Comparison of national "safety distances" at professionally fired firework displays and distances derived from ShellCalc©

Dr Tom Smith[a] and Dr Christian Lohrer[b]

[a] CarnDu Ltd, 8 Aragon Place, Kimbolton, Huntingdon, Cambs UK PE28 0JD. Email: tom@carndu.com

[b] Federal Institute for Materials Research and Testing (BAM), Unter den Eichen 87, 12205 Berlin, Germany

Email: christian.lohrer@bam.de

Abstract*: There is a wide variety of approaches across the world in determining appropriate "safety distances" for firework displays. Comparison of the different national approaches and distances for shells derived from ShellCalc© highlights the variety and derivation of the "safety distances" adopted and these distances are related to the various failure modes of shells that may affect the audience. It is not intended that this paper should encourage the maximum distances derived always to be adopted, but that an appreciation of the probabilities and hazards of various accident scenarios and therefore the risks involved be part of the decision making process for designers and commissioners of displays as well as enforcing authorities.*

Introduction

The adoption of diverse "Safety Distances" for professionally fired firework displays around the world illustrates the different appreciation of what a "safety" distance really means. To some it is an inviolable distance beyond which people are 100% "safe" – that is, not subject to any risk, whereas to others it is no more than a recommended distance based on history, custom and practice which bears little relationship to the risks posed.

Far too often we hear after a display "we got away with it". This generally means that there was no major incident or misfiring and that the debris from the show fell into an area which had been loosely described as the "fallout" area. How this actual area was determined in practice in relation to the site and conditions prevailing at the specific display is often little more than arbitrary. This paper attempts to provide some quantification of the distances that may be rationally applied, and to examine the risks posed and to compare these mathematically derived risk minimisation approaches based on shell trajectory modelling distances – using the ShellCalc© program[1] developed by John Harradine and extended by Tom Smith – to the "safety distance" regimes from a number of countries.

A recent paper by Lohrer[2] has already made comparisons of the "safety" distances applied to a wide variety of fireworks across a number of European member states. This paper concentrates on what we consider to be the highest hazard items (shells) given that shells are usually the determinant of the overall site suitability and layout. However for smaller shows or shows on restricted sites other firework types may become the determinants of appropriate "safety distances" and the same general principles outlined here may also be applied to such fireworks. ShellCalc© now models a variety of firework types including

- shells
- Roman candles
- mines
- fountains (gerbs)

and it is apparent that on some sites, especially with Roman candles or mines fired at low trajectories, these may pose greater risks than smaller calibre shells fired vertically at the same display.

This paper highlights the effect of firing angles and wind strength/direction on shell trajectories and derived "safety distances". As Lohrer points out, there is a great diversity of approaches and therefore derived distances throughout Europe, with the UK adopting an unusual approach in that "safety distances" are calculated on the basis of site and product specific risk assessment rather than using "fixed" distances related to, for example, calibre.

It is important to appreciate that risk is, in simple terms, the product of the frequency (likelihood) of an event and the hazard of that event – i.e. the consequences. Events can be high risk because they have a high frequency or high hazard, or both.

We have sought advice from practitioners in the various countries commented on and acknowledge their help and expertise. However any misinterpretations are entirely our own.

What is a "safety" distance anyway?

The main issue we encounter when discussing "safety" distances is what people actually mean by the term. Is a safety distance a distance at which people are "safe" – that is, at **no risk**, or is it a distance at which people are at an

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acceptably low risk? The difference is important and has implications not only for event design, but for litigation following any incident.

We do not live in a risk free world, and although obviously anyone attending a firework display should expect not to be injured by the fireworks from the display, accidents will continue to occur because of the nature of the products that are used. In essence fireworks are relatively cheap items with a very low (but quantifiable) failure rate but are items that cannot be subject to individual testing. By necessity fireworks may (and should) be subject to both a "Type" approval and "Batch" approval regime – it simply is impossible to test every item, as testing it necessarily causes it to function irreversibly!

The Type/Batch approach is that adopted in essence by the European Standards[3] for professional display fireworks, although its history is in similar regimes developed in the UK for the British Standard 7114[4] for consumer fireworks. The major difference between Category 1/2/3 Standards (for consumer fireworks) and Category 4 (for professional fireworks) is that professionals may manipulate and fire fireworks in creative ways using their professional skills and training to determine both the suitability of a particular firework for a display (at a particular site under a particular set of conditions) and the manner in which it is fired.

The latter is the biggest contrast between consumer fireworks (fired by non-professionals using equipment provided and according to fixed instructions) and professional ones and may involve consideration of:

- Fusing methods
- Firing positions
- Firing angles
- Mortar construction (e.g. for shells)
- Mortar rack construction (e.g. for shells)
- Supporting methods
- Risk reduction methods

However, it is also clear that despite their greater knowledge professional display operators sometimes find themselves in the unenviable and unjustified position of having to apply greater "safety" distances than non-professionals for what are, in performance terms at least, identical items.

Lohrer states that in Germany, for example, the distances are derived on the basis of hazard – i.e. that an assumption is made that the item will fail. However this paper demonstrates that these distances do not, in fact, represent such an approach – for example ignoring any ground burst of a "blind" shell. Other European countries with significantly lower prescribed "safety" distances must therefore be applying a risk based approach (albeit potentially unwittingly) rating high frequency events (such as "normal" fallout) greater than low frequency events (such as blind shells).

For simplicity this paper will concentrate on aspects of the firing of a small variety of shells, but the principles can be extended across a much larger range of fireworks. For instance mines, Roman candles or single shot devices fired from elevated structures at angles far from vertically upwards may actually be the biggest determinant of appropriate "safety" distances in shows with limited use of shells.

In this paper we will also concentrate on the effect on members of the audience and the "safety distance" that is appropriate to them. However in most cases there are other potential areas affected by the display:

- The firers – these may be at a considerably higher level of risk but this may be an acceptable position because
  - They are at work and cognisant of the risks involved
  - There are only a limited number of firers at risk, as opposed to large numbers of audience
- Structures – particularly where the display is fired from a structure itself, or is in close proximity to other structures (e.g. rooftop firing)
- Other hazards – e.g. car parks, power lines etc

Mortar angles and the effects of wind

It is commonplace to find shells fired from angled mortars. Modern display design often uses angled firing to maximise the spread of shell bursts in the sky and to create patterns from "tailed" shells and to attempt to fire shells "away" from the audience.

Firing angles for aesthetic reasons typically range up to 30° from the vertical and are generally angled pto create teh greatest spread for the majority of the audeince.

Firing angles for safety reasons are usually away from the audience for obvious reasons.

The problems come when the audience is not simply on one side of the firing site, or when the conditions prevailing at the time of the display take debris from the display towards the audience. A previous paper attempted to quantify the risks from firing shells and noted that if an audience subtends 360° around the firing area then the overall risk of a "blind" shell or debris falling on the audience is necessarily increased from the situation where the audience only subtends, say, 36° – i.e. by a factor of 10!

A maximum wind speed of 20 km h^{-1} was chosen for this study because in our experience this wind speed can be considered as that under which most shows in Europe will be able to be fired (or should be able to be fired) without significant modification. It simply is not sensible to plan a display assuming the wind speed will be significantly lower than this (except where local conditions indicate that such conditions are the norm). On the other hand, when the wind speed is above about 20 km h^{-1} then we would expect that significant portions of the display would have to be removed if the wind is in a direction towards the audience or other hazards, simply because the various fallout distances increase significantly. ShellCalc© is a useful tool therefore, for companies to produce curtailment or cancellation criteria based on their own range of fireworks and their own display designs. Some "fixed rule" approaches extend the wind strength considerably above 20 km h^{-1} but it is our belief that at such speeds and in directions which are specific to each site it is likely that removal of certain fireworks or types may be the most appropriate response.

It is extremely difficult to compare the "fixed rules" approaches under a variety of conditions of firing angle and wind conditions as each system applies its own criteria. We have attempted to make comparisons between the systems below.

Vertical mortars falling over

One failing of many systems is the assumption that mortars will fire in their design orientation – and determination of the relevant "safety" distances as a result. Even the most pessimistic regime does not appear to consider the low frequency/high consequence failure in which one shell displaces an adjacent mortar from which a second shell is then fired.

It is simply not realistic to apply a reduced set of distances for mortars which "cannot fall over" unless extreme measures have been put in place to completely remove such a risk, or to safeguard the audience completely (by use of, for instance, "catchers") in the event that they do.

For a complete assessment of risks this situation must be considered. It may be rated low risk (because of the very low frequency) but it is still a risk. Figure 1 shows the ShellCalc© plot for a 100 mm shell fired in 21 km h^{-1} wind.

This paper therefore also considers the risk from such events.

Failure modes and types of incident

In any process of risk assessment the various failure modes should be assessed and rated for their effects on all potential hazard areas. These may include, for example:

- The structure from which the fireworks are fired or which may be affected by impact (e.g. a building)
- The operators
- Local hazards (e.g. car parks)
- The audience
- Other people who may not be the "intended" audience

As noted above this paper concentrates on the audience, but the principles apply to all. The two main sources of risk from shells at a display may be considered as

- Low hazard/high frequency events – such as lightweight debris or sparks carried by the wind and which could cause minor injuries and which will be generated at almost every show (i.e. the frequency is very high)
- High hazard/low frequency events – such as a shell falling directly into the crowd and potentially functioning on impact

These risks could be regarded as equally important, and equally in need of risk reduction measures. Obviously a high hazard/high frequency event poses an unacceptable risk and should not be continued or contemplated until sufficiently robust risk reduction measures have been put into place and the risks reassessed.

Hence there are a variety of incident types which should be considered as part of an overall assessment of risk. In approximate order of increasing hazard (and decreasing frequency) to the audience these are shown in Table 1.

A previous paper by Smith[5] has attempted to quantify these risks and concluded that the overall risk to the audience or operators at any display is very low. However it is still a quantifiable risk and it is obvious that incidents and accidents do still occur. The job of the display company is to minimise these risks by minimising the frequency or the potential hazard (or both) and it is the job of event organisers to guide the display company in determining what risks are acceptable.

Types of approach

In the first instance therefore we must decide which are the relevant hazards to the audience, and which will determine the appropriate distance to them or limit the variety of fireworks used. This generally should be a decision made in partnership between the event organiser and the display company

- Is the display to pose a low (but generally acceptable) risk either from low frequency/high hazard events (such

Table 1. *Hazards from shells*

	Hazard	Comments
1	Long duration sparks from normally fired shell (e.g. Kamuro)	Lightweight sparks that will not cause major injury but may be a source of ignition
2	Long duration sparks from unintentionally angled mortar	E.g. if mortar is disrupted by previous shell misfire
3	"Normal" debris from normally fired shell	Shell fragments
4	"Normal" debris from unintentionally angled mortar	E.g. if mortar is disrupted by previous shell misfire
5	Shell "blind" from normally fired shell	Except in high wind conditions or from angled mortar will most likely not reach audience
6	Shell "blind" from unintentionally angled mortar	E.g. if mortar is disrupted by previous shell misfire
7	Shell "blind" and ground burst from normally fired shell	
8	Shell "blind" and ground burst from unintentionally angled mortar	E.g. if mortar is disrupted by previous shell misfire

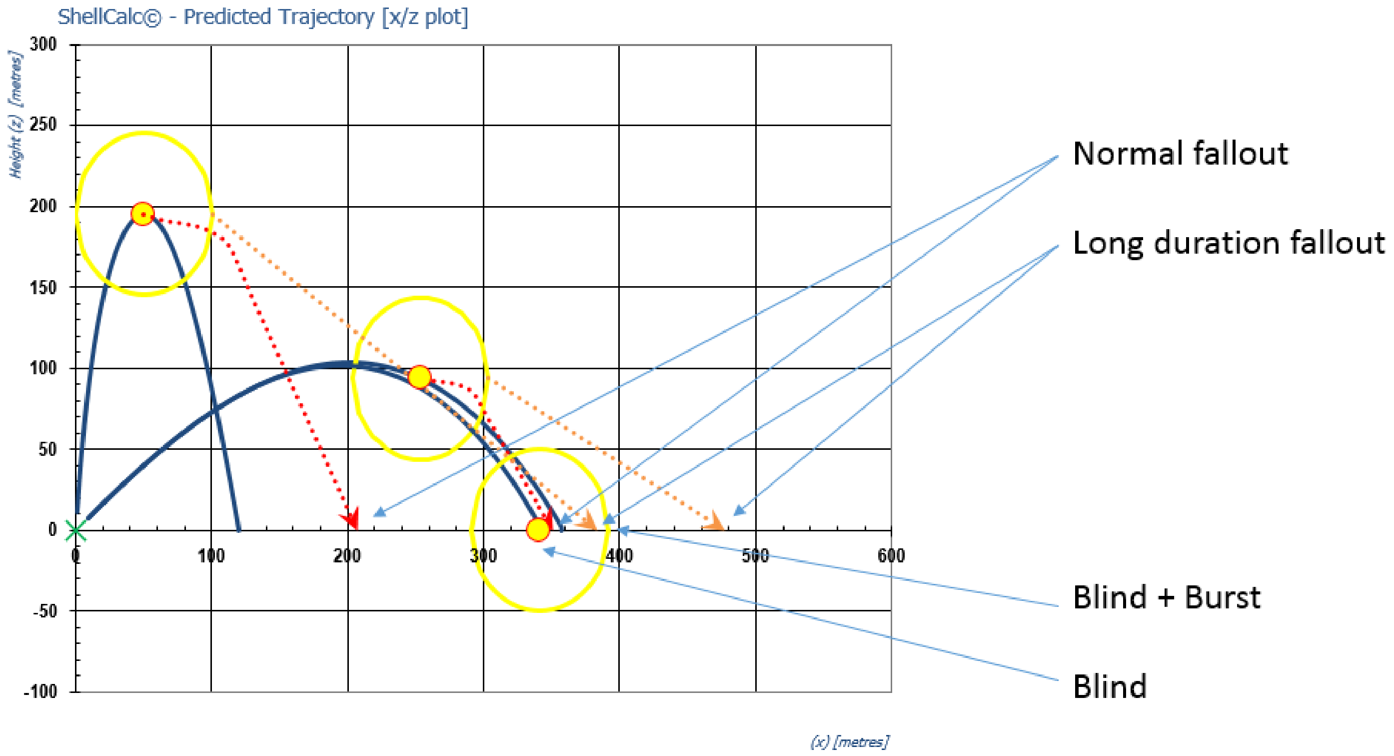


Figure 1. *Shellcalc© plot showing Normal, Long duration, Blind and Blind+burst for vertical and 45° launching of a 100 mm shell in 21 km h^{-1} wind.*

as shell "blinds") or high frequency/low hazard events (such as long duration stars)?

- Is the display to pose NO or at least very near-zero risk? This may be required for a very large televised event such as an Olympic opening ceremony, where the consequences of even a very low risk incident could be significant, not least in terms of adverse publicity from the world's watching media.

In addition there are two basic approaches to determining "safety distances".

The first is what we will term a "fixed rules" approach – it is based on some rules which may include multipliers of shell diameter (for convenience) or shell apogee (which is a better measure) and consists of a set of values or tables which can be applied by the display designer and the enforcing authorities to provide "standard" distances which, although they may not truly be "safe", provide an acceptable level of risk.

The second is based on specific modelling of shell trajectories and fallout patterns on a shell-by-shell basis taking into account firing angles and wind strengths and directions.

How do you determine a safety distance?

The determination of an appropriate "safety distance" depends on many factors. The problem with most "fixed rules" systems is that they do not address all of these factors adequately. Features which may affect what is an appropriate "safety distance" include:

- Shell calibres
- Shell types
- Firing angles
- Position of the audience in relation to the mortars (i.e. are the audience areas restricted)

In addition a number or features related for the rigging and firing may need to be considered:

- Mortar construction and possible failures
- Effect on other fireworks (e.g. rack construction)
- Mortar support methods (and "fail-safe" issues)

Finally the environment and meteorology at the time of firing (which may be quite different from that during site surveys or even during rigging):

- Wind speed
- Wind direction (especially in relation to firing angles)
- Firing elevation
- Topography

In addition it is apparent that the basis of many "fixed rule" systems differ – presumably because of the history, custom and practice prevailing within each country and probably as a result of recommendations made after investigations of accidents. In general the approaches seem to be based on either the expected "normal" debris arising from the "normal" firing of shells, or from a calculation of the maximum range a shell could achieve if it failed to burst at the design height (i.e. a "blind"). The reasons for this diversity are not important in the discussions that follow,

Table 2. *Comparison of systems*

	Name	Basis	Comments
US	NFPA 1123[6]	Fixed distance per shell diameter	
Canada	Display Fireworks Manual[7]	Fixed distances dependent on shell diameter, site layout and firing angles	
Australia	Safe use of outdoor fireworks in Western Australia[8]	Fixed distances up to 300 mm shells based on dud shells landing on the ground	Vulnerable sites require 2× distance
France		Fixed distance per shell diameter or apogee and effect	Differentiation between normal shell and "report shell" (aural main effect)
Germany		Fixed distance per shell diameter or apogee and effect. Marking of shell burst height on the shell label is mandatory in Germany and usually is the predominant determinant of distance	Differentiation between normal shell and "report shell" (aural main effect)
UK			There are no fixed distances for professional users – distances are determined by companies on the basis of their own site and product risk assessments

but suffice to say we believe neither represents all the risks that arise from both the "normal" firing of shells at a variety of angles and in varying meteorological conditions and in particular the risks arising from the abnormal functioning of shells (for instance where a shell is fired at an unplanned trajectory because of disruption of the mortar from a previous shell failure).

Table 2 outlines the basic methodology of the various systems in use throughout the world and Table 3 outlines the basic methodology for dealing with firing angles and wind speed/direction.

Distances

Table 4 highlights the derived distances for a variety of scenarios across the various countries examined for a variety of similar situations. In some cases various assumptions have been made which are expanded below.

The ShellCalc© distances are shown as those calculated for the intended firing angle in the relevant wind, and for a displaced mortar angled at 45° with a "tailwind" – i.e. the greatest possible combination of effects.

Given the various systems and the relationship between metric and imperial measurements we have attempted to make "like for like" comparisons but in some cases the derived distances may vary slightly.

Table 3. *Wind and angled firing*

	Angled shells	Wind	Comments
US	Offset changes position of mortars within secured diameter (which does not change)		
Canada	Does not appear to have fixed rules	Fixed increase dependent on wind strength or reduction in maximum shell calibre or angling mortars into wind	Canada has two types of site defined "Oblong" and "Circular" but these extremes are not really representative of modern display scenarios
Australia	Table considers various launch angles up to 45°and increases distances based on dud shells	Operators should consider the effect of wind to increase flight distances – table illustrates values for vertically fired shells	We presume the minimum distances apply unless the "shell drift" distance is greater
France	Does not appear to have fixed rules	Does not appear to have fixed rules	
Germany	Distances increased depending on firing angles (distances may be decreased in opposite direction)	Distances increased depending on wind strength in direction of wind(distances may be decreased in opposite direction)	

Table 4. *Derived distances*

			"Safety" distances (m)					Calculated ShellCalc© distances (m)				Calculated ShellCalc© "45°" distances (m)			
Shell calibre (mm)	Firing angle (°from vertical)	Wind speed (km h^{-1})	USA	CA	AUS	FR	DE	Blind	Blind + Burst	Fallout	LD fallout	Blind	Blind + Burst	Fallout	LD Fallout
75	0	0	64	95	45	60	60	31	69	16	54	214	252	167	204
100	0	0	85	115	75	80	80	40	90	21	71	283	333	216	266
125	0	0	107	145	100	100	100	46	109	24	87	327	390	250	313
150	0	0	128	175	150	120	120	49	124	27	102	370	445	280	355
200	0	0	171	230	200	160	160	59	159	33	133	442	542	335	435
75	10	0	64	95	64	60	84	96	134	62	103	214	252	167	204
100	10	0	85	115	79	80	112	126	176	80	134	283	333	216	266
125	10	0	107	145	100	100	140	146	209	92	160	327	390	250	313
150	10	0	128	175	150	120	168	161	236	94	169	370	445	280	355
200	10	0	171	230	200	160	224	194	294	113	213	442	542	335	435
75	20	0	64	95	119	60	108	149	187	99	140	214	252	167	204
100	20	0	85	115	145	80	144	196	246	128	182	283	333	216	266
125	20	0	107	145	169	100	180	227	290	147	215	327	390	250	313
150	20	0	128	175	191	120	216	252	327	157	232	370	445	280	355
200	20	0	171	230	230	160	288	304	404	187	287	442	542	335	435
75	0	10	64	95	45	60	60	52	90	69	141	234	272	205	264
100	0	10	85	115	75	80	80	66	116	87	181	309	359	263	339
125	0	10	107	145	100	100	100	74	137	98	210	356	419	301	394
150	0	10	128	175	150	120	120	81	156	107	237	400	475	335	442
200	0	10	171	230	200	160	160	93	193	124	288	473	573	396	533
75	0	20	64	125	59	60	60	76	114	121	228	256	294	244	324
100	0	20	85	145	75	80	80	95	145	152	291	334	384	310	414
125	0	20	107	175	100	100	100	105	168	171	334	384	447	353	476
150	0	20	128	205	150	120	120	113	188	187	373	427	502	391	531
200	0	20	171	260	200	160	160	126	226	215	444	505	605	458	633
75	20	20	64	125	179	60	108	197	235	192	293	256	294	244	324
100	20	20	85	145	210	80	144	254	304	244	374	334	384	310	414
125	20	20	107	175	236	100	180	290	353	277	430	384	447	353	476
150	20	20	128	205	261	120	216	321	396	305	480	427	502	391	531
200	20	20	171	260	302	160	288	377	477	357	572	505	605	458	633

Blind = shell fails to burst and lands on ground.
Blind + Burst = shell fails to burst in air and ignites on impact with ground, diameter of shell burst as designed.
Fallout = "normal" fallout – shell fragments etc.
LD Fallout – long duration stars – e.g. Kamuro.

CA = Canada, AUS = Australia, FR = France, DE = Germany.
Shellcalc© calculations done with "typical" mortar barrelling/tumbling enabled.
Complex (i.e. wind and angle) distances are taken as cumulative – i.e. angled mortars in wind need both terms applied.

The following graphs illustrate the differences between the different approaches.

Figure 2 shows plots for vertically fired mortars with zero wind. In this situation the distances calculated using ShellCalc© are generally less than the "fixed rule" approaches. This is to be expected, but zero wind situations are not realistic. Obviously the 45° ShellCalc© values are greater than both the undisturbed mortar values from ShellCalc© and the "fixed rule" distances – but they represent, for example, "worst case" failures of mortars in racks.

The low ShellCalc© values for vertically fired mortars are not surprising – in a truly zero wind situation a shell fired vertically which failed to burst would, theoretically, land

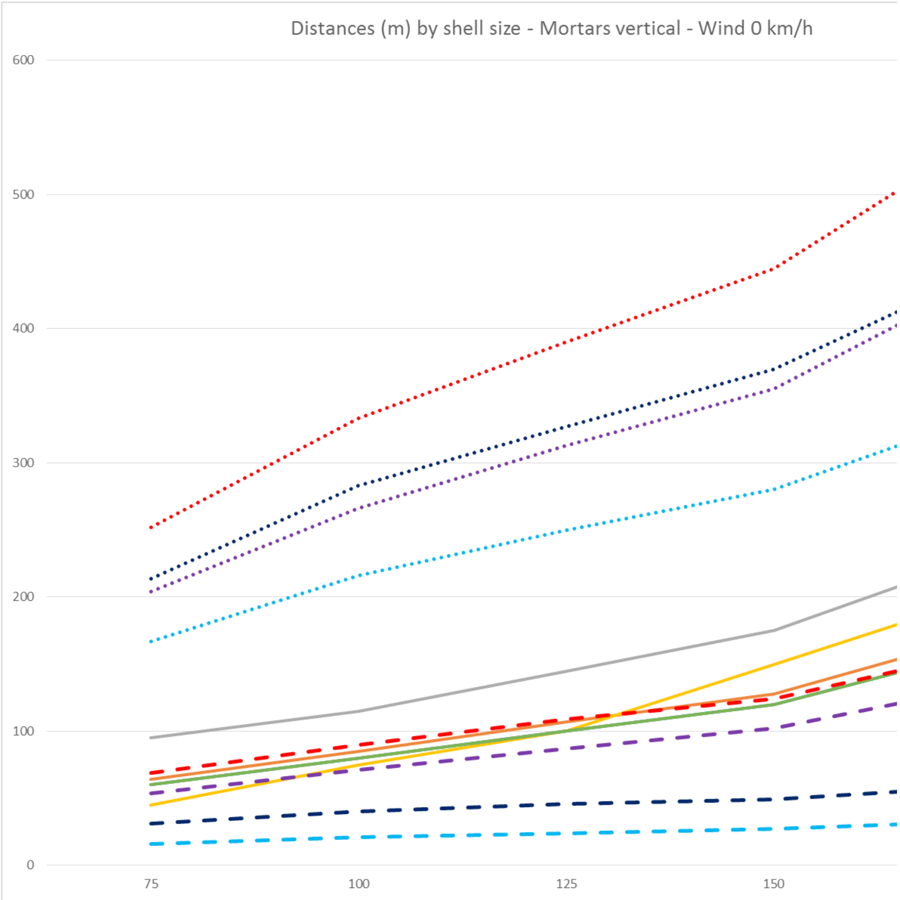


Figure 2. *Mortars vertical, wind 0 km h^{-1}.*

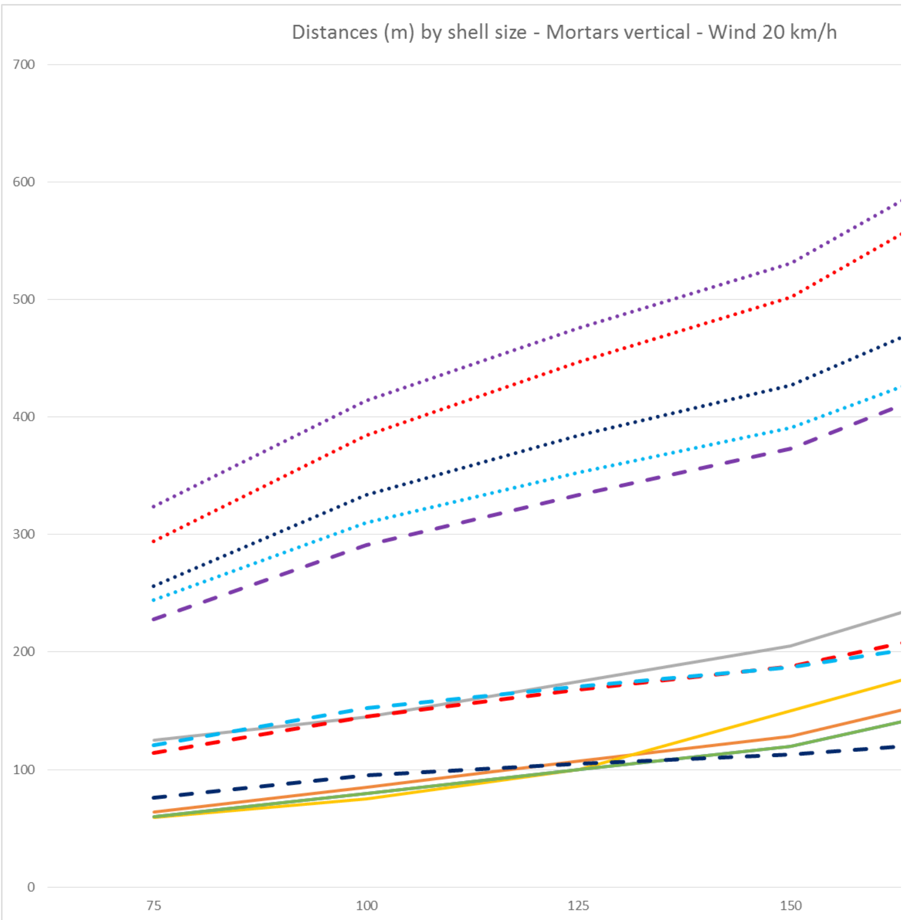


Figure 3. *Mortars vertical, wind 20 km h^{-1}.*

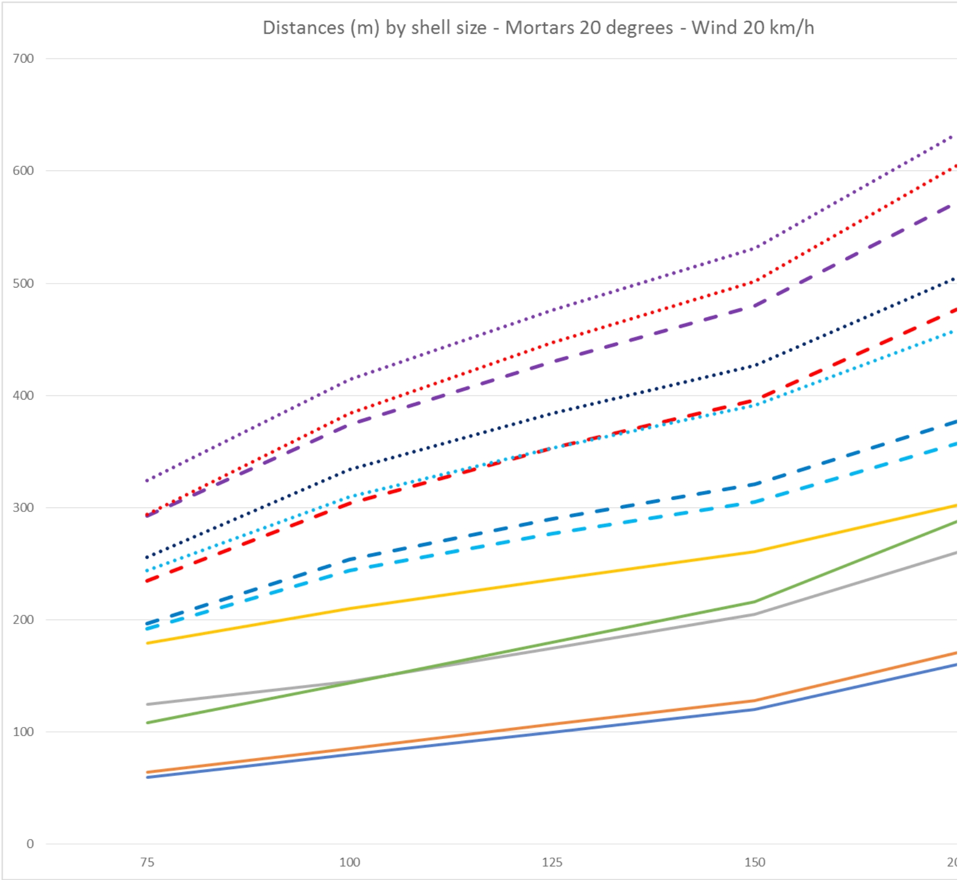
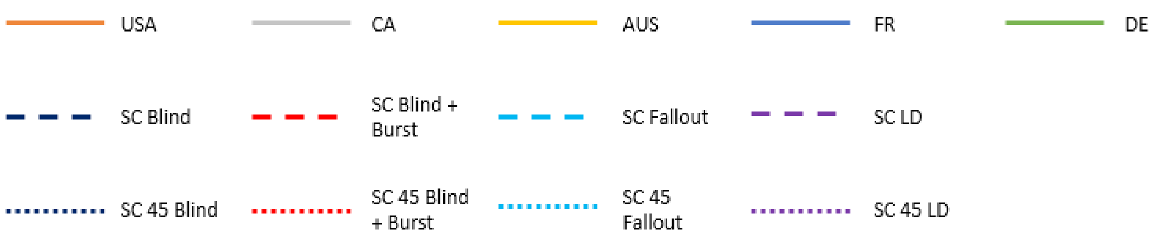


Figure 4. *Mortars 20 degrees, wind 20 km h^{-1}.*

Key to Figures 2, 3 and 4



SC Blind = "blind shell"
SC Fallout = "normal" debris
SC Blind + Burst = "blind" shell bursting on impact
SC LD = Lightweight (or long duration) debris and sparks
SC 45 = figures if shell discharged at 45°.

back in the mortar! ShellCalc© factors in shell tumbling and mortar barrelling to more accurately reflect this situation.

Figure 3 shows plots for vertically fired mortars with 20 km h^{-1} wind. In this situation the ShellCalc© distances approximate to the Canadian distances. This is to be expected, since the Canadian "fixed rule" approach pays more attention to wind speed (at 20 km h^{-1}) than other systems. Again the 45° ShellCalc© values are greater than both the undisturbed mortar values from ShellCalc© and the "fixed rule" distances

Figure 4 shows plots for mortars angled at 20° to the vertical with a 20 km h^{-1} "tailwind" – that is, in the same direction. Here both the "normal" (i.e. 20° angled) and 45° angled ShellCalc© values exceed any of the "fixed rule" approaches and although the German system, which takes into account both factors, now exceeds the other "fixed rule" approaches it still does not approach the ShellCalc© values.

Assumptions made and observations of the various systems

We have had to make some assumptions in our analysis of systems in other countries and we are grateful to colleagues in those countries for correcting us where necessary.

US

- The distances are not increased for varying wind strengths

- 1/3 offset distances for angled shells are not applied to angled firing for aesthetic effect
- It is acknowledged that the figures are a compromise between enforcers and industry and not based on tests or modelling
- Does not deal with fireworks angled in fan shapes. It seems confusing what distances should be applied using the 1/3 offset principles – are these "correspondingly increased" in the direction of the angle for all angles?
- No quantification of "angle"
- No apparent increased distances for wind

Australia

- The maximum of the "minimum separation distance" and the shell "dud" distances are used where mortars are angled in varying wind strengths

Canada

- Does not address angled fireworks adequately
- Proposes that on circular sites shells are fired into the wind (even if this is towards the audience) – in the case of a dud shell this could be a high hazard event
- Proposes reducing shell size in windy conditions – but the proposals are arbitrary (alternatively increases distance by fixed amount)

France

- Considers malfunction of the shell burst only (i.e. a "blind" shell) but ignores crucial aspects of shell/mortar failure (see below)
- Does not consider mortar angles or wind

Germany

- Considers malfunction of the shell burst only (i.e. a "blind" shell) but ignores crucial aspects of shell/mortar failure (see below)

General points

In general "fixed rule" systems do not attempt to reflect different performance parameters of shells, nor their construction. The German and French systems allow for calculations to be made on the basis of shell apogee as well as shell diameter and in Germany it is mandatory to mark this value (the "shell burst height), on the shell itself. In practice therefore this is a better determinant of "safety distance" than suggested by the table above.

We believe that the approach of the European Standard for shells (part of the Category 4 standard[3]) which will label shells with their performance characteristics including

- Burst height (mandatory)
- Burst diameter (optional)

under "standard" conditions will go a long way to providing relevant information to users to enable them to calculate appropriate distances at a display. However it is recognised that such "Standard" conditions may not reflect the practices used by individual display companies – for instance mortar lengths and inside diameters may vary – in realistic conditions on display sites. However the "Standard" information provided will allow display designers a reference point in their calculations using a variety of methods. Future versions of ShellCalc© will enable such reference points to be added to the input criteria for trajectory modelling, together with parameters to reflect each company's individual experience.

Comparison of the German system and distances derived from ShellCalc©

Following Lohrer's paper on comparison of European Safety distances and the conclusion that the Dutch and German systems generally set the greatest "safety distances", the remainder of this paper compares the German distances with those derived from ShellCalc© for a variety of scenarios.

The comparison of distances with the German system, based on "100%" failure rate, are interesting. We do not believe that the German system actually represents the worst case scenarios as outlined above, for two reasons:

1. For "blind" shells it fails to allow for a shell bursting upon impact with the ground
2. It fails to allow for accidental disruption of a mortar by an adjacent shell failure

It is not alone in these two shortcomings, but we do not believe that the system can truly be described as representing the worst case scenarios or to assume 100% failure. The two points above are both extremely rare – but they still are realistic possible failure modes which have caused accidents in the past.[9,10]

The German system also draws a distinction between colour shells (e.g. peony) and report shells and in general increases the "safety distance" for the latter. However we do not believe that this accurately reflects the similarities in hazards from the two types of shell in a "blind" situation.

ShellCalc© has been used extensively at some of the largest displays in the UK and the rest of the world to model fallout and shell failures under a wide variety of wind conditions (ShellCalc© allows wind strength and relative direction to be set when, for instance, the mortar orientation is fixed due to design or site constraints) and to develop objective cancellation or curtailment criteria at these shows. Some examples are given in Tom Smith's book *Firework Displays: Explosive Entertainment*.[11]

Responsibilities at a display

The discussion necessarily highlights the roles and responsibilities of the various parties involved. We believe that the increasing threat of litigation and the public perception of risk have altered the relationship between these organisations in a positive way. However we believe it is important to emphasise the role each must take and illustrations of such roles are given in Table 5.

Table 5. *Illustrative roles*

Organisation	Role and responsibilities
The display company (contractor)	To provide a spectacular, appropriate and low risk display.
	To carry out site and product specific risk assessment to determine which fireworks are appropriate for the site and expected conditions and to provide objective cancellation or curtailment criteria (this may be done in conjunction with other bodies or consultants)
The event organiser (creative design or production)	To provide clear instructions as to level of acceptable risk (or no risk) depending on venue and event
	To facilitate the safe rigging up, firing and de-rigging of the event by, for example, providing sterile areas and maintaining the fallout area clear from people
The enforcing or licensing authority	To understand the requirements of the event organiser and the limitations and opportunities the site may provide
	To enforce consistently
Consultants	To act, perhaps, as "broker" between event organisers and contractors to ensure realist expectations are met and low risk as appropriate
	To prepare an objective set of cancellation/curtailment criteria

Risk assessment aspects

The above discussions highlight, we hope, the merits of the UK approach to "safety distances" at displays. We believe a site and product specific risk assessment, leading to objective criteria for cancellation or curtailment of a display, is the best way to ensure both a low (or near-zero) risk display and realistic expectations for the event organisers and, perhaps, the media without the pressure on the display company to carry on firing in a "the show must go on" approach.

"Fixed rule" regimes undoubtedly have the benefit of simplicity, but we do not believe that they always highlight all of the risks involved, be they high hazard/low frequency or low hazard/high frequency.

Of course, the obvious question that arises from this is "What is an acceptable level of risk?". This depends on several factors and it would be presumptuous to dictate what levels of risk are acceptable in different countries and at different events. However the following should be considered by event organisers and enforcing authorities, and hence by display designers in determining appropriate fireworks for the specific event and the curtailment/cancellation criteria that are appropriate:

- The risk of fatalities (e.g. from shell failures)
- The risk of major injuries (e.g. from normal fallout)
- The risk of minor injuries (e.g. from long burning debris)
- The type of event, the location of the audience and, perhaps, the media coverage
- The scale of the event (e.g. how many shells of various calibres, fired at various angles may contribute to the risks)
- The flexibility (or not) of the site to maximise the "safety" distances
- The types and sizes of fireworks from an artistic and practical point of view.

What we are not advocating

It is important to appreciate that a risk based determination of "safety distances" does not mean that the greatest possible calculated distance from trajectory and fallout modelling must be used in deciding where an audience should be positioned (or more likely what maximum shell calibre and firing angles are appropriate).

A risk based approach seeks to quantify the risks and to accept that the risks are reduced to acceptable levels – but recognises that they are not eliminated.

For some shows it may be necessary to reduce the risks to as near zero as possible, but this is a fundamental decision which must be taken early by the event organisers and the contractors. It is not acceptable to make late changes under pressure to perform.

Sensible and systematic assessment of the risks from a display must be done at the planning stages, and ideally contingency planning built into the display so that clear objective criteria may be developed and "signed off" to curtail or even cancel a display.

For small events simple distance tables may be appropriate (but necessarily pessimistic) but for the largest displays, where the planning timescales and the nature of the event allow proper risk assessments to determine the distances to address both high frequency/low hazard events and low frequency/high hazard events, a more rigorous approach is both necessary and justified.

It is neither practical nor sensible to require display operators to be running ShellCalc© or similar programs at the display site just as the show is about to be fired. Planning is necessarily before the display even starts and ideally all parties are "signed up" to what curtailment or cancellation criteria are appropriate for the site and the display in question. However we recognise that for smaller displays, where there is not the requirement for such in-depth planning, the display operators could use a simple tool on site given the ubiquity of smartphones and tablets.

Debris and Fallout Distances

Enter "Safety" Distance (SD)			200	m - highlighted cells are >SD					Force	0	1	2	3	4	5	6	7	8
									m/s	0	1	2.5	5	7.5	10	12.5	15	17.5
				Bursts - Shellcalc©		Blinds - Shellcalc©			knots	0	2	5	8	13	19	24	29	34
Shell calibre (mm)	Firing Angle (deg)	Burst height (m)	Debris Fall time (s)	range (m)	max range (m)	range (m)	max range (m)	Burst diameter (m)	Max star distance (m)	Normal debris distance (downwind) related to windspeed								
75	0	154	11.3	0	25	0	40	75	78	13	24	41	69	97	126	154	182	210
100	0	183	13.5	0	30	0	49	100	99	15	29	49	83	116	150	184	218	251
125	0	208	15.3	0	35	0	57	123	119	18	33	56	94	132	171	209	247	285
150	0	230	16.9	0	38	0	65	150	140	19	36	61	104	146	188	230	273	315
200	0	267	19.7	0	45	0	78	200	178	23	42	72	121	170	220	269	318	367
250	0	298	21.9	0	50	0	89	250	214	25	47	80	135	189	244	299	354	408
300	0	324	23.9	0	55	0	100	300	250	28	51	87	147	207	267	326	386	446
75	10	150	11.0	40	65	66	101	75	139	33	44	60	88	115	143	170	198	225
100	10	178	13.1	50	80	81	123	100	173	40	53	73	106	138	171	204	237	269
125	10	203	14.9	55	90	94	144	123	206	45	60	82	120	157	194	231	269	306
150	10	224	16.5	65	100	106	162	150	237	50	67	91	133	174	215	256	298	339
200	10	260	19.1	75	120	127	194	200	294	60	79	108	156	203	251	299	347	394
250	10	290	21.4	85	135	146	223	250	348	68	89	121	175	228	282	335	389	442
300	10	315	23.2	90	150	163	249	300	399	75	98	133	191	249	307	365	423	481
75	20	139	10.2	80	105	122	150	75	188	53	63	78	104	129	155	180	206	231
100	20	165	12.2	95	125	149	183	100	233	63	75	93	124	154	185	215	246	276
125	20	187	13.8	112	142	173	212	123	274	71	85	106	140	175	209	244	278	313
150	20	207	15.2	125	175	195	239	150	314	88	103	126	164	202	240	278	316	354
200	20	239	17.6	150	190	235	288	200	388	95	113	139	183	227	271	315	359	403
250	20	267	19.7	165	215	269	329	250	454	108	127	157	206	255	305	354	403	452
300	20	290	21.4	185	235	301	367	300	517	118	139	171	225	278	332	385	439	492
75	30	122	9.0	115	135	166	186	75	224	68	77	90	113	135	158	180	203	225
100	30	145	10.7	140	165	202	226	100	276	83	93	109	136	163	190	216	243	270
125	30	164	12.1	160	190	235	263	123	325	95	107	125	156	186	216	246	277	307
150	30	180	13.3	180	210	264	295	150	370	105	118	138	172	205	238	271	305	338
200	30	208	15.3	215	250	317	354	200	454	125	140	163	202	240	278	316	355	393
250	30	232	17.1	240	280	364	405	250	530	140	157	183	226	268	311	354	397	439
300	30	252	18.6	265	310	404	450	300	600	155	174	202	248	295	341	388	434	481
75	45	89	6.6	160	175	207	216	75	254	88	94	104	121	137	154	170	187	203
100	45	105	7.7	195	210	251	260	100	310	105	113	124	144	163	182	201	221	240
125	45	118	8.7	225	240	291	300	123	362	120	129	142	164	185	207	229	251	272
150	45	130	9.6	245	265	327	337	150	412	133	142	157	181	205	229	253	277	301
200	45	149	11.0	295	320	390	399	200	499	160	171	188	215	243	270	298	325	353
250	45	165	12.2	330	360	443	455	250	580	180	192	211	241	272	302	333	363	394
300	45	178	13.1	170	400	492	503	300	653	200	213	233	266	298	331	364	397	429
				Note 1	Notes 1&5	Note 2	Note 2		Note 3	Note 4				Note 5				

Figure 4. *Simple spreadsheet to highlight "safety distances" on site.*

Figure 4 shows a simple Excel© spreadsheet developed by the authors for such a purpose. It takes values from trials and ShellCalc© and allows user-input of a single parameter – the "Safety Distance". It then colours (by conditional formatting) those items whose distances exceed the input value.

Conclusions

The variety of systems in use throughout the world inevitably is led by varying historic custom and practice as well as revision post-incident investigation.

In general we have identified that there are low frequency/high hazard events which exceed the distances in most countries, sometimes significantly. However we believe that a proper appreciation of the potential risks, and a sound relationship between event organisers, enforcing authorities and the display companies, do not mean that the maximum distances have always to be applied.

References

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2 Christian Lohrer, *JPyro*, Issue 32, 2014, pp. 38–51.

3 EN 16261:2013 Standard series for Pyrotechnic articles – Fireworks, Category 4, consisting of four parts, CEN/TC 212 WG2, 2013.

4 BS7714 – available from BSI Publications.

5 Tom Smith, *JPyro*, Issue 29, 2010, pp. 12–31 (http://www.jpyro.com/wp/?p=1164)

6 NFPA 1123 is available from http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=1123

7 *Display Fireworks Manual 2010* available from http://www.nrcan.gc.ca/explosives/fireworks/9903

8 Safe use of outdoor fireworks in Western Australia is available from http://www.dmp.wa.gov.au/documents/Code_of_Practice/DGS_COP_SafeOutdoorFireworks.pdf

9 See for example http://www.huffingtonpost.com/2013/07/08/simi-valley-fireworks-accident_n_3561811.html

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11 T. Smith, *Firework Displays: Explosive Entertainment*, ISBN: 0820600903; see http://www.fd-ee.com