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When Is Wind Speed Excessive for the Safe Display of Fireworks?

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While working on the 2006 edition of NFPA-1123 *Code for Fireworks Display*, the Technical Committee on Pyrotechnics of the National Fire Protection Association (NFPA) received a request for a "Formal Interpretation" regarding the 2000 edition of the code. In effect, a request for a Formal Interpretation is a request for the committee to provide clarification or a ruling regarding one or more paragraphs in the code. According to NFPA practice, a request for a Formal Interpretation must always be phrased in such a way that it can be answered either "yes" or "no". This article addresses that request for a Formal Interpretation and was written because: 1) the question being posed was reasonable and important; 2) a simple yes or no will not meet the needs of the requestor; and 3) to stimulate a discussion of the issue, such that the display fireworks industry might then provide guidance to the committee before they address the issue at their next committee meeting.

The paragraph of interest to the requestor was:

> *5.1.4.2 If high winds, precipitation, or other adverse weather conditions prevail such that a significant hazard exists in the opinion of the operator or the authority having jurisdiction, the fireworks display shall be postponed until the weather conditions improve to a reasonable level.*

Apparently because the code gives no guidance as to how much wind is too much wind, the Formal Interpretation requestor asked (yes or no):

> *Given the following conditions: (1) The display site meets the minimum separation distances in Table 3.1.3 and no additional separation distance is provided between the display site and spectator viewing area; and (2) The display site is on the same elevation with the spectator viewing area; and (3) the other minimum code requirements of NFPA 1123 have been met. Is it the intent of paragraph 5.1.4.2 to postpone a fireworks display if the maximum continuous wind speed exceeds 5 mph?*

The requestor then asked the same question, but for 10, 15 and 20 mph (16, 24 and 32 k/hr) wind speeds.

As readers of *Fireworks Business* certainly know, there may be cases where even a 5 mph (8 k/hr) wind might be excessive and yet other cases where a 20 mph (32 k/hr) wind is not excessive (at least in terms of safety). Thus, there are no simple answers for the requestor of the Formal Interpretation, and the requestor is unlikely to find the committee's response will have supplied the information being sought. All this notwithstanding, the committee (and the industry) should probably be grateful to the requestor for raising the issue. It is appropriate for the code to provide guidance for the enforcing authority regarding what constitutes excessive wind, and it is likely that such guidance will now be crafted and added as advisory information to the next edition of the code. The remainder of this article is devoted to presenting background information about aerial shell and shell debris ballistics, discussing the specific question about excessive wind, and then suggesting guidance to be considered for possible inclusion in the code by the committee.

Technical Background

If the wind is blowing away from the spectator viewing area (or all spectator viewing areas) the chance of hazardous debris posing a risk to spectators is reduced. If the wind is blowing toward the spectator viewing area (or any spectator viewing area) the chance of hazardous debris posing a risk to spectators is increased. As an additional consideration, the displacement downwind for debris from exploded aerial fireworks will be much greater than for dud shells. (This is because the mass of the debris is relatively low and their drag coefficient is relatively high, as compared to dud shells). See Figure 1, which is a computer calculation[1] of the trajectory of a typical 6-inch aerial shell fired from a mortar tilted 6.6 degrees into a 40 mph (64 k/hr) wind.[2] Each symbol identifies the location of the aerial shell (triangles) and a substantial piece of debris from the exploded shell (diamonds) after successive one second intervals have elapsed. Note that this mortar tilt angle is sufficient to compensate for the effect of the wind to the extent that the aerial shell reaches its apex directly above the mortar (not considering shell drift[3] from bore balloting[4] and Magnus forces). The point of fall of the dud shell (assuming it does not explode near its apex) is calculated to be approximately 200 feet (61 m) downwind from the mortar. The point of fall of a substantial piece of shell debris is approximately 800 feet (244 m) down range (assuming the shell explodes near its apex). (The substantial piece of shell debris in this case has a mass that is approximately 3% of the shell's total mass upon firing, which corresponds to approximately 1/3 of one hemisphere of the shell's casing.) Such a substantial piece of shell debris was chosen because it is about the most massive single piece of debris that is likely to be produced from a normally effective star shell burst. Note that lighter weight shell debris will come to fall even further downwind. (As a point of comparison, this piece of debris will come to fall at a point that is about twice the minimum separation distance (from the spectators to the mortar), which is only 420 feet [128 m].)

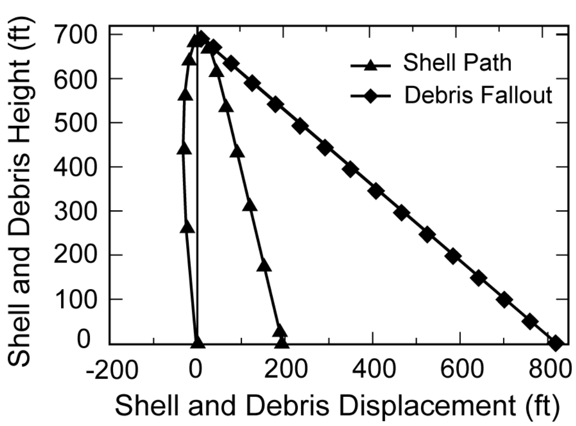

Figure 1. A graphical representation of the trajectory of an aerial shell fired from a mortar angled slightly into a strong wind (40 mph [64 k/hr].

A third category of material might have been considered in Figure 1; that is dud components from exploded shells. Based on their typical mass and size, these dud components would be expected to fall to the ground somewhere between the points of fall of dud shells and the more massive pieces of debris from exploded shells.

Figure 1 helps to make the point that while skilled mortar angling may be able to compensate for the effect of a significant wind on (1) the location of the apex of the shell, (2) the point of fall of a dud shell, or (3) the point of fall of substantial shell debris; it is not possible to fully compensate for more than one of these effects at the same time, as documented in Table 1. A mortar tilt of 13 degrees into the wind will compensate for where a dud shell will land, but the relatively heavy debris will still fall 650 feet (198 m) downwind. To fully compensate for the heavy debris would require a mortar tilt angle of approximately 40 degrees into the wind, but that tilt angle will result in a dud shell falling at a point nearly 600 feet (183 m) up wind.

Table 1. Displacements Downwind for Selected Mortar Tilt Angles into the Wind.

Mortar Tilt Angle (deg)	Displacement Downwind (ft)		
	Shell at Apogee	Dud Shell at Impact	Debris Fallout
6.6	0	195	820
13.0	–115	0	650
39.1	–460	–590	0

(Negative displacements are upwind from the point of discharge.)

The inability to simultaneously compensate for the points of fall for both dud shells and debris, even with the most skilled angling of the mortars, is one reason for concern when attempting to perform a display when there is a significant wind. While on the subject of skilled mortar angling, Tables 2 and 3 are offered for possible assistance. Table 2 gives calculated results for the approximate average downwind displacement in the point of fall of typical dud 3-, 6- and 12-inch (75-, 150- and 300-mm) aerial shells, as a function of wind speed for displays fired from sites approximately 1000 feet (305 m) above sea level. (The amount of displacement for other wind speeds and other size shells can be estimated by interpolation.) Table 3 gives calculated results for the approximate average down range shift in the point of fall of typical dud 3-, 6-, and 12-inch (75-, 150- and 300-mm) spherical aerial shells, as a function of mortar tilt angle (as measured from vertical).

Table 2. Calculated Approximate Average Downwind Displacement of Dud Spherical Shells Based on Wind Speed.[2]

Wind Speed (mph)	Downwind Displacements by Shell Size					
	3 in. (ft)	75 mm (m)	6 in. (ft)	150 mm (m)	12 in. (ft)	300 mm (m)
0	0	0	0	0	0	0
5	49	15	53	16	56	17
10	98	30	105	32	113	34
15	147	45	158	48	170	52
20	197	60	212	65	227	69
25	245	75	266	81	285	87

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

Table 3. Calculated Approximate Average Down Range Displacement of Dud Spherical Shells Based on Mortar Tilt Angle.[2]

Mortar Tilt Angle (deg.)	Down Range Displacements by Shell Size					
	3 in. (ft)	75 mm (m)	6 in. (ft)	150 mm (m)	12 in. (ft)	300 mm (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	203	1130	345

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

By comparing Tables 2 and 3, one can conclude that the approximate amount of mortar tilt needed to correct the point of fall of dud shells for each 5 mph (8 k/hr) of wind speed is that indicated in Table 4. One complicating factor for making such corrections for wind is the difficulty in accurately achieving such small tilt angles. However, an even greater problem is that it is the average wind aloft, and not that at ground level, that needs to be compensated for. Because of obstructing near surface objects such as trees and houses, the wind speed at ground level will almost always be less than the winds aloft. As a way of crudely estimating wind speed aloft, one might assume as a very rough rule-of-thumb that the wind aloft is about twice the speed at ground level.

Table 4. Calculated Approximate Mortar Tilt from Vertical for Each 5 mph (8 k/hr) of Wind Speed Needed To Compensate for Downwind Displacement of Dud Aerial Shells.

Shell Size (in.)	Shell Size (mm)	Approximate Mortar Tilt Angle into the Wind (degrees)
3	75	2.4
6	150	1.4
12	300	0.9

Discussion

There probably are two main areas in which excessive wind represents a safety concern: 1) when hazardous debris is carried to and falls into a spectator area because of the wind, and 2) when there is a risk of fire that is significantly exacerbated as a result of it being more difficult to control because of the wind.

The first area of concern, hazardous debris reaching spectators, is relatively easy to address. There are three main types of hazardous debris that are of primary concern, debris from exploded shells, dud components from exploded shells and dud (unexploded) shells. Generally of least concern are the debris from exploded shells; the next greater concern is for any dud components from exploded aerial shells; of much greater concern are dud aerial shells (which can cause serious injury if striking a person, or which might ignite upon impact with the ground).

In discussing this, recall that in addition to meeting the separation distance requirement, the requestor of the Formal Interpretation included the provision that the other minimum code requirements of NFPA 1123 (2000) have been met. Accordingly, code paragraphs 2.3.2 and 5.1.4.3 will have been (and presumably are being) complied with. These code paragraphs state that:

> *2.3.2 … Under no circumstance shall mortars be angled toward the spectator viewing area.* …; and

> *5.1.4.3 … If any unsafe condition is detected, such as hazardous debris falling into the audience, the spotter shall signal the shooter to cease firing until the unsafe condition is corrected. …*

That the downwind displacement is greater for the debris from exploded aerials shells than it is for dud components, and it is significantly greater than for dud shells is important in the context of determining when wind speed is too great for reasonable safety. This is because, while the smoldering debris from exploded shells is relatively easy to spot at night, falling dud components and dud aerial shells are not. Thus, before a wind is blowing strong enough to significantly increase the probability of a dud component or a dud shell falling into a spectator area, relatively easily visible smoldering debris will likely be seen to approach dangerously close or into spectator areas, thus causing the display to be halted at that time. That is to say, in the context of this question, if smoldering debris is not being driven into spectator areas by the wind, then neither will the more dangerous dud components.

There is, however, still the question of how one can easily determine, before a display has started, whether a wind blowing toward a spectator area is excessive. In that case, it may be necessary to draw upon the experience of the operator (and hopefully the enforcing authority) as to whether it is safe to begin the display. As an alternative, one or more small caliber test shells might be fired and their performance used as a guide in determining whether it is safe to begin the display. Similarly, displays typically start with relatively small caliber shells, whose debris is generally less dangerous and whose down range displacement by the wind will generally be slightly less than for larger shells. Thus, if there is uncertainty as to whether the wind is excessive, a display might be started, closely observed, and then halted at such time as it becomes apparent that an unsafe condition exists for the firing of larger shells.

The second area of concern regarding potentially excessive wind for a fireworks display is in regard to the potential difficulty in controlling a fire that might be ignited by the display. In this case, both the direction and speed of the wind are important considerations. Wind direction has a controlling effect on what might be set alight by burning or smoldering fallout, and wind speed can strongly affect the rate of spread of a fire once started. Addressing these issues generally lies squarely with the local fire authority, and it is pretty much their call as to whether the wind conditions are safe enough to proceed with a display from a fire safety standpoint. However, it should be considered that it may be possible to mitigate a fire safety problem by means other than postponing the display.

Suggestion

Because at the time, the Pyrotechnic Committee was nearly beyond the point in the revision process where the public can comment on adjustments made to the code, it seems prudent that the issue regarding excessive wind should only be addressed in Annex A (formerly Appendix A) of the code, which is for non-binding guidance. Accordingly, as a starting point for work by the committee, the following text was offered as a possible annex note to NFPA-1123 code paragraph 5.1.4.2.

> *A.5.1.4.2 In considering when wind speed is excessive for the reasonably safe performance of a fireworks display, there are two primary considerations (1) the potential for an increased risk of hazardous debris from the display falling into spectator areas, and (2) the potential for an increased probability of a fire*

that is made excessively difficult to control. Under some extreme conditions, winds as slight as 5 mph might pose a problem; while under other conditions winds in excess of 20 mph may not pose a problem.

An increased fallout hazard only occurs when the wind is traveling in a direction toward one or more spectator areas. What is probably the least dangerous debris, smoldering remnants from exploding aerial shells, is the type of fallout that is most greatly affected by wind and is the easiest to observe. Accordingly, if such smoldering debris is not seen to fall dangerously near or into any spectator area, the wind is unlikely to be excessive regarding more dangerous fallout from the display. However, when the wind is a problem, there are some possible mitigation strategies that might be considered regarding hazardous fallout. These are: to move the spectators out of the path of the fallout, to redirect the fallout by moving the fireworks or re-angling the mortars, to increase the separation distance between the fireworks and spectators, to modify the content of the display to eliminate the fireworks of greatest concern, and to delay the display until weather conditions have improved.

Any increased fire hazard because of the wind is best evaluated by the local fire authority and is not addressed in this code. If the wind is found to be a problem in this regard, some possible mitigation strategies to be considered regarding fire risk are: to water down the areas and items of concern immediately before the display, to modify the content of the display so as to eliminate the fireworks of greatest concern, to increase the amount of fire suppression equipment and personnel in the immediate area, and to delay the display until weather conditions have improved.

(Any readers wishing to comment regarding this issue, and whose interests are represented by one of the fireworks groups or associations serving on the Pyrotechnics Committee, were encouraged to work through their representatives. Any others wishing to make input were encouraged to communicate with the authors of this article.)

References

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3) K. L. and B. J. Kosanke, "Aerial Shell Drift Effects", *Proceedings of the First International Symposium on Fireworks*, Montreal, Canada, 1992; also in *Selected Pyrotechnic Publications of K.L. and B.J. Kosanke, Part 2 (1990 through 1992),* Journal of Pyrotechnics, 1995.

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