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Configuration and "Over-Load" Studies of Concussion Mortars

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ABSTRACT

Although concussion mortars have been used for many years at band concerts and in theatrical performances, there has been relatively little investigation of the effectiveness of their basic design. Measurements of the effect of two modifications of the design of concussion mortars indicate that significant improvements in their performance were achieved; however, only for light powder loads. Though somewhat disappointing, these designs may be of use in situations where increased loudness of report is needed without an increase in smoke production. Measurements were also made of the effect of loading materials (whether inert, a fuel, or an oxidizer) on top of a commonly used concussion powder. It was found that all of these produced increased sound output. However, this seemed to be mostly the result of added confinement of the concussion powder.

Introduction

This is the third in a series of articles examining the performance of concussion mortars. The first article[1] investigated air blast pressure (sound pressure level), internal mortar pressure, and mortar recoil force as functions of the load mass of one type of concussion powder. The second article[2] was a comparative study of air blast pressure and internal mortar pressure for a collection of six commercially produced concussion powders. In the present article, the effect of two modifications of the standard concussion mortar design were investigated. In addition, so called "over-load" studies were conducted. In this context, over-load refers to the practice of placing an increment of some other material on top of (over) the normal charge of concussion powder (load). The motivation for the study was to determine the extent to which these materials might act to modify and potentially improve the performance of concussion mortars.

Background

In its most common form, a concussion mortar consists of a thick cylindrical steel bar, welded to a heavy base plate. The mortar contains a combustion chamber (barrel), typically produced by drilling a hole on-axis into the top end of the steel bar. The basic mortar used in this study was 2 inches (50 mm) in outer diameter, with a 1-inch (25-mm) hole drilled to a depth of 4.5 inches (115 mm). The construction of the mortar is illustrated in Figure 1, which also shows it loaded with a charge of powder and an electric match for ignition.

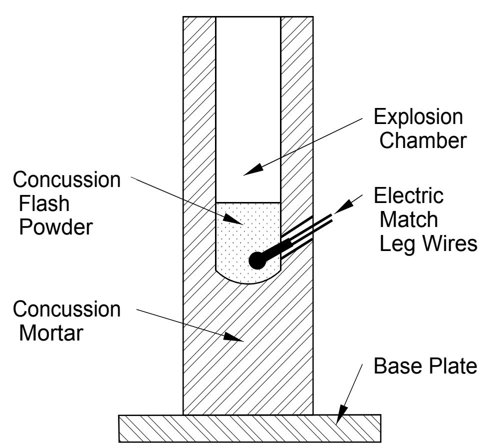

Figure 1. An illustration of the construction and setup of a concussion mortar.

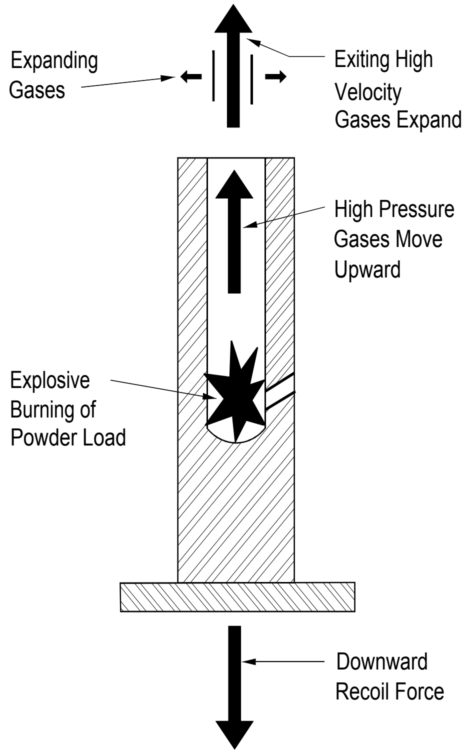

Figure 2. An illustration of the firing of a concussion mortar.

Upon ignition, because of the confinement provided within the combustion chamber, the concussion powder burns explosively, see Figure 2. The high internal pressure causes the combustion products (gases and solid particles) to be accelerated upward. As the gases exit the end (mouth) of the mortar, they expand to produce a shock wave that is heard and felt by the audience. As a result of the ejection of combustion products, a downward recoil force is produced.

Figure 3 illustrates a theoretical air blast (overpressure) profile. Before the arrival of the blast wave, there is no indication (with respect to pressure) that an explosion has taken place or that the blast wave is approaching. When the leading edge of the shock wave arrives, it produces an essentially instantaneous rise in pressure from ambient to some maximum value. Thereafter, the pressure decays much more gradually back to ambient pressure. This portion of the blast wave is referred to as the positive phase. Following the positive phase, there is a negative phase, during which pressure drops below ambient. In essence, this is caused by over expansion of the gases, wherein the outward rush of air continues beyond that necessary to relieve the pressure produced by the explosion. Thus, a partial vacuum forms at the seat of the explosion, producing the negative phase of the blast wave. This is less extreme than the positive phase and lasts longer.

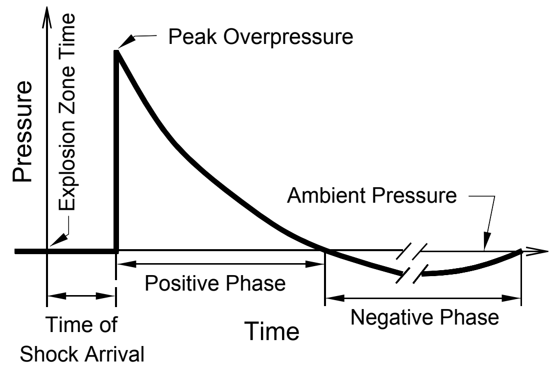

Figure 3. An illustration of a typical overpressure profile (blast wave) produced by an explosion.

The sound qualities of potential interest with regard to the firing of concussion mortars are sound pressure level, loudness and tonal quality. Except for a few brief comments in this article, readers wishing more information are referred to a previous article in this series,[2] or to reference texts on the subject.[3–5] Sound pressure level (SPL, in decibels, dB) is a physically measurable quantity and can be calculated from air blast overpressures. There is a logarithmic relationship between blast pressure and SPL. Loudness (*N*, in sones) is a subjective measure of sound level, dependent on the processing of nerve impulses by the brain. The loudness scale is linear, such that a sound with a loudness value twice that of another sound will be perceived by a typical listener to be twice as loud. The tonal quality of the concussion mortar sound may also be of interest. That is to say, does the sound produced tend toward being a sharp crack or a more mellow boom? The feature of a blast wave that is conjectured to correlate with perceived tonal quality is the duration of the positive and negative phases. All else being equal, shorter phase durations are expected to be heard more nearly as sharp cracks,

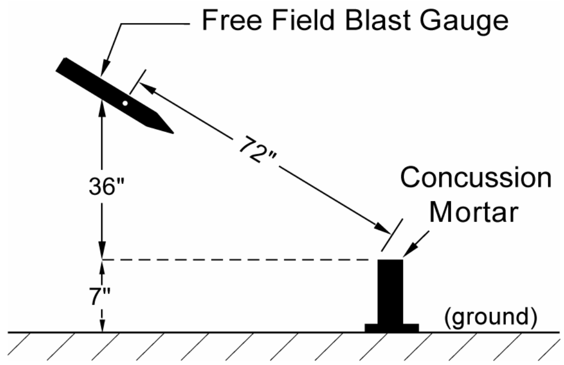

Figure 4. An illustration of the physical setup for one detector used to collect concussion mortar overpressure data. (Not to scale.) (For conversion to SI units, 1" =25.4 mm.)

and longer phase durations, as more mellow booms.

Experimental Method

Data was recorded outdoors in a large open space, with the concussion mortar placed with its base directly on the ground. Air blasts (overpressures) produced by the firing of the concussion mortar were measured using two piezoelectric free field blast gauges (PCB Piezotronics model 137A12). The physical arrangement for one of the detectors with respect to the concussion mortar is shown in Figure 4. The second detector was positioned at the same height but at twice the total distance, 144 inches (3.65 m), from the muzzle of the mortar. The electrical overpressure signals were amplified (PCB Piezotronics model 480D09 amplifying detector power supply) and digitally recorded (Fluke model 99 oscilloscope).

In the first portion of this study, combinations of two new configurations to the basic mortar design were investigated. One new configuration was a modification to the bore of the concussion mortar, such that the last 1.5 inches (38 mm) tapered from 1.0 inch (25 mm) to a diameter of 1.75 inches (44 mm). This is illustrated in Figure 5 and is referred to as the "trumpet mortar" configuration in this article. The idea for this configuration originated with M. Grubelich and T. DeWille[6] and was proposed as a way of increasing sound output for low mass powder loads. The other new configuration was a modification of the electric match hole. A 0.22-inch (5.6-mm) hole was drilled 0.25 inch (6.4 mm) deeper into the bore of the mortar, and an intersecting 0.16 inch (4.1 mm) hole was drilled from the side of the mortar. This configuration is also illustrated in Figure 5 and is referred to as the "confined match" configuration. The idea for this configuration originated with the Kosankes as a way of achieving reproducible positioning of electric matches, which was needed for other planned concussion mortar studies. Because of the close fit of the electric match in its hole, it was necessary to insulate the match head contacts to prevent occasional misfires due to short circuiting. This was accomplished either with a single wrap of tape or by dipping the match heads in nitrocellulose lacquer.

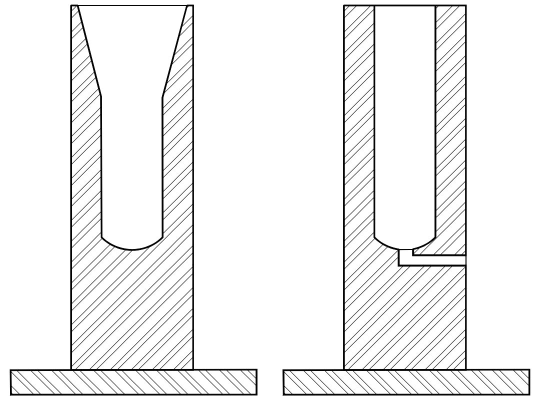

Figure 5. Illustrations of the "trumpet" and "confined match" concussion mortar configurations.

In all cases in this study the concussion powder used was Pyropak Concussion Powder supplied by Luna Tech, Inc. This is a fuel-rich powder based on magnesium and strontium nitrate.[2] Similarly, all of the electric matches used in this study were Pyropak ZD matches.

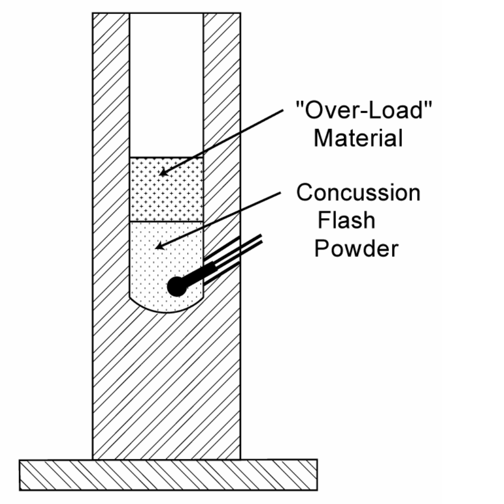

Figure 6. An illustration of the use of "over-load" materials in a concussion mortar.

In the second portion of this study, so called "over-loads" were studied. In each case some other material was placed over the normal load of concussion powder, see Figure 6. A variety of over-load materials were tested. These materials fell into three categories: relatively inert materials, used to provide added confinement of the concussion powder; fuels that might react after mixing with oxygen in the air above the concussion mortar; and oxidizers that might react with the excess magnesium (vapor) produced when firing Pyropak concussion powder. (Pyropak concussion powder has approximately 50% excess of magnesium fuel, which normally reacts in the air above the mortar producing light and possibly additional sound output.[1]) More information about the over-load materials and the reasons for their selection will be given when discussing the results.

The presence of statistical noise in the blast overpressure data sometimes makes it difficult to determine accurately the peak overpressures and durations of the positive phase. This is especially true for light (low mass) powder loads. For example, see the top graph in Figure 7, which is for the firing of a 7 g powder load as recorded by the near blast wave detector. To facilitate unbiased and consistent interpretation of the data, it was decided to digitally filter the data using a 15 coefficient digital finite impulse response 20 dB/octave filter, which began its rolloff at 10% of the Nyquist frequency for the data rate.[7] The middle graph in Figure 7 is the original data after being filtered. The initial small dip in the filtered data, just before the onset of the leading edge of the blast wave, is an artifact of the filtering process and should be ignored. However, the prominent features seen in the "Filtered (near)" data are felt to be real and not just lower frequency statistical noise. This view is supported by the observation that the data recorded for the "Filtered (far)" detector appears to be quite similar, although reduced in amplitude and delayed in time as expected (see the bottom graph of Figure 7). Figure 8 is a similar set of raw and filtered data; however this time for a more substantial pow-

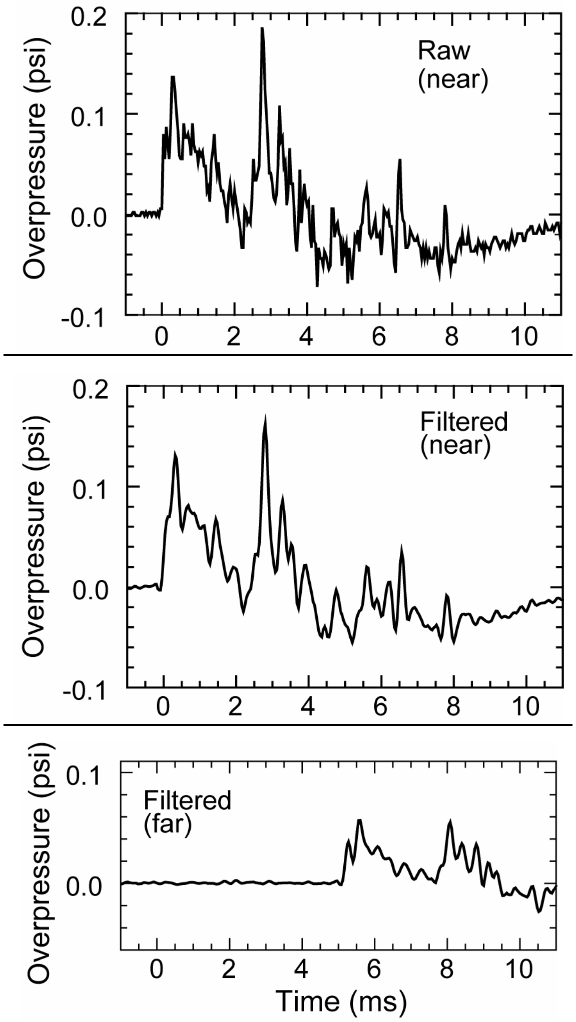

Figure 7. Raw and filtered blast pressure data from the firing of a 7 g concussion powder load.

der load (28 g). This graph has more nearly the shape expected for a blast wave. The feature seen in the graph about 1 ms after the arrival of the blast wave has been shown to be reflections from the holder of the detector, although that reflection seen in Figure 8 appears more prominent than most. The need for filtering the data from heavier loaded mortar firings is significantly less than for the light loads. However, in an attempt to produce consistent results, all data sets were filtered.

For this article, peak blast pressure was taken as the maximum pressure observed in the filtered data. The duration of positive phase was taken to be one data point (0.04 ms) less than the time interval between when the positive excursion of the unfiltered pressure data reached 10% of its peak value and the first negative excursion in the filtered data. Pressure impulse was simply the area under the positive phase waveform as seen in the filtered data.

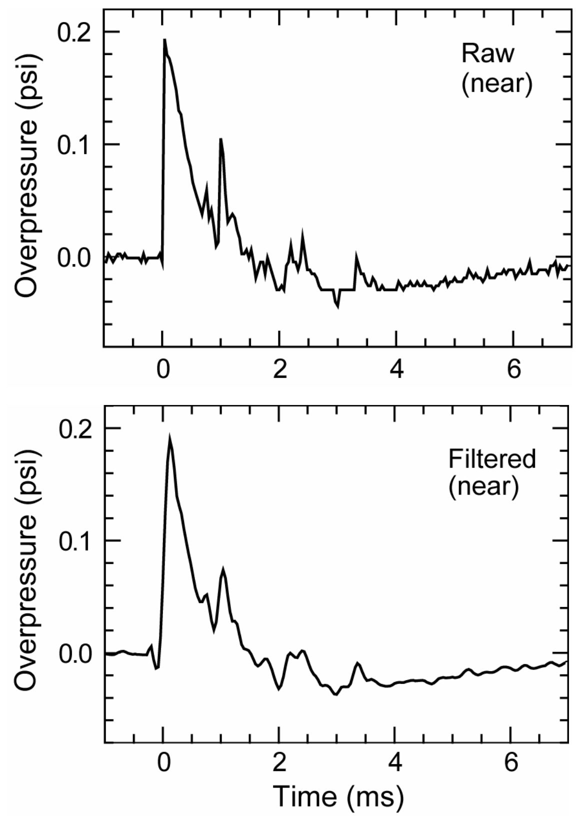

Figure 8. Raw and filtered blast pressure data from the firing of a 28 g concussion powder load.

Results

For each mortar configuration, powder load, and over-load condition examined, three repeat measurements were made. Table 1 presents a listing of the results of those measurements. However, because average results are presented in the process of discussing the various sets of test conditions, Table 1 appears appended to the end of this article. Further, the degree of statistical precision in these measurements is not high, and accordingly, the accuracy of the averages reported below, is relatively low, and it is only the general magnitude of the various effects that should be relied upon in drawing conclusions.

If human hearing of concussion effects occurs as presumed, then: greater peak pressures correspond to louder sounds; greater pressure impulses correspond to greater total energy production; and longer and shorter positive phases correspond to more mellow and sharp sounds, respectively.

Trumpet Mortar Effect

Table 2 presents a summary of the results comparing the trumpet configuration with the regular mortar design, both with the electric matches in the standard Luna Tech match hole location. For the lightest load (7 g), note that: there was an approximate doubling of both the peak pressure and pressure impulse for the trumpet mortar, while the duration of positive phase decreased by about one third. Since pressure and impulse both increased by approximately the same amount, this suggests there was a greater production of sound energy from the same amount of powder (i.e., greater efficiency). For this to be consistent with the observation of a decrease in positive phase duration, there must also have been a change in the shape of the blast wave. For heavier loads (14 and 28 g) some differences were observed between the blast waves from regular and trumpet mortars. However, these differences seem to be primarily a statistical artifact.

Table 2. Average Trumpet Mortar Effect Using Standard Electric Match Location.

Mortar Position →	Near Mortar (72")			Far Mortar (144")		
Test Variable →	**Peak Pressure** (psi)			**Peak Pressure** (psi)		
↓ Test Condition →	Regular	Trumpet	% Change	Regular	Trumpet	% Change
7 g	0.10	0.21	+110	0.036	0.072	+100
14 g	0.85	0.72	–15	0.36	0.39	+8
28 g	1.75	1.97	+13	0.66	0.73	+11
Test Variable →	**Pressure Impulse** (psi ms)			**Pressure Impulse** (psi ms)		
↓ Test Condition →	Regular	Trumpet	% Change	Regular	Trumpet	% Change
7 g	0.08	0.18	+110	0.050	0.075	+50
14 g	0.58	0.62	+7	0.29	0.34	+17
28 g	1.09	1.03	-6	0.53	0.58	+9
Test Variable →	**Positive Phase** (ms)			**Positive Phase** (ms)		
↓ Test Condition →	Regular	Trumpet	% Change	Regular	Trumpet	% Change
7 g	2.1	1.5	–29	3.0	1.8	–40
14 g	1.5	1.7	+13	1.7	2.1	+24
28 g	1.7	1.4	–18	1.5	1.7	+13

For conversion to SI units, 1 psi = 6.89 kPa, 1" (inch) = 25.4 mm.

For more specific information of the test conditions, see Table 1 and its notes.

Confined Match Effect

Table 3 presents a summary of the results of the effect of changing the electric match hole from the standard Luna Tech position on the side of the mortar to the new confined match location. For the lightest powder load (7 g), note that: the peak pressure nearly doubled, the

Table 3. Average Match Hole Effect Using the Standard Concussion Mortar Shape.

Mortar Position →	Near Mortar (72")			Far Mortar (144")		
Test Variable →	**Peak Pressure** (psi)			**Peak Pressure** (psi)		
↓ Test Condition →	Standard	Confined	% Change	Standard	Confined	% Change
7 g	0.10	0.18	+80	0.036	0.067	+86
14 g	0.85	0.63	–26	0.36	0.31	–14
28 g	1.75	1.61	–8	0.66	0.69	+5
Test Variable →	**Pressure Impulse** (psi ms)			**Pressure Impulse** (psi ms)		
↓ Test Condition →	Standard	Confined	% Change	Standard	Confined	% Change
7 g	0.08	0.13	+62	0.050	0.065	+23
14 g	0.58	0.55	–5	0.29	0.30	+3
28 g	1.09	0.97	+11	0.53	0.51	–4
Test Variable →	**Positive Phase** (ms)			**Positive Phase** (ms)		
↓ Test Condition →	Standard	Confined	% Change	Standard	Confined	% Change
7 g	2.1	1.6	–24	3.0	1.8	–40
14 g	1.5	1.7	+13	1.7	2.0	+18
28 g	1.7	1.4	–18	1.5	1.4	+7

For conversion to SI units, 1 psi = 6.89 kPa, 1" (inch) = 25.4 mm.

For more specific information of the test conditions, see Table 1 and its notes.

Table 4. Average Combined Trumpet Mortar And Confined Match Effects.

Mortar Position →	Near Mortar (72")			Far Mortar (144")		
Test Variable →	Peak Pressure (psi)			Peak Pressure (psi)		
↓ Test Condition →	Reg./Std	Trum./Conf	% Change	Reg./Std	Trum./Conf	% Change
7 g	0.10	0.27	+170	0.036	0.10	+180
14 g	0.85	0.71	–16	0.36	0.32	–11
28 g	1.75	1.84	+5	0.66	0.69	+5
Test Variable →	Pressure Impulse (psi ms)			Pressure Impulse (psi ms)		
↓ Test Condition →	Reg./Std	Trum./Conf	% Change	Reg./Std	Trum./Conf	% Change
7 g	0.08	0.17	+110	0.050	0.081	+62
14 g	0.58	0.59	+2	0.29	0.35	+21
28 g	1.09	1.04	–5	0.53	0.58	+9
Test Variable →	Positive Phase (ms)			Positive Phase (ms)		
↓ Test Condition →	Reg./Std	Trum./Conf	% Change	Reg./Std	Trum./Conf	% Change
7 g	2.1	1.3	–38	3.0	1.5	–50
14 g	1.5	1.9	+27	1.7	2.3	+35
28 g	1.7	1.5	–12	1.5	1.6	+7

For conversion to SI units, 1 psi = 6.89 kPa, 1" (inch) = 25.4 mm.

For more specific information of the test conditions, see Table 1 and its notes.

pressure impulse increased by a little less than half, and the duration of positive phase decreased by about one third. As in the case of the trumpet mortar configuration, there does seem to have been an increase in energy production. However, because peak pressure increased somewhat more than pressure impulse, some of the increase in peak pressure came as a result of a decrease in the positive phase duration. The differences, between the blast waves produced with the electric matches in the standard and confined locations, observed for the higher powder loads (14 and 28 g) seem to be statistical in nature. Thus, as with the trumpet mortar configuration, the effect of the confined match configuration seems to be limited to the lightest powder loads.

Combined Trumpet Mortar and Confined Match Effect

Table 4 presents a summary of the combined effect of using the trumpet mortar and confined match configurations. For the lightest powder load (7 g), note that: the peak pressure nearly tripled, the pressure impulse nearly doubled, and the positive phase duration decreased to about half. For heavier loads, the differences seem to be primarily statistical in nature. These results are generally consistent with what would be expected, based on the study of the individual effects.

Over-Load Effects

Table 5 presents a summary of the effect of over-loads that mostly provided a confinement effect. For these tests, materials were chosen that were not expected to participate in an exothermic chemical reaction. In the first case, perhaps not literally meeting the definition of an over-load, two thicknesses of gaffer's tape were applied across the muzzle of a mortar loaded with 7 g of concussion powder. In the trials for two other materials, the load of concussion powder was 14 g. In one case, there was an over-load of 7 g of a fine fluffy aluminum oxide powder. In the other case the over-load was a loose fitting wooden plug (bullet?), also with a mass of 7 g. For each over-load tested there was an increase in peak blast pressure (roughly 25 to 60%), however, without a significant increase in pressure impulse. Thus, there was no added energy release in the blast wave. The increase in peak pressure is a result of a corresponding

Table 5. Over-Load Confinement Effect.

Mortar Position →	Near Mortar (72")			Near Mortar (72")		
Test Variable →	**Peak Pressure** (psi)			**Peak Pressure (psi)**		
↓ Test Condition →	Without	With	% Change	Without	With	% Change
7 g + Tape (×2)	0.10	0.15	+50	0.04	0.06	+50
14 g + 7 g Al_2O_3	0.63	0.85	+35	0.31	0.37	+19
14 g + 7 g Plug		1.13	+79		0.45	+45
Test Variable →	**Pressure Impulse** (psi ms)			**Pressure Impulse** (psi ms)		
↓ Test Condition →	Without	With	% Change	Without	With	% Change
7 g + Tape (×2)	0.08	0.08	0	0.05	0.04	–20
14 g + 7 g Al_2O_3	0.55	0.63	+15	0.30	0.32	+7
14 g + 7 g Plug		0.65	+18		0.33	+10
Test Variable →	**Positive Phase** (ms)			**Positive Phase** (ms)		
↓ Test Condition →	Without	With	% Change	Without	With	% Change
7 g + Tape (×2)	2.1	1.5	–29	3.0	1.6	–47
14 g + 7 g Al_2O_3	1.7	1.7	0	2.0	1.7	–15
14 g + 7 g Plug		1.3	–24		1.6	–20

For conversion to SI units, 1 psi = 6.89 kPa, 1" (inch) = 25.4 mm.

All tests were conducted using the regular mortar design with the confined match configuration. For more specific information of the test conditions, see Table 1 and its notes.

decrease in positive phase duration (roughly 10 to 40%).

Table 6 presents a summary of the effect of over-loads of aluminum metal powder (which has the capability of acting as a fuel in a reaction with atmospheric oxygen). Except for the 28 g over-loads, increases in peak pressure ranged from about 30 to 75%, increases in pressure impulse ranged from about 20 to 50%, and no systematic effect was seen in positive phase durations. Accordingly, it would seem that at least some of the aluminum powder is contributing to sound production. Also, it is expected that the reaction of excess fuel with air oxygen produces a brighter flash of light; however, no attempt was made to measure this effect.

For the 28 g over-loads in both the regular and trumpet mortars, there was an approximate doubling of both peak pressure and pressure impulse, coupled with increases in positive phase duration ranging from about 20 to 50%. A check in Table 1 for the results for the individual firings, confirms that the increases in positive phase are quite consistent and thus probably not likely to be merely a statistical artifact. Such an increase is in contrast with what has been seen in other cases (mortar configurations or over-loads) where there have been increases in sound level (peak pressure). Typically in those cases there was a reduction of positive phase duration or at best no systematic effect. However, in this case, there is an increase in sound output, apparent mellowness of that sound, and presumably the light produced a potentially desirable combination.

Table 7 presents a summary of the effect of over-loads with the capability of reaction with the excess fuel (magnesium) in the Luna Tech concussion powder. At high temperatures, sulfates act as oxidizers, especially with active metal fuels such as magnesium.[8] Further, the combination of magnesium and magnesium sulfate has shown the ability to produce powerful explosions with the potential for use as a flash powder.[8,9] Accordingly, the use of calcium and magnesium sulfate as oxidizing over-loads was investigated. When using these materials, there was observed an increase of about one third in peak pressure, little if any increase in pressure impulse, and a small decrease in positive phase duration. In comparing these results with those

Table 6. Average Over-Load Fuel Effect.

Mortar Position →	Near Mortar (72")			Far Mortar (144")		
Test Variable →	**Peak Pressure** (psi)			**Peak Pressure** (psi)		
↓ Test Condition →	Without	With	% Change	Without	With	% Change
14 g + 7 g Al	0.63	1.05	+67	0.31	0.50	+61
14 g + 7 g Al + 2% Cab		0.83	+32		0.39	+26
14 g + 7 g Al (H2)		1.00	+59		0.41	+32
14 g + 14 g Al		1.12	+78		0.52	+68
14 g + 14 g Al + 2% Cab		0.99	+57		0.48	+55
14 g + 28 g Al		1.40	+120		0.64	+110
14 g + 7 g Al, Trum.	0.71	1.00	+41	0.32	0.50	+56
14 g + 14 g Al, Trum.		1.41	+99		0.59	+84
14 g + 28 g Al, Trum.		1.19	+68		0.59	+84
Test Variable →	**Pressure Impulse** (psi ms)			**Pressure Impulse** (psi ms)		
↓ Test Condition →	Without	With	% Change	Without	With	% Change
14 g + 7 g Al	0.55	0.75	+36	0.30	0.40	+33
14 g + 7 g Al + 2% Cab		0.70	+27		0.36	+20
14 g + 7 g Al (H2)		0.66	+20		0.34	+13
14 g + 14 g Al		0.77	+40		0.44	+47
14 g + 14 g Al + 2% Cab		0.80	+45		0.44	+47
14 g + 28 g Al		1.16	+110		0.66	+120
14 g + 7 g Al, Trum.	0.59	0.80	+36	0.35	0.43	+23
14 g + 14 g Al, Trum.		0.86	+46		0.48	+37
14 g + 28 g Al, Trum.		1.10	+86		0.62	+77
Test Variable →	**Positive Phase** (ms)			**Positive Phase** (ms)		
↓ Test Condition →	Without	With	% Change	Without	With	% Change
14 g + 7 g Al	1.7	1.5	–12	2.0	1.7	–15
14 g + 7 g Al + 2% Cab		2.2	+29		2.6	+30
14 g + 7 g Al (H2)		1.7	0		2.1	+5
14 g + 14 g Al		1.6	–6		1.8	–10
14 g + 14 g Al + 2% Cab		1.7	0		2.1	+5
14 g + 28 g Al		2.5	+47		2.7	+35
14 g + 7 g Al, Trum.	1.9	1.6	–16	2.3	1.9	–17
14 g + 14 g Al, Trum.		1.5	–21		2.2	–4
14 g + 28 g Al, Trum.		2.5	+32		2.7	+17

For conversion to SI units, 1 psi = 6.89 kPa, 1" (inch) = 25.4 mm.

Except as noted, all tests were conducted using the regular mortar design with the confined match configuration. For more specific information of the test conditions, see Table 1 and its notes.

found in Table 5 for unreactive over-loads, it would seem that if any reaction was occurring between the excess magnesium (vapor) fuel and the oxidative over-loads, it did not contribute significantly to sound production.

The high fluorine content of Teflon makes it a powerful oxidizer in combination with active metal fuels such as magnesium. So much so that these are the primary components used in military infrared decoy flares.[10] The use of Teflon as an over-load material produced an

Table 7. Over-Load Oxidizer Effect.

Mortar Position →	Near Mortar (72")			Far Mortar (144")		
Test Variable →	**Peak Pressure** (psi)			**Peak Pressure** (psi)		
↓ Test Condition →	**Without**	**With**	**% Change**	**Without**	**With**	**% Change**
14 g + 7 g $CaSO_4$	0.63	0.91	+44	0.31	0.39	+26
14 g + 7 g $MgSO_4$		0.92	+46		0.38	+23
14 g + 7 g Teflon		0.91	+44		0.39	+26
Test Variable →	**Pressure Impulse** (psi ms)			**Pressure Impulse** (psi ms)		
↓ Test Condition →	**Without**	**With**	**% Change**	**Without**	**With**	**% Change**
14 g + 7 g $CaSO_4$	0.55	0.59	+7	0.30	0.32	+7
14 g + 7 g $MgSO_4$		0.61	+11		0.32	+7
14 g + 7 g Teflon		0.73	+33		0.40	+33
Test Variable →	**Positive Phase** (ms)			**Positive Phase** (ms)		
↓ Test Condition →	**Without**	**With**	**% Change**	**Without**	**With**	**% Change**
14 g + 7 g $CaSO_4$	1.7	1.5	–12	2.0	1.7	–15
14 g + 7 g $MgSO_4$		1.4	–18		1.5	–25
14 g + 7 g Teflon		1.6	–6		1.6	–20

For conversion to SI units, 1 psi = 6.89 kPa, 1" (inch) = 25.4 mm.

All tests were conducted using the regular mortar design with the confined match configuration. For more specific information of the test conditions, see Table 1 and its notes.

effect similar to that of the other potential oxidizers, with the exception that some of the added sound production is probably the result of its reaction with magnesium. Evidence for this is the increase in pressure impulse by one third.

Conclusion

As mentioned above, significant variations were often observed for measurements made under apparently identical conditions. Accordingly, any minor effects observed may merely be statistical in nature (may not be real), and only those results that are fairly certain will be addressed in this section.

The only concussion powder used in these tests was Luna Tech's Pyropak Concussion Powder. This is a fuel-rich powder that uses a nitrate oxidizer, which is fairly unique among commercial concussion powders.[2] Accordingly, the results reported from this study, may not apply to the use of other concussion powders.

Both the trumpet and confined match configurations produced significantly increased peak air blast pressures (louder sounds), but only for the lightest powder loads (7 g). This seems to have been the combined result of somewhat greater sound producing efficiency (increased pressure impulse) and a consequence of a decrease in positive phase duration. When a trumpet mortar with the confined electric match feature was tested, there was a further significant increase in sound output, but again only for the lightest powder loads. However, to put this into perspective, the sound output from 14 g of concussion powder in a standard mortar is substantially greater than that produced by 7 g of powder in a trumpet mortar with a confined electric match. Accordingly, the only obvious situation where the achievements of the new mortar configurations would be preferred over using a larger load of concussion powder would be in cases where the production of smoke needed to be minimized.

The use of aluminum metal powder overloads probably does produce a brighter flash of light upon firing, but that was not measured in this study. Regarding sound output, for light powder loads (7 and 14 g) it was found that the use of aluminum metal powder over-loads did not produce substantially greater output than that accomplished with an over-load of an equal mass of unreactive material. There was, however, the potentially useful observation that the 28 g over-loads produced blast waves with noticeably greater sound pressure and also longer positive phase durations.

The use of oxidative over-loads also produced results fairly similar to using unreactive material. This was a surprise, it was thought there was significant potential for a powerfully explosive reaction between the excess vaporized magnesium and these oxidizers.

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Table 1. Results from Individual Tests of Mortar Configurations and Over-Load Conditions.

Mortar Position →	Near Mortar (72")			Far Mortar (144")		
Test Variable →	Peak P.	Impulse	Pos. Ph.	Peak P.	Impulse	Pos. Ph.
↓ Test Condition	(psi)	(psi ms)	(ms)	(psi)	(psi ms)	(ms)
7g, Regular, SH(b,c)	0.088	0.066	2.2	0.036	0.028	2.3
	0.093	0.093	2.4	0.031	0.067	4.4
	0.116	0.095	1.8	0.042	0.055	2.4
14g, Regular, SH(b,c)	0.91	0.55	1.3	0.38	0.29	1.5
	0.81	0.55	1.5	0.35	0.29	1.6
	0.84	0.63	1.8	0.35	0.30	2.0
28g, Regular, SH(b,c)	1.99	1.16	1.6	0.79	0.56	1.6
	1.57	1.01	1.7	0.61	0.50	1.5
	1.69	1.11	1.7	0.59	0.54	1.5
7g, Regular, NL(a,b)	0.17	0.11	1.3	0.059	0.054	1.4
	0.16	0.11	1.6	0.055	0.060	1.9
	0.21	0.18	1.8	0.087	0.081	2.0
14g, Regular, NL(a,b)	0.54	0.56	1.7	0.29	0.30	1.9
	0.68	0.49	1.6	0.32	0.28	1.9
	0.68	0.59	1.8	0.33	0.32	2.3
28g, Regular, NL(a,b)	1.60	0.91	1.2	0.73	0.49	1.2
	1.38	0.95	1.9	0.57	0.51	1.6
	1.85	1.06	1.2	0.78	0.53	1.4
28g, Regular, TH(k,l)	1.41	0.88	1.4	0.58	0.51	1.9
	1.37	0.84	1.4	0.60	0.53	2.2
	1.47	0.84	1.3	0.63	0.52	1.9
7g, Trumpet, SH(b,c)	0.17	0.12	1.4	0.061	0.058	1.7
	0.24	0.20	1.7	0.087	0.094	2.2
	0.21	0.15	1.4	0.067	0.072	1.6
14g, Trumpet, SH(b,c)	0.72	0.58	1.8	0.38	0.33	2.0
	0.80	0.67	1.6	0.43	0.35	2.0
	0.64	0.60	1.8	0.35	0.33	2.4
28g, Trumpet, SH(b,c)	1.90	1.06	1.5	0.69	0.58	1.8
	1.90	1.08	1.6	0.74	0.60	1.8
	2.11	0.94	1.0	0.77	0.57	1.4
7g, Trumpet, NL(a,b)	0.25	0.18	1.6	0.094	0.082	1.4
	0.30	0.17	1.2	0.125	0.087	1.4
	0.25	0.15	1.2	0.082	0.075	1.7
14g, Trumpet, NL(a,b)	0.84	0.58	1.7	0.37	0.35	2.1
	0.74	0.58	1.7	0.34	0.35	2.1
	0.56	0.62	2.2	0.25	0.34	2.6
28g, Trumpet, NL(a,b)	1.83	1.05	1.6	0.64	0.55	1.7
	1.86	1.11	1.5	0.64	0.58	1.8
	1.82	0.95	1.4	0.78	0.54	1.4
7g, Regular, SH, Tape(b,c,h)	0.16	0.068	1.8	0.061	0.057	1.9
	0.16	0.087	1.2	0.065	0.039	1.2
	0.14	0.079	1.5	0.054	0.036	1.6
14g + 7g Al, Reg., NL(a,b,d)	1.09	0.75	1.6	0.54	0.41	1.8
	0.99	0.72	1.4	0.49	0.39	1.5
	1.07	0.77	1.6	0.48	0.41	1.8

Table 1. Results from Individual Tests of Mortar Configurations and Over-Load Conditions. (Continued)

Mortar Position →	Near Mortar (72")			Far Mortar (144")		
Test Variable →	Peak P.	Impulse	Pos. Ph.	Peak P.	Impulse	Pos. Ph.
↓ Test Condition	(psi)	(psi ms)	(ms)	(psi)	(psi ms)	(ms)
14g + 14g Al, Reg., NL[(a,b,d)]	1.11	0.74	1.6	0.51	0.43	1.6
	1.11	0.78	1.6	0.56	0.45	2.2
	1.13	0.80	1.7	0.50	0.43	1.6
14g + 21g Al, Reg., NL[(a,b,d)]	1.20	0.95	1.6	0.57	0.51	2.6
14g + 28g Al, Reg., NL[(a,b,d)]	1.53	1.13	2.5	0.69	0.67	2.8
	1.58	1.20	2.2	0.69	0.69	2.7
	1.08	1.14	2.8	0.55	0.62	2.6
14g + 7g Al, Trum., NL[(a,d,k)]	0.72	0.84	2.0	0.44	0.48	2.4
	1.20	0.82	1.4	0.56	0.42	1.7
	1.08	0.74	1.4	0.50	0.39	1.7
14g + 14g Al, Trum., NL[(a,d,k)]	1.43	0.93	1.9	0.59	0.50	2.2
	1.26	0.85	1.3	0.59	0.50	2.2
	1.55	0.81	1.3	0.58	0.44	2.1
14g + 28g Al, Trum., NL[(a,d,k)]	1.27	1.23	2.6	0.64	0.67	2.6
	1.30	1.08	2.4	0.61	0.59	2.6
	0.99	1.00	2.6	0.53	0.61	3.0
14g+7g Al+Cab, Reg., NL[(a,b,e)]	1.04	0.71	1.6	0.50	0.39	1.7
	0.87	0.70	1.7	0.40	0.40	2.1
	0.57	0.68	3.2	0.27	0.30	4.0
14g+14g Al+Cab,Reg., NL[(a,b,e)]	1.11	0.78	1.6	0.56	0.45	2.2
	0.89	0.81	1.8	0.39	0.44	2.0
	0.97	0.82	1.8	0.48	0.42	2.2
14g + 7g Al (H2), Reg., NL[(a,k,m)]	0.69	0.49	2.3	0.35	0.26	2.6
	1.20	0.76	1.4	0.43	0.40	1.9
	1.12	0.74	1.4	0.44	0.37	1.7
14g+7g Al_2O_3, Reg., NL[(a,b,f)]	0.82	0.64	1.6	0.36	0.32	1.6
	0.93	0.64	1.8	0.37	0.33	1.8
	0.79	0.60	1.6	0.39	0.32	1.8
14g + 7g Plug, Reg., NL[(a,k,n)]	1.28	0.70	1.2	0.50	0.33	1.4
	1.05	0.61	1.3	0.41	0.32	1.7
	1.07	0.65	1.3	0.43	0.34	1.6
14g + 7g $MgSO_4$, Reg., NL[(a,b,j)]	0.99	0.62	1.3	0.39	0.32	1.4
	0.94	0.63	1.6	0.38	0.33	1.6
	0.82	0.57	1.3	0.37	0.32	1.5
14g + 7g Teflon, Reg., NL[(a,b,j)]	0.75	0.69	1.8	0.36	0.39	1.8
	1.14	0.72	1.2	0.43	0.41	1.5
	0.83	0.78	1.7	0.37	0.40	1.6
14g+7g $CaSO_4$, Reg., NL[(a,b,g)]	0.92	0.62	1.4	0.39	0.33	1.6
	0.88	0.57	1.3	0.39	0.31	1.8
	0.92	0.59	1.8	0.40	0.32	1.6

(a) The electric match hole was in the new location (NL), below the bottom of the combustion chamber in the "confined match" configuration as shown in Figure 5.

(b) The electric matches used were Luna Tech ZD matches (supplied in early 1996) and appear to have smaller tips than those supplied in 1997.

(c) The electric match hole was the standard hole (SH) installed by Luna Tech on the side of the mortar as shown in Figure 1.

(d) The aluminum metal powder used was product number ATA-105 (6 micron, atomized), supplied by Alcan-Toyo.

(e) The aluminum metal powder used was product number ATA-105 (6 micron, atomized) supplied by Alcan-Toyo, blended with 2% M-5 Cab-O-Sil from Cabot.

(f) The Al_2O_3 was a very fine powder.

(g) The $CaSO_4$ was fresh (dry) Plaster of Paris, from a local hobby shop.

(h) Two layers of gaffer's tape were crossed over the top end of the mortar.

(i) The Teflon (polytetrafluroethylene) was a very fine powder.

(j) The $MgSO_4$ (anhydrous) was prepared by reacting $MgCO_3$ with H_2SO_4 and drying at 220 °C.

(k) The electric matches used were Luna Tech ZD matches supplied in 1997 and appear to have larger heads than those supplied in early 1996.

(l) The electric match hole was located 2-1/4 inches (80 mm) down from the muzzle of the mortar, which placed it approximately 1/4 inch (9 mm) below the top of the powder load.

(m) The aluminum metal powder used was product number H-2 (2.5 micron, atomized) supplied by Valimet.

(n) A wooden plug weighing approximately 7 g and with a tapered end (to prevent jamming in the bore of the mortar) was made from 7/8-in. (31-mm) dowel stock.