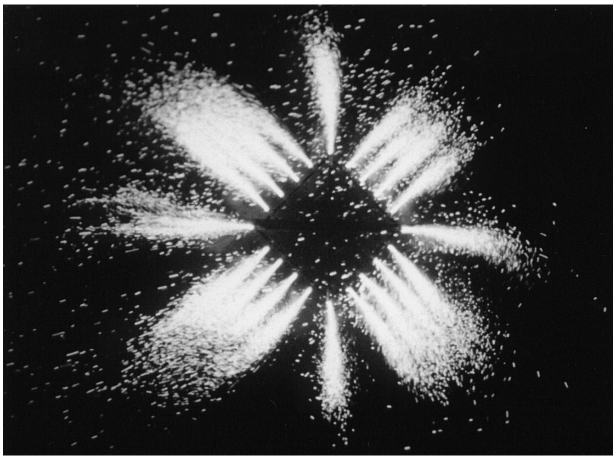


FOUNTAIN AND GERB EXAMPLES

Examples of display firework fountains and gerbs, ranging in size from 1 to 3 inches (25 to 75 mm) in inside diameter.



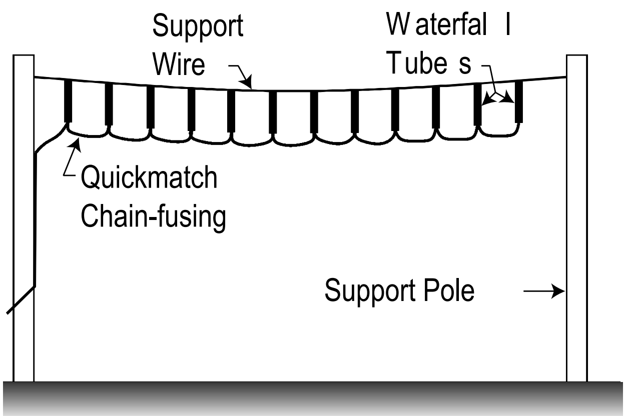
A display produced by mounting a collection of small gerbs on a framework. In this case, all the gerbs were chain fused together using quick match.



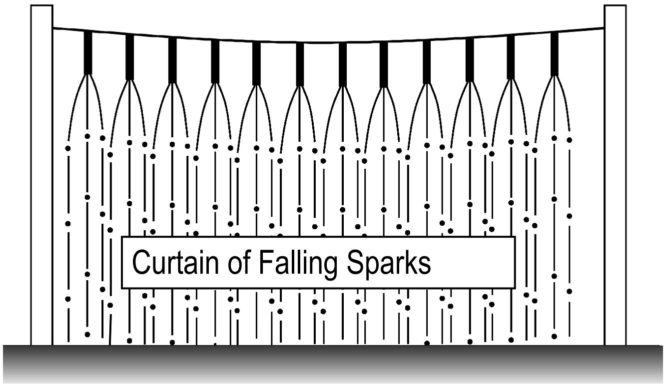
[Photo courtesy of R. Winokur]

WATERFALL EXAMPLE

A waterfall is made by suspending gerb-like devices upside-down from a wire.



An illustration of a waterfall as it might appear in operation.



Characteristics:

- ♦ Fountains generally range from less than 1/2-inch (13-mm) ID and perhaps 5-inches (125-mm) long to at least 3-inches (75-mm) ID and more than 12-inches (300-mm) long. However, gerbs and waterfall tubes generally do not exceed 1-inch (25-mm) ID.
- ♦ The projected sparks from fountains range in height from about 3 feet (1 m) to more than 20 feet (> 6 m).
- ♦ Burn time for these items ranges from less than 5 seconds to more than a minute.
- ♦ Spark colours range from dim gold (made using charcoal), through moderately bright yellow (made using ferrotitanium alloy), to dazzling white (made using aluminium or titanium metal), depending on the spark materials used.

Malfunctions:

- ♦ In the event that the internal pressure exceeds the strength of the tube, it will explode. However, this malfunction is not likely to cause a spectator injury (unless the explosion damages or repositions other fireworks).
- ♦ If the item comes loose from its mounting, it might dangerously propel itself towards the audience.

LANCEWORK

Lancework is literally a “picture in fire”. It is made by attaching many small tubes (lance tubes) containing coloured flame producing pyrotechnic composition to a framework in a pattern.

Typically lancework forms the outline of a familiar object or forms letters to spell out words.

The individual lance tubes are typically attached to the frame by pressing them onto an exposed headless nail(s) and gluing them in place. Most commonly, the lance tubes are all chain fused using quick match attached to their tips.

Characteristics:

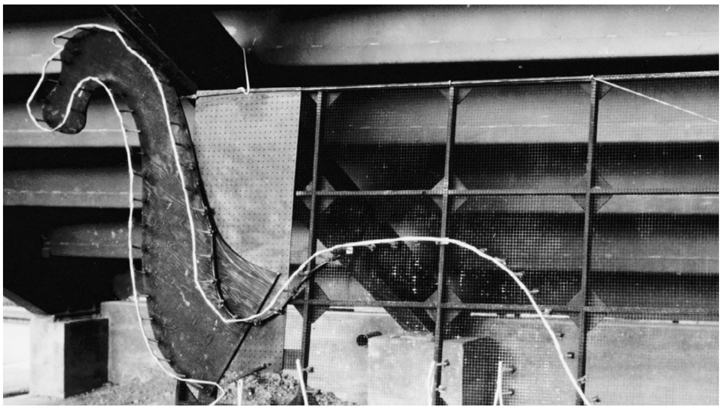
- ♦ Lance tubes are typically about 3/8-inch (10-mm) in diameter by 4-inches (100-mm) long.
- ♦ Lance composition can be made to burn various colours and may produce sparks as well.
- ♦ Generally, lance burns from 40 to 60 seconds.

Malfunctions:

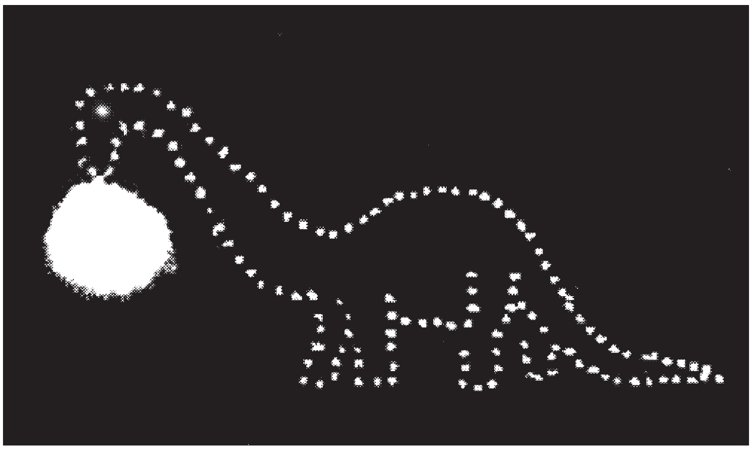
- ♦ There is essentially no way for a lancework to injure spectators unless there are other pyrotechnic devices included in its design.

LANCEWORK EXAMPLE

Lancework of a dragon being prepared. The head of the dragon can be moved up and down and appear to breathe fire and sparks on command.

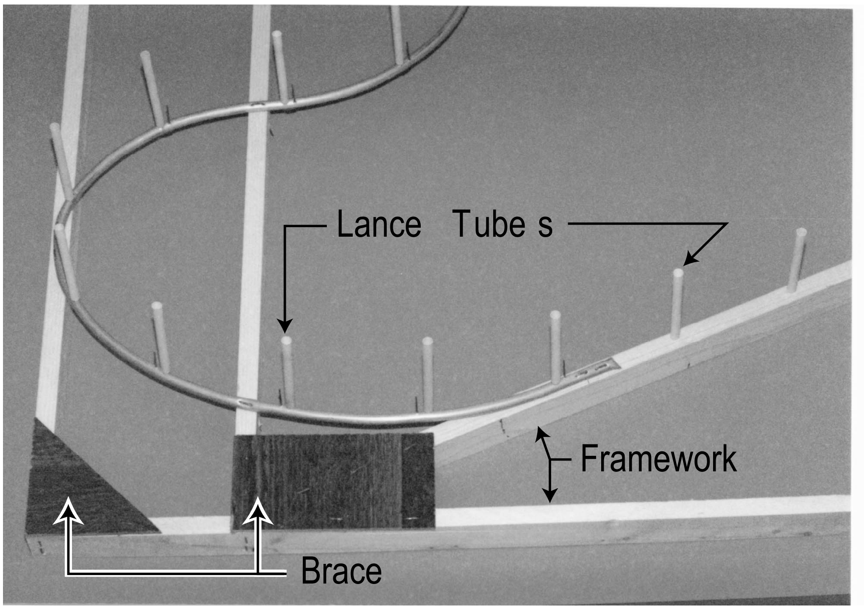


Dragon lancework with head bent downward breathing fire and sparks.

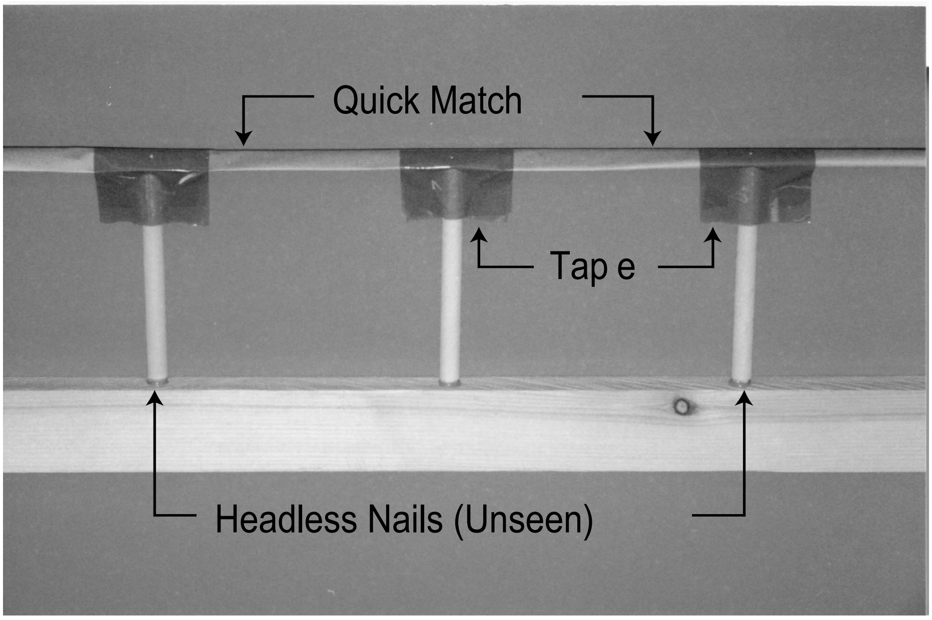


LANCEWORK CONSTRUCTION EXAMPLE

Lance tubes attached to a frame by pressing onto headless nails or into receptacles attached to the frame and then glueing in place. (The framework is usually painted black to make it less visible.)

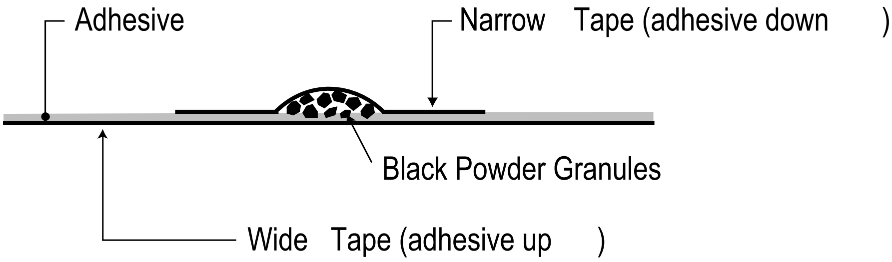


Quick match attached to the tips of lance tubes.



TAPE MATCH FUSING

Sticky Match™ is a newer fuse material that makes fusing lancework somewhat easier. It is formed from two-widths of plastic tape with a trail of Black Powder between. The adhesive on the wider tape provides attachment to the lance tubes.



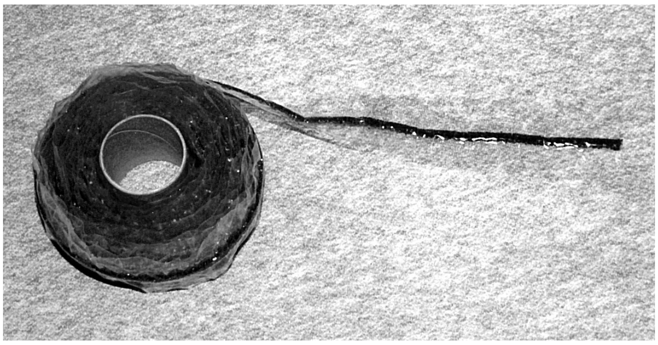
However, unlike quick match, the burn rate of Sticky Match is temperature dependent and can be quite slow in very cold weather. (Note that Sticky Match is supplied as fast or slow burning. The data below is for the fast variety.)

Temperature		Burn Rate	
(°F)	(°C)	(ft/s)	(m/s)
100	37	4.5	1.4
58	14	4.0	1.2
12	–11	2.0	0.6
–18	–28	1.0	0.3

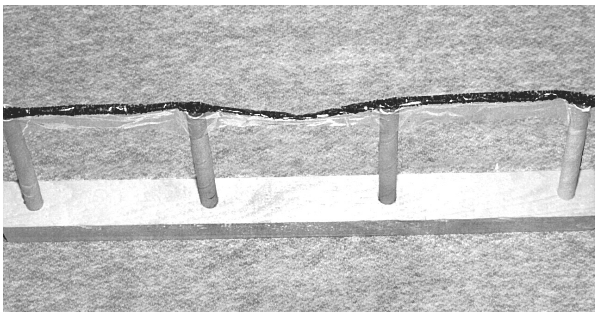
Sticky Match is also somewhat more sensitive to accidental ignition from sparks than quick match.

STICKY MATCH™ FUSING EXAMPLE

A roll of Sticky Match fuse.



Sticky Match in use as fusing for a series of lance tubes.



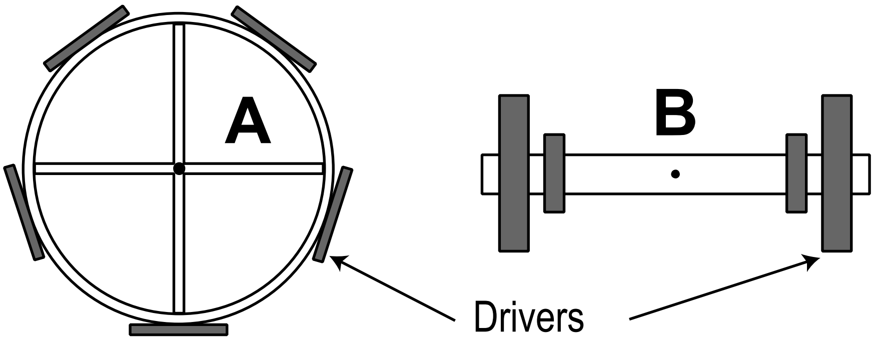
FIREWORK WHEELS

A typical firework wheel has a number of spark and thrust producing "drivers" attached to a framework capable of relatively free rotation about a central hub or axle.

Characteristics:

Firework wheels come in two basic variations, vertical and horizontal wheels, which rotate in the vertical or horizontal plane, respectively.

The wheel may appear round with two or more diagonal spokes (A) or may simply be a single board with an axle in the middle (B).

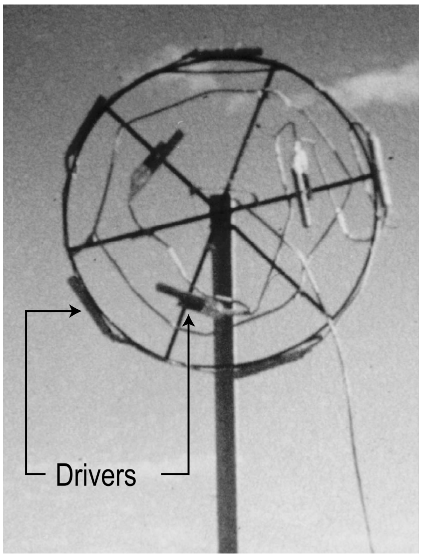


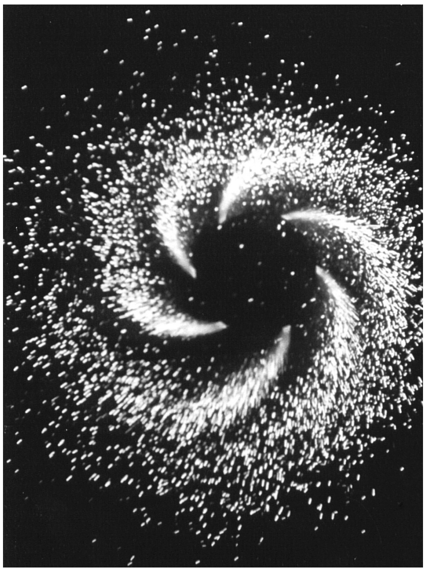
The size and number of drivers range widely, as do the number and type of other pyrotechnic items attached to the wheel.

Malfunctions: About the only malfunctions that threaten safety are if drivers fly from (or devices are thrown from) the wheel, or if the wheel comes loose from its mounting and rolls along the ground.

EXAMPLE OF FIREWORK WHEELS

A somewhat typical firework wheel mounted on a wooden pole, with its quick match fusing visible.





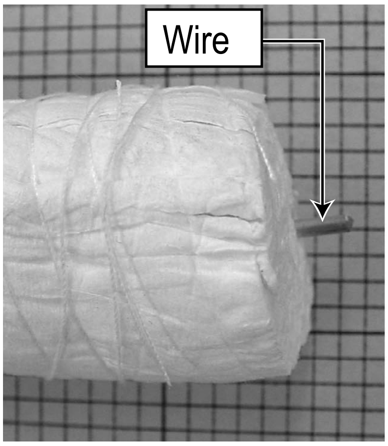
A firework wheel in operation at night.

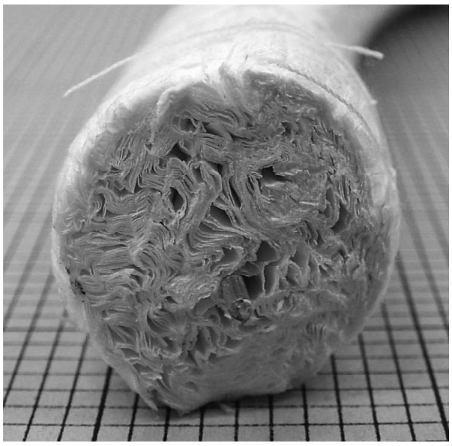
(Photos courtesy of R. Winokur)

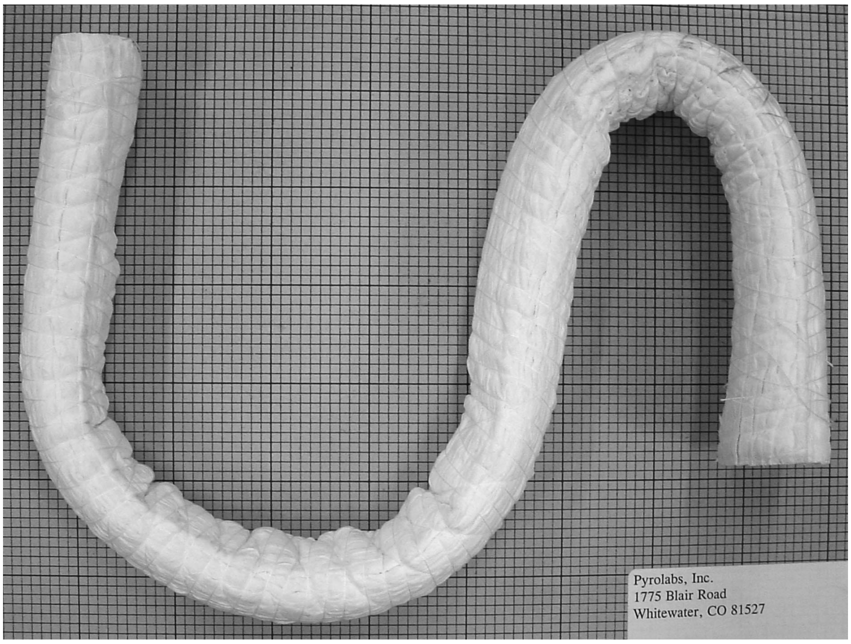
FIRE ROPE

Although not strictly a pyrotechnic effect, Fire Rope and designs produced with it are somewhat commonly used in other countries

Fire Rope is a thick cord of absorbent material (~1 inch or ~25 mm in diameter) formed around a malleable central wire that helps to hold the Fire Rope in its intended shape. [0.1 inch (2.5 mm) per div.]







Fire Rope displays are created by:

- Bending Fire Rope segments into the shape of the intended design and then securing the segments to a non-combustible framework.
- Shortly before its actual use, the Fire Rope is thoroughly wetted with a flammable liquid (typically diesel fuel).
- To produce the display, the design is ignited using any of a variety of methods (manually or electronically), and it burns for 10 to 15 minutes.

Below is an example of a display made using Fire Rope.

Fire Rope is also available with a loose plastic sleeve that retards the evaporation of the flammable liquid. This allows a longer time to elapse between wetting the Fire Rope and burning it.

SECTION 7 - GENERAL DISPLAY SITE REQUIREMENTS:

TERMS

- Firing area - this area is the area in which the fireworks are setup.
- Safety area - this area is the area between the firing area and the audience area and any other hazards such as buildings, roads, etc.
- Audience area - is the area in which the audience are positioned.
- Fallout area - this area is the area into which the fallout from the display is designed to land. However, care must be taken to ensure that the fallout from the display is actually going to fall in the fallout area - if the wind is from an usual direction and/or is particular strong then the debris from the fireworks may not land in the fallout area.
- Display site - is the whole area encompassing the firing area, safety area, audience area and fallout area.

DISPLAY SITE SIZE

Display site size is the single most important factor regarding public safety, generally with increased size resulting in increased safety.

The size and nature of the display site depends on a number of factors.

- The type of fireworks to be used (for instance shells vs cakes).
- The calibres of fireworks to be used (in general larger calibre fireworks require greater distances).
- The expected debris from the fireworks (for instance shells with long burning stars require greater distances than shells with ordinary stars).
- Other hazards near or on the site (such as trees, buildings, overhead wires etc.).
- The nature of the firing area and the general “lay of the land” (for example displays from roof tops or from barges or where there are trees or geographical features that restrict the type of fireworks that may be used).
- The expected number of audience.
- Other features including stages, car parks, lakes etc. - all of which may determine the types of fireworks which may be suitable.
- The client expectations and brief.

SITE SECURITY

Site security must be initiated immediately upon the arrival of the fireworks. This level of security can usually be provided by the display crew on site as opposed to needing to hire security guards.

Security requirements:

- No un escorted persons (non-crew members) are allowed in the area of the fireworks.
- No smoking within 50 feet (15 m) of any fireworks.
- No person present that is under the influence of alcohol or drugs.
- Protection of fireworks from theft.
- The fireworks are never left unattended.
- Protection of fireworks from weather damage (when necessary).
- Protection of fireworks from sparks (e.g., from bonfires).
- Only the operator, authorised assistants, and the authority having jurisdiction are permitted in the

firing area during the fireworks display.

- Electromagnetic radiation, e.g. from mobile phones or other hand held or other radio devises

Barriers and warning signs are appropriate.

Site security is made easier when:

- Boundaries are easily secured, for example, by fencing or other barriers, or where the features of the site themselves provide a barrier (for instance a lake)
- The firing site is one or more barges on a large body of water and patrol boats are present.
- An ample number of crowd stewards are present.

Site security must remain in effect after the display until the area has been inspected and declared safe by the senior firer.

OTHER SITE REQUIREMENTS

There must be no overhead obstructions of the fireworks. Obstructions include wires, tree limbs, light poles. An obstruction could cause the redirection or explosion of a firework striking the object.

The display site must be:

- Free of spectators, spectator vehicles, etc.
- Mostly free of combustibles, thus reducing the chance of a significant fire ignited by the display.

An example of an unacceptable large open area.

The tall thick grass makes a ground fire likely, and it will be nearly impossible to locate any duds.

Buildings and structures are allowed in the display site, with the permission of the Enforcers and the building owner.

THE CHRONOLOGY OF A DISPLAY

Prior to the display

- Visit the site
- Note distances, buildings, hazards etc.
- Complete a Risk Assessment (RA) including using ShellCalc as appropriate
- Select suitable fireworks

Planning the display

- Preparation of the fireworks
- Packing the fireworks for transport
- Loading the vehicle
- Driving to the display

At the site on the day of the display (and setting up)

- Is the display site still suitable for the planned display
- Check weather forecast and site plan
- If weather forecast and site have not changed continue with original plan
- If weather or site have changed, consult and modify plan or consider cancelling the display

During the display

- Monitor the display and fallout and prepare to stop the display if necessary
- Note any misfires or malfunctions for later action

After display

- Address any malfunctions or misfires and render safe
- Consult the organiser of the event to ensure that there have been no problems with the display.
- If there have been any injuries or other incidents then make notes NOW including details of firing area, wind strength and direction, where the incident occurred, details of those injured, collection of any debris if available etc.
- Clear up
- Repackage any unused fireworks, reload vehicle and vacate the site
- Travel back
- Unload and unpack
- Debrief if necessary

SITE PLAN

Site Plan — Why make one ?

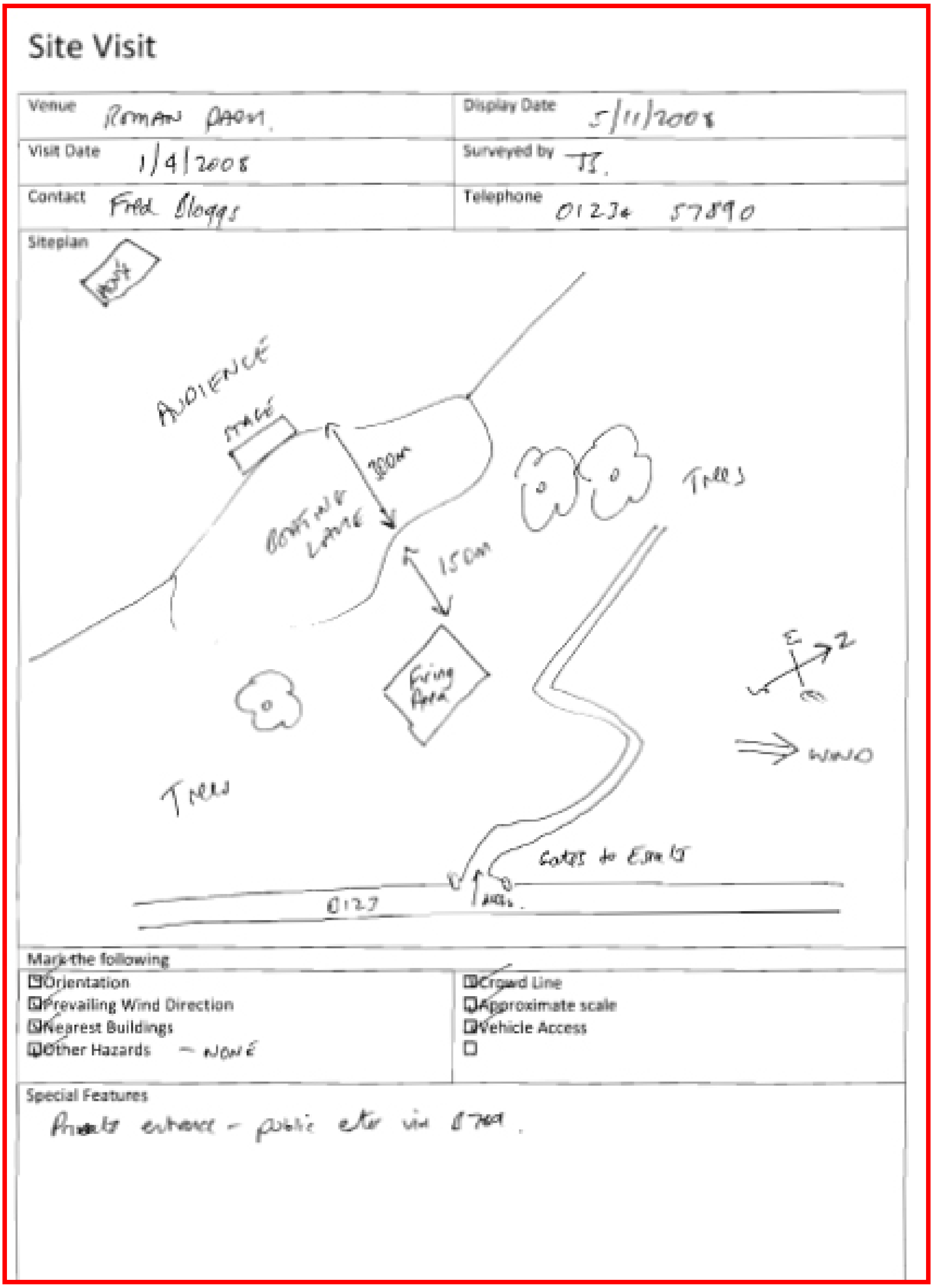
- It probably will be required for the RA.
- It will help decide what supplies and equipment are necessary for the display.
- It will help to evaluate the appropriateness of fireworks to be displayed.
- It will help to decide on the appropriate number and placement of crowd stewards.

- It will facilitate the setup of the display.

Site Plan — What should be included?

- Critical distances must be shown, but the plan need not be accurately drawn to scale.
- The planned location of firing area, safety area etc.
- The secured boundaries, and the location and number of crowd control stewards.
- The location of spectator and parking areas.
- Note anything needing special attention.

EXAMPLE SITE PLAN



Site Visit

Venue	Roman Park.	Display Date	5/11/2008
Visit Date	1/4/2008	Surveyed by	TJ.
Contact	Fred Bloggs	Telephone	01234 57890

Siteplan

Mark the following

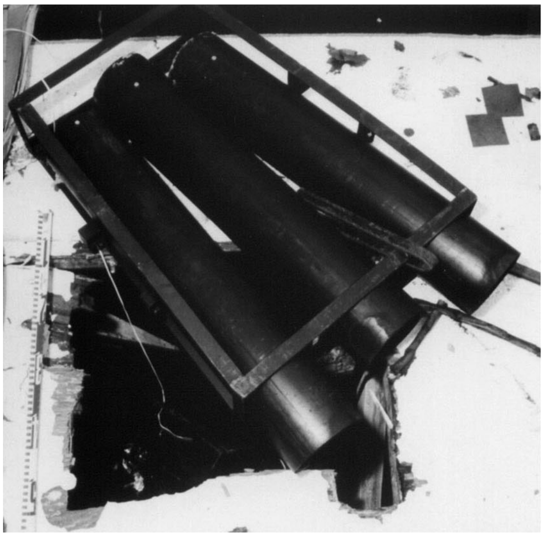
- ☑ Orientation
- ☑ Prevailing Wind Direction
- ☑ Nearest Buildings
- ☑ Other Hazards – NONE
- ☑ Crowd Line
- ☑ Approximate scale
- ☑ Vehicle Access
- ☐

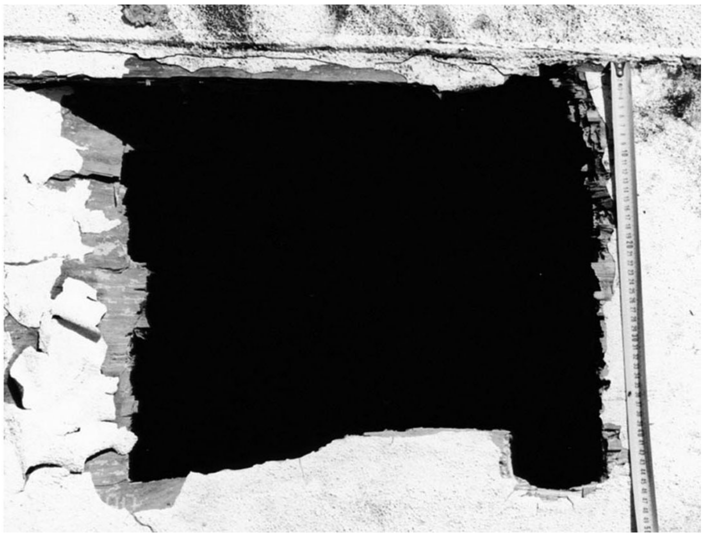
Special Features

FLOATING VESSELS AND PLATFORMS GENERAL REQUIREMENTS

Displays can be fired from floating vessels and platforms; they may be manned or unmanned but must be kept under control at all times. In general, all the requirements for on-land sites apply to displays fired from floating vessels and platforms. In addition, the vessel or platform decking must be sufficiently strong and stable to allow the safe firing of the display.

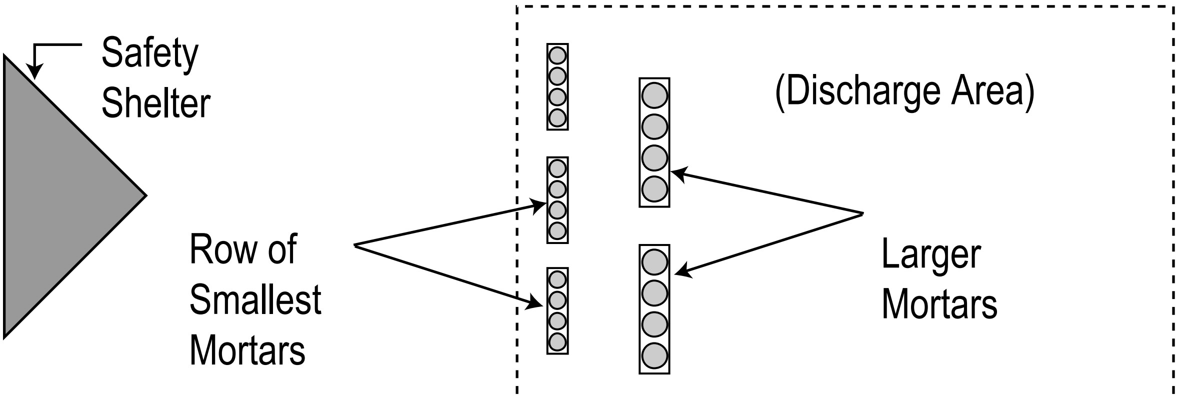
An example where a wooden barge deck was not sufficiently strong (as evidenced by the hole).



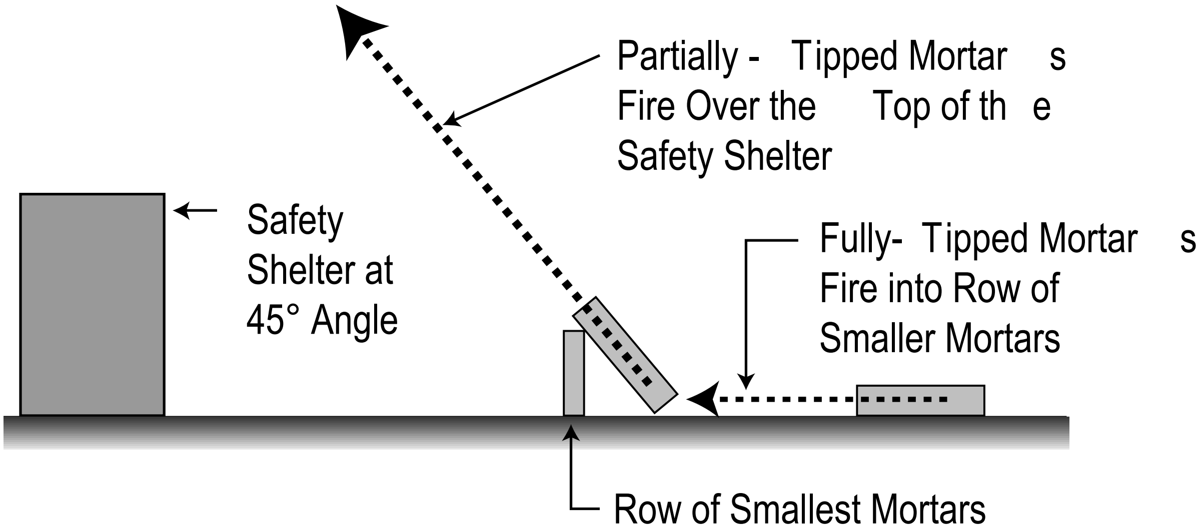


FIRING POSITION

Instead of placing one side wall of the safety shelter facing directly towards the firing area, consider placing two walls, each at a 45-degree angle to the firing area.



Consider using a row of small diameter (3- or 4-inch / 75- or 100-mm) mortars closest to the safety shelter to act as a barrier. In the event that larger diameter mortars become aimed at the safety shelter, any shells fired from those mortars will either strike the barrier or will pass safely over the top of the shelter.



DIFFICULT SITES

Displays can also be fired from a number of more challenging sites including the following:

- Barges
- Roof tops
- Bridges
- City Centres

The same general principles apply to all sites. However, there are challenges associated with firing displays from such sites including:

- The nature of the firing surface (e.g. concrete or steel rather than fields)
- Electricity (e.g. substations or cables)
- Vents
- Gas Holders
- Sky lights
- Rubbish

SECTION 8 - FIREWORKS DISPLAY EQUIPMENT:

Firework mortar types

- FRE
- HDPE
- Paper
- ABS
- Metal
- PVC

Firework mortar requirements:

- Diameter
- Strength (wall thickness)
- Length
- Mortar plugs

Mortar inspections

Mortar racks, boxes (troughs) and barrels

Shell box

Other display equipment

Personal protective equipment (PPE)

Emergency equipment

FIREWORK MORTARS

All mortars are capable of producing dangerous flying debris under some conditions when aerial shells explode within them. Accordingly, when personnel are to be near the mortars when they are being fired some type of barricading should be provided to help protect those personnel.

The Canadian Explosives Research Lab (CERL) conducted tests of mortars with aerial shells exploding within them. The results helped to establish the relative safety of various firework mortar materials.

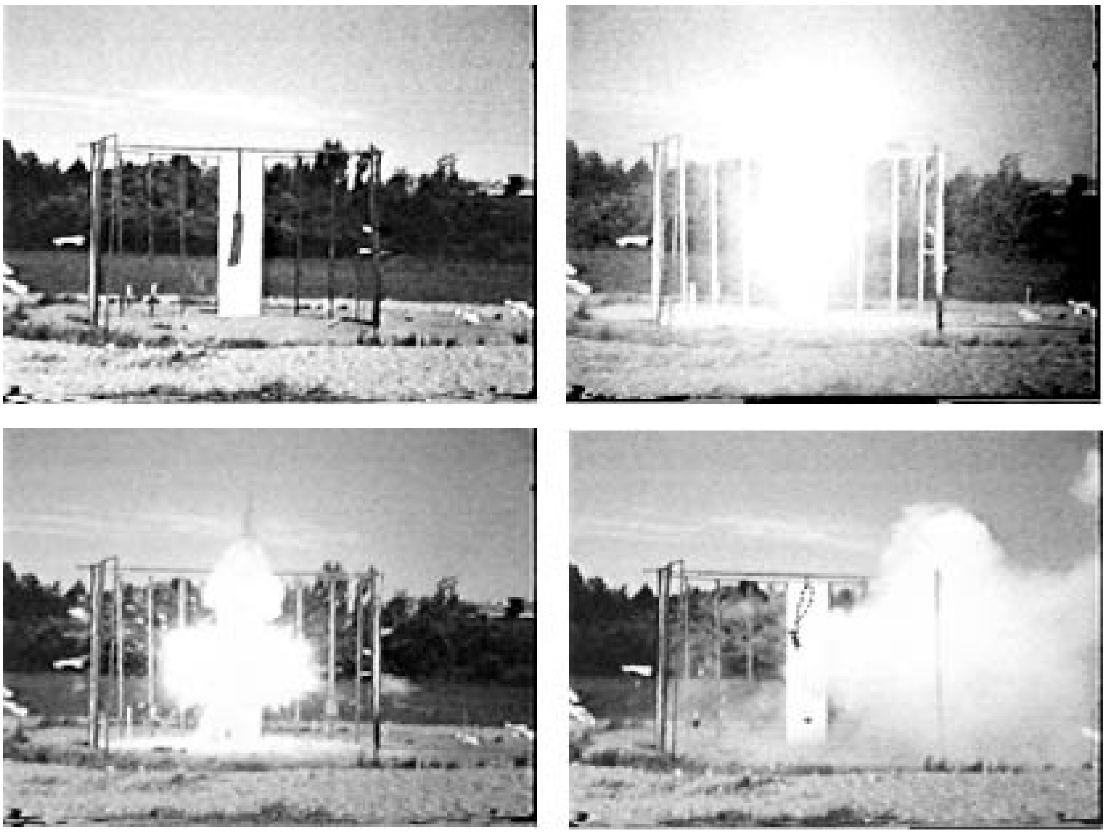
Unless otherwise noted the following photos are of 5-inch (125-mm) mortars tested at 68–77 °F (20–25 °C).

While there was often a range of test results, the photos chosen were of typical results.

It is not possible to rank the relative safety of mortars under all conditions in a single list. However, the following is an attempt to do that for typical conditions of a manually fired display. The list starts with mortar material types that are probably the safest and ends with some that are completely unacceptable.

CERL MORTAR TESTS

A sequence of images of one of CERL'S mortar tests.



Upper left, a suspended mortar just before test. Upper right, the first instant of explosion. Lower left, some mortar fragments that are sufficiently illuminated by the explosion are seen travelling away from the explosion. Lower right, a remnant of the mortar is seen still attached to the support structure.

FIREWORK MORTAR TYPES

Approximate relative safety rank of mortar types:

GRP — Fibre Reinforced Epoxy (Fibreglass) —Mortar fragments are generally of relatively low hazard. If the mortar is closed with a wooden plug, that can become a dangerous fragment(s).

HDPE — High Density Polyethylene — Mortar fragments are generally of moderately low hazard. If the mortar is closed with a wooden plug, that can become a dangerous fragment(s).

Paper/Cardboard — Either spiral- or convolute-wound tubes:

Mortar fragments are of moderately low hazard. The wooden plug can produce a dangerous fragment(s).

Impregnating the mortar with something to make it moisture resistant is a good practice.

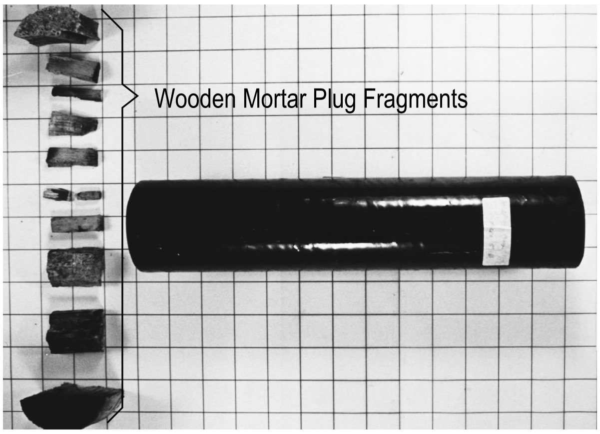
Generally all paper mortars that are placed in the ground or sand will need to be protected from moisture using a plastic bag or something equivalent.

Loose internal wraps of paper can cause an aerial shell to get caught momentarily when fired from the mortar and can cause malfunctions as a result. Also the mortar itself may catch fire.

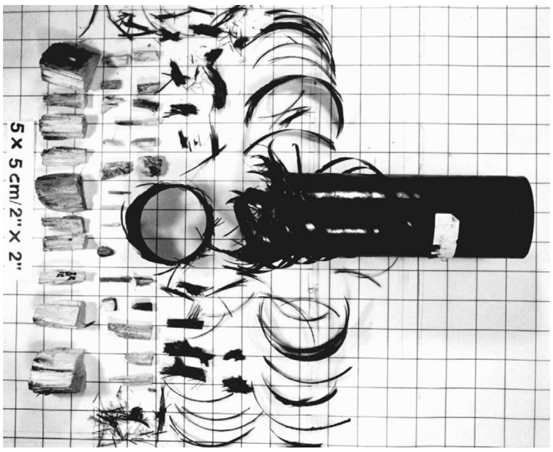
(This list continues following photos of these mortar types.)

GRP OR FIBREGLASS MORTARS

Result of a star shell exploding in a GRP mortar.

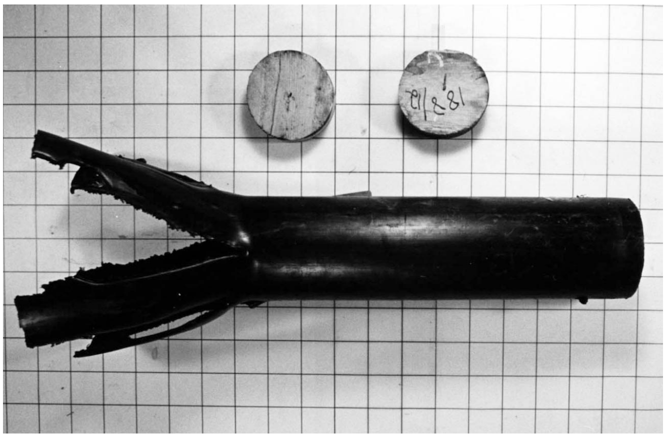


Result of a salute exploding in a GRP mortar.

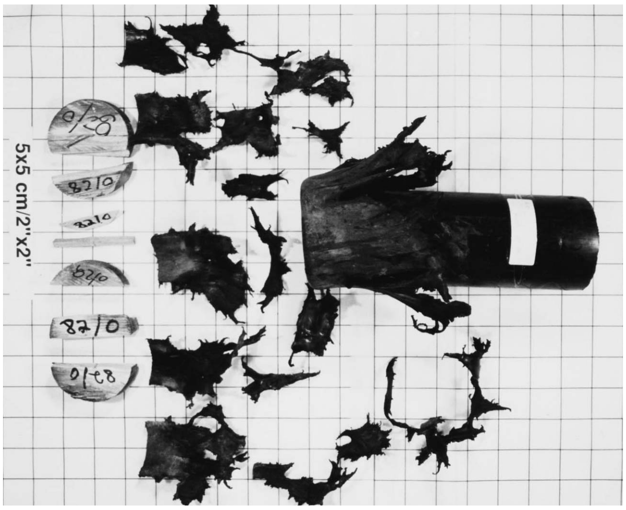


HIGH DENSITY POLYETHYLENE MORTARS

Result of a star shell exploding in an HDPE mortar.

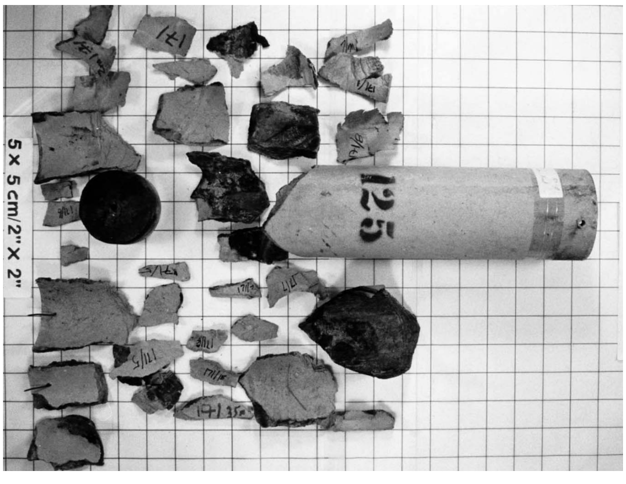


Result of a salute exploding in an HDPE mortar.

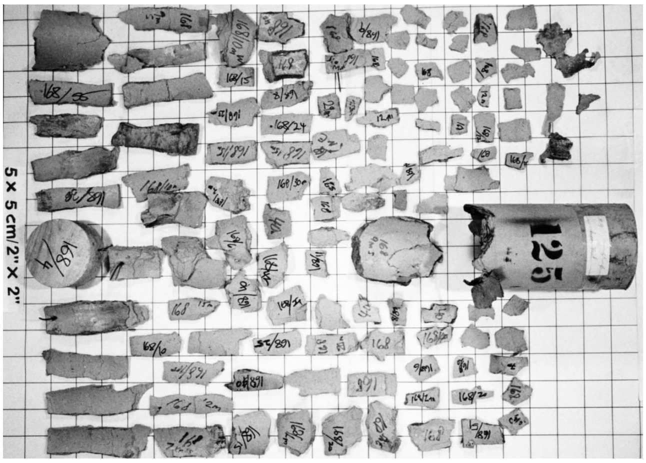


PAPER OR CARDBOARD MORTARS

Result of a star shell exploding in a paper mortar.

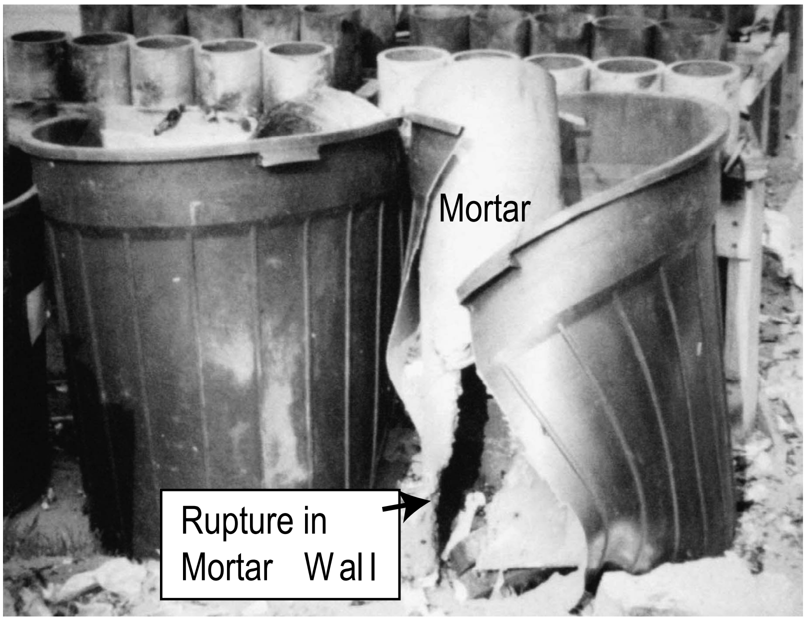


Result of a salute exploding in a paper mortar.

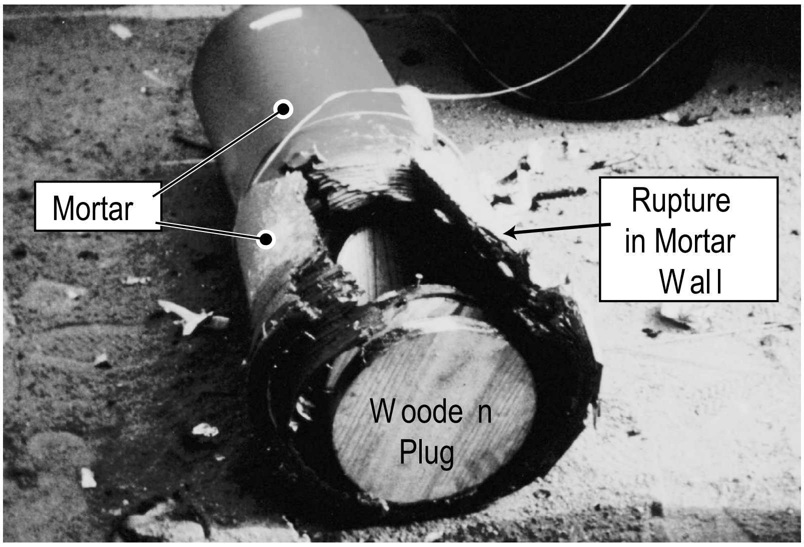


MOISTURE WEAKENED PAPER MORTARS

An example of a 12-inch (300-mm) paper mortar rupture as a result of moisture having weakened it.



The results of moisture damage. Note that tube above the moisture damage is still in excellent condition.



An example of a moisture damaged paper mortar.

An example of delamination of a moisture damaged paper mortar.

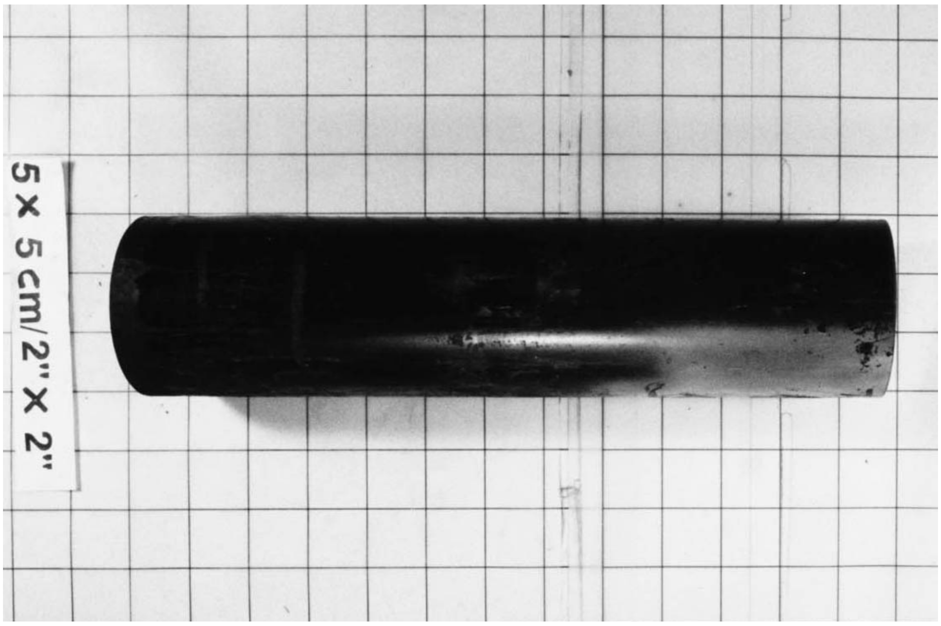
Metal mortars - Their strength is generally sufficient to withstand the forces of an exploding star shell. However, when they do rupture, such as from a salute or star shell "detonation", they produce very dangerous fragments. The fragments and the mortar itself can travel a great distance and carry much impact energy.

These mortars are high strength and may be necessary when firing large multi-break shells.

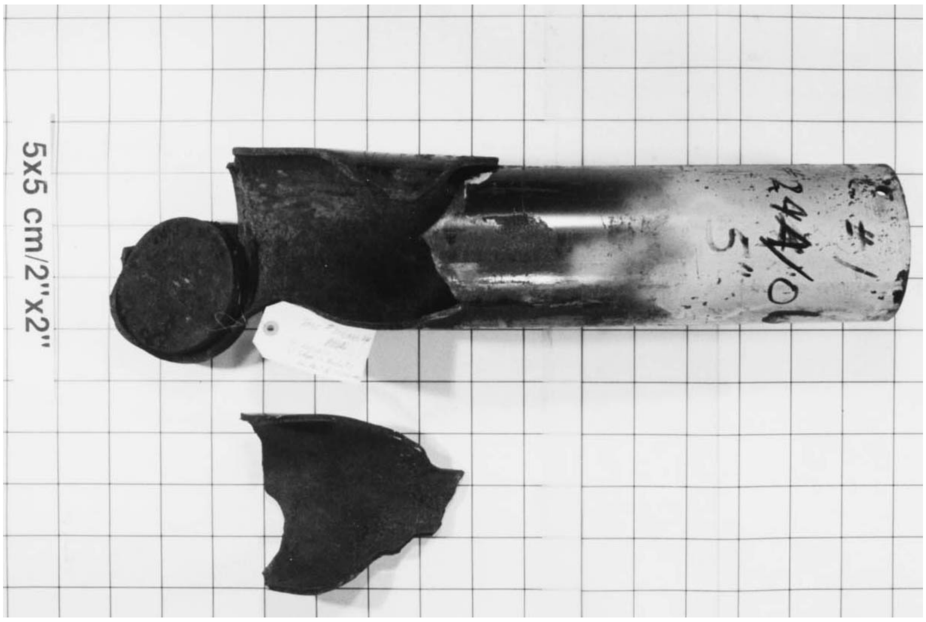
ABS — Acrylonitrile-Butadiene-Styrene) — A somewhat resilient plastic of moderate strength. Fragments are substantially more hazardous than those from HDPE mortars. If closed with a wooden plug, that too can produce additional dangerous fragments.

STEEL MORTARS

Result of star shell exploding in a thick steel mortar.

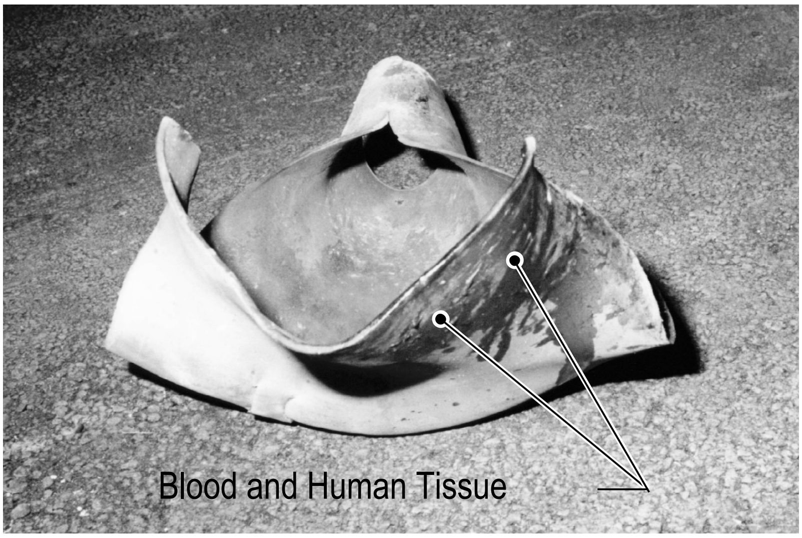


Result of salute exploding in a thick steel mortar.



STEEL MORTAR INJURY SCENE

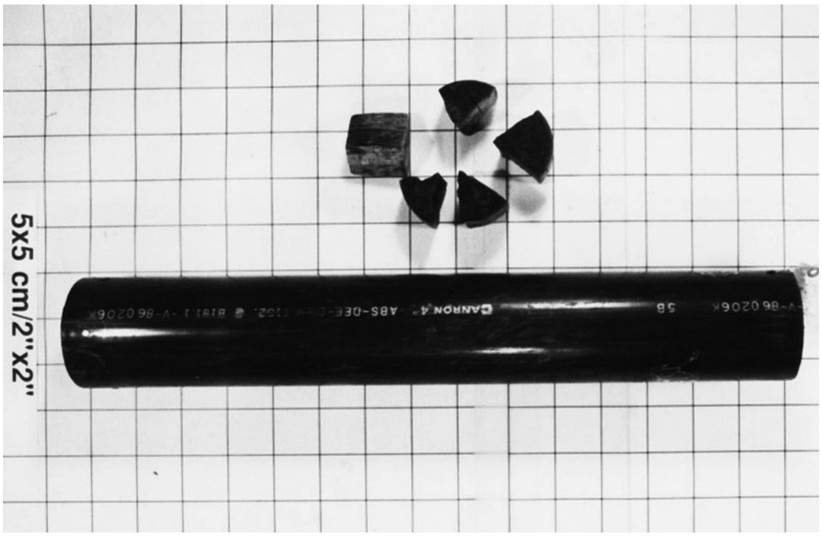
A properly buried 5-inch (125-mm) steel mortar that burst and landed more than 150 feet (45 m) away.



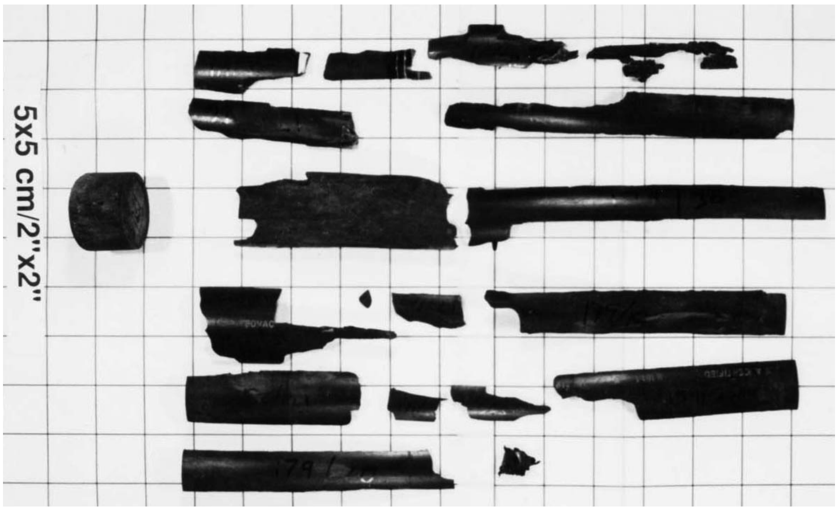
Example of a 12-inch (300-mm) steel mortar with damage from a shell “detonation”.

ACRYLONITRILE-BUTADIENE-STYRENE MORTARS

Result of a star shell exploding in an ABS mortar.



Result of a salute exploding in an ABS mortar.

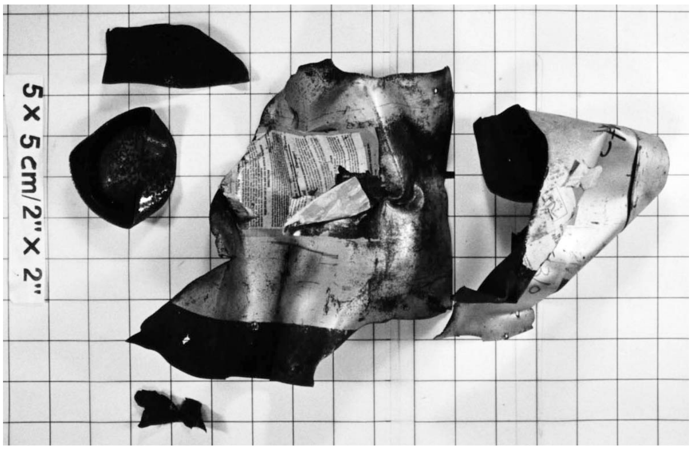


Sheet Steel and Aluminium (seamed or seamless) — These mortars are much weaker than Schedule 40 steel and fail more often. At close range the fragments are quite dangerous, but their maximum range is probably less than for thick steel mortars.

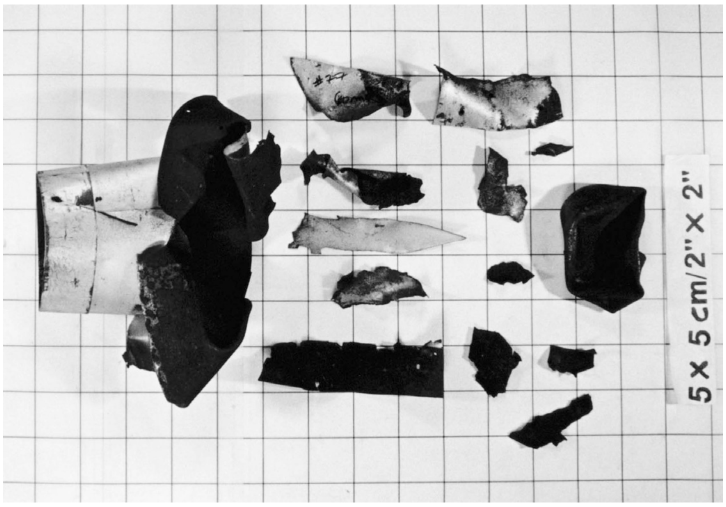
PVC — (Polyvinyl Chloride) — A moderate strength material, but its low elasticity will often cause it to shatter from an internal explosion. At close range the fragments are very dangerous, but their maximum range is less than for thick steel mortars. [No PVC mortars were tested by CERL; however photos of low temperature ABS fragments appear very similar to those produced at normal temperature by PVC mortars.]

SHEET STEEL MORTARS

Result of star shell exploding in a sheet steel mortar.

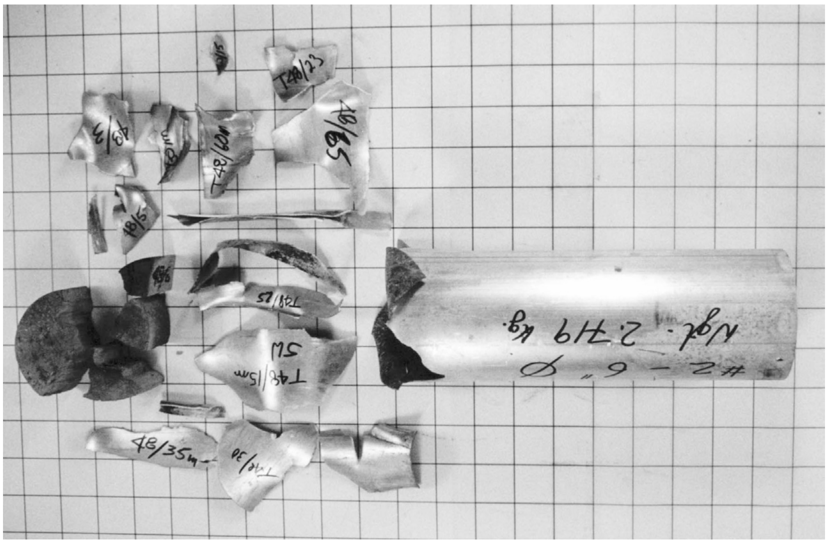


Result of salute exploding in a sheet steel mortar.

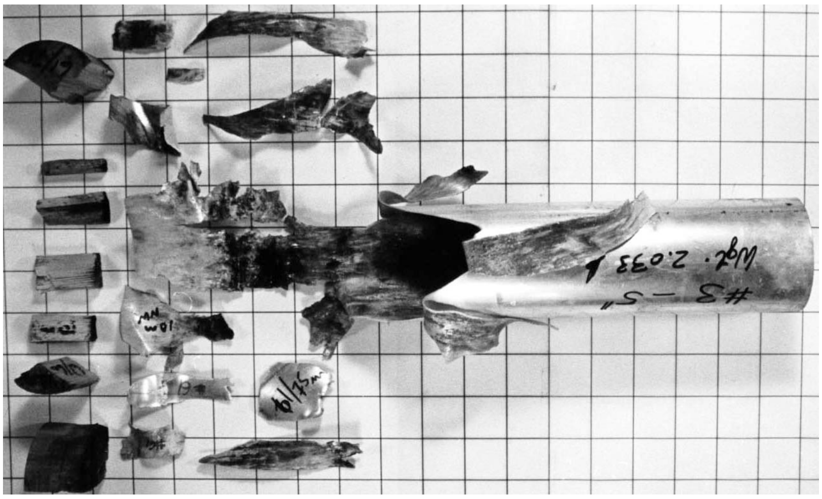


ALUMINIUM MORTARS

Result of star shell exploding in an aluminium mortar.

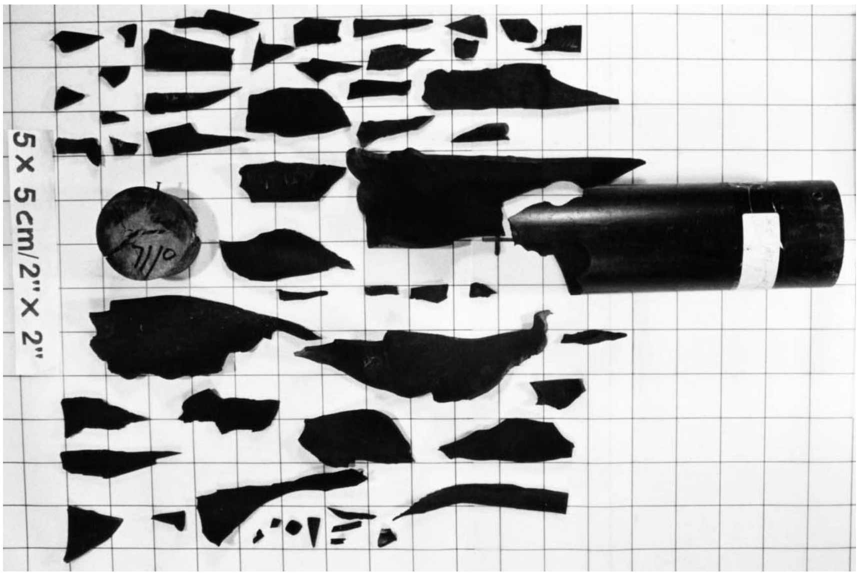


Result of a salute exploding in an aluminium mortar.

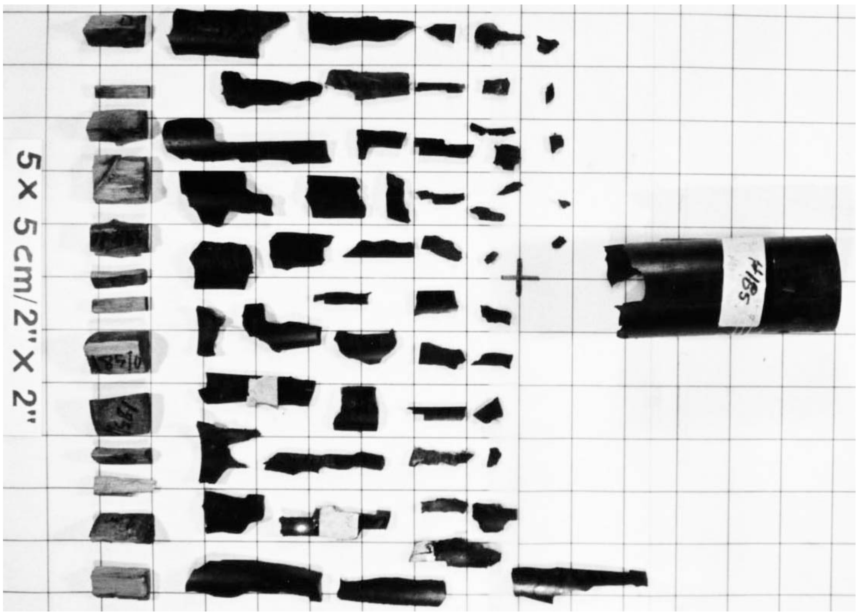


PVC MORTARS

Expected result for a star shell exploding in a PVC mortar (same as ABS at low temperatures).



Expected result for a salute shell exploding in a PVC mortar (same as ABS at low temperatures).



UNACCEPTABLE MORTAR TYPES:

Cast iron and ceramic tile pipe are unacceptable for mortars as well as brittle plastics and carpet rolls. The material is low strength and/or shatters to produce highly dangerous, long range fragments. Other unacceptable mortar materials include stove pipe, corrugated culvert, clay, bamboo and wood and other readily available tubing such as carpet rolls and brittle plastics

CERL — TEST MORTAR SPECIFICATIONS

Following are the specifications for the mortars displayed in the previous photos.

Mortar Material	Size		Wall Thickness		Plug Length	
	in.	mm	in.	mm	in.	mm
FRE	5	125	0.09	2.4	3.1	79
HDPE + Plug	5	125	0.27	6.9	3.7	95
Steel - Sch. 40	5	125	0.26	6.6	0.5	13
ABS	4	105	0.20	5.2	2.6	65
Sheet Steel	5	125	0.03	0.8	0.6	15
Aluminium	5	125	0.08	2.1	2.9	73

All of the mortars used were new or virtually new prior to testing.

As some types of mortars age they seem to become more brittle (e.g.,steel where the chemical reaction of carbon monoxide (CO) on the iron causes the steel to lose its strength).

HDPE mortars have a long use history, there is no evidence that they weaken over time.

Paper mortars generally have a short useful lifetime.

TEMPERATURE EFFECTS ON MORTARS

As the temperature is lowered, all materials become more brittle. This is particularly noticeable for plastic mortars.

Material	Moderate Temp. ~ 70 ºF (~ 20 ºC)	Low Temp. < 0 ºF (<–17 ºC)
FRE	Low Hazard	Low Hazard
HDPE	Thin Pieces	Large Chunks *
ABS	Large Chunks *	Shatters +
PVC	Shatters +	Shatters +

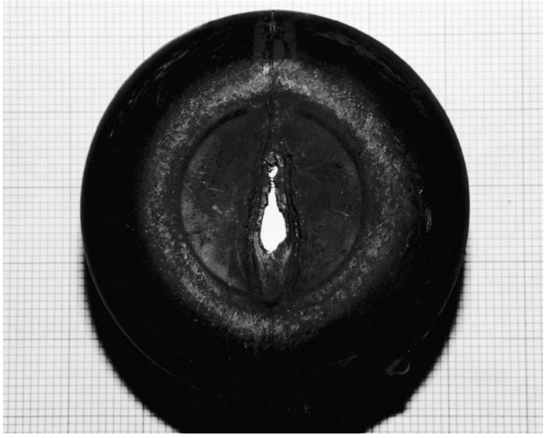
*This poses a safety concern if personnel are in the immediate area.

+The pointed and sharp nature of these mortar fragments is such that the use of such mortars is generally unacceptable.

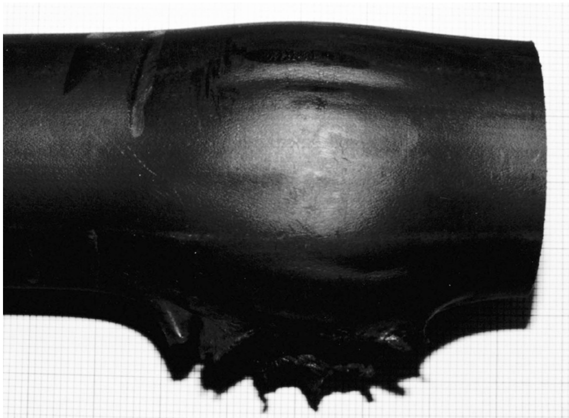
If plastic mortars are fired repeatedly (5 to 10 times) in a relatively short time span (< 30 minutes), the temperature of the mortar may rise to a point where the mortars lose most of their strength and can fail as a result.

PLASTIC MORTAR FAILURE AT HIGH TEMPERATURE

A minor opening in the bottom of a molded HDPE mortar occurred after 10 shell firings in 5 minutes.



A major opening in an HDPE mortar produced by the firing of an aerial shell after repeated firings had raised its temperature to more than 190 ºF (88 ºC).

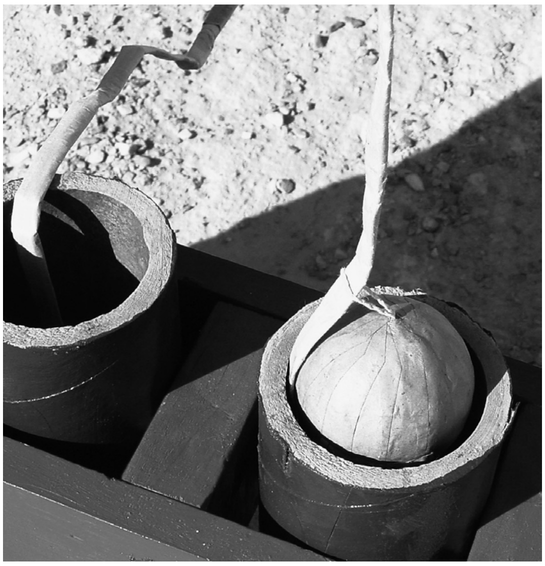


-

FIREWORK MORTAR REQUIREMENTS

Mortar Diameter:

A reasonably close fit of the shell is necessary to sufficiently contain the propelling lift gases. However, the fit must be loose enough to allow the shell to slide freely into and out of the mortar.



The mortar's internal diameter should be within approximately 5% of the nominal size.

Total clearance between shell and mortar wall.

Aerial Shell Size		Typical Clearance (Total)	
(inches)	(mm)	(inches)	(mm)
2.5 to 4	63 to 100	1/4	6
5 to 6	125 to 150	3/8	9
8 to 12	200 to 300	1/2	12

Strength Required:

The mortar must have sufficient strength to withstand the internal pressure of normal shell firings plus a safety margin.

Note that the combination of wall thickness and material tensile strength determines the burst strength of mortars.

To compensate for the use of lower tensile strength mortar material, the wall thickness of the material can be increased.

If there is doubt about the strength of a mortar, conduct a test.

MORTAR STRENGTH — GENERAL GUIDANCE

Fibreglass or Fibre Reinforced Epoxy (FRE) Mortars: Adequate Mortar Wall Thickness.

Fibre Reinforced Epoxy (FRE) Mortars

Mortar ID (in.)	Adequate Mortar Wall Thickness (in.)[a]		
	Spherical[b]	Cylindrical Single-Break	Cylindrical Two-Break
2	0.07	0.11	0.11
2.5	0.07	0.11	0.11
3	0.07	0.11	0.11
4	0.11	0.11	0.11
5	0.11	0.11	0.11
6	0.11	0.11	0.11
8	0.25	(c)	(c)
10	0.25	(c)	(c)
12	0.25	(c)	(c)
>12	(c)	(c)	(c)

For SI units, 1 in. = 25.4 mm.

(a) The tensile strength of fibreglass should be at least 11,000 psi (76 MPa).
(b) Mortars for spherical two-break shells should use cylindrical single-break wall thickness.
(c) Data not currently available.

HDPE Mortars: Illustrative Mortar Wall Thickness.

High-Density Polyethylene (HDPE) Mortars:

Mortar ID (in.)	Adequate Mortar Wall Thickness (in.)[a]		
	Spherical[b]	Cylindrical Single-Break	Cylindrical Two-Break
2	0.12	0.17	0.17
2.5	0.12	0.17	0.17
3	0.15	0.17	0.17
4	0.20	0.25	0.25
5	0.25	0.25	0.25
6	0.30	0.32	0.32
8	0.32	(c)	(c)
10	0.32	(c)	(c)
12	0.37	(c)	(c)
>12	(c)	(c)	(c)

For SI units, 1 in. = 25.4 mm.

(a) The tensile strength of the plastic should be at least 3,300 psi (22.75 MPa).
(b) Spherical two-break shells should use cylindrical single-break mortar wall thickness.
(c) Data not currently available.

Paper Mortars: Illustrative Mortar Wall Thickness.

Paper Mortars:

Mortar ID (in.)	Adequate Mortar Wall Thickness (in.)[a]		
	Spherical[b]	Cylindrical Single-Break	Cylindrical Two-Break
2	0.18	0.25	0.37
2.5	0.18	0.25	0.37
3	0.25	0.25	0.37
4	0.25	0.33	0.50
5	0.31	0.42	0.62
6	0.37	0.50	0.75
8	0.50	(c)	(c)
10	0.62	(c)	(c)
12	0.75	(c)	(c)
16	(c)	(c)	(c)

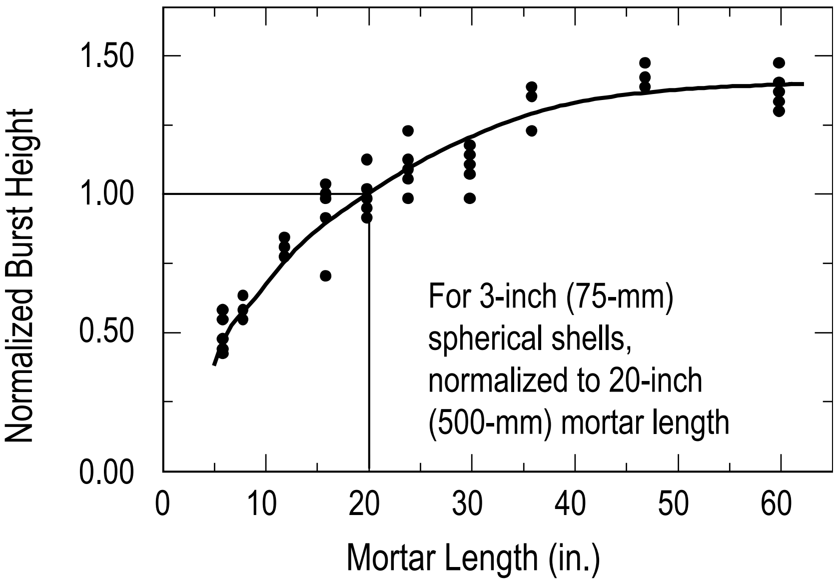
For SI units, 1 in. = 25.4 mm.

(a) The cross-grain tensile strength of the paper should be at least 2,300 psi (16 MPa).
(b) Spherical two-break shells should use cylindrical single-break mortar wall thickness.
(c) Data not currently available.

MORTAR LENGTH

Mortar Length Required:

The length of the mortar has an effect on the height to which an aerial shell will be propelled.



A generally appropriate recommendation:

Shells <8” ID (<200 mm), mortar length ≥5 times ID.

Shells ≥8" ID, mortar length ≥4 times ID.

If in doubt of sufficient mortar length, conduct a test by firing a hard-breaking spherical aerial shell. If the shell height is at least twice the star spread radius, the mortar length is sufficient.

Suggested Minimum Inside Mortar Length.

Mortar ID (in.)	Minimum Mortar Length (in.)[(a)]		
	Single-Break	Double-Break	Up to 4-Break
2[(b)]	10	12	15
2.5[(b)]	12	15	18
3	15	18	21
4	20	23	27
5	24	28	32
6	28	32	37
8	34	40	46
10	40	46	54
12	46	52	62
>12[(b)]	(c)	(c)	(c)

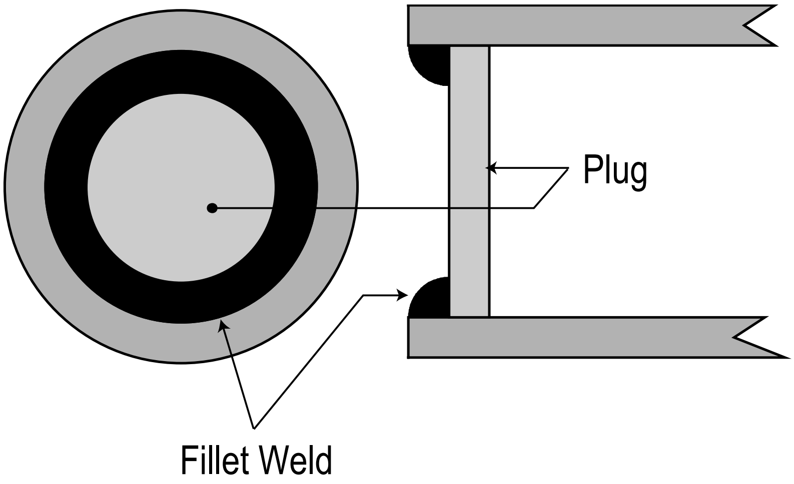
For SI units, 1 in. = 25.4 mm.

o Mortar length is measured from the top of the mortar plug to the mouth of the mortar.

o Data not currently available.

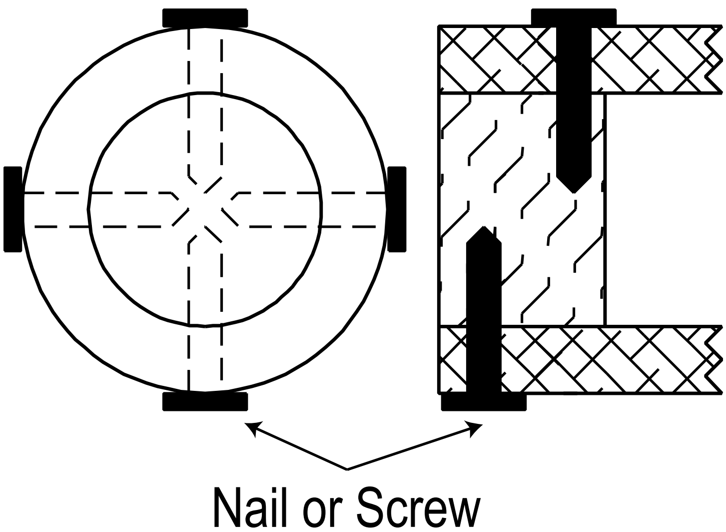
MORTAR PLUGS

Welded Plugs: In mortars, such as steel, aluminium and some plastics, a welded plug can be attached. This should be a “fillet” weld (as opposed to being a “butt” weld). The plug should be at least as thick as the mortar wall.



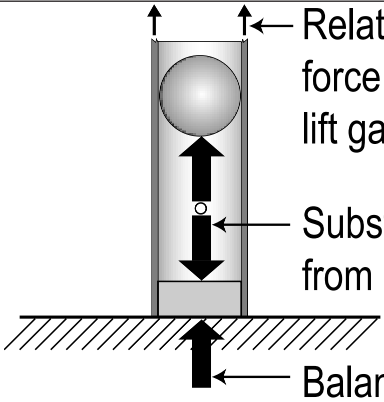
Integral Plugs: For some types of plastic mortars, such as GRP and HDPE, the plugs may be molded or formed as an integral part of the mortar. Generally, this is preferred because separate wooden plugs can become dangerous flying debris in the event there is an explosion within the mortar. Also any screws or nails used to fasten wooden plugs can be weakened over time by corrosion and in a catastrophic failure, they can become an additional projectile hazard.

Wooden Plugs: Any mortar may be plugged using a wooden plug. Most commonly, paper and plastic mortars use wooden plugs. The plug should be the same diameter as the ID of the mortar such that there are no gaps around the plug. If the mortar is paper or cardboard, the plug should be equal in length and diameter. For plastic and metal mortars, the plug thickness should be at least half the plug’s diameter. These plugs are generally nailed, screwed or bolted in place.



BELOW MORTAR SUPPORT

When the support below a mortar is not very strong, a much greater stress is placed on the plug fasteners, and it is much more likely that the plug will be blown out. The reason for this is illustrated below:



To reduce the chance of plugs blowing out, use a sufficient number of strong fasteners, and provide solid support below the mortars.

Strong support is more of a problem when mortars are angled from vertical.

MORTAR INSPECTIONS

An inspection of mortars is required before shipping and before use and should include:

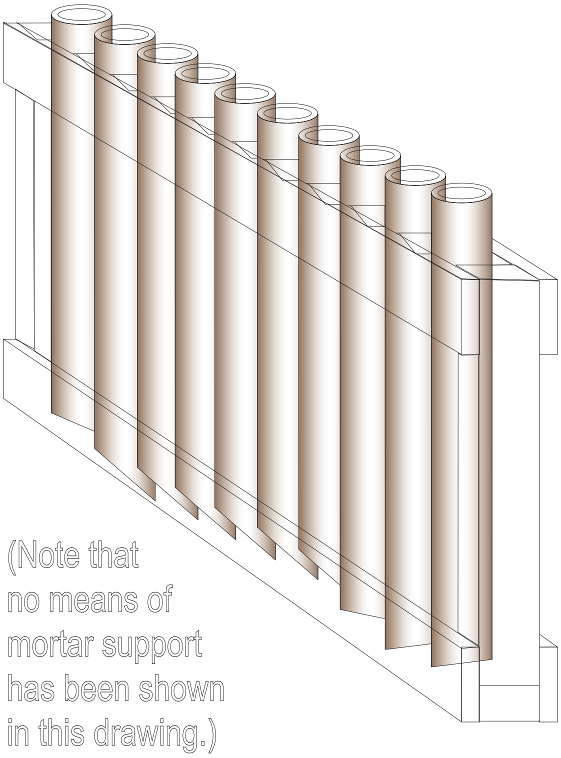
- Mortars must be the proper diameter (test by inserting the aerial shells to be fired).
- Mortar plugs must be secured with little or no gap between the plug and mortar wall.
- There must be no constricting dents in the wall of the mortar.
- Mortar interiors must be reasonably clean and free of snags that could catch on an exiting aerial shell.
- Mortars should have reasonably smooth interiors. (Torn paper from the mortar wall can be a substantial concern for paper mortars.)
- There should be no moisture deterioration. (This is especially a concern for paper mortars.)

It may be an aid to have the mortar size (ID) clearly marked on their top exterior.

Defective mortars must not be used

MORTAR RACKS AND SIMILAR EQUIPMENT

Sturdy rack construction is required. The rack should be able to withstand the explosion of a mortar within the rack, and if it does fail to do so in such a way that adjacent mortars do not tip over and potential aim towards the crowd.

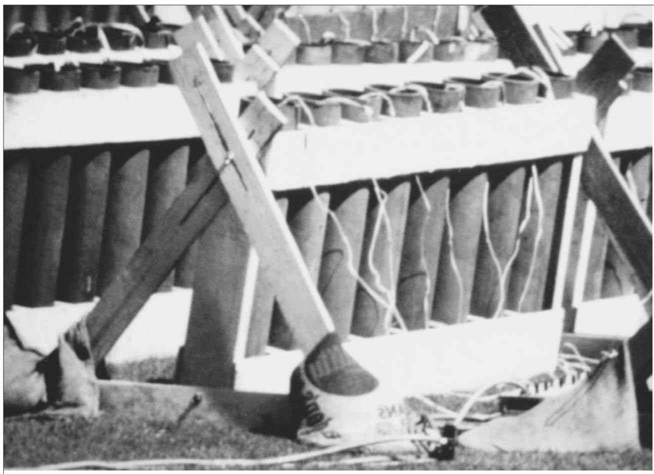


Racks for small calibre shells (e.g. 2.5” - 4”) may be constructed as shown above as there is no evidence that the failure of a shell of these calibres in, for instance HDPE mortars, leads to disruption of the rack. For larger calibre shells (e.g. 5”- 6”) it has been shown that a “ladder rack” type of racking system ensures that the failure of any one mortar does not effect adjacent mortars. Further details of such “ladder rack” systems will be made available shortly.

The Health and Safety Laboratories (HSL) and Kimbolton Fireworks have carried out extensive research on Mortar failures in racking systems and the results of this research will be published in the *Journal of Pyrotechnics*

WOODEN RACK EXAMPLES

A wooden rack with adjustable bracing for angling and sand bags on the legs for stability.



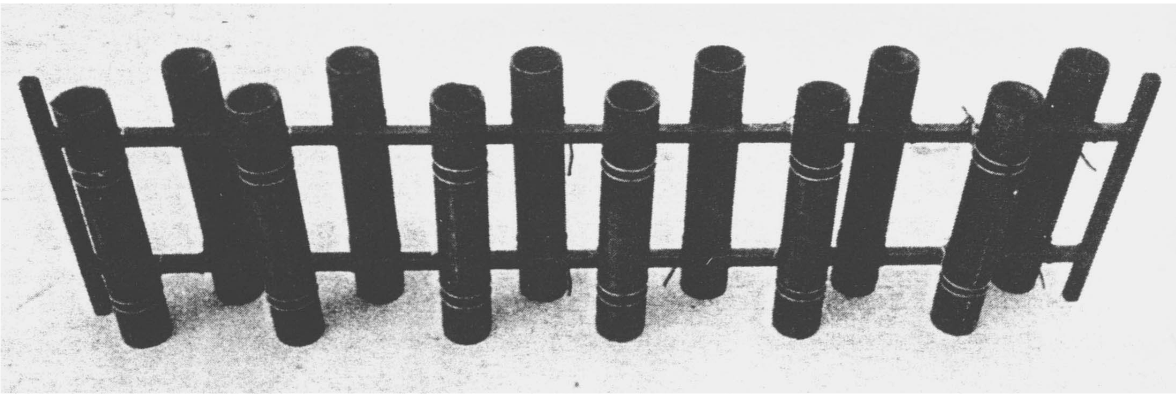
A wooden rack partially buried for stability.

EXAMPLES OF RACK FAILURES

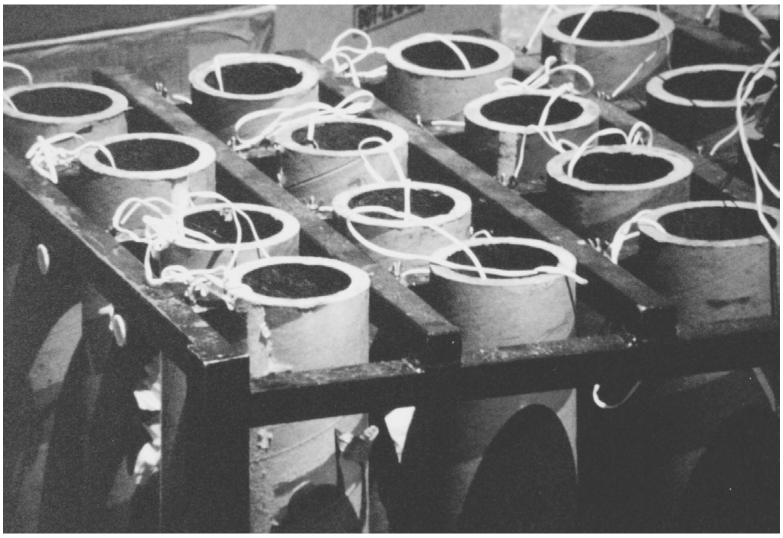
Examples of insufficiently braced mortar racks that were repositioned by a mortar explosion.

EXAMPLES OF STRONG RACK CONSTRUCTION

A rack made with a square tubular steel backbone and widely separated mortars attached using slightly elastic nylon cord.



An especially strong “dense-pack” or “matrix” rack made using three levels of welded criss-crossing square tubular steel members.



Racks should only be used for mortars 6 inch (150 mm) and smaller.

Larger mortars (8” and above) should not be racked and where possible buried and separated. Fragments from mortar racks, in addition to mortar fragments, often become dangerous flying debris if a mortar in the rack explodes. Properly constructed sand-filled wooden boxes or troughs are acceptable for the support of mortars.

SAND-FILLED MORTAR BARRELS

A row of large plastic-covered mortars in barrels.

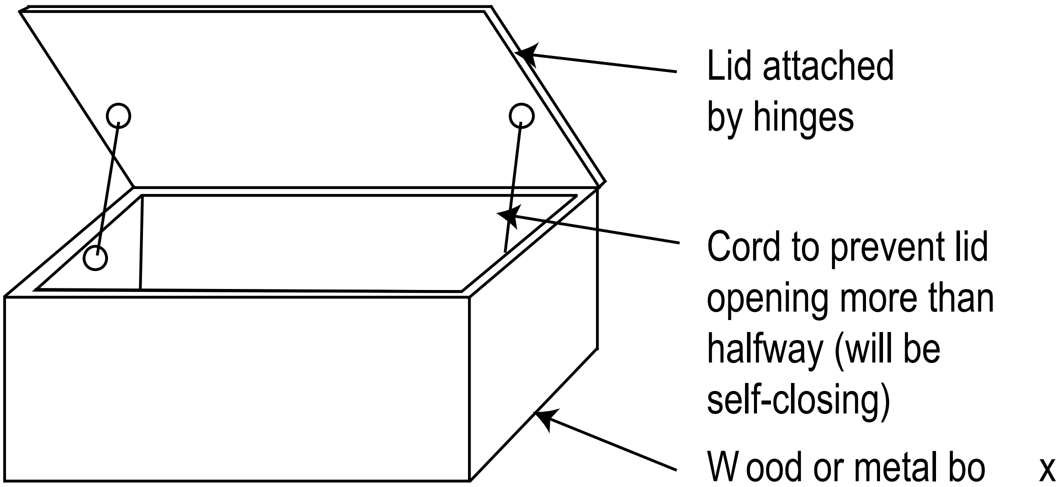
Plastic bust bins split easily and lack sufficient stability from tipping over.

SHELL BOXES

Shell boxes are used for aerial shell storage during manually fired displays. The BPA does not recommend the reloading of shells during a display, but if shell boxes are to be used then they:

♦ Should be of sturdy construction and provide a level of protection from adverse weather.

♦ Must have an attached self-closing lid.



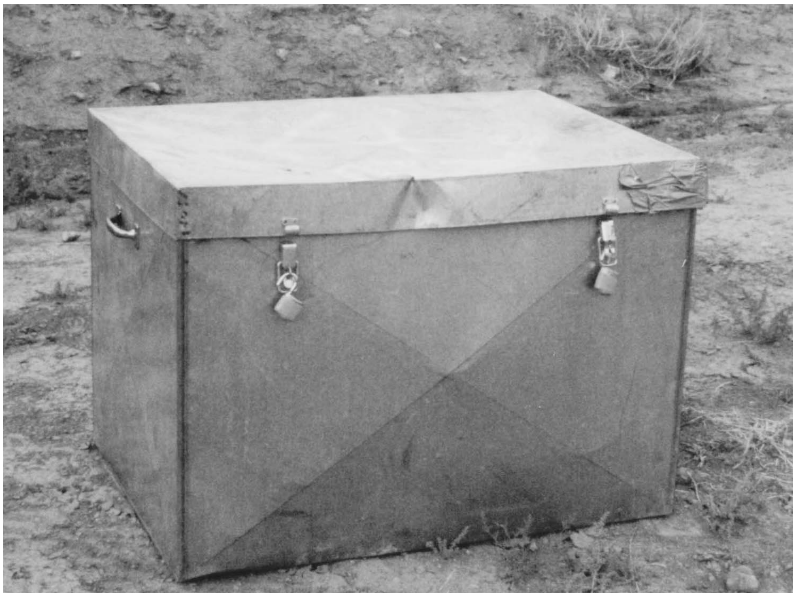
To help in the protection from sparks, the lid must be oriented to open on the side away from the mortars. A tarp covering the shell box is useful, but a tarp alone covering aerial shells affords insufficient protection.

Dustbins as shell boxes are a poor choice.

♦ They have unattached lids and are not self closing.

♦ They are too tall; sometimes requiring putting one's head inside.

An example of a sheet metal shell box.

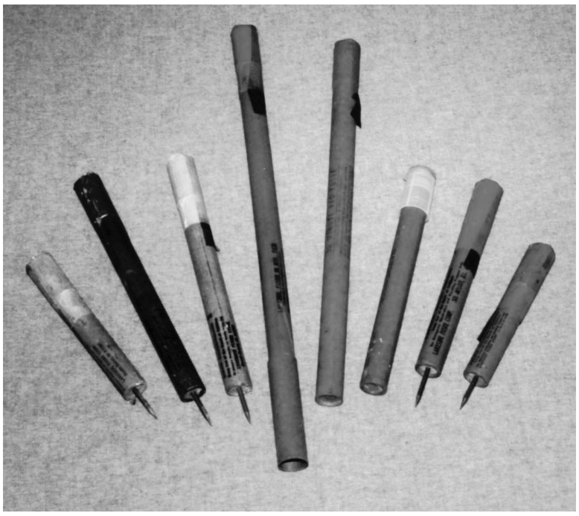


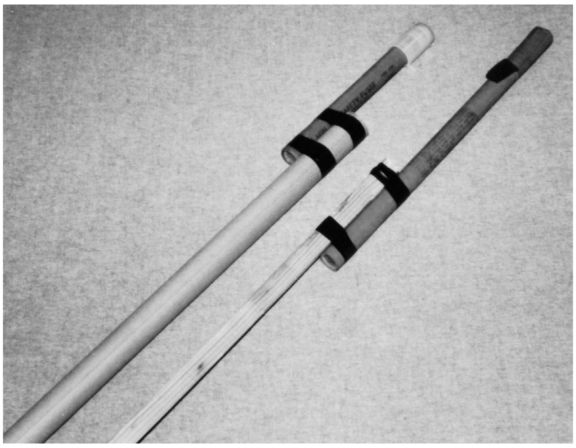
An example of a wooden shell box.

OTHER DISPLAY EQUIPMENT

A portfire is often used to manually ignite fireworks, the fuses should be attached to a stick or other extender.

The additional 18 inches (1/2m) of separation provided by a stick should reduce the risk by about one half from a serious injury from a mortar explosion while lighting aerial shells.





OPERATIONAL LIGHT:

Each firer should have a light that must come from a non-flame source. Head lamps (e.g. made by Petzl) are ideal because they leave the hands free but care should be taken not to blind other operators.

It is a good idea to provide some light along the line of mortars to aid loaders and shooters.

COMMUNICATION EQUIPMENT:

Communications may be provided by the event organiser, or the display company may provide radio communication for their staff and may also provide suitable communication to the event organiser on the same network. What ever system is used it must be :

- ♦ Simple
- ♦ Reliable
- ♦ Weatherproof

It may be worth considering the use of noise cancelling radio equipment, especially for operator to operator communication. Mobile phones are useful as a last resort.

The igniters used for firing displays are somewhat RF (radio frequency) sensitive and therefore care must be taken to ensure the igniters are not exposed to high power radio transmission. Recent research has shown that in most cases a separation of one metre between the RF source and the igniter is sufficient to reduce the risk of ignition from hand held radio sources (most walkie-talkies and mobiles) to acceptable levels.

Igniters are sensitive to a number of stimuli but friction and impact are more relevant in most cases than RF energy.

PPE

Clothing (Minimum requirements during a manually fired display):

- ♦ Long-sleeved shirt
- ♦ Long trousers
- ♦ Clothing should be of heavy COTTON fabric (cotton fabric resists ignition from burning debris). Probanised material is advisable
- ♦ High visibility vests are recommended
- ♦ Life jackets or other safety equipment should be worn if appropriate
- ♦ Foot protection (e.g., boots or at least closed-toe shoes)
- ♦ Leather gloves are recommended

Protective items for use during a manually fired display:

- ♦ Head protection (for all), hard hat or helmet
- ♦ Eye protection
- ♦ Hearing protection

Some protective equipment is advised during the setup before and the cleanup after the display.

SECTION 9 - MORTAR PLACEMENT ISSUES:

❷ *Please note that this chapter is all level 2*

- Mortar placement within the secured area:

= Recommended for manual firing with reloading

= Optional for manual firing without reloading

= Optional for electrically fired displays

- Separation distance requirements
- Organization of mortars
- Burial of mortars
- Mortar angling

= Down-range aerial shell trajectory displacement

= Angling for wind drift

- Placement of mortar racks and troughs

= Rack bracing

= Rack barricading

= Rack orientation

= Trough orientation

- Placement of shell boxes

RECOMMENDED MORTAR PLACEMENT FOR MANUALLY FIRED DISPLAYS WITH RELOADING

❷ *Reloading during a display is only allowed for manually fired displays.*

When there will be reloading of aerial shells during the display, if possible, the mortars should be angled off from vertical and away from spectators for the greater safety of the crew and spectators.

In this way duds, low breaks and burning fallout from flowerpots will tend to be diverted away from the crew and the fireworks ready boxes.

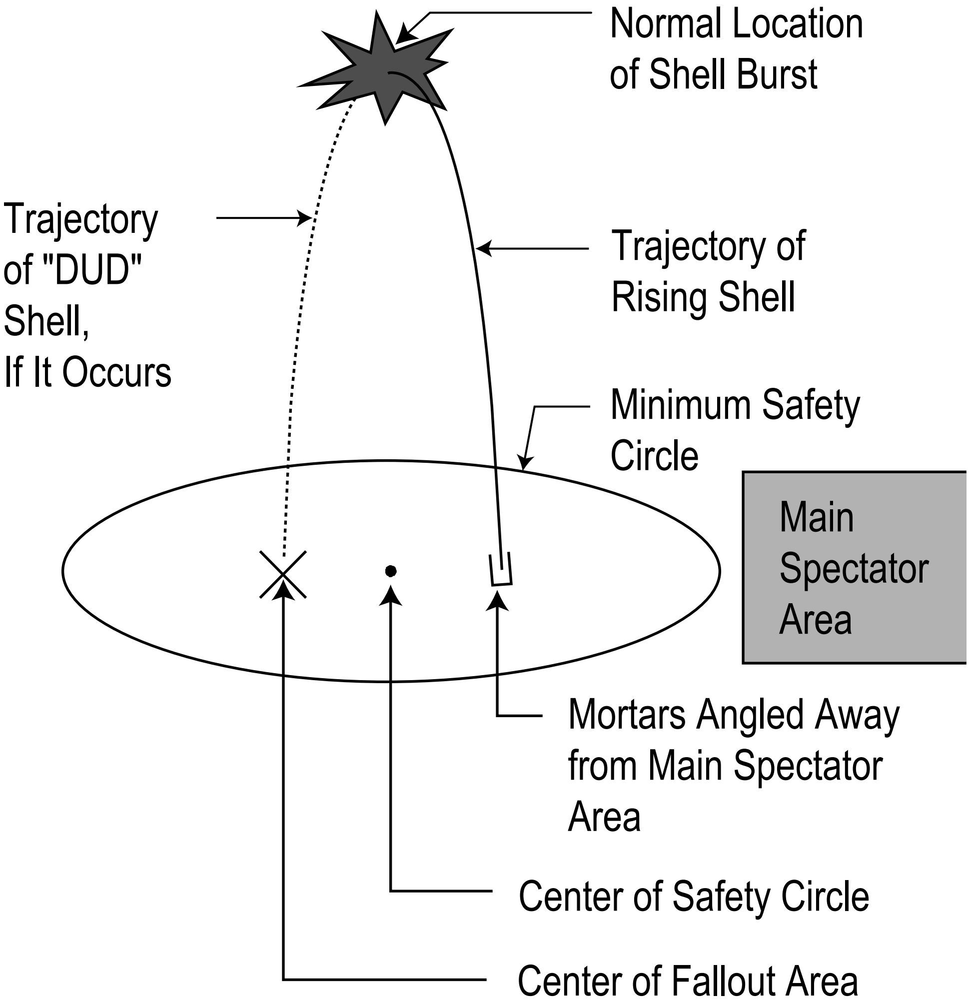
This reduces the chance that these malfunctions will directly injure the crew or will cause injury by igniting shells in storage or while being loaded.

When spectators are fairly uniformly distributed around a display site, angling of the mortars may pose a safety risk for those spectators that are down range from the mortars. In that case, it will generally be appropriate to position the mortars vertically.

With vertical mortars, the crew should take extra precautions for their personal safety.

PLACEMENT OF ANGLED MORTARS

❷ *When spectators are somewhat concentrated in one location, overall spectator safety will be maximized when the mortars are moved a little closer to the main spectator area, and the mortars are angled slightly away from the main spectator area.*



Unless there is an excess of open (unoccupied) space in the down range direction, angled mortars must be offset from the centre of the display site.

BURIAL OF FIREWORK MORTARS

❷ *For manually fired displays, mortars are often set up by burying them in the ground.*

This affords an acceptable level of crew protection and a relatively high level of spectator protection in the event of an explosion of a mortar.

The ground provides the support needed to hold the mortars in their proper alignment.

Burial considerations:

The depth of burial must be at least 2/3 the length of the mortar, as measured from the original ground surface. However, burial to a depth of at least 3/4 their length is recommended as this gives significantly greater protection in the event of a mortar explosion.

For additional crew protection on manually fired displays, sand bags or other barriers should be placed up to the approximate level of the muzzle of metal mortars. (This is also recommended for non-metal mortars.)

MORTAR BURIAL AND BARRIERS

❷ *Loose soil around a mortar is ineffective in stopping debris from an exploding mortar and does not count toward the 2/3 mortar length burial requirement.*

MOISTURE PROTECTION

❷ *Paper/cardboard mortars lose their strength and can fail when they become damp. Accordingly, when the ground is damp or when the mortars will be in the ground for more than 12 hours, paper mortars must be protected from moisture damage.*

For example, place the mortars into plastic bags before burial.

If there is a possibility of water seepage into the bottom of a mortar, the mortar needs to be protected.

For example, place the mortars into plastic bags before burial.

All mortars must be covered when rain threatens. Usually plastic sheeting or tarps are used.

PLASTIC SHEET COVERED MORTARS

❷ *Example of buried mortars barricaded with sandbags on the end and covered with plastic sheeting.*

Example of many individual buried mortars covered with pieces of plastic sheeting.

Inter-mortar spacing:

When buried mortars are to be fired manually, they must be separated by a distance at least equal to their ID (when practical, more separation is strongly recommended).

When mortars 6 inch (150 mm) or less in size are fired electrically and are not chain-fused, inter-mortar separation distance at least equal to their ID is strongly recommended, but it is not absolutely required.

Mortar placement in troughs and drums:

When manually firing, mortars must be placed to afford the shooter a high level of protection.

When manually firing, all mortars must be placed with at least the greater of 2 inches (50 mm) or 1/2 the mortar's diameter from other mortars and the wall of the trough or drum.

When electrically firing, mortars must be at least 2 inches (50 mm) from the wall of the trough or drum.

Requirements for burial of chain-fused mortars:

When mortars are to be chain fused, such that a single ignition will produce a series of aerial shell firings, additional safety measures are required.

In the event of a mortar explosion, these measures are needed to reduce the chance that adjacent mortars will become misaligned and aerial shells will be fired in dangerous directions.

Possible additional safety measures include:

The inter-mortar distance should be at least 2 times the mortar ID. (When practical, even greater separation is strongly recommended.)

If the mortars are placed at twice the minimum separation distance to spectators, then additional inter-mortar distance is not required (i.e., a separation equalling the mortar ID is acceptable).

Unless the firing crew leaves the area of the chain-fused shells as they are fired, the mortars should be barricaded for the protection of the crew.

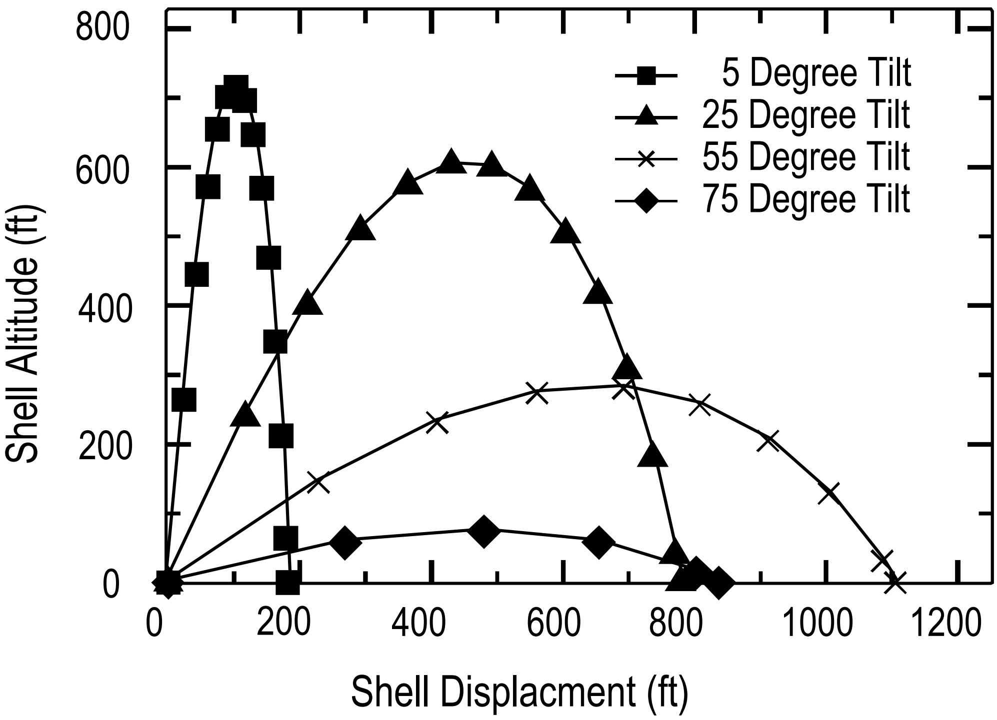
Requirements for mortars in racks will be discussed later in this section.

EFFECT OF MORTAR ANGLING

❷ *Mortar angling is recommended when aerial shells will be reloaded during the display.*

Angling must always cause aerial shells to travel away from the main spectator area.

The amount of displacement of an aerial shell when it reaches its apogee, and where a potential dud will fall, is a function of mortar tilt angle. This has been calculated for typical 6-inch (150-mm) spherical shells under fairly typical conditions:



The data points correspond to the aerial shell's calculated position after each one second of its flight.

MORTAR ANGLING FOR WIND

❷ *Wind acts to blow aerial shells and their debris off course.*

The wind speed of consequence is not the wind that can be measured at ground level, but rather the average wind speed throughout the entire flight of the aerial shell.

Under most conditions, the winds aloft will be significantly greater than those at ground level. In large part, this is because of the interference caused by shrubs, trees, buildings, etc. The average effective wind speed aloft is probably about twice that measured near ground level.

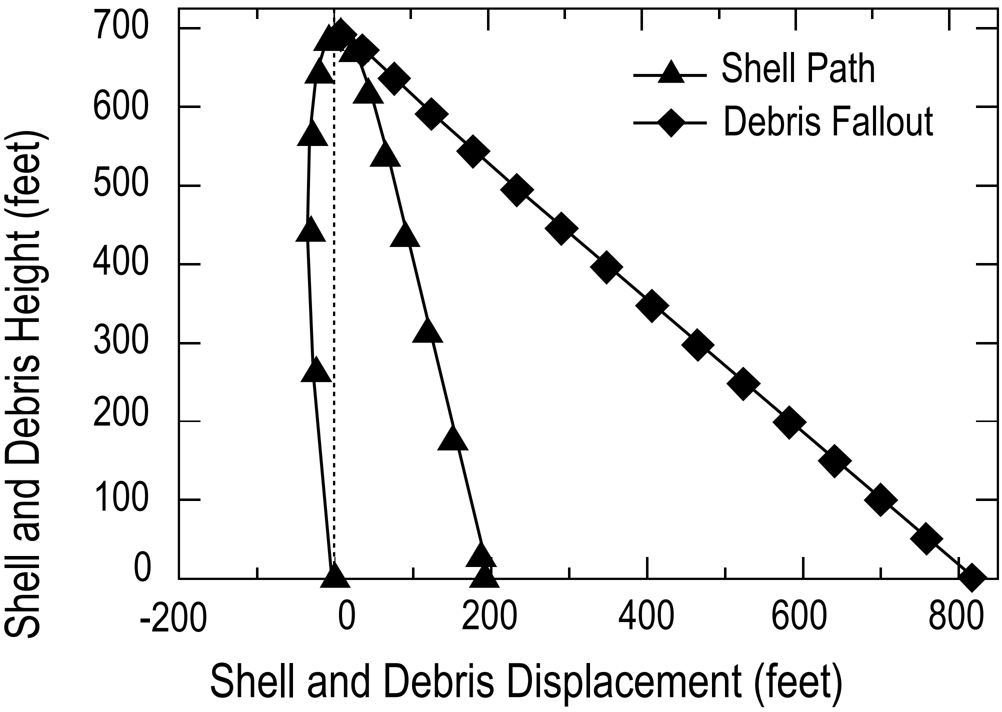
Mortars may need to be angled slightly to correct for the effects of wind on the trajectory of aerial shells and their debris. Thus dangerous debris (duds, burning fallout, and heavy debris) will be more likely to fall inside the secured area of a fireworks display.

Because the speed and direction of winds aloft are never accurately known, it is not possible to know in advance exactly how mortars should be angled. Accordingly, the flight of aerial shells and debris during a display must be closely monitored to determine when the mortars must be re-angled.

The BPA recommend the use of Shellcalc© for determining the effect of wind direction and strength on shells. More information about this program are given towards the end of this book.

WIND EFFECT ON AERIAL SHELLS

❷ *Proper mortar tilt angle can only counter the effect of wind to a limited extent. For example, the calculated trajectory of a 6-inch (150-mm) aerial shell, in 40 mph (65 km/hr) wind, fired from a mortar angled approximately 7 degrees into the wind is shown below (each point is one second in time).*



Note that one cannot correct for all three, where the shell will burst, where duds will fall and where burning debris may be blown.

PLACEMENT OF MORTAR RACKS

❷ *The location of mortar racks, when aerial shells are individually fired, is the same as for buried mortars:*

Mortar racks are offset from centre of the display site for angled mortars and mortar racks are placed at the approximate centre of the display site for vertical mortars.

The location of racks that contain chain-fused shells:

If very strong (e.g., steel) racks are used, those racks may be located at the same distance as racks containing individually fired mortars. When racks of typical wood construction are used, they are sufficiently weak that they must be placed at twice the normal spectator separation distance.

Physical requirements:

Racks must be rigidly braced to prevent accidental re-alignment or tipping over. This is especially important when the racks will fire chain-fused aerial shells.

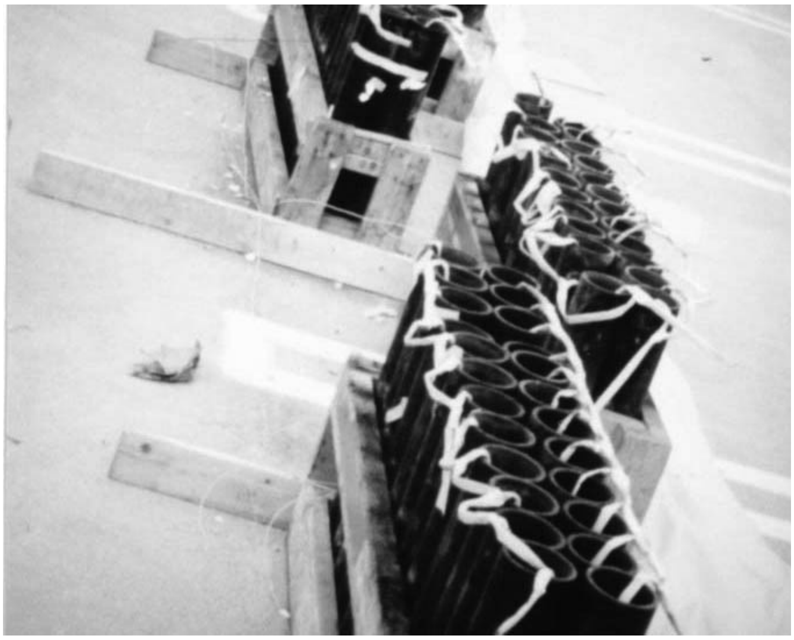
RACKS WITH METAL STAKES FOR BRACING

❷ *Pairs of metal stakes with rope tied between can provide a high degree of support for mortar racks.*

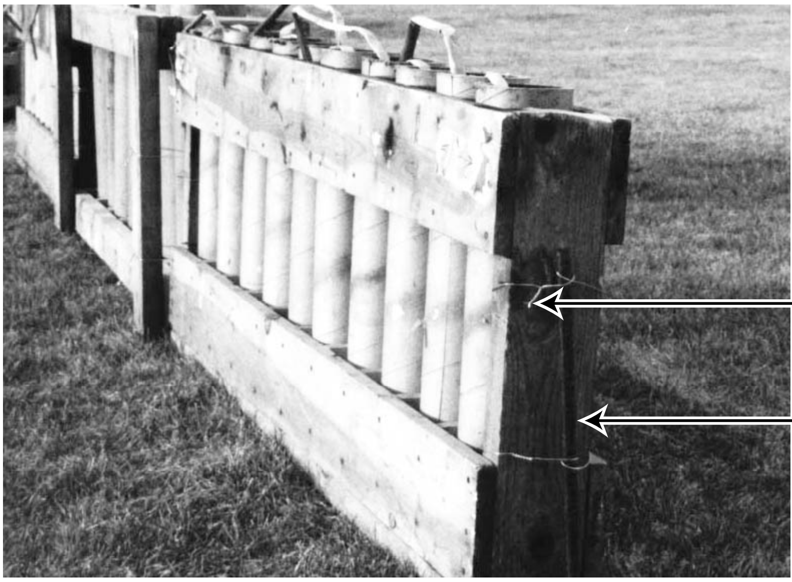
This method will also allow angling of the racks.

MORTAR RACKS WITH LEGS FOR BRACING

❷ *Example of racks using long 2×4 legs for support.*



A single short and thin metal stake at each end of a mortar rack is unacceptable bracing for racks.



When manually firing, it is recommended that racks be barricaded or sand bagged for crew protection. In addition to fragments from the aerial shell and mortar, parts of the rack can become dangerous flying debris in the event of a powerful mortar explosion.

Barricading is not required. The firing crew may choose to accept the risk of not barricading.

Chain-fused racks, when the shooter retires a long distance (>25 ft or 8 m) after igniting, do not need barricading.

WEATHER AND SPARK PROTECTION:

❷ *Covering racks with tarps or heavy plastic sheeting will provide relatively good weather protection but only modest spark protection.*

Covering racks with aluminium foil will give good protection from sparks and light-weight burning debris but may still allow the penetration of heavier burning debris (e.g., burning stars).

"CATCHERS"

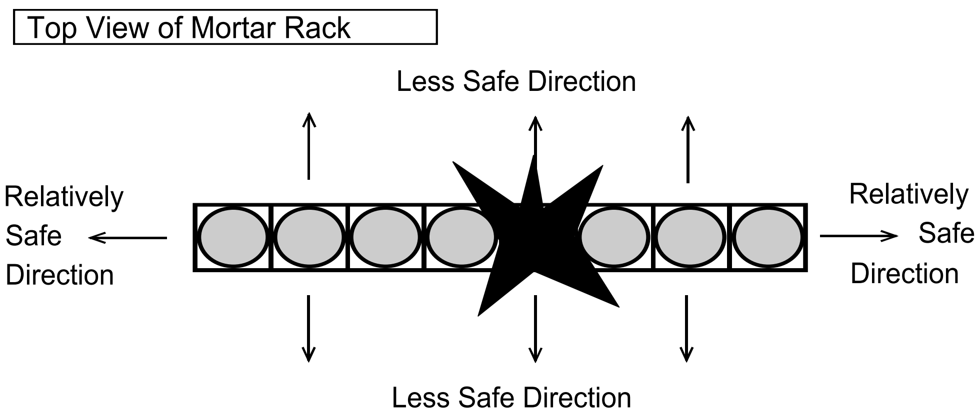
The use of "catchers" (i.e. protective barriers between the mortars and, for instance, the audience) can reduce the risk of displace mortars discharging towards the audience or other areas. However, if they are used they must be:

- ♦ *Positioned to "catch" the shells at an appropriate angle*
- ♦ *Strong enough to prevent the shell from escaping*
- ♦ *Easy and cheap to instal*

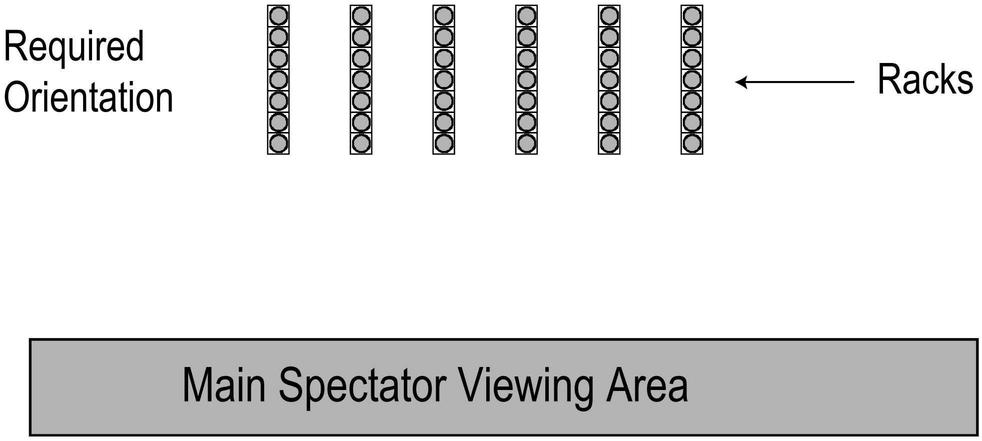
"Catchers" may find application on sites where repeated displays are fired (e.g. the Disney Theme Parks), where it can be cost effective to use them because the cost is spread over a number of events.

MORTAR RACK ORIENTATION

❷ *When an explosion destroys a mortar in a rack, other mortars in the rack may come to be aimed in dangerous directions. In the event of a mortar explosion in a rack, it is more likely that the remaining mortars will come to be tipped somewhat toward the sides of the rack rather than toward the ends. Accordingly, if aerial shells fire from those tipped mortars, they are more likely to be sent in directions perpendicular to the original orientation of the rack.*

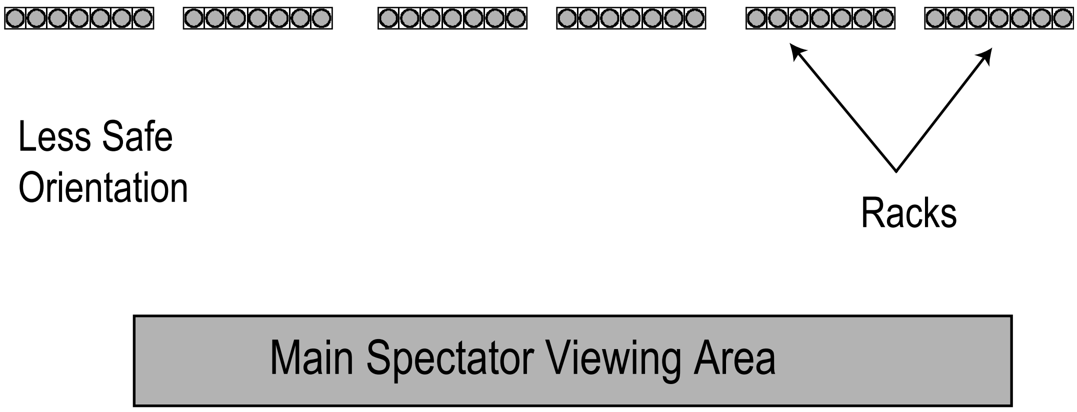


Accordingly, chain-fused racks must be oriented so as to be perpendicular to the main spectator area.



It is preferred that the firing of the shells within racks start from the end nearest the spectators, leaving those mortars empty in the event of a subsequent mortar explosion in that rack.

Unfortunately it is relatively common to have chain-fused racks placed more dangerously (i.e., parallel to the main spectator area).



It is preferred that the mortars in the end of the trough nearest to the main spectator viewing area be fired first, leaving them empty in the event of a subsequent mortar explosion within the trough.

PLACEMENT OF SHELL BOXES

❷ *Location of ready boxes (storage containers for aerial shells during a display with reloading):*

The ready boxes must be placed at least 25 feet (8 m) upwind from mortars.

The orientation of the shell boxes must be such that the lid opens on the side away from mortars to help avoid the accidental entry of sparks.

The number of ready boxes - Generally, there should be at least two ready boxes, one on each side of the line of mortars. (See page 13-3.)

To help eliminate reloading errors, if the box contains more than one size of aerial shells, they should not contain shell sizes differing by only one inch (25 m).

3- and 4-inch (75- and 100-mm) in same box — NO.

3- and 5-inch (75- and 125-mm) in same box — OK.

On larger shows, it is useful to have one ready box for each aerial shell size.

SECTION 10 - FUSING TECHNIQUES:

Chain fusing methods

Preparation of finale chain fusing

Methods for slowing quick match burning

Comparison of slowing methods

Delay elements for quick match

Self made

“Pyroclock” units

Making slow-burning fuse chains

Short fusing

Re-ignition points

Other ignition systems

“No-Match” shock tube

“Lightning Thermo Tube”

CHAIN FUSING OF AERIAL SHELLS

The most efficient method for firing large numbers of aerial shells in a barrage or finale is to chain their quick match shell leaders together. In this way, one ignition will cause many shells to fire sequential. Often aerial shells can be purchased already chain fused together. At other times, it will be necessary to do the chain fusing one's self.

There are two common methods used for normal firing-rate chain fusing of aerial shells with black match as their ignition point.

Method 1: When the aerial shell leaders are long enough, no additional use is necessary. In effect, each successive quick match fuse is simply inserted into the preceding shell's fuse.

Method 2: When the shell leaders are not long enough (or as a matter of convenience), a specially made series of connecting fuses can be used to chain-fuse the individual shells.

CAUTION: Chain fusing (or operations that could possibly cause an ignition) must never be attempted in or near magazine or aerial shell storage areas.

CHAIN-FUSED AERIAL SHELLS

Loading strings of chain-fused shells into mortars.

CHAIN-FUSING METHOD #1 (PROVIDING SHELL LEADERS ARE LONG ENOUGH)

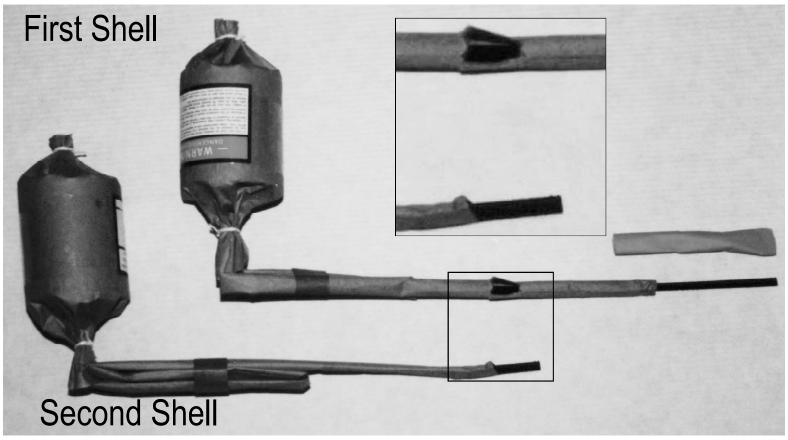
Procedure (see photos following):

- A short distance back from the end of the first shell's leader fuse, cut an approximately 1-inch (25-mm) long slice into the centre of the fuse.
- Remove the safety cap from a second shell leader and cut off all but about 1 inch (25 mm) of the black match on the end of the shell's leader fuse.
- Insert the end of black match of the second shell into the slice made in the first shell's fuse, such that the black match of each fuse is touching.
- Tie the fuses together with string where the black match fusing is touching.

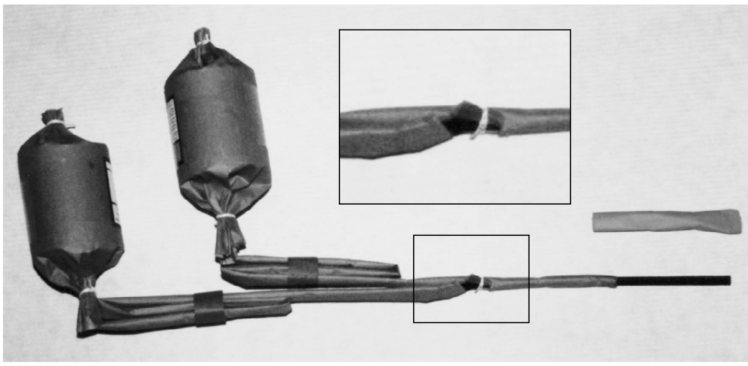
- Tape the area of exposed black match to protect it from stray sparks.
- A short distance back on the second shell's leader (from the point where it is joined to the first shell) cut a slice into the fuse and attach the leader from the third shell as described above.
- Continue this process until the appropriate number of aerial shells has been chained together.

CAUTION: All quick match fuse cutting must be done slowly using a sharp knife or a sharp, anvil-type pruning shears. When cutting fuse, because of the possibility of an ignition, have no unnecessary pyrotechnic materials in the immediate area.

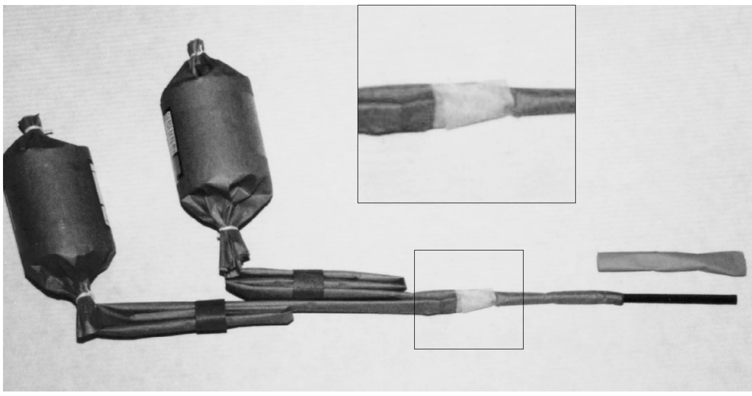
The first shell's leader has been sliced open and the second shell's black match has been trimmed.



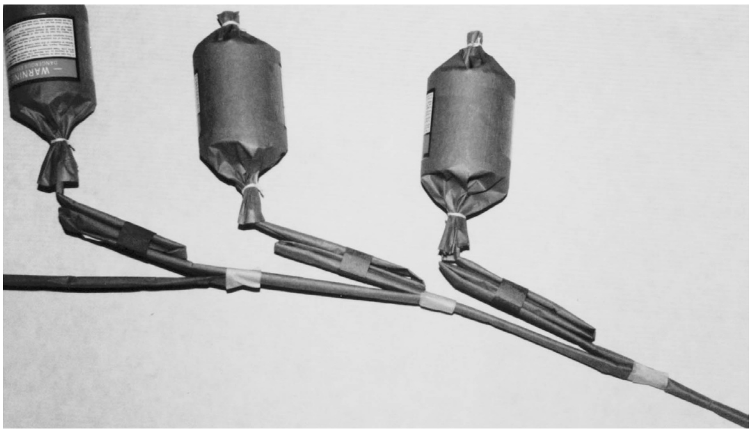
The black match from the second shell has been inserted and tied onto first shell's leader.



Tape is applied to the splice to protect it from sparks.



An example of several aerial shells chained together using this method.



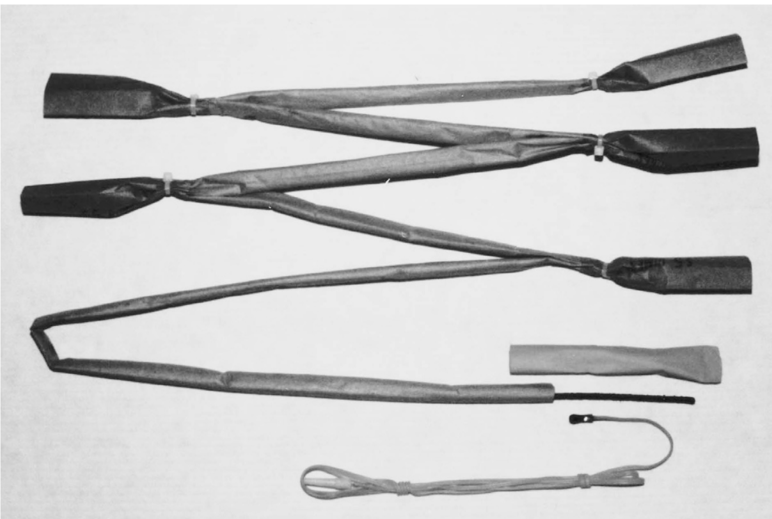
CHAIN-FUSING METHOD #2 (WHEN AERIAL SHELL LEADERS ARE NOT LONG ENOUGH OR SIMPLY IF IT IS PREFERRED)

Procedure (see following photos):

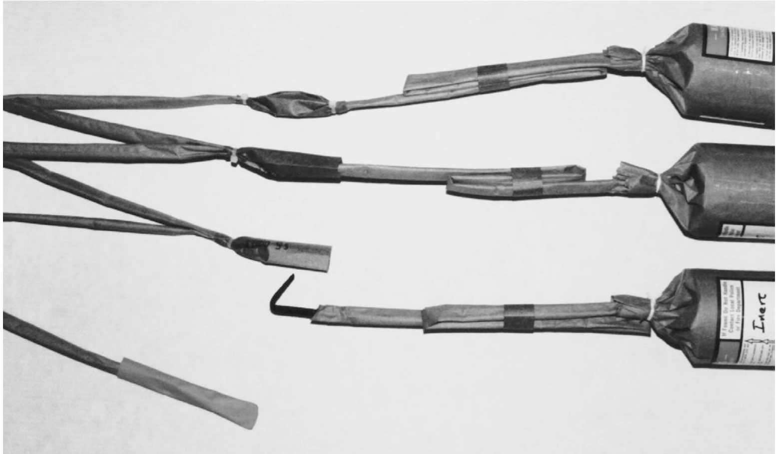
- Purchase pre-made finale chain fuses with "bucket splices", or assemble them using quick match and coin wrappers. (See page 10-11.)
- Remove the safety cap from the first shell's leader fuse and fold over the black match on itself such that it will easily fit into the open end of the bucket splice (coin wrapper). Make sure the black match is completely covered.
- Insert the end of this first shell leader into the bucket splice and tie it securely.
- Repeat the above process until all aerial shells have been attached to the finale chain fuse.
- If several chains need to be linked together, leave the last bucket splice unused. This can then be used to link to the next chain of aerial shells.

CAUTION: All quick match fuse cutting must be done slowly using a sharp knife or a sharp, anvil-type pruning shears. When cutting fuse, because of the possibility of an ignition, have no unnecessary pyrotechnic materials in the immediate area.

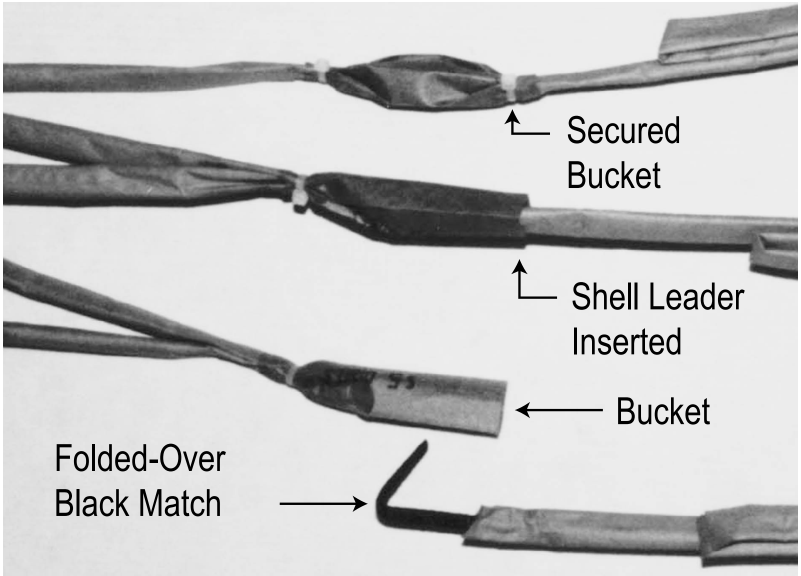
Obtain or make finale fuse chains.



Connect aerial shells to finale fuse chain.



Details of the attachment method:



The aerial shell's safety cap is removed to expose the black match of the shell leader, which is folded over to better fit into the bucket. Make sure all black match is completely covered.

The black match and a short portion of the quick match of the shell leader are inserted into one of the "buckets" of the finale fuse chain.

The shell leader is secured into the bucket using string, a cable tie, etc.

CHAIN-FUSED AERIAL SHELLS

Loading chain-fused aerial shells into mortars.

A close up of chain fusing using bucket splices.

PREPARATION OF CHAIN FUSING

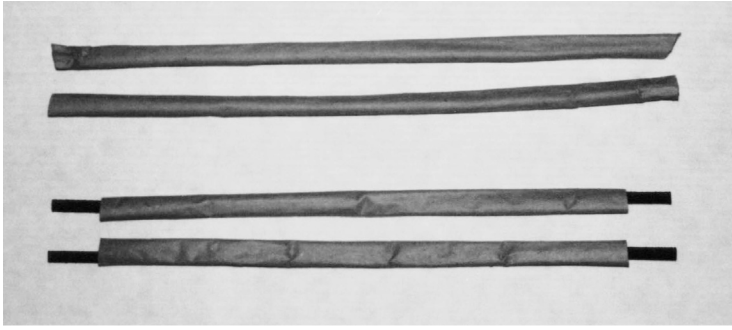
Procedure (see following photos):

- ♦ Cut a sufficient number of pieces of quick match each about 1 foot (300 mm) long, and expose about 1 inch (25 mm) of black match on each end by tearing off the paper wrap.
- ♦ Tie a coin wrapper on one end of one piece of quick match.
- ♦ Insert the other end of the first piece of quick match plus a second piece of quick match a short distance into the end of another bucket (coin wrapper) and tie securely.
- ♦ Continue this process until the appropriate number of buckets (coin-wrapper connection points) has been made. To complete the process, on the final end, attach a longer length of quick match with a length of exposed black match and a safety cap. This

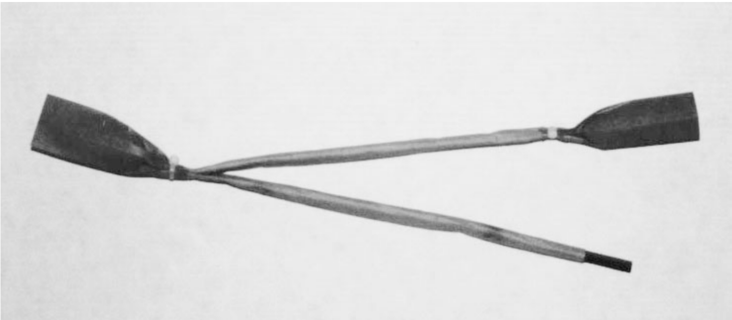
is where the chain will be ignited. (As an alternative an electric igniter can be inserted into the quick match at that point.)

CAUTION: All quick match fuse cutting must be done slowly using a sharp knife or a sharp. When cutting fuse, because of the possibility of an ignition, have no unnecessary pyrotechnic materials in the immediate area.

Cut quick match and expose black match ends.



Connect to coin wrappers.

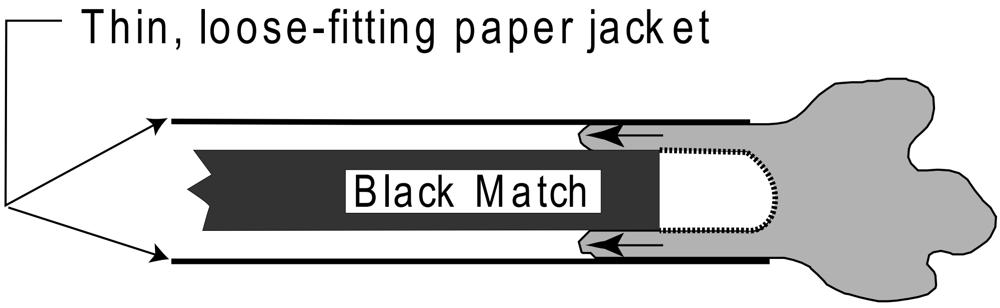


Continue until a sufficient number of attachment points (buckets) have been included in the chain.

METHODS OF SLOWING QUICK MATCH

To slow the rate at which finale shells fire, it is sometimes necessary to add a series of short delays in the quick match chain.

Quick match burns rapidly because fire races down its length in the gap (fire path) between the central black match and the paper wrap. Accordingly, if the fire path is tightly closed, burning of the quick match will be momentarily slowed at that point.



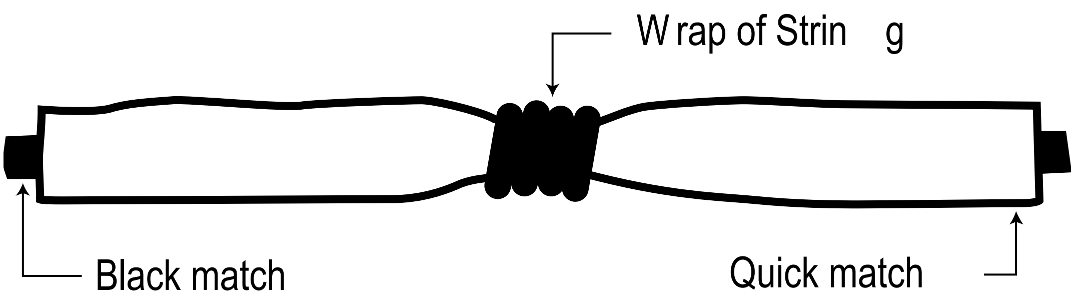
Flame races along the inside of the paper jacket, rapidly igniting more and more black match. Quick match typically burns at 10 to 20 feet (3 to 6 m) per second (about 200 times faster than black match).

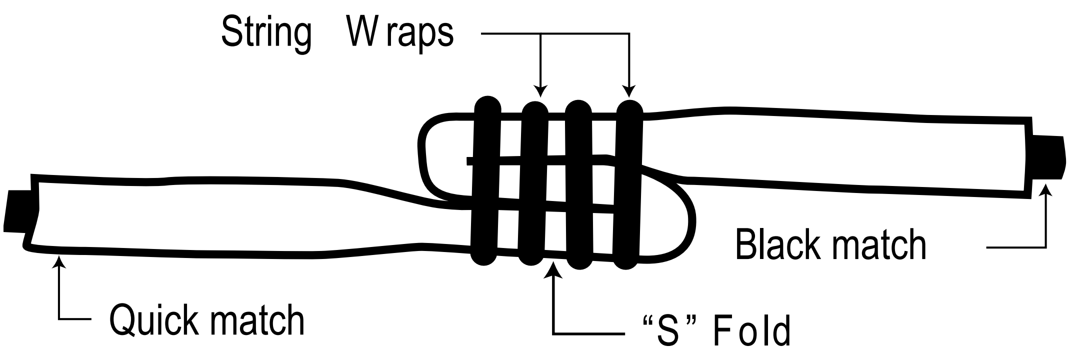
As a rough guide, each time a string is tied tightly around a piece of quick match, a 1/4-second delay will be introduced when the quick match burns.

The string tie method works well providing the quick match is of high quality and is not excessively damp from exposure to high humidity.

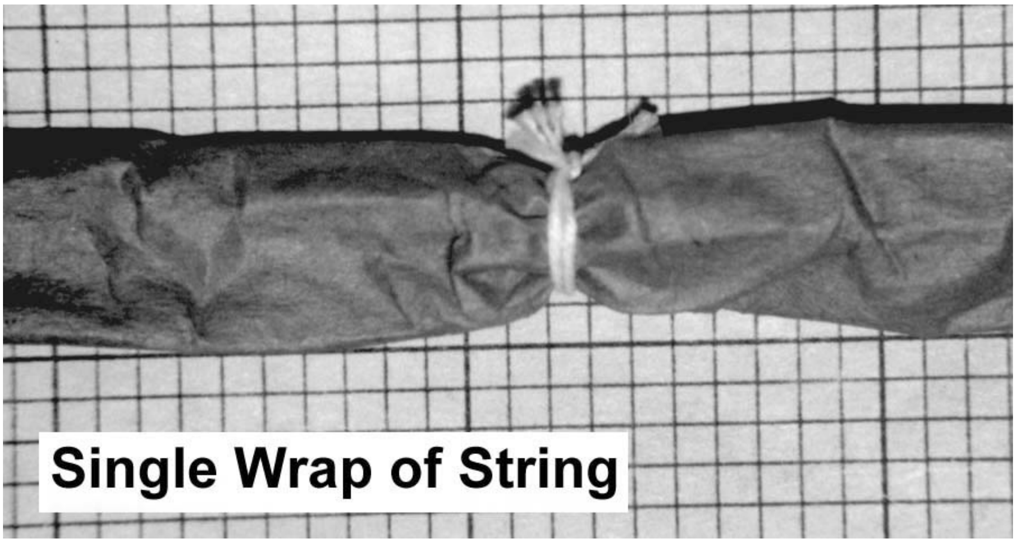
When this method is tried on poor quality and/or damp quick match, there can be a failure to propagate past the point of fire path closure.

Somewhat longer delays can be achieved by tightly wrapping string around the quick match, or by tying string around quick match folded in an “S” pattern.

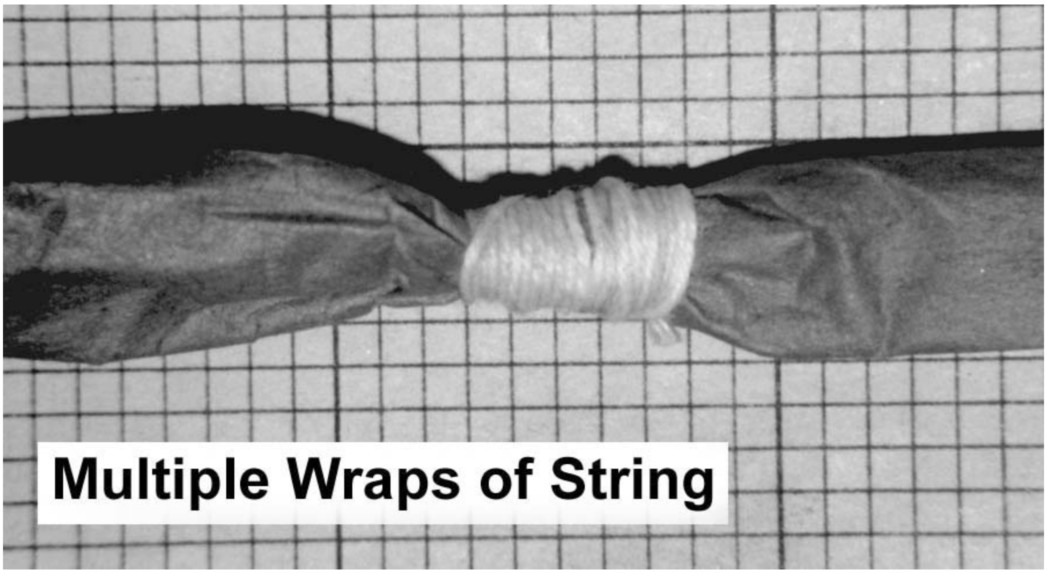




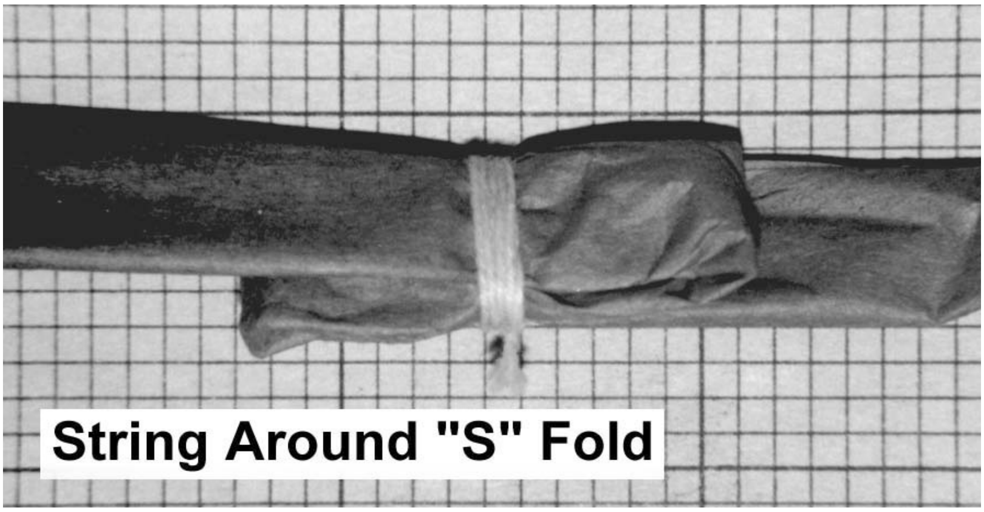
A single tight wrap of string.



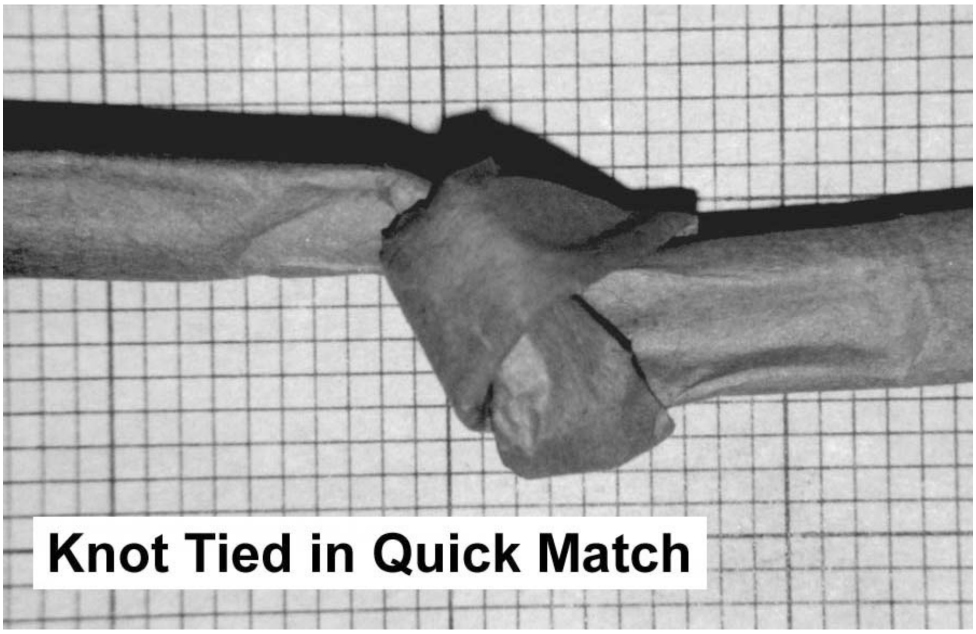
An extended tight wrap of string.



String tied around an “S” fold in the quick match.

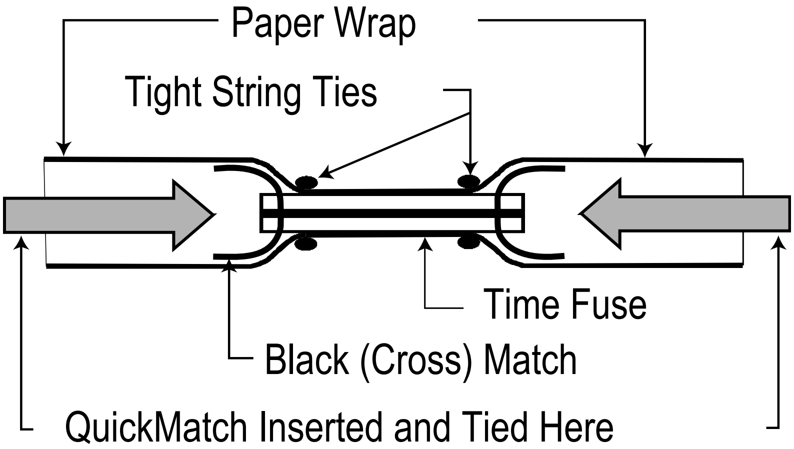


A knot tied in the quick match itself.

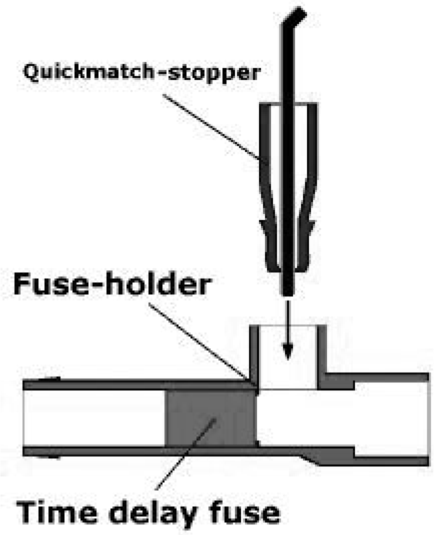


DELAY ELEMENTS FOR QUICK MATCH

When an especially long or precise delay time is needed for quick match, a delay element can be used.



A delay element can be made using a short cross-matched length of firework time fuse, which is encased by a coin wrapper or a few wraps of Kraft paper. The cross matching helps assure proper ignition.



The two ties of string around the time delay fuse must be quite tight to assure that the fire will not pass around the time delay fuse segment.

Connection to the quick match is made just like using bucket splices described previously.

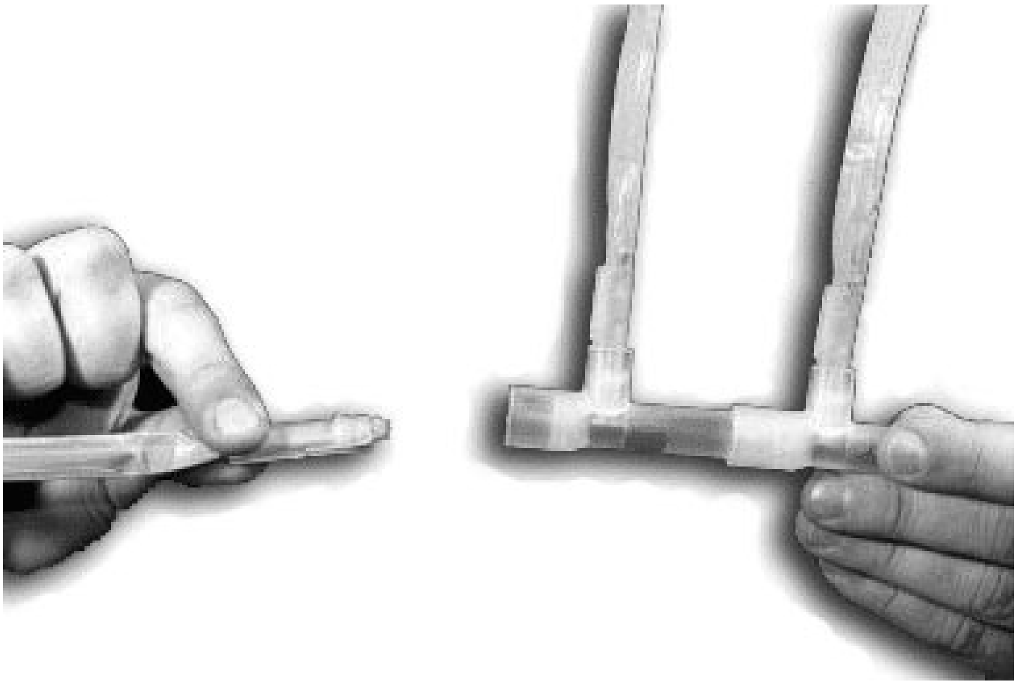
The length of delay is determined by the length of time delay fuse between the cross matching. Most time delay fuse burns at a rate of ~3 seconds per inch (25 mm).

PYROCLOCK — TIME DELAY DEVICE

A commercially produced system can be used to provide variously timed firing of chain-fused aerial shells.

The system consists of small units with built-in time fused delays ranging from 1 to 5 seconds.

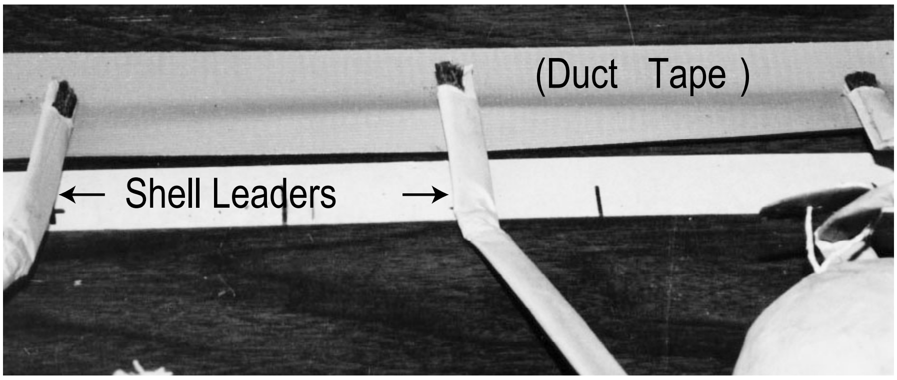
The shell leaders are attached using “quick match stoppers” and the delay elements are simply snapped together.



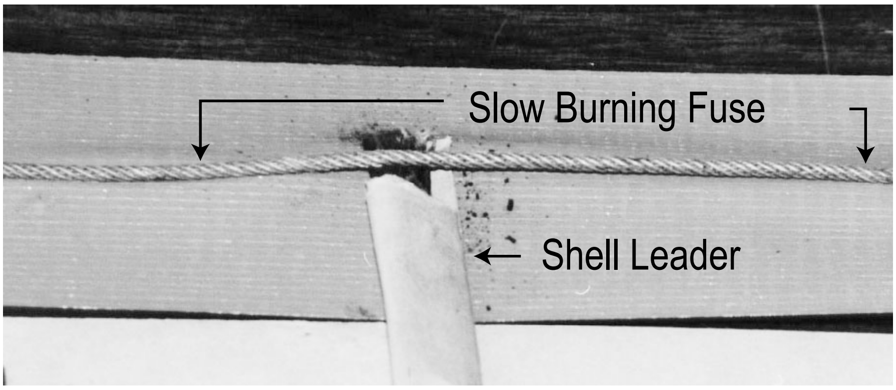
MAKING SLOWER BURNING FUSE CHAINS

A slower burning version of chain fusing can be made using fuse types that burn slower than quick match. For example, visco fuse (~2.6 s/in., ~0.1 s/mm) or plastic igniter cord (~1.2 s/in., ~0.05 s/mm) can be used. One method for doing this is illustrated below:

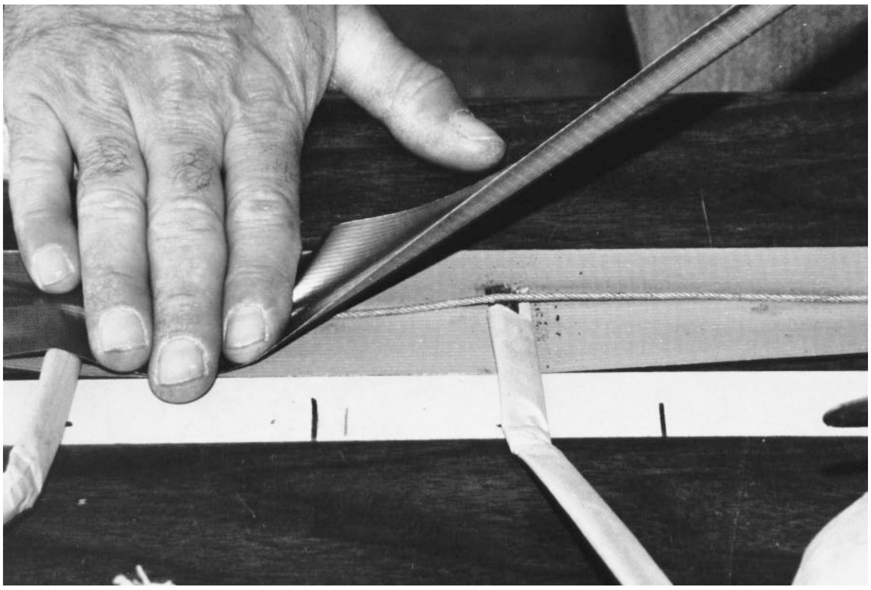
Lay out a wide strip of heavy adhesive tape, such as duct tape with adhesive side up. On this tape lay out a series of shell leaders with about 1/2 inch (6 mm) of exposed black match at the ends.



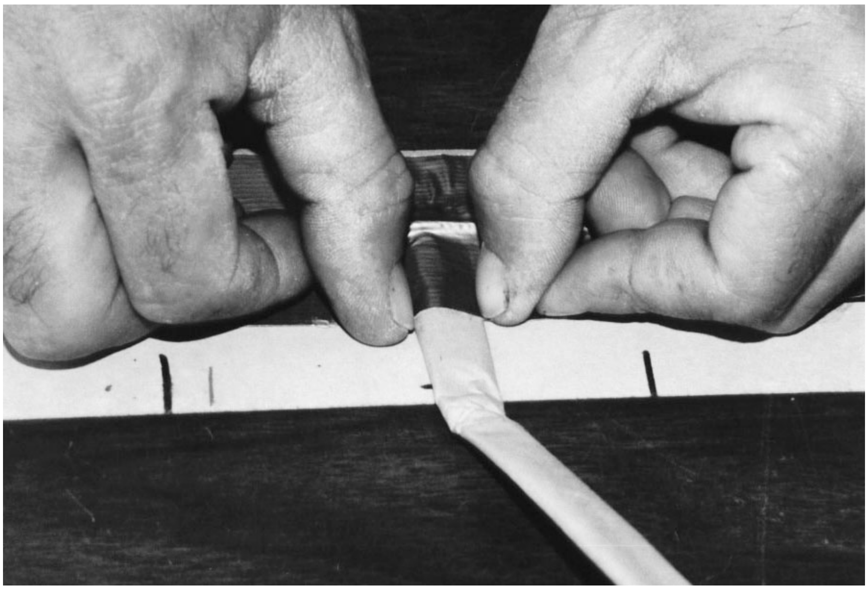
Lay a length of visco fuse or plastic igniter cord on the tape and over the ends of the exposed black match of each shell leader.



Apply a second strip of heavy, wide adhesive tape (adhesive side down) over the first strip of tape.

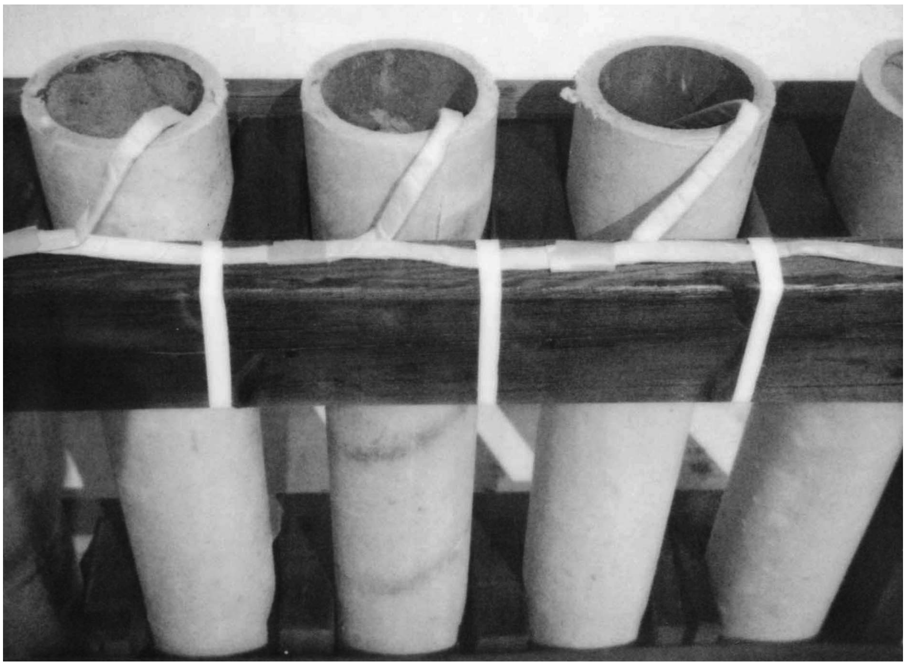


Tightly seal all of the fuse segments between the two strips of tape.



SHORT FUSING

“Short Fusing” is the term for firmly securing the chain fusing to the mortar rack. Most often this is accomplished using strapping tape or string.



If a mortar explodes destroying a mortar rack, short fusing can reduce the likelihood of aerial shells accidentally continuing to fire, possibly into spectator areas.

During normal firing, short fusing also may help to assure that all the chain-fused shells will fire by making it more likely the fusing will remain intact during firing.

Short fusing must never be accomplished by stapling over or through the quick match as this has resulted in a number of accidental ignitions.

RE-IGNITION POINTS

Occasionally a series of chain-fused aerial shells will fail to burn completely. (Generally this is because it was improperly made or installed.) When a chain fuse fails, it may be desired to relight the chain to complete the firing.

Relighting a series of chain-fused aerial shells is dangerous, unless it is done properly. Only a previously installed re-ignition point should be used; one that has been designed to provide a delay, allowing the shooter time to safely retreat before shells again begin to fire.

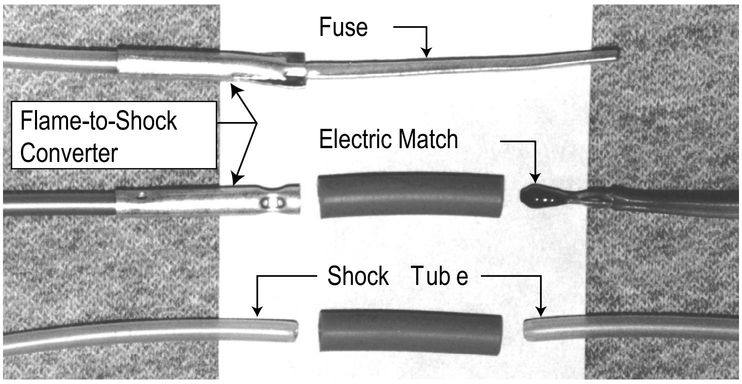
If such re-ignition points are not used, and an aerial shell malfunction causes a mortar to explode while the shooter is still near a mortar rack, the shooter may be seriously injured by debris from the shell, the mortar and the mortar rack.

A re-ignition point will generally be a length of quick match at least 3 feet (1 m) long that has at least 3 inches (75 mm) of exposed black match that is covered by a safety cap. The other end of the length of quick match is connected into the series of chain-fused aerial shells.

As an alternative, multiple short chains could have been used, each with its own ignition point.

SHOCK-TUBE IGNITION SYSTEMS

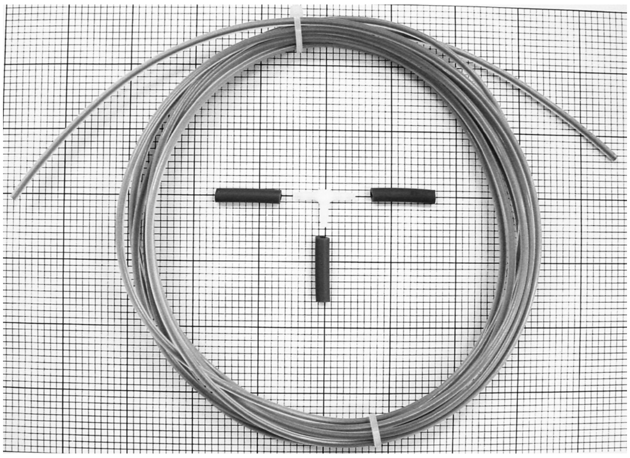
❷ *In the 1990s a shock-tube system (No Match™) was introduced and showed some promise. However, problems with cost and availability have generally limited its use. Shock tube has a propagation rate of greater than 6000 feet/second (2000 m/s). Shock tube requires a flame-to-shock converter for its ignition by a fuse or electric igniter. These are the two thin metal tubes shown in the top two examples below.*



Shock tube can be spliced or split using inert tubing and plastic tees. (See lower example above and page 04-31.) Shock tube requires a shock-to-flame converter to ignite fuse, aerial shell leaders, Black Powder, etc.

THERMO-TUBE IGNITION SYSTEM

❷ *A new product with great potential (Lightning Thermo-Tube™) has been introduced. An example of thermo-tube and components for splicing and splitting it. [0.1 inch (2.5 mm) per division.]*

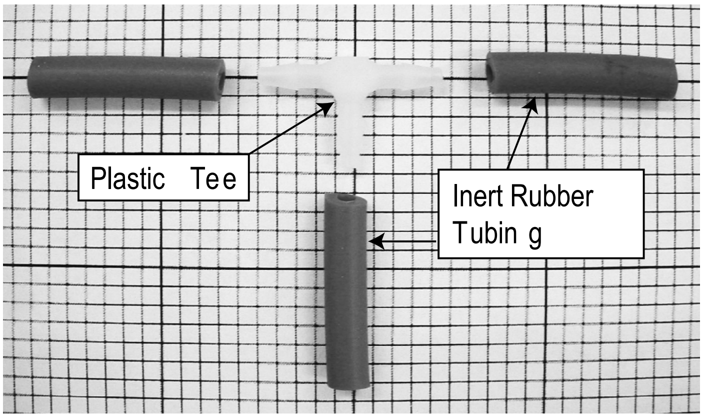


Thermo-Tube:

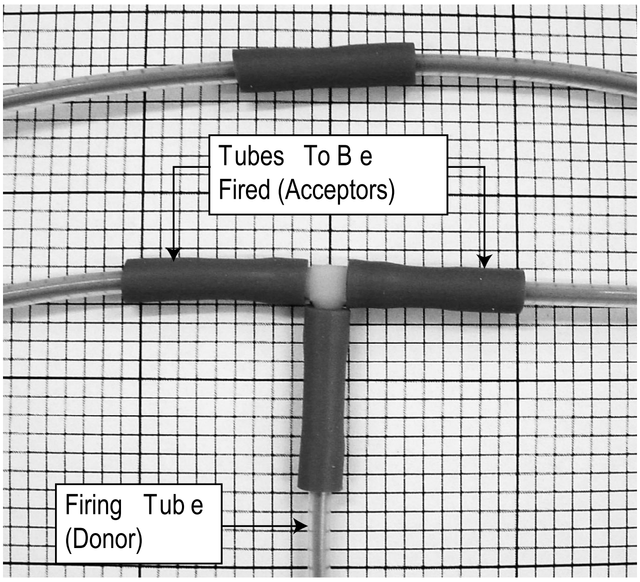
- *Has a propagation rate of ~3700 ft/s (~1200 m/s).*
- *Can be initiated directly by coupling to an electric igniter.*
- *Can be used directly to ignite visco fuse, aerial shell leaders, Black Powder, etc.*
- *Can be spliced or split using inert tubing and plastic tees. (See next page.)*

COUPLING AND SPLITTING SHOCK AND THERMO-TUBE

❷ *Example of inert tubing used for coupling and plastic tees used for splitting shock and Thermo-Tube.*

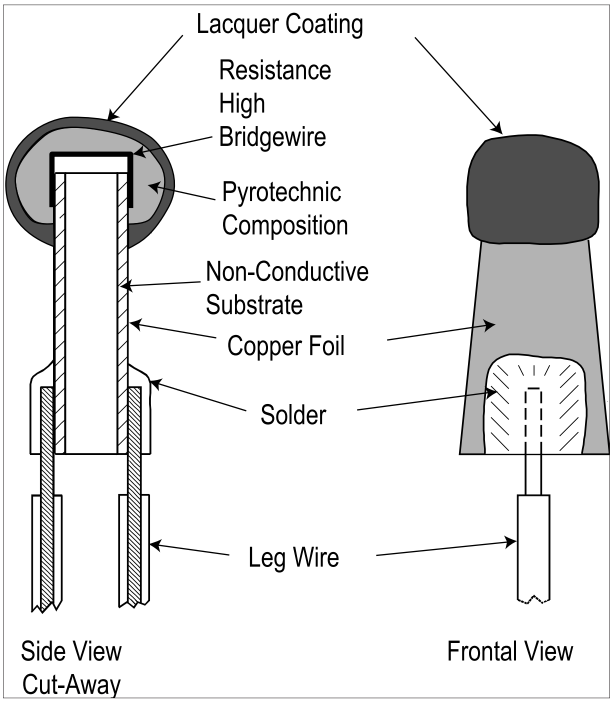


Examples of coupling and splitting shock and Thermo-Tube.

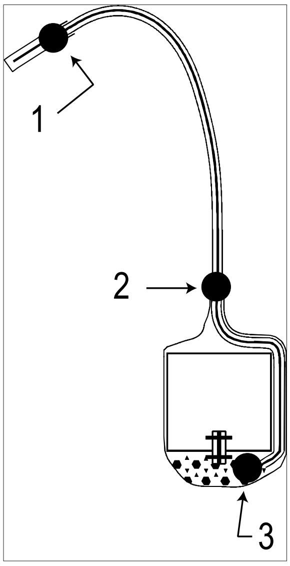


ELECTRIC IGNITERS

An electric igniter (also known as "e-match" or "electric fusehead" or "electric igniters") consists of a high resistance bridge wire surrounded by a heat sensitive pyrotechnic composition. When an electric current is applied through the leg or lead wires of the electric igniter, the bridge wire heats up and ignites the pyrotechnic composition. This produces a small burst of fire, not unlike that from a common safety match.



Electric igniters may be installed at any point along the ignition train of an aerial shell, but three places are most common.

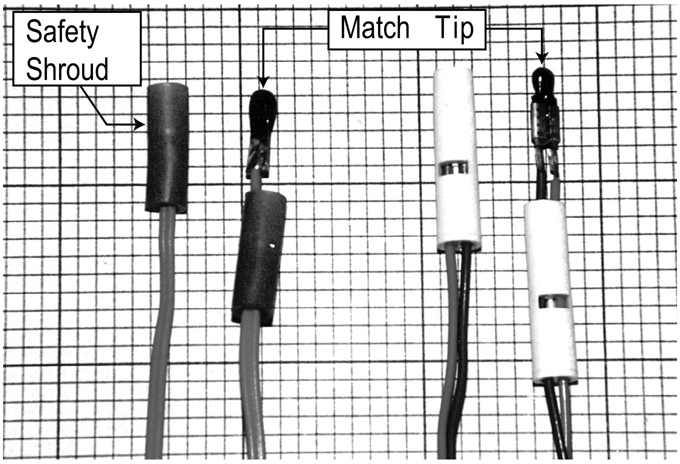


Points 1 and 2 are most common for aerial shells originally manufactured for manual ignition.

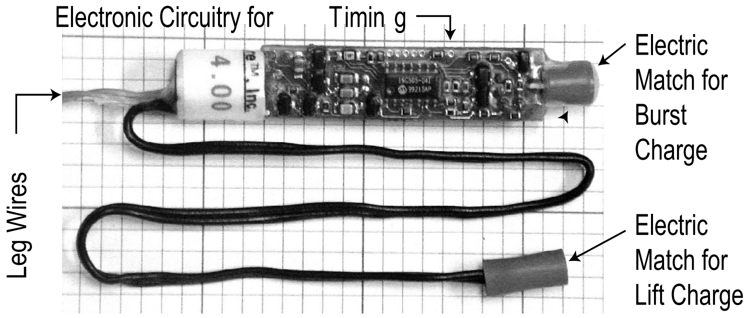
(1) Attachment at the end of the shell leader is made by removing the safety cap, inserting the electric igniter into the shell leader, securing it in place and replacing the safety cap.

(2) Attachment near the aerial shell is made by cutting the shell leader, inserting the electric igniter into the aerial shell leader, securing it in place, and covering the attachment point with tape. Attachment is often made directly into the lift charge by the aerial shell manufacturer (Point 3).

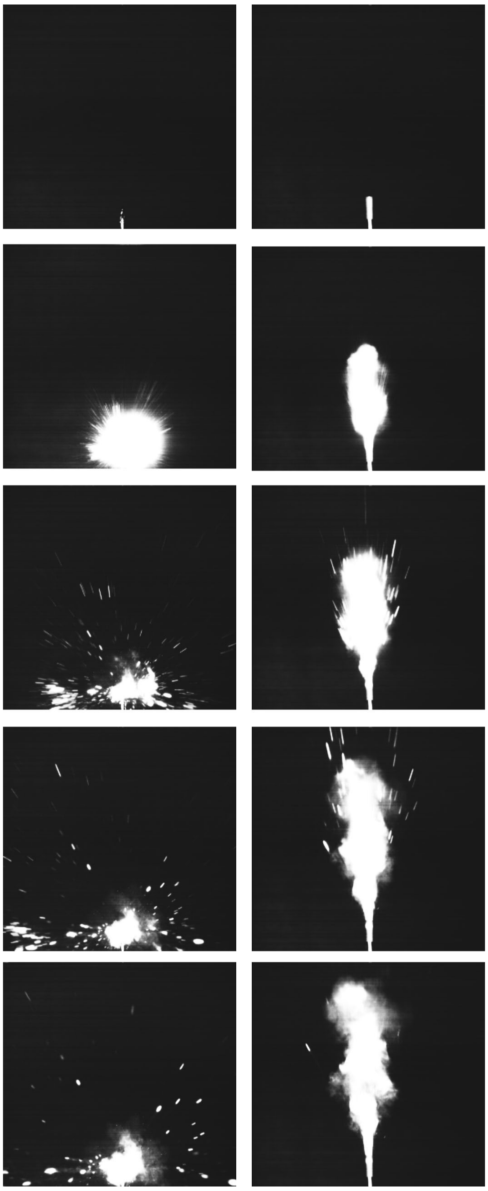
Electric igniter examples. [0.1 inch (2.5 mm) per division.]



A Magicfire™ igniter that contains two electric igniters. One is installed into the lift charge and fires immediately. The other is installed into the aerial shell in place of the time delay fuse and uses electronics to fire the aerial shell after a very precise time delay.



ELECTRIC IGNITER FIRING SEQUENCE



A series of photos 0.001 second apart in time. On the left is an un-shrouded electric igniter and on the right is one with its shroud in place.

Note that the shroud causes much greater directionality of the sparks and flame. It also results in the flame persisting for a longer time.

Electric igniters with their shrouds removed are very much more likely to be accidentally ignited. In almost all situations, the safety shroud should be left in place during installation and use.

ELECTRIC IGNITER CONNECTORS (E-MATCH LINKS OR SHOGUN OR VULCAN)

The use of this connector reduces the chances of an accidental ignition of an electric igniter because it leaves the safety shroud in place.

This cross section of an assembled unit shows that the shroud of the electric igniter is inserted into the connector. The connector contains additional pieces of black match that enhance the firing of the device.

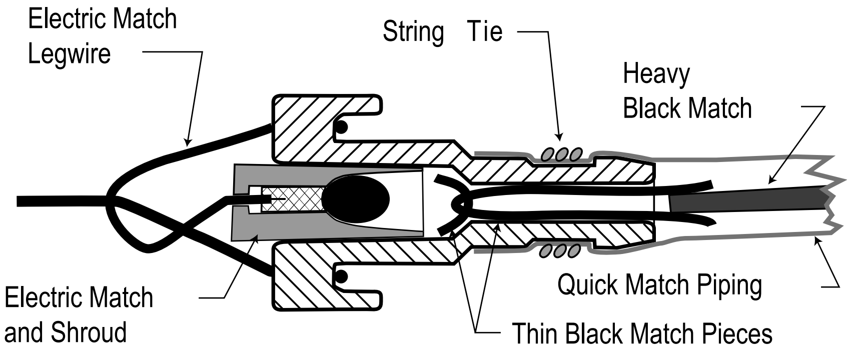
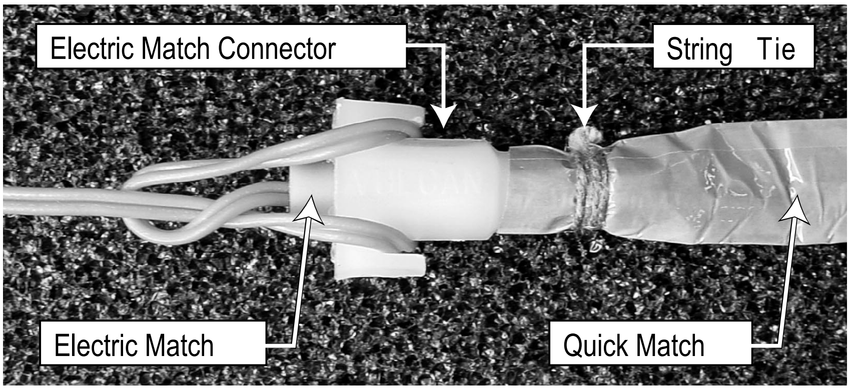
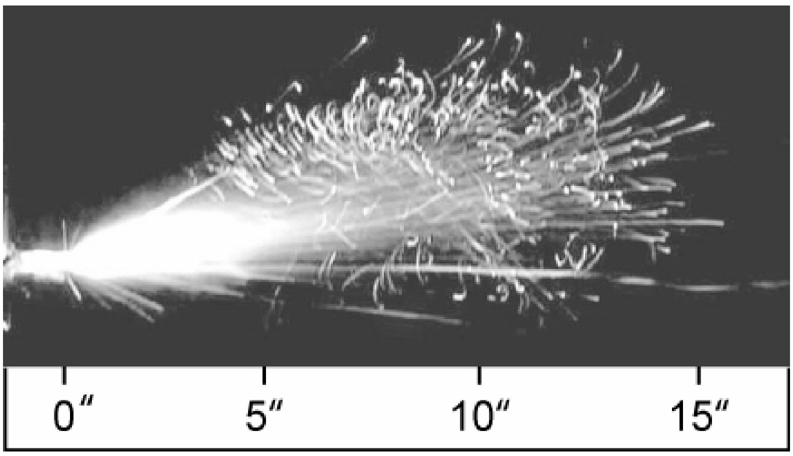


Photo of an assembled unit attached to quick match.



A photo of the quantity of spark material produced by a firing electric igniter held in one of the Shogun connectors. Note that the unobstructed “spit” of fire travels over 10 inches (750 mm) even without the presence of any additional black match by the user.



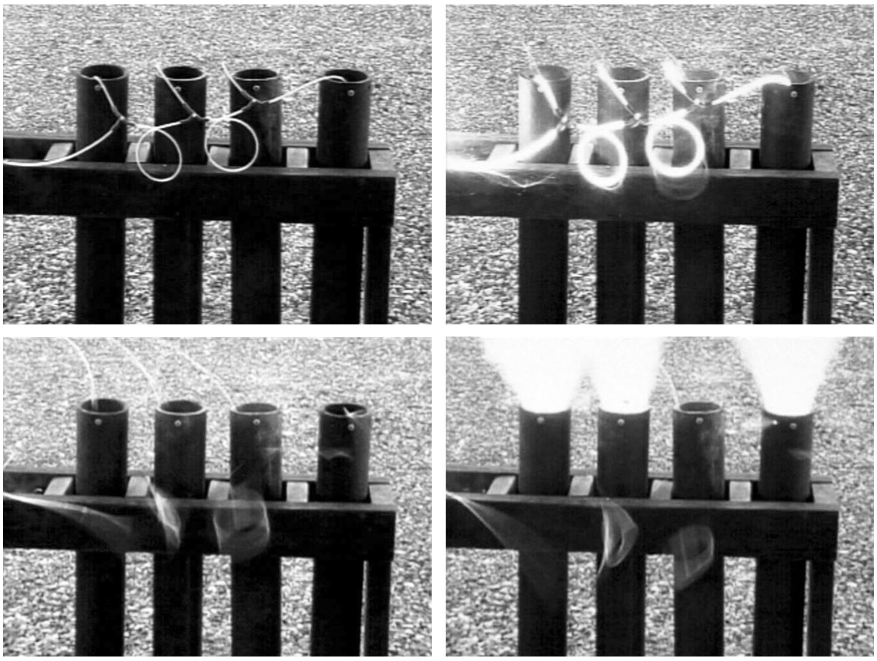
When these connectors are installed by the manufacturer, they save much time when installing (or removing) electric igniters by the user.

The use of these connectors improves safety because this provides added protection of the electric igniter, and there is no reason to remove the electric igniter safety shroud.

SHOCK TUBE FIRING EXAMPLE

Photos of aerial shell firing using the NoMatch shock tube system (the time between photos is ~0.017 second).

•



- Upper right – shock tube as it fires.
- Upper left – shock tube running to the mortars.
- Lower left – shock tube blowing free.
- Lower right – shells starting to fire.

Similar firing can be produced using thermo-tube.

SECTION 11 - MAKING REPAIRS TO FIREWORKS:

Most often needed repair supplies

Appropriate fuse cutting tools

Specific repairs to aerial shells:

- Missing shell leader safety cap
- Short black match delay element
- Damaged delay element
- Short shell leader
- Tear in shell leader
- Seriously damaged shell leader
- Fuse loop / suspender torn or missing
- Leaking lift powder
- Damaged casing or water-damaged shell

Repairs to other fireworks

Loose components

Damaged nosing

REPAIR OF FIREWORKS

Occasionally aerial shells and other fireworks sustain minor damage during shipping or from handling on the display site.

Minor repairs may be made if the crew has the knowledge and the needed repair materials.

Repairs should be limited to those that do not require actual disassembly of the fireworks.

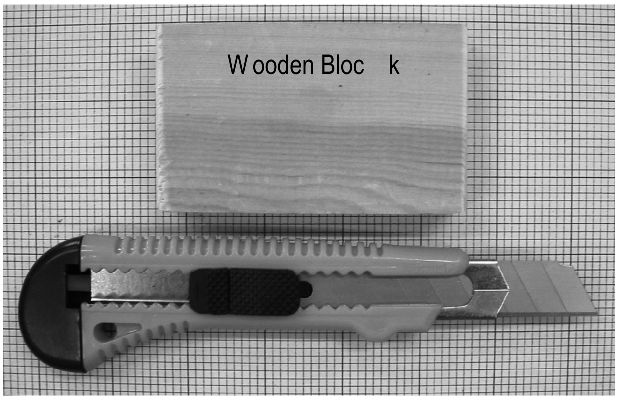
All repairs should be made in a secure area that is separated from other activities, is at least 200 feet (60 m) from the public and is at least 50 feet (15 m) from any firework storage area.

Among the most often needed repair materials are:

Masking tape	Black match strands
Strapping tape	Visco (hobby) fuse
String or cord	Razor knife (or box slitter)
Construction wire	Pliers (regular and cutting)
Quick match	Scissors
Kraft paper	Fuse cutters

APPROPRIATE FUSE CUTTING TOOLS

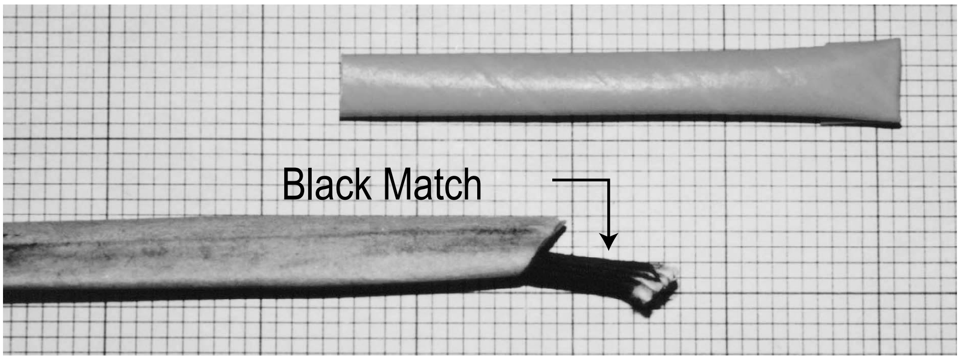
The most common method is to use a razor knife and cut the fuse on a block of wood. [0.1 inch (2.5 mm) per division]



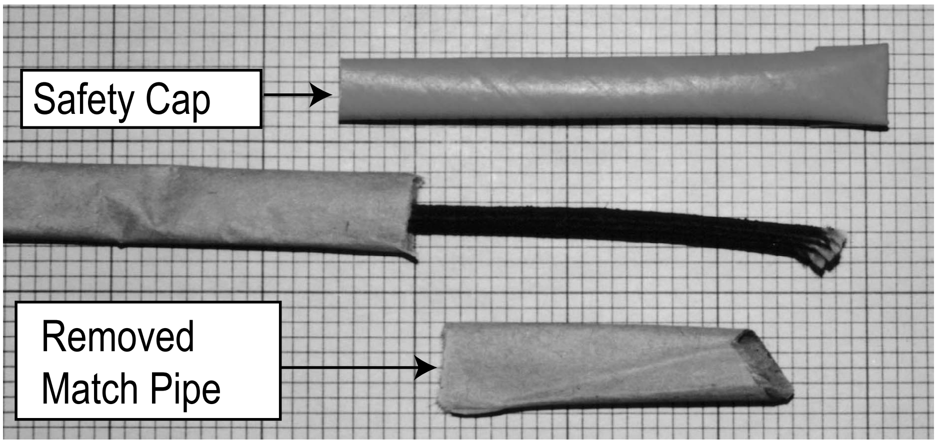
ALWAYS anticipate that cutting a fuse could cause its ignition.

SHORT BLACK MATCH DELAY ON SHELL LEADER

Problem: If the exposed black match delay element is short (≤3 inches or 75 mm) the amount of time between its ignition and the aerial shell firing will be too short for shooter safety. [0.1 inch (2.5 mm) per division]



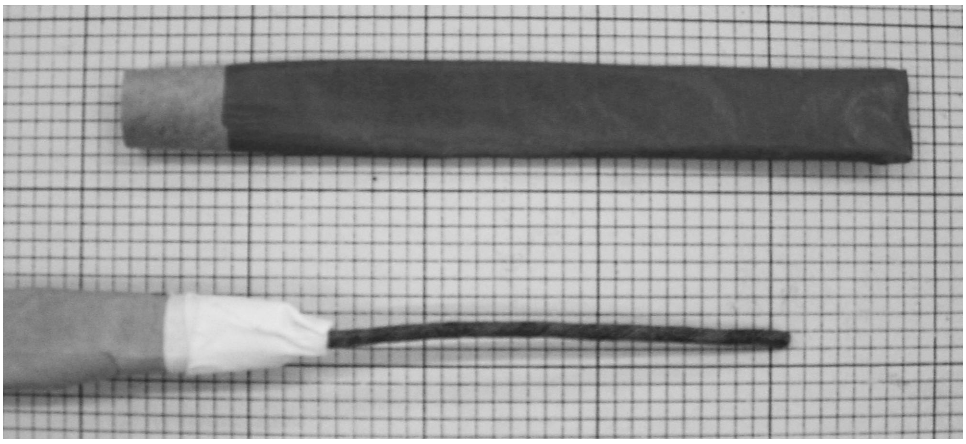
Solution A: If the shell leader is long enough to extend 6 inches (150 mm) out of the mortar, tear off an additional amount of the paper covering from the end of the shell leader to expose more black match.



Solution B: If the shell leader is not sufficiently long that it will extend about 6 inches (150 mm) out of the end of the mortar, then either:

Add a short length of quick match with a proper length of black match on its end. (See page 11 – 9.)

Cut-off the short length of black match and add a short length of visco fuse (also called hobby or cannon fuse). This is done by inserting the visco fuse about 1 inch (25 mm) into the end of the shell leader and wrapping the joint securely with tape. [0.1 inch (2.5 mm) per division]



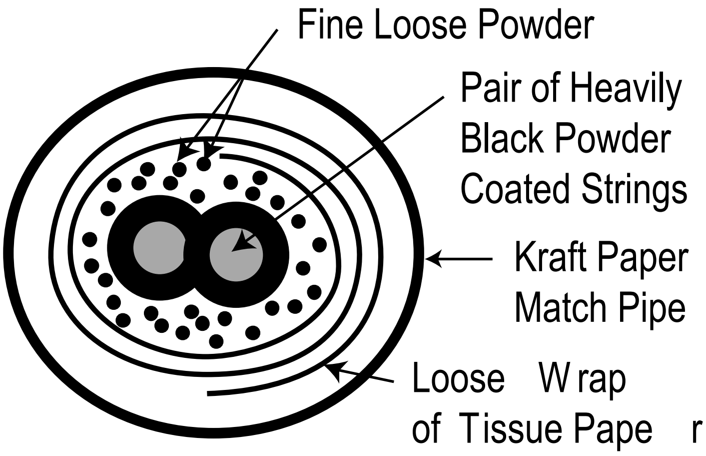
In any case, reinstall the safety cap over the fuse end.

CAUTION: REGARDING A FUSE SIMILAR IN APPEARANCE TO BLACK MATCH

There is a type of shell leader occasionally used that appears to have a black-match-like fuse inside it, however, the black-match fuse actually performs radically different.

Where black match typically burns at about 1 inch (25 mm) per second, the similar appearing fuse burns nearly as fast as quick match (>10 feet per second). Thus, even exposing several inches of this type of fuse will provide essentially no delay after igniting it.

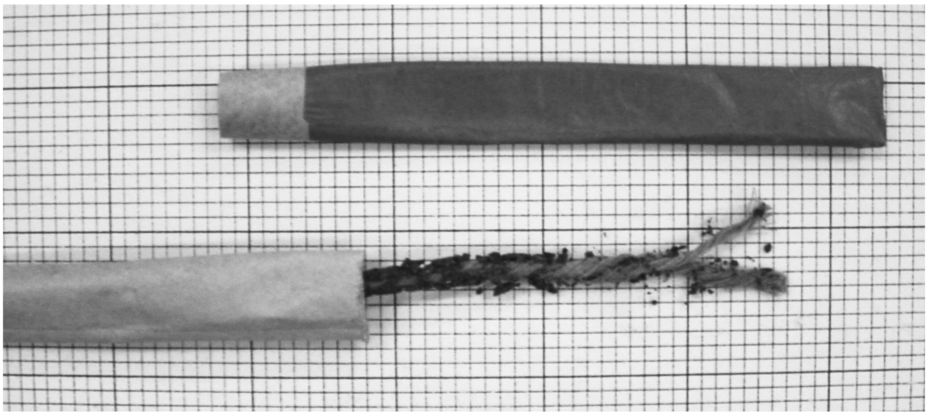
This type of fuse is made as illustrated below.



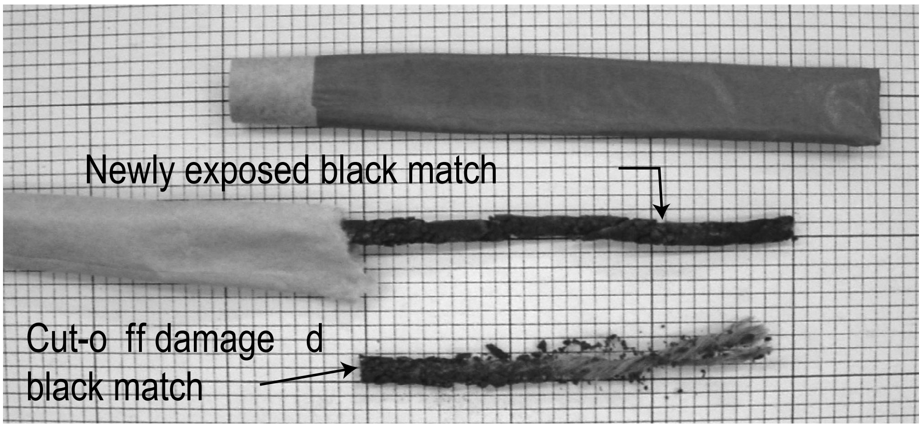
If this type of fuse is encountered, the only way to provide an acceptable delay is to cut the shell leader and use a length of standard black match or visco fuse inserted into the shell leader for a delay element.

REPAIR OF DAMAGED BLACK MATCH DELAY

Problem: If the black match delay element is very seriously damaged, the fuse may fail to take fire or to burn completely. Alternatively, if the fuse is only moderately damaged, the amount of time between its ignition and the aerial shell firing could be too short for shooter safety. [0.1 inch (2.5 mm) per division]



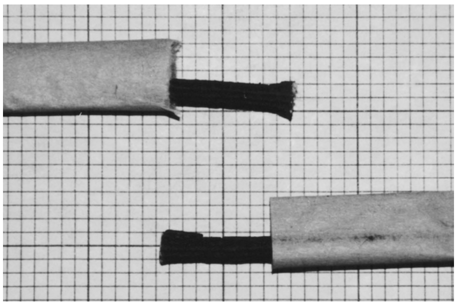
Solution: Cut-off the damaged black match and follow solutions A or B on pages 11-5 and 11-6.



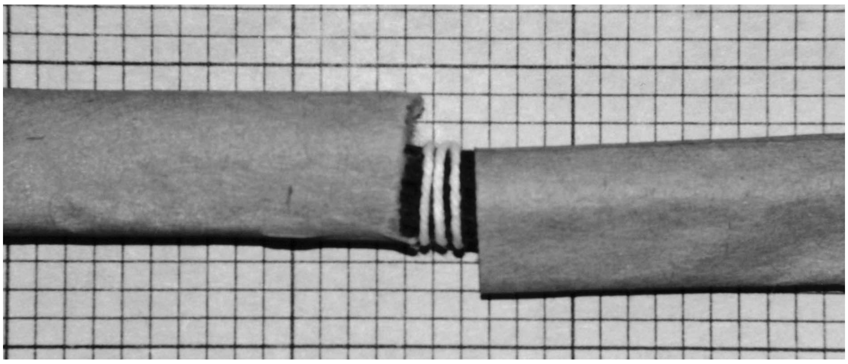
SHELL LEADER IS TOO SHORT

Problem: A short shell leader may not extend a safe distance (6 inches or 150 mm) out of the mortar. It is possible that the end of the short shell leader will slip down into the mortar after the shell is loaded, making it impossible to safely ignite the shell leader.

Solution: Splice on an additional short length of quick match. The ends to be spliced together are prepared by first exposing short lengths (approx. 1 inch or 25 mm) of black match. [0.1 inch (2.5 mm) per division]

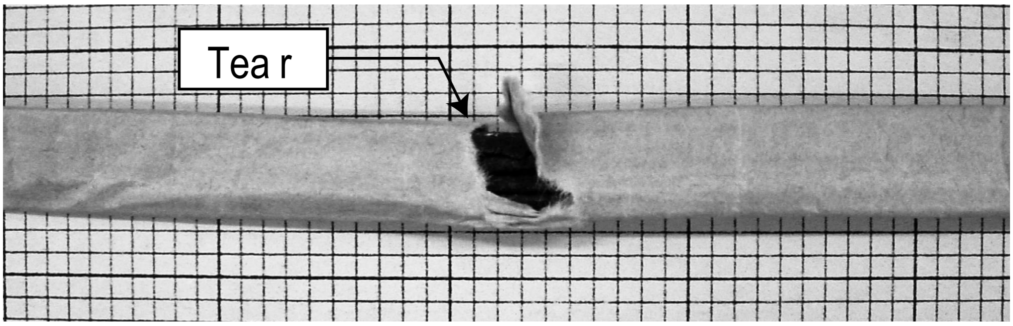


Complete the splice by inserting the black match ends into the paper wraps, tying with string, and covering with tape. (As shown on the next page.)

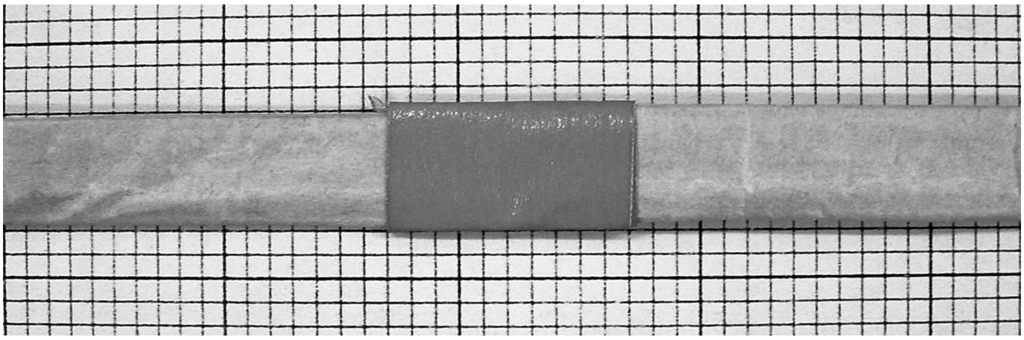


TEAR IN QUICK MATCH PAPER WRAP

Problem: When there is a tear in the paper covering of a quick match shell leader, some black match will be exposed and could accidentally be ignited by a stray spark. Also the paper wrap provides some strength to the quick match and protects the black match inside when the shell leader is handled. [0.1 inch (2.5 mm) per division]

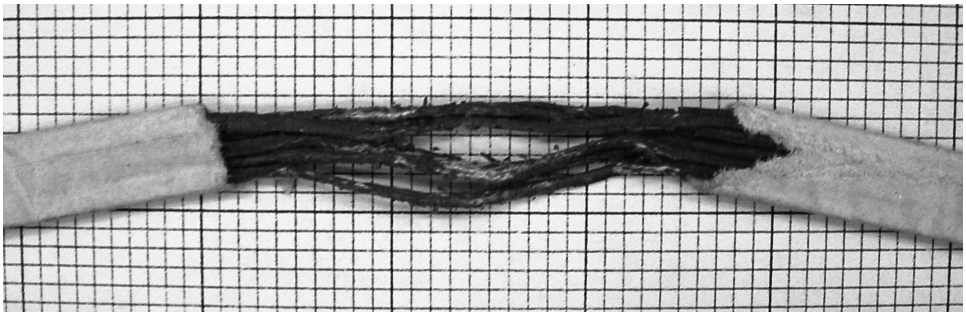


Solution: If the black match has not been seriously damaged, wrap a short length of masking tape around the tear to protect and strengthen the fuse. For seriously damaged black match see next page.



SERIOUSLY DAMAGED SHELL LEADER

Problem: If the shell leader is seriously damaged, it may fail to function properly. Thus a hangfire, a misfire or an accidental ignition from a stray spark may result when attempting to fire the aerial shell. [0.1 inch (2.5 mm) per division]



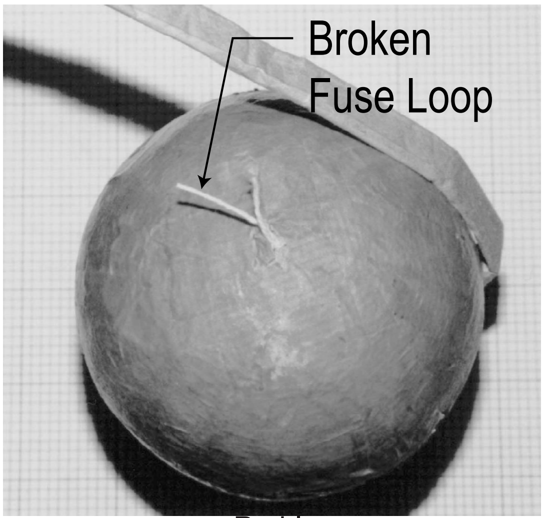
Solution: After cutting out the damaged portion of the shell leader, do one of the following:

A) If a sufficient length of leader remains to extend about 6 inches (150 mm) out of the end of the mortar, simply splice the two fuse pieces back together.
B) If an insufficient length of leader remains to extend about 6 inches (150 mm) out of the end of the mortar, splice in an appropriate length of additional quick match.

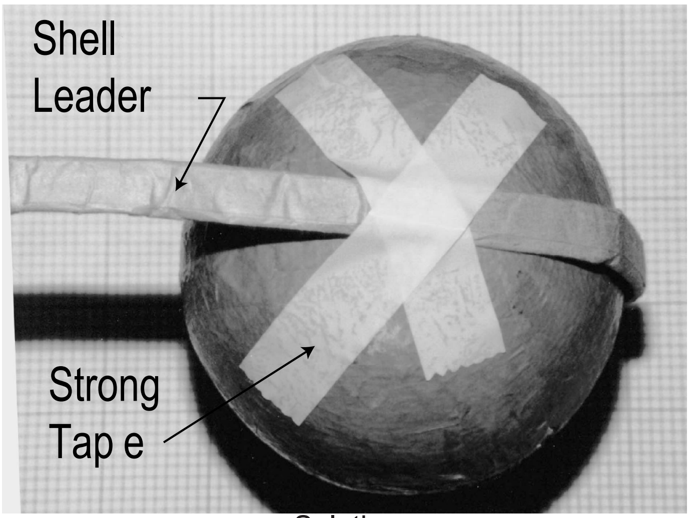
FUSE LOOP / SUSPENDER TORN OR MISSING

Problem: The fuse loop (or suspender) is generally a small loop of cord attached to the top of the aerial shell through which the shell leader passes. In this way when the aerial shell is held up by the leader for lowering into the mortar, the shell will be oriented properly (i.e., with the lift charge on the bottom).

If the fuse loop is missing or torn and the shell is held by the shell leader, it could orient itself upside down. If the shell is loaded up side down, the shell will not leave the mortar when fired and will explode in the mortar after a few seconds delay. [0.1 inch (2.5 mm) per division]



Problem



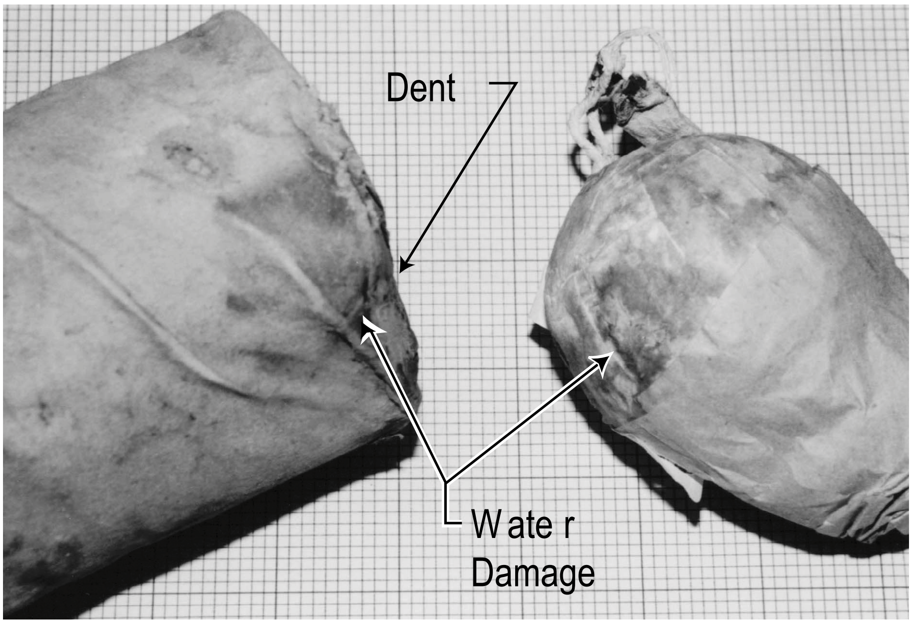
Solution

Solution: Using strong tape (strapping tape), tightly secure the shell leader to the top of the aerial shell.

If the aerial shell cannot be returned for repair, it should be disposed of as per the supplier's instructions.

AERIAL SHELL DAMAGED OR HAS GOTTEN WET

❷ *Problem: When an aerial shell is used that has been damaged or has otten wet, it may malfunction in any of a number of unpredictable ways. [0.1 inch (2.5 mm) per division]*



Solution: A field repair should not be attempted and the aerial shell must not be used.

After the display, the damaged aerial shell should be returned to the supplier or disposed of as per the supplier's instructions.

REPAIR OF OTHER FIREWORKS

When the damage to other types of fireworks is to the quick match, repairs such as suggested for aerial shell leaders may be made as described previously in this section.

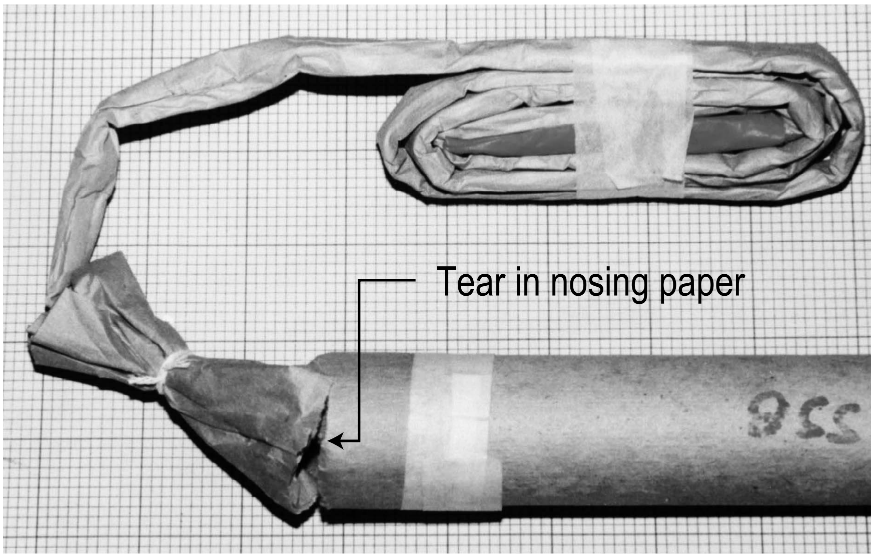
When a component has become loosened from a wheel or other set piece, it may be re-attached using string, strapping tape or wire depending on the strength of attachment that is required.

When the nosing paper wrap on an item has become torn, it should be removed and replaced. This will provide a strong attachment for its primary fuse and will keep stray sparks from prematurely igniting the item.

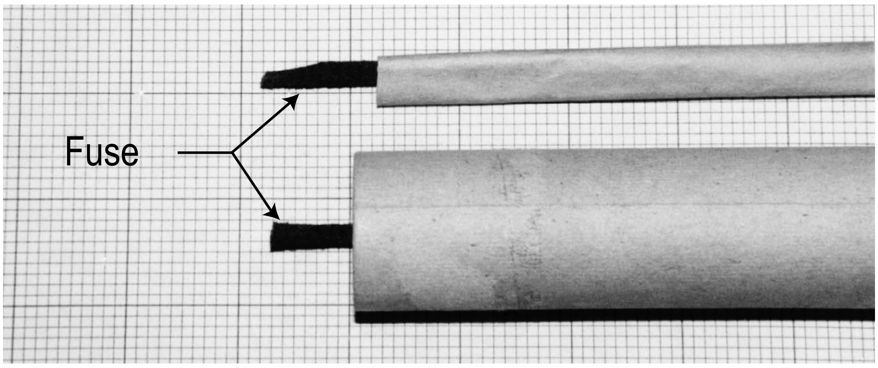
Other less common damage may be repaired when it is clear that no hidden damage has occurred, provided the necessary materials and knowledge are available on site. When one is in doubt concerning how a repair should be safely and effectively made, set the firework aside and do not use it.

REPAIR OF DAMAGED CAPPING

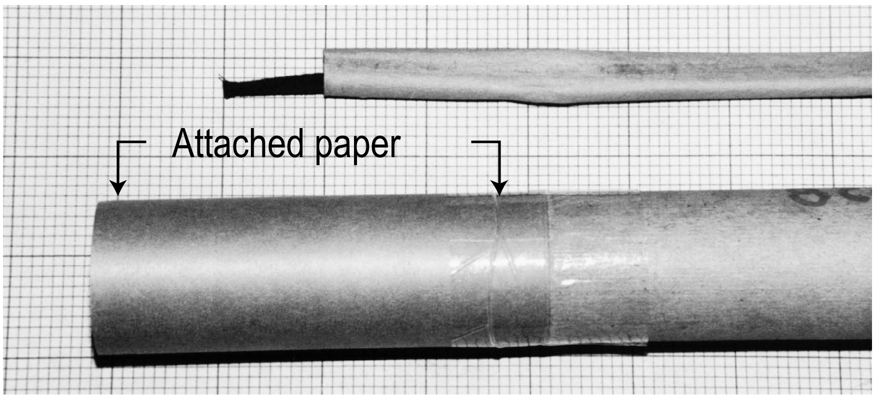
An example of a fountain (also called a gerb) with torn nosing paper.



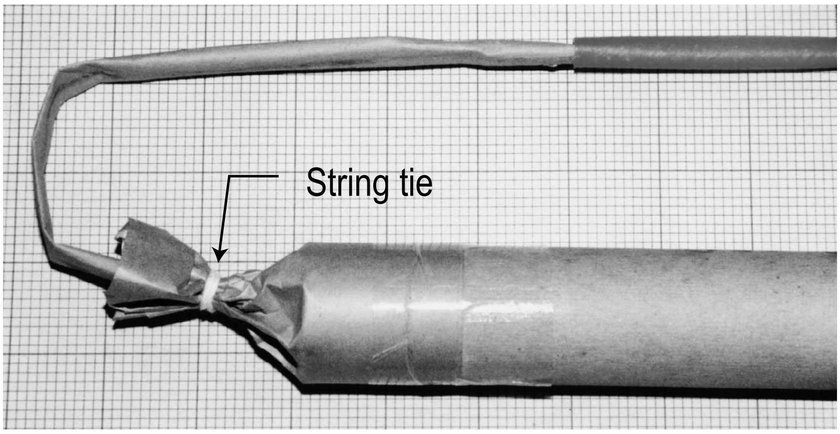
First remove existing torn nosing and free the external fuse.



Attach a wrap of at least two full turns of Kraft paper on the end of the device to make a new nosing.



Secure the quick match fusing into the paper nosing using tightly tied string.


String tie

SECTION 12 -SETUP OF GROUND AND LOW-LEVEL AERIAL FIREWORKS:

Separation distances for ground and proximate audience displays

Setup of fireworks on poles

Guy wire safety tips

Separation distances for comets and mines

Setup of low-level aerial fireworks

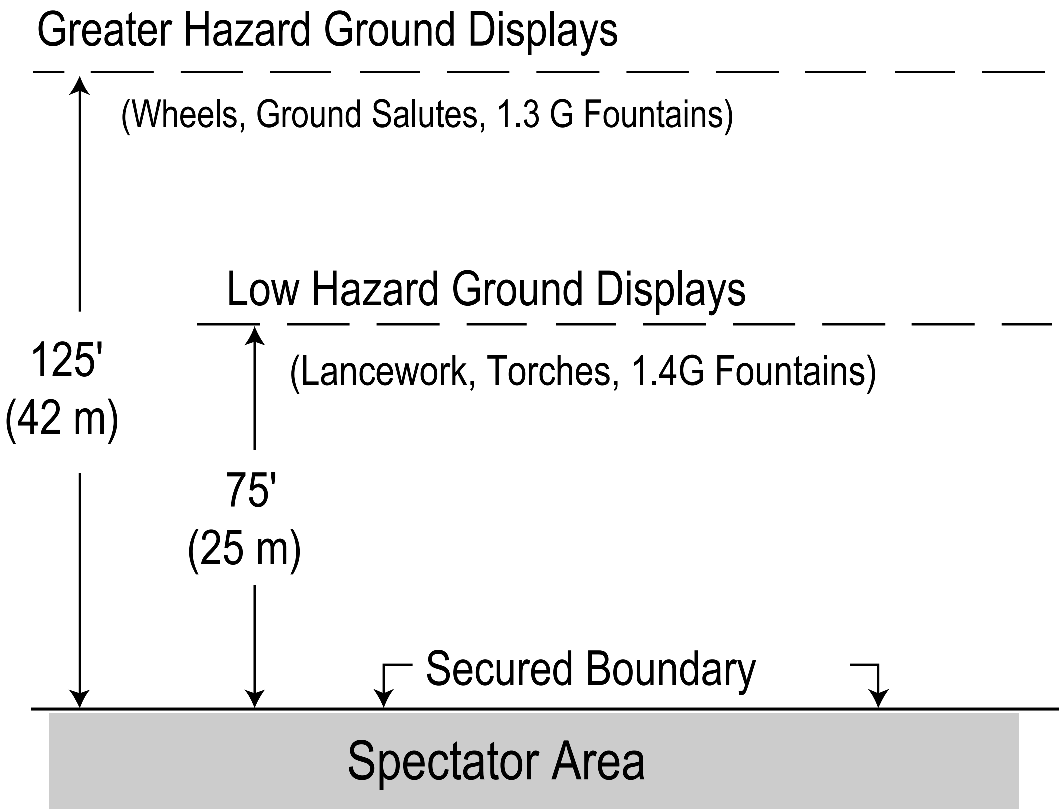
Accidental ignition considerations

Moisture protection

Iron wire tie example

SEPARATION DISTANCE FOR GROUND AND PROXIMATE AUDIENCE DISPLAYS

These are the minimum separation distance requirements of for ground displays.



The actual separation distances used must consider the potential hazard posed by each item in the event of its possible malfunction.

When a display includes some proximate audience pyrotechnic items, which are set-up and fired in full accordance, the reduced separation distances as prescribed may be used for those proximate audience items.

SETUP OF FIREWORKS ON POLES

If the fireworks device is small enough, it may be possible to attach the device to a stake or fence post driven into the ground using wire or strapping tape, depending on the needed strength of attachment.

Many ground display items will require mounting and erection. This will almost always be the case for wheels, which will need to be attached to a pole or post of some sort.

The point of attachment of a wheel must be secure, such that the wheel will not become separated from the pole during its use or if it malfunctions.

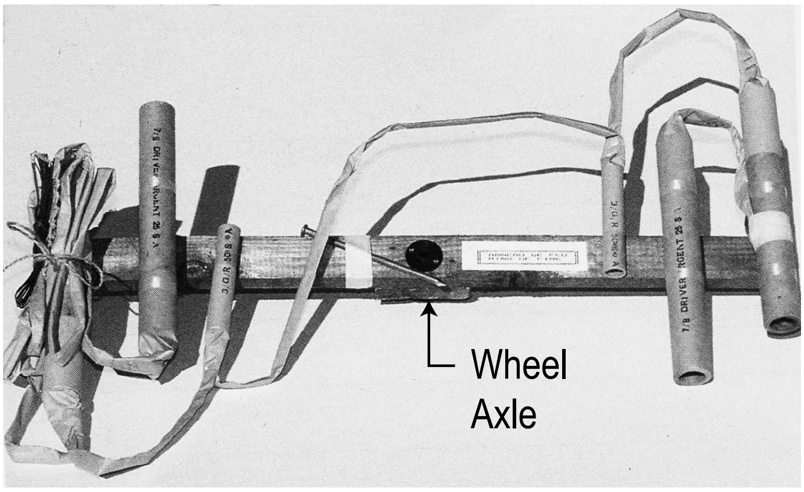
The pole will need to be erected, and it should be sufficiently secure such that it does not fall over from wind or during use.

Larger firework items will need to have guy wires or ropes (each tied to stakes in the ground) to keep the pole erect.

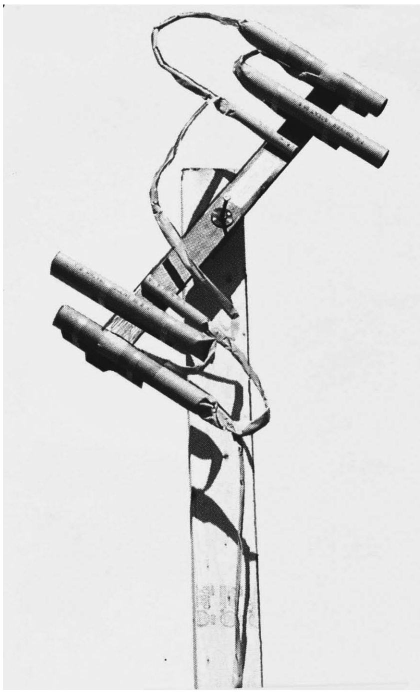
For very large items, the bottom of the pole should also be secured such that it will not move.

SETUP OF FIREWORKS WHEEL

An example of one type of wheel as it may be delivered.



The wheel attached to a pole and ready for use.

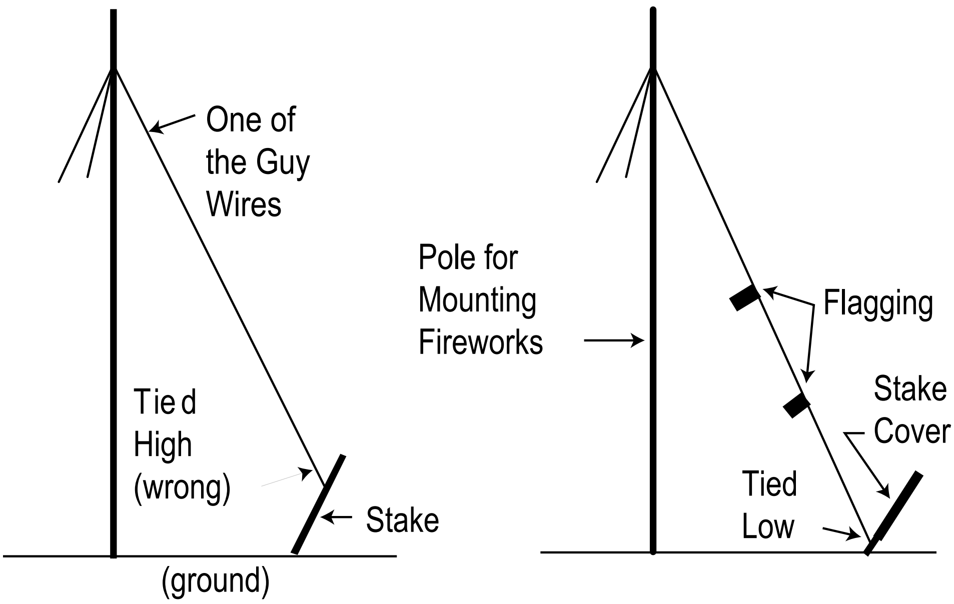


ERECTING LARGE DISPLAY WHEEL

This large ground display wheel is attached to a 4" × 4" (100 × 100-mm) post, which is being inserted into a pipe buried in the ground.

The erection of this wheel was completed by attaching four guy cables to the pole and running them to stakes securely driven into the ground.

GUY WIRE SAFETY TIPS



When guy wiring is required for stability:

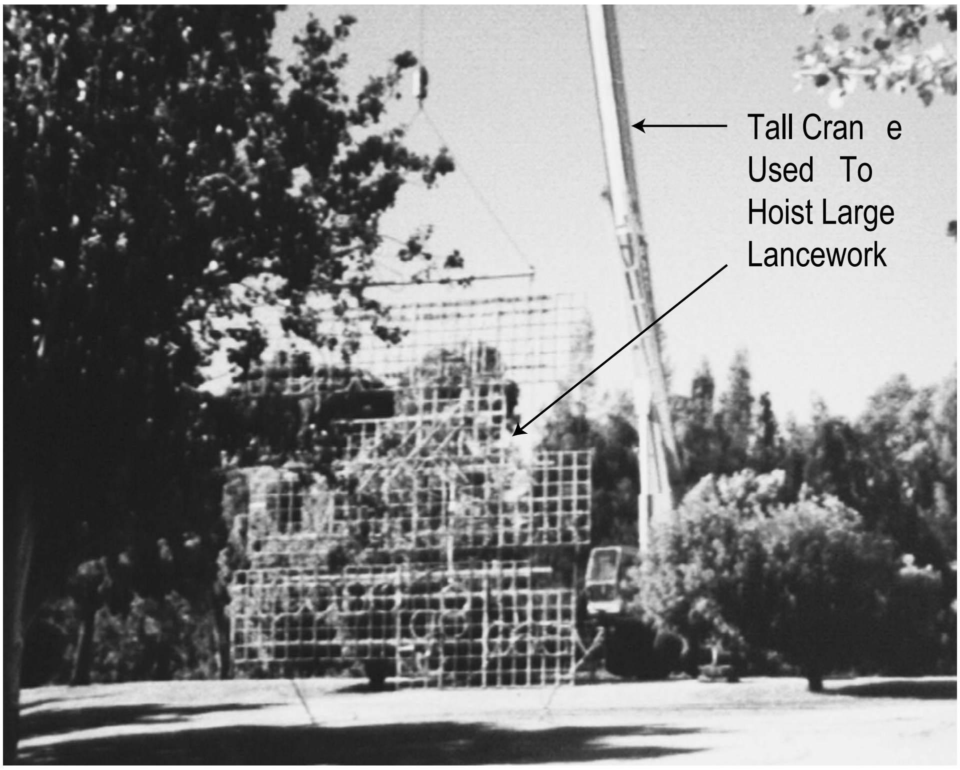
- For greater strength, the attachment point to stakes should be near ground level.
- Some type of flagging should be attached to guy wires for added visibility (useful in daylight — even more important at night).
- Metal stake tops often become sharp and can cause serious cuts if left exposed. Stakes are also trip hazards. Stake covers are advisable; they prevent cuts and make the stakes more visible.
- In some cases, rope may be used for guying.

MASSIVELY LARGE GROUND DISPLAY

Massively large Castillos, popular in Latin America, have their own unique engineering requirements.

MASSIVELY LARGE LANCEWORK

This large approximately 25-foot (8-m) square lancework is to be hoisted into place and supported using a tall crane.



During the display the lance work will be ignited when near the ground but hidden behind a wall of trees. Then it will be seen to mysteriously rise-up through the trees to become visible to spectators.

Crew members on the ground will provide stability using cables attached to the bottom of the lancework frame.

SETUP OF LOW-LEVEL AERIAL FIREWORKS

When possible, low-level aerial fireworks (small Roman candles, comets, mines and consumer multi-shot cakes) should be angled so that their effects are propelled away from spectator areas.

When the separation distance is greater than the maximum range of the item, angling is not useful.

Low-level aerial fireworks should be securely positioned to keep them from possibly tipping over and firing in dangerous directions. This could happen from the normal recoil of the item as it fires or because of the malfunction of an item. Secure positioning may be accomplished by:

Secure attachment to a framework.

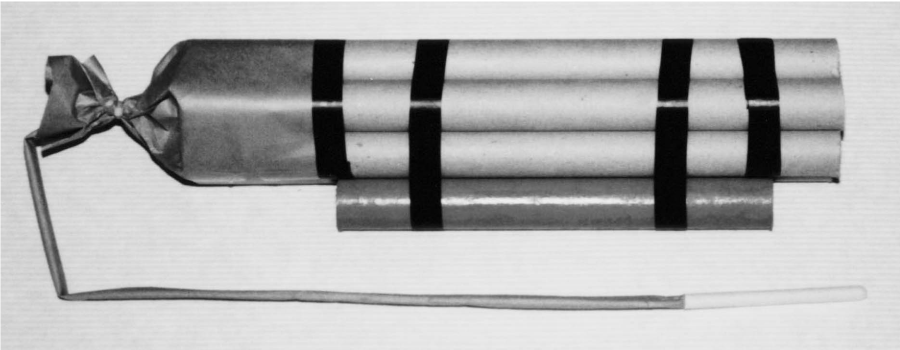
Barricading low-level aerial fireworks on the spectator side is a useful precautionary measure (See next page.) Unless spectator separation distances are particularly great.

Small cakes can be stabilized using sand-weighted containers.

Small calibre barrage racks can be stabilized using legs and sand bags.

STAKED ROMAN CANDLE BATTERY

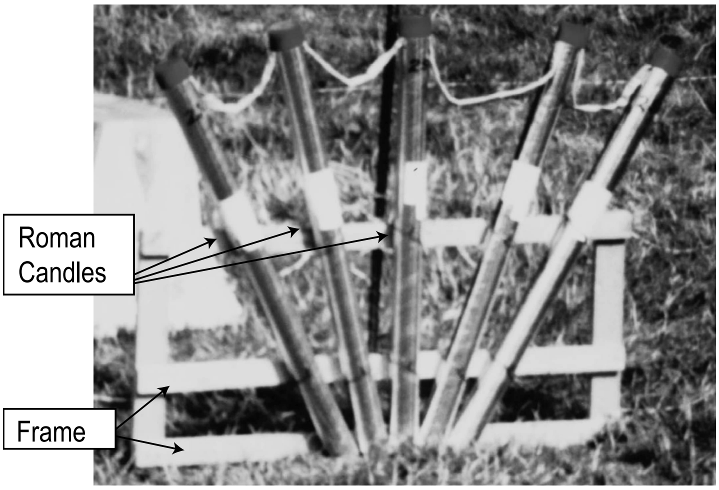
A collection of Roman candles, often called a Roman candle battery.



The Roman candle battery is secure staked and angled away from spectators.

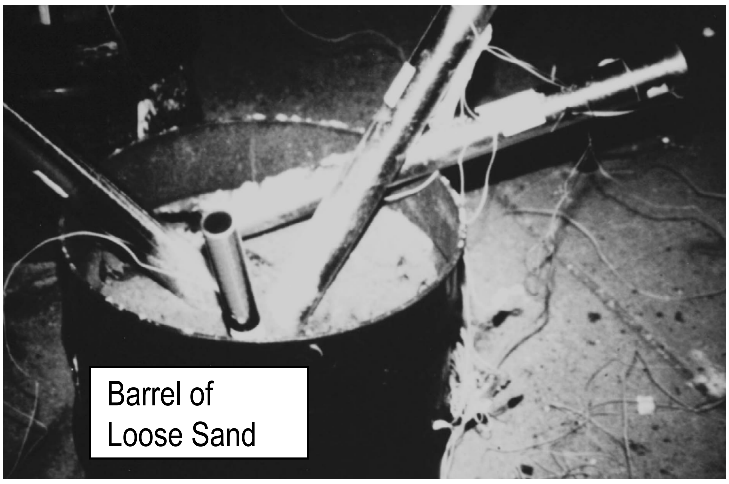
ROMAN CANDLE BATTERY ATTACHED TO A FRAME

A Roman candle battery securely attached to a strong wooden frame. The frame should be positioned on the spectator side of the battery and the entire frame should be placed on the rear side of the stake.

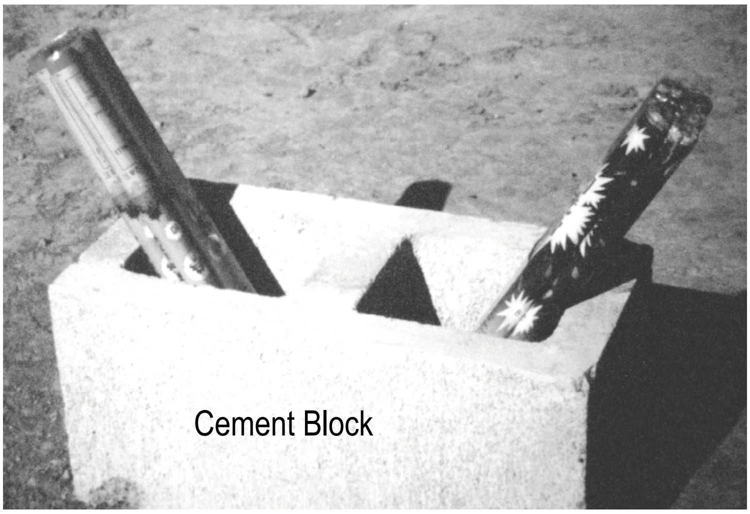


UNACCEPTABLE PLACEMENT OF ROMAN CANDLES

These Roman candles were simply placed directly into loose sand. Almost any malfunction (as in this case) can cause a serious realignment.



These Roman candles are too loosely held by merely placing them into the holes in a cement block.



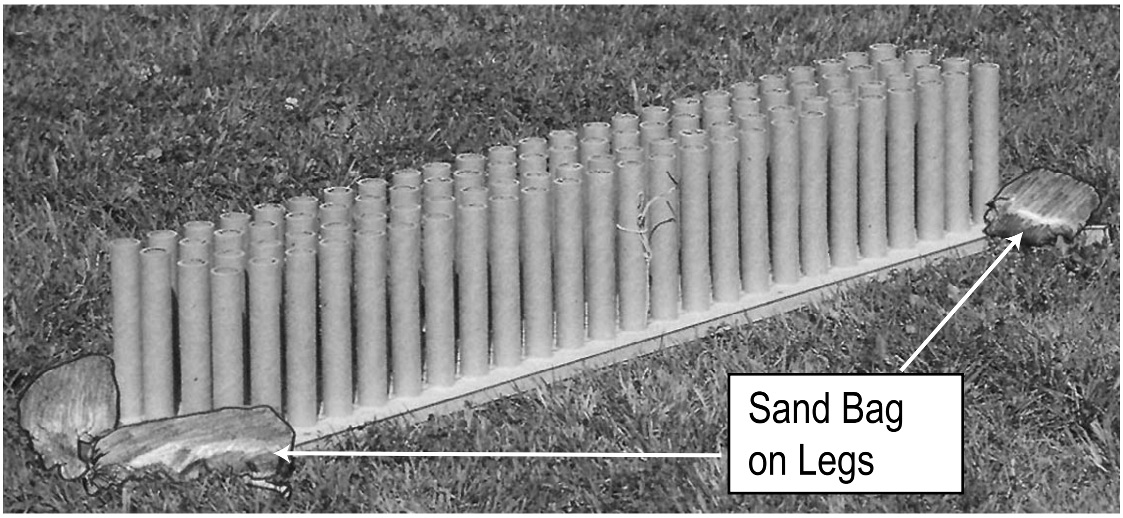
PLACEMENT METHODS FOR CAKES

The important things to remember when placing cakes for firing are:

- The cake is placed on flat ground, or alternatively on a board
- The cake must be stable - this is particularly important for cakes that are higher than they are wide - in which case staking may be required

SMALL CALIBRE BARRAGE RACKS

Racks of small calibre items must be secured, such that they will not fall over and fire in dangerous directions during use or in the event of a malfunction.



The use of attached legs plus sand bags are helpful in providing support.

When its design makes it possible, securely staking the item in place is the preferred method.

Barricading on the side(s) toward spectators is a useful spectator safety measure.

ACCIDENTAL IGNITION CONSIDERATIONS

In placing ground and low-level aerial fireworks, thought should be given to minimizing the chances of accidental ignitions caused by sparks and burning debris from the various fireworks.

To help avoid accidental ignition of aerial shells:

- Ground and low-level aerial fireworks should not be located in the immediate area where mortars have been loaded.
- Sparks from ground displays must not be produced near ready boxes or where shell loading is occurring.

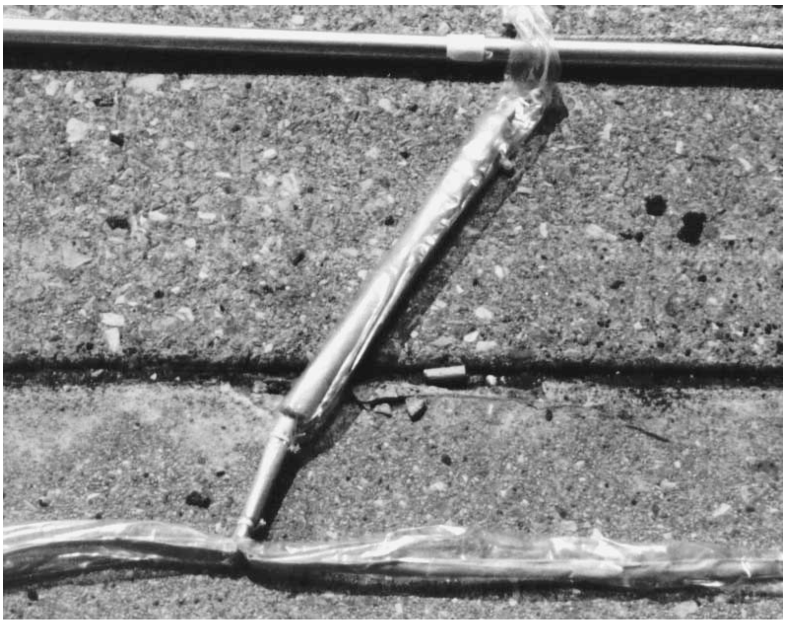
To help avoid accidental ignition of ground items:

- When practical, separate these items from other ground displays.
- Attempt to locate ground displays reasonably far from the fallout from high-level aerial displays.
- If necessary, ground displays can be protected using tarpaulins or aluminium foil.

MOISTURE PROTECTION

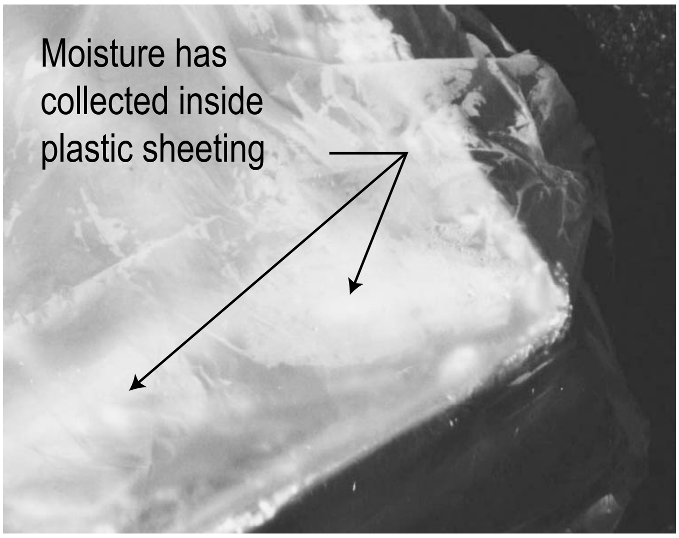
Very thin plastic tubing can often be used to protect quick match from moisture.

The same tubing can be used to protect small components (e.g., Niagara falls tubes and gerbs).



Large plastic bags or sheeting can be used to protect larger items from external moisture.

However, when the items are too tightly sealed, the moisture already contained within the item may condense inside the plastic covering, possibly to the point of affecting the item's ignition or performance.



SECTION 13 - MANUAL DISPLAY FIRING PROCEDURES:

Display operator responsibilities

Firing crew personnel assignments

Aerial shell loading

Aerial shell firing

Firing crew protection

Ready box tending

Aerial shell spotting during display

Crowd control monitors

Show interruptions

After the show

Requirements for barge and roof-top displays

Requirements for firing salutes

Preloaded manually fired displays

DISPLAY OPERATOR RESPONSIBILITIES

Senior Firer: The person with overall responsibility for safety, and the setting up, firing derigging of an outdoor fireworks display.

Responsibility:

With regard to the Public:

- ♦ No single failure of fireworks or equipment can be allowed to injure a member of the public.

With regard to the Crew:

- ♦ Training: Tell them the correct way and WHY.
- ♦ Crew Size: Do not have too many or too few.

With regard to the Display Company and Sponsor:

- ♦ First and Foremost: A Safe Show.
- ♦ Second: A Great Performance.

Operator Participation:

- ♦ Before and after the display — Oversee and check on the proper completion of all work.
- ♦ During the display — Monitor safety and crew performance and take all needed corrective measures.

AERIAL SHELL FIRING, GENERAL GUIDANCE

Keep one's posture low and with head tucked in, approach the mortar with one's side somewhat toward the mortar.

Make sure no body part is ever placed over the mortar opening.

Remove the safety cap from the shell leader.

Using a portfire on an extender ignite the very tip of shell leader fuse.

After ignition of the shell leader delay fuse, immediately turn away and retreat at least one step.

Crouch down with one's back toward the mortar. Maintain that position until the aerial shell fires.

Only attempt to accomplish a single aerial shell ignition on each approach to the mortar line.

Attempting more than one ignition will prevent the Firer from taking the proper position when the first aerial shell fires and may preclude detecting a hangfire if it occurs.

Control the situation if a hangfire or misfire occurs.

Wait several extra seconds for the shell to fire.

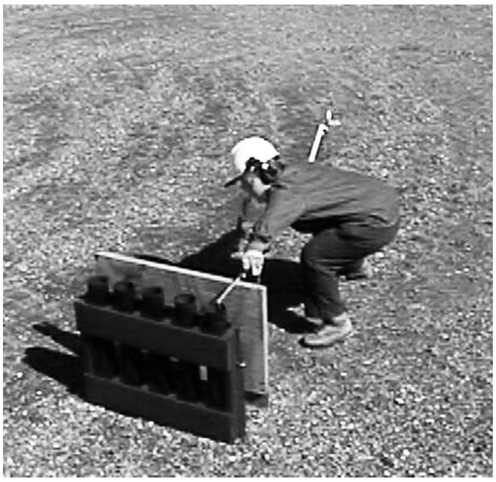
If the aerial shell still does not fire, mark that mortar as a warning so that it will not be reloaded or reused during the display.

Verbally warn the rest of the crew and the operator that a hangfire or misfire has occurred and that the mortar has been marked to prevent its future use.

MANUAL AERIAL SHELL FIRING PROCEDURE

Approach the already loaded mortar with a lighted fuse on an extender held away from the mortar.

Reach forward, extending one's free hand and remove the safety cap on the shell leader fuse.



Step back and rotate to bring the fuse on its extender forward.

Keeping low, ignite the very tip of the delay element on the end of the shell leader.

Immediately turn away, take another step, and crouch down as the delay element on the aerial shell leader fuse burns.

Maintain the low-crouch position until the aerial shell fires. Only then is it safe to rise and prepare to fire another shell.

SHELL BOX TENDING

- Use only artificial light (e.g., chemical light sticks).
- Only open ready box lid when it is necessary and when there are no sparks in the immediate area.
- To help avoid loading errors, take care to give the correct size aerial shells to each loader.
- Watch for changes in ground level wind direction because this may require relocating the ready boxes.

AERIAL SHELL SPOTTING (OFTEN DONE BY THE OPERATOR)

- Closely watch the first few aerial shells (to judge whether there has been proper angling of the mortars).
- Monitor that debris is falling out safely.
- Watch for and count dud shells.
- Watch for changes in winds aloft.
- Inform the operator if any problems are observed.

CROWD CONTROL MONITORS

- Take all reasonable efforts to maintain crowd control by keeping unauthorised people out of the display site.
- Communicate to operator if there is loss of control.
- Generally this will require having a radio, cell phone or a signal light of some type.
- It is useful to take measures to help identify the control monitors as a display official.

Crowd control must be maintained after the display, until the operator has declared the area safe. (This may require an hour or more to happen.)

SHOW INTERRUPTIONS

Try to decide in advance under what circumstances one must interrupt the show. For example, be prepared to temporarily interrupt the show when:

There is a loss of crowd control.

There are any serious crew errors or injuries.

There are aerial shell problems and the use of some type of shells must be discontinued.

There are weather problems (e.g., a wind shift or excessive wind speed).

Interrupting a display to fix a problem will detract from the overall performance less than most operators think. This is especially true if the interruption occurs early in the show or when the audience can be informed of the reason for the delay.

Avoid the "Show Must Go On" Syndrome. This is where an operator ignores safety and foolishly continues a display for the sake of a better performance.

AFTER THE SHOW

Maintain full site security until the operator declares the display site safe (i.e., free of live fireworks).

Persons in the firing and fallout areas after the display should conduct themselves as though misfires and dud shells are present.

Take a short break say at least 5 minutes for mortars, thus allowing a "cool-down" period, before searching for and handling duds and misfires.

Search for known and UNKNOWN duds.

Handle duds properly:

- ♦ Wait at least 15 minutes before approaching.
- ♦ Douse the dud shell with water.
- ♦ Wait at least 5 minutes longer.
- ♦ Remove dud with as little direct contact as possible.

After a cool-down period of at least 15-minutes, check all mortars for misfires and remove any live fireworks.

Typically the check is performed by using a stick with a handle to the side. This allows probing each mortar for unfired aerial shells without placing one's hand directly over the mortar.

Handle misfires properly:

- ♦ Fill the mortar partly with water.
- ♦ Wait at least 5 minutes longer.
- ♦ Remove the mortar and dump out the shell – taking care to never have any body part over the mortar.

Misfired aerial shells from an electrically fired display, where the failure to fire is due to an electrical fault, may be salvaged.

Properly transport and store all live fireworks, including duds and misfires.

If disposal is necessary, follow the supplier's instructions.

PRELOADED MANUALLY FIRED DISPLAYS

Manual firing exposes the Firer to the risk of injury from an aerial shell malfunction. However, the reloading of shells during the display poses a far greater risk to the entire crew!

Reloading is hazardous, it:

- Requires the storage of aerial shells in the immediate area of much fire and sparks, thus posing an explosion hazard.
- Requires the presence of additional people in the firing area and thus exposed to all of the hazards posed during the display.
- Requires the handling of explosives in the dark while rushed and in the immediate presence of fire and sparks.

Preloading of all aerial shells is greatly preferred.

It requires more equipment and more setup time; however, it eliminates approximately 80% of the most serious crew injuries during a display!

SECTION 14 - BASIC ELECTRICITY:

❷ *Please note that this chapter is all level 2*

Ohm’s law

Wire resistance

Electric circuit symbols

Series circuits

Parallel circuits

Internal battery resistance

ELECTRICITY AND WATER ANALOGY

❷ *The flow of electricity through an electrical circuit is somewhat analogous to water flowing through pipes.*

The utility of this analogy is that it can make it easier to understand the basic physics of simple electric circuits.

Analogous terms:

Electrical Units			Water Analogy
Parameter	Symbol	Unit	
Voltage	E	volt	Pressure
Current	I	ampere	Rate of Flow
Resistance	R	ohm	Resistance to Flow

For Example:

For plumbing, the size (diameter) and length of pipes are the physical attributes that determine the amount of water that will flow through the pipe in response to a given water pressure.

For electricity, the size (diameter) and length of the wire are the physical attributes that determine the amount of electric current that will flow through the wire for a given voltage.

OHM'S LAW

❷ *Ohm's law is the basic defining relationship for simple electric circuits.*

Stated in words, Ohm's Law says that the amount of electric current (I, for electric Intensity) that will flow in a circuit is proportional to the applied voltage (E, for Electro-motive force) and is inversely proportional to the circuit's electrical Resistance (R).

$$I = \frac{E}{R} \qquad \left[\text{Flow Rate} = \frac{\text{Pressure}}{\text{Flow Resistance}} \right]$$

Considering the water analogy, Ohm's law makes sense.

For plumbing, everyone knows that:

- *Increasing water pressure → Increases flow rate*
- *Longer or smaller water pipe → Decreases flow rate*

Analogously for electrical circuits:

- *Increasing voltage (E) → Increases current flow (I)*
- *Longer or thinner wire (>R) → Decreases current flow (I)*

OHM'S LAW EXAMPLES

❷ *For an electric circuit, which has a total of 10 ohms of resistance (R), how much current (I) will flow when it is connected to a 12 volt (E) power source?*

Ohm's Law

$$I = \frac{E}{R}$$

Substituting Values

$$I = \frac{12\text{ volts}}{10\text{ ohms}}$$

The electric current $I = 1.2$ amperes

For an electric circuit that has a total of 8 ohms of resistance, what voltage is required to cause a current of 0.5 ampere to flow?

Ohm's Law

$$I = \frac{E}{R}$$

Rewriting Ohm's Law $E = I \times R$

Substituting Values $E = (0.5\text{ ampere})(8\text{ ohms})$

Voltage Required $E = 4$ volts

COPPER WIRE RESISTANCE TABLE

❷ *The resistance of copper wire becomes greater as the diameter of the wire becomes smaller. (Water analogy: small pipes mean more resistance to water flow).*

Standard annealed solid copper wire resistance as a function of American Wire Gauge (AWG):

AWG	Wire Diameter (in.)	Wire Diameter (mm)	Resistance / 100 ft (30m) (Ohms)
16	0.051	1.29	0.41
18	0.040	1.02	0.65
20	0.032	0.81	1.04
22	0.025	0.64	1.65
24	0.020	0.51	2.62
26	0.016	0.41	4.16
28	0.013	0.33	6.62

When electrically firing a device that is 100 feet (30 m) away, the total wire length is actually 200 feet (100 feet out plus 100 feet back) (60 m; 30 m out plus 30 m back).

The resistance of wire is proportional to its length. For example, for 20 AWG copper wire:

Length	(feet) / (meters)	3 / 10	15 / 50	30 / 100	60 / 200	300 / 1000
Resistance (One Way)	(ohms)	0.10	0.52	1.04[(a)]	2.08	10.4
Circuit Resistance (Both Ways)	(ohms)	0.20	1.04	2.08	4.16	20.8

a) From Table on previous page.

Resistance table for 24 AWG copper wire:

Length	(feet)	3	15	30	60	300
	(meters)	10	50	100	200	1000
Resistance (One Way)	(ohms)	0.26	1.31	2.62[(a)]	5.24	26.2
Circuit Resistance (Both ways)	(ohms)	0.52	2.62	5.24	10.48	52.4

a) From Table on previous page.

Similar tables can be made for other wire gauges and lengths.

WIRE RESISTANCE CALCULATIONS

❷ *A 24 gauge copper wire runs from a 1.5 volt power source to a point 33 ft (10 m) away and back again to the power source. What is the resistance of the wire and what current will flow when it is connected?*

From the wire table:

For 24 gauge wire the resistance is 2.62 ohms / 100 ft (30 m)

Total wire length (out and back):

2 x 33 ft (10 m) = 66 ft (20 m)

Wire resistance (Rw):

$$R_w = \frac{2.62\ \text{ohms}}{100\ \text{ft}\ (30\ \text{m})} \times 66\ \text{ft}\ (20\ \text{m})$$

$$R_w = 1.74\ \text{ohms}$$

Ohms Law:

$$I = \frac{E}{R_w}$$

Substituting values:

$$I = \frac{1.5\ \text{volts}}{1.74\ \text{ohms}} = 0.86\ \text{ampere}$$

If a wire must be run a total distance (out and back) of 400 ft (120 m) and must carry at least 1.0 ampere when attached to a 12 volt power source, what is the thinnest gauge wire that can be used?

Ohms Law:

$$I = \frac{E}{R}$$

Rewriting:

$$R = \frac{E}{I} = \frac{12\ \text{volts}}{1\ \text{ampere}} = 12\ \text{ohms}$$

Maximum total wire resistance:

$$R = \frac{12\ \text{ohms}}{400\ \text{ft}\ (120\ \text{m})} = \frac{3\ \text{ohms}}{100\ \text{ft}\ (30\ \text{m})}$$

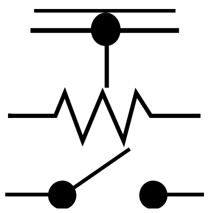
From the wire table:

24 gauge wire is the smallest diameter wire with a resistance less than 3 ohms per 100 ft (30 m).

(Water analogy: If a long water pipe has too small a diameter, then the flow rate through it may not be sufficient for the need.)

ELECTRIC CIRCUIT SYMBOLS

❷ *When electric circuits get more complex, it is often necessary to draw the circuit on paper to analyze it. To do this, some important symbols are often used.*



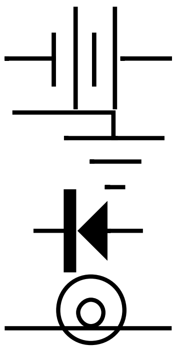
= a wire

= an electrical connection point between two wires

= a resistor or an item in the circuit with some electrical resistance

= an electric switch (shown in the open position)

Other, less often needed symbols:



= a battery

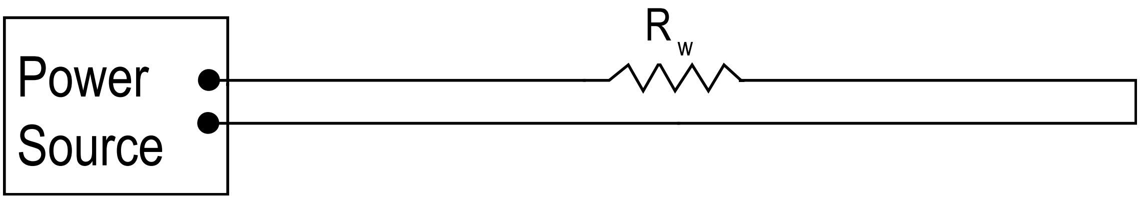
= a point of electric ground

= a diode (for the isolation of firing circuits)

= a light bulb

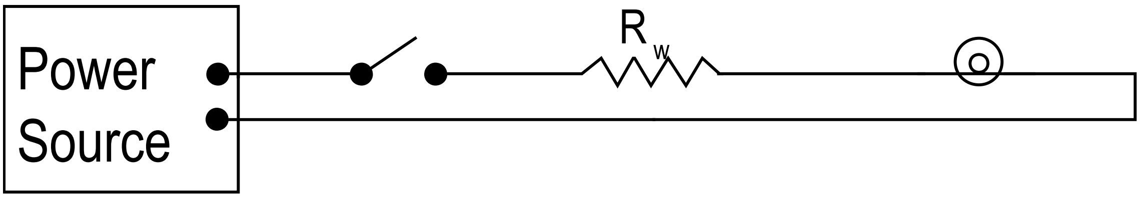
ELECTRIC CIRCUITS

❷ *The electric circuit drawing for the wire resistance (Rw) examples can be drawn as:*

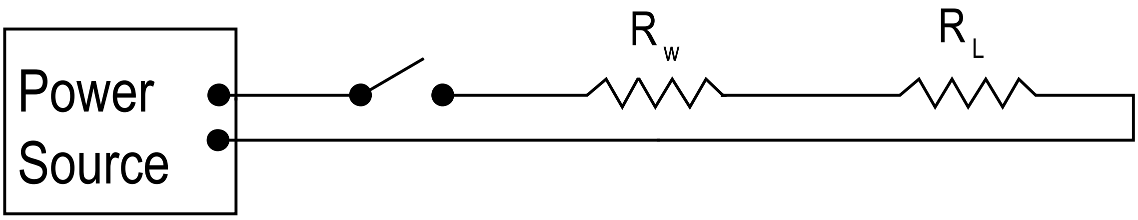


For simplification, in such a circuit drawing, it is common to show all the resistance of the wire concentrated at one point, using the symbol for a resistor.

If the purpose of running the wire is to power a light bulb, and a switch is included, then the circuit drawing would be:

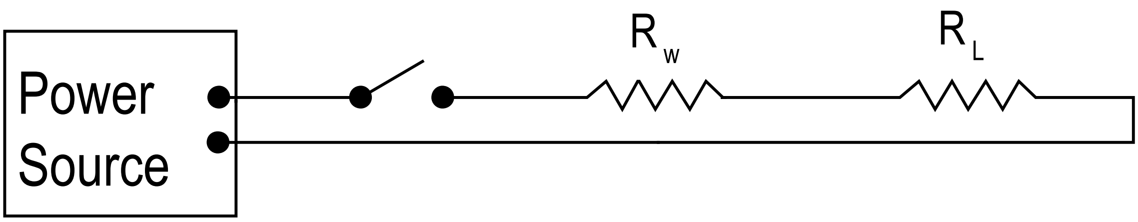


Because the light bulb has electrical resistance (RL), the equivalent circuit could be drawn:



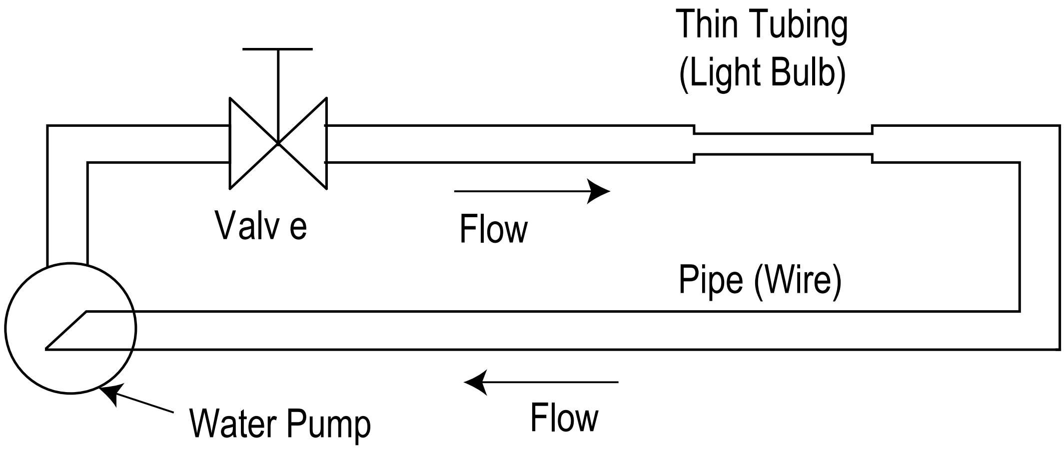
SERIES CIRCUITS

❷ *The circuit drawing for a light at the end of a long wire is an example of a series circuit, if the wire resistance is taken into consideration as it must be.*



In a series circuit there is only one path for the electric current; all current flows through each of the elements in the circuit (i.e., both the wire and the light bulb) when the switch is closed.

This may be more clearly seen using the water pipe analogy. The water flow rate (gal/min or l/min) has to be the same everywhere in the system.



In a series circuit the resistance of the series elements (RS) is equal to the sum of the resistance's of the circuit elements.

RS = R1 + R2 + R3 + R4 + … + Rn

For the light bulb example, the total circuit resistance (RT) must add in the resistance of the wire (Rw),:

RT = Rw + RL

For example, if the wire in the circuit is 10 ft (3 m) of 20 gauge wire, and the light bulb resistance is 100 ohms, the total resistance would be:

From the table for 20 gauge wire

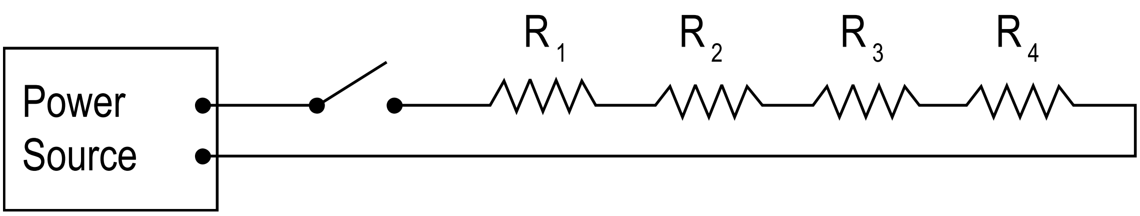
10 ft (3 m) = 0.10 ohms

Then RT = 0.10 + 100 = 100.1 ohms.

In a case where the resistance of the wire in the circuit is negligible, compared with other circuit elements, it is safe to ignore wire resistance.

Note, in electrical firing circuits, this will generally NOT be the case. That is because the resistance of Electric igniteres is often less than the resistance of the wire leading to the electric igniter.

In a series circuit with several light bulbs, the same resistance addition rule applies.



RS = RL1 + RL2 + RL3 + RL4

If all the lights are the same type, then:

RS = 4 RL

Ignoring wire resistance:

RT = RS

For example, if the power source provides 220 volts and the resistance of each of the four lights is 100 ohms, what current will flow in the circuit when the switch is closed?

From Ohm's Law:

$$I = \frac{E}{R_T}$$

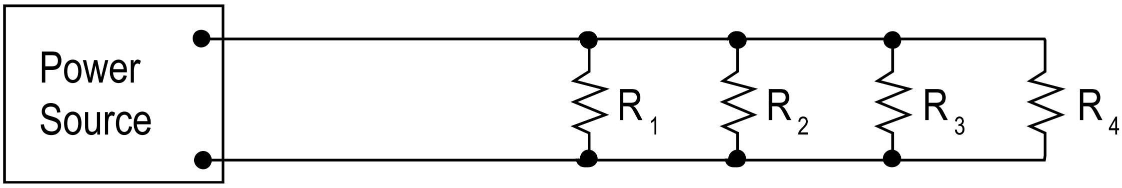
Substituting values:

$$I = \frac{E}{4\,R_L} = \frac{220 \text{ volts}}{4(100) \text{ ohms}} = \frac{220 \text{ volts}}{400 \text{ ohms}}$$

I = 0.55 ampere

PARALLEL CIRCUITS

❷ *In a series circuit there is only one path for current. However, in a parallel circuit there are multiple electric current paths.*



This parallel circuit using water pipes would be:

In the water pipe circuit it is more clear that the water (electric current) flowing through the valve (switch) will divide at various points, with some water flowing through each of the individual segments of thin tubing (light bulbs).

In general, in a parallel circuit, the resistance of the parallel elements, RP (ignoring wire resistance) is:

$$R_P = \frac{1}{1/R_1 + 1/R_2 + 1/R_3 + \dots + 1/R_n}$$

When each branch in a parallel circuit has the same resistance, the amount of electric current will divide equally between each branch.

Thus, if the total current from the power source is IT, then the current in each branch (Ib) is IT ÷ n, where n is the number of equal branches in the circuit.

$$I_b = \frac{I_T}{n}$$

For this special case when all the resistances are the same (R1= R2 = R3 = … = R) the equation for resistance of the parallel elements (RP) simplifies to:

$$R_P = \frac{R}{n}$$

For example: If there are 3 branches in a parallel circuit and the resistance of each branch is 2 ohms, what is the parallel resistance (Rp) for the 3 branches? Ignoring wire resistance, how much current will flow from a 9-volt power source, and how much of that current will flow in each of the 3 branches?

$$R_P = \frac{R}{n}$$

Substituting values:

$$R_P = \frac{2\text{ ohms}}{3} = 0.67\text{ ohm}$$

Ignoring wire resistance:

$$RT = RP$$

From Ohm's Law:

$$I = \frac{E}{R}$$

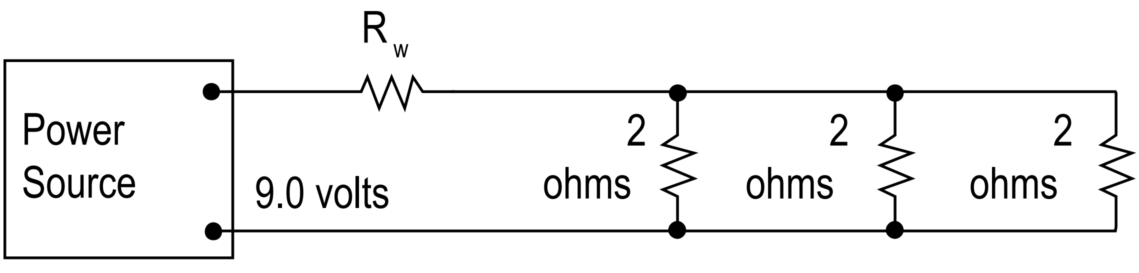
Substituting values:

$$I_T = \frac{9.0\text{ volts}}{0.67\text{ ohm}} = 13.4\text{ amperes}$$

Because the current will divide equally between each branch; thus:

$$Ib = \frac{I_T}{3} = \frac{13.4}{3} = 4.5\text{ amperes}$$

Wire resistance, when it is in series with parallel elements of the circuit, must be added to the resistance of those parallel elements. Consider the case of the preceding example, where the 3 branches are 100 ft (30 m) from the power source, and 20 gauge wire is being used.



Rw = 2 x 100 ft (30 m) x 1.04 / 100 ft (30 m)

Rw = 2.08 ohms

The combined resistance of the three parallel branches (RP) is:

RP = R / n = 2 ohms / 3 = 0.67 ohm

The wire resistance is in series with the three branches, thus the total circuit resistance (RT) is:

RT = Rw + RP = 2.08 + 0.67 = 2.75 ohms

From Ohm's Law:

$$I_T = \frac{E}{R_T} = \frac{9 \text{ volts}}{2.75 \text{ ohms}} = 3.3 \text{ amperes}$$

Current in each branch is:

$$I_b = \frac{I_T}{3} = \frac{3.3 \text{ amperes}}{3} = 1.1 \text{ amperes}$$

These values are substantially different than in the preceding example.

Not including wire resistance, the current flowing in each branch (Ib) was predicted to be 4.5 amps.

Including wire resistance, the current flowing in each branch (Ib) is predicted to only be 1.1 amps.

In this example (and generally for electrical ignition of fireworks), wire resistance cannot be ignored.

SERIES - PARALLEL CIRCUIT COMPARISON

❷ *In a series circuit:*

The total resistance always increases as more elements are added to the circuit. As a result, the total amount of current flowing always decreases.

To maintain the same current as more elements are added, greater and greater voltage will be needed from the power source.

If the wire size is sufficient (or can be ignored) for a single element in the circuit, then wire size will generally be sufficient if more elements are added.

In a parallel circuit:

The total resistance always decreases as more branches are added to the circuit. As a result, the total amount of current flowing always increases.

To maintain the same current through each branch, as more branches are added, the power source and wire must be capable of supplying all of the additional current.

As more branches are added, the resistance of the wiring becomes increasingly important and cannot be ignored.

INTERNAL BATTERY RESISTANCE

❷ *When the power source is a battery, there may be another important source of circuit resistance. Internal battery resistance may need to be considered when calculating circuit current flow.*

Some examples of internal battery resistance for "dry cell" batteries (new alkaline, heavy duty batteries) are:

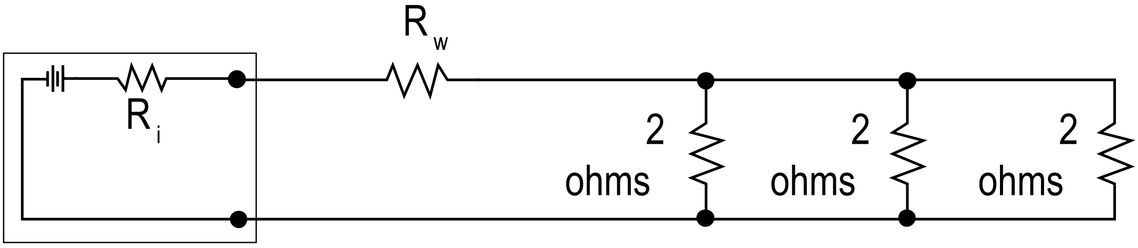
Battery Type	Internal Resistance
1.5 V D Cell	0.3 ohms
1.5 V AA Cell	0.5 ohms
9 V Transistor	3. ohms

Note that these values are for fresh batteries, are only approximate, and the value depends on the amount and duration of the current flow.

Wet cell batteries (such as car batteries) and gel cell batteries generally have very low internal resistance, which can almost always be ignored.

The effect of internal battery resistance is to add to the resistance of a firing circuit, much like the wire resistance does.

Consider again the earlier example, a parallel circuit with 3 branches, 2-ohms resistance per branch, 200 ft (60 m) of 20 gauge wire, and a 9 v power source. Suppose that power source were a 9 v transistor battery, what will the current be in each of the three branches?



It was previously established that:

Wire resistance = Rw = 2.08 ohms

Combined branch resistance = RP = 0.67 ohm

From the battery internal resistance table, the 9-volt battery's internal resistance (Ri) is

Ri = 3 ohms

Then total circuit (series) resistance:

RT = Ri + Rw + RP

RT = (3. + 2.08 + 0.67) ohms = 5.75 ohms

From Ohm's Law:

$$I_T = \frac{E}{R_T} = \frac{9.0 \text{ volts}}{5.75 \text{ ohms}} = 1.6 \text{ amperes}$$

Current in each branch (Ib) is:

$$I_b = \frac{I_T}{3} = \frac{1.6\ \text{amperes}}{3} = 0.53\ \text{ampere}$$

Comparing results from this example:

Calculation	R_T (ohms)	I (amperes)	I_b (amperes)
Ignoring R_i and R_w	0.67	13.4	4.5
Ignoring only R_i	2.75	3.3	1.1
Including R_i and R_w	5.75	1.6	0.53

Obviously, in this example, neither the wire resistance nor the internal battery resistance can be ignored.

NOTE: Candidates will not be expected to carry out calculations during the examination.

SECTION 15 - SET-UP AND SAFETY OF ELECTRICALLY FIRED DISPLAYS:

ELECTRICALLY FIRED DISPLAYS

On an electrically fired display, there will be one mortar for each aerial shell to be fired (as there is for a preloaded manually fired fireworks display).

Thus, many mortars will usually be needed for an electrically fired display.

There will also be a need for much cable and wire.

Because of the large number of mortars, they will often be placed quite close together.

There will usually be some method used to protect mortars from sparks and Burning debris that could prematurely ignite the fireworks as other nearby aerial shells are fired or from malfunctions.

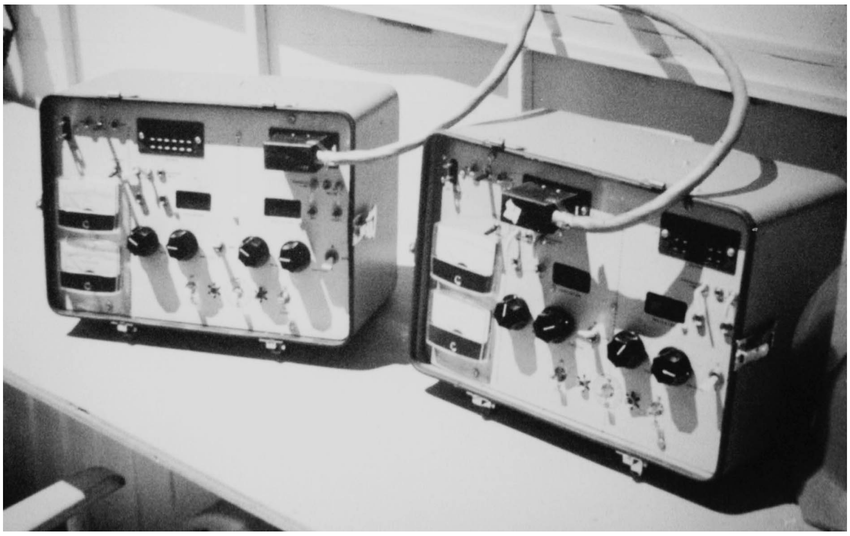
Probably the most common method is to use one or both aluminium foil and plastic sheeting held in place with tape or rubber bands.

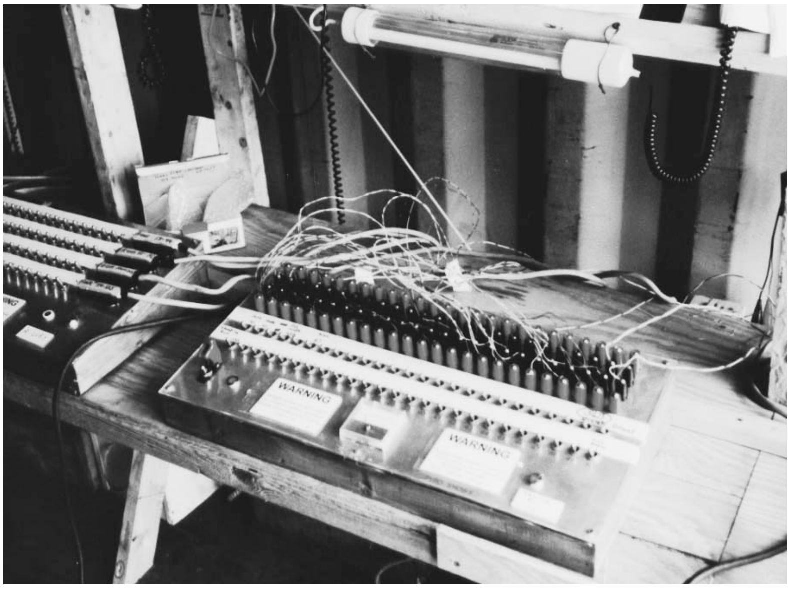
Aluminium foil offers protection from sparks and some protection from heavier burning debris.

Plastic sheeting mostly provides moisture protection.

At a point at least 75 feet (25 m), and generally 100 to 200 feet (30 to 60 m), from the mortars a firing control area will be set-up. (Examples below)

The fireworks will be ignited electrically from the control area, using specially built firing units.

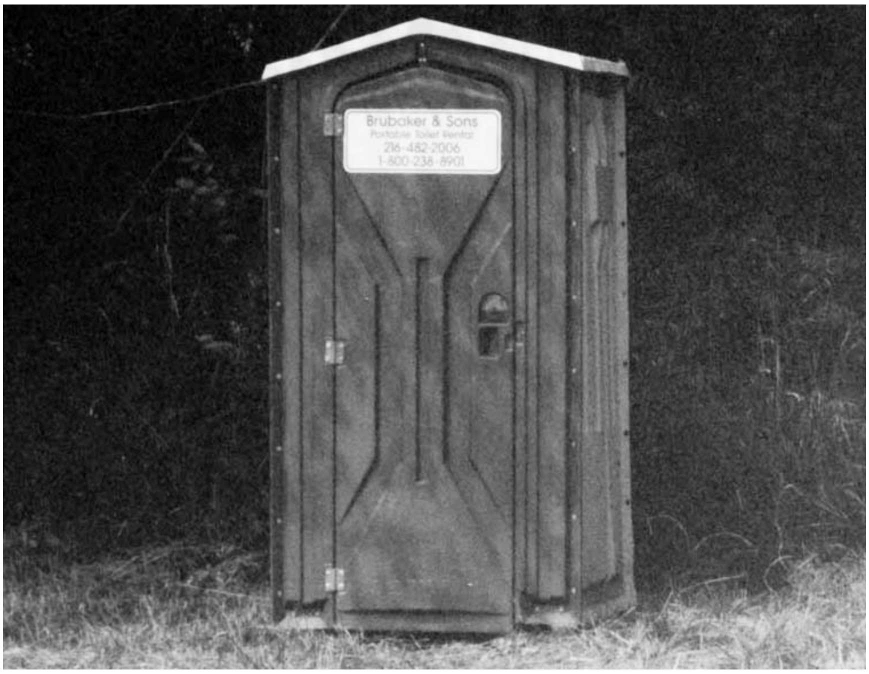




It may be necessary to safely store the fireworks on site for several days while the display is set-up.

It may be advisable to arrange for onsite lighting - especially to assist during derigging.

Because of the high daytime temperatures and long work schedules, it is essential to provide for abundant non-alcoholic liquid refreshments and personal relief.



PUBLIC AND CREW SAFETY

Electrical firing may have undesirable effects on public safety, for instance when fireworks may be discharged automatically even though it is no longer safe to do so.

The requirements for display site size and mortar-to-spectator separation distance is unchanged from those for manually fired displays.

Electrical firing will essentially eliminate many of the display crew accidents common in manually fired displays. This is because:

There is a much greater separation distance between the crew and serious aerial shell malfunctions such as muzzle breaks and shell "detonations".

There is no bulk storage of fireworks in the firing area that could be ignited during the display.

No personnel are present and handling fireworks in the dark when rushed and in the proximity of sparks and fire.

However, electrical firing may result in new types of display crew accidents.

Although these new accidents should be easily avoidable, in actuality the risks to the crew from these new types of accidents seem to be approximately the same as those from manual firing.

It is essential that the crew be properly trained so as to avoid these especially needless accidents.

For Crew Safety:

- ♦ The firing unit must have a key or interlock.
- ♦ The firing unit must be electrically isolated from AC power sources.
- ♦ The firing unit must require 2 actions to apply power.
- ♦ The firing unit test circuit must be current limited to 0.05 ampere or 20% of electric igniter no-fire current.
- ♦ Any VOM or continuity tester to be used must have been properly tested for safely low current output.
- ♦ No circuit testing is allowed while the crew is near the fireworks.
- ♦ Exercise great care when handling electric igniters.

For Public Safety:

- ♦ Must inspect mortars for safe orientation after explosive malfunctions in the mortar area.
- ♦ Computer firing equipment must have a "dead man switch".

THE EARTH CAN ACT AS A SOURCE OF ACCIDENTAL FIRING CURRENT

Most common electric igniters have an “all fire” current of no more than approximately 0.5 ampere.

Any source of electric current exceeding their “no fire” current (typically no more than approximately 0.25 ampere) might ignite an electric igniter.

If points in the electric firing circuit are grounded (electrically connected to the earth), accidental firings may be possible from:

Telluric Currents — Electro-chemical (battery-like) currents developed within the damp ground.

“Stray Voltage” — Produced by nearby unbalanced AC power lines passing electric current through the ground.

Electrostatic Firing — Nearby lightening strikes, or personnel and equipment firings.

Because of momentary accidental electrical groundings during setup operations, there should be no intentional grounding of the firing system.

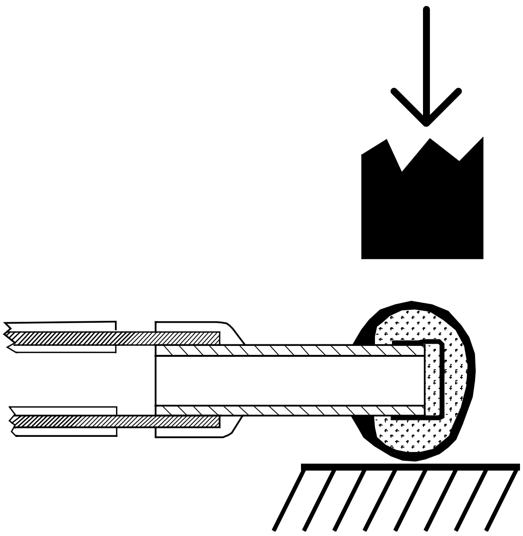
ELECTRIC IGNITER SENSITIVITY

Electric igniters are sensitive to accidental ignition with only relatively minor degrees of mishandling.

Often this will result in an accident involving one or more members of the crew.

Electric igniters are far and away the most sensitive items present on a display site.

Most electric igniters are quite sensitive to impact.



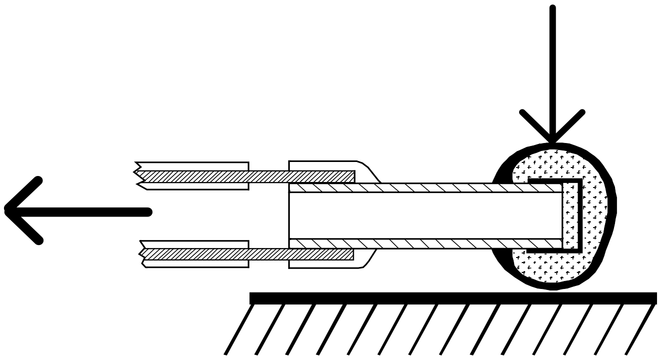
The electric igniter tip can easily be crushed between two hard surfaces and may ignite as a result.

For example, electric igniters are many times more impact sensitive than most flash powders.

Cutting into the head of an electric igniter with a scissors or electrical wire cutter can cause its ignition.

Most electric igniters are moderately sensitive to friction.

Friction results when an electric igniter is held against and dragged along a rough surface such as black match.



For example electric igniters are much more sensitive to friction than most flash powders.

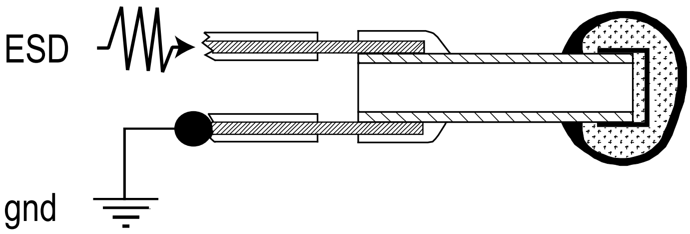
Their friction sensitivity may be increased when the electric igniter is in contact with sulphur containing compositions such as black match.

Electric igniters are relatively insensitive to low-power radio frequency energy. Nonetheless, avoid the use of electric igniters near radio transmissions.

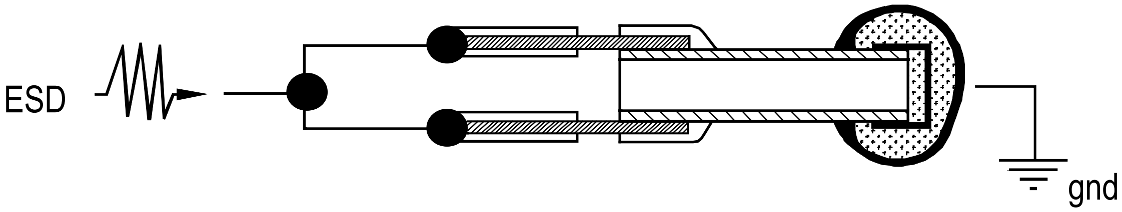
Probably a greater potential hazard is the exposed charging terminals of a radio, cell phone or pager. They can fire an electric igniter if the electric igniter wires accidentally contact the terminals.

Electric igniters are sensitive to electrostatic firing (ESD).

Electric igniters have relatively low sensitivity to human caused ESD through their bridge wires.



Many electric igniters have a very high sensitivity to ESD from their bridge wires and through the match composition. Such accidental ignitions are more likely when the match tip has been damaged.



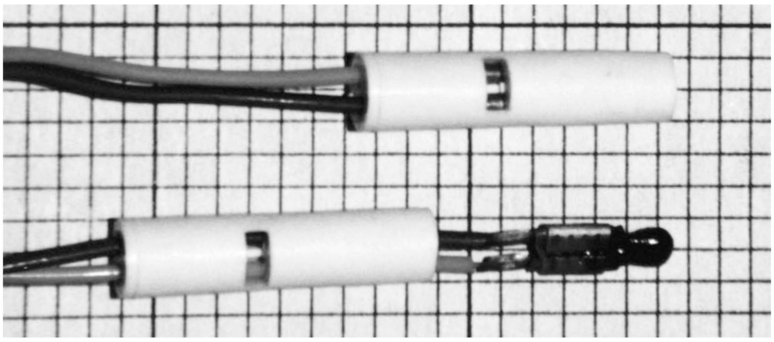
For example, electric igniters are more sensitive to this type of ESD than most flash powders.

ESD from a person or a nearby lightening strike can initiate electric igniters.

PRECAUTIONS BECAUSE OF ELECTRIC IGNITER SENSITIVITY

Unless special precautions are taken, it is preferred not to transport fireworks that contain an attached electric igniter.

Whether installed in the shell leader or in the lift charge, the safety shroud of the electric igniter must be left in place.



Always treat electric igniters with the respect they demand.

- ♦ NEVER forcefully crush an electric igniter.
- ♦ NEVER forcibly remove an electric igniter.
- ♦ ALWAYS be mindful of electrostatic problems.

MORTAR MALFUNCTIONS AND ELECTRICAL FIRING

When firing manually, it is clearly apparent to a shooter when a mortar has been dangerously misaligned as the result of a nearby aerial shell malfunction.

Because of the large distance between the firers, who is electrically firing, and the mortars, mortar realignments will generally not be visible. Thus, it is necessary to stop and inspect the mortars after any exploding aerial shell malfunction occurs in the mortar area.

Such malfunctions happen often enough that there should probably be a runner standing-by ready to check mortar alignment and signal if it is safe to continue firing. (This inspection should only require a 10 to 15 second interruption of the show).

Electrical firing of aerial shells from misaligned mortars is an all too common cause of serious spectator injuries. (See next page.)

On musically choreographed displays it is useful to be able to interrupt the musical program if a mortar inspection is needed.

IT IS ABSOLUTELY UNACCEPTABLE TO "TEST" FOR PROPER MORTAR ALIGNMENT BY CONTINUING TO FIRE AERIAL SHELLS ! ! !

Fixing of or igniter leads

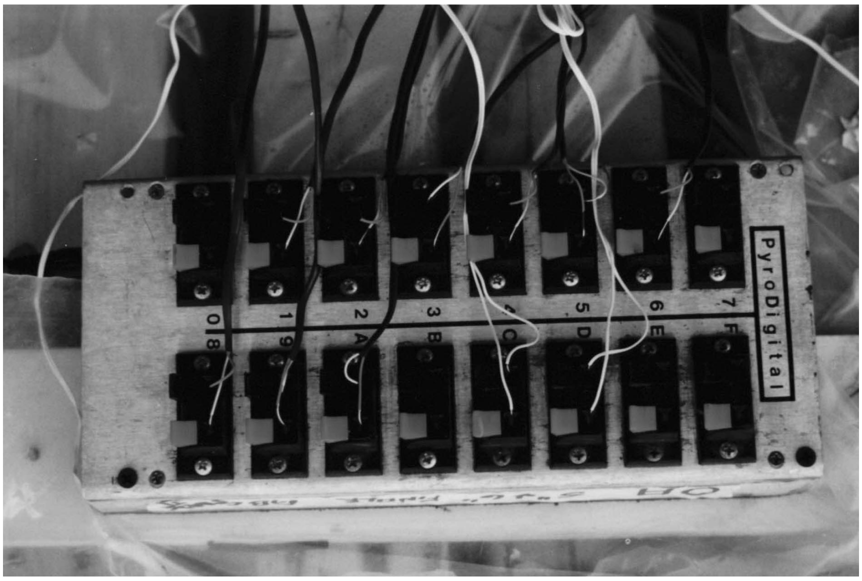
When one aerial shell fires and pulls along with it the electric igniter leg wires, that action may cause the wiring for the next shell to pull out of its electrical terminals. Short wiring will prevent this from happening.

However, the primary reason to use the short wiring technique is that it helps reduce the likelihood of a aerial shell being mistakenly shot into the crowd from a misaligned mortar. If a mortar explodes destroying a rack or mortar trough, the remaining mortars will be redirected. If the electric igniter wiring survives intact, there is the chance that the operator (or computer) may attempt to fire the remaining shells, possibly sending shells into the crowd. Short wiring will help to eliminate this possibility by reducing the probability that the wiring will survive the explosion.

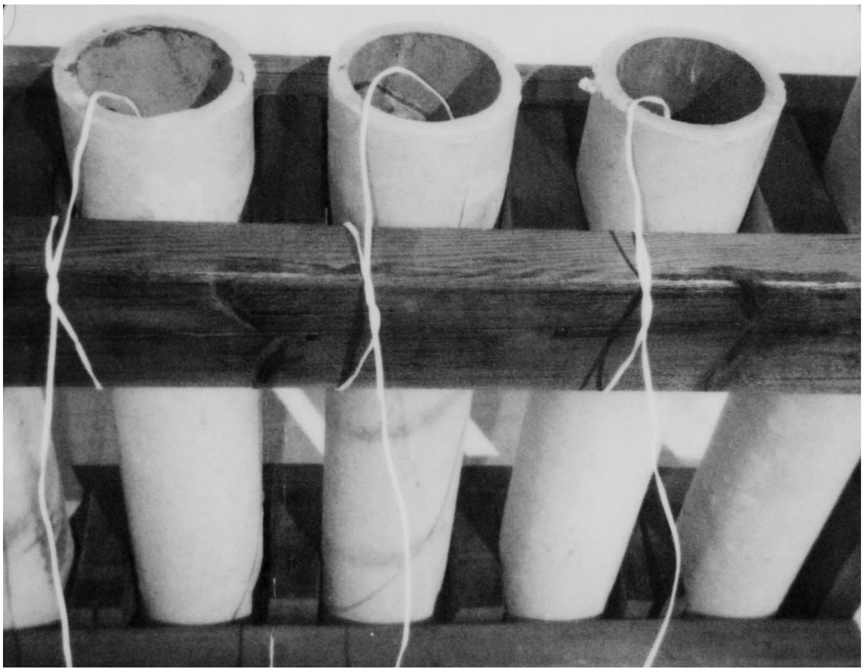
Short wiring is appropriate but it does not eliminate the need to inspect mortar racks and mortar troughs after a possible mortar explosion.

EXAMPLES

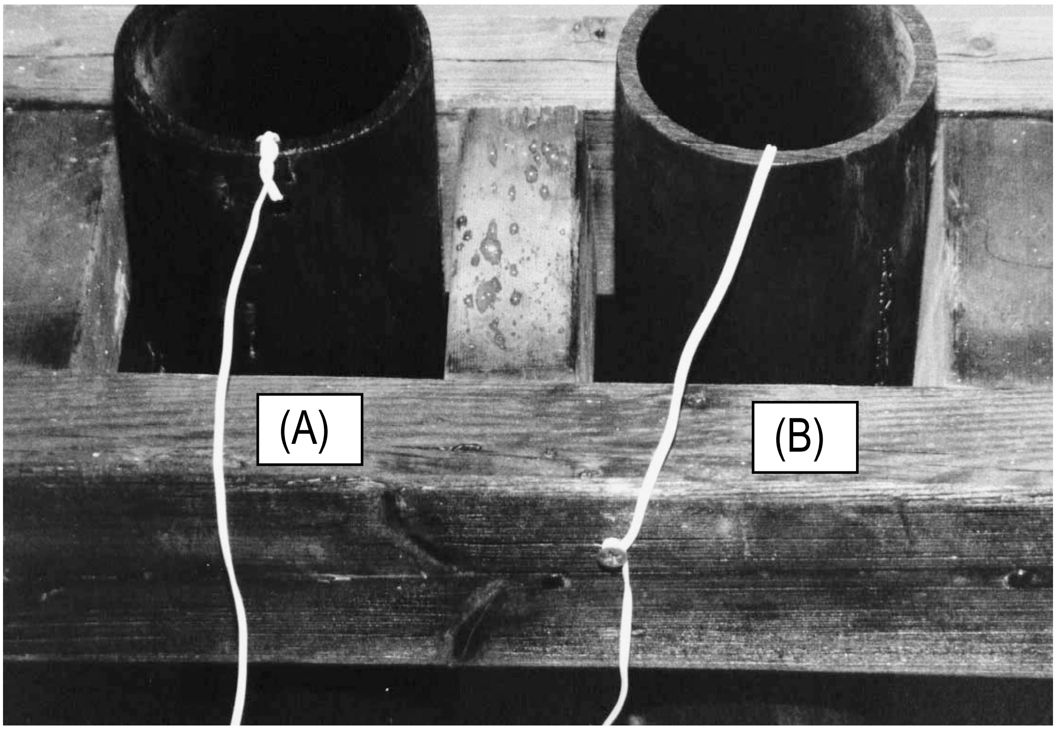
One type of electrical connection board with electric igniter leg wires attached.

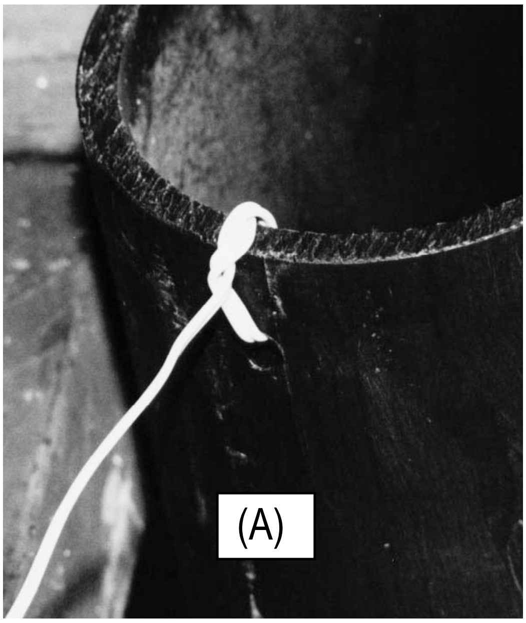


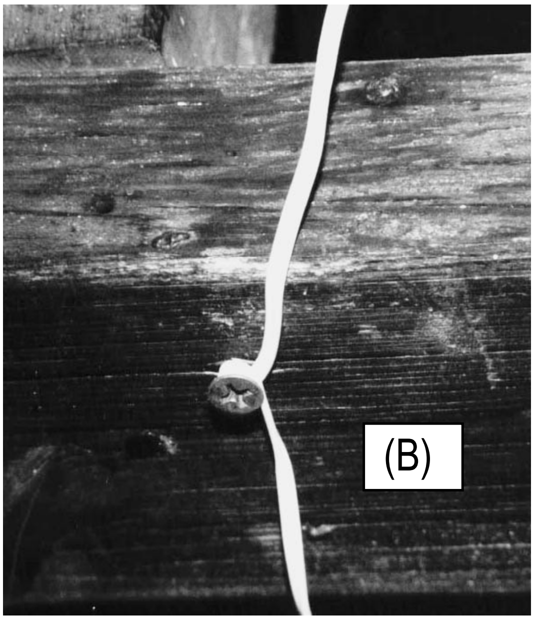
An example of electric igniter wires “short wired” to a mortar rack by tying.



Short wiring by securing (A) to the top of the mortar or (B) to a screw head mounted on the mortar rack.

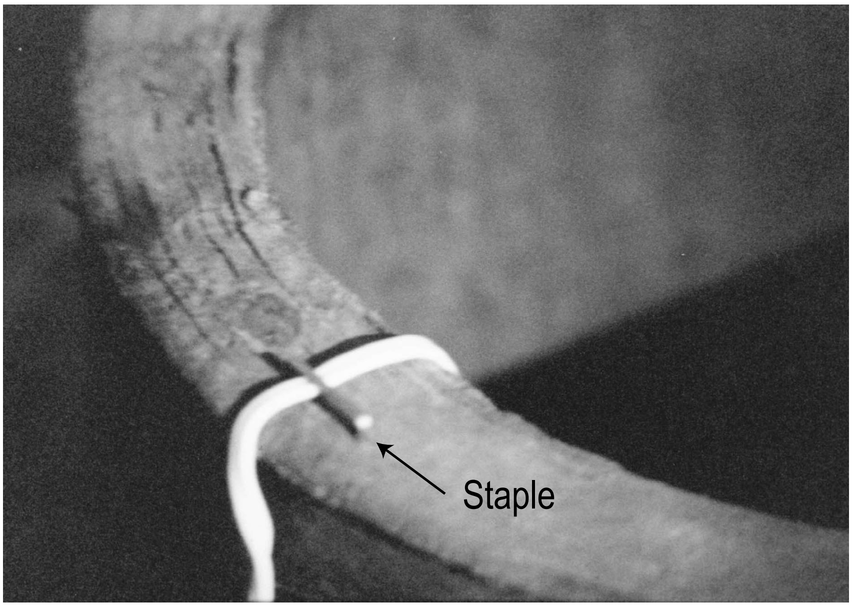

(A)
(B)


(A)


(B)

EXAMPLES OF UNACCEPTABLE WIRING

An electric igniter wire stapled to the top of a paper mortar is totally ineffective as short wiring.



Electric igniter wires held in place with a piece of tape; this is totally ineffective as short wiring.

SECTION 16 - TECHNIQUES FOR ELECTRIC FIRING:

Basic electric firing circuit

Electric igniters

Characteristics of electric igniters

Electric igniter attachment methods

- Attachment points
- “Quick Fire” clips
- “Magic Fire” igniters

Series firing circuits

Parallel firing circuits

Comparison of series and parallel firing circuits

Testing firing circuits

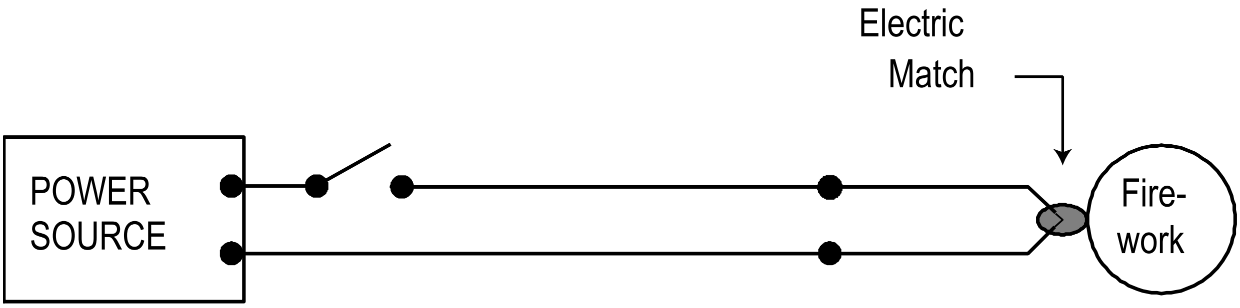
Types of electric firing units

Wire and splicing wire

Covering electrically fired mortars

BASIC ELECTRICAL FIRING CIRCUIT

A switchable source of electric current applies power to an electric igniter (also called an e-match or electric fusehead). (Large firing units have many more firing circuits.)



Firing current:

- ♦ Generally about 1 ampere is required for a high level of firing reliability of most electric igniters.

Firing time:

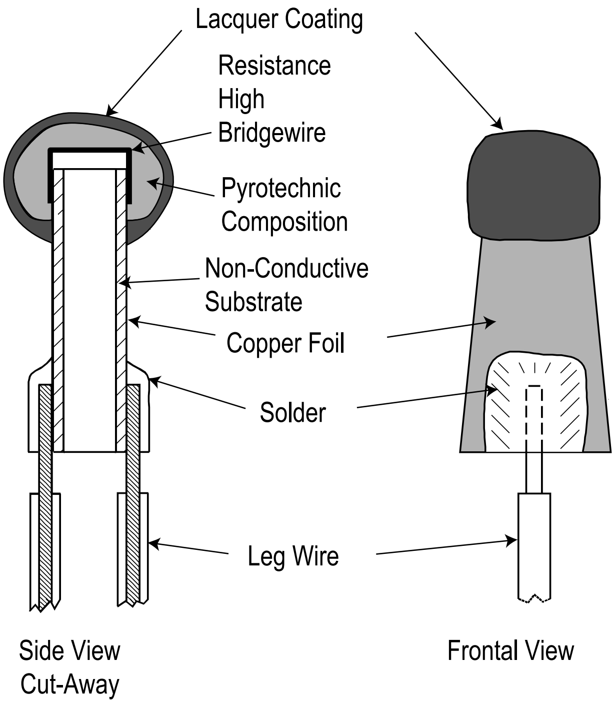
- ♦ Depends on firing current, generally ranging from 1 to 10 milliseconds (0.001 to 0.01 second)

Firing voltage:

- ♦ Depends on total circuit resistance, including: electric igniter, all wiring and the internal resistance of the power source.
- ♦ From 1.0 to 1.5 volts may be sufficient under some circumstances; but 12 to 36 volts is most common.

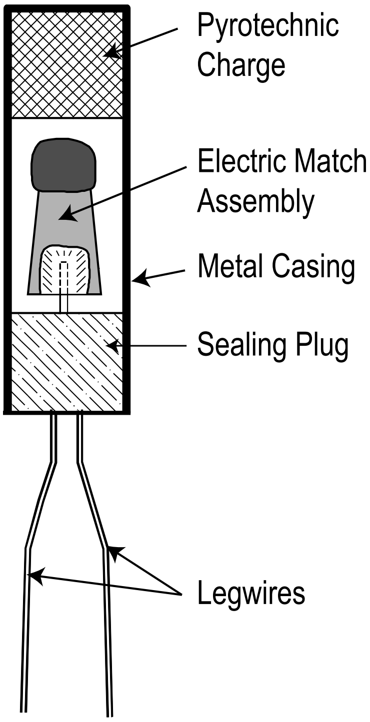
ELECTRIC IGNITER

An electric igniter consists of a high resistance bridge wire surrounded by a heat sensitive pyrotechnic composition. When an electric current is applied, through the leg wires, the bridge wire heats up and ignites the pyrotechnic composition. This produces a small burst of fire, not unlike that from a common safety match.



ELECTRIC SQUIB

An electric igniter and squib are not the same thing. A squib contains an electric igniter plus a base charge, not unlike a detonator (blasting cap). However, while a squib contains a pyrotechnic base charge, a detonator contains a high explosive base charge.



It is common for squibs to have a metal casing, and to appear much like a small detonator (blasting cap).

Squibs are not used in fireworks.

ELECTRIC IGNITERS AND SQUIBS

Photo of a collection of electric igniters. [0.1 inch (2.5 mm) per division]

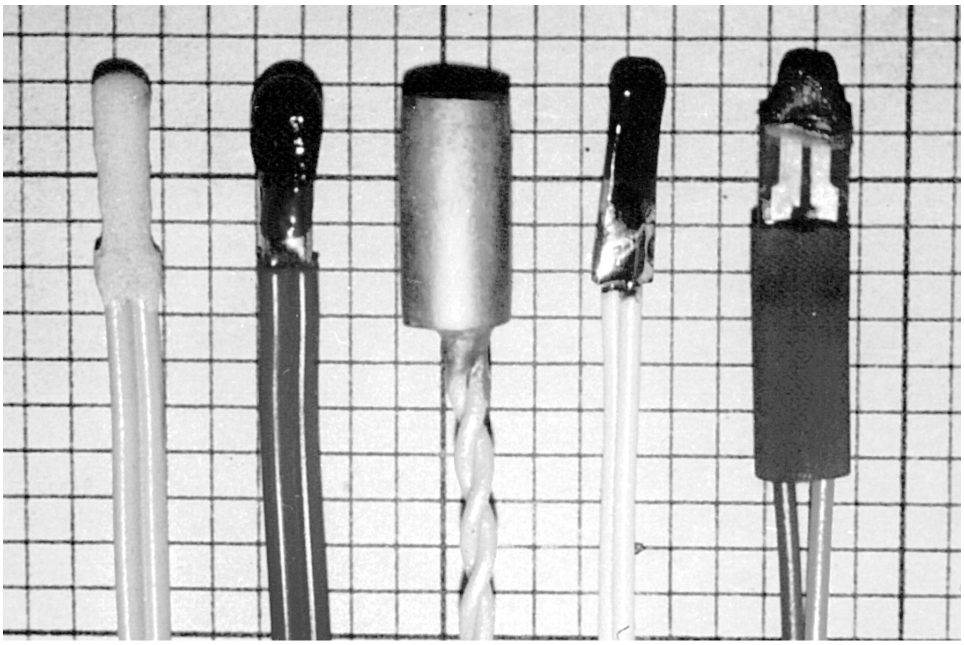
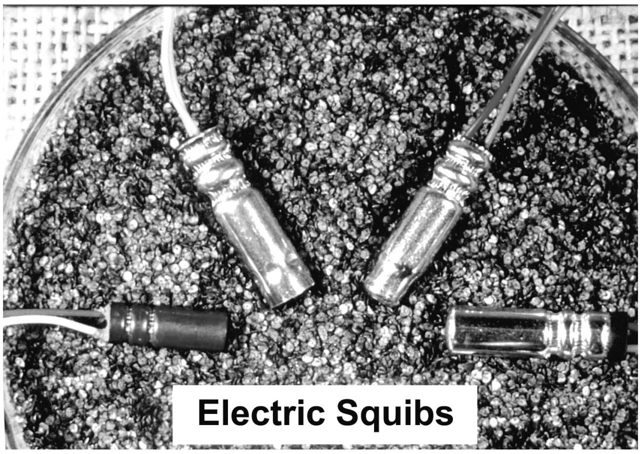


Photo of a collection of electric squibs.

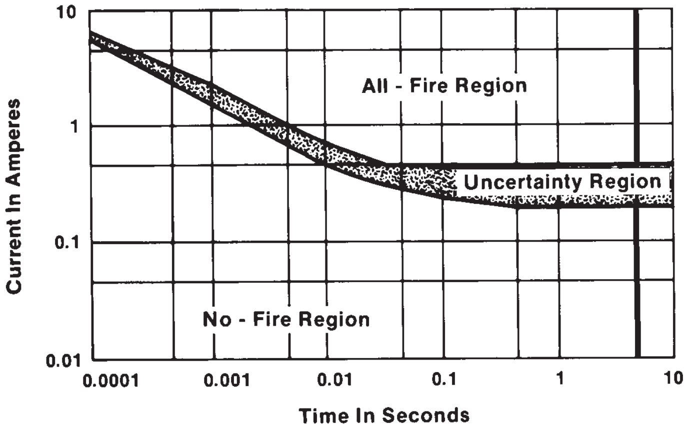


ELECTRIC IGNITER FIRING REQUIREMENTS

No Fire Current: The maximum electric current that can be applied to an electric igniter for 5 seconds that produces zero ignitions in trials of 100 igniters.

All Fire Current: The minimum electric current that can be applied to an electric igniter for 5 seconds that produces 100 ignitions in trials of 100 igniters.

The current required for an electric igniter to fire is a function of the length of time that the current is applied. This is shown in the graph below. [Courtesy of Atlas Powder Co.]



Note: There is an uncertainty region between the All-Fire and No-Fire regions. This is mostly because of small differences between individual electric igniters.

ELECTRIC IGNITER CHARACTERISTICS

❷ *There are many manufacturers of electric igniters, and there are significant differences in their performance characteristics.*

Match Supplier	Product Designation	Match Resistance (ohms)[(a)]	Firing Current (amps)[(b)]	Fire Time (ms)[(c)]	Comp. Mass (mg)[(d)]
Daveyfire	A/N28B	1.6	0.90	1.6	40
	A/N28BR	1.6	0.90	1.8	80
	A/N28F	1.6	2.00	3.1	80
Luna Tech	BGZD	1.6	1.00*	11[(e)]	10
	Flash	1.0	4.00*	14.4[(f)]	20
	OXRAL	1.7	0.80	5[(e)]	40
Martinez Spec.	E-Max	2.5	0.90	1.8	20
	E-Max Mini	0.9	1.00	1.9	6
	Titan	2.7	2.00	4.7	20

a) Measured to the nearest 0.1 ohm and reported as the average value for 10 electric igniters.
b) The approximate value recommended by the supplier for series firing. When no series firing value was recommended by the supplier [indicated with an asterisk (*)], the authors' estimated value was used.
c) The average of five test firings, as determined by noting the time interval between application of the firing current and when significant light output was first detected. (ms = millisecond)
d) The mass of the composition on the tip of one electric igniter, reported to only 1 significant figure. (mg = milligram)
e) Even though the photo detector was set to be very sensitive to light, these electric igniters produced a slowly increasing light signal. This made it somewhat difficult to determine when first light output occurred.
f) Even though the times to first light output were quite long, they could be accurately determined because of the rapid rise in the light signal.

There are a variety of electric igniters used for igniting fireworks. However, as a general rule for the most commonly used electric igniters, ignition will be assured if, in performing calculations:

- ♦ *Resistance is assumed to be — 2 ohms.*
- ♦ *Minimum firing current is — 1 ampere.*

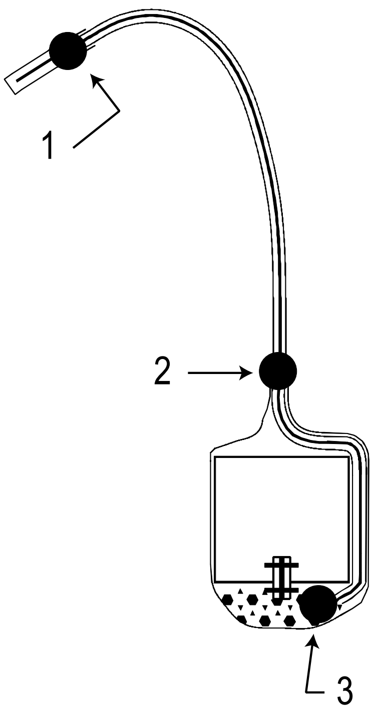
In testing electrical firing circuits, the test current should be limited to whichever is less:

- ♦ *0.05 ampere or*
- ♦ *20% of the no-fire current.*

Any test unit used to measure circuit resistance or continuity must either have been specifically designed for use with electric igniters (or for use with detonators) or has been properly tested to determine that the maximum electric current it delivers is safely low.

The firing time of all electric igniters ranges from less than 0.001 to more than 0.01 second, but it is sufficiently short so as to appear to be instantaneous to an observer.

COMMON POINTS FOR ATTACHMENT OF ELECTRIC IGNITERS



Electric igniters may be installed at any point along the ignition train of an aerial shell, but three places are most common. (See photos on following pages.)

Points 1 and 2 are most common for aerial shells originally manufactured for manual ignition.

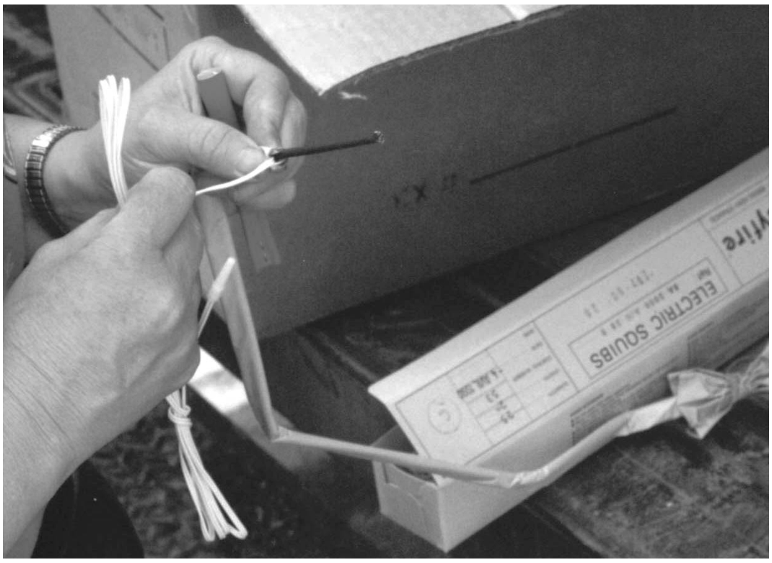
(1) Attachment at the end of the shell leader is generally made by removing the safety cap, inserting the electric igniter, and tying it in place.

(2) Attachment near the aerial shell is made by cutting the shell leader, inserting the electric igniter between the black match and paper, and tying it in place.

Attachment is often made directly into the lift charge by the aerial shell manufacturer (Point 3).

ELECTRIC IGNITER ATTACHMENT AT END OF SHELL LEADER (POINT 1)

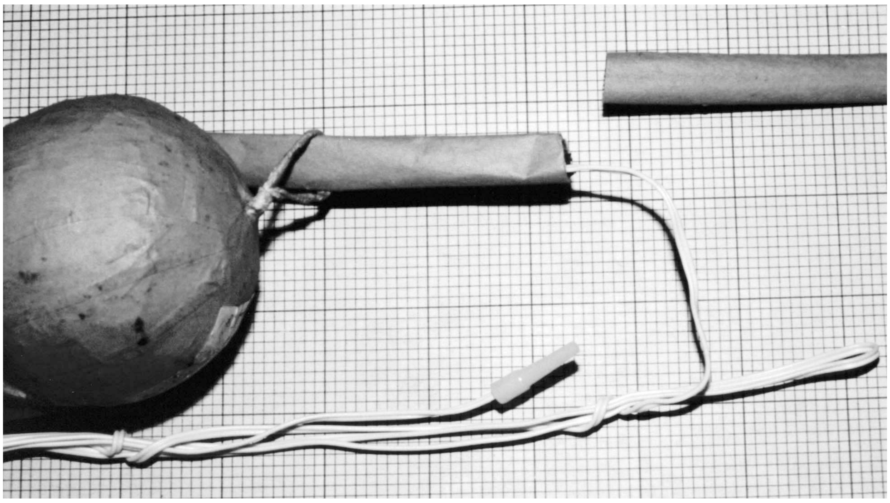
Electric igniter is inserted about 2 inches (50 mm) into the shell leader (between the black match and paper wrap.



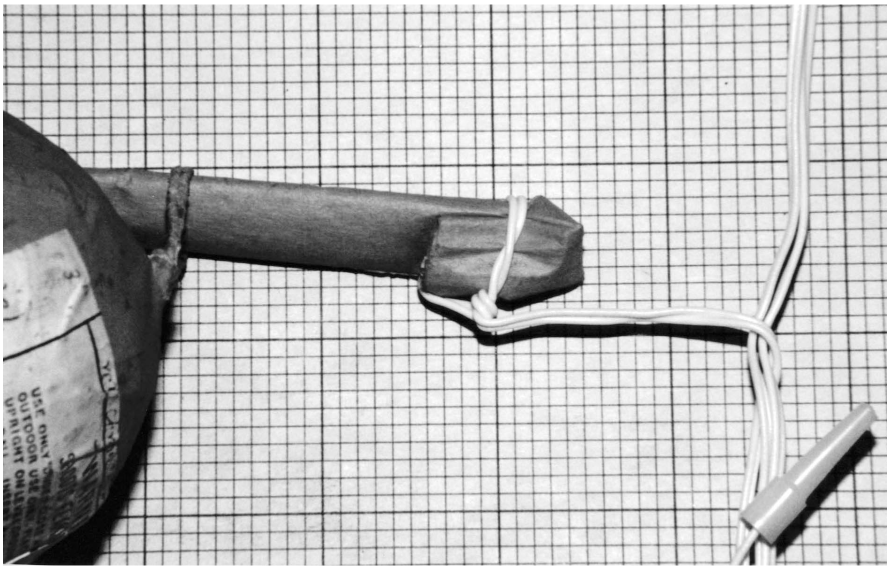
The safety cap is re-installed and the electric igniter is securely tied in place using the electric igniter wires.

ELECTRIC IGNITER ATTACHMENT IN SHELL LEADER NEAR AERIAL (POINT 2)

Shell leader is cut short and an electric igniter is inserted about 2 inches (50 mm) into the shell leader between the black match the and paper wrap. [0.1 inch (2.5 mm) per division]



Electric igniter is tied in place in the shell leader fuse.



Aerial shells that are manufactured for electric ignition most often will have the electric igniter installed directly in the lift powder (Point 3). (See next page.)

Typical firing delay times and firing precision depends on which attachment point (1, 2, or 3) is used. (See data in table below.)

Typical firing delay and precision:

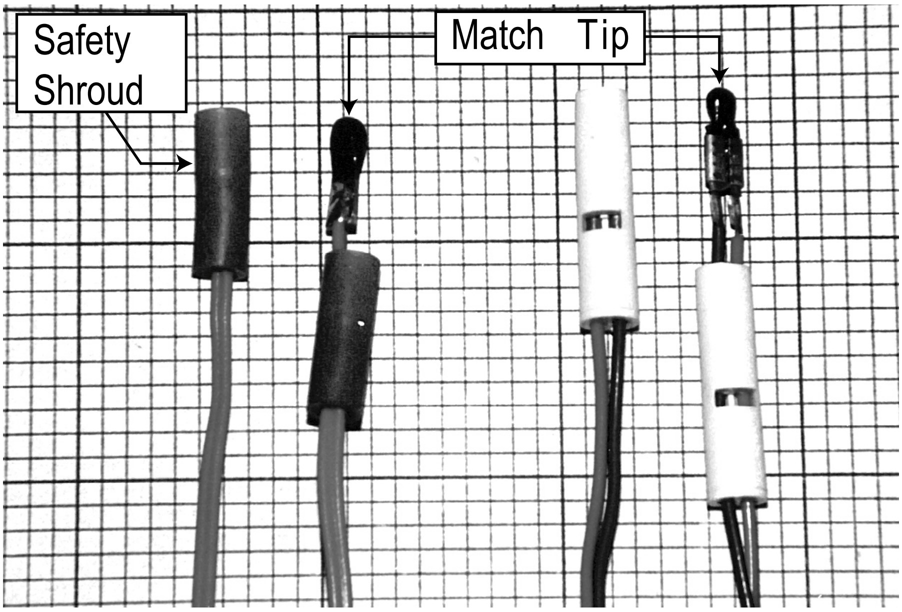
Electric Match Attachment	Average Firing Delay[a] (seconds)	Typical Firing Precision[b] (seconds)
1	0.32	0.14
2	0.11	0.02
3	0.04	0.005

(Averages from at least 8 tests for each attachment point.)

a) This is the time elapsing between applying the firing current and the aerial shell leaving the mortar.

b) This is a measure of the repeatability in the delay times; the smaller the value, the more consistent the delay times.

Electric igniters with plastic safety shrouds to protect them and direct fire out their open end.



ADDITIONAL ISSUES CONCERNING THE ATTACHMENT OF ELECTRIC IGNITERS

Points (1), (2), and (3): Only electric igniters with their safety shrouds should be used, and their safety shrouds must remain in place.

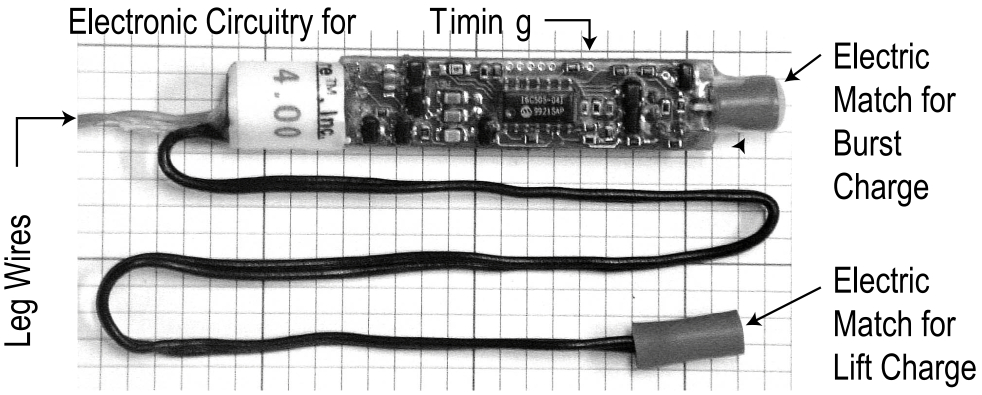
Point (1): This does not permanently alter the aerial shell, and small shells can be lowered into mortars using the shell leader. However, it provides the least precise firing times and probably the greatest chance for a hang fire or misfire.

Point (2): This has none of the shell leader exposed to weather and sparks (outside the mortar) and provides highly precise firing times. However, there is a small amount of black match exposed (if not taped). There is still a small chance of producing a hangfire or misfire. There is no shell leader to use for lowering the aerial shell into the mortar.

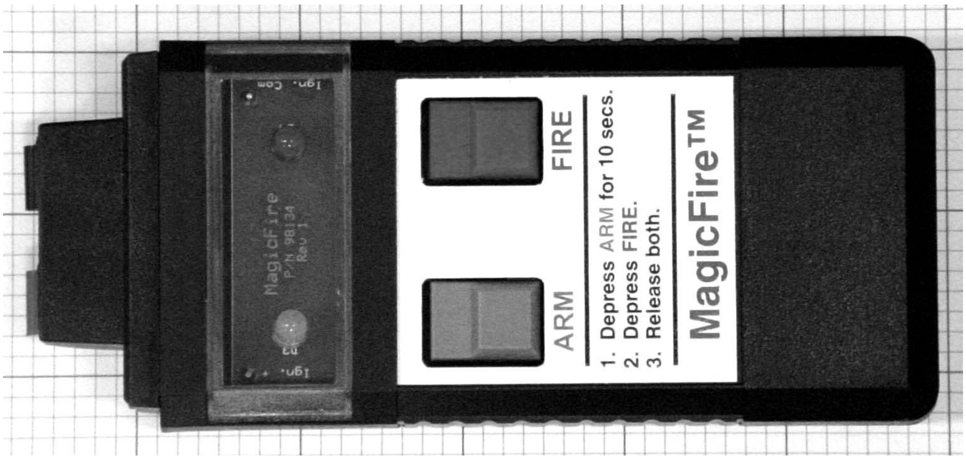
Point (3): This provides the highest precision in firing times. There is essentially no chance of a hangfire, and it is probably the least likely to produce a misfire. However, there is no shell leader for use in lowering the aerial shell into the mortar.

MAGICFIRE™ ELECTRIC IGNITER UNITS

A Magicfire™ igniter contains two electric igniters. One is installed into the lift charge and fires immediately. The other is installed into the aerial shell in place of the time delay fuse and uses electronics to fire the aerial shell after a very precise time delay. [0.1 inch (2.5 mm) per division]



Because of the need to pre-charge power capacitors on the circuit board, a special firing unit is required to use MagicFire electric igniters.



REDUNDANT ELECTRIC IGNITERING

The firing of some fireworks devices is especially important to the overall performance of the display. For example, very large aerial shells, the logo of the sponsor, or the finale.

On such particularly important devices, it is a common practice to install more than one electric igniter, Typically this will be on a completely different electric circuit. In this way the ignition is virtually assured because if the primary circuit fails, the backup circuit can be used.

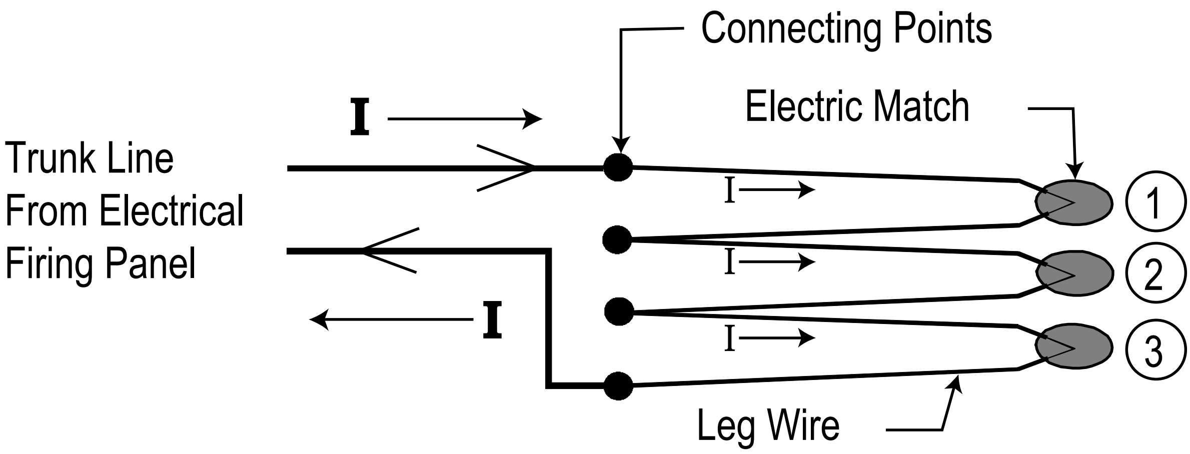
On a finale, often additional electric igniters will be installed along the finale chain. In this way it can be re-ignited if it fails to propagate completely.

Often a finale will be broken into shorter segments and each segment is fired separately. This will allow for better control of the rate of firing. It will also allow for the interruption of the firing if a safety problem develops.

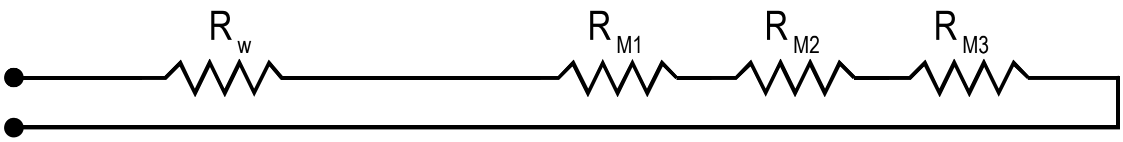
On musically choreographed displays it is common to install an additional electric igniter at the very end of the finale chain. This is fired shortly before the end of the music and helps to assure that all firing will have ceased by the time the music ends.

SERIES CIRCUIT

In a series circuit the same electric current (I) flows through each of the electric igniters, one after the other (i.e., the devices are in series with one another).



The electric circuit drawing for this is:



In most cases, unless dry cell batteries are used, the internal resistance of the battery can be ignored.

In most cases, the wire resistance (Rw) must be considered in addition to the resistance of the individual electric igniters (RM).

SERIES CIRCUIT example 1

In a series firing circuit the total resistance (RT) in the circuit is the sum of the resistance of each element [i.e., the wire (Rw) plus each of n electric igniters].

RT = Rw + RS

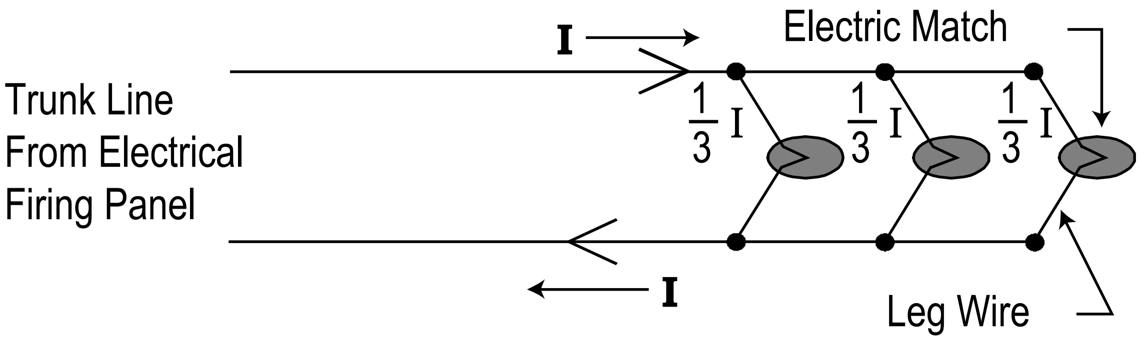
RT = Rw + RM1 + RM2 + RM3 + ... + RMn

Or, if all electric igniters are the same

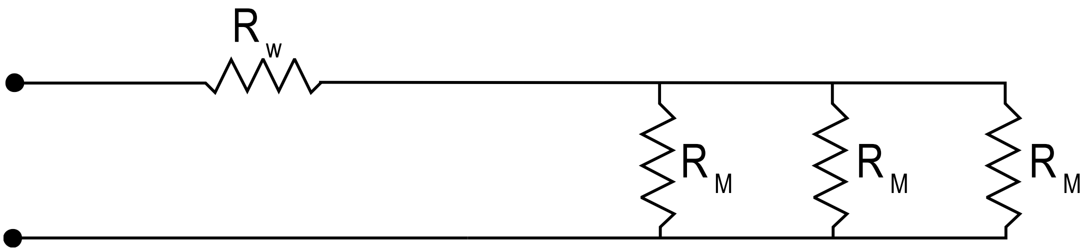
RT = Rw + RS = Rw + (n × RM)

PARALLEL FIRING CIRCUIT

In a parallel circuit the electric current (I) divides between each of the parallel branches (i.e., the electric igniters are parallel to each other).



The electric circuit drawing for this is:



In most cases, unless dry cell batteries or many electric igniters are used, the internal resistance of the battery can be ignored.

Because of the higher total current flowing in parallel circuits, the wire resistance will be a more important factor than for series circuits.

In a parallel firing circuit, total resistance (RT) is the sum of the resistances of the wire (Rw) and the combined resistance of the parallel branches. (RP)

$$RT = Rw + RP$$

$$RT = Rw + \left(\frac{1}{\frac{1}{R_{M_1}} + \frac{1}{R_{M_2}} + \frac{1}{R_{M_3}} + \ldots + \frac{1}{R_{M_n}}} \right)$$

COMPARISON OF SERIES AND PARALLEL FIRING CIRCUITS

Series firing circuits:

- Are preferred when wire lengths are long, the wire is thin, or when the power source is limited in the current it can produce (i.e., it has a high internal resistance).
- When any electric igniter in the circuit is open or there is a break anywhere in the wiring, none of the electric igniters will fire.
- When any electric igniter is shorten, only that one electric igniter will fail to fire.
- For reliable results, different types of electric igniters should not be mixed.

Parallel firing circuits:

- Are preferred when wire lengths are short, and when the power source has low internal resistance but is limited in the voltage it produces.
- When any electric igniter is open, only that one electric igniter will fail to ignite.
- When any electric igniter is shorted, none of the electric igniteres will fire.
- Mixing types of electric igniteres should not cause problems.

Take special care with long cable runs, where the resistance of the cable itself becomes a significant feature. The greater residence of the circuit leads to a reduce current at each igniter and hence a greater possibility of failure.

TESTING FIRING CIRCUITS

All operators should be away from the firing area before any testing takes place.

Electrical firing circuits must only be tested for continuity or total resistance using instruments that produce no more current than 0.05 ampere or 20% of the no-fire current of the electric igniters being used.

Continuity and resistance measuring instruments operate by passing a small electric test current through the circuit.

If the test equipment has not been certified by its manufacturer as safe for use with electric igniters, then it MUST be tested by its user to determine the maximum current (including any transients) it can produce before it is used to test firing circuits.

Most electric firing units have built-in continuity test circuits.

While these can not detect short circuits in the wiring, they can detect open circuits.

Although it is unlikely that testing of firing circuits with a proper test instrument will cause any devices to fire, accidental firings should ALWAYS be considered to be a possibility.

One reason for this is operator error, such as mistakenly having the firing unit in the armed position rather than in the test position.

Other possibilities include so-called stray voltage from power lines, telluric (earth) currents, etc.

Because of the possibility of accidental firings while testing:

All operators should be away before testing.

All personnel working in any area with electrical connection to the firing unit MUST leave that area before the testing begins.

Whenever testing is not being conducted, the electric firing unit should be disconnected from all the firing lines and be disabled (e.g., key switch). Also, if the power source is external to the firing unit, the power source should be removed from the immediate area.

This will help eliminate accidental firings.

TYPES OF ELECTRIC FIRING UNITS

Unless the firing controller has been designed and manufactured by the person operating the unit, instructions for setup and use must be available to the user.

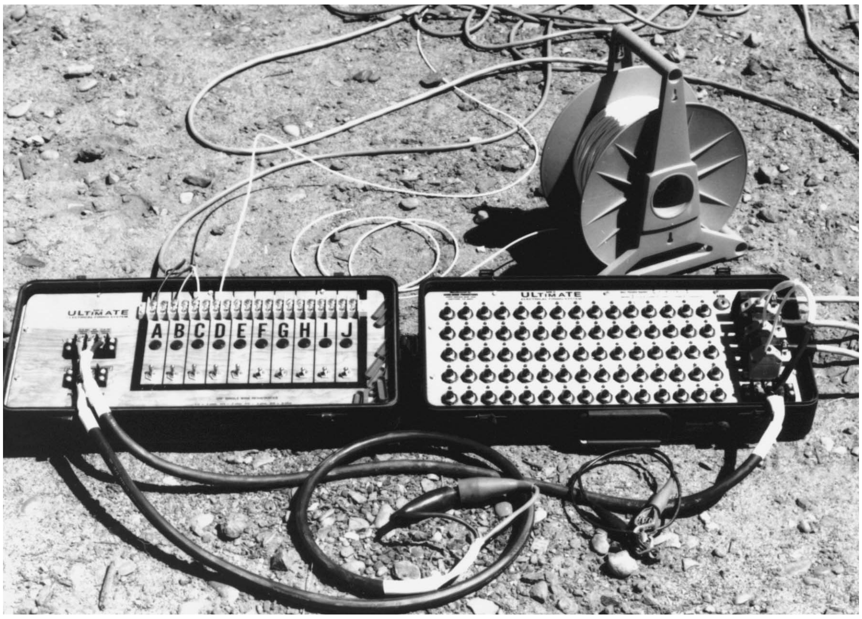
There are three main types of electric firing units:

Manual systems, in which switches are manually operated to control the routing of electric current to the various fireworks. Often these units can power several hundred different firing circuits.

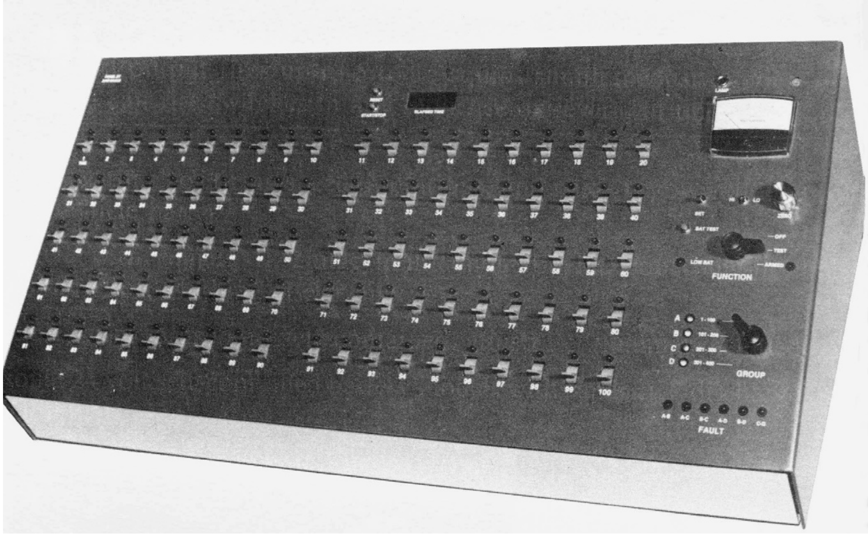
Portable or hand-held units, which are very small and typically can activate only a few firing circuits. Automated systems, which are generally computer based, can be programmed for a specific firing sequence and for precisely timed firings. The actual firing can then take place without the need for human action.

MANUAL FIRING UNITS

One example of a manual firing unit.

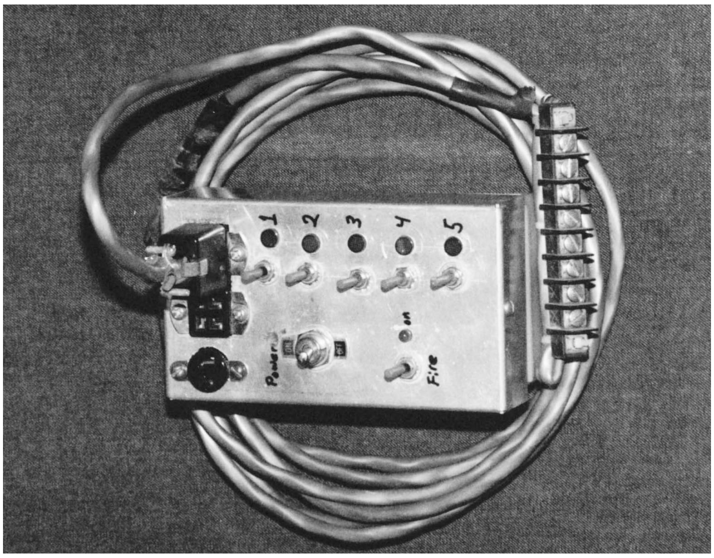


Another example of a manual firing unit.



HAND-HELD FIRING UNITS

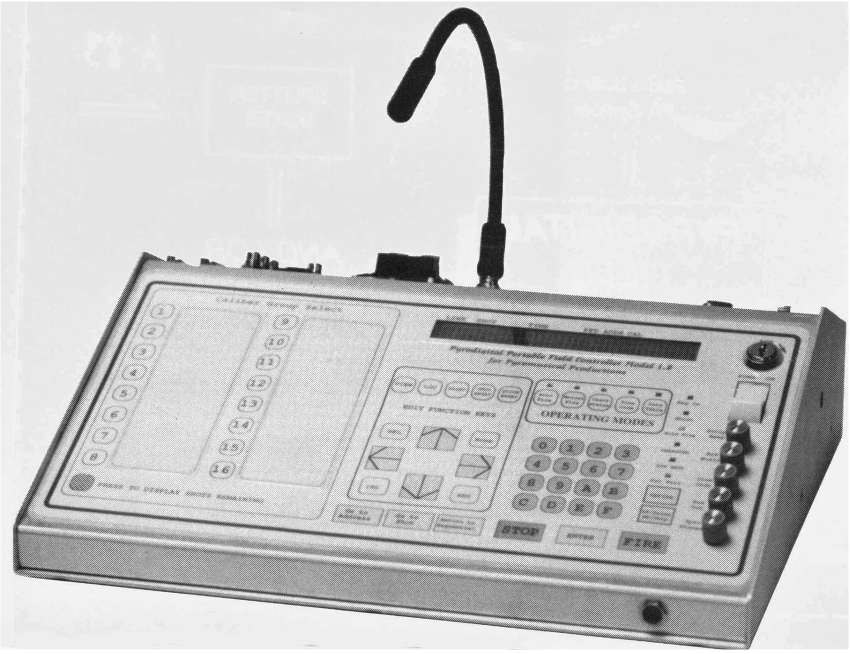
A hand-held firing unit for up to 5 firing circuits.



A hand-held firing unit using a high voltage capacitor firing for simultaneously firing many electric igniters, at a great distance.

AUTOMATED FIRING UNITS

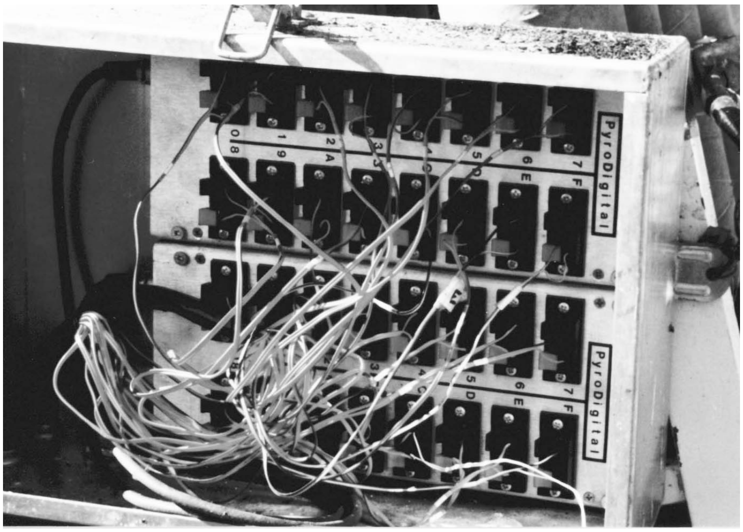
An example of an automated firing unit.



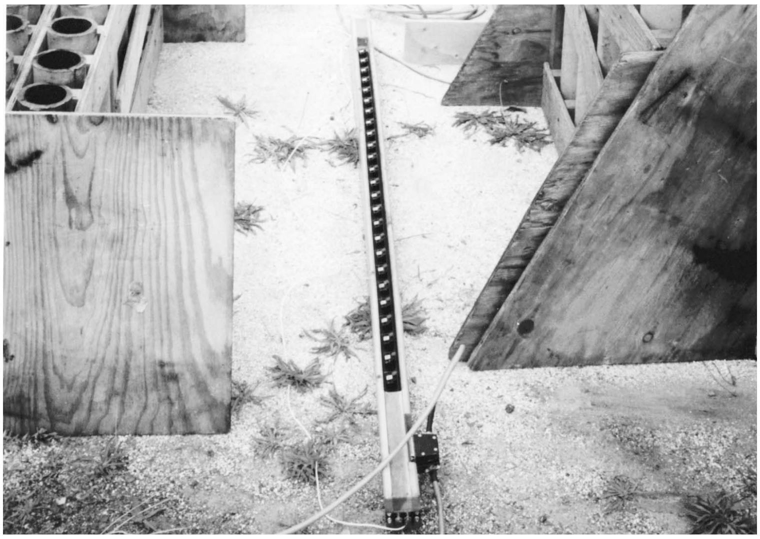
Another example of an automated firing unit.

CONNECTOR BOXES AND STRIPS

Remote from larger firing units will be some type of connector box or terminal strip for attaching the individual electric igniters.

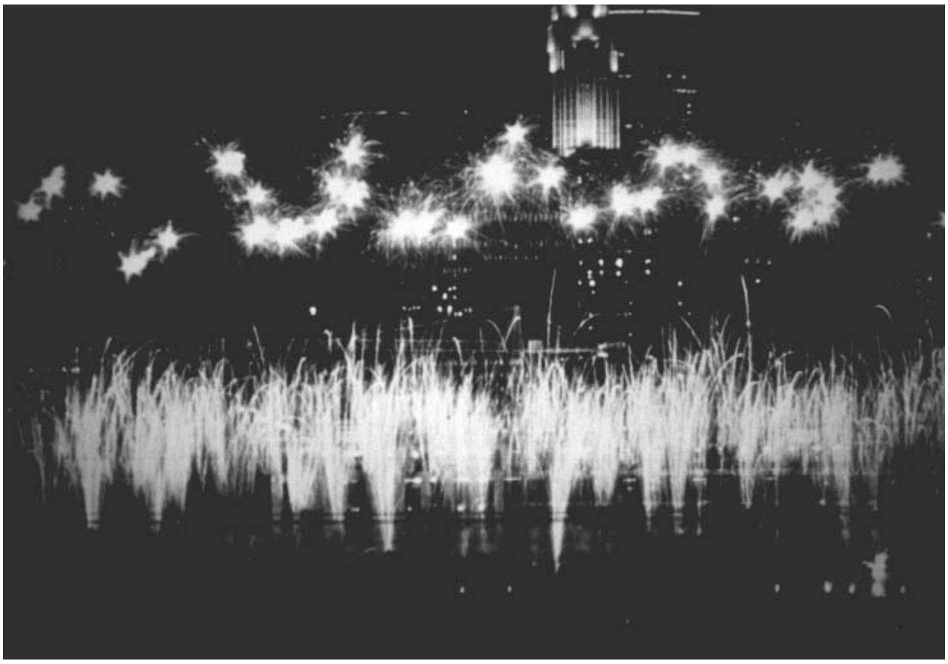


One type of connector strip, often called a “rail” or “slat”.



BELL WIRE

Some of the most interesting effects for fireworks displays are mine fronts and long Niagara Falls. Often the fireworks will be separated by large distances. Also, it may be expedient or necessary to electrically connect the electric igniters from all of the fireworks into a single firing circuit.



When the leg wires on electric igniters are too short to reach to the connecting points of the electrical firing equipment, they will need to be lengthened. The relatively thin, paired, solid conductor wire used for this purpose is sometimes called “bell wire”.

When many connections of this type have to be made, a quick and relatively inexpensive method is needed for making splices in the wiring. There are three common methods for doing this.

Method 1:

First the ends of both wires are stripped for about 1/2-inch (12 mm), brought together and the exposed copper wires are twisted together. Then the spliced wire ends are laid back in opposite directions and twisted around the main wires.

Method 2:

First the two main wires are tied together in a knot. Then the ends of the wires are striped, brought together, twisted together, laid back in opposite directions, and twisted around the main wires.

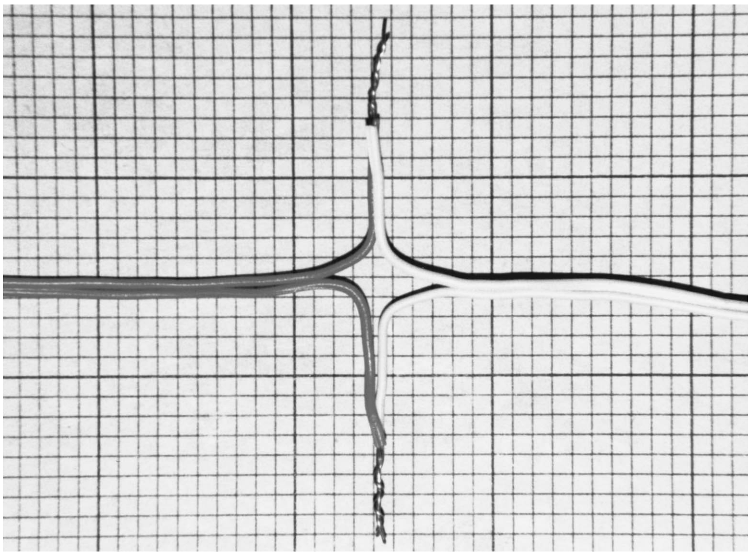
Method 3:

First the two main wires are tied together in a knot, then electrical crimp connectors, such as “Scotchlok” or other lower-cost connectors, are used to complete the splice without the need to strip the wires.

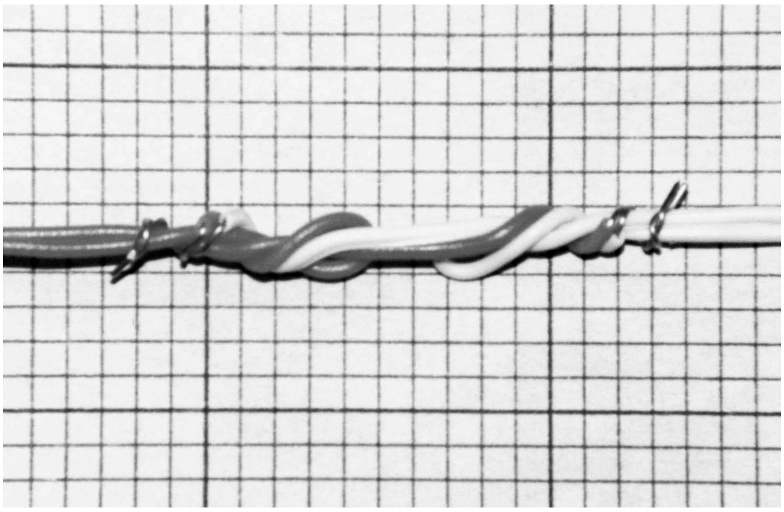
When using either method 1 or 2, tape is often applied to the exposed wire splices to reduce the chance of a short circuit.

SPLICE METHOD 1

Individual wires are stripped and twisted together. [0.1 inch (2.5 mm) per division]

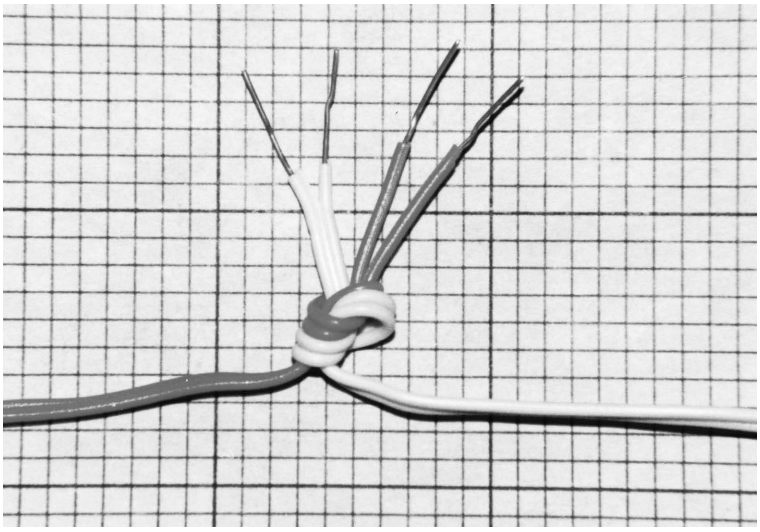


Spliced ends wound around main wire. Tape is often applied over the bare wire ends.

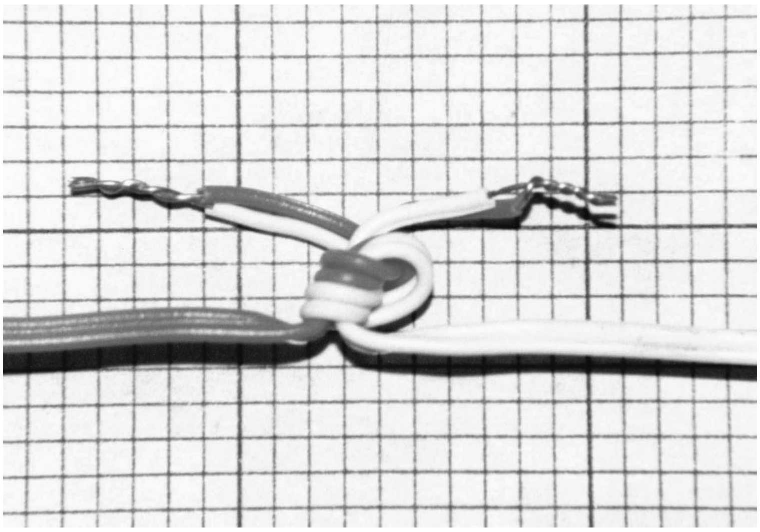


SPLICE METHOD 2

Wires are tied together in a knot and stripped. [0.1 inch (2.5 mm) per division]

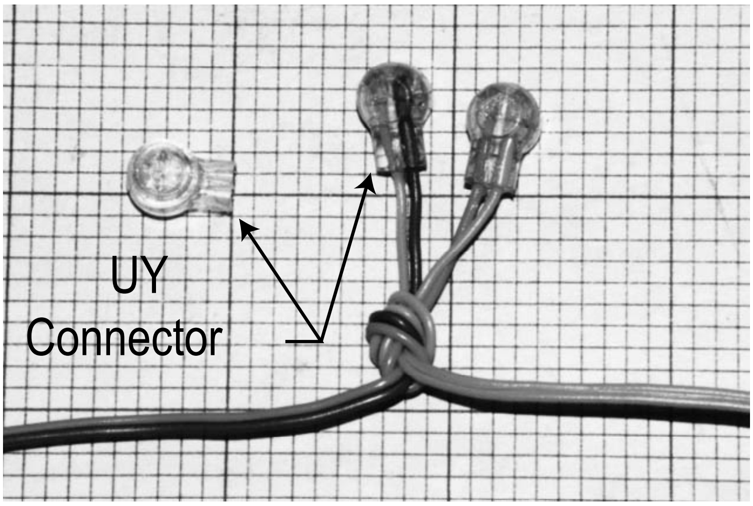


The stripped wire ends are then twisted together. Tape is often applied over the bare wire ends.

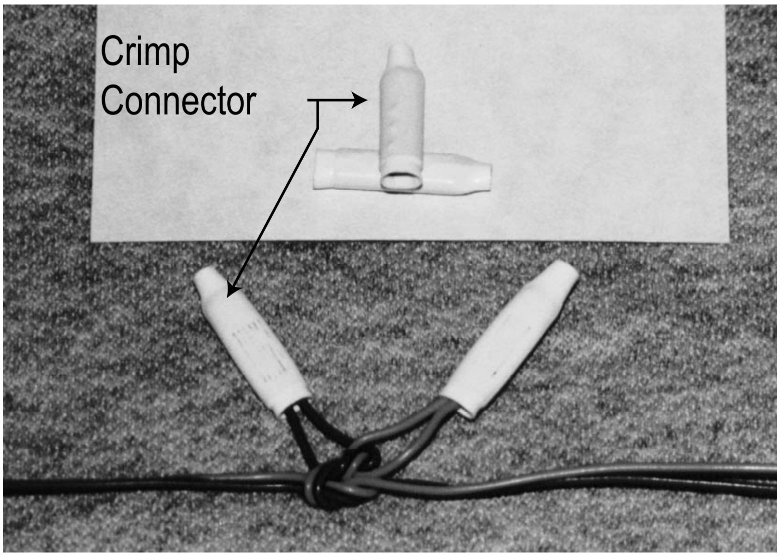


SPLICE METHOD 3

Example of connection made using “Scotchlok” UY connectors (from the 3M company). [0.1 inch (2.5 mm) per division]



Example of lower cost alternative crimp connectors.



COVERING ELECTRICALLY FIRED MORTARS

Because of the large number of preloaded mortars in one area, it is generally useful to take measures to reduce the chance of premature ignition as nearby aerial shells are fired.

The measures generally consist of covering the mortars with something to keep out sparks and burning debris. There are two common methods for covering mortars.

Aluminium Foil Method — Pieces of aluminium foil are placed over the tops of the mortars and held in place using tape or other means.

Advantages:

- Relatively inexpensive
- Fairly quick and easy to install
- Also affords some degree of moisture protection

Disadvantages:

- There is a mess to clean up after the display
- The foil may possibly short circuit exposed electrical connections
- The foil often will blow-off in the wind or as nearby aerial shells fire

ELECTRICALLY FIRED DISPLAY MORTAR COVERING

Electrically fired displays generally have very many mortars, which are often quite close together.

Photos from Nixon

Covering the mortars protects from moisture and some types of burning debris.

SECTION 17 - THE SHELLCALC© PROGRAM

❷ *Please note that this chapter is all level 2*

The Shellcalc© program

Illustrations of Use

Copy of Shellcalc© paper

"SAFETY" DISTANCES

❷ In the UK there are no prescribed "safety" distances for the use of category 4 fireworks. Indeed the BPA argue strongly that a risk-based approach is more appropriate for users of professional fireworks. Even where there are prescribed "safety distances", for instance in the US, the distances do not remove all risk to the audience from firing aerial fireworks - to achieve that the "safety" distances would have to account for

- *Worst case mortar angles and "Ground hopping"*
- *Shell burst diameters*
- *Effects of wind*
- *Local terrain and geography*

UK regulations require the RISKS to have been examined - this necessarily involves some measure of the frequency of failures - which are very low. However, as part of the risk assessment and risk reduction process (see later) it may be determined that additional control measures are required to minimise the risks to acceptable levels. For instance this may be achieved (for firing shells) by:-

- *Having no chain-fused shells*
- *Having a firing system that can be stopped instantly in case of mortar failure*
- *Barricades or "catchers" to trap low trajectory shells*
- *Mortar construction and mortar rack design*

Shellcalc is one tool used to enable professional firers to quantify the hazards arising from shell and comet use.

THE SHELLCALC© PROGRAM

❷ The BPA have adopted the Shellcalc© trajectory prediction program to allow planners and practitioners of firework displays to quantify the potential fallout from shells and comets in their displays. It is important to note

- *Shellcalc© looks at normal functioning of display shells and comets*
- *Shellcalc© uses standard parameters (although these are able to be modified) for shell heights and burst radii*
- *Shellcalc does not examine debris from normal functioning (e.g. shell fragments)*

USES OF THE SHELLCALC© PROGRAM

❷ It is important to realise the uses and limitations of the program. The following is illustrative of the potential of this powerful tool:-

- *Estimating normal start "reach" and hence fallout from shells and comets fired vertically and at angles*
- *Examining the effects of wind to determine "most likely" and "worst case" scenarios for various shells on specific sites*
- *Examining "reach" for shells and comets fired at angles in order to determine maximum safety distances (NOTE however - that this determines hazard - frequency and therefore risk will need to be examined - see later)*

COPY OF ORIGINAL SHELLCALC© PAPER PUBLISHED IN JPYRO ISSUE 22

Prediction of Aerial Shell and Comet Trajectories Using SHELLCALC©

John Harradine[a] and Tom Smith[b]

[a]Manly, Queensland, Australia

[b] Davas Ltd, 8 Aragon Place, Kimbolton, Cambs PE28 0JD, UK

Abstract: *This paper describes a model for predicting the path of aerial shells and Roman candle comets. This model, incorporated in a Microsoft® Excel-based freeware program, SHELLCALC©, predicts the trajectory of these fireworks using point mass equations for range and height. These equations are modified to take into consideration mortar/candle angle, launch altitude above sea level, wind speed and direction, comet consumption, air density and terrain, and incorporate an approximation of shell drift through tumbling motion and mortar balloting. The graphical output from the model also incorporates typical shell burst diameters.*

Keywords: *Shells, comets, ballistics, trajectory, fall-out*

Introduction

On many occasions it is useful to predict the path of an aerial shell or Roman candle effects (comets) given certain initial conditions. In response to this need, the authors have developed a Microsoft® Excel-based predictor, SHELLCALC©, which is easy to use, and provides graphical outputs which may be readily understood by the lay person and be included in reports and presentations.

SHELLCALC© may be used to assist:

- fireworks operators to plan a display, especially where a risk or hazard assessment is required;
- fireworks regulators to develop safe distances and establish risk regimes for fireworks displays;
- enforcement and investigative agencies to predict possible outcomes of "near misses", or to confirm actual incident data, particularly for presentation in court or in investigation reports;
- fireworks testers to establish a safe template for test firings; and
- fireworks manufacturers to establish safe distances for their products and predict the effect of variable fuse delay times on burst height.

General Layout

The SHELLCALC© data input and output screen is shown in Figure 1. All information is entered and displayed on the same page. In this way it is possible to readily examine the effect of changing a single parameter on the results calculated.

For instance it may be particularly useful to set the fuse delay time to the total flight time of the shell – to examine the possible spread of stars in this, one of the highest consequence failure modes of aerial shells.

Program Input

SHELLCALC© requires that several parameters be input before a meaningful output can be achieved. These inputs, for the aerial shell and roman candle predictors, are shown in Figures 2 and 3, respectively. The user can choose between imperial or metric input, and between calculations on shells or comets. The difference choosing shells or comets is twofold – the graphical output only displays approximate shell burst sizes for shells, and the calculations for shells assume that the shell's mass remains constant throughout its flight. Conversely for comets, no burst diameter information is displayed, and the calculations assume the comet's mass decreases to zero during its flight time.

In addition to choosing the calibre of the shell or comet star, the user can also enter other optimal parameters including the fuse delay time for shells

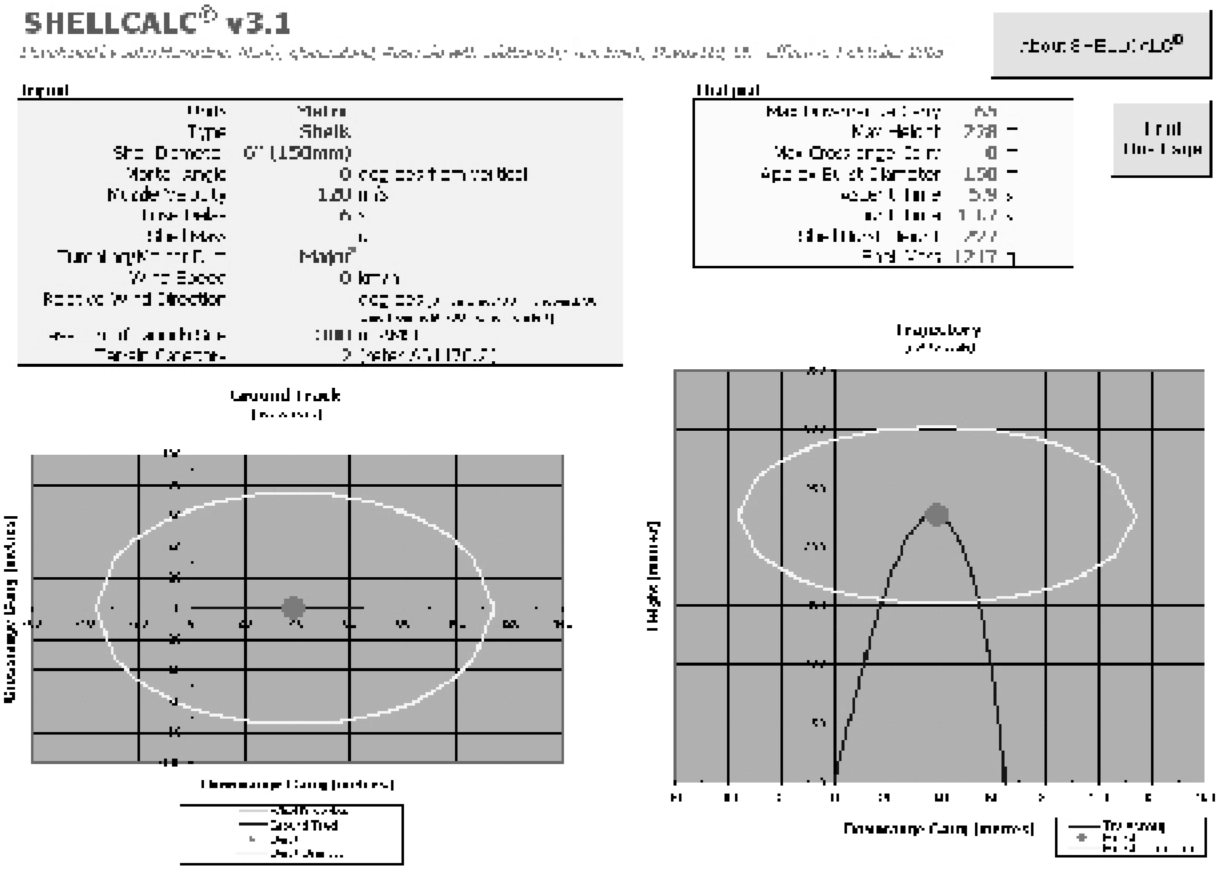


Figure 1. ***General layout of SHELLCALC© data input, data output and graphical output screen.***

(if no value is entered the shell is assumed to burst at the apex of its flight), the mass of the shell (if no value is entered the mass is calculated), the muzzle velocity (default values are provided), the wind speed and direction, the elevation of the launch site and a parameter to reflect the terrain category.

Trajectory Prediction

The basis of SHELLCALC©'s trajectory prediction is a point mass trajectory model which, in the case of the Roman candle predictor, has been modified to take into account the burning of the comet during flight (described later). The point mass model is accepted as the simplest useful trajectory prediction technique which takes air resistance into consideration.[1] The point mass model predicts both range (x, y) and height (z) components of acceleration for a projectile of given mass m. The Cartesian points of reference for the point mass model are shown in Figure 4.

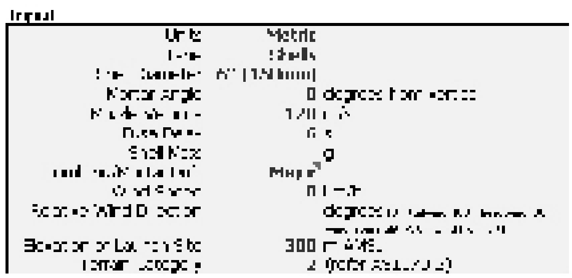


Figure 2. ***Aerial Shell input parameters.***

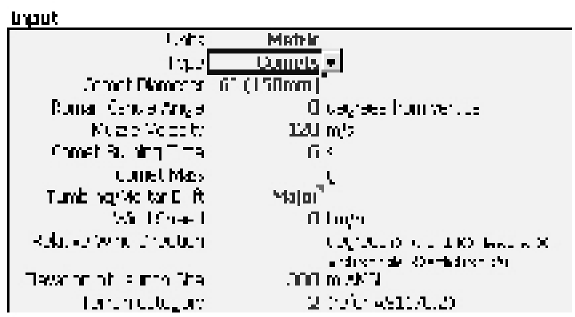


Figure 3. ***Comet Shell input parameters.***

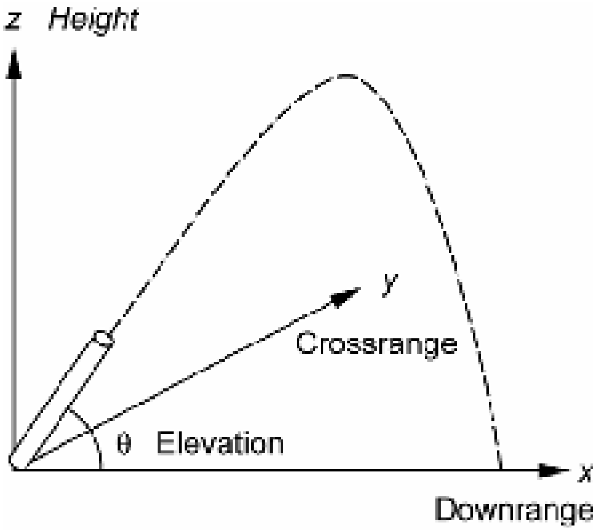


Figure 4. *Cartesian space used in* SHELLCALC©.

The equations for range and height are:

$$m\ddot{x} = \rho V^2 \pi d^2 C_D \left(\frac{\dot{x}}{8V}\right)$$

$$m\ddot{y} = \rho V^2 \pi d^2 C_D \left(\frac{\dot{y}}{8V}\right)$$

$$m\ddot{z} = -\rho V^2 \pi d^2 C_D \left(\frac{\dot{z}}{8V}\right) - mg$$

where:
- m = mass of projectile [kg]
- x = downrange distance [m]
- ρ = density of air [kg m^{-3}]
- V = velocity of projectile [m s^{-1}]
- d = effective diameter of projectile [m]
- C_D = drag coefficient of projectile [–]
- g = acceleration due to gravity [m s^{-2}]
- y = crossrange distance [m]
- z = height [m]

These equations are numerically integrated to solve for x, y and z based on a time interval of 0.1 s (this was found to give an acceptable level of accuracy without increasing the file size to an unacceptable level).

Correction for Drag Coefficient

The drag coefficient (C_D) of aerial shells is, at best, difficult to quantify. Such factors as roundness, surface roughness, effective Reynolds number and rotation will vary markedly from shell to shell and affect C_D, in some cases markedly. Given that these vagaries exist, an approximate value of C_D for shell diameters of 2 in (50 mm) to 12 in (300 mm) was determined by applying a best-fit model to Shimizu's empirical work on aerial shells,[4] resulting in:

$$C_D = -0.0921 \ln D + 0.9283$$

where D = effective presented diameter of projectile to airflow [mm]

Shimizu's C_D values are most likely on the low side; he used Japanese shells which were most likely of better quality than those of Chinese manufacture, which represent the majority of shells used worldwide today.

C_D for comets is more difficult to predict, as a comet in flight is a deflagrating cylinder that is inherently unstable. For simplicity's sake, the C_D of comets was taken to approximate that of an aerial shell of similar diameter.

Estimated Shell Mass

An approximate value of mass, m, for aerial shells with diameters of 2 in (50 mm) to 12 in (300 mm) was determined by applying best fit to values from various sources:[2,3]

$$m = 205.25 d^{2.7909}$$

The user can enter the mass of the aerial shell in question if this is known; otherwise the program will use the estimated value.

Correction for Comet Mass Consumption

Unlike aerial shells, which are assumed to remain intact during flight, an allowance must be made for the consumption of the burning comet in flight. If the effect of pressure on burning rate is ignored (that is, burning rate remains constant), and surface burning of a cylindrical comet is assumed, the mass of the comet m after elapsed time t can be calculated using:

$$m = \frac{\pi\rho_P}{4}\left(d_0 - 2rt\right)^2\left(l_0 - 2rt\right)$$

Table 1. *Typical dimensional and burning rate parameters for a 2 in (50 mm) roman candle comet.*[4]

Parameter	Value
m	0.068 kg
ρ_p	1860 kg m^{-3}
d_0	0.045 m
l_0	0.023 m
r	0.00143 m s^{-1}

where: ρ_p = density of comet [kg m^{-3}]
d_0 = initial diameter of comet [m]
l_0 = initial thickness of comet [m]
r = linear burning rate of comet composition [m s^{-1}]

Typical values for these parameters for 2 in (50 mm) roman candles are shown in Table 1. These values for density ρ^p and burning rate r should be reasonably accurate when applied to all solid black-powder or flash powder effects (including comets and stars), and these values are used by default in SHELLCALC©. The user has the option of inputting a different comet burn time if this is known; in this instance, the program will alter r to achieve the required total burn time.

Effective Comet Diameter

As a comet is consumed during flight, its effective diameter reduces, thereby reducing the effective presented area of the comet. SHELLCALC© uses the following formula to achieve an approximation of the effective presented diameter, d:

$$d = d_0 - 2rt$$

Correction for Wind

SHELLCALC© permits the user to input wind direction and speed relative to the direction of aim of the mortar or Roman candle. The program requires the user to input a wind bearing relative to the direction of aim as shown in Figure 4. For example, a headwind has a relative bearing of 0°, and a wind from the right has a bearing of 90°.

Based on the wind direction and speed input by the user, SHELLCALC© resolves the velocity vectors in the x and y axes and adjusts the values of V, $\dot{x}$ and $\dot{y}$ in the relevant point mass equations.

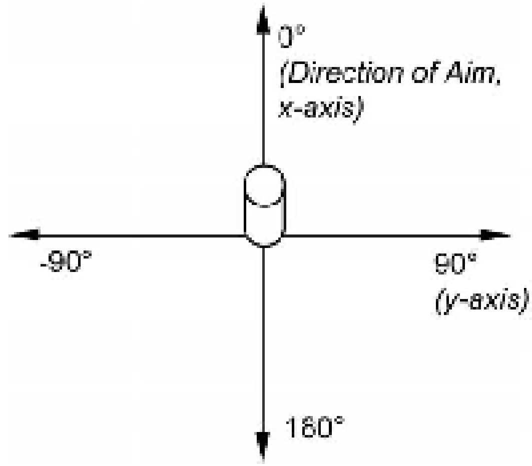


Figure 5. *Relative wind bearings used in SHELLCALC©.*

Correction for Mortar/Roman Candle Angle

When the mortar or roman candle is set at an angle other than vertical, the user can nominate the appropriate angle from vertical. Based on this angle, SHELLCALC© calculates the mortar elevation θ (refer Figure 1), resolves the velocity vectors in the x and z axes and adjusts the values of $\dot{x}$ and $\dot{z}$ in the relevant point mass equations.

Correction for Terrain

Terrain affects actual wind speed at ground level. If turbulence and other anomalies are ignored, a good estimate of wind speed w for a given height above ground level z can be estimated if the AS/NZS 1170.2 terrain category is known.[5] The value of w for terrain category 2 (open spaces and water) is:

$$w = w_0(0.1036\ln(z+1) + 0.8731)$$

where w_0 = wind speed out of ground effect [ms^{-1}].

Similarly, the value of w for terrain category 3 (sports grounds and built-up areas) is:

$$w = w_0(0.139\ln(z+1) + 0.7503)$$

Based on user input, SHELLCALC© corrects V using the appropriate equation. If the user does not nominate a terrain category, the program ignores terrain effects on V.

Correction for Air Density

As air density ρ changes with altitude, SHELLCALC© calculates ρ at each 0.1 second increment and uses this value in the relevant point mass equations. Air density at a given altitude $(z + z_0)$ is calculated according to the following equation:

$$\rho = \rho_0 e^{-0.0001057(z+z_0)}$$

where: ρ_0 = density of air at sea level [kg m^{-3}]
z_0 = elevation of launch site above sea level [m]

Program Output

Once the user inputs all data, SHELLCALC© will provide both numerical (Figure 6) and graphical (Figures 7, 8 and 9) outputs. The graphical outputs are Excel charts, and so may be copied to other applications for inclusion in reports or presentations.

Shell Burst Diameters

Shellcalc© also displays the typical burst diameter of shells at either the time selected by the user, of if this parameter is not entered, at the apex of the shell's flight. The values for typical shell burst diameters are taken from work on Japanese Shell Break Radii7 and are a mathematical close fit to the typical values cited in that paper (Figure 10). However, the authors noted that the maximum observed break radii can exceed the typical values by a significant amount, and that shells from different suppliers, and shells comprising different effects may also deviate significantly from the "typical" values. The user is cautioned to consider the graphical output as illustrative only.

Output

Max Downrange Carry	30	m
Max Height	236	m
Max Crossrange Carry	0	m
Approx Burst Diameter	150	m
Time at All Burst	6.0	s
Height at All Burst	235	m
Comet Mass	1217	g

Figure 6. ***Numerical output for aerial shell prediction.***

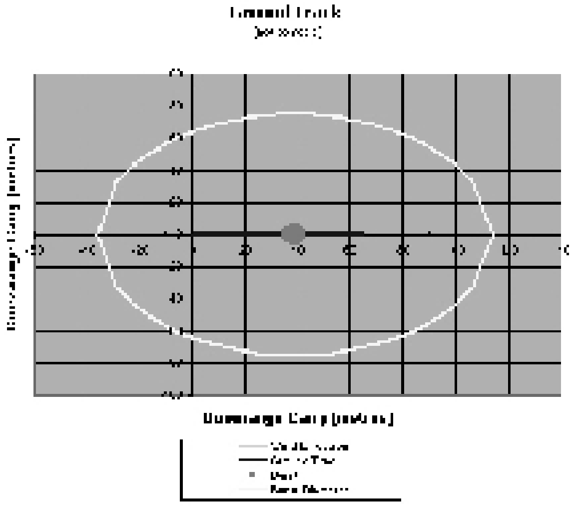


Figure 7. ***Ground track of aerial shell showing location of shell burst and approximate shell burst size***

Shell Drift

Firework shells are subject to several mechanisms to account for the observed shell drift, even in completely still conditions. Such factors include shell spin (Magnus effect) and shell balloting due to the fit of the shell in a mortar and the mortar length. SHELLCALC© uses shell balloting data from Norton[7] to attempt to factor in, albeit in a crude way, the observed deviations. SHELLCALC© allows the user to select three values related to this effect,

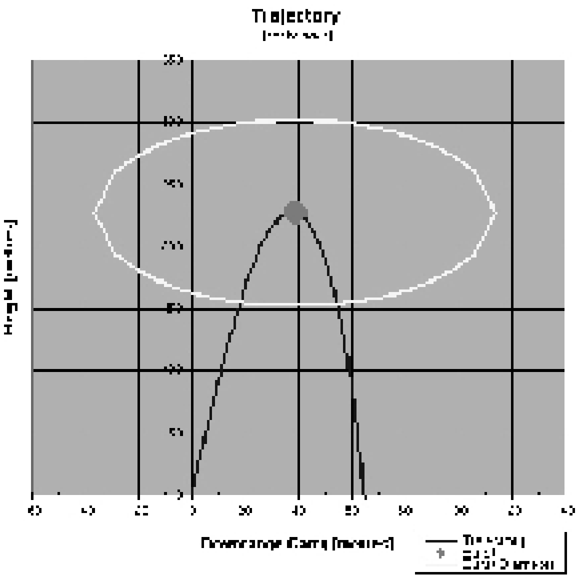


Figure 8. ***Trajectory of aerial shell showing location and approximate shell burst size.***

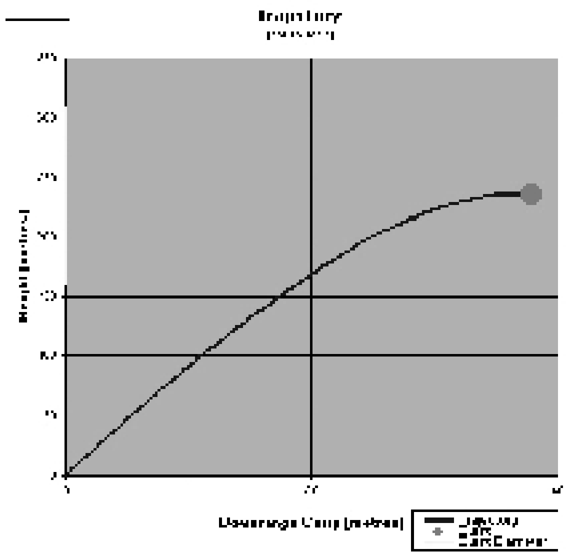


Figure 9. ***Trajectory of comet showing location of "burn out".***

and to incorporate this into the final output values and graphs.

None – shell drift parameters are ignored.

Typical – an average value of shell deviation from Norton is used (approx. 2° deviation)

Maximum – the largest value of shell deviation calculated by Norton is used (approx. 5° deviation)

The user should note that shell drifts are due to many factors, and the incorporation of this parameter into SHELLCALC© is largely to prevent the program calculating that in still conditions, where a shell is fired vertically, that it would necessarily return to earth exactly at the point of firing. It is also useful to use this parameter when estimating "worst case" scenarios, for instance angled mortars, significant tailwind, maximum shell drift and

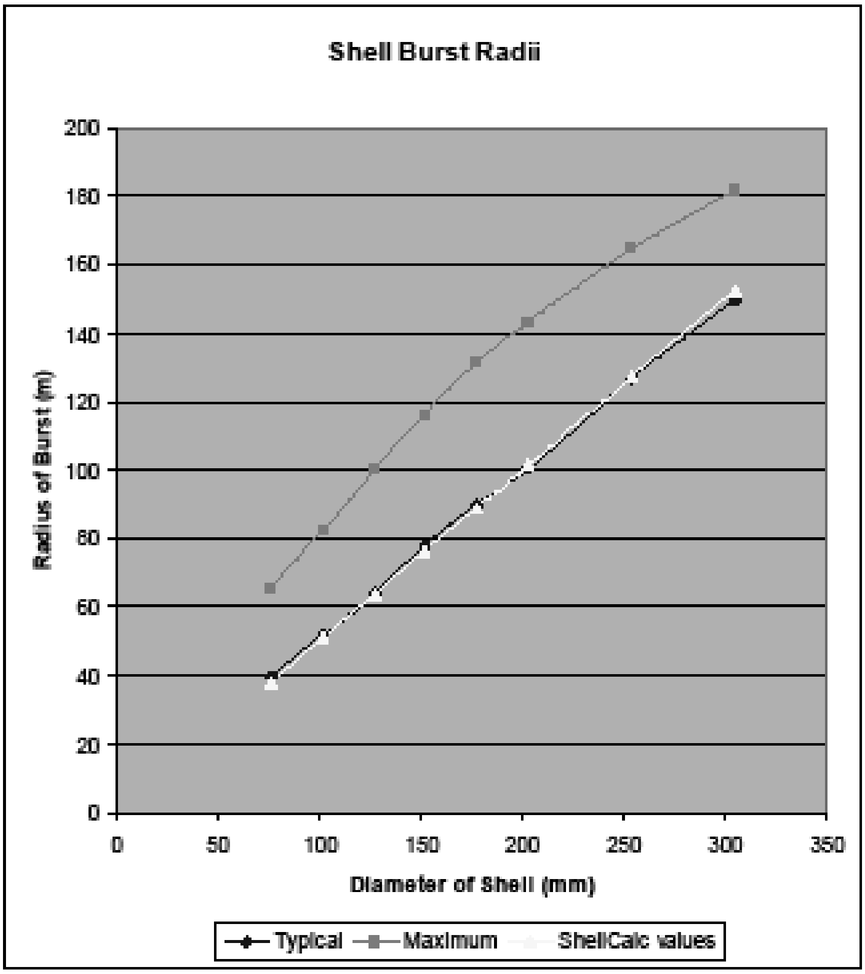


Figure 10. ***Typical, Maximum and SHELLCALC© values for burst radius as function of shell diameter used in SHELLCALC© calculations.***

shell bursting at ground level. The extent of shell balloting depends on the shell–mortar clearance and to the effective length of the mortar and in general better shell–mortar fit and longer mortars decrease this effect.

Agreement with Observation

Based on the authors' observation and Shimizu's work,[2] the predictions made by SHELLCALC© are close to the actual behaviour of aerial shells and Roman candle comets. As SHELLCALC© is still a basic program with limited accuracy, the authors would appreciate any feedback on improvements.

References

1 Aeromechanical Systems Group, *Basic External Ballistics Lecture Notes*, Royal Military College of Science, Shrivenham, UK, 1992.

2 T. Shimizu (translated by A. Schuman), *Fireworks From a Physical Standpoint – Part III*, Pyrotechnica Publications, 1985.

3 J. B. Harradine, *Chemical and Physical Analysis of Roman Candles, Other Types of Fireworks and Their Residues*, Explosives Inspectorate, Department of Natural Resources and Mines, Brisbane, 2001.

4 J. B. Harradine, *Dynamic Testing of Roman Candles and Other Types of Fireworks, Safety and Health Division*, Department of Natural Resources and Mines, Brisbane, 2001.

5 Standards Australia, *AS/NZS 1170.2:2002: Structural design actions - Wind actions*, 2002.

6 K. L. and B. J. Kosanke, *Pyrotechnics Guild International Bulletin*, No. 59 (1988), p. 104.

7 Randall K. Norton, *Journal of Pyrotechnics*, Issue 13, 2001, p. 31.

Note

SHELLCALC© is a freeware program and is designed to run on Microsoft® Excel 95 or later.Copies and updates may be obtained directly from the download section of the Journal of Pyrotechnics Website:

http://www.jpyro.com/downloads/shellcalc/

SECTION 18 - RISK ASSESSMENTS

INTRODUCTION

The BPA have adopted a risk assessment scheme based on ranking of hazards and frequency on a 0-10 scale which gives risk factors on a 0-100 scale.

The BPA risk assessment methodology is not the only way to carry out a "suitable and sufficient" risk assessment, but it is one which has found favour amongst both users and enforcers alike.

The remainder of the section is a reproduction of a presentation on risk assessment for the BPA .

RISK ASSESSMENT PRESENTATION

❷ *What is a risk assessment (HSE website)*

- *Risk management involves you, the employer, looking at the risks that arise in the workplace and then putting sensible health and safety measures in place to control them. By doing this you can protect your most valuable asset, your employees, as well as members of the public from harm.*

❷ *5 steps to risk assessment (hse website)*

- *Step 1: Identify the hazards*
- *Step 2: Decide who might be harmed and how*
- *Step 3: Evaluate the risks and decide on precaution*
- *Step 4: Record your findings and implement them*
- *Step 5: Review your assessment and update if necessary*

❷ *What a RA Isn't for*

- *So you can give it to a client or venue to "tick" the right boxes*
- *So you can overwhelm them with the volume of paperwork you produce*
- *So you can have a "warm feeling" that you've done it*
- *It is not merely a photocopying exercise*
- *It doesn't have to be complex – but it must not be too simple*
- *It doesn't have to be too time consuming (you can rely on "standard" bits PLUS "Site specific/ product specific" bits*

❷ *What a RA is really for*

- *A means for you to:-*
- *Identify risks in a systematic way*
- *Rank risks*
- *Determine if some risks are unacceptable*
- *Priorities those risks which need to be addressed*
- *See if addressing those identified reduces the overall risks*
- *Set in place procedures that do actually reduce the risks*

❷ *Why do RAs?*

- *Because you have to.*
- *End of story – no questions, no "ifs" no "buts" – you are not going to change the World*

- *It might actually identify a problem you haven't foreseen*
- *It might demonstrate that something you are doing isn't actually reducing the risk to a particular sector*
- *It may give OBJECTIVE criteria for cancellation/curtailment of a display*

❷ *Risk assessment vs assessing the risks*

- *You should be assessing risks – NOT "doing a risk assessment"*
- *You should take into account site and product specific features*
- *Even if the law doesn't necessarily require it - it should be written down*
- *Your staff and the venue/organiser should be aware of it*

❷ *The fundamentals*

- *Individual Risks*
- *Risk to a specified individual*
- *Fairly easy to quantify*
- *Societal Risks*
- *Risks to population as a whole (public perception)*
- *But is this company specific or across the industry as a whole?*
- *More difficult to quantify*
- *BUT in general we can deal with individual risks*

❷ *Individual Risk*

- *10^{-6} – broadly acceptable*
- *10^{-5} – 10^{-4} ALARP (10^{-3} for workers)*
- *>10^{-4} - unacceptable*

❷ *societal risk*

- *Number of people affected vs frequency*
- *Public perception*
- *Society has a greater aversion to an accident killing 10 people than to 10 accidents killing one person each*
- *Nuclear disasters*
- *Road traffic accidents*
- *Firework accidents*

❷ *alarp*

- *As Low As Reasonably Practical*
- *Has Cost/Benefit implications (but these cannot be used to justify unacceptable risks)*
- *Control measures may vary depending on the circumstances of the risk (e.g. multiple shows)*
- *http://www.hse.gov.uk/risk/theory/alarp1.htm*

❷ *alarp (hse website)*

- *Determining that risk has been reduced ALARP*

- *Thus, determining that risks have been reduced ALARP involves an assessment of the risk to be avoided, of the sacrifice (in money, time and trouble) involved in taking measures to avoid that risk, and a comparison of the two.*
- *This process can involve varying degrees of rigour which will depend on the nature of the hazard, the extent of the risk and the control measures to be adopted. The more systematic the approach, the more rigorous and more transparent it is to the regulator and other interested parties. However, duty-holders (and the regulator) should not be overburdened if such rigour is not warranted. The greater the initial level of risk under consideration, the greater the degree of rigour HSE requires of the arguments purporting to show that those risks have been reduced ALARP*

❷ *Fundamentals of practical RAs*

- *Have a system for recording*
- *Have a systematic way of identifying hazards (don't rely on just one person)*
- *You are only required to record significant risks – but we advise being broader than that to demonstrate that you have a systematic approach*

❷ *risk vs hazard*

- *A hazard is anything that may cause harm, such as chemicals, electricity, working from ladders, an open drawer etc.;*
- *The risk is the chance, high or low, that somebody could be harmed by these and other hazards, together with an indication of how serious the harm could be.*
- *Hazard is the consequence of an event*
- *Frequency (likelihood) is some measure of how often this happens*
- *Risk is a measure of how important the product of hazard and frequency are*

❷ *Methods - overview*

- *Some means of rating hazards*
- *Some means of rating frequency*
- *Therefore rate risk*
- *Some means of determining if risk is broadly acceptable, ALARP, unacceptable etc.*
- *Some means of determining if control measures reduce risk*

❷ *methods - rating systems*

- *Very Simple*
- *HIGH/MEDIUM/LOW*
- *Bit more complex*
- *Hazard = 1-3 x Freq = 1-3 gives risks = 1-9*
- *More complex still*
- *Hazard = 1-5, Freq = 1-5 gives risks 1-25*
- *Our preferred*
- *Hazard = 0-10, Freq = 0-10 gives risks 0-100*

Hazards (to people)

Value	Description	
0	No hazard	Ash on hand
1	Trivial injury to one	Lit ash on hand
2	Trivial injury to many	
3	Minor injury to one	Ash in eye
4	Minor injury to many	
5	Major injury to one	Loss of limb
6	Major injury to many	
8	One fatality	Death – immediate OR as a result of injury
10	Multiple fatalities	

Hazards (to structures)

Value	Description	
0	Nothing of consequence	
1	Single superficial damage	Minor marking washes off with rain
2	Multiple superficial damage	
3	Single minor damage	Requires repainting
4	Multiple minor damage	
5	Single major damage	Requires replacement
6	Multiple major damage	
8	Significant damage – partial collapse	
10	Significant damage – total collapse	

Frequency

Value	Description		Frequency
0	Never happens	Debris landing 2 miles upwind	$F = 0$
1	Very Unlikely		$F < 10^{-6}$
2	Happens rarely	Shells explodes and busts mortar	$10^{-4} > F > 10^{-6}$
3	Happens occasionally		$10^{-3} > F > 10^{-4}$
4	Happens	Fuse fails	$10^{-2} > F > 10^{-3}$
6	Frequently happens		$10^{-1} > F > 10^{-2}$
8	Almost always happens	Lit debris in firing area	$10^{-1} > F > 1$
10	Always happens	Firework debris lands on ground	$F = 1$

♦

❷ *Who do you consider?*

- *Risks to:-*
- *Operators*
- *The public*
- *Other people on site*
- *Structures etc.*

❷ *Examples or problems*

- *Electric firing of shells*
- *Reduce risk to operator*
- *Further away*
- *May increase risk to public*
- *Can't tell if mortar has fallen over*
- *So*
- *May have to introduce additional features/controls to ensure risk to public is not increased*

❷ *site layout/frequency*

- *People on one side of firing area (say 60° only)*
- *People 360° around firing area (6 times more likely to be affected)*
- *One display a year*
- *10 displays a year (societal risk is 10 times higher)*

❷ *RA - Process*

- *Rank the risks*
- *Determine if broadly acceptable, ALARP or unacceptable*
- *Put in place measures to reduce overall risks where necessary*
- *Monitor that those are actually being done*
- *Review and revise as necessary*

❷ *RAs should include*

- *Name of RA (or display/date etc)*
- *Date it was done*
- *By whom*
- *Hazards identified*
- *Initial risks*
- *Means of controlling those risks*
- *"mitigated" risks*
- *Review date*

❷ *General vs site specific vs product specific elements*

- *ALL displays are different*
- *ALL display RAs will have site/product specific elements*

❷ ***general***

- *Stacking vans*
- *General rigging techniques*
- *Firing systems*

❷ ***site specific***

- *Car parks*
- *Crowd lines*
- *Firing area*
- *Prevailing wind vs other weather conditions*
- *Duration of display*
- *Frequency of display*

❷ ***prodiuct specific***

- *Types of fireworks*
- *Effects – kamuro vs ring shells*
- *Specific items (e.g. lancework)*
- *New items*

❷ ***mitigating risks***

- *You can affect hazard OR frequency – BUT NOT BOTH*
- *Frequency*
- *Crate construction*
- *"Shell catchers"*
- *Testing*
- *Crowd distances*
- *Hazard*
- *Different fireworks (calibre, effect, chemistry)*

❷ ***RA example - poor***

- *Too simple or too complex*
- *Not site/product specific*
- *Obviously just a photocopy*
- *Many control measures reducing a risk without explanation*
- *Too "glib" mitigation measures*
- *Most suggest that all firework displays are inevitably "Low Risk"*

❷ ***RA Examples - Good***

- *Extensive enough to demonstrate that you have actually considered what you are doing!*
- *Be logical*
- *Draw conclusions if necessary*
- *General and Product Specific/Site Specific*

RA – VERY poor!

XYZ Firework Display

- Identified Hazards – Fireworks falling on crowd
- Other risks - None
- Measures in place – Use only trained firers
- Overall Risk – Low

RA – poor!

Hazard and Effect	Risk	Control risks by	Residual risk
Fire •Injury to persons •Destruction of property	Medium	• Train operators •Appropriate PPE •Fireproofing •Self-extinguishing equipment •Minimise fireworks on site •Store fireworks in approved packaging •Communicate to safety officer •Minimum 3 technicians on site	Low

- *BPA common formats*
- *Tabular*
- *Colour code if you can (highlights high risk activities and emphasises that they have been addressed)*
- *Addresses*
- *Overall RA*
- *Specific operations*

❷ *what comes out of an RA?*

- *Effectively produces operating procedures*

Risk Assessment

0-10 weighted scales - see key

Event: BALE - London - NYE 2006

Date: 31/12/2005

				Initial Risk				Managed Risk		
Item	Hazard and effect	Site/date	To whom	Hazard Index	Frequency Index	Risk Product	Minimise risk by	Hazard Index	Frequency Index	Risk Product
1	Premature ignition of items on firing plate during unloading	Site during rigging	Public	10	2	20	Keep public remote from unloading/transport route (via barge). Keep items packaged until on BALE	4	1	4
2	Premature ignition of items on firing plate during unloading	Site during rigging	Operators/Staff	10	2	20	Only pyrotechnists/riggers to handle materials. BALE riggers to be supplied with fire-retardant PPE	10	1	10
3	Mass explosion of entire holding in transport vehicle leading to onsite risk	General	Any	10	3	30	Stock remain in transport boxes throughout	10	1	10
4	Mass explosion of entire holding in storage leading to off site fatality etc	General	Public	10	2	20	Maintain safety distances to barrier for public. No access to site for public. Consider crew/staff ID badges.	6	1	6
5	Unexpected violent event from ignition due to incorrect types	General	Operators/Public	10	2	20	Good housekeeping, labelling of boxes, clear instructions and monitoring	6	1	6
6	Ignition through poor handling of items/containers	General	Operator	10	2	20	Clear procedures from operator and monitoring	10	1	10
7	Protestor attack leading to compromising safety of site	General	Public	10	2	20	Adequate security	10	1	10
8	Accidental ignition during loading/unloading	General	Operators	10	1	10	Restrict numbers of personnel and stock at any one point in time	8	1	8
9	Premature ignition from smoking/matches etc	General	Operator	10	2	20	All sources of ignition banned from immediate pyrotechnic working site	1	1	1
10	Transport of fireworks from vehicle to working area	General	Operator	10	2	20	Boxes to be closed. Procedures to prevent excessive quantity/unsafe transport (eg overloaded trolley) being used	8	1	8
11	Adding electric fuses to piped match/firework body	General	Operator	10	3	30	Exposed fireworks to be kept to minimum. Igniters to be protected by sheath or similar. Majority of work completed offsite	6	1	6
12	Manipulation of blackmatch fuse	General	Operator on barge	10	2	20	Exposed quantity to be kept to a minimum	6	1	6
13	Adding delay fuse to existing firework	General	Operator on barge	10	2	20	Exposed quantity to be kept to a minimum	6	1	6
14	Packing of fireworks for transport	General	Operator	10	2	20	Exposed quantity to be kept to a minimum. Approved packaging and methods	6	1	6
15	Loading vehicle	Vehicle	Operator	8	2	16	Good manual handling, monitoring etc	5	1	5
16	Collapse of stack of fireworks in vehicle leading to ignition	Vehicle	Operator	8	2	16	Good manual handling, monitoring etc	5	1	5
17	Premature ignition of fireworks while loading vehicle due to poor handling	Vehicle	Operator	8	2	16	Good manual handling, monitoring etc	5	1	5
18	Premature ignition of igniter whilst in vehicle	Vehicle	Operator	10	2	20	All wires "shunted". Transmission equipment prohibited from loading area	10	1	10

BPA Fireworks Limited

Risk Assessment and Essential Operating Procedures

Process Description:	Use and handling of electric igniters				
Location:	Worksheds				
Assessment No:	16/02	Prepared by:	CP	Date:	2/11/2006
Reviewed by:	TS	Next Review Date:	1/11/2007	Initials:	

Processes and methods

Electric igniters are added to existing fireworks to enable their ignition on a display site. Electric igniters are added to fireworks or to make igniter/fuse assemblies in several ways:

1. By inserting an electric igniter into the sleeve of piped match
2. By connection of pre-made igniter/fuse assembly to existing firework
3. By direct insertion into the firework (eg into the lifting charge of a shell)
4. By indirect insertion into a fireworks (eg by surrounding with blackmatch prior to insertion into the top of a Roman candle tube)

See also

Risk Assessment No	Description
????	Removal of igniter from firework
	Disposal of igniters
	Normal Housekeeping arrangements
	Enhanced Housekeeping arrangements

- *If all the mitigation measures are in place and working*
- *Contingency planning*

Hazards Identified and Initial Risk Rating - **Use and handling of electric igniters**

Electric igniters are sensitive to friction, impact, and electrostatic energy and present a significant risk of ignition.
Ignition of an igniter while being handled can cause localised burns to the operator
Ignition of an igniter during fitting to a firework will lead to the ignition of that fireworks and, potentially, any adjacent items.

Serial No	Hazard/Cause/Effect	To Whom	Initial Hazard rating	Initial Frequency rating	Initial Risk	Notes
1	Ignition by friction			4		See below for effects
2	Ignition by impact			4		See below for effects
3	Ignition by RF			4		See below for effects
4	Ignition by static			4		See below for effects
5	Ignition causing burns	Operator	5	4	20	
6	Ignition causing ignition of fireworks operation is being carried out on	Operator + others in vicinity	10	4	40	
7	Ignition causing spread of fire to adjacent stock	Operator + others in vicinity	10	4	40	

Maximum Initial Risk - 40

Managed Risk Rating and Matrix - **Use and handling of electric igniters**

Serial No	Hazard/Cause/Effect	To Whom	Risk reduction methods/Comments	Managed Hazard rating	Managed Frequency rating	Managed Risk
1	Ignition by friction		Igniters not to be inserted into piped match without protective sleeve		3	
			Work areas to be kept clean and free from loose composition		2	
2	Ignition by impact		Boxes to be fitted with rubber strips on opening surfaces		2	
			No tools to be used		2	
3	Ignition by RF		No transmitting devices (radios/mobiles etc) permitted in workplace and adjacent areas when work with igniters being carried out		2	
			All igniter wires to be shunted before operations start		2	
4	Ignition by static		Operator and equipment to be earthed. Operator to wear earth strap		2	
			Non-static clothing to be worn		2	
			Work to cease in case of approaching lightning storm		0	
5	Ignition causing burns	Operator	See note 1 below	5	4	20
6	Ignition causing ignition of fireworks operation is being carried out on	Operator + others in vicinity (note 2)	Only one item to be fitted with electric igniter to be exposed at any one time. For fitting igniter to chain fused items fit igniter first or use pre-made igniter/match assembly	10	3	30
			Operations to be carried out behind safety screen	10	3	30
7	Ignition causing spread of fire to adjacent stock	Operator + others in vicinity (note 2)	All other stock in workshed to be in closed boxes (see enhanced housekeeping procedures – RA ????)	10	2	20
			Minimise stock in workshed (see enhanced housekeeping procedures – RA ????)	10	2	20

Maximum Managed Risk - 30

Notes

Note 1: Manual dexterity is an important feature. Use of gloves may reduce dexterity leading to more force being applied to igniter during operations. We recommend that no gloves are worn

Note 2: Visitors to be excluded from defined work areas during work operations involving igniters

Essential Operating Procedures – **Use and handling of electric igniters**

1. Ensure areas are clean before work commences
2. Expose only a single firework at any one time
3. Keep all other fireworks in closed boxes
4. Do not remove plastic cap from igniter head
5. Ensure igniter wires are shunted
6. Ensure that you are connected to earth strap before commencing work
7. Cease work if lightning storm approaches

- *OBJECTIVE CRITERIA for cancellation/modification*
- *Identify things NOT TO DO*
- *(but don't use it as a justification for something that isn't really true!)*

❷ *conclusions*

- *You have to do it - so*
- *You might as well do it in a way that gives meaningful information*
- *In such a way that you can demonstrate that you take the process seriously*

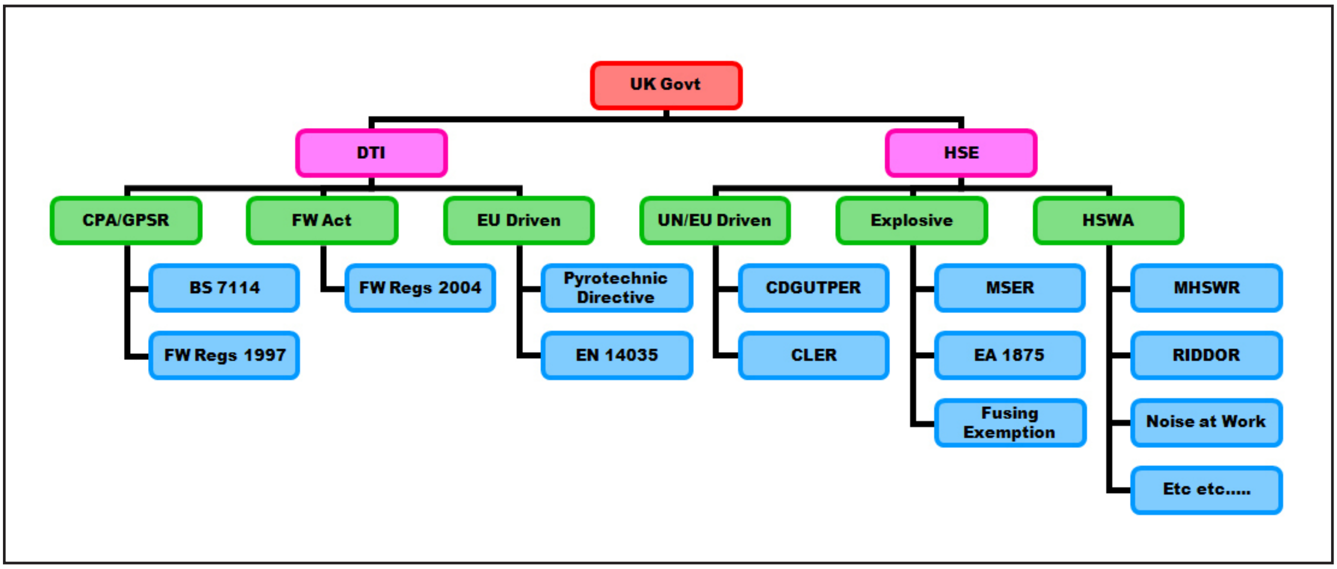
Wind Direction	Wind Strength	Consequence	Actions
N	< Force 4	Debris falls as predicted	
N	> Force 4	Debris area extended upriver	
N	> Force 7	Debris falls on Westminster Bridge and potentially Parliament	Consider removing larger calibre shells or cancelling display
NE	< Force 4	Debris falls as predicted	
NE	> Force 4	Debris area extended upriver.	
NE	> Force 6	Debris falls on Westminster Bridge and Embankment	Consider removing larger calibre shells or cancelling display
E	< Force 4	Debris falls as predicted	
E	> Force 4	Debris area extended onto Embankment.	
E	> Force 5	Debris falls on Embankment	Consider removing larger calibre shells or cancelling display
SE	< Force 4	Debris falls as predicted	
SE	> Force 4	Debris area extended onto Embankment.	
SE	> Force 7	Debris falls on Embankment	Consider removing larger calibre shells or cancelling display
S	< Force 4	Debris falls as predicted	
S	> Force 4	Debris area extended downriver.	
S	> Force 7	Debris falls on Jubilee Bridge	Extend barriered area. Consider removing larger calibre shells or cancelling display
SW	< Force 4	Debris falls as predicted	
SW	> Force 4	Debris area extended downriver.	
SW	> Force 7	Debris falls on Jubilee Bridge and Jubilee Gardens	Extend barriered area. Consider removing larger calibre shells or cancelling display
W	< Force 4	Debris falls as predicted	
W	> Force 4	Debris area extended onto South Bank.	
W	> Force 7	Debris falls on Jubilee Gardens, BALE and surrounding area	Extend barriered area. Consider removing larger calibre shells or cancelling aerial display
NW	< Force 4	Debris falls as predicted	
NW	> Force 4	Debris area extended to Queens Walk/Westminster Bridge	
NW	> Force 7	Debris falls on Queens walk/Westminster Bridge	Extend barriered area. Consider removing larger calibre shells or cancelling display

- *Draw conclusions that actually help you*

SECTION 19 - UK LAW RELATING TO DISPLAYS

OVERVIEW OF UK LEGISLATION

❷ *UK explosives law is predominantly based on the United Nations recomendations for the Transport of Dangerous Goods and is related to the hazards posed by fireworks in transport, and by extension, in storage.*



HEALTH AND SAFETY AT WORK ACT

- *Most HSE legislations is made as regulations under this Act*
- *General duties not to put yourself or others at risk from your acts or omissions*

FIREWORKS (SAFETY) REGULATIONS 1997

- *Apply to all fireworks sold to the public.*
- *Minimum age 18*
- *Fireworks sold to the public must comply with BS 7114*
- *Bans bangers, mini-rockets, fireworks of erratic flight, aerial shells, aerial maroons, shells-in-mortar*
- *Also bans supply of some large and powerful fireworks to the public*

FIREWORKS ACT

- *Enabling Legislation*
- *Provides provisions to ban or otherwise control fireworks*
- *Training*
- *Import Monitoring*
- *Restriction on sale*
- *Possibility of introducing Noise Limits?*

UN "ORANGE" BOOK

- *"Model regulations"*
- *Classification*
- *Default Classification for Fireworks*
- *Packaging*
- *Test methods*

UN DEFAULT CLASSIFICATION

- *UN-wide default for fireworks*
- *In general raises hazard from old UK position*
- *CHAF Research*

All fireworks are classified by HSE into one of 5 Hazard Divisions, each of which has an associated UN Number (a 4 digit code). The following table is a very simple overview of the Hazard Divisions relating to fireworks

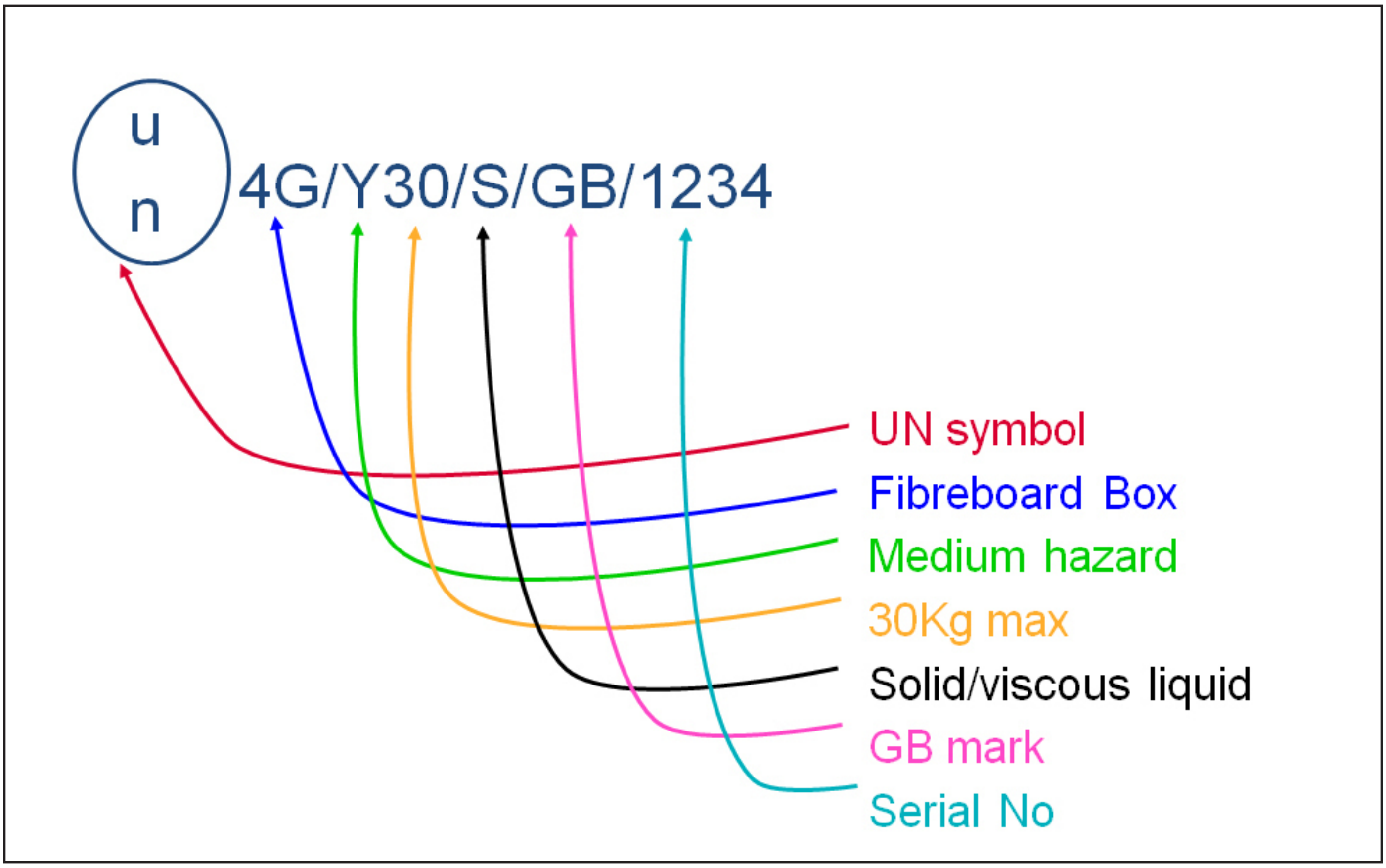
UN Number	Hazard Division	Hazard	Example of fireworks
0333	1.1G	Mass explosion hazard (blast hazard)	Very large shells Maroon shells
0334	1.2G	Fragment hazard or small blast hazard	Large calibre Roman candles
0335	1.3G	Thermal hazard or small blast hazard	Small calibre Roman candles Rockets
0336	1.4G	Minor hazard	Fountains
0337	1.4S	Minor hazard confined to packaging	Very low hazard items (not display items)

❷ *Classifications can be achieved by test (according to the UN schemes), by analogy to existing products, or by application of the UN Default scheme for fireworks (a copy of the current version is at the end of this chapter - but you ought to check for newer versions on the HSE's website). In all cases application has to be made to the HSE for assignment of a classification - it is not a "self classification" process!*

The UN Recomendations also proscribe tests for packagings which test their suitability for containing the fireworks they contain.

UN SYMBOL AND CLASSIFICATION

UN PACKAGING MARKS



ADR

❷ ADR adopts the UN Recomendations into European Law and addresses

- Vehicle Construction
- Loads and Types which may be carried
- Documentation
- Adopts UN Default Classification of Fireworks

CLER

- Classification and Labelling of Explosives Regulations
- Hazard Divisions & Compatibility groups
- Alignment with UN

CLASSIFICATION

- UK is based on UN Model Regulations
- Basis for all new explosives law
- Determines HAZARD AS PRESENTED FOR TRANSPORT (but is used for much more)

LOCEF

- *List of all UK classified explosives (including fireworks)*
- *Searchable (www.locef.co.uk)*

CDGUTPER

- *Carriage of Dangerous Goods and Use of Transportable Pressure equipment Regulations*
- *Adopts ADR into UK*
- *Repeals*
- *CER*
- *CLER (or at least modify it)*
- *PEC*
- *TDGSA*

MSER

- *Manufacture and Storage of Explosives Regulations*
- *Repealed most of the 1875 Explosives Acts*
- *April 2005*
- *Hazard Types*
- *Quantity/Distance relationships*
- *Local Authority vs HSE sites*
- *Allowed quantities/Time without registration (eg display sites)*

HAZARD TYPES

- *4 Types (note similarity to UN hazard Divisions)*
- *HT1 – mass explosion hazard*
- *HT2 – projection hazard*
- *HT3 – fireball hazard*
- *HT4 – low hazard*
- *Quantity allowed to be stored depends on Hazard Type*

EU PYROTECHNIC DIRECTIVE

- *Essential Safety Requirements*
- *CE Marking*
- *Testing*
- *Labelling*
- *Category 4 Fireworks will be covered from 2014*

OTHERS (NOT DEALT WITH HERE)

- *Control of Major Accident Hazard Regulations (COMAH)*
- *Noise at Work Regulations*
- *Reporting of Diseases and dangerous Occurrences (RIDDOR)*
- *Management of Health & Safety at Work Regulations (MHSWR)*

UK LEGISLATION - FURTHER DETAIL (FOR INFORMATION ONLY)

CDGUTPER

❷ Carrying goods by road or rail involves the risk of traffic accidents. If the goods carried are dangerous, there is also the risk of an incident, such as spillage of the goods, leading to hazards such as fire, explosion, chemical burn or environmental damage.

Most goods are not considered sufficiently dangerous to require special precautions during carriage. Some goods, however, have properties which mean they are potentially dangerous if carried.

Dangerous goods are liquid or solid substances and articles containing them, that have been tested and assessed against internationally-agreed criteria - a process called classification - and found to be potentially dangerous (hazardous) when carried. Dangerous goods are assigned to different Classes depending on their predominant hazard.

There are regulations to deal with the carriage of dangerous goods, the purpose of which is to protect everyone either directly involved (such as consignors or carriers), or who might become involved (such as members of the emergency services and public). Regulations place duties upon everyone involved in the carriage of dangerous goods, to ensure that they know what they have to do to minimise the risk of incidents and guarantee an effective response.

Carriage of dangerous goods by road or rail is regulated internationally by agreements and European Directives, with biennial updates of the Directives take account of technological advances. New safety requirements are implemented by Member States via domestic regulations which - for GB - directly reference the technical agreements.

SECURITY IN TRANSPORT

❷ The safety of dangerous goods by all modes is already well regulated and there are good controls in place, for example, on storage, parking and training of staff involved in its handling and carriage. Those regulations address the risk of accidents involving the transport of dangerous goods. The aim is to minimise the risk of spillage and, if spillages do occur, to make it easier for the emergency services to deal with them. Further details are available on the dangerous goods safety pages .

DEVELOPMENT OF NEW SECURITY MEASURES

❷ In response to the events of 11 September 2001, the United Nations agreed proposals to enhance the security of transporting dangerous goods. These proposals have been taken forward by the international bodies responsible for the international carriage of dangerous goods by road and rail - with some small changes that were relevant to their particular modes of transport.

The European Commission has adopted the new road and rail security measures. The requirements are split into two levels: a general level applicable to the carriage of all dangerous goods and a higher level for the carriage of high consequence dangerous goods. These are defined as those which have the potential for misuse in a terrorist incident and which may, as a result, produce serious consequences such as mass casualties or mass destruction.

The measures for road and rail were introduced into law through the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007 and are supported by a comprehensive set of guidance .

The movement of all civil nuclear material, as defined by the Nuclear Industries Security Regulations 2003 (NISR), is not covered by this guidance [and these Regulations]. The transport of such material is regulated by the Office for Civil Nuclear Security (OCNS) in accordance with the NISR.

Any incident involving dangerous goods is potentially very serious, especially if it involves high consequence dangerous goods. That is why the Government brought in new security regulations. These regulations are part of wider Government efforts to:

- *improve the resilience of the UK in the transport sector; and*
- *help industries to protect themselves against a range of threats including accidents, deliberate sabotage and acts of terrorism.*

The Department for Transport has set up an industry advisory group for the security of transport of dangerous goods by road and rail, to develop and monitor the implementation of these security measures and the guidance that goes with them.

The new security regulations will require any company or organisation that is involved in the transport of dangerous goods to:

- *only offer dangerous goods to carriers that have been appropriately identified;*
- *make sites that temporarily store dangerous goods secure;*
- *have a security awareness training programme in place; and,*
- *have a security plan in place, if involved with high consequence dangerous goods.*

MSER

❷ *The Manufacture and Storage of Explosives Regulations 2005 (SI Number 2005/1082) came into force on 26 April 2005.*

Copies of the published regulations are available to purchase from the Stationery Office. The text of the regulations is available to view and download from the HMSO website. The Approved Code of Practice and guidance to the regulations is available from HSE Books. and from other booksellers.

The main requirements of the regulations are as follows:

- *anyone manufacturing or storing explosives must take appropriate measures to prevent fire or explosion; to limit the extent of any fire or explosion should one occur; and protect persons in the event of a fire or explosion. These are the key requirements of the regulations and are backed up by extensive guidance in the Approved Code of Practice;*
- *in most cases a separation distance must be maintained between the explosives building and neighbouring inhabited buildings. This is intended to ensure that risks to those living or working in the area are kept to an acceptable level. If there is development in this separation zone then the quantity that may be kept must be reduced;*
- *with certain exceptions a licence is required for the manufacture or storage of explosives. HSE licenses manufacturing activities because of the greater risks involved. HSE also licenses larger explosives storage facilities. In most cases, stores holding less than two tonnes of explosives are either licensed or registered by the local authority or the police;*
- *HSE may not grant a licence for a manufacturing facility or, in most cases, store until the local authority has given its assent (normally following a public hearing). This is an important safeguard in the present system that is to be retained.*

The Manufacture and Storage of Explosives Regulations 2005 permit you to keep up to 50 kg (net) of Hazard type 4 fireworks for no longer than 21 days provided that these are not for sale or for use at work . This is intended to assist private individuals and voluntary organisations that wish to organise a *larger firework display. (Hazard type 4 fireworks are the types of less powerful fireworks generally sold at retailers - these provisions do not apply to Category 4 fireworks and may not apply to certain more powerful Category 3 fireworks). If you are in doubt please check with your supplier or with your local licensing authority. Please note that the requirements of the regulations to store the fireworks safely will continue to apply.*

If you wish to use the fireworks for a commercial display or for some other work purpose, or you wish to store a larger quantity of fireworks, or more powerful fireworks then you will normally need to register with your local licensing authority. Please note that if you wish to buy more than 50 kg of fireworks you will need to produce your registration certificate.

The Health & Safety at Work Act 1974 and subsidiary legislation covers firework displays which involves a work activity (ie where at least one person will be involved on a professional basis). This legislation places duties in respect of the health and safety of everyone involved in arranging and giving the display, the spectators and other people near the display site.

If you want to store or manufacture explosives you will need a licence or to register with your local licensing authority. This applies to a wide variety of substances and articles including:

- *blasting explosives*
- *munitions*
- *ammunition and shooters' powders*
- *fireworks*
- *marine flares*
- *pyrotechnic articles*
- *car airbags and seatbelt pretensioners*
- *party poppers*

STORAGE

❷ *There are a number of exemptions for the storage of small quantities and for temporary storage. For example there are allowances for storage of shooters' powders and for certain lower-risk pyrotechnic articles which include consumer fireworks and articles such as flares, fog signals, car airbags and seatbelt pre-tensioners.*

LICENCES AND REGISTRATIONS

❷ *Registration is a simplified process designed for those wanting to store smaller quantities of explosive - for example most registrations are for shops selling fireworks during the firework season. You can store up to 250kg of the least hazardous types of firework - for more hazardous explosives (including more hazardous fireworks) the amount you can keep with a registration is reduced. For more information please follow this link. Please note that all quantities referred to are the net mass (weight) of explosive contained in the article - not the gross weight of the article itself.*

MANUFACTURE

❷ *A licence is required for most manufacturing activities. 'Manufacturing' includes processes where explosive articles or explosive substances are made or assembled, or unmade or disassembled. The term also includes the repair or modification of explosive articles and the reprocessing, modification or adaptation of explosive substances. It does not include packing, unpacking, repacking, labelling or testing explosives. Nor does it include dividing explosives into smaller storage containers.*

Anyone wishing to manufacture explosives will need to apply to HSE for a licence. There are some exemptions to this such as exemptions for fusing of firework displays. For more information please click on the link.

WHERE TO APPLY

❷ *This will depend on the quantity and type of explosive you want to store and where you live.*

- *If you wish to store two tonnes or more of explosive you will need a licence from HSE.*
- *If you wish to store up to two tonnes of an explosive that requires an explosives certificate (eg blasting explosive or black powder) you will need a licence or registration from your local police.*
- *If you live in the metropolitan counties, ie West Midlands, Merseyside, Greater Manchester, Tyne and Wear, or South, and West Yorkshire you will need to apply to the fire and rescue service.*
- *In other areas you will normally need to contact the trading standards department of your local authority.*

Please see the contacts page on the HSE explosives website for contact information.

HOW TO MAKE AN APPLICATION

❷ *The first step is to contact the licensing authority. They will be happy to proxide an application form, alternatively you can download a form from the Forms page.*

The amount of information needed for the application will depend on the type of registration or licence. For most licences the licensing authority will need to know:

- *the name of the applicant;*
- *nature of the business;*
- *where you plan to keep the explosives;*
- *the type(s) and quantities of explosives to be kept*

More extensive information will be required for applications to HSE for a licence for manufacturing or a larger store, where the licence will be subject to local authority assent.

FEES FOR APPLICATIONS

❷ *A fee will be payable before the licensing authority will consider an application. Information on current fee levels can be found on the fees page.*

The process for considering licence applications

If the application is for a licence, the licensing authority will normally wish to visit the proposed store. The licensing authority may also wish to visit the storage place if the application is for a registration. In most cases where HSE is the licensing authority, once HSE has apporved the application, the applicant will then need to ask the local authority for its assent before HSE can grant the licence.

CAN A LOCAL AUTHORITY REFUSE AN APPLICATION?

❷ *An application can be refused, but normally only in exceptional circumstances. There are two circumstances when a licensing authority might refuse a licence:*

- *if it believes that the site of the proposed store is unsuitable on safety grounds. An obvious example would be someone wanting to store fireworks at a petrol station;*
- *if it has evidence that leads it to take the view that the applicant is not a fit person to store explosives.*

There is a right of appeal to the Secretary of State for Work and Pensions.

LICENCE/REGISTRATION DOCUMENT

❷ *The licensing authority will issue a certificate which will in most cases set out:*

- *the name and address of the licensee/registered person*
- *the address of the store*
- *the amount and type of explosive that may be kept there*

HSE licences may include more detailed information on, for example:

- *the layout of the site*
- *construction of the buildings*
- *the use of the buildings (some buildings may be used for storage only, and some for manufacturing only).*

LENGTH OF A LICENCE OR REGISTRATION

❷ *Initial registrations and licences may be granted for any period not exceeding two years. Renewal registrations and licences may be granted for any period not exceeding one year. The exceptions to this are:*

- *licences from HSE for manufacturing or larger stores - these normally continue indefinitely;*
- *where the applicant already holds a firearms or explosives certificate, the licensing authority may set a renewal date so that the licence or registration comes up for renewal at the same time as the firearms or explosives certificate; and*
- *registrations and licences solely for the storage of smokeless powder which may be granted for any period not exceeding three years.*

REVOCATION OF REGISTRATIONS/LICENCES

❷ *A registration or licence can be revoked, in exceptional circumstances.*

COMAH

❷ *The Control of Major Accident Hazards Regulations 1999 (COMAH) which came into force on 1 April 1999 and are amended by the Control of Major Accident Hazards (Amendment) Regulations 2005 from 30 June 2005. They implement Council Directive 96/82/EC known as the Seveso II Directive, as amended by Directive 2003/105/EC and replaced the Control of Industrial Major Accident Hazards Regulations 1984 (CIMAH).*

Land-use planning requirements of the Directives are implemented by separate land-use planning legislation that is the responsibility of the Office of the Deputy Prime Minister, the Scottish Executive, and the National Assembly for Wales.

COMAH applies mainly to the chemical industry, but also to some storage activities, explosives and nuclear sites, and other industries where threshold quantities of dangerous substances identified in the Regulations are kept or used.

CLER

❷ HSE has responsibility for the approval of classifications of non-military explosives in Great Britain.

Relevant legal requirements are contained in:

- *The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007*
- *The Classification and Labelling of Explosives Regulations 1983 (CLER)*

The regulations apply to all explosives (including fireworks and other pyrotechnic articles) manufactured or imported into Great Britain (separate parallel regulations apply in Northern Ireland.

The classification of explosive materials must be approved before they may be inported into Great Britain or transported within it. The purpose of classification is to identify the hazard posed by explosive substances and articles as packaged for transportation. It involves the assessment of an explosive to determine whether it is assigned to, or excluded from Class 1 of the UN classification scheme for the transportation of dangerous goods.

HSE issues a Competent Authority Document (CAD), which records the classification granted with reference to the requirements that the applicant has agreed to meet. HSE adds the explosive to LOCEF - Database of Classified Explosives and Fireworks in the UK

Application Forms, Guidance Notes and Fees information is available from the forms page.

COER

❷ The Control of Explosives Regulations 1991 (COER) covers all explosives used in commercial, military or leisure activities; this includes blasting explosives, detonators, fuses,ammunition, propellants, pyrotechnics and fireworks - although controls on acquisition, transfer and record-keeping (see below) do not apply to sporting ammunition, fireworks or many pyrotechnic devices.

COER Schedule 1 lists the explosives which, together with smokeless powder, do not require an explosives certificate

The main provisions of COER are:-

- *anyone wanting to acquire or keep certain explosives must have an Explosives Certificate, issued by the police*
- *duties are placed on anyone wanting to transfer certain explosives to others*
- *anyone who has committed certain offences or been sentenced to certain terms of imprisonment must not acquire, keep, handle or control certain explosives or substances which could be used as explosives*
- *occupiers of licensed explosives stores or magazines must appoint someone to be responsible for explosives security*
- *comprehensive, accurate and up-to-date records must be kept of certain explosives*
- *the loss or theft of explosives must be reported immediately to the police*

COER was amended by the Manufacture and Storage of Explosives Regulations 2005

HSE has issued guidance on the recommended standards of security for licensed and registered stores holding explosives which require an Explosives Certificate from the police to acquire and keep. HSE Circular to Chief Officers of Police No 1/2005 replaces the previous circular issued to enforcing authorities as HSE/Local Authority Circular (HELA) 26/5.

❷ *This is the current version of the default classification list as presented in the UN recomendations and ADR. You should check if amendments have been made - the original can be found at*

http://www.unece.org/trans/danger/publi/adr/adr2007/English/02-1 E_Part2a.pdf

2.2.1.1.7 *Assignment of fireworks to divisions*

2.2.1.1.7.1 Fireworks shall normally be assigned to divisions 1.1, 1.2, 1.3, and 1.4 on the basis of test data derived from Test Series 6 of the Manual of Tests and Criteria. However, since the range of such articles is very extensive and the availability of test facilities may be limited, assignment to divisions may also be made in accordance with the procedure in 2.2.1.1.7.2.

2.2.1.1.7.2 Assignment of fireworks to UN Nos. 0333, 0334, 0335 and 0336 may be made on the basis of analogy, without the need for Test Series 6 testing, in accordance with the default fireworks classification table in 2.2.1.1.7.5. Such assignment shall be made with the agreement of the competent authority. Items not specified in the table shall be classified on the basis of test data derived from Test Series 6.

NOTE 1: *The addition of other types of fireworks to column 1 of the table in 2.2.1.1.7.5 shall only be made on the basis of full test data submitted to the UN Sub-Committee of Experts on the Transport of Dangerous Goods for consideration.*

NOTE 2: *Test data derived by competent authorities which validates, or contradicts the assignment of fireworks specified in column 4 of the table in 2.2.1.1.7.5 to divisions in column 5 should be submitted to the UN Sub-Committee of Experts on the Transport of Dangerous Goods for information.*

2.2.1.1.7.3 Where fireworks of more than one division are packed in the same package, they shall be classified on the basis of the most dangerous division unless test data derived from Test Series 6 indicate otherwise.

2.2.1.1.7.4 The classification shown in the table in 2.2.1.1.7.5 applies only for articles packed in fibreboard boxes (4G).

2.2.1.1.7.5 *Default fireworks classification table* [1]

NOTE 1: *References to percentages in the table, unless otherwise stated, are to the mass of all pyrotechnic composition (e.g. rocket motors, lifting charge, bursting charge and effect charge).*

NOTE 2: *"Flash composition" in this table refers to pyrotechnic compositions containing an oxidizing substance, or black powder, and a metal powder fuel that are used to produce an aural report effect or used as a bursting charge in fireworks devices.*

---

[1] *This table contains a list of firework classifications which may be used in the absence of Test Series 6 data (see 2.2.1.1.7.2).*

- 94 -

NOTE 3: *Dimensions in mm refer to:*

- *for spherical and peanut shells the diameter of the sphere of the shell;*
- *for cylinder shells the length of the shell;*
- *for a shell in mortar, Roman candle, shot tube firework or mine the inside diameter of the tube comprising or containing the firework;*
- *for a bag mine or cylinder mine, the inside diameter of the mortar intended to contain the mine.*

Type	Includes: / Synonym:	Definition	Specification	Classification
Shell, spherical or cylindrical	Spherical display shell: aerial shell, colour shell, dye shell, multi-break shell, multi-effect shell, nautical shell, parachute shell, smoke shell, star shell; report shell: maroon, salute, sound shell, thunderclap, aerial shell kit	Device with or without propellant charge, with delay fuse and bursting charge, pyrotechnic unit(s) or loose pyrotechnic composition and designed to be projected from a mortar	All report shells	1.1G
			Colour shell: ≥ 180 mm	1.1G
			Colour shell: < 180 mm with > 25% flash composition, as loose powder and/or report effects	1.1G
			Colour shell: < 180 mm with ≤ 25% flash composition, as loose powder and/or report effects	1.3G
			Colour shell: ≤ 50 mm, or ≤ 60 g pyrotechnic composition, with ≤ 2% flash composition as loose powder and/or report effects	1.4G
	Peanut shell	Device with two or more spherical aerial shells in a common wrapper propelled by the same propellant charge with separate external delay fuses	The most hazardous spherical aerial shell determines the classification	
	Preloaded mortar, shell in mortar	Assembly comprising a spherical or cylindrical shell inside a mortar from which the shell is designed to be projected	All report shells	1.1G
			Colour shell: ≥ 180 mm	1.1G
			Colour shell: > 50 mm and < 180 mm	1.2G
			Colour shell: ≤ 50 mm, or ≤ 60 g pyrotechnic composition, with ≤ 25% flash composition as loose powder and/or report effects	1.3G

Type	Includes: / Synonym:	Definition	Specification	Classification
Shell, sherical or cylindrical *(cont'd)*	Shell of shells (spherical) (*Reference to percentages for shell of shells are to the gross mass of the fireworks article*)	Device without propellant charge, with delay fuse and bursting charge, containing report shells and inert materials and designed to be projected from a mortar	> 120 mm	1.1G
		Device without propellant charge, with delay fuse and bursting charge, containing report shells ≤ 25g flash composition per report unit, with ≤ 33% flash composition and ≥ 60% inert materials and designed to be projected from a mortar	≤ 120 mm	1.3G
		Device without propellant charge, with delay fuse and bursting charge, containing colour shells and/or pyrotechnic units and designed to be projected from a mortar	> 300 mm	1.1G
		Device without propellant charge, with delay fuse and bursting charge, containing colour shells ≤ 70mm and/or pyrotechnic units, with ≤ 25% flash composition and ≤ 60% pyrotechnic composition and designed to be projected from a mortar	> 200 mm and ≤ 300 mm	1.3G
		Device with propellant charge, with delay fuse and bursting charge, containing colour shells ≤ 70 mm and/or pyrotechnic units, with ≤ 25% flash composition and ≤ 60% pyrotechnic composition and designed to be projected from a mortar	≤ 200 mm	1.3G
Battery/ combination	Barrage, bombardos, cakes, finale box, flowerbed, hybrid, multiple tubes, shell cakes, banger batteries, flash banger batteries	Assembly including several elements either containing the same type or several types each corresponding to one of the types of fireworks listed in this table, with one or two points of ignition	The most hazardous firework type determines the classification	

Type	Includes: / Synonym:	Definition	Specification	Classification
Roman candle	Exhibition candle, candle, bombettes	Tube containing a series of pyrotechnic units consisting of alternate pyrotechnic composition, propellant charge, and transmitting fuse	≥ 50 mm inner diameter, containing flash composition, or < 50 mm with > 25% flash composition	1.1G
			≥ 50 mm inner diameter, containing no flash composition	1.2G
			< 50 mm inner diameter and ≤ 25% flash composition	1.3G
			≤ 30 mm inner diameter, each pyrotechnic unit ≤ 25 g and ≤ 5% flash composition	1.4G
Shot tube	Single shot Roman candle, small preloaded mortar	Tube containing a pyrotechnic unit consisting of pyrotechnic composition, propellant charge with or without transmitting fuse	≤ 30 mm inner diameter and pyrotechnic unit > 25 g, or > 5% and ≤ 25% flash composition	1.3G
			≤ 30 mm inner diameter, pyrotechnic unit ≤ 25 g and ≤ 5% flash composition	1.4G
Rocket	Avalanche rocket, signal rocket, whistling rocket, bottle rocket, sky rocket, missile type rocket, table rocket	Tube containing pyrotechnic composition and/or pyrotechnic units, equipped with stick(s) or other means for stabilization of flight, and designed to be propelled into the air	Flash composition effects only	1.1G
			Flash composition > 25% of the pyrotechnic composition	1.1G
			> 20 g pyrotechnic composition and flash composition ≤ 25%	1.3G
			≤ 20 g pyrotechnic composition, black powder bursting charge and ≤ 0.13 g flash composition per report and ≤ 1 g in total	1.4G

Type	Includes: / Synonym:	Definition	Specification	Classification
Mine	Pot-a-feu, ground mine, bag mine, cylinder mine	Tube containing propellant charge and pyrotechnic units and designed to be placed on the ground or to be fixed in the ground. The principal effect is ejection of all the pyrotechnic units in a single burst producing a widely dispersed visual and/or aural effect in the air or: Cloth or paper bag or cloth or paper cylinder containing propellant charge and pyrotechnic units, designed to be placed in a mortar and to function as a mine	> 25% flash composition, as loose powder and/ or report effects	1.1G
			≥ 180 mm and ≤ 25% flash composition, as loose powder and/ or report effects	1.1G
			< 180 mm and ≤ 25% flash composition, as loose powder and/ or report effects	1.3G
			≤ 150 g pyrotechnic composition, containing ≤ 5% flash composition as loose powder and/ or report effects. Each pyrotechnic unit ≤ 25 g, each report effect < 2g; each whistle, if any, ≤ 3 g	1.4G
Fountain	Volcanos, gerbs, showers, lances, Bengal fire, flitter sparkle, cylindrical fountains, cone fountains, illuminating torch	Non-metallic case containing pressed or consolidated pyrotechnic composition producing sparks and flame	≥ 1 kg pyrotechnic composition	1.3G
			< 1 kg pyrotechnic composition	1.4G
Sparkler	Handheld sparklers, non-handheld sparklers, wire sparklers	Rigid wire partially coated (along one end) with slow burning pyrotechnic composition with or without an ignition tip	Perchlorate based sparklers: > 5 g per item or > 10 items per pack	1.3G
			Perchlorate based sparklers: ≤ 5 g per item and ≤ 10 items per pack; Nitrate based sparklers: ≤ 30 g per item	1.4G

Type	Includes: / Synonym:	Definition	Specification	Classification
Bengal stick	Dipped stick	Non-metallic stick partially coated (along one end) with slow-burning pyrotechnic composition and designed to be held in the hand	Perchlorate based items: > 5 g per item or > 10 items per pack	1.3 G
			Perchlorate based items: ≤ 5 g per item and ≤ 10 items per pack; nitrate based items: ≤ 30 g per item	1.4G
Low hazard fireworks and novelties	Table bombs, throwdowns, crackling granules, smokes, fog, snakes, glow worm, serpents, snaps, party poppers	Device designed to produce very limited visible and/ or audible effect which contains small amounts of pyrotechnic and/or explosive composition.	Throwdowns and snaps may contain up to 1.6 mg of silver fulminate; snaps and party poppers may contain up to 16 mg of potassium chlorate/red phosphorous mixture; other articles may contain up to 5 g of pyrotechnic composition, but no flash composition	1.4G
Spinner	Aerial spinner, helicopter, chaser, ground spinner	Non-metallic tube or tubes containing gas- or spark-producing pyrotechnic composition, with or without noise producing composition, with or without aerofoils attached	Pyrotechnic composition per item > 20 g, containing ≤ 3% flash composition as report effects, or whistle composition ≤ 5 g	1.3G
			Pyrotechnic composition per item ≤ 20 g, containing ≤ 3% flash composition as report effects, or whistle composition ≤ 5 g	1.4G
Wheels	Catherine wheels, Saxon	Assembly including drivers containing pyrotechnic composition and provided with a means of attaching it to a support so that it can rotate	≥ 1 kg total pyrotechnic composition, no report effect, each whistle (if any) ≤ 25 g and ≤ 50 g whistle composition per wheel	1.3G
			< 1 kg total pyrotechnic composition, no report effect, each whistle (if any) ≤ 5 g and ≤ 10 g whistle composition per wheel	1.4G

Type	Includes: / Synonym:	Definition	Specification	Classification
Aerial wheel	Flying Saxon, UFO's, rising crown	Tubes containing propellant charges and sparks- flame- and/or noise producing pyrotechnic compositions, the tubes being fixed to a supporting ring	> 200 g total pyrotechnic composition or > 60 g pyrotechnic composition per driver, ≤ 3% flash composition as report effects, each whistle (if any) ≤ 25 g and ≤ 50 g whistle composition per wheel	1.3G
			≤ 200 g total pyrotechnic composition and ≤ 60 g pyrotechnic composition per driver, ≤ 3% flash composition as report effects, each whistle (if any) ≤ 5 g and ≤ 10 g whistle composition per wheel	1.4G
Selection pack	Display selection box, display selection pack, garden selection box, indoor selection box; assortment	A pack of more than one type each corresponding to one of the types of fireworks listed in this table	The most hazardous firework type determines the classification	
Firecracker	Celebration cracker, celebration roll, string cracker	Assembly of tubes (paper or cardboard) linked by a pyrotechnic fuse, each tube intended to produce an aural effect	Each tube ≤ 140 mg of flash composition or ≤ 1 g black powder	1.4G
Banger	Salute, flash banger, lady cracker	Non-metallic tube containing report composition intended to produce an aural effect	> 2 g flash composition per item	1.1G
			≤ 2 g flash composition per item and ≤ 10 g per inner packaging	1.3G
			≤ 1 g flash composition per item and ≤ 10 g per inner packaging or ≤ 10 g black powder per item	1.4G

SECTION 20 - THE BRITISH PYROTECHNISTS ASSOCIATION

Aims of the BPA

- Membership

BPA Firers Training

- Log Books
- ID Cards

AIMS OF THE BPA

The British Pyrotechnists Association (BPA) is the trade body that represents the majority of professional firework display companies in the UK. The BPA is committed to raising the already high standards of professional firework display firers, both through its normal membership activities and through the wider community through training and education.

AIMS AND OBJECTIVES

The British Pyrotechnists Association exists to promote the highest standards of professionalism and safety within the UK Fireworks Display Industry.

The BPA aims to achieve these objectives by the following means

- Developing a Code of Practice for member companies
- Offering training courses for display operators
- Offering schemes of continued professional development
- Promoting and continually reviewing methods of 'best practice'
- Encouraging membership of the BPA
- Maintaining relationships with government and regulatory bodies

THE BPA CODE OF PRACTICE

BPA Members are required to

- Set up and fire professional displays according to the BPA's published 'Standard Operating Procedure'
- Possess adequate public and products liability insurance cover
- Possess adequate legal storage for display fireworks
- Provide training for display operators, via the BPA Training Scheme
- Meet all legal requirements in respect of the transportation of fireworks
- Carry out all statutory risk assessments and safety procedures
- Maintain high standards of professionalism in all aspects of their work

ADMINISTRATION AND OPERATION OF THE BPA

The BPA comprises members whose main business is the provision of professional 'operator fired' fireworks displays. However, together with other organisations, the interests of some BPA members extends over a much wider field of pyrotechnics. This may include the provision of products to the theatre industry, governments, local authorities and agriculture. Some members are engaged in the physical manufacture of fireworks and associated products. All members are involved, to a greater or lesser degree, in the provision of professional fireworks displays.

As a central representative body, the BPA encourages the highest standards with respect to safety, on-site practice, and performance of fireworks displays. The BPA is a central source of information on all questions relating to the display industry and is responsible for maintaining close liaison with the appropriate authorities on all matters concerning the manufacture, storage, transportation and exhibition of display fireworks. It also considers, makes recommendations, or takes other necessary action on all related aspects of UK and European legislation governing professional fireworks and related pyrotechnic products

The BPA is managed by a small committee and decisions are taken on a democratic basis. All attendees at meetings are entitled to vote on any issue raised at a particular meeting. The current BPA chairman is Chris

Pearce and the general administration is undertaken by Davas Ltd, who provide an independent secretariat facility.

MEMBERSHIP

Criteria for membership of the Association are as follows:-

- the member's principal or substantial trade involves pyrotechnics and the provision of professional display services (which may include indoor and/or outdoor displays)
- the maintenance by the members of insurance cover at no less a level than that determined from time to time by the committee currently deemed to be £5 million.
- the observance by the member of any voluntary agreement entered into by the Association from time to time, including BPA codes of practice.
- the provision by the members, on request, to the Secretary of details of any licenses issued by any regulatory authority, or other information as required, to ensure that membership criteria are satisfied.
- the payment when due of the annual membership fee plus a joining fee
- members enrol their firers onto the BPA Firers Exam Scheme

Candidates for membership shall submit an application in such a form as the Management Committee may subscribe and provide such further information as the Management Committee may reasonably require.

Candidates shall be elected to membership by a simple majority of the Management Committee and ratified by the General Membership at the next BPA Meeting. In the case of rejection, the BPA shall not be obliged to give any reason for an explanation of a vote against the candidate.

A member shall cease to be a member of the Association if:

- the member persists in failing to meet the criteria specified above (section 2.1). Prior warning shall be given in writing, by the Secretary, whereupon the members shall be given the opportunity to remedy such failure(s) within a reasonable period (being not less than fourteen days).
- a Management Committee meeting convened for the purpose shall resolve that such membership shall not continue. No such resolution shall be valid unless the relevant meeting shall have been convened on not less than three weeks' prior written notice. The member concerned shall be given the opportunity either in person, or by nominated representative, to answer any allegations and give reasons why such a resolution should not be passed.
- the member gives written notice of resignation to the Secretary.

BPA FIRERS TRAINING

The BPA is committed to improving safety at professionally fired firework displays, both to operators of displays and to the public.

The BPA have set up a Firer training scheme, which currently has over 1000 registered persons. The scheme, which will be developed and adapted to accommodate changing legislation and practices, is based on a sound knowledge of the hazards associated with

- Firework types
- Firework effects
- Fireworks in transport
- Rigging techniques
- Site design
- Firing methods

- Fallout considerations
- Disposal

It is not a replacement for other statutory provisions (e.g. relating to training of drivers) but provides a sound basis for safe operation.

In addition to the courses, each candidate is required to maintain a 'log book' of their display experience. This log book will prove invaluable in verifying that operators have the necessary practical experience, in a variety of display environments, to complement their formal training.

The course is presently available at two levels:

Level 1 - for firers at display sites with limited experience

Level 2 - for senior firers at display sites who have passed Level 1 and have extended their experience

In future it is planned to add additional levels:

Level 3 - Trainers Training

For Trainers of the BPA Firers Exam. Level 1 and 2 syllabus will be based around these notes.

Level 1 and Level 2 courses are available for PROFESSIONAL display operators, whether or not they are associated with BPA companies. However, all training is provided by BPA members, with exams available on the 3rd weekend of every month except November.

The course is NOT suitable or available to

- Firers of solely Category 3 fireworks
- Freelance firers who are not associated with a professional company
- Stage or theatrical technicians

LOG BOOKS

Integral to Firers' qualifications is the maintaining of log books by all firers. Log books (sample pages reproduced below) detail the essential nature of each display fired by the firer, and identify any particular features of the display which may assist them in proving experience in the future - e.g. the nature of the site (barges, rooftops etc), the types of materials used (e.g. calibre of shells), the nature of the display (e.g. to music) and any issues that arose during the display.

ID CARDS

Upon successful completion of the examination each firer will be awarded a certificate, and an ID card with their photograph, date of passing each level, and the expiry date (c. 5 years). The details of each firer are also maintained on a publicly accessible Internet database (go to www.pyro.org.uk) so that enforcing authorities and others may confirm the validity of each card. You may renew your certificate 3 months before expire date.

SECTION 21 - FURTHER INFORMATION

GLOSSARY OF FIREWORK TERMS

Topic	Description
1.1G (0333)	The UN classification of fireworks packaged for transport that pose a mass-explosion (detonation) hazard
1.2G (0334)	The UN classification of fireworks packaged for transport that pose a projectile hazard
1.3G (0335)	The UN classification of fireworks packaged for transport that pose a fiery projectile or thermal radiation hazard
1.4G (0336)	The UN classification of fireworks packaged for transport that pose a limited hazard
1.4S (0337)	The UN classification of fireworks packaged for transport that pose a very limited hazard, the effects of accidental ignition are confined within the package itself.
Aerial bomb	Preferred term:- Aerial shell
Aerial firework	In general a firework which functions above the immediate area of the ground - i.e. rockets, shells, roman candles and mines.
Aerial shell	A shell designed to function at high altitude. cf. water shell
Alloy	A combination, usually of 2 metals, which takes on some of the characteristics of its components. Alloys cannot be separated into their constituent parts by normal physical methods.
Aqueous	Pertaining to water. In fireworks, aqueous usually refers to solutions used for damping stars in manufacture. Cf organic
Atomic pattern	In a shell burst, usually taken to be three contiguous circles representing the orbits off electrons around a central nucleus (rather than the atomic “hazard” symbol)
Bag mine	A mine without a rigid case that is fired from a mortar. The advantage of bag mines is their very low debris pattern, although their performance is rarely as good as mines similar mines with a rigid case.
Banger	Usually a complete firework, designed to produce a loud ban, rather than a component of a larger firework (e.g. a mine) - which are better referred to as crackers.
Bare match	Black match without a sleeve, preferred term:- Black match
Barrage	A combination of several fireworks, most usually Roman candles and/or mines, designed to be fired with a single ignition
Battery	In fireworks a combination of, say Roman candles, fused together for increased effect and/or duration.
Battle in the clouds	A shell producing a series of salutes after bursting.
Bengal	A pyrotechnic coloured flare
Bickford fuse	A slow burning fuse used either for preparation of internal shell delays, or for timing sequential firings
Black match	Usually a cotton thread coated with blackpowder, in its raw state. Black match contains within a paper tube is usually referred to as piped match.
Black shell	Preferred term:- Blind shell

Blackpowder	A composition, comprising Potassium Nitrate, Sulphur and Charcoal in the ration 75:15:10 widely used in fireworks manufacture as a propellant and as the basis for compositions containing metal powders. It is considered by most people that blackpowder does not detonate on ignition, but merely burs extremely fast!
Blasting powder	Blasting powder may be made with either Potassium Nitrate (type A) or Sodium Nitrate (type B) as the oxidant.
Blind shell	A shell that fails to bust, having been successfully launched from its mortar. Potentially very dangerous.
Blinker	An effect of periodic burning giving the effect of a flashing composition or strobe.
Bomb	Inappropriate term for shell
Bombardo racks	Usually a bottom fused multiple firing assembly.
Bombette	In essence a mini shell, usually found as a component of a Roman candle, and less often as a component of a mine or even as a sub component of a shell.
Bottom fused	The normal method of fusing of a shell, where the shell delay is ignited by the lifting charge of the shell. Also, for cakes where fusing is at the base of each tube.
Bottom shot	Typically a maroon as the last shot of a multibreak shell
Bounce	A charge of blackpowder at the base of a gerb - used to give an audible “crack” at the end of the burning of the gerb, and to enhance the effect.
Boxed finale	A rapid firing array, usually of shells, with a single point of ignition. Physically they comprise a number of pre-loaded mortars, very often with titanium salute shells.
BPA	British Pyrotechnics Association - a trade association concerned with all aspects of fireworks safety and use in the UK. Recently split into Retail and Display sections.
Break	A normal shells is referred to as “single break”. In a multibreak shell there are many sequential bursts, each a separate entity (cf shell of shells for instance).
British standard	Prepared in the late 1980’s for consumer fireworks. The standard sets performance, labelling and constructional requirements for a variety of consumer fireworks available to the public in the UK and also prescribes test regimes and methods for compliance.
Brocade	Long burning star similar to but brighter and shorter burning than a kamuro star
Burning	Typically an exothermic oxidation/reduction reaction. For fireworks the oxidant is usually a solid oxygen-rich ionic salt such as Potassium Nitrate.
Bursting charge	The internal charge in a shell designed to break the shell at the predetermined time, spreading and igniting the contents of the shell. Bursting charges are typically made of blackpowder (for effects shells) or flash powder (for colour shells).
Butterfly burst	A bust of a cylindrical tube from a central point, thus producing an effect akin to the wings of a butterfly. The term is also used for the more complicated burst pattern of a “butterfly” shell, although in many ways the theory of action is similar.
Cake	Colloquial term for a multishot battery, arising from the outward appearance of many of the smaller items (e.g. 90 shot cakes).
Calibre	In firework terms usually the inside diameter of the firing tube, although strictly the diameter of the projectile.
Candle	Abbreviated term for Roman candle
Cannonade	Usually an aerial shell containing several shots fused to explode at the same time after the shell bursts. Also a popular generic name for a multishot battery from China.

Capping	Usually a rolled kraft paper tube used to connect several fuses together in a spark-proof join.
Case	Typically the tube containing the pyrotechnic composition of the firework.
Category 1 firework	Indoor firework as defined by British standard 7114; part 2
Category 2 firework	Garden firework as defined by British standard 7114; part 2
Category 3 firework	Display firework as defined by British standard 7114; part 2
Category 4 firework	Fireworks defined in the British Standard as being not suitable for sale to the general public. Generally, but erroneously, taken to mean larger display fireworks.
Catherine wheel	The traditional name for the generic wheel. The name derives from St. Catherine ...
Celebration cracker	Usually a roll of many hundreds or thousands of individual cracker units designed to be unrolled and hung from a solid object prior to lighting. These items, traditionally part of Chinese New year celebrations are now widespread, however recent legislation has banned their sale in the UK.
Chain fused	A method of fusing several elements, particularly in a finale box or shell sequence.
Changing Relay	A low light intensity composition used, particularly in Japanese shell manufacture, to accentuate and regularise the colour change in stars of a chrysanthemum or Peony shell.
Charging	Usually the process of filling a tube with composition or units (e.g a gerb or Roman candle)
Cherry bomb	A small powerful banger containing flash powder now banned in the US. The item was usually covered in red paper - hence “cherry”.
Chinese cracker	syn. Celebration cracker
Choke	The narrowing of a tube, most often associated with fountains and rockets. Chokes may be made by physically distorting the tube, by means of an end piece, or by clay or other material.
Chrysanthemum shell	A spherical burst, typically Japanese, in which the stars leave a visible trail. Cf Peony shell.
Chuffing	The sound produced by the unstable burning of some rocket motors - usually a sign of instability.
Class B firework	The US categorisation for Display fireworks
Class C firework	The US categorisation for Consumer fireworks
Closed circuit	A complete electric circuit, usually in the context of a circuit ready to fire.
Coconut shell	Usually a shell containing large comets (gold, silver or crackle) which produce a typical coconut palm type effect on bursting. Typically the shell will also be fitted with a complementary colour rising tail.
Colour enhancing agent	Usually a chlorine donor such as PVC or Cerechlor added to a colour composition to enhance the intensity of the colour. The chlorine forms metal-Cl species in the flame which emit strongly in the visible part of the spectrum. It is thought that potassium chlorate/perchlorate may play a similar, though diminished, role.
Comet	Usually a solid cylinder of composition, manufactured in a mould by hand or by machine. The effect is that of a large star rising (from say a Roman candle). The comet is completely self consuming and thus particularly suitable for sites where debris is a problem.
Comet pump	A larger version of a star pump typically used to make Roman candle stars and splitting comets
Composition	The generic and widely used term for all pyrotechnic mixtures. More specifically composition is taken to mean the list of ingredients in a particular pyrotechnic mixture. All compositions contain at least an oxidant and a fuel, together with additional ingredients for colour/effect production etc.

Cone	A specialised type of fountain in the shape of a cone. The advantages of a cone are predominantly ease of filling, and the fact that the burning area increases as the fireworks proceeds, thus compensating for the increase in diameter of the choke.
Confinement	The process by which some explosives, e.g blackpowder, can change from extremely rapid burning to something approaching detonation. For instance, blackpowder confined in a tube will produce a loud report when lit, whilst blackpowder burning loose does not.
Continuity	An electric circuit is said to be continuous when it is complete - thus a continuity check of a circuit is carried out to ensure that the circuit is not open.
Convolute wound tube	A tube wound from a piece of paper the same width as the tube is long. Convolute tubes tend to be stronger than spiral wound tubes, although they are also more expensive to produce.
Covalent bond	A type of chemical bond in which electrons are shared by the participating atoms. This type of bond typically occurs between nonmetallic elements. In fireworks the important occurrence is in high energy species in the flame producing colours.
Cracker	A better term ,and less emotive, than banger. Also an assembly of many crackers often referred to as a "Chinese cracker". A novelty cracker, commonly used at Christmas in the UK is another use of the term.
Crackle	A relatively recent effect comprising many small sharp bangs, thrown from a relatively low intensity comet. Chemically, most crackle compositions contain either lead or Bismuth oxides.
Croaker	Syn. Screecher
Cross match	Typically a piece of thin raw match used to facilitate ignition of a shell's internal time fuse. Generally made by either splitting or punching the time fuse.
Crossette	The American term for a splitting comet.
Crossing stars	Typically a pyrotechnic effect formed by fitting two stars together in a tube with a central bursting charge. Also known as French Splits.
Crown	As in "Crown Chrysanthemum" shell - syn. Kamuro
Crown chrysanthemum	syn. Diadem chrysanthemum. Typically a chrysanthemum like shell bursts with longer burning stars that continue to fall to the ground after the normal maximum burst diameter. Very often the stars have a colour change at the end of their flight.
Crown wheel	syn. Flying saucer
Cut star	A star, usually cuboid in form, prepared from a rolled sheet of composition.
Cylinder shell	An aerial shell of typically European manufacture which is cylindrical in form. Very often a "stack" of cylinder shells is combined, with suitable modification, to produce a typical multibreak shell. Cylinder shells are usually "spiked" to produce a harder burst.
Dahlia shell	A spherical shell burst, similar to a peony, but usually with fewer, brighter, stars.
Dark fire	In Roman candle terminology the low light-emitting composition applied to the surface of Roman candle stars acting as a sort of prime. The term has also been applied to the composition applied between colours in colour changing stars.
Daylight shell	A shell designed to be fired in daylight and thus incorporating one or more of the following effects:- noise units (crackers, whistles etc.), smoke, magnesium stars.
Deflagration	A particular type of explosive propagation in which propagation is faster than mere burning, but is not detonation.

Delay	Usually a pyrotechnic composition that burns at a predetermined rate and used for timing either within a firework assembly (e.g a Roman candle) of between firework elements (e.g in a shell sequence).
Delay fuse	A pyrotechnic composition designed to give a delay before functioning the next device in the explosive train. The most common use for a delay fuse is to provide a number of seconds for the operator to retire from the device before it functions. Also the internal delay within a shell used to ignite the bursting charge.
Detonating cord	A high powered explosive material encased in a plastic or cloth sleeve that burns by propagation of a detonating shock wave (typically 5000-7000 metres/sec)
Detonation	An exothermic chemical reaction in which the propagating front travels at supersonic speeds and thus an explosion always results.
Detonator	Not to be confused with a firework igniter, or squib, a detonator is used to initiate high explosives. As such, detonators are security attractive items and their possession is controlled in many countries.
Display area	Usually the area in which the rigging of the display takes place (syn. firing area), but more generally the entire area encompassing spectator area, firing area, safety area and fallout area..
Display firework	Usually a large firework intended for use at large public/private displays. In the US it is erroneously synonymous with UN 0335 (1.3G) fireworks.
DOT	Abbreviation for the US Department of Transportation. In the UK the similar department is now called the Department of Environment and the Regions (Abbr. DETR)
DOT classification	The assigning of fireworks by the US DOT into one of three classes.
Double base propellant	Homogeneous propellants which usually contain nitrocellulose in nitroglycerine and typically used in small arms ammunition and military rockets but rarely in fireworks.
Draw-out shell	A two break shell in which the first burst is usually colour, the second colour and report.
Driver	A specialised gerb, usually more powerful tan a gerb used on a static set piece, whose primary purpose is in turning a wheel or similar item. In the past turning cases were invariably gold, usually made with neat blackpowder with the addition of charcoal, and produced very few sparks. Modern drivers often include titanium for additional visual effect.
DTI	In the UK the Department of Trade and Industry, responsible for aspects of the sale of fireworks to the general public.
EIG	The Explosive Industry Group of the British Confederation of British Industry. The EIG is not a trade organisation and as such does not actively promote the firework industry. Its primary purpose is liaison with Government on safety and legislative matters.
Electric firing	The process of firing a display electrically. Many varied systems have been developed ranging from simple “nail boards” to automatic, computer controlled systems.
Electric igniter	The preferred term for the device used to ignite pyrotechnics electrically.
Electric match	syn. Electric igniter
Electrostatic Sensitivity	The tendency of a composition to ignite (usually accidentally) from the energy supplied by an electric spark.
European standard	A proposed standard (CEN 212) for consumer fireworks in the EU The standard is due to come into force in 1999.
Explosive	technically - any material that is capable of undergoing a self-contained and self-sustained exothermic chemical reaction at a rate that is sufficient to produce substantial pressures on their surroundings thus causing physical damage. ALL fireworks are classified as explosives.

Explosive train	The progress of fire from one explosive element to another. For instance within a hand-lit shell the train is Delay Fuse->shell leader->lifting charge->shell delay->bursting charge->star prime->star
Fallout area	The area designated for debris to fall at a firework display. Obviously the position and size of the fallout area are critically dependent on the wind direction and strength at the time of the display. Careful planning at the design stage must allow for variations in the fallout area and position.
Ferro-Titanium	An alloy of Iron and Titanium which is finding increasing use in firework manufacture. Different ratios of Fe:Ti are available although generally all burn with a much more silver flame than Fe alone.
Finale barrage	A rapid firing, pre-fused, sequence (usually of aerial fireworks) that is typically fired at the end of a display.
Firecracker	syn. Cracker
Firework	Technically an explosive assigned one of five UN numbers (0333->0337). For our purposes a device which is designed for entertainment and that comprises pyrotechnic composition.
Firing area	The best term for the actual area of firing (rather than display area)
Firing current	The current that is applied to an electric igniter that causes it to function.
First fire	A composition used, particularly in gerbs, to initiate the explosive train. It is not synonymous with prime.
Fix	Old English term for a gerb that is not a turning case. Very often these gerbs had a “bounce”.
Flanked	Usually applied to racks or mortars or Roman candles on a frame in which 3 tubes are angled to produce a dispersed effect.
Flare	A pyrotechnic device used to produce coloured light when ignited. In the US this is typically a tube, similar to a large lance. In the UK the term is often applied to distress signals.
Flash paper	A form of nitrocellulose, easily ignited and used to produce a puff of flame.
Flash powder	An extremely powerful pyrotechnic composition, typically made from Potassium perchlorate (or rarely pot. chlorate) and powdered aluminium (or magnesium). In fireworks flash powder is often used for powerful maroon shells, ad for bursting colour shells.
Flash rocket	A rocket that usually only contains flash powder as its payload and thus functions with a loud report and a flash. Flash rockets should never be fired in multiples from cones for risk of detonation. Flash rockets find much use for bird scaring.
Flight rocket	Usually a small calibre (approx. 14mm) rocket fired in a large number simultaneously from a rocket cone or rocket frame to produce a characteristic fan-like effect.
Flitter	A spark effect (usually silver/gold) produced by the incorporation of relatively coarse metal powders (usually aluminium). the glitter effect is similar but distinct.
Flower pot	A shell misfunction in which the shell bursts within the mortar propelling the shell contents upwards as if from a mine. Cf Muzzle break
Flying saucer	An unusual firework device, usually constructed from a ring of plastic or wood, with turning cases and lifting cases. The functioning of the device usually involves rotation around a vertical axis, followed by ascent into the air. “Double acting” saucers fall and then reascend to the crowd’s delight!
Flying squib	A toy firework of erratic flight now banned in many countries. Not to be confused with the electrical squib.
Fountain	A device comprising pyrotechnic composition charged into a tube which may or may not be choked. The composition may be hand charged, or more commonly nowadays, machine charged.

Friction Sensitivity	The tendency for a composition to ignite as the result of frictional energy (i.e. rubbing).
Front	Usually an arrangement of fountains, mines, set pieces or Roman candles along a line parallel to the spectators and fired simultaneously.
Fuel	In a pyrotechnic composition that which the oxidant oxidises. Common fuels include charcoal, sulphur, aluminium and magnalium. All common pyrotechnic compositions contain at least an oxidant and a fuel.
Funnel and wire	One method of charging tubes with firework composition.
Fuse	The generic term for the means of transferring fire to a firework, or from one part of a firework to another.
Fuse cover	The protective cover for the initial fuse of a firework. Often coloured to aid identification in the dark.
Fusee	A long duration flare, usually red, which may be used as a warning flare on the highway or railway. Fusees may also be used to light fireworks. Cf Portfire
Garden firework	A firework, usually of limited power and composition weight, intended to be used in restricted areas outdoors.
Gerb	Usually a relatively thick-walled tube filled with composition and having a choke. A gerb functions by throwing out a shower of sparks. From French - gerb - sheaf of corn
Girandole	syn. Flying saucer
Glitter	An effect that produces drossy droplets of molten composition which reach with the air to produce a sparkling or glittering effect that is not as distinct as a strobe effect. Similar but distinct from flitter.
Glutinous rice starch	A binding agent much favoured by Japanese star makers
Greek fire	Used in combat, Greek fire was an early use of pyrotechny. It comprised sticky long-burning composition usually fired from catapults.
Green man	The symbol of the Pyrotechnics Guild International depicting the
Ground burst	A low level burst of a shell and potentially very dangerous.
Ground firework	A firework designed to function at ground level.
Ground maroon	A single powerful cracker designed to produce a loud report and a flash.
Ground salute	syn. Ground maroon
GRP mortar	Glass Reinforced Plastic - a relatively recent addition to the design of mortars. GRP mortars, usually spirally would, are light, cheap and extremely strong. However some there is some doubts as to their suitability for cylinder shells especially in larger calibres.
Gums	Usually applied to binding agents soluble in water
Gun	A poor term for mortar
Gunpowder	Fireworkers prefer the term Blackpowder although chemically and physically the two are the same.
Hammer shell	A shell, typically multibreak, comprising colour breaks and reports timed to break in alternation.
Hanabi	Japanese word for Fireworks, roughly translated as “flowers of fire”
Hang fire	A fuse or pyrotechnic composition that continues to burn very slowly, often almost invisibly, rather than at it’s design speed. As such a hangfire presents a serious danger to firers.

HDPE mortar	High Density PolyEthylene - an extremely useful material for mortars. Belling rather than fragmentation of HDPE mortars tends to occur with failure of normal (not salute) shells.
High explosive	An explosive that is capable of detonating when unconfined.
HSE	The British Health and Safety Executive - the legislative and enforcement body in the UK
Hummer	A device that produces a humming sound, usually made from a thick walled tube filled with composition, sealed at both ends, and pierced tangentially to the inner diameter. The sound is made as the device spins rapidly in flight.
Hygroscopic	The property of a material that causes it to absorb and retain moisture from the air. As such, Hygroscopic compounds find only limited use in firework manufacture.
Igniter	Shortened term for Electric igniter
Igniter cord	Also, more properly, called Plastic Igniter Cord generally made for the blasting industries in several speeds. The slow cord finds use in fireworks manufacture, particularly for fitting of delay fuses.
Ignition	The initiation of burning of a pyrotechnic material
Indoor firework	In terms of the British and European standards devices of very limited power suitable for use indoors. Types include sparklers, snakes and other novelty items.
Ionic bond	A type of chemical bond characterised by transfer of electrons from one atom to another. Thus common salt is written Na+Cl-. Most oxidants and colouring agents for firework compositions are ionic compounds.
Japanese style shell	The ultimate spherical burst shell. The Japanese strive to produce perfect symmetry and patters in their shells. Japanese shells are also noted for the contrasting coloured pistils that form part of the burst of many effects.
Kamuro	A long burning star, usually silver or gold, that falls a substantial distance from the shell burst before, perhaps, changing colour at the end of its flight.
Kraft paper	A strong paper used for pasting shells and for capping.
Lance	Usually a small, thin walled, tube containing coloured composition used to make lancework.
Lancework	Usually a message, logo, or design made on a wooden lattice work frame comprising many lances fused together
Leader	The initial fuse of a shell that transfers fire from the delay fuse (if any) to the lifting charge of the shell. For small calibre shells the leader may be used to lower the shell to the bottom of the mortar tube, but this is not good practise with larger calibre shells.
Lifting charge	The charge beneath an aerial shell (or Roman candle unit) which propels the unit into the air. The listing charge almost universally used in firework manufacture is granulated blackpowder.
Line	In electrical firing one “line” is a single circuit, perhaps comprising many individual ignitions, that are fired simultaneously.
Line rocket	A rocket designed to travel along a wire or rope.
Low explosive	An explosive that burns or deflagrates on ignition rather than detonating. Almost all pyrotechnic compositions are low explosives.
M-80	A type of small, but powerful, device containing flash powder. M-80s are now banned from sale in the US.
Machine	A construction, commonly used in the 19th and early 20th Centuries, to “enhance” the spectacle of f fireworks display. Great efforts were made to disguise the presence of fireworks within statues and ornaments, which would then be ignited to produce the intended, but concealed, firework effect.

Magnalium	The most commonly used alloy in firework making. Magnalium is usually a 1:1 mixture of magnesium and aluminium and is described chemically as a eutectic mixture of Al_2Mg_3 in Mg_2Al_3.
Manufacture	The process of making fireworks from the raw materials. The term is more generally applied to any manipulation of firework components (e.g fusing shells).
Maroon	An exploding device that produces a loud bang. Aerial maroons are the most common, the composition being wither blackpowder or flashpowder. From French - marron - chestnut (from the noise they make in a fire)
Match	The generic term for quickmatch, black match etc
Meal powder	Finely divided blackpowder available in several grades.
Mesh size	The designation of the number of wires of standard thickness per inch used to make a sieve. For instance a 60 mesh sieve has a screen size of 250 microns.
Metal salt	The combination of an electropositive metal ion with an electronegative anion. For instance Potassium Nitrate.
MIDI	A method of computer control of firework displays in which cues are programmed like notes on a score. MIDI is an internationally recognised coding standard usually used for composing music.
Mine	Typically a complete with firing tube, but generally the firework itself.
Mine bag	syn. mortar mine.
Mini mine	A Roman candle in which each shot produces a mine effect many stars, rather than the more typical single star per shot.
Misfire	In general any failure of a firework to function as predicted. Modern usage restricts the term to the failure of a firework fuse.
Mixture	Usually synonymous with “composition”, but may mean the list of ingredients of a composition.
Mortar	The tube used to fire an aerial shell, or mine. Mortars can be constructed from paper, plastic, GRP or metal.
Mortar mine	A mine fired from a mortar.
Mosaic	The French term for splitting comet
Multibreak shell	An aerial shell comprising more than one section producing a separate effect in sequence and ignited by the bursting of the preceding section. The public may incorrectly refer to a “shell of shells” as a multibreak effect.
Multishot battery	The generic term for a collection of pyrotechnic pieces lit at a single ignition point, but often used exclusively for items referred to as “cakes”
Muzzle break	A malfunction of a shell where the bursting charge operates just as the shell leaves the mortar. This is a common point of shell failure as the pressure changes that act on the shell are great at this point.
Niagara falls	Brocks often fitted Niagara falls with a loud whistle accompanying the visual effect.
No-fire current	The upper limit for a current that will not fire an igniter, and thus the upper limit for a test current for electrical circuits.
Noise mine	A mine in which the principle effect is ejection of pyrotechnic noise units (e.g crackers or whistles)
Nomatch	A specialised system for igniting fireworks using a shock tube. The advantage of Nomatch is the extremely high speed of propagation leading to almost simultaneous ignition of several pieces at great distances.

Ohm meter	A device for measuring the resistance of a circuit, and typically build into electrical firing panels. The current applied by the Ohm meter must be less that the no-fire current!
Open circuit	An electric circuit that is not complete - i.e will not fire when a current is applied.
Orange book	The United Nations book on the Classification and Testing of Dangerous Goods
Organic	In our terms a solvent that is not based on water (e.g Acetone or Cyclohexanone)
Oxidant	The component of a firework composition that supplies the oxygen to the reaction (e.g Potassium Nitrate)
Oxidising agent	In firework compositions syn. Oxidant
Palm burst	The central bust, similar to a coconut shell, of a colour shell. For instance a “Red peony with palm core”
Parallel circuit	An electrical circuit in which the current is divided to pass through several igniters. Parallel circuits are less easy to test for line breaks and short circuits than series circuits.
Paste	The most common usage is that referring to the pasting of aerial shells to enhance the burst of the shells.
Pattern shell	A shell, usually with many fewer stars than a chrysanthemum shell of the same calibre, whose burst patter in such that a pattern rather than a sphere of stars is produces. Pattern shells come in many levels of complexity, but perhaps the most pleasing is the simple single circle.
Pellet	An alternative term for a star, usually restricted to pumped, cylindrical form, stars.
Peony shell	A typical Japanese style of shell in which the stars do not leave a trail of sparks.
PGI	The American “Pyrotechnics Guild International”
PIC	Plastic Igniter Cord
Pigeon	A specialised type of novelty firework in which a rocket motor is forced to run horizontally along a wire or rope, usually accompanied by a whistling effect. Often, the pigeon will make the journey several times, first in one direction, then the other.
Pillbox star	A star made from pressing (usually by hand) composition into a small thin-walled cardboard tube. Pill box stars are rarely made nowadays, but their effect can be dramatically different to round or pumped stars. Pill box stars usually have a longer burning duration that pumped or round stars.
Piped match	Raw match enclosed in, usually, a paper tube used for transferring fire from one firework to another. Piped match also forms the leader of a shell.
Pistil	In typical Japanese shells a central core to the burst of a contrasting or complementary colour to the main burst.
Plug	Typically the closure of a mortar tube, but more generally the closure of any tube (e.g a Roman candle tube)
Poka shell	A weak busting shell of Japanese design commonly used for deploying parachutes or tissue-paper flags.
Polverone	syn. Pulverone
Portfire	Usually a thin-walled tube filled with slow burning composition used to ignite other fireworks. It is similar to a fusee, but its flame is usually less fierce and usually burns white. A test for a good portfire is that it should continue to burn after being dropped vertically onto its lit end at arm’s length!
Post	A geographical position on a firing site used to identify the layout of the site. For instance, there may be 3 posts of Roman candles spread along the front of a site.

Press	A machine used to fill composition into tubes (e.g gerb press), or for making fireworks (e.g Roman candle press).
Prime	Often a slurry of blackpowder, a binder and water occasionally with added ingredients (e.g silicon) to increase the burning temperature used for ensuring ignition of reluctant compositions.
Priming	A process carried out to ensure ignition of a pyrotechnic composition when the composition itself is difficult to ignite. For instance, round stars are often primed for use in shells where the ignition time is short, whereas the same stars may be used without priming in a mine where the ignition time is longer.
Propellant	A composition used, typically, in a rocket motor to provide force. In more general terms any composition used to propel a firework into the air.
Pulverone	Granulated rough powder (usually of the same composition as blackpowder) used as the bursting charge of a shell.
Pumped star	A star produced by compressing composition in a mould. Pumped stars are usually cylindrical in form.
Punk	A wick for lighting small fireworks.
PVC	Poly Vinyl Chloride - one of many chlorine donors used as colour enhancing agents in firework compositions.
Pyrotechnic	The generic term for any item (or composition) which reacts in a self-sustaining chemical reaction and is generally produces an effect of light, smoke, noise or heat. Pyrotechnic articles are classified differently to fireworks and the term is usually restricted to theatrical effects and specialised items such as mole smokes or thermite charges.
Quickmatch	syn. Raw match
Rack	An apparatus, usually for firing rockets. The term may also be applied to “racks” of mortars.
Rain	Usually Silver rain or Gold Rain, in modern fireworks the long lasting stars from a shell or rocket that fall all the way to the ground. Care must be taken in the use of rain shells. In older terminology a “Golden Rain” was a particularly attractive type of hand held fountain.
Ram	The rod which is used to compress powder within a tube. The ram is usually quite a tight fit to the tube (cf funnel and wire)
Ramming	The process of filling a firework case with composition. Ramming is usually applied to a mechanical process rather than to a manual process.
Raw match	Blackpowder coated thread used for linking fireworks.
Reducing agent	The chemical role of a fuel in a firework composition. As the oxidising agent oxidises the fuel, the fuel can be said to reduce the oxidant.
Repeater shell	Usually a cylinder shells with several timed colour bursts at regular intervals. Repeater shells are often fired in sequence - 1 break, 2 break, 3 break, 4 break etc. Cf Multibreak shell
Resins	Usually applied to binding agents soluble in organic solvents e.g Accaroid resin
Resistance	The property of a material which acts to impede the flow of electrical current. In electrical firing of fireworks the resistance of a line is measure to prevent accidental “open” or “short” circuits.
Ring shell	An aerial shell that produces a symmetric ring of stars on bursting. Ring shells often are stabilised in flight with a rope “tail” to control the orientation of burst.
Rising effect	Often synonymous with “tail effect”, but may also be applied to shells in which, for instance, whistles or small shells (rising flowers) have been attached and which function on the shell’s ascent.

Rocket	A aerial device propelled into the air by a motor (cf shell). many of the public will describe any aerial firework as a "rocket".
Rocket cone	A device for firing flight rockets usually made from sheet steel curved into the characteristic cone shape.
Rocket motor	The power unit of a rocket, typical manufactured nowadays by pressing blackpowder into a choked tube without a spindle. Rocket motors occasionally find other uses in pyrotechnics - as wheel drivers, and as short duration fountains,
Rocket rack	A rack, usually made of wood or metal, for mounting many rockets prior to firing.
Rocket spindle	The spike (usually metal) used to form the older type of rocket motor with a central cavity for increased burning pressure.
Roman candle	A tube, usually cardboard, in which several charges are loaded, each with their own delay fuse and lifting charge, which function in a sequential manner.
Round shell	An aerial shell in the form of a sphere. Round shells usually contain coloured stars.
Round star	A star prepared by rolling, thus applying layer upon layer of composition onto a central core.
Roundel shell	An aerial shells comprising several maroons that burst in a ring pattern one after another
Safe current	The current level that it is safe to test an electric igniter without ignition.
Safety area	The area around a display site, usually not including the fall out area which is considered separately.
Safety cap	syn. Fuse cover
Safety fuse	A specialised fuse, designed for commercial blasting of construction similar to Bickford fuse but with a heavy waterproof coating.
Salute	American term for maroon.
Saturn pattern	Usually refers to a "Chrysanthemum in Circle" type shell rather than an "Atomic" pattern shell.
Scratch mix	A coarsely sieved mixture of Potassium Nitrate, Charcoal and Sulphur primarily used as a prime for stars.
Screecher	Physically a whistle with a hole through it, producing a much more "rasping" sound. In a screecher the instability arising from the oscillations of burning interfere with each other almost to the point of causing the resulting firework to detonate.
Senko hanabi	A delicate pyrotechnic sparking effect, commonly produced in Japan, produced from the burning of a sulphur-rich blackpowder composition. When burned, the droplets of molten composition that form react further with air to produce attractive branching sparks.
Sensitivity	The ease of ignition of a firework composition. Highly sensitive compositions (e.g flash powder) require extremely careful handling.
Sequence	Usually refers to the pattern of firing of a section of a display. For instance a sequence could comprise 10 x 3" gold shells followed by 10 x 4" gold shells followed by 5 x 5" gold shells.
Sequencer	An electrical firing system used to send regular electric pulses to fire a number of fireworks in a very accurately controlled manner.
Series circuit	The preferred method of linking multiple electric igniters. Series circuits are arranged so that the current runs through each igniter in a sequential way. Series circuits are much easier to test for continuity and correct wiring than parallel circuits.

Serpent	Usually a small tube filled with composition and possible a report charge, that is fired en masse from shells, mines, or rarely Roman candles. The serpents fly about in a random fashion prior to bursting with a report or stars.
Set piece	A generic term for a ground firework but usually distinguished from Lancework. The set piece may be static or revolving and is made up from gerbs and/or noise and colour units.
Shell	The most spectacular of fireworks comprising a lifting charge (to propel the shell into the air) and a bursting charge to eject stars or subassemblies in the air after a predetermined delay. Shells are fired from mortars.
Shell delay	A more precise term than delay fuse, this refers to the internal delay within a shell to permit it to ascent to its desired height before igniting the bursting charge. Shell delays are commonly made from composition pressed into a card tube (for cylinder shells, especially those with plastic moulded cases) and variations of Bickford fuse.
Shell of shells	An aerial display shell that contains internal shells that are ignited when the main shell bursts, and subsequently produce secondary bursts.
Short circuit	Usually the accidental completion of an electrical circuit which causes the current not to flow through the electric igniters and thus leads to line failure. Short circuits can usually be discovered readily in series circuits by electrical testing of the circuit with an ohmmeter.
Shot	Usually refers to the single functioning of, say, a Roman Candle. Thus typically Roman candles are referred to as “8 shots”.
Siatene shell	An aerial shells comprising several maroons that burst in a ring pattern at the same time.
Sieve size	The size of the hole in a sieve.
Smoke	An air suspension of particles usually from incomplete combustion of a composition.
Smokeless powder	A pyrotechnic mixture containing nitrocellulose and nitroglycerine so called because, unlike blackpowder, it does not produce much smoke on burning. In this way it found favour as a propellant in small arms devices, although its use in fireworks is rare.
Spark	The typical effect caused by incandescent particles ejected from the burning surface of a composition.
Sparkler	Usually a wire coated with pyrotechnic composition that gives off small sparks when burnt. Sparklers, although considered safe, are the cause of the greatest number of hospitalised accidents in the UK each season.
Spider shell	An aerial shell having a small number of relatively large stars producing an asymmetric break. Spider shells having 24 large comets are sometimes called Octopus shells.
Spiking	syn. stringing.
Spiking horse	The device used to facilitate the spiking, or stringing, of shells.
Spiral wound tube	A paper tube wound from several narrow paper strips at an angle. Roman candles made with spiral tubes are prone to failure if fire can be transferred by loose composition trapped in the spiral winding.
Splitting comet	A comet in which there is an internal charge (usually of flash powder) which when ignited splits the comet into several pieces. The effect is of a comet that travels for some period and then fragments. Splitting comet stars are typically found in shells, mines, and especially Roman candles. syn. Crossette
Spolette	A shell or Roman candle delay fuse usually made from pressing blackpowder into a small bore tube.
Squib	syn. Electric igniter

Star	Pellets of composition (usually cylinders, cubes or spheres) used in mines, shells, roman candles, rockets and occasionally gerbs.
Star mine	A mine in which the projection of coloured stars is the principle effect.
Steel mortar	A mortar made from steel tube, usually with a welded steel base. Steel mortars are increasingly rarely used due to worries about their fragmentation should a powerful shell burst within the tube. However, for some shells (particularly cylinder shells) they are still the material of choice for most people.
Storage	The holding of fireworks prior to their use. In most countries storage of fireworks above a certain quantity requires a licence.
Stringing	syn. Spiking. the process of winding a strong string around the outer surface of a shell to produce a more regular bursting pattern.
Strobe	The effect of a strobe is the regular pulsing "on-off-on-off" of light as a firework composition burns, There are several proposed explanations of this effect. Strobe effects are most often seen in ground fireworks (strobe pots) or as stars in an aerial shell or rocket.
Tail effect	Usually a term applied to a shell in which a star (comet) has been attached to the outside and which produces a rising column of sparks on the shell's ascent. "Tail" may also be applied to rockets, Roman candle stars or even whistle units where a persistent (usually silver) spark follows the flight of the device.
Temple	syn. Machine
Thermal stability	The tendency for a composition to ignite from the energy applied by heat. Thermal stability testing is routinely carried out as part of the authorisation procedure for fireworks in many countries.
Thermite	A mixture of aluminium and iron oxide (FE3O4) still used for in situ welding of railway tracks.
Thunderflash	A generic term for a report with flash.
Tiger tail shell	Usually a solid sphere of composition fired in exactly the same manner as a shell. The effect produced is of an extremely thick rising comet. Optionally there is a small shell burst at the apex of its flight.
Titanium	A silver metal much used for producing brilliant white sparks (e.g in a maroon or gerb). Titanium does not corrode (cf aluminium), but is extremely hard and may increase the friction sensitivity of a firework composition.
TNT equivalent	A measure of explosive strength used as a comparison to TNT, usually for determining safe loading of buildings.
Top fused	Usually an aerial shell in which the time fuse (shell delay) for the functioning of the bursting charge is physically at the tope of the shell and lit independently to the lifting charge.
Torbillion	Also Tourbillion. Either very similar to a serpent unit, or a lager aerial firework comprised of a saxon and wing, designed to rise into the air on ignition.
Torch	syn. flare
Torpedo	A flying squib or throwdown.
Transportation	The process of consigning a load of fireworks, usually taken to apply once the consignment has left the factory gates. Transportation of fireworks is subject to heavy legislative control.
Trunk	The rising effect seen on willow shells, and increasingly on man other shells.
Turning case	A specialised type of gerb used for driving wheels. Typically turning cases are made from composition containing a larger proportion of blackpowder than the equivalent gerb.
UN classification	The assignment of a packaged firework into one of the UN's 5 classes for fireworks

UN compatibility group	The "G" of 1.3G. The compatibility group, largely irrelevant for most firework usage, prescribes which explosives may be transported with which others. For instance detonators should not be transported with primary explosives, explosives containing toxic agents should not be transported AT ALL!
UN hazard code	syn. UN number
UN mark	A complicated index assigned to the PACKAGING of a dangerous good. (Cf UN number)
UN number	A four digit number assigned to any hazardous goods after classification in its TRANSPORT PACKAGING according the methods prescribed in the "orange book". For fireworks the relevant numbers are 0333 (1.1G), 0334 (1.2G), 0335 (1.3G), 0336 (1.4G) and 0337 (1.4S). The UN number should always be quoted as it uniquely identifies an item AND its hazard.
Visco fuse	A fuse, commonly used on consumer fireworks as the delay fuse, which is usually made by wrapping a core of blackpowder with thread and lacquer.
Volley	A term usually applied to a mass firing or rockets.
Warimono shell	A Japanese term for the type of shell that produces a spherical burst of stars. Most shells are of this type. Cf Poka shell.
Water firework	The generic term for any firework fired on the surface of water to maximise the visual effect of its reflections.
Water gerb	Usually a gerb or fountain weighted at one end and attached to a piece of cork designed to function on the surface of water. A water gerb may be lit by hand and thrown onto the water's surface, or fired like a shell from a mortar (in each case with a suitable delay fuse).
Water shell	A shell designed to function on the surface of water (e.g a lake) producing a hemisphere of stars. Water shells may be fired from mortars angled at a low angle, or may be set up on the water's surface prior to the star to the display.
Waterfall	Usually an extended curtain of silver sparks form vertical or horizontally burning tubes filled with a composition containing aluminium. Waterfall shells produce the same effect and are best fired en masse to produce a spectacle.
Weeping willow shell	Syn. Willow shell
Wheel	A rotating set piece, usually powered by gerbs or turning cases, and most often rotating in a vertical plane.
Whistle	Usually a tube containing a composition made using potassium benzoate, potassium salicylate, or rarely nowadays, potassium picrate. On burning the composition burs in a rapidly oscillating manner, and the resulting pressure waves are amplified by the tube in a manner similar to an organ pipe.
Whizzer	American alternative name for hummer
Willow shell	An extremely attractive shell comprising stars made with a high percentage of charcoal. the effect is of long-burning golden stars which often (but undesirably) fall all the way to the ground. The shell may optionally be fitted with a "trunk".

ABBREVIATIONS AND ACRONYMS

ACDS	Advisory Committee on Dangerous Substances
ALARP	As Low As is Reasonably Practical
BATNEEC	Best Available Technology not Entailing Excessive Costs
CDGRR	Carriage of Dangerous Goods by Road and Rail Regulations
CER	Carriage of Explosives by Road Regulations
CLER	Classification and Labelling of Explosives Regulations 1983
COMAH	Control of Major Accident Hazard Regulations 1999
EA75	The Explosives Acts 1875
ES	Exposed Site
ESTC	Explosive Safety and Transport Committee (MOD)
FMEA	Failure Modes and Effects Analysis
HAZOP	Hazard and Operability study
HD	Hazard Division (Classification for Transport)
HSC	Health & Safety Commission
HSE	Health & Safety Executive (based at Bootle)
HSL	Health & Safety laboratories (based at Buxton)
HT	Hazard Type
MAH	Major Accident Hazard
MANC	Major Accident Notification Cascade
MAPP	Major Accident Prevention Policy
MSER	Manufacture and Storage of Explosives Regulations
PEC	Packaging of Explosives for Carriage Regulations 1991
PES	Potential Explosion Site
QD	Quantity/Distance relationships
QRA	Quantified Risk Assessment
R2P2	Reducing Risks, Protecting People - HSE's overall strategy for risk enforcement
RA	Risk Assessment
SFAIRP	So Far As is Reasonably Practical
SMS	Safety Management System
SRAG	Safety Report Assessment Guide
SRAM	Safety Report Assessment Manual
TOR	Tolerability of Risk - the frameowrk of risk management adopted by HSE
XI	HSE's Explosive Inspectorate