An earlier draft appeared in *American Fireworks News*, No. 181, 1996.

Simple Measurements of Aerial Shell Performance

K. L. and B. J. Kosanke

In designing the most effective choreographed aerial fireworks displays, it is useful to know when, where, and how each shell burst will appear. To do this, in addition to aesthetic features like colors, etc., three aerial shell performance parameters are needed. These parameters are: time to shell burst after firing, burst height above the ground, and burst spread. It can be difficult and expensive to generate these. However, all three can be generated using a slightly modified video camera and videocassette recorder (VCR). Further, it will generally be possible to collect the raw information during the performance of actual displays; so there is no cost for the test fireworks. This article suggests a method to gather shell performance data.

The setup for making the video recording is illustrated in Figure 1. A video camera is mounted on a tripod, located in the general vicinity of the firing mortars[(a)] and aimed vertically to record the shell bursts. A typical camera, when set on its maximum wide-angle setting, has an approximately 40º field of view. The burst radius of hard breaking spherical shells is about 45 feet per shell inch[1,2] and burst heights are about 120 feet per shell inch.[3] This corresponds to an approximately 40º-spread angle. (See Figure 2.) Because of shell drift,[4] bursts will occur somewhat shifted from the point directly in line with the mortar. To be able to calculate a shell's performance characteristics, it is only necessary to capture the central point of the shell burst and its maximum spread in at least one direction (see Figure 3). However, to improve the chances of capturing a sufficient portion of the shell breaks in the video image, an inexpensive (≈$20) wide-angle adapter can be added to the camera lens. This should increase the wide-angle field of view to about 50º.

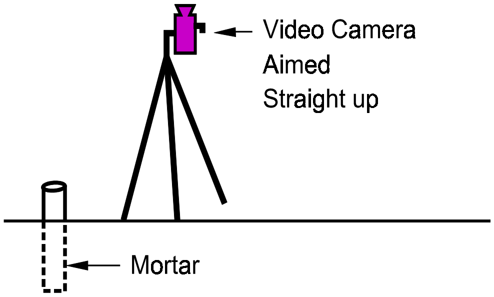

Figure 1. Illustration of basic setup for making shell performance measurements.

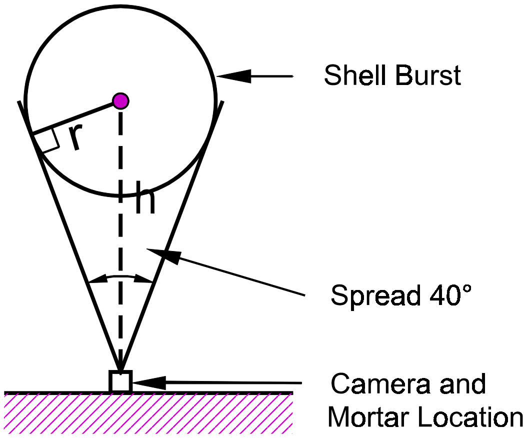

Figure 2. Geometry of a typical hard breaking spherical shell.

In the following discussion, it is assumed that the VCR has a time counter (in seconds), a counter reset button, and the ability to advance the tape by individual video fields.[(b)] It is possible to perform the operations described below without these features; however, that requires a stop watch, would be more difficult, and is less accurate.

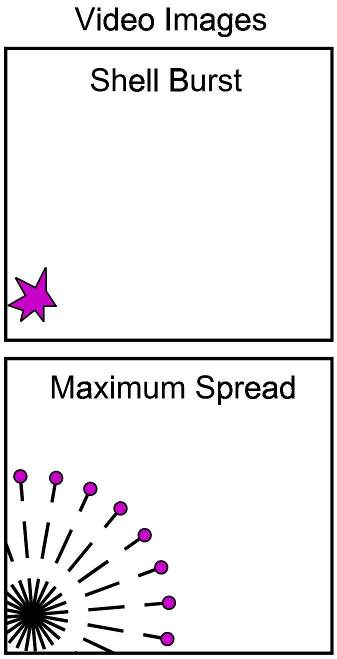

Figure 3. Illustration of the minimum video image requirement to be able to calculate shell performance characteristics.

Time to Shell Burst

Time to shell burst is the simplest performance characteristic to determine. Using the time counter on the VCR, start timing by pushing the reset button when the shell fires from the mortar. Use either the muzzle flash from the firing (if this can be seen) or the sound of the firing. (Because of the relative closeness of the camera to the mortar, the flash and sound will be essentially simultaneous.) Next, advance the videotape to the point where the shell bursts, and note the time (T_s) on the tape counter. This is the time to shell burst in seconds, rounded down to the next lowest integer. To determine the additional fraction of a second, advance the VCR field by field, counting the number of images (n) until the time counter increases to the next second. The shell burst delay time (T_b) is then

$$T_b = T_s + \left(1 - \frac{n}{60}\right)\text{seconds} \qquad (1)$$

Shell Burst Height

One way to determine the height of the shell burst is to measure the time lapse between the appearance of the first light from the shell burst and the arrival of the sound of the burst. (Reference 6 presents a more complete description of the basis for this method.) To be able to make this determination using a video camera and VCR, a slight modification is necessary. Almost all VCR's block the sound when advancing the tape field by field; thus this feature needs to be defeated. (It cost the authors $60 to have a video repair shop add a switch to their VCR to accomplish this.)

To measure burst heights, the videotape is advanced to the first field with light appearing from the shell burst. At this point, the time counter reset button should be pushed. Next, listening to the sound produced with each advancing field, count the number of fields (m) until the sound of the shell burst is heard. This is not as easy as it might seem. Even when there is essentially no background sound, with each advance of the tape, a sound (something like "chuff") will be heard. The time of arrival of the shell burst sound will be when the chuff sound is suddenly noticeably louder. Identification of when this occurs is made easier if the listener knows about when to expect it. (For 3 or 4-inch shells the time of arrival will be after approximately 25 fields; for 5 or 6-inch shells it will be after approximately 35 fields; and for 8 to 12-inch shells, it will be after approximately 50 fields.) Shell burst height (H_b) is then

$$H_b = m \cdot D_s \qquad (2)$$

where D_s is approximately 19 feet, the distance sound travels in 1/60 second.(c) Because these times are only determined to the nearest 1/60 second, there will be an uncertainly in burst height averaging about 20 feet.

Shell Burst Spread

To determine a shell's spread, it is necessary first to calibrate the video camera's field of view as presented on the TV monitor to be used. To do this, a video recording must be made of (at least) two objects approximately perpendicular to the view of the camera, at a known distance from the camera (D_c) and a known width (W_c) between the two objects. Preferably, the two objects will appear somewhere near the center of the TV monitor screen.(d) The use of two burning highway flares is often convenient for this. The camera must be set for the maximum wide-angle setting (just as when recording the shell bursts). When the calibration scene is played back, the distance between the two markers as seen on the TV screen—the screen calibration distance (S_c)—is measured. A thin transparent ruler may be convenient for this. The needed calibration constant (K) is

$$K = \frac{W_c}{S_c \cdot D_c} \tag{3}$$

When the playback of a shell burst is observed, and the burst-spread distance on the screen is measured (S_b), the width of the burst spread in the air (W_b) is

$$W_b = S_b \cdot H_b \cdot K \tag{4}$$

Recall that H_b is the previously determined shell burst height. Note that the measured, calibrated distances W_c and D_c must be in the same units (e.g., feet), as are the measurements from

Table 1. Five-Inch Aerial Shell Performance Values.

Shell Name	Brand	Burst Time(a) (s)	Time to Sound(b) (fields)	Burst Height(c) (feet)	Radial Spread(d) (inches)	Burst Radius(e) (feet)
Red Silk	Horse	4.4	36	680	n/a(f)	n/a(f)
White Rose	Horse	4.0	38	720	3.5	140
Green Peony	Horse	4.5	39	740	3.9	160
Red Peony	Horse	3.7	26	490	6.2	170
Red Peony	Horse	3.8	36	680	3.3	130
Average		4.1		660		150
Std. Dev.(g)		0.4		100		20
Double Ring	Sunny	3.8	34	650	3.5	130
Double Ring	Sunny	3.7	36	680	2.7	100
Double Ring	Sunny	3.9	39	740	2.8	120
Double Ring	Sunny	3.9	39	740	2.8	120
Average		3.8		700		120
Std. Dev.(g)		0.1		40		10

(a) This is the time in seconds between the shell firing from the mortar and its bursting, and was calculated using equation 1. Burst times are reported to the nearest 0.1 second.

(b) This is the time in video fields (in this case 1 field = 1/60 s) between the first light from the shell break and the arrival of the sound.

(c) This is the height of the shell burst, calculated using equation 2 using a speed of sound of 19 feet per 1/60 second. Burst heights are reported to the nearest 10 feet.

(d) This is the maximum radial spread of the stars, as measured in inches on the screen of the TV monitor.

(e) This is the maximum radial spread of the stars, calculated using equation 4. The calibration constant K was equal to 0.0056/inch, and was calculated using equation 3. Burst radii are reported to the nearest 10 feet.

(f) This was a very weak breaking (poka) shell dispersing sizzling red stars. The burst spread was too small to be included appropriately with the other hard breaking (warimono) shells.

(g) Because of the limited amount of data, the standard deviations were determined using the so-called *n*–1 method.

the TV monitor S_c and S_b (e.g., inches or centimeters), and that burst width W_b will have the same units as W_c and D_c.

The shell burst dimension determined using equation 4 is the "apparent" dimension as seen at the location of the camera. Because of a geometrical effect, which is described in reference 2, this over estimates the true burst dimension by approximately 6%. If desired, the true shell burst dimension (W_t) can be calculated using equation 5.

$$W_t = W_b \sin\left[\tan^{-1}\left(\frac{H_b}{W_b}\right)\right] \qquad (5)$$

Performance Measurements

A collection of 5-inch aerial shells was fired for the purpose of measuring the performance parameters discussed above. The results are presented in Table 1. This testing was performed in western Colorado, at an elevation of approximately 4600 feet. (Note that because of the relatively high elevation, there is a little less aerodynamic drag acting on the shells after they leave the mortar. This allows the shells and stars to travel a little further than would be the case nearer sea level.) For each shell performance parameter, the Sunny brand shells behaved more consistently than the Horse brand shells. While this is not unexpected, given the reputation of the two shell brands, because of the limited number of test shells fired, it cannot be assumed that this will always be the case.

Conclusion

One could spend a considerable sum of money on the equipment and test shells to make the above measurements. However, using the method suggested, the cost for equipment is minimal (if you already have access to a camcorder and VCR), and there need be no cost for test shells (if data is collected during displays). Further, any hobbyist collecting and publishing such shell performance data would be doing a service to the industry.

Notes

a) It is not absolutely necessary that the video camera be relatively close to the mortar. However, some calculations will be easier to perform and some results will be more accurate if it is close.

b) The difference between a field by field VCR (sometimes called an AB VCR), which displays 60 video images per second, and a frame by frame VCR (sometimes called an AA VCR), which displays only 30 video images per second, is explained more fully in reference 5.

c) The speed of sound (i.e., D_s) depends on temperature. At 50 °F, D_s is 18.4 feet; at 68 °F, D_s is 18.8 feet; and at 86 °F, D_s is 19.1 feet. These values are derived from reference 7.

d) Color TV monitors can generally be relied upon to be approximately linear with respect to the horizontal and vertical scale of images. However, black and white monitors may not be sufficiently linear for reasonably accurate results. If desired, a simple test can be performed by video taping a piece of graph paper and measuring the linearity when viewed on the TV monitor.

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