Bullet Impact Sensitivity Testing of Class B Fireworks and Ingredients and Detonability Testing of Flash Powders

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Introduction

The Treasury Department's Bureau of Alcohol, Tobacco and Firearms (BATF) requested the Bureau of Mines to perform bullet impact sensitivity tests on a selection of class B (display) fireworks shells and some ingredients thereof (flash powder, "stars"), and also to establish that the flash powder used in salute shells is a detonable material, something which is widely presumed but apparently not documented.

The fireworks and ingredients to be tested were procured by BATF from two different domestic suppliers and included a variety of foreign as well as domestic shells, two different flash powder compositions, and two different kinds of "stars."

Suppliers of the shells and ingredients are designated in this report as Manufacturer K and Manufacturer M.

In most cases, there was only one shell of each kind; where more than one shell of the same kind was available, the shell was impacted in two different orientations: through the center of the lateral surface when seated vertically, and through the center of the bottom when lying on its side. In a very few cases there were more than two shells, and in these cases a replicate shot using the shell in one or the other of these orientations was performed. Manufacturer K supplied shells in both the "lifted" and "unlifted" form. "Lifted" refers to the inclusion of a small charge (several grams to a few ounces depending on the size of the shell) of coarse black powder which serves as the propellant charge to eject the shell from the mortar for aerial displays.

Description of Tests/Results

Bullet Impact Tests

The bullet impact sensitivity test used was that implied in Institute of Makers of Explosives (IME) Safety Library Publication No. 3 ("Suggested Code of Regulations for the Manufacture, Transportation, Storage, Sale, Possession and Use of Explosive Materials"): the sample is subjected to the impact of a 150 gr, .30 caliber ball ammunition having a nominal muzzle velocity of 2700 ft per second (i.e., .30-06 M2 ammunition) fired from a distance of 100 ft, with the sample against a 0.5 in. steel backing plate.

The charge stand was made from 8 in. × 8 in. × 24 in. oak lumber; for most of the firings, in addition to the backing plate behind the sample the sample was set on a 6 in. × 6 in. × 0.125 in. mild steel witness plate to serve as additional diagnostic for the violence of the reaction. A sketch of the charge stand is shown in Figure 1.

No instrumentation was used in the bullet impact sensitivity tests except that all firings were recorded by color video camera and tape recorder.

Those samples (i.e., the flash powders and "stars") that were provided in bulk were packed in 3.4 in. in diameter × 3.4 in. high (1 pint) cylindrical pasteboard cartons for the tests. (It may be noted here that manufacturer M's "stars" do

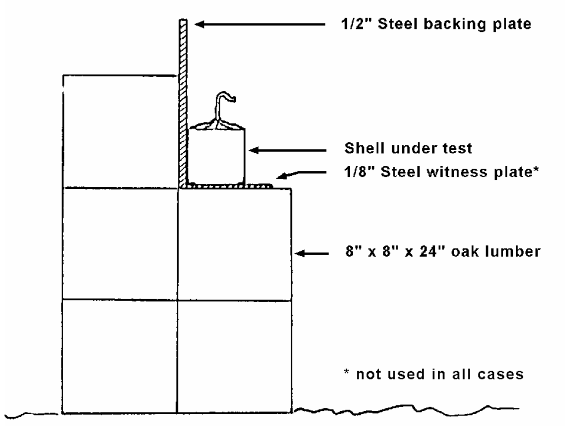

Figure 1. Test setup for bullet impact sensitivity.

not resemble the stars used by any other manufacturer within the authors' experience. They are approximately 1.3 in. outside diameter × 1.3 in. long cylindrical pellets with a 0.3 in. diameter axial hole, and look exactly like the black powder pellets from a cartridge of "pellet powder." They burn very slowly and neither brightly nor colorfully.)

All of the samples without exception were ignited by the impact of the bullet, and most exploded with greater or lesser violence. Detailed results are given in Table 1. (Note: in Table 1 the firing numbers are keyed to the numbering of the firings on the video tape.) Generally speaking, the results were not particularly violent except for the salute shells and flash powder. Table 1 includes a subjective impression of the intensity of the flash and report.

In a few cases, two shells were placed side by side, only one being impacted by the bullet, to determine whether the explosion of the first shell could propagate to its neighbors; in all cases the second shell exploded, but in the case of star shells there was a 1 to 2 s delay: evidently the explosion of the first shell merely lit the fuse of the second; with salute shells however, the explosion of the two shells was, as nearly as can be resolved by the human ear, simultaneous.

Damage to the witness plate, indicating a mode of reaction which either is or approximates detonation was observed only for salute shells, the flash powder ingredient of salute shells, or shells which contained a salute component.

Detonation Rate Determination: Flash Powder

Attempts were made to determine the detonation rate of each of the flash powder compositions supplied by manufacturers K and M. For this purpose a sample of the flash powder was placed in polymethylmethacrylate tube 2.5 in. in outside diameter and 12 in. long, having a wall thickness of 0.25 in., closed at the bottom end with a sheet of the same material 0.25 in. thick cemented to the tube bottom; a Hercules J-2 detonator was inserted through a hole in the center of the bottom plate. The flash powder was loaded to the density obtained by sharply tapping the container several times during filling. This density was approximately 0.8 g/cc. Two methods were used to determine the detonation rate. In one, a continuous rate probe[1] was inserted down the inner wall of the plastic tube. This probe contains an inner core of insulated resistance wire and an outer sheath of thin-wall aluminum tubing crimped to the core at the bottom. As a shock or detonation wave moves up the tubing, the latter crushes through the insulation of the wire—the effect is that one has a slide wire rheostat whose length and electrical resistance are proportional to the distance from the shock/ detonation wave to the upper end. If a constant current is applied between the tubing and the resistance wire, a voltage proportional to this distance is obtained and may be recorded oscillographically.

The other method used was to photograph the detonation with a high-speed framing camera operating at a known framing rate against a background containing distance markers.

Table 1. Results of Bullet Impact Sensitivity Tests.

Firing No.	Mfr.	Shell Type	Impact Model[1]	Shell Burst	Contents Ignited	Report
IA	K	3" Star, lifted	L	Yes	Yes	Mild
1B	K	3" Star, lifted	L	Yes	Yes	Mild
1C	K	3" Star, lifted	B	Yes	Yes	Mild
2A	K	3" Star, unlifted	L	Yes	Yes	Mild
2B	K	3" Star, unlifted	L	Yes	Yes	Mild
2C	K	3" Star, unlifted	L	Yes	Yes	Mild
3A	K	6" Star (yellow & green) lifted	L	Yes	Yes	Mild
3B	K	6" Star, red, lifted	L	Yes	Yes	Mild
3C	K	6" Star, variegated, lifted	B	Yes	Yes	Mild
4A	K	6" Star, unlifted	L	Yes	Yes	Mild
4B	K	6" Star, unlifted	L	Yes	Yes	Mild
4C	K	6" Star, unlifted	B	Yes	Yes	Mild
5A	K	Japanese 3" star, lifted	L	Yes	Yes	Mild
5B	K	Japanese 3" star, lifted	L	Yes	Yes	Mild
5C	K	Japanese 3" star, lifted	B	Yes	Yes	Mild
6A	K	Japanese 6" star, lifted	L	Yes	Yes	Violent
6B	K	Two Japanese 6" star, lifted	L[4]	Yes	Yes	Violent
7A	K	Chinese 3" star, lifted	L	Yes	Yes	Mild
7B	K	Chinese 3" star, lifted	L	Yes	Yes	Mild
7C	K	Chinese 3" star, lifted	B	Yes	Yes	Moderate
8A	K	Chinese 6" star, lifted	L	Yes	Yes	Mild
8B	K	Two Chinese 6" star, lifted	L[4]	Yes	Yes	Moderate
9A	K	3" Flash salute, lifted	L	Yes	Yes	Very loud
9B	K	Two 3" Flash salute, lifted	L[4]	Yes	Yes	Very loud
10A	K	3" Flash salute, unlifted	L	Yes	Yes	Very loud
10B	K	Two 3" Flash salute, unlifted	L[4]	Yes	Yes	Very loud
11A	K	(Cut stars)[5]	L	No	Yes	None
11B	K	(Cut stars)[4]	L	Yes	Yes	Loud
12A	K	(Flash powder)[5]	L	Yes	Yes	Violent
12B	K	(Flash powder)[5]	L	Yes	Yes	Violent
14	M	6" "R.W.S. Tit."	L	Yes	Yes	Violent
15	M	6" Color change red-to-green	L	Yes	Yes	Loud
16	M	6" No markings	L	Yes	Yes	Mild
17	M	Taiwan 6" "Red-blue to Flash Chrysanthemum"	L	Yes	Yes	Loud
18A	M	5" "Wizzer"	L	Yes	Yes	Moderate
18B	M	5" "Wizzer"	B	Yes	Yes	Moderate
19	M	5" "#508 Red-to-Glittering Silver peony"	L	Yes	Yes	Very loud

NOTES:

1 L - lateral impact; B - bottom impact (shell lying on side)

2 witness plate not used

3 no visible stars produced

4 shells side by side, only one impacted by bullet

5 in 3.4 in.×3.4 in. cylindrical carton

Table 1. Results of Bullet Impact Sensitivity Tests (continued from opposite page).

Firing No.	Mfr.	Stars Thrown	Charge Stand Destroyed	Indentation of Witness Plate	Comments
IA	K	20'	No	—[2]	
1B	K	20'	No	—[2]	
1C	K	20'	No	—[2]	
2A	K	20'	No	—[2]	
2B	K	50'	No	—[2]	
2C	K	20'	No	—[2]	
3A	K	50'	No	—[2]	Brighter flash than firings 1 or 2
3B	K	75'	No	—[2]	Brighter flash than firings 1 or 2
3C	K	100'	No	—[2]	Brighter flash than firings 1 or 2
4A	K	50'	No	—[2]	Brighter flash than firings 1 or 2
4B	K	50'	No	—[2]	Brighter flash than firings 1 or 2
4C	K	20'	No	—[2]	
5A	K	35'	No	—[2]	
5B	K	35'	No	—[2]	
5C	K	100'	No	—[2]	
6A	K	[3]	Yes	None	No flash seen
6B	K	>100'	Yes	None	Second shell exploded after delay of 1 sec.
7A	K	20'	No	None	
7B	K	50'	No	None	Brighter flash than 7A
7C	K	40'	No	None	
8A	K	30'	No	None	Stars burned more slowly than previous shots
8B	K	50'	No	None	Brighter flash than most previous shots, 2nd shell delayed 2 sec. before exploding
9A	K	[3]	Yes	0.5"	
9B	K	[3]	Yes	0.75"	Both shells fired nearly simultaneously
10A	K	[3]	Yes	0.25"	
10B	K	[3]	Yes	0.75"	Both fired nearly simultaneously
11A	K	[3]	No	No	Top of container popped off, stars and container burned quietly
11B	K	100'	No	0.4"	
12A	K	[3]	Yes	1.25"	Bright flash
12B	K	[3]	Yes	1.0"	Bright flash
14	M	[3]	Yes	—[2]	Little flash
15	M	30'	No	None	Two small secondary reports
16	M	20'	No	None	Two small secondary reports
17	M	>100'	No	None	
18A	M	[3]	No	None	
18B	M	[3]	No	None	
19	M	>100'	No	None	

Table 1. Results of Bullet Impact Sensitivity Tests (continued).

Firing No.	Mfr.	Shell Type	Impact Model[1]	Shell Burst	Contents Ignited	Report
20	M	4" Red star	L	Yes	Yes	Moderate
21	M	4" Italian star	L	Yes	Yes	Moderate
22	M	4" #725A-2 Gold rippling Chrysanthemum with rising gold tail	L	Yes	Yes	Moderate
23A 23B	M M	3" (no markings-probably a salute) 3" (no markings-probably a salute)	L B	Yes Yes	Yes Yes	Very loud Very loud
24	M	3" red-dot	L	Yes	Yes	Mild
25	M	3" "R & R"	L	Yes	Yes	Mild
26A	M	Flash Powder[5]	L	Yes	Yes	Violent
26B	M	Flash Powder[5]	B	Yes	Yes	Violent
27A	M	"stars" (see text)[5]	L	No	Yes	None
28A	M	"stars" (see text)[5]	B	No	Yes	None

NOTES: 1 L - lateral impact; B - bottom impact (shell lying on side)

2 witness plate not used

3 no visible stars produced

4 shells side by side, only one impacted by bullet

5 in 3.4 in.×3.4 in. cylindrical carton

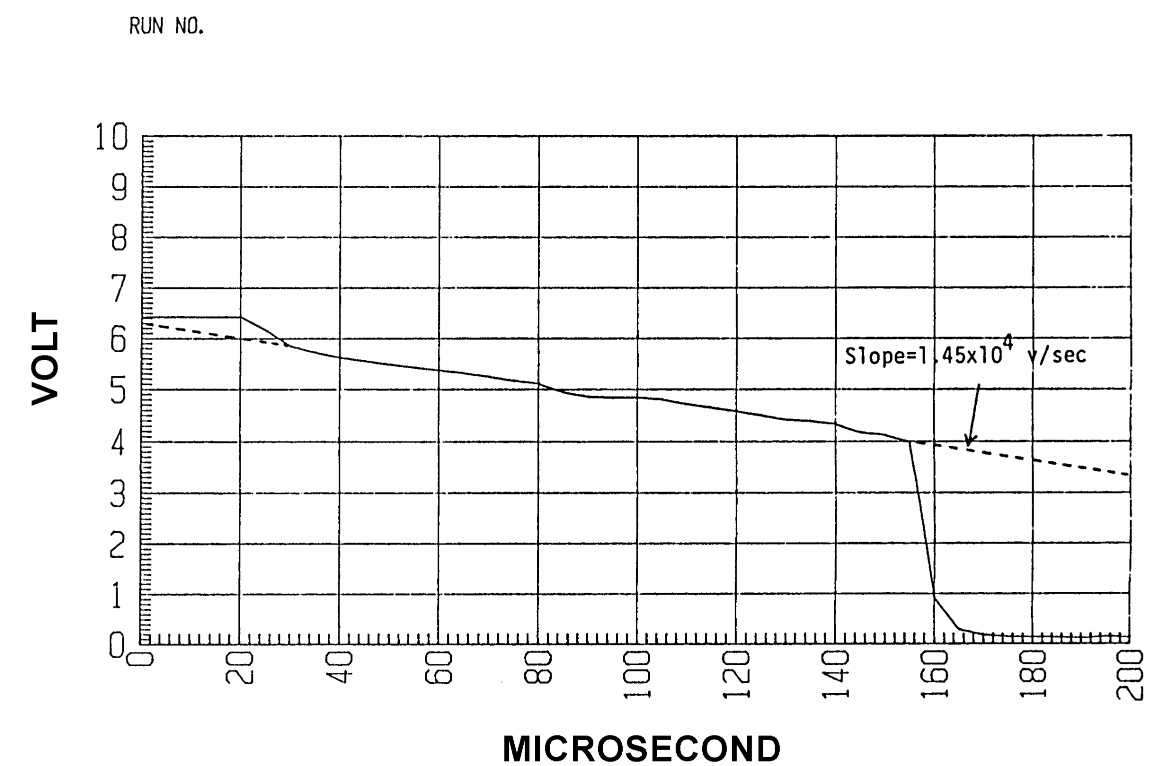

Figure 2. Oscilloscope trace of time and voltage.

Table 1. Results of Bullet Impact Sensitivity Tests (continued from opposite page).

Firing No.	Mfr.	Stars Thrown	Charge Stand Destroyed	Indentation of Witness Plate	Comments
20	M	30'	No	None	
21	M	30'	No	None	
22	M	[3]	No	No	
23A	M	[3]	Partly	0.4"	
23B	M	[3]	Partly	0.5"	
24	M	20'	No	None	
25	M	20'	No	None	
26A	M	[3]	Yes	1.8"	
26B	M	[3]	Yes	1.0"	Even backing plate was slightly bent
27A	M	[3]	No	None	some "stars" ignited and burned slowly with weak orange flame; some remained unburned
28A	M	[3]	No	None	as 27A

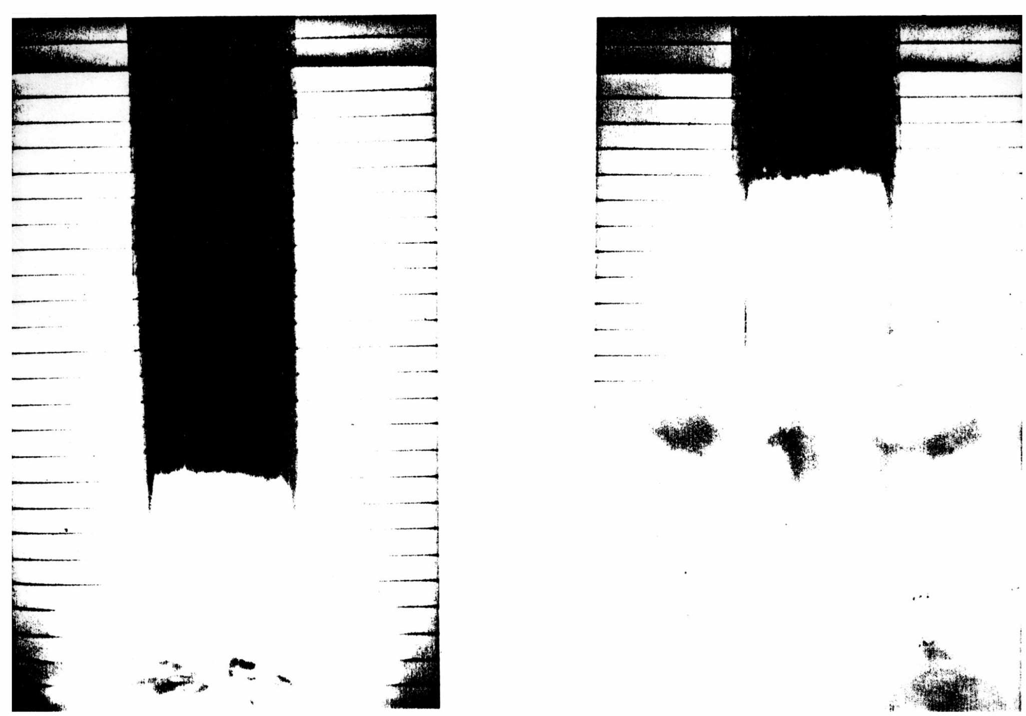

Figure 3. Selected frames from a high-speed framing camera sequence of manufacturer K's flash powder; background lines are 1 cm apart; frames shown are 90 microseconds apart. [Best available photo reproduction.]

The first method was tried using manufacturer K's flash powder. For reasons not exactly known in this test the rate probe short-circuited at its upper end 155 µs after the detonator fired. This may have been caused by high-velocity fragments or a shock wave in the plastic tube. In any case, before the probe ceased functioning, it recorded a relatively stable rate of ca 800 m/s. This trace is shown in Figure 2. To obtain the rate, the slope of the voltage/time trace must be

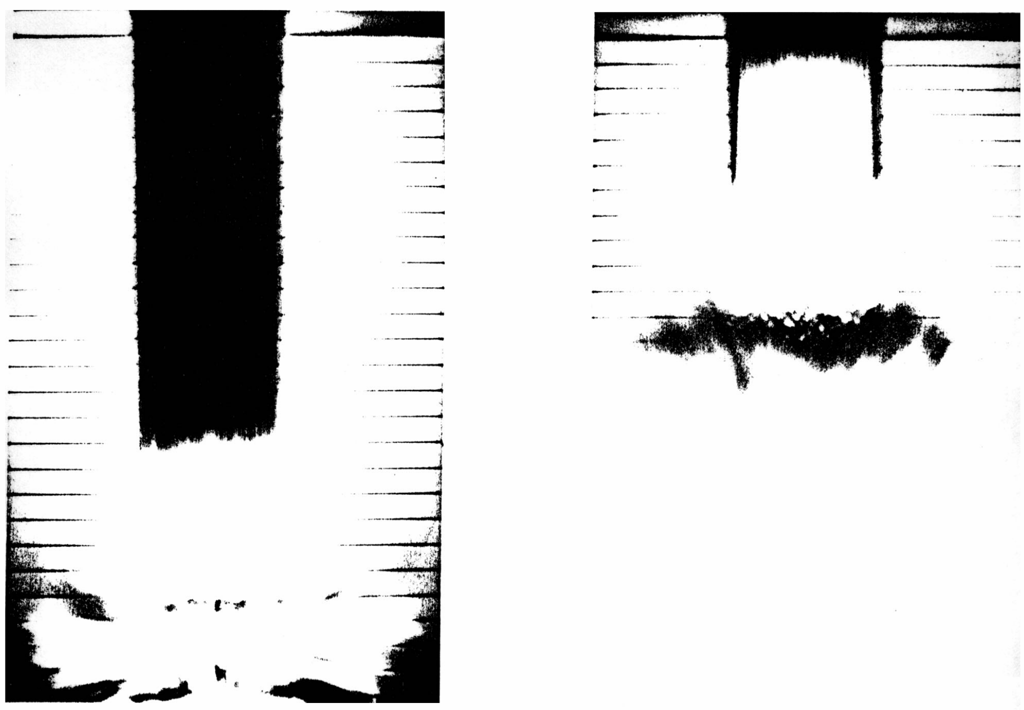

Figure 4. Selected frames from a high-speed framing camera sequence of manufacturer M's flash powder; background lines are 1 cm apart; frames shown are 70 microseconds apart. [Best available photo reproduction.]

divided by the product of the wire resistance/unit length (2.98 Ω/cm) and the applied current (0.06 milliamperes). The rate obtained is rather low for a detonation, even in a low-density powder, but results with the framing camera show definite evidence of a detonation.

Results obtained using the rotating-mirror framing camera are illustrated in Figures 3 and 4 for manufacturer K's and manufacturer M's flash powder, respectively. In both cases the flash powder was contained in an acrylic plastic tube of 2.5 in. outside diameter with 0.25 in. wall thickness and 12 in. long. Initiation was by a Hercules J-2 detonator. (Often such framing camera studies use an explosive booster for initiation, but the object here was to determine how detonation built up from a "weak" stimulus; it was not practical however to use a very weak stimulus such as an electric matchhead because the synchronization of the framing camera requires an initiator with a time "jitter" of only a few microseconds.) Based on the rate observed with the rate probe, the camera was run at a relatively slow speed of 10 µs/frame. Even at this low speed the light from the flash powder was found to be so persistent that in the first firing the film was washed out by exposures on successive revolutions of the mirror so that the use of a high-speed capping shutter was necessary.

Sample densities were those obtained by sharply tapping the plastic tube a few times after loading until no further perceptible settling occurred, and were 0.85 and 0.91 for manufacturer K's and manufacturer M's flash powder, respectively.

The frames shown in Figures 3 and 4 are 90 and 70 µs apart, respectively, giving a rate of 1.3 and 1.6 km/s, respectively, notably higher than the rate obtained with the rate probe using manufacturer K's flash powder. The most interesting thing about these pictures is that most of the frames (except for the earliest frames from the sequence using manufacturer M's flash powder) show a long zone of intense luminosity well in advance of any significant expansion of the tube walls, i.e., the development of high

Figure 5. Lead-block compressions obtained in D.O.T. cap sensitivity tests for (a) Manufacturer K's flash powder, (b) Manufacturer M's flash powder. [Best available photo reproduction.]

pressure lags far behind the development of luminosity, though this may not be too surprising in a material most of whose reaction products are expected to be nongaseous.

Department of Transportation (DOT) Cap Sensitivity Test

Following discussion of the results above with BATF and DOT personnel, it was decided to attempt to determine whether these flash powders were cap sensitive according to DOT specifications [Title 49 *Code of Federal Regulations* Part 173.53(c)]. Sufficient sample (703 g) remained of manufacturer K's flash powder to nearly fill the standard 3.38 in. diameter by 6.38 in. cylindrical fiberboard container used in this test. However, very little sample (216 g) remained of manufacturer M's powder and a much smaller container, viz., 2.0 in. diameter by 5.0 in. high, was used for this sample. The samples were set on a 4 in. long by 2 in. diameter lead block and primed with a No. 8 electric detonator and fired.

In both cases a compression of the lead block considerably in excess of the criterion value of 0.125 in. was obtained, viz., 0.450 in. and 0.586 in for manufacturer K's and manufacturer M's flash powder, respectively. Thus both are class A explosives according to DOT standards.

The mushrooming of the lead blocks is shown in Figure 5.

Summary

The Bureau of Mines was requested by the Treasury Departments' Bureau of Alcohol, Tobacco and Firearms (BATF) to conduct bullet impact sensitivity testing of a sampling of Class B (display) fireworks, and some ingredients thereof, and also to demonstrate that the flash powder used in salute shells is detonable, and to determine its detonation rate. All of the fireworks shells and ingredients were ignited/initiated by the impact of a bullet, though the violence of the resulting reaction varied greatly, from gentle burning to a violence which seemed characteristic of detonation. Both types of flash powder detonated, though at a very slow rate, and both exhibited cap sensitivity in the Department of Transportation cap sensitivity test.

Acknowledgment

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References

1) J. R. Ribovich, R. W. Watson, F. C. Gibson. "Instrumented Card-Gap Test", *AIAA Journal*, Vol. 6, No. 6, 1968, pp 1260–1263.