An earlier version appeared in: *Pyrotechnics Guild International Bulletin*, No. 154, 2007.

A Study Evaluating the Potential for Various Aluminum Metal Powders To Make Exploding Fireworks

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Scope

This investigation was commissioned[1] to evaluate a range of various aluminum metal powders for their potential use in compounding flash powders for use in powerfully exploding devices such as so-called M-80s and devices of similar construction.

Introduction

Flash powders are used in fireworks to produce a bright flash of light and the loud sound of an explosion.[2] There is a general understanding among both pyrotechnic chemists and firework manufacturers of approximately what pyrotechnic compositions constitute being a flash powder. For example, to produce the bright flash of light, all flash powders must be capable of producing a high temperature as well as refractory reaction products.[3] Both of these results can be accomplished using some types of small particle-size aluminum metal powders.[4,5]

However, it needs to be understood that there are a wide variety of aluminum metal-containing pyrotechnic compositions, many of which are used for purposes other than to produce a bright flash of light and the loud sound of an explosion.[6,7] For those reasons, the question of exactly which pyrotechnic compositions are and which are not flash powders can be difficult to answer, especially for those compositions falling in the middle of the range of light and sound producing properties.[8]

The question, regarding exactly what is and what is not a flash powder, is further complicated by the fact that flash powder has never been quantified for regulatory purposes, [9] rather it has only been specified by the intended use of the composition, as in "intended to produce an audible report and a flash of light". Because of the lack of quantitative guidance from either science or regulation, it must be concluded that "flash powder" is a term of art. Accordingly, this study focuses more narrowly on the central issue at hand, i.e., which aluminum metal powders are reasonably suitable for the production of flash powders as used in relatively small salutes[10] (so called M-80s and other similarly-sized exploding items) as they are typically constructed by individuals (hobbyists).

There are two paramount requirements for the flash powders used in such salutes, and these two requirements form the basis for quantifying the flash powder performance of the range of aluminum metal powders being evaluated. The first requirement is that the potential flash powder be reasonably capable of ignition and subsequent propagation using a common firework safety fuse.[11,12] The second requirement for the aluminum metal powder is that it is capable of producing a flash powder that will explode relatively powerfully when confined inside a paper tube, as is typically used for so called M-80s and other similarly-sized exploding items as they are commonly constructed by individuals.[13]

Power is defined as the time rate of energy production or release. Thus, powerful explosions result when much energy is released and that energy is released very quickly. For pyrotechnic chemical reactions, the first of the two principal characteristics that determines its ability to produce powerful explosions is the amount of energy that is released in the pyrotechnic chemical reaction. For flash powders, the amount of energy produced is directly related to the choice of ingredients, with the combination of potassium perchlorate and aluminum producing more energy than any other commonly available chemicals.[5] The second characteristic relating to the power of explosions is the rate of the pyrotechnic chemical reaction that occurs upon its ignition. For flash powders, the rate of the chemical reaction is most directly related to the surface-to-mass ratio of the individual aluminum metal particles, which in turn relates directly to its particle size and form (e.g., flakes versus spheroids[14]).[15]

Test Conditions

Over the period of the last 50 years, the most commonly used flash powder is one composed of an intimate mixture of 70% potassium perchlorate and 30% aluminum metal powder. While other formulations are occasionally used to manufacture exploding fireworks, an earlier study of the explosive power of a range of flash powders under modest confinement found that none of the other formulations investigated were more powerful than the 70:30 composition.[16] For this reason, and because this is the most commonly used formulation in the US, only the 70:30 flash powder formulation was used in this study.

In addition to a number of aluminum powders available in this laboratory, additional aluminum metal powder samples were provided by two suppliers of small quantity chemicals to the firework trade (Skylighter, Inc. and Firefox, Inc.). Appendix A lists information regarding the aluminum metal powders being evaluated.

Examples of the test salutes prepared for use in this study are shown in Figure 1, which consists of a photograph (showing both side and end views of a test salute) and a cross sectional drawing. The test units consisted of a spiral-wound paper tube with the following dimensions: outside diameter, 5/8 inch; wall thickness, 1/16 inch; and length, 1-1/2 inch.[17] The amount of powder encased in each of the tubes in preparation for testing was 1.00 gram.[18] The end plugs were 0.04 inch thick and were inserted to a total depth of approximately 0.5 inch into the ends of the tubes. The ignition fuse was a length of standard firework safety fuse, 3/32 inch in diameter visco fuse with an ample core of Black Powder.[19] The end plugs and fuse were glued in place using common white carpenter's glue, and the glue was allowed to dry for a day before the salutes were test fired.

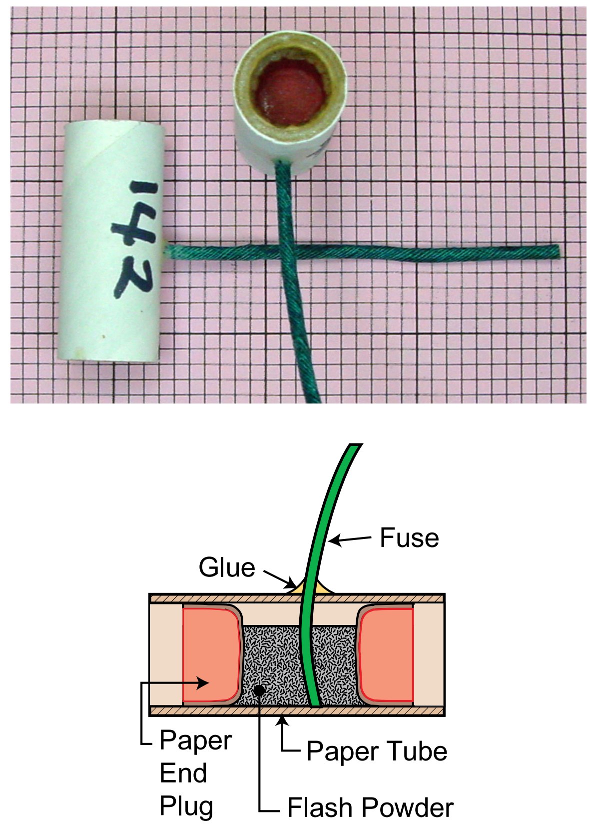


Figure 1. A photograph and cross sectional drawing of the test salutes used in this study.

Potential flash powder compositions were made using each of the various aluminum metal powders (see Appendix A) in the standard flash powder formulation (70% potassium perchlorate and 30% aluminum metal powder). The potassium perchlorate was –200 mesh technical grade of the type generally available for use in making pyrotechnic compositions.[20] The compositions were mixed using a combination of sieving and rotary tumbling. In preparation for testing, each of the potential flash powders was used to construct a group of 5 test salutes (as described and shown above). One at a time, a test salute was positioned at the top of a thin metal rod at a height of 4 feet above the ground. A pair of instruments[21] was used to measure the explosive sound output (blast pressure) of each test salute. This was accomplished by recording sound pressure levels at a distance of 10 feet from the test salute and at the same height above the ground as the test salute. One instrument was set to record peak sound pressure levels with linear frequency weighting (Linear-Peak). These settings were selected because they would allow a direct conversion to the peak air blast pressure of the explosion (in pounds per square inch),[22] which can then be used to establish the power of the explosion.[23] The other instrument was set to record the maximum impulse sound pressure level using A-weighting of the frequency spectrum (A-weighted-Impulse).[24] The fuse of the test salute was ignited and the functioning (or lack of functioning) of the test salute was visually monitored. On many occasions, the test salute failed to explode (i.e., the flash powder failed to be ignited or did not appreciably propagate a chemical reaction). On those occasions when the test salute did explode, the resulting sound pressure levels were recorded.

Test Results

The full set of individual results from this series of explosive output measurements are presented in Appendix B of this report. Table 1 presents the average relative sound power results for each set of five test salutes for each aluminum metal powder evaluated. The results are listed in decreasing order of sound power.

Table 1. Explosive Output Measured for the Test Salutes.

Aluminum Metal Powder Type[(a)]	Relative Explosive Output [(b)] (%)
S-CH0100, ≈ 5 μ Atomized	100
S-CH0140, ≈ 50 μ Flake	69
Valimet-H2, 2.5 μ Atomized	67
US Alum-809, ≈ 40 μ Flake	64
ATA-2000, 36 μ Flake	59
US Alum-807, 11 μ Flake	53
S-CH0152, ≈ 8 μ Flake	50
Reynods-400, 4.5 μ Atomized	44
FF-C103GD, ≈ 15 μ Flake	43
S-CH0144, ≈ 3 μ Flake	39
US Bronze-913, ≈ 20 μ Flake	38
FF-C099B5M, ≈ 3 μ Atomized	36
FF-C099B2M, 1.5 μ Atomized	34
FF-C100, 36 μ Flake	22
S-CH0142, ≈ 40 μ Flake	21
FF- C102, ≈ 60 μ Flake	16
KSI 100 Mesh, ≈ 80 μ Flake	11
FF-C099C, ≈ 60 μ Flake	7
S-CH0155, 40–325 mesh Flitter	0 [(c)]
S-CH0148, –20 Flitter	0 [(c)]
S-CH0141, 16–325 mesh Flitter	0 [(c)]
S-CH0150, 10–12 mesh Flitter	0 [(c)]
Reynolds-S10, ≈ 12 μ Atomized	0 [(c)]
FF-C099B71, 13 μ Atomized	0 [(c)]
S-CH0105, ≈ 20μ Atomized	0 [(c)]
S-CH0103, ≈ 20μ Atomized	0 [(c)]
FF-C099BND, 21 μ Atomized	0 [(c)]
FF-C099B, 24 μ Atomized	0 [(c)]
FF-C099B14, 36 μ Atomized	0 [(c)]
S-CH0120, 80–325 mesh Atom.	0 [(c)]
FF-C099AFF, 40–270 m G. Flk.	0 [(c)]
FF-C099A150, 50–150 m Gran.	0 [(c)]
FF-C099M100, 100 mesh Gran.	0 [(c)]
FF-C099ES, Granular Chips	0 [(c)]

a) Average particle sizes are given in microns, abbreviated with the symbol μ for particle sizes up to 100 microns. For information on why this was done and a definition of micron, see note "b" to Appendix B.

b) Sound power is proportional to the square of the peak air blast pressure. Thus the measured average sound pressures from the table in Appendix A were squared, normalized to the greatest average sound pressure observed for any aluminum metal powder, and reported a percentage.

c) The test salutes made with these aluminum metal powders failed to explode; thus their explosive power was zero.

Conclusions

A. It was established that there are two requirements that qualify an aluminum metal powder as having a reasonable potential for use in making exploding items such as so-called M-80s and similarly constructed items. The first requirement is that the flash powder made from the aluminum metal powder must be reasonably readily ignited by the thermal action of a burning firework safety fuse (i.e., common visco fuse) and that the pyrotechnic reaction then propagates explosively under the expected confinement conditions. From the detailed data reported in the table in Appendix B and listed as having zero sound power in Table 1, it can be seen that 16 of the aluminum metal powders tested failed to meet the ignition and propagation requirement for an aluminum metal powder to be suitable for making a flash powder.

B. The second requirement established for an aluminum metal powder to be useful in making a flash powder is that the flash powder made with the aluminum metal powder produces a relatively powerful explosion. Deciding just how powerful an explosion qualifies as a relatively powerful explosion is a subjective decision. It is not readily amenable to being answered scientifically, and so it is left to others to decide. However, if the threshold were set at 50% in Table 1, then another 11 of the aluminum metal powders would be eliminated as being reasonably suitable flash powder aluminums for salutes of the size and construction as used in these tests. If the explosion power threshold were set at 30 %, then only an additional 5 aluminum metal powders would be eliminated as reasonably suitable flash powder aluminums.

C. It is generally true that aluminum metal powders with a small average-particle size tend to be suitable for making flash powders,[25] and those with a large average-particle size are not suitable for making flash powders.[26] However, for those aluminum metal powders with an average-particle size in a broad mid-range, considering particle size alone will not allow one to assuredly determine their usefulness to make flash powders.[27] Because the performance of individual types of aluminum metal powder of a given particle size may vary widely, the only way to be assured of properly quantifying their performance in flash powders is to test them under the expected conditions of use. This not withstanding, it is possible to separate aluminum metal powders into three generalized categories regarding their potential to qualify as suitable for making flash powders for use in small salutes (such as so-called M-80s and other similarly sized and constructed items). Based on the results of this study and consistent with prior experience in this laboratory, the conclusions are summarized in the Table 2.

Table 2. The Suitability of Various Aluminum Metal Powders for Making Flash Powders.

Powder Type	Particle Size Range		
	Suitable	Questionable	Unsuitable
Atomized	Less than 6 microns	6 to 10 microns	Greater than 10 microns (a)
Flake	Less than 40 microns	40 to 75 microns	Greater than 75 microns (b)

a) This would correspond to a mesh size of approximately 1000, if such a sieve existed.

b) This corresponds to a mesh size of approximately 200.

Acknowledgment

The authors gratefully acknowledge the suggestions of L. Weinman, H. Gilliam, J. Steinberg and T. Handel on an earlier draft of this article.

Notes and Literature References

1) Because of the authors' long term research interest in the subject of the chemistry and characteristics of flash powder, combined with an agreement that this laboratory was free to publish and use any or all of the results produced in the current study, the authors funded the major portion of the current study. Some additional funding was provided by the Pyrotechnics Guild International, Inc.; the Fireworks Foundation, Inc.; and Skylighter, Inc.

2) *The Illustrated Dictionary of Pyrotechnics*, K. L. and B. J. Kosanke, et al., Journal of Pyrotechnics, 1996.

3) "From a Technical Standpoint, What is Flash Powder?", K. L. Kosanke and L. Weinman, *Fireworks Business*, No. 246, 2004; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 and 2004),* 2006.

4) In this investigation, only aluminum metal powders were investigated for use in making flash powder. The reasons for this are two fold. 1) Thermodynamic free energy minimization calculations reveal that aluminum produces the greatest amount of energy in pyrotechnic reactions, in contrast with other po-

tentially usable metal powder candidates. [5] 2) In the US, aluminum metal powder is by far the most commonly used fuel in making exploding fireworks.

5) Thermodynamic calculations were performed using the ICT (Institute for Chemical Technology) and the NASA (National Aerodynamics and Space Administration) thermodynamic modeling codes.

6) These other common uses probably account for roughly 80 to 90 percent of the aluminum metal powder used in pyrotechnic compositions. Some examples of other common uses for small particle size aluminum metal powders are: 1) in common hand-held sparklers, 2) as a flame brightening agent for colored flame effects, 3) as the active ingredient in both glitter and flitter comet effects, and 4) as an agent used to modify the burn rate of pyrolants.

7) **"**Aluminum Metal Powders Used in Pyrotechnics", K. L. and B. J. Kosanke, *Pyrotechnics Guild International Bulletin*, 85, 1993; *FPAG*, Vol. 6, No. 7, 1997; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 3 (1993 – 1994),* 1996.

8) The burning of essentially any firework composition – by its very nature as a pyrotechnic material – is capable of a self-contained and self-sustained chemical reaction that releases energy,[2]**Error! Bookmark not defined.** will produce some light and, if sufficiently well confined, will have the potential for producing the sound of an explosion.

9) "As Defined in Regulation, What is Fireworks Flash Powder?", K. L. Kosanke and L. Weinman, *Fireworks Business*, No. 244, 2004; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 7 (2003 – 2004),* 2006.

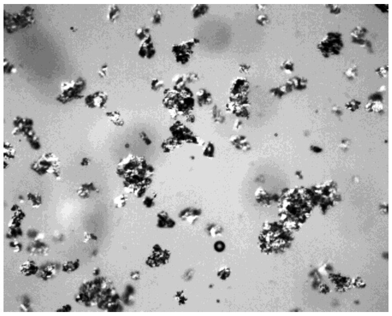
10) A salute is the descriptive term for a firework that is principally designed to explode violently so as to produce a loud sound. [2]

11) Fireworks safety fuse is also known as visco fuse, hobby fuse and cannon fuse. It is composed of an ample core of fine-grained Black Powder and is relatively heavily wrapped with two layers of cotton thread.[2]

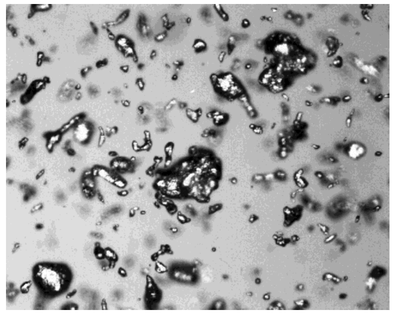
12) If the potential flash powder can not be ignited or does not propagate reasonably completely, then it cannot produce a bright flash of light and the sound of an explosion as are required for a flash powder.

13) If the aluminum metal powder to be used in a potential flash powder does not produce a reasonably powerful explosion, then there is little if any reason for someone to devote the time, expense and effort to acquire all of the needed chemicals and materials, to make the flash powder and then to construct the salute.

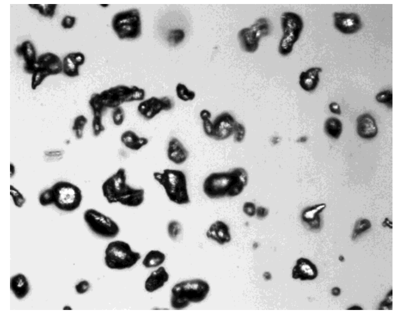
14) Flake aluminum metal powders are typically produced in a milling process wherein larger particles are in effect hammered into thin flakes. However, to keep the flakes from sticking together and being hammered back into larger particles, it is necessary to use a lubricant such as stearin to coat the individual particles during the milling process.[7] Spheroidal aluminum metal powders are produced in an atomizing process wherein molten aluminum is sprayed into a more or less inert atmosphere. When the atmosphere has modest oxygen content, an oxide coating quickly forms on the particles, which results in their freezing-out as distorted spheroids (grossly out-of-round particles). If the atmosphere is more nearly inert, the atomized aluminum particles take comparatively well-rounded shapes (more nearly spherical) before they solidify. Below are three photomicrographs, demonstrating the typical appearance of aluminum metal powder as flakes, and so called spheroidal and spherical atomized particles of aluminum metal powder.



Eckart, SDF 4-591, flake



Toyal, ATA-101, spheroidal



Valimet, H-30, spherical

15) *Pyrotechnic Chemistry*, Chapter 5, "Control of Pyrotechnic Burn Rate", K. L. and B. J. Kosanke, et al., Journal of Pyrotechnics, 2005.

16) "Flash Powder Output Testing: Weak Confinement", K. L. and B. J. Kosanke, *Journal of Pyrotechnics*, No. 4, 1996; *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 4 (1995 through 1997),* 1999.

17) Historically, this is the approximate size of a typical consumer M-80 or Silver Salute.

18) This amount of flash powder is 20 times the maximum powder content allowed in consumer firecrackers and is approximately the same powder content of currently available pest and predator control devices. (Pest and predator control devices are relatively small exploding items most typically used by individuals and various agencies to disperse wildlife from crops, fishing nets, airport runways, etc. These items tend to be quite similar in physical construction to the test salutes used in this study.)

19) This is also the type of fuse almost universally used to make this type of exploding firework as well as that used to manufacture pest and predator control devices.

20) It had been confirmed in earlier studies that the explosive power of flash powders are relatively independent of the exact nature of the potassium perchlorate used in their manufacture.[16]

21) These instruments were Quest Technologies models 1800 and 2700, set to record "Linear-Peak" and "Maximum A-Weighted Impulse" sound pressure levels, respectively.

22) Calculated as described in *Van Nostrand's Scientific Encyclopedia*, 5th ed., Van Nostrand Reinhold, 1976, p 25.

23) "Correspondence: Flash Powder Output Testing: Weak Confinement", K. L. and B. J. Kosanke, *Journal of Pyrotechnics*, No. 5, 1997.

24) Standards for the permissible exposure to impulse sounds (e.g., the sounds of explosions) are typically based on measurements made with instrument settings of A-weighted Impulse sound pressure levels.

25) It would be a mistake to assume that the only reasonable or practical use for small particle size aluminum metal powders is to make flash powders. (See again references 6 and 7 for more information.)

26) In properly formulated flash powders, small particle size aluminum metal powders are relatively easily ignited, and once ignited the aluminum particles participate vigorously and fully in the energy producing chemical reactions to produce a powerful explosion. To the contrary, large particle size aluminum metal powders used in flash powders will be difficult or impossible to ignite, and if ignited, they generally will not propagate throughout the composition. Even if ignition and propagation of larger particle size aluminum particles were somehow achieved, only a portion of the energy producing potential for the aluminum will be realized. This is because a significant amount of the energy is produced after the explosion (if there is one) as the still burning aluminum particles (seen as sparks) radiate outward.

27) For example, for flake powders, it is more nearly the thickness of the individual flakes that is the determinant factor (in whether an aluminum metal powder will be useful in making flash powders), rather than the other linear dimensions (size) of the flakes. The nature of the distribution of particle size about

the average will also affect the aluminum metal powder's performance in flash powder. Further, the lubricant coating on the flakes, such as almost always necessitated in the small flake manufacturing process, also generally limits the effectiveness of the flake aluminum in making flash powders. Beyond this, the thickness of the oxide coating that is allowed to form on the flakes affects the aluminum metal powder's usefulness in making flash powders. There are similar factors that affect the performance of atomized aluminum metal powders. However, atomized particles (being spheroids) are substantially thicker than flakes of the same particle size. The result is that only very much smaller particle size atomized aluminum metal powders, in comparison with flake powders, are useful in making flash powders.

Appendix A: Information Regarding Aluminum Metal Powders Used in This Study.

Designation [(a)]	Manufacturer and Product Number	Product Type	Average Particle Size and Other Information [(b)]
S-CH0144	Unknown, Indian GD	Flake	≈ 3 microns [(c)]
Obron GD	Obron Atlantic, 5413	Flake	≈ 5 microns [(c)]
S-CH0152	Eckart, 5413-H Super	Flake	≈ 8 microns [(c)]
USA-807	US Aluminum, 807	Flake	11 microns, coated [(d)]
FF-C103GD	Eckart, 10980	Flake	≈ 15 microns [(b)]
USB-913-S	US Bronze, 913-S	Flake	≈ 20 microns [(c)]
ATA-2000	Alcan-Toyo America, 2000	Flake	36 microns, coated [(d)]
FF-C100	Alcan-Toyo America, 2500	Flake	36 microns, coated [(d)]
S-CH0142	Eckart, SDF 4-591	Flake	≈ 40 microns [(c)]
USA-809	US Aluminum, 809	Flake	≈ 45 microns [(c)]
S-CH0140	US Aluminum, 808	Flake	≈ 50 microns [(c)]
FF-C099C	Eckart, U2	Flake	≈ 60 microns [(c)]
FF-C102	Eckart, HL/NE	Flake	≈ 60 microns [(c)]
KSI-100	Unknown	Flake	≈ 80 microns [(c)]
S-CH0155	Transmet, unknown	Flitter [(e)]	40-325 mesh [(f)]
S-CH0148	Eckart, 41813/G	Flitter [(e)]	–20 mesh [(f)]
S-CH0141	US Aluminum, 812	Flitter [(e)]	16–325 mesh [(f)]
S-CH0150	Transmet, K-102	Flitter [(e)]	10–12 mesh [(f)]
FF-C099B2M	Alcan-Toyo America, ATA 5621	Atomized	1.5 microns [(d)]
Val-H2	Valimet, H2	Atomized	2.5 microns, spherical [(d)]
RA-400	Reynolds Aluminum, 400	Atomized	4.5 microns, spheroidal [(d)]
S-CH0100	Unknown	Atomized	≈ 5 microns, spherical [(c)]
FF-C099B5M	Alcan-Toyo America, ATA105	Atomized	5.5 microns spherical [(d)] [(g)]
RA-S10	Reynolds Aluminum, S10	Atomized	≈ 12 microns, spherical [(c)]
FF-C099B71	Alcan, XC-71	Atomized	13 microns, spherical [(d)]
S-CH0105	Unknown	Atomized	≈ 20 microns, spheroidal [(c)]
S-CH0103	Unknown	Atomized	≈ 20 microns, spherical [(c)]
FF-C099BND	Alcoa, 1641/L	Atomized	21 micron spherical, coated [(d)]
FF-C099B	Valimet, H-30	Atomized	24 microns, spherical [(d)]
FF-C099B14	Toyal America, ATA101SS	Atomized	36 microns, spheroidal [(d)]
S-CH0120	Unknown	Atomized	80–325 mesh, spheroidal [(f)]
FF-C099AFF	Unknown	G. Flk. [(h)]	40–270 mesh [(f)]
FF-C099A150	Unknown	Granular	50–150 mesh [(f)]
FF-C099M100	Unknown	Granular	≈ 100 mesh [(c)]
FF-C099ES	Unknown	Gran. Ch.	Fine chips [(f)]

a) This is how the aluminum metal powders are identified in the table of results in this report. The aluminum powders starting with "S" were from Skylighter and those starting with "FF" were from Firefox.

b) For consistency and convenience in this study, most aluminum metal particle sizes are stated as averages given in microns. Only the very largest particles list a mesh range. For comparison, a 325-mesh standard sieve has openings that are 34 microns, and a 100 mesh standard sieve has openings that are 150 microns.)
c) This is the approximate average particle size estimated using photo micrographs of the aluminum powders.
d) This is the average particle size as taken from the manufacturer's specification for the product.
e) Flitters are a type of relatively large, thick flakes, usable almost exclusively for spark effects in comets.
f) This is the particle size as stated by the pyro-chemical supplier.
g) Based on photo micrographs, the average particle size appears to be approximately 3 microns, rather than the 5.5 microns as reported in the manufacturer's product specifications.
h) Described by the supplier as "ground flake".

Appendix B: Explosive Output Measured for the Test Salutes

Powder Type	Explosive Output (a) Peak Air Blast Pressure (psi) / A-Weighted Impulse) (dB)					
	Test 1	Test 2	Test 3	Test 4	Test 5	Averages
S-CH0100, ≈ 5μ Atomized	0.32/130	0.32/131	0.46/132	0.32/131	0.32/131	0.348/131.0
S-CH0140, ≈ 50μ Flake	0.32/131	0.29/131	0.26/131	0.29/130	0.29/130	0.290/130.6
Valimet-H2, 2.5μ Atomized	0.29/129	0.26/129	0.29/130	0.29/130	0.29/130	0.284/129.6
US Alum-809, ≈ 40μ Flake	0.26/127	0.29/129	0.29/130	0.26/129	0.29/130	0.278/129.0
ATA-2000, 36μ Flake	0.26/129	0.29/129	0.18/127	0.32/131	0.29/130	0.268/129.2
US Alum-807, 11μ Flake	0.26/128	0.26/129	0.23/127	0.29/130	0.23/130	0.254/128.8
S-CH0152, ≈ 8μ Flake	0.32/130	0.23/128	0.16/128	0.23/130	0.29/130	0.246/129.2
Reynods-400, 4.5μ Atom.	0.29/128	0.16/129	0.16/126	0.29/130	0.26/129	0.232/128.4
FF-C103GD, ≈ 15μ Flake	0.23/131	0.16/131	0.23/130	0.26/130	0.26/131	0.228/130.6
S-CH0144, ≈ 3μ Flake	0.16/130	0.23/130	0.23/130	0.23/130	0.23/130	0.216/130.0
US Bronze-913, ≈ 20μ Flake	0.29/130	0.07/122*	0.13/126*	0.29/130	0.29/131	0.214/127.8
FF-C099B5M, ≈ 3 μ Atom.	0.18/130	0.23/131	0.23/131	0.23/131	0.18/130	0.210/130.6
FF-C099B2M, 1.5 μ Atom.	0.20/131	0.23/131	0.20/130	0.20/130	0.18/130	0.202/130.4
FF-C100, 36 μ Flake	0.14/127*	0.29/130	0.16/129	0.08/124*	0.14/127	0.162/127.4
S-CH0142, ≈ 40μ Flake	0.16/124	0.06/118*	0.02/107*	0.26/128	0.29/130	0.158/121.4
FF- C102, ≈ 60 μ Flake	0.09/126*	0.08/124*	0.26/130	0.11/126	0.16/128	0.140/126.8
KSI 100 Mesh, ≈ 80 μ Flake	0.08/124	0.04/120*	0.16/130	0.23/129	0.08/124*	0.118/125.4
FF-C099C, ≈ 60 μ Flake	0.06/121*	0.10/125*	0.13/126*	0.11/125*	0.06/123*	0.092/124.0
S-CH0155, 40-325 M Flitter	ftp	ftp	ftp	ftp	ftp	ftp

Powder Type	Explosive Output (a) Peak Air Blast Pressure (psi) / A-Weighted Impulse) (dB)					
	Test 1	Test 2	Test 3	Test 4	Test 5	Averages
S-CH0148, –20 Flitter	ftp	ftp	ftp	ftp	ftp	ftp
S-CH0141, 16–325 M Flitter	ftp	ftp	ftp	ftp	ftp	ftp
S-CH0150, 10–12 M Flitter	ftp	ftp	ftp	ftp	ftp	ftp
Reynolds-S10, ≈ 12 µ Atom.	ftp	ftp	ftp	ftp	ftp	ftp
FF-C099B71, 13 µ Atom.	dne	dne	ftp	dne	ftp	ftp/dne
S-CH0105, ≈ 20µ Atomized	ftp	ftp	ftp	ftp	ftp	ftp
S-CH0103, ≈ 20µ Atomized	ftp	ftp	ftp	ftp	ftp	ftp
FF-C099BND, 21 µ Atom.	ftp	ftp	ftp	ftp	ftp	ftp
FF-C099B, 24 µ Atomized	ftp	ftp	ftp	ftp	ftp	ftp
FF-C099B14, 36 µ Atomized	ftp	ftp	ftp	ftp	ftp	ftp
S-CH0120, 80–325 M Atom.	ftp	ftp	ftp	ftp	ftp	ftp
FF-C099AFF, 40–270 M Gr.	ftp	ftp	ftp	ftp	ftp	ftp
FF-C099A150, 50–150 M. G.	ftp	ftp	ftp	ftp	ftp	ftp
FF-C099M100, 100 M. Gran.	ftp	ftp	ftp	ftp	ftp	ftp
FF-C099ES, Granular Chips	ftp	ftp	ftp	ftp	ftp	ftp

a) Peak air blast pressures (P) in units of pounds per square inch are derived from Linear-Peak decibel values (dBLP) using the definition of decibel (dBLP = 170.8 - 20 log P). In this study, the individual measurements and the averages are reported to two and three decimal places, respectively. The individual measurements and the averages of the A-Weighted Impulse sound pressure levels are reported to the nearest dB and to one decimal place, respectively.

* means that the tube itself did not explode, but rather blew-out one or both end plug(s).

"ftp" means that there was a "Failure to propagate". There was no reaction and the test salute did not explode. In essence the potential flash powder did not ignite (but it may have produced a few sparks out of the fuse hole as long as the fuse was still burning within the test salute).

"dne" means that the test salute "Did not explode", but the flash powder did burn somewhat with a brief jet of flame and sparks from the fuse hole.