FIREWORKS SAFETY STANDARDS DEVELOPMENT PROJECT FY 2013 STATUS REPORT

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EXECUTIVE SUMMARY

The U.S Consumer Product Safety Commission (CPSC, the Commission) is evaluating the need to amend its regulations for fireworks devices. CPSC staff evaluated issues concerning the explosive power of aerial fireworks.

Aerial fireworks devices intended to produce an audible effect are limited to 130 mg (2 grains) of pyrotechnic composition, according to 16 C.F.R. § 1500.17(a)(3). Because the regulation only limits the amount of pyrotechnic composition for devices intended to produce an audible effect, compliance determinations can be made only after a subjective determination of intent to produce an audible effect. In 2012, staff conducted testing to evaluate two different approaches to replacing the regulation limiting pyrotechnic composition of devices intended to produce an audible effect; staff considered potential alternative regulations, based on the explosive power of fireworks devices. The American Fireworks Standards Laboratory (AFSL) had previously developed a "Black Powder Equivalency Test." CPSC staff investigated and found that this test can distinguish between the energetics of black powder, hybrid powders, and flash powder, but the test does not consider the particular construction of a shell. Staff also investigated directly testing the energy released from an actual shell, as constructed, minus the propelling (lift) charge.[1] Staff found that it was possible to measure the total overpressure produced by the explosion of fireworks shells, measuring the explosive pressure from five different angles to account for the effects from explosion directionality.

The pressure waves produced by exploding fireworks shells typically were found to exhibit a rise time of about 10 nanoseconds and an overall duration of about 100 nanoseconds. Typical small shells (1-inch diameter) from devices meeting current regulations were found to produce approximately 15−30 psi total overpressure at a distance of 5.5 inches from the center of the device. Large shells (1.5 to 2 inch diameter) from "display rack" devices meeting current regulations were found to produce total overpressure similar to that of an illegal M-80 device, approximately 100−200 pounds per square inch (psi) at a distance of 5.5 inches from the center of the device. While pressures of this magnitude pose potentially significant injury risk at close distances, these devices are designed to explode more than 100 feet in the air, mitigating the risk to consumers.

Following the recommendations outlined in the *FY 2012 Fireworks Safety Standards Development Status Report*,[2] staff conducted experiments related to the Black Powder Equivalency Test developed by the American Fireworks Standards Laboratory (AFSL). The first experiment examined the contributing factors in aerial shell overpressure. Previously, staff found that the power associated with the powder alone could not be used to predict the total pressure released by the exploding shell. Staff investigated whether a tandem testing scheme of first determining powder energetics, along with total powder content, could be used to develop a "pressure potential." However, staff found that the effects of the shell's integrity (*e.g.*, shell

[1] The lift charge is the pyrotechnic charge that propels the device into the air. By removing this charge, it is possible to test the energetics of the remaining shell while the device is at rest.

[2] Musto, Christopher, "Fireworks Safety Standards Status report," January 2013.

thickness, number of glue tape wraps, tightness of wraps) were a large contributing factor and did not predict the explosive power of shells tested "as built." The second set of experiments was conducted to determine whether the Black Powder Equivalency Test could be modified to allow for "whole-shell" testing. Multiple permutations of mortar tube, ball, and blast box were examined. Staff concluded that the dynamic range associated with this technique was insufficient to include many aerial shell devices because of the large range of pressures generated.

Due to the high precision, overall robustness, and large dynamic range, CPSC staff recommends that further testing involving the use of pressure transducers should be conducted to consider possible changes to 16 C.F.R. § 1500.17 (a) (3), which bans fireworks devices intended to produce an audible effect, if the audible effect is produced by a charge of more than 130 mg of pyrotechnic composition. For FY 2014, CPSC staff has proposed a project for Commission consideration to finalize methods based on pressure transducers measuring the overpressure created by the explosion of "as-built" shells and conducting testing of a range of fireworks devices by this method, with the goal of preparing a briefing package once regulatory flexibility is considered.

INTRODUCTION

The CPSC is evaluating the need to amend the regulations for fireworks devices at 16 C.F.R. §§ 1500.17 and 1507. An advance notice of proposed rulemaking (ANPR) was initiated under the Federal Hazardous Substances Act (FHSA) on June 26, 2006. The ANPR identified the following possible alternatives to increase compliance with fireworks regulations and reduce the number of injuries associated with fireworks devices: (1) issue a rule requiring mandatory certification to the fireworks regulations under FHSA; (2) issue additional mandatory requirements that fireworks devices must meet; (3) rely on a voluntary standard; or (4) pursue corrective action on a case-by-case basis under section 15 of the CPSA. In 2011, staff prepared a report[3] summarizing the work done and the results of the staff effort since issuance of the ANPR. The summary included an explanation of relevant changes to the fireworks regulatory landscape since the ANPR was issued and identification of a path for staff to develop additional information to brief the Commission.

Staff is considering whether CPSC regulations regarding fireworks devices (*e.g.*, 16 C.F.R. §§ 1500.17 and 1507) may be improved or clarified, especially considering changes that have occurred over time in the design and manufacture of newer devices. Manufacturing changes are noteworthy in the case of aerial devices, where "hybrid powders"[4] have replaced conventional black powder to enhance the expelling charge (break charge) and may also produce an audible effect. Rulemaking could be considered to clarify the language in these regulations or to address break charges containing hybrid powder.

Background

Aerial fireworks devices "intended to produce an audible effect" are restricted by CPSC regulations in the amount, by weight, of the pyrotechnic materials composition. Devices not intended to produce an audible effect have no CPSC limitation on the amount of pyrotechnic materials composition. Under 16 C.F.R. § 1500.17(a)(3), aerial fireworks devices intended to produce an audible effect are limited to 130 mg (2 grains) of pyrotechnic composition. This regulation was promulgated by the U.S. Food and Drug Administration (FDA) before formation of the CPSC. The FDA indicated in the *Federal Register*: "The intention is not to ban so-called "Class C" common fireworks, but only those designed to produce audible effects caused by a charge of more than two grains of pyrotechnic composition. Propelling and expelling charges consisting of a mixture of sulfur, charcoal, and saltpeter are not considered designed to produce audible effects. The Commissioner's primary concern in this matter is to close the loophole through which dangerously explosive fireworks, such as cherry bombs, M-80 salutes, and similar items, reach the general public.[5]"

[3] Musto, Christopher, "Fireworks Safety Standards Status Report," September 2011.
[4] Hybrid powders contain potassium perchlorate or similar oxidizers but no metal powder. This represents a hybrid between black powder, which does not contain perchlorates, and flash powder, which consists of perchlorates and metal powder.
[5] FR Vol. 35, No 93 (May 13, 1970) Fireworks Devices: Classification as Banned Hazardous Substances and Revocation of Exemption.

When this regulation was enacted, consumer aerial fireworks shells were commonly constructed with black powder, used as the expelling or break charge. “Reports” or “salutes,” intended to produce an audible effect, were small, paper-wrapped firecrackers contained within the shell, which would function after the shell burst. At that time, the 130mg limit was easily applied to the paper-wrapped reports. Later, the industry moved away from black powder as the break charge, using instead, more energetic hybrid powders that spread the effects more rapidly. Furthermore, the hybrid powders created a more “impressive” function than black powder but also provided greater energetics. These newer hybrid powders, depending upon the construction of the shell, packing density, and quantity of powder, in some cases, might produce an audible effect, considered to be the type of “report” in the regulation; but in other cases, the sound produced is considered to be incidental to the necessary function of expelling the effects of the device.

Over the years, CPSC staff has provided extensive training to the fireworks industry to help improve the consistency of the audible determination of whether a particular device produces an audible effect as considered in this regulation. CPSC staff is investigating the possibility of developing a more objective, measurable method to determine what devices pose excessive risk, based on their energetics, rather than applying the regulation limiting pyrotechnic composition to 130 mg to devices based on their being “intended to produce an audible effect.” A replacement for the current regulation has been suggested by many in industry, as well as the American Fireworks Standards Laboratory (AFSL). It is important to note that this regulation is not designed to protect against hearing damage; but rather, the regulation uses the sound of the report (which is qualitatively similar to that of an illegal M-80 device) as a grading mechanism to determine whether these are the type of fireworks that were intended to be limited to no more than two grains of pyrotechnic material. This case of limitation to two grains of pyrotechnic material, based on the grading of the sound, contrasts with the case of “so called “Class C” common fireworks,” which contain propelling and expelling charges for which no such limit is applied, as described in the aforementioned *Federal Register* notice from 1970.

CURRENT STATUS

One significant change in fireworks regulations since issuance of the ANPR is the requirement under Pub. L. No. 110-314, Aug. 14, 2008, the Consumer Product Safety Improvement Act of 2008 (CPSIA), section 102 (a)(1), that manufacturers of consumer fireworks must issue a General Conformity Certification, based on a test of each product, or upon a reasonable testing program, indicating that such product complies with all the rules, bans, standards, or regulations applicable to the product under any Act enforced by the Commission. This regulatory change deals with the first option considered in the ANPR, specifically, to issue a rule requiring mandatory certification to the fireworks regulations under the FHSA.

Among the other alternatives to the current regulations under consideration is relying on the voluntary standards developed by the American Fireworks Standards Laboratory (AFSL). The AFSL intends its standards to incorporate both the CPSC and U.S. Department of Transportation regulations (currently APA 87-1), as well as a number of standards developed by AFSL that are in addition to federal requirements.

Fireworks injuries continue to occur. According to the CPSC's *2012 Fireworks Annual Report*,[6] CPSC staff received reports of six nonoccupational fireworks-related deaths during 2012. CPSC staff has reports of five fireworks-related deaths in 2011, four deaths in 2010, and two deaths in 2009. Reporting is not complete for those years, and the actual number of deaths may be higher. Fireworks were involved in an estimated 8,700 injuries treated in U.S. hospital emergency departments during calendar year 2012. According to the report, there is no statistically significant trend in estimated department-treated injuries from 1997–2012.

Review of Staff Developments in FY 2012

In the following sections of this report, CPSC staff presents the results of testing and evaluation work on the break charge audible reports issue, including both electronic and nonelectronic techniques for revision or replacement of the current regulations.

Break Charge/Audible Reports:

The current test method for determining whether an aerial fireworks device produces an audible "report" that is subject to the limit of 130 mg of pyrotechnic composition is subjective. The test method relies on listening to the functioning device for qualitative similarities to such illegal devices as M-80s and "Cherry Bombs" to make an assessment. A method directly testing the energy released from ignition of a one gram sample of the break charge composition used in a device was designed by AFSL. CPSC staff found that this "black powder equivalency" test can distinguish between the energetics of black powder and hybrid powders but does not consider the particular construction of a shell, which has the potential to make a significant contribution to the pressure produced from the explosion. Another alternative that staff investigated was testing the energy released from an actual shell, as constructed, minus the lift charge.

Review of the AFSL Black Powder Equivalency Test[7]:

In the *2012 Fireworks Status Report*, staff described, in detail, the AFSL-developed Black Powder Equivalency Test. Data showed that although the test did not distinguish between devices based upon varying hybrid powders, the method may yet be useful if used together with other information.

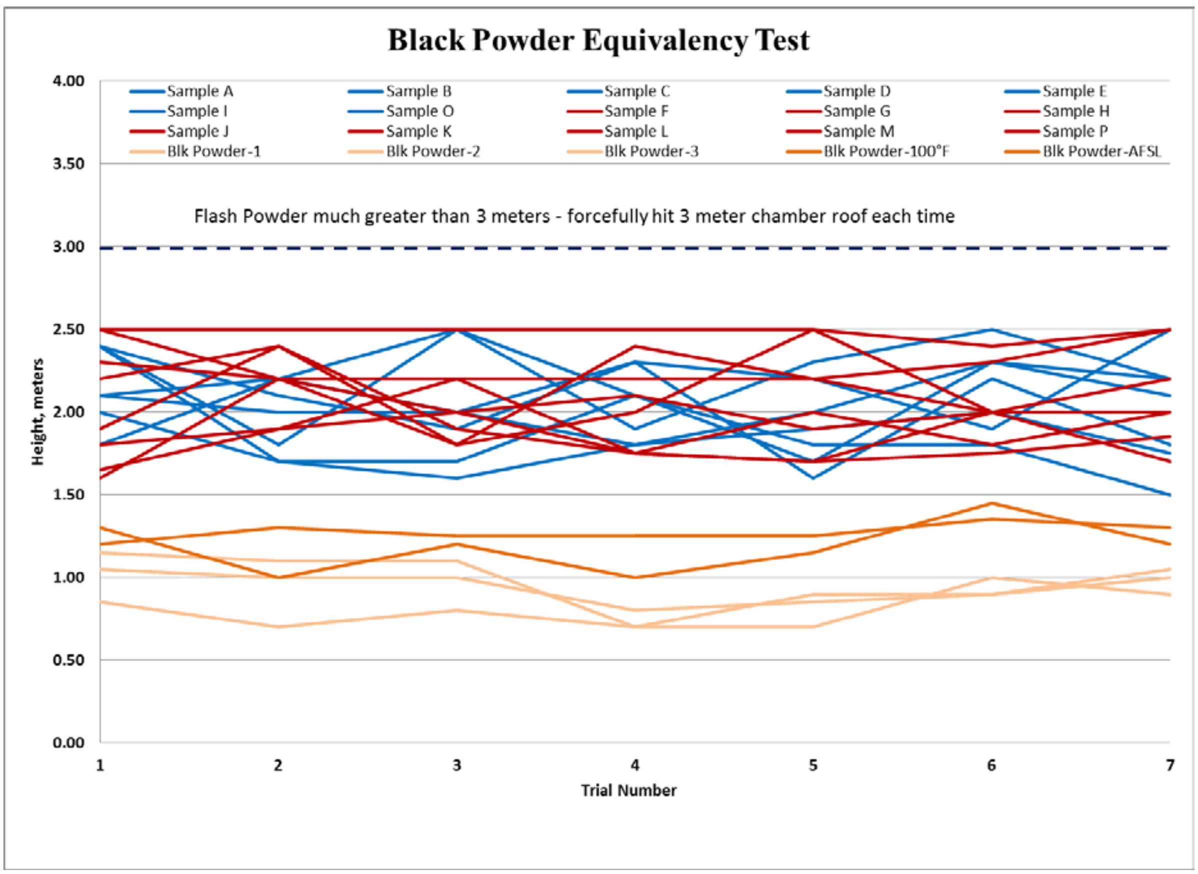
Figure 1 is a graphical representation of data collected via the AFSL's Black Powder Equivalency Test. Red and light blue lines represent hybrid powders; the red lines represent devices found to produce an audible effect, while the blue lines represent devices found not to produce an audible effect. Amber lines represent black powder, while the dashed navy blue line at the top represents flash powder. Staff experience testing fireworks devices for compliance with current regulations indicates that the majority of fireworks devices are currently made with hybrid powders, similar to those seen in the red and blue lines in Figure 1.

[6] Tu, Yongling and Granados, Demar, "*2012 Fireworks Annual Report*," June 2013.

It is clear in the graph that three distinct regimes can be identified: (1) black powder typically attains a maximum height below 1.5 meters; (2) flash powder is capable of displacing the steel ball much higher than 3 meters, the maximum height allowed in the current testing chamber; (3) commonly used "hybrid" powders cluster in the range of 1.5–2.5 meters, with the exception of Sample H (the nearly straight red line running along the 2.5 meter mark), which hit the upper plate set at 2.5 meters six of seven times. Out of 105 trials (15 samples each tested seven times), the steel ball struck the plate a total of 13 times, four were due to Sample H, and four were due to samples found not to produce an audible report.

Figure 1: "Ball Test" Results

Red and light blue lines represent hybrid powders; the red lines represent devices found to produce an audible effect, while the blue lines represent devices found not to produce an audible effect. Amber lines represent black powder, while the dashed navy blue line at the top represents flash powder.



Review of Overpressure Measurements via Dynamic Pressure Transducers:

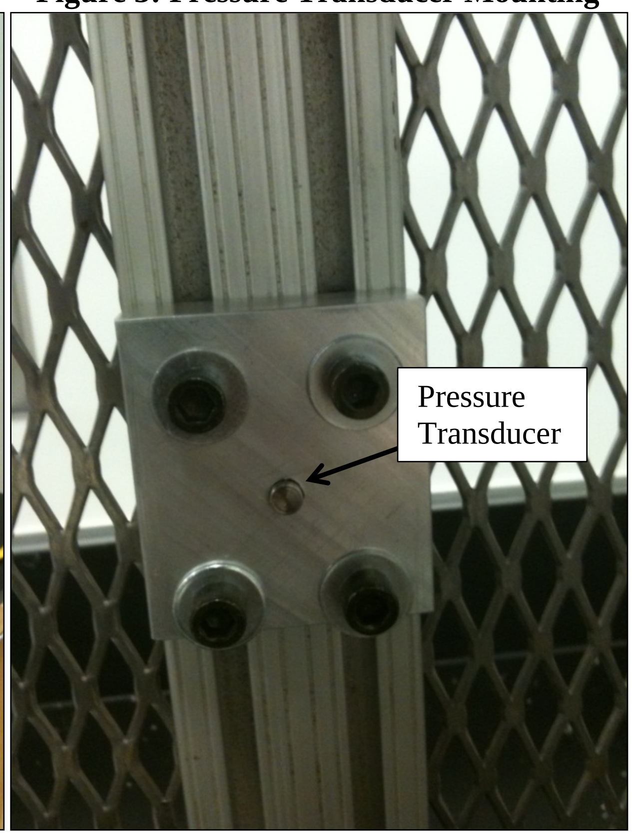
In FY 2012, CPSC staff designed a new test method based on the overall pressure released from a shell during functioning. CPSC staff conducted tests as a proof-of-concept to determine if these types of measurements could be used to evaluate the potential risks associated with break charges from consumer fireworks aerial shells from typical devices.

A reinforced containment cage was assembled with two different containment screens built into the walls (Figure 2). Five high-speed dynamic pressure transducers were affixed on the inside of the cage frame using in-house-designed aluminum blocks (Figure 3). The transducers were threaded into the aluminum blocks at equal distances from the center of the box. Four sensors were placed along the horizontal plane of the center of the box, with the fifth sensor directly above the center at an equal distance to those placed horizontally. Electronic igniters were used to trigger the functioning of the shells. The pressure sensors and data acquisition system parameters are summarized below:

Dynamic Pressure Sensor Range:	0–500 psi
Pressure Sensor Distance to Shell:	5.5 inches to center
Data Acquisition Rate:	50,000 acquisitions per second
Pressure Sensor Sensitivity:	~10 millivolts per psi (1 volt = 100 psi)
Dynamic Sensor Mounting:	3/16" past flush

Figure 2: Constructed Blast Cage

Figure 3: Pressure Transducer Mounting

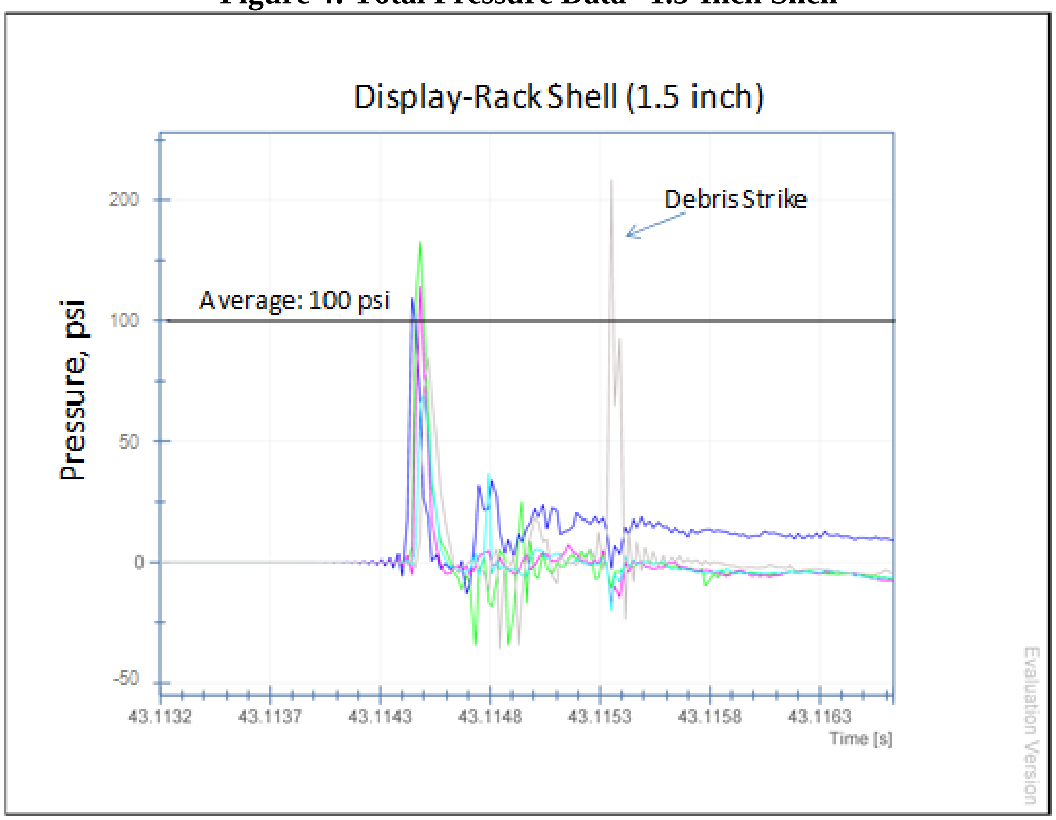


Staff has conducted dozens of tests using the blast chamber, and aside from some discoloration, the cage has proven to be durable. Testing has included a range of aerial devices from 1-inch diameter shells to 3-inch diameter display rack shells, as well as multiple sizes of mine/shell devices.

As a proof of concept, staff conducted experiments on a range of aerial shells. Starting with the smallest, a reloadable single-shot device, staff showed that the sensor cage could repeatedly measure the total pressure produced by the explosion of the shell. The average pressure produced was 15 psi. Staff found that smaller nonspherical shells explode nonsymmetrically, with lower pressures seen along the axis of the cylinder, versus radially from the center. To examine this phenomenon further, staff constructed several cylindrical devices filled with varying amounts of either black powder or flash powder. The results indicated that more powerful shells, which produced high pressures did not exhibit directionality, as compared to less powerful shells, where low quantity or energetics of the powder resulted in a smaller pressure rise. These smaller shells sometimes did exhibit directionality, such that the sensors above, left, right, sometimes recorded significantly different pressures than one another.

Figure 4 shows a sample of the waveform graphs that are produced during the testing of the overpressure generated from aerial shells using the transducer-mounted blast cage discussed above. The vertical axis indicates the pressure in pounds per square inch (psi), while the horizontal axis depicts time in seconds. The graphs show each of the five sensors; each is represented by a different color. In some cases, an additional peak to the right of the overpressure peaks represents a direct hit to the sensor by either shell or effect debris.

Figure 4: Total Pressure Data─1.5-Inch Shell



The fireworks device tested to generate the graph above was one which was not found to produce an audible report when tested in the field. As such, the device was not found to be subject to the limit of 130 mg of pyrotechnic composition. Other display rack shells with up to two-inch shells (from devices which were not found to produce an audible report) produced pressures from about 100 psi to 200 psi, similar to the pressure produced by an M-80 device at this same distance of 5.5 inches from the center of the device. Unlike M-80 devices (which explode on the ground), aerial devices are designed to explode between 100 and 300 feet in the air, reducing the risk of the explosion occurring in proximity to consumers.

Staff Developments in FY 2013

Based on the progress and developments from FY 2012, CPSC staff outlined future endeavors toward possible rulemaking. Given the large number of samples that were tested using the systems outlined in the previous year, steps needed to be taken to ensure that the pressure transducers were functioning adequately, particularly after exposure to dozens of explosions at close range. Also, staff wanted to investigate alternative methods that may not require the use of dynamic pressure transducers with high-frequency data acquisition and analysis. Thus, an outline of important milestones was developed, including the following:

- continue collecting data to further prove the effectiveness of the methods developed in FY 2012.
- examine the relationship between audible reports (sound) and the potential risk of injury (pressure) associated with aerial devices.
- begin designing a simpler, less expensive aerial shell overpressure testing method, based on the work done in FY 2012.

Audible Reports vs. Potential Risk:

Staff has examined whether there is a direct correlation between a device's ability to produce an audible effect and the potential risks from explosive overpressure. Several devices, selected randomly from a pool of compliance samples, were tested in the field and collected for subsequent pressure testing, using the methods outlined in last year's status report. The devices were tested blindly (with no knowledge of what the field report concluded), and afterward, the results were compared with findings from field testing. The results are shown in Table 1.

Table 1: Relationship of Audible Report to Overpressure

Sample Name	Sample Type	Field Testing Summary	Pressure, in psi
Sample #1	Mine/Shell	No Report	87
Sample #2	Display	No Report	60
Sample #3	Mine/Shell	Report	70
Sample #4	Display	No Report	110
Sample #5	Display	Report	100

Examining the waveform shapes from the pressure waves produced during this exploratory testing suggests that for these devices, there was no relationship between our determination of intent to produce an audible effect and the potential risk of injury due to the pressure wave. This does not mean that the requirement limiting the size of devices intended to produce an audible effect is an ineffective safety measure. In fact, staff believes that the requirement does force manufacturers of fireworks to limit the explosive power of large shells to prevent the devices from producing a sound which would be considered under the regulation to show that the device was "intended to produce audible effects." However, the results in this report do seem to indicate that, given modern fireworks production, intent to produce an audible effect may not be the best means of controlling fireworks explosive power risks. Figures 5 and 6 are representative graphs from the 15 experiments performed while generating the table above. Figure 5 shows the responses from the five dynamic pressure transducers for a sample that has been found to produce an audible report during field testing. Figure 6 shows the same for a sample that was found not to produce an audible report. It is important to recognize that the rise-times and overall peak shapes are very similar for the five transducers.

Figure 5: Overpressure from Sample w/ Report

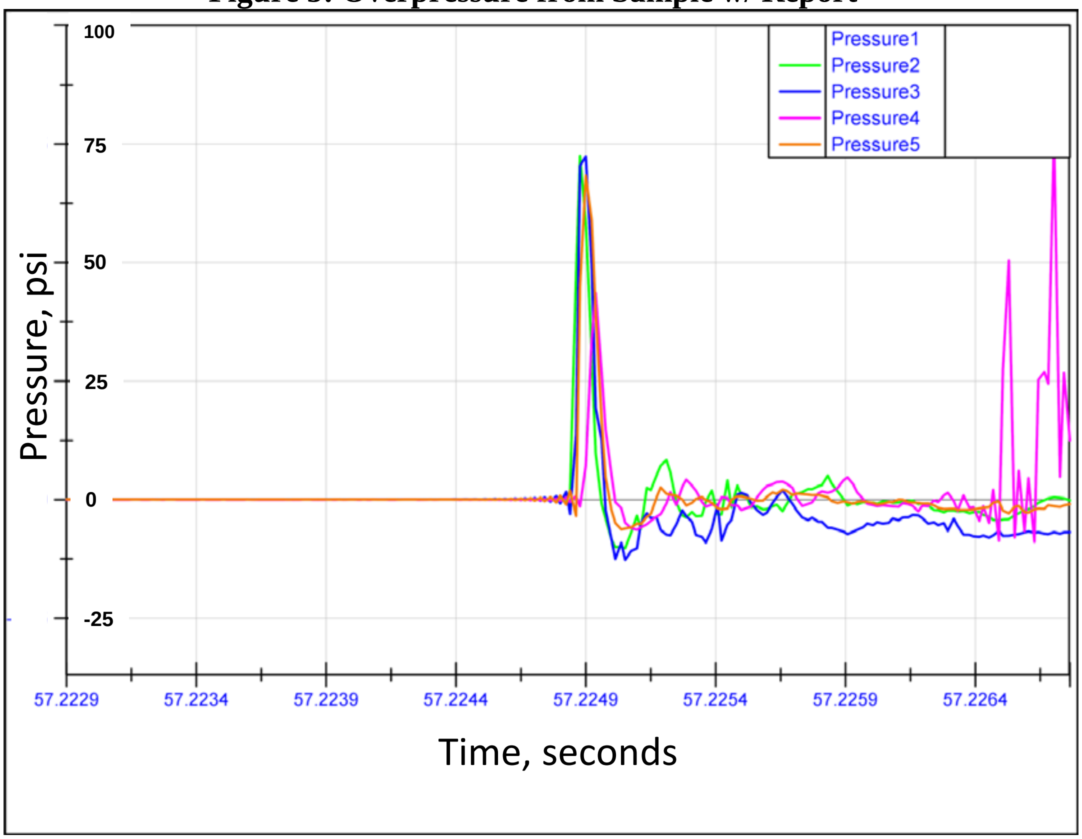
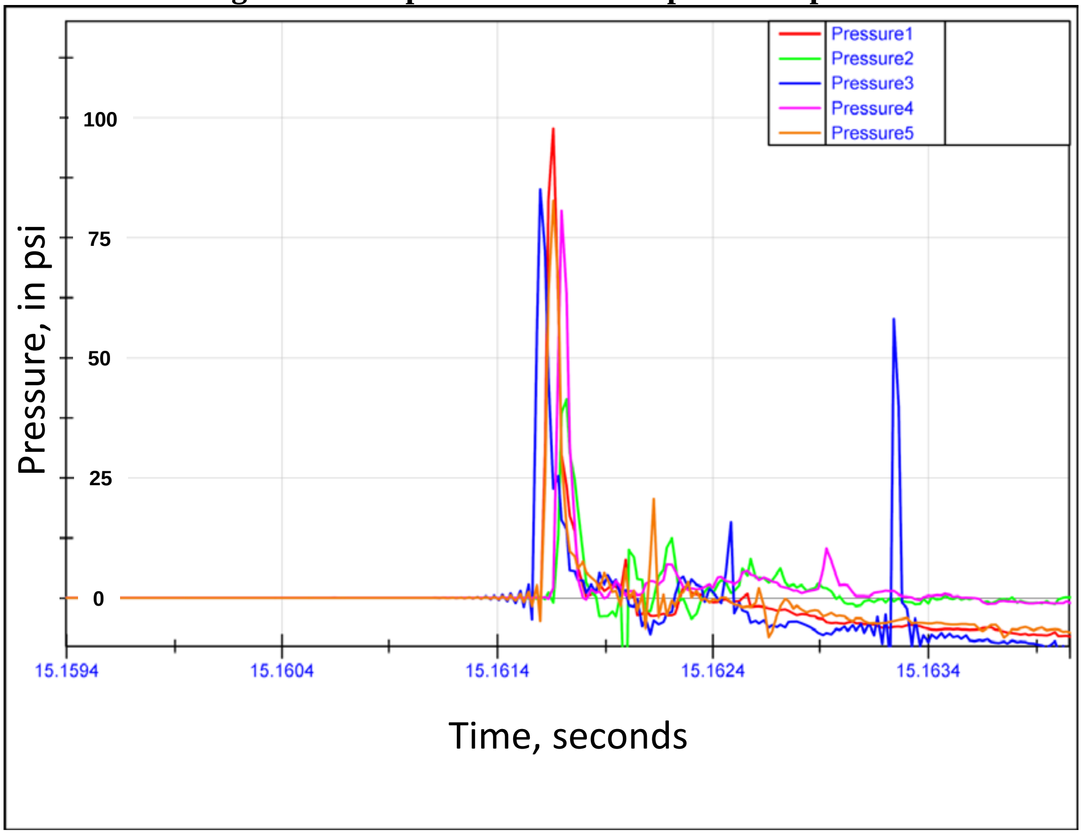


Figure 6: Overpressure from Sample w/o Report



Alternative Methods for Pressure Testing:

The methods described for obtaining and logging the overpressure can be complex and expensive. Given the necessary high sampling rate and resistance to explosive forces and chemical reactions, each of the five dynamic pressure transducers cost approximately $500. The data acquisition system used in the development of the current method, costs approximately $4,000. More importantly, the system was complex with multiple sensors each collecting 50,000 data points per second to capture the rapid pressure wave. To reduce the total cost of testing and to simplify the methodology, CPSC staff considered several methods that would be equally effective in determining the overall pressure from aerial devices.

One approach included indirect techniques that relied on the force of the pressure wave to affect an object physically. In this way, the motion of the affected object could be measured and a correlation to the pressures measured, using the five-sensor method.

Another approach was to multiply the specific energy of the break charge (calculated using the AFSL's previously discussed test) by the mass of the powder in the device to predict the energetics. Other methods, including direct measuring of pressure, closely followed the sensor approach, while trying to optimize and simplify the testing setup.

Indirect Physical Methods:

By using physical methods to measure pressure, it may be possible to eliminate the use of expensive, complex equipment. One example of a relatively inexpensive and simple indirect measurement technique employs the use of a pendulum. In theory, any force that acts on the pendulum will cause a shift in the pendulum bob's position. The total change in position of an object would be directly proportional to the amount of force acting on the object. The use of a pendulum would also restrict the motion of an object, leading to a safer test. The object (in our case, a ball) could be placed in a horizontal or vertical orientation to the blast, and pressure could be measured as a function of arc length or vertical displacement. Some potential issues would include: the condition and treatment of the fulcrum (pivot point) of the pendulum. Small changes regarding the fulcrum (*e.g.*, impingement, friction) could influence drastically the radial distance the object would travel. Changing the orientation to that of a vertical displacement of a ball would eliminate the issue.

Staff designed and performed experiments based on the methods discussed above. Using either a pendulum or a ball displaced vertically, results were difficult to measure and not easily repeatable. When using lab-produced M-80s, the position of the ball could be followed with some difficulty. However, use of actual shells resulted in near-impossible tracking of the ball, due to the presence of "effects" in the shells that produce a bright light upon exploding, along with large quantities of smoke and debris. Another issue that staff experienced was a lack of repeatability from trial to trial. A lack of uniform pressure release is believed to be one of the reasons for this. Previous status reports demonstrated that aerial shells sometimes show a great deal of directionality when functioning. To overcome the issue of nonspherical pressure waves, devices were exploded inside a steel tube, whereby all of the pressure would be aimed in one direction. While this did make the measurements slightly more consistent, the increased brightness and smoke from the steel tube made visually tracking the ball even more difficult.

From previous studies, staff has concluded that the potential pressure released by exploding aerial shells is directly related to three distinct factors: (1) the break charge powder's explosive efficiency─the amount of "hot gas" produced; (2) the amount of break powder (below 100 mesh particle size) that the device contains; and (3) the manner in which the device has been manufactured (*e.g.*, packing of the pyrotechnic contents, cardboard/plastic shell thickness, amount of glue-tape applied, tightness of the wrappings). Previously, it was unknown how much of a role each of the factors played in the overall pressure produced upon functioning.

One possible method that would alleviate the need for "as-built" shells to be tested relied on the assumption that the powder energetics and amount of powder used accounted for the majority of the total pressure. To test this hypothesis, staff began a study to measure the break charge powder energetics via the AFSL's Black Powder Equivalency Test. Meanwhile, the test also measured the amount of powder used for a variety of devices. By factoring these two measurements together (ball height x mass of powder below 100 mesh), staff hoped to define a "power potential" to predict the energetics of the device. Table 2 shows the results of those experiments.

Table 2: Correlative Power Potential vs. Actual Pressure

Sample #	Avg. 100 Mesh-g	Avg. Height-m	*Power Potential*	Average Pressure-psi
CM001	6.0	2.3	*12.5*	N/A
CM002	2.3	2.2	*5.7*	72
CM003	3.2	2.7	*9.1*	86
CM004	3.5	2.4	*9.0*	95
CM005	6.6	2.7	*15.2*	45
CM006	0.6	2.6	*1.6*	130
CM007	6.8	1.5	*9.5*	10
CM008	3.4	2.1	*6.5*	23
CM009	3.0	3.0	*8.9*	87

As evident in Table 2, there was no relationship between the calculated potential power and the actual pressure recorded using the whole shell. Specifically, sample CM005 and CM006 (highlighted in red) show that the power potential is not a good predictor for the overpressure, perhaps due to effects of shell design and construction. In fact, while both samples registered similar ball heights—suggesting similar powder energetics—sample CM005 used 11 times as much powder, yet exhibited less than 35 percent of the pressure measured from sample CM006. Staff concluded that any newly developed test method must take into account the whole shell.

Another potential alternative method was an adaptation of the AFSL Black Powder Equivalency Test, using whole shells inside of the mortar tube in place of the one gram of break charge powder. Staff conducted research to determine whether certain modifications to the test could be made to allow for the measurement of pressure from "whole-shell" aerial devices (initial tube and ball designs can be seen below in Figures 7 & 8).

Figure 7: Steel Mortar Launch Tube

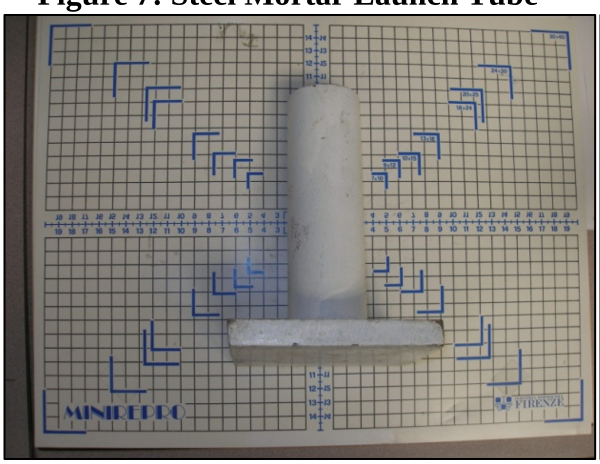
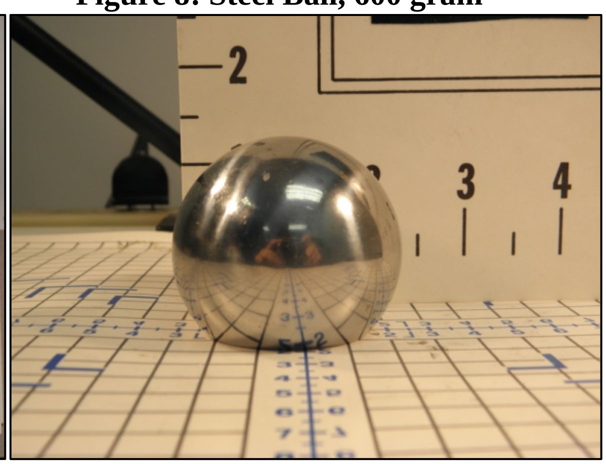
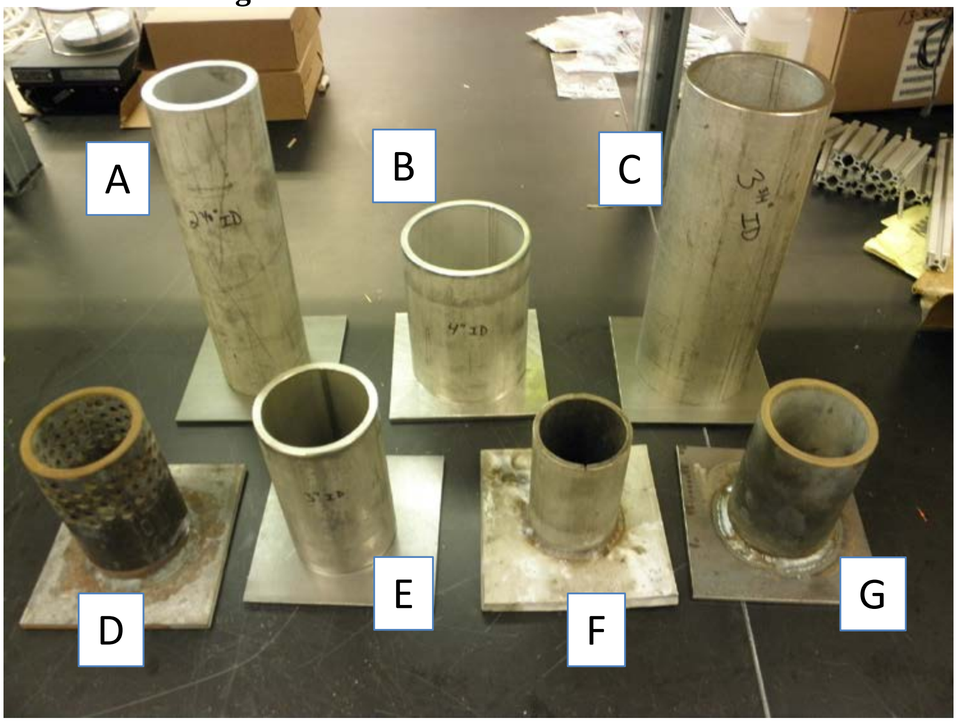


Figure 8: Steel Ball, 600 gram



Variations in the size, weight, and material of the ball were examined, as were multiple permutations of the launch tube itself. A large array of design possibilities can be seen in Figure 9. Attempts to increase or relieve pressure were made through changing the diameter or length of the tube, or by the addition of "pressure-relieving" holes added to the body of the launcher.

Figure 9: Steel Launch Tube Variations



Initial testing began with a slightly larger version of the standard AFSL launch tube (see launch tube F in Figure 9). A 1.8 kg (4 lb.) steel ball was used in place of the standard 0.6 kg (1.3 lb.) ball. Because lab-designed M-80s had exhibited a similar overpressure to the strongest devices coming from consumer samples, M-80s were used as a developmental testing standard. Unfortunately, even the heavier ball was launched with too much force, resulting in the steel ball striking the upper plate of the reinforced blast chamber (steel plate set at 9 feet in height). The rapid expansion of gases within the chamber also caused the door of the chamber to sustain damage. In the design of the next launch tube, staff considered relieving the pressure from the initial blast, thereby reducing the overall pressure and the total ball height.

The launch tube labeled "D" in Figure 9 shows a perforated steel tube designed so that 35 percent of the total area of the tube is open to the atmosphere. Using the same M-80-type of device, as described in previous tests, the steel ball was still launched with great force, once again making contact with the upper steel plate of the chamber. Prior to redesigning the tube for more open space, staff tested what were considered "high-energy" aerial shells that had registered relatively high pressures when tested against pressure transducers. The results were similar to those of the M-80s, with the ball striking the upper steel plate. To test the lower-power devices, a 1-½" aerial shell was used. Employing the same tube and ball, tests showed that the lower pressure-producing devices were unable to launch the ball off of the perforated launch tube. It became apparent that the same issues that plagued the pendulum technique were also present with this method. Staff concluded that the limited dynamic range of this method, together with the difficulties posed by smoke and other effects limiting visibility of the ball, meant that this method was not likely to be dependable.

Direct Pressure Measurements:

Previous work demonstrates that dynamic pressure transducers are capable of measuring the pressure waves produced from aerial devices with great precision, accuracy, and with a large dynamic range. Some of the drawbacks included the cost associated with the sensors and the instrumentation necessary to collect data, as well as the complexity and prerequisite training on how to interpret the data. CPSC staff sought to design a method whereby reliable results could be obtained with minimal cost, minimal complexity, and minimal training.

To reduce cost and complexity, limiting the number of transducers needed was an obvious starting point. Multiple sensors were initially used to account for the effects of blast directionality observed in many smaller or nonspherical shells. One approach to help alleviate these limitations is to direct the entire shell pressure in one direction.

Using the launch tubes shown in Figure 9 to contain the shell and direct the pressure wave in one direction, staff was able to reduce the number of necessary sensors from five to one, while reducing the number of acquisition modules and the size of the data acquisition chassis. This resulted in reducing the costs and complexity of the system in an effort to demonstrate means by which such testing could be done practically in commercial fireworks testing. The initial design of a blast-box capable of measuring the pressure while providing some protection to staff can be seen in the computer-generated model (Figure 10). An “as-built” version of the box is shown in Figure 11. In the real model, additional pieces of the material 80/20 were attached to the inside of the box to extend the pressure transducer to the same distance from the walls as the inner arc of the launch tube. The sides of the box are inlayed with ¼" perforated steel plates to help relieve the pressure and contain any debris that travels horizontally and still allows staff to observe the experiment. A steel-inlayed “cap” is used to reduce further the chances of shrapnel and/or burning debris escaping.

Figure 10: Design of Blast Box

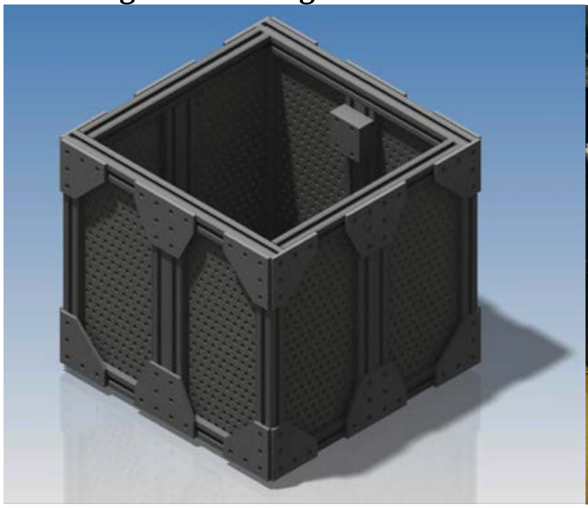
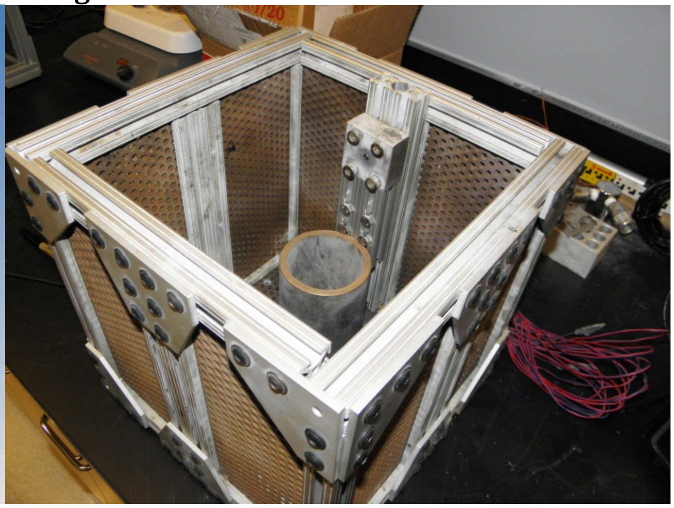


Figure 11: As-Built Blast Box w/ Sensor

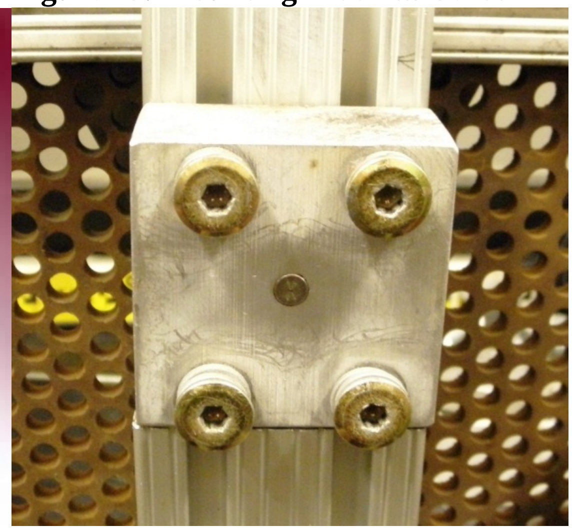


Once the box was constructed, the dynamic pressure transducer could be mounted on the inner frame. Initially, the distance between the top of the launch tube and the sensor was variable. Staff was able to adjust the height of the sensor and determine the optimal distance.

Figure 12 below shows the dynamic pressure transducer prior to mounting in a 1"-thick aluminum block. Mounting the sensor and orienting the sensor horizontally to the pressure wave results in more accurate readings, reduces the effects from debris striking the sensor, and extends the life expectancy of the sensor. In Figure 13, the sensor has been mounted, flush with the aluminum block (center of block).

Figure 12: Dynamic Pressure Transducer

Figure 13: Mounting Block w/ Sensor



The key element in generating a well-defined pressure curve is rise time. Generally speaking, rise time is the time taken by a signal to change from a relatively low value (often zero) to a much higher value. Dynamic pressure transducers are designed to register any change in pressure extremely quickly and record tens of thousands of points per second. A sampling rate of less than 10,000 measurements per second could result in inaccurate data, due to the peak pressure occurring between measurements.

The pressure transducer was subjected to the directed blast from an M-80-type device. The sensor platform was adjusted to four different heights and measurements taken at each. For consistency, the launch tube rests on the bottom of the blast box, with one side of the base against the side wall of the box. In this manner, it is possible to ensure that the inner walls of the tube are lined up accurately with the sensor. Multiple experiments have shown that small variations from true alignment make little to no noticeable difference in the pressures obtained.

The resulting waveforms were extremely similar to the waveform diagrams shown above, with the largest difference being the number of peaks on the graph. Figure 14 shows a representative pressure graph collected using the same M-80 devices used in previous experiments. The distance between the top of the launch tube and the sensor was six inches. Figure 15 shows the relationship between the tube-sensor distance and the pressure measured.

Figure 14: Pressure Graph; Single Pressure Transducer

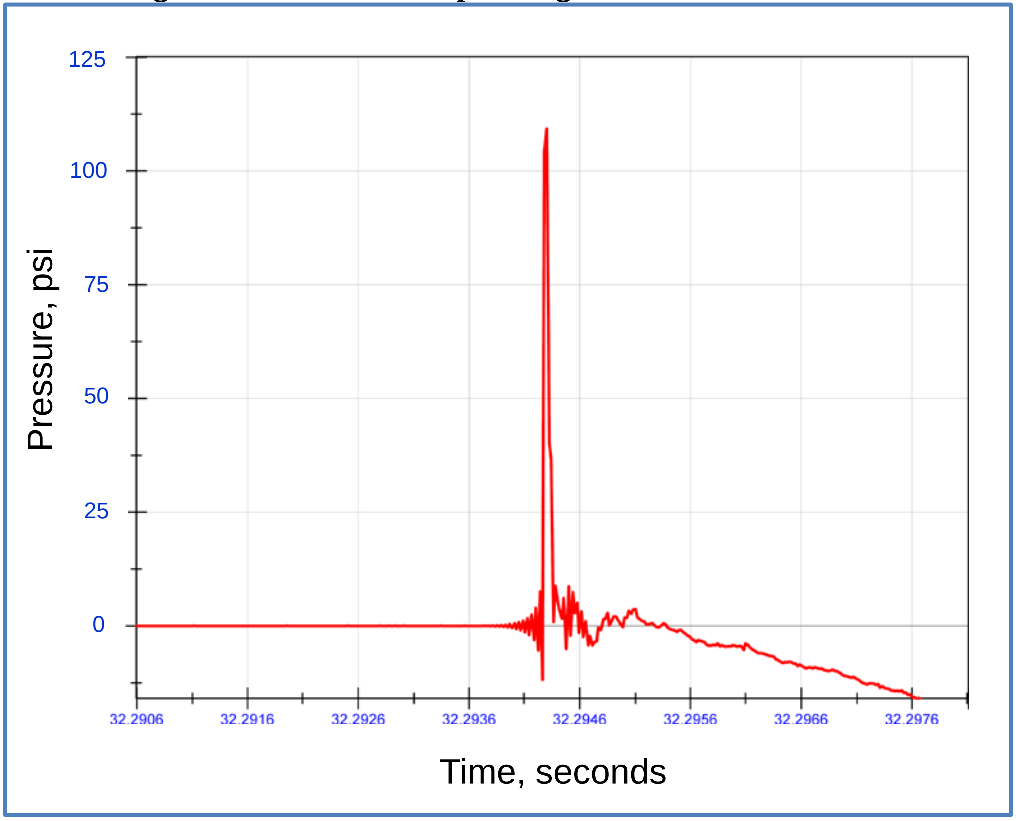
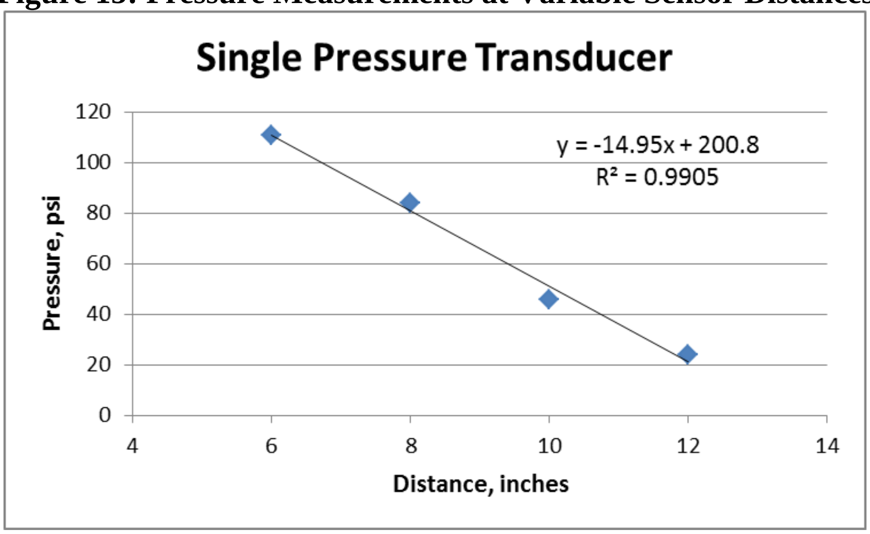
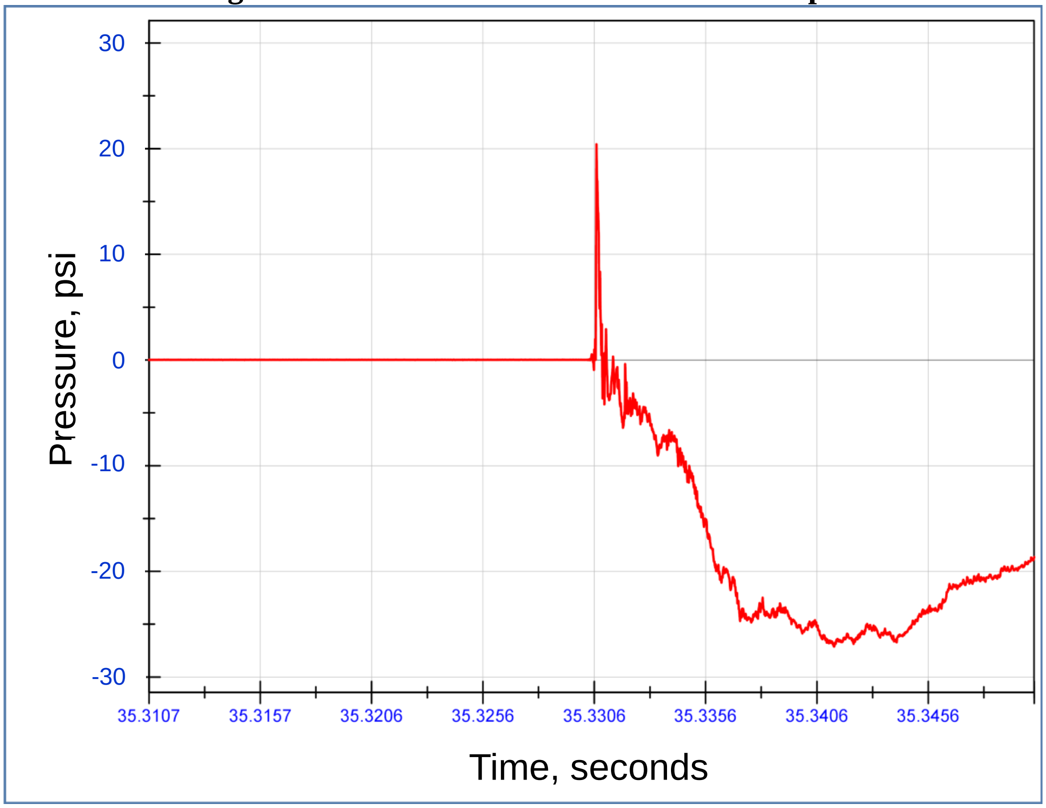


Figure 15: Pressure Measurements at Variable Sensor Distances



Using the same mortar launch tube (3" inner diameter) and sensor mounting position (~6 inches above the top of the steel tube used while testing with M-80s), we examined a variety of real-world samples. As expected, many of the devices registered pressures well below the stronger M-80 trials. It is important to note, however, that even small aerial devices known to produce relatively small pressures generated well-defined pressure curves. Figure 16 shows one such representative sample.

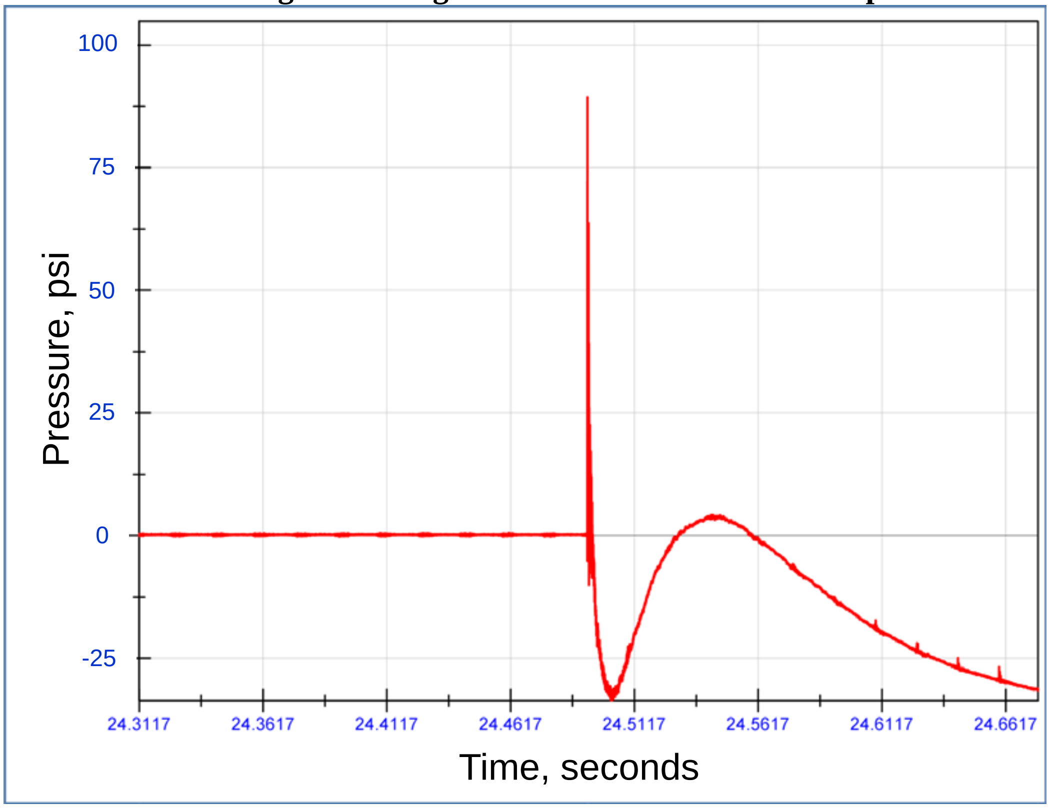
Figure 16: Lower-Pressure Aerial Shell – 20 psi



A strong negative pressure is evident in the pressure graph shown in Figure 16. Staff believes that using real-world aerial devices in this simplified setup with a tube to direct the blast in one direction can result in different extents of confinement for different geometries of shells, because a large shell would substantially reduce the amount of remaining space when using a smaller mortar tube. M-80 devices are filled with three grams of flash powder and typically take up only a small percent of the total tube space; whereas, the shells taken from consumer fireworks can reach diameters as great as three inches, substantially reducing the amount of free space within the tube. Increased confinement of fireworks shells increases the overpressure created. As a result, more numerous “aftershock” peaks, as well as a large negative pressure are frequently observed. Initial work was done using non-confined shells with sensors along five spatially diverse locations to avoid the potential issue of confinement differences, but the work just described was for the purpose of beginning to develop a more simplified test that could be conducted more easily for routine testing of fireworks.

To reduce differences in confinement for different geometries of shells, staff has been experimenting with a range of sizes of mortar tubes. Typically, tube heights range from five inches to six inches, while inner diameters range from 2-½ inches to 4 inches. Varying the tube dimensions can have a drastic effect on the size and shape of the peak generated during testing. Figure 17 shows another representative pressure graph when testing a relatively large (2-¼ inch aerial shell) and a tube with an inner diameter of 3-¼ inches. The time scale for this graph has been lengthened to show the total peak shape. It may be necessary to employ a range of tube sizes with larger devices placed in larger tubes and smaller devices in smaller tubes, such that a similar confinement is present.

Figure 17: Higher-Pressure Aerial Shell – 90 psi



Dynamic Pressure Transducer Calibration:

Given the extreme environment in which the dynamic pressure transducer operates, it would be necessary to test the accuracy and precision of the sensor periodically. The sensors used in this work were calibrated by the manufacturer. Currently, several methods for sensor calibration and for daily calibration verification exist; many of them commercially available. Staff is considering effective, low-cost calibration methods and calibration verification methods as part of FY 2014 activity.

Conclusion

In FY 2013, staff continued to explore alternatives to the current test methods for aerial consumer fireworks devices, including the examination of alternative methods to determine the hazards related to aerial shells exploding in close proximity to bystanders. According to the current regulation, aerial devices designed to produce an audible report are limited to 130 mg of pyrotechnic composition. Data from the experiments conducted suggest that current manufacturing practice for fireworks results in devices where the injury potential due to blast overpressure in close proximity functioning of aerial shells may be similar in some cases for devices whether or not intended to produce an audible effect. This does not mean that the requirement limiting the size of devices intended to produce an audible effect is an ineffective safety measure. In fact, staff believes that the requirement does force manufacturers of fireworks to limit the explosive power of large shells to prevent the devices from producing sounds that might be considered to produce audible effects intentionally.

CPSC staff concluded that the most reliable method for measuring the explosive power of fireworks shells is to measure directly the pressure generated upon explosion. For this purpose, an array of dynamic pressure transducers was used in concert with a commercially available data acquisition system to determine blast overpressures from consumer fireworks of a variety of shapes and sizes, along with lab-made M-80devices to use as a measuring guide to potential danger.

Staff began to examine less expensive, less complex techniques to determine whether these methods could measure the pressure released from consumer aerial devices while continuing to provide the necessary accuracy, precision, and integrity. Methods based on a more indirect approach (*i.e.*, measuring the height of a steel ball launched from a mortar tube) did not show promise as the range of pressures from consumer fireworks was larger than the dynamic range of any such method. Instead, staff has focused on modifying the pressure transducer array discussed in the FY 2012 Fireworks Safety Status Report to try to reduce the cost and complexity. Thus far, staff has shown that focusing the blast toward a single dynamic pressure transducer is sufficient to collect reproducible and accurate pressures. Less expensive, less complex data acquisition systems have been examined and, while more experiments must be performed to establish test system technical reliability and reproducibility, the pressure measurement approach looks viable for consideration in a potential rule update.

Recommendations

As suggested in the previous year's status report, staff is continuing to evaluate possible changes to 16 C.F.R. § 1500.17 (a) (3), which bans fireworks devices intended to produce an audible effect if the audible effect is produced by a charge of more than 130 mg of pyrotechnic composition.

One such option would be to replace § 1500.17 (a) (3) with a restriction on the explosive power of the shells, regardless of intent to produce an audible effect, possibly by evaluating the shells as constructed by the manufacturers, with a simplified version of the total overpressure testing described in last year's memo. An advantage of this option would be that it assesses directly the explosive power of the shells, as constructed. A disadvantage is that it may be a more burdensome testing regimen for both the affected industry and for CPSC enforcement. Staff will consider possible simplifications of the method used in this memo, based on the findings of the work conducted to date in FY 2013.

A difficulty in adopting any standard that limits overall pressure is determining at what pressure the limit should be set. Staff has identified two possible limit scenarios regarding capping of blast overpressure:

1. *Setting the pressure limit based on allowing pressures similar to those currently measured in the marketplace*

Staff has accepted, based on discussions with AFSL over the years, that the market for large, multiple-tube devices with shells exceeding 1.5 inches in diameter has expanded significantly from 1996 to the present day, but the annual fireworks injury report does not find a statistically significant trend in injuries in that period. Staff believes that the requirement in 16 C.F.R. § 1507.12─that these larger devices shall not tip over when subjected to a 60-degree, tip-angle test, helps prevent accidental tip overs that could cause the shells to explode near bystanders. Therefore, staff may consider the appropriateness of an approach to assume that the current market norms for the level of pressure released upon explosion of shells typical to the marketplace is reasonable, and could be used to set guidelines on future pressure maximums. Staff could perform experiments using samples collected from the current marketplace and use the data to determine where a maximum pressure limit should be implemented with the aim of maintaining the status quo for the market while replacing a subjective test to determine intent to produce an audible effect with an objective measurement of the explosive power of the device.

Additionally, staff could consider having different requirements for shells from devices subject to the 60-degree tip-angle test in 16 C.F.R. § 1507.12, with a more stringent requirement for those smaller shells which are not subject to 16 C.F.R. § 1507.12, recognizing the greater chance of tip over for such devices. In the case of smaller shells, not subject to the tip-angle test, staff may consider the appropriateness of an approach to assume that the current market norms for the level of pressure released upon explosion of shells typical to the marketplace is reasonable, and could be used to set guidelines on future pressure maximums.

The aim of this possible staff approach of potentially developing new limits to the pressure produced from the explosion of shells, based on approximating the pressure produced by the explosion of “normal” current fireworks would be to maintain as close as possible to no changes in costs or benefits, but with a more efficient, objective standard and test method as compared to the current regulations which rely on determination of intent to produce an audible effect.

2. Setting the pressure limit based on health effects expected at particular pressures

The potential risks of injury to the human body due to overpressure, including what pressures are required to cause damage, such as ruptured ear drums, broken bones, deformations of skin and muscle, and other bodily harm could be used to set a different limit to explosive pressures from fireworks than the level suggested by current market norms. Injury data stemming from M-80s have been collected for years and might provide a good starting point for a pressure limit based on potential injury. This potential approach could possibly result in more disruption to the marketplace if the standard were set below the current industry norms for explosion overpressure. On the other hand, this approach could potentially have more benefits from injury reduction.

Future Endeavors

In FY 2014, staff has proposed a project to finalize a method for, and conduct testing of samples from the marketplace to evaluate alternatives to the current break charge testing. If the project is approved by the Commission for inclusion in the FY 2014 Operating Plan, additional testing will be conducted to assess lower cost alternatives for the data acquisition system. Several techniques to verify sensor accuracy will be tested. The work described in this status report was conducted with a long-term aim, beyond FY 2014, for staff to consider regulatory flexibility and the effects of potential limits on the marketplace, and on injury rates and severities, with the aim of developing a briefing package for Commission consideration.