Small-scale chamber test for internal blast performance

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Abstract. The viability of using gram-scale amounts of explosives in a small test chamber to assess internal blast performance and predict effects at larger scales is investigated. Peak quasi-static pressures from five explosive formulations were measured, and energy released per gram was calculated. The smaller test used 12-g charges loaded in a steel holder, while data selected from the larger test was from bare charges between 2.7 and 21 kg. The energies for a given explosive were comparable for each size charge tested in the larger chamber. In the smaller chamber the energies were less, most likely due to heat losses to the holder. Explosives with the highest concentration of explosive ingredients incurred the highest energy losses in the small chamber. The current design of the smaller test provides a reasonable ranking of explosives with similar concentrations of explosive ingredients, thereby validating the use of the test for the newer explosives being assessed. However, it may be possible to obtain consistent rankings for all explosives given a change to the holder design in the smaller test.

1. Introduction

The internal blast performance of explosives is characterized by the long time (milliseconds) overpressure observed in closed structures when an explosive charge is detonated. The overpressure results from the energy released from the detonation and subsequent combustion of detonation products and added fuels with the air. Tests in closed structures provide the best measurements of maximum energy release from explosives. The reason is that the ambient air is trapped inside the chamber providing an environment of efficient mixing as pressure waves, produced by the initial blast, reverberate around the structure. Local pressure measurements will record these waves, as well as a slower, near-uniform rise in pressure around the entire chamber. The latter is referred to as the quasi-static overpressure. The peak quasi-static overpressure (PQS) has been used as a metric to compare performance of different explosives of the same mass [1-3]. It is also possible to convert the PQS to an energy release [4]. This energy release may be expressed in terms of energy per unit mass (kcal/g), which allows a comparison across a range of charge masses in a given structure. Our objective is to see if a similar ranking of performance between different explosives can be made between two chambers that are very different in size, thereby allowing adequate assessment of newer explosive compositions in small scale before incurring the costs of scaling up formulations for larger scale testing.

Internal blast testing is similar to the closed bomb tests modified for detonating explosives reported by Ornellas [5] and more recently by Davis [6]. Davis [6] extended Ornellas’ [5] work to aluminized
explosives to measure anaerobic combustion of aluminum in the detonation products. The principle differences in our work are the introduction of ambient air to allow the possibility of aerobic combustion of all fuels associated with the explosive and the determination of energy release from quasi-static overpressure instead of classic bomb calorimeter techniques.

The largest internal blast test performed so far has been in our bombproof chamber (180 m³) with a variety of explosives over a range of masses. Granholm compared results from these tests to his 100 mg scale test in a 3-liter chamber [7]. His tests required heavy confinement to avoid issues with improper detonation of explosives with unconfined critical diameters larger than his sample size. Compensation of losses resulting from the steel confinement block was necessary to bring the energy release close to that measured for the larger unconfined charges tested in the bombproof. The objective of this study was to determine how a larger 89-liter chamber with a 10-g main charge would compare to the larger scale bombproof tests.

Five explosive formulations from the earlier bombproof tests were selected and tested in the 89-liter chamber. The experimental goals centered on proofing the repeated containment capabilities of the 89-liter chamber subjected to repeated stress and use rather than reporting on any specific explosives.

2. Experimental Details

2.1. Large-Scale (Bombproof) Chamber

The bombproof chamber is 6.1 m x 6.1 m x 4.9 m high and designed to withstand the effect of up to 24 kg of TNT detonated inside. The internal volume after removing various features inside is 180 m³. Charges of various masses were placed at the chamber center 1.2 m above the floor. Gauges were located in boxes 2 m off the floor in each vertical corner placing them 3.66 m from the center of the charge.

The explosive charge, booster, and detonator holder were taped together with fibrous strapping tape. A harness, made from the same tape was used to hang the charge from a chain suspended from the ceiling. Results from cylindrical charges between 2.15 and 20.45 kg were used for this comparison. Charge diameters varied between 10.2 and 20.3 cm and lengths between 15.2 and 50.8 cm. Pentolite boosters with an output interface between 9.5 and 14.7 cm and nominal mass of 0.55 kg was used to ensure the booster covered most of the top surface of the main charge.

Kulite XTE-190 piezoelectric-resistive pressure transducers were used to record the pressure-time history over 5 seconds although the PQS was typically achieved within 100 ms. An average PQS was determined from all gauges in a given shot. Gauges were baffled with a small amount of cotton which was kept in place by a small bolt with a pin hole. The baffling protected the gauge from high-pressure reflections and bright light associated with the combustion process.

2.2. Small Scale Chamber (Red Pig)

The small-scale chamber is an octagonal system with 0.089 m³ internal volume shown in figure 1. Charges were loaded at one end of the chamber in a source section shown in figure 2. This section was mounted at one end of the chamber and was identical to that used in Felts’ small-scale tunnel tests [8]. It was purposely separated from the rest of the volume to limit heating of the steel confinement cell after the exodus of explosive products. Earlier tests, with the confinement cell mounted inside the chamber, indicated heavier losses than those when the cell was positioned outside of the main chamber volume. The confining wall thickness was 2.86 cm. A rubber wrapping was placed around the confinement cell to mitigate fragment damage to the walls of the source section and further exclude air from around the confinement cell to minimize post-detonation heating. The source section was bolted onto the end of the chamber with a plastic ring between it and the chamber. The plastic ring mitigated shock transfer from the source section to the chamber and aided in keeping fragments from entering the chamber. The booster was a plastic-bonded explosive pressed into a conical region at the back of
the confinement cell so that its mass could be minimized (2 g) and the booster would cover the entire
input surface of the main charge. The main charge was a 10 g cylinder with a diameter of 1.91 cm.

2.3. Data Reduction

Following the detonation of the test charge, a pressure wave rapidly propagates across the chamber
and reflects off the walls repeatedly. Each gauge experiences a series of pressure waves as these
waves reflect from the various surfaces within the chamber as shown in figure 3. Since the chamber is
virtually sealed during the time of interest, the average pressure or quasi-static pressure increases
slowly in comparison to the rapid pressure waves. The only vent for pressure in the bombproof is a
baffled stack via a 28.5 cm ID pipe located in the ceiling towards one corner. The smaller chamber
vents through a 1 cm ID pipe extending 6 cm beyond the inner surface of the chamber located at its
mid-section. The developing quasi-static pressure is seen as a baseline shift in the overall wave
mechanics as depicted by the decimated curve in figure 3. Decimation is a smoothing technique
whereby many data points are averaged to create a single value.

The various pressure waves riding on top of the quasi-static pressure obscure the quasi-static peak,
thereby requiring a consistent technique for defining its value. The technique employed in the earlier
bombproof study involved extrapolation of a linear fit of the data over a period of time after the PQS
[2]. Alternative approaches have been to smooth the curve either by data averaging (decimation) or by
fitting a 10th order polynomial to the data. These latter two techniques have been employed
successfully when the PQS is achieved over many pressure reverberations [9]. This was not the case
for the small chamber used here. The PQS was achieved within several reverberations, requiring a
different technique to determine PQS.

The technique used here for both large and small scales is illustrated in figure 4. Each pressure
record is integrated producing a near linear region for a short time after the peak. The slope of this
portion of the integral yields a good determination of the PQS. This was checked at both scales for
selected tests that lent themselves to the other previously mentioned techniques with favorable
comparisons within 2%.

Energy per unit mass (kcal/g) was determined from the PQS assuming the ideal gas law as
described by Granholm [4]. This technique is relatively easy to use and yields results similar to the
thermo-equilibrium code CHEETAH [10] as long as the products do not exceed 10% of the total
gases. Additional assumptions are that (1) the PQS is the result of the energy release from the
explosive heating the air within the chamber, (2) the specific heat of the combined products and air
within the chamber is equivalent to that of air, and (3) the specific heat of air varies over the range of
temperatures achieved and the variation must be taken into account. Any difference between the
measured energy and that calculated was taken as a loss from inefficient combustion or from heat
transfer to the chamber walls or confinement (in the case of the small chamber).
2.4. Booster Compensation

The energy release for the main charge is obtained by subtracting the energy release attributed to the booster. Energies from each booster configuration were determined by testing charges of the booster explosive at comparable masses to those tested in each chamber. For instance a 12 g charge of the booster explosive was tested in the small chamber with the charge holder a number times to determine an average energy release with associated losses. This energy was then applied for 2 grams of booster to remove its contribution from the overall result. It is worth noting that the assigned energy release for the booster in the holder was 81.2% of its total potential and that bare charges of the same explosive yielded close to 100%. The results from 2 g charges were not used for determining booster compensation since the combined effects of 12 grams of explosive (booster and charge) were expected to yield a more complete reaction of detonation products with the air in the chamber. The same technique was employed for the bombproof booster compensation.

2.5. Explosives Compositions

Five plastic-bonded, cast-cured explosives were selected from the earlier bombproof study and tested in the small chamber. The ingredients were nitramines (RDX or HMX), aluminum, an oxidizer, and a plastic binder system. Table 1 provides a general description of the booster and test formulations with regards to the presence of these ingredients. All were cut from larger slabs to ensure uniform samples. Explosives are designated A-E and are the same A-E reported by Felts for a small-scale tunnel test validation [8]. So, the A-E is in descending order of initial energy release measured in the small-scale tunnel. Data from other explosive formulations tested in the small chamber but not the larger bombproof are used to support statements concerning heat loss and relative performance.

| Name  | Nitramine Level | Aluminum | Oxidizer |
|-------|----------------|----------|----------|
| Booster | High          | No       | No       |
| A     | Low           | Yes      | Yes      |
| B     | Low           | Yes      | Yes      |
| C     | High          | Yes      | No       |
| D     | High          | No       | No       |
| E     | Low           | Yes      | No       |

Low nitramine level indicates less than 50% by mass of the formulations.
3. Results and Discussion

The results are summarized in figure 5. The average energy per unit mass for explosive are normalized by that from A in the small chamber. Note that explosive A had the least difference between the smaller and larger scales. The explosives are ranked from left to right with respect to decreasing energy release in the small chamber. The letters assigned to each explosive are not in order because these names are consistent with those reported by Felts [8]. The error bars for the small chamber reflect the extreme values obtained for three tests. The error bars for the bombproof are standard deviations over all the tests done between 2.7 and 21 kg (charge and booster). The data below 2.7 kg were excluded because these charges yielded erratic results that could be lower or higher than that associated with the larger charges. This bar chart shows that the ranking between scales is preserved for explosives E, B, and A, respectively. However, explosives C and D do not follow this trend. It is interesting to note that these two explosives comprise the highest concentrations of explosive ingredients of the five explosives. The reason for this will be discussed more fully.

The small chamber always yielded lower energies than the bombproof. This was expected, since losses to the holder were also reported by Granholm [7]. In addition, these losses appear to be tied to the ratio of explosive surface area in contact with the holder. Preliminary tests with the booster explosive using 12.7 mm diameter charges yielded higher losses than the 19.1 mm diameter charges. The losses were not a result of critical diameter: Those explosives with the highest losses had critical diameters less than the sample diameter. The presumption is that the detonation products give up some heat to the confinement prior to being ejected from the confinement. However, the magnitude of this loss varied with the explosive formulation, which produced the departure in relative ranking observed in figure 5. Explosives C and D at the far right of figure 5 had the highest nitramine concentrations, which is why they did not follow the trend set by the other three explosives. Moreover, these two explosives display the biggest differences between small and large scale tests. Where B and A have the least amount of nitramine concentration and consequently the least differences between scales.

The Second-order Hydrodynamic Automated Mesh Refinement Code (SHAMRC) [11] was used to simulate the evolution of pressure in the small chamber for the 12 g charge of the booster explosive, which contained the highest concentration of nitramine. The simulations matched the measured results very well, capturing what was the highest measured loss due to the presence of the
charge holder. Other simulations involved explosives outside this comparison but with lower concentrations of nitramine than that of the booster explosive, indicating lower temperatures and consequentially lower losses. So, it appears that the current test arraignment will work well with families of explosive that contain similar concentrations of fast reacting energetic ingredients. A change in the holder or a judicious exclusion it when not required may be required to compare results across all possible explosive formulations.

4. Summary
Results from a small-scale chamber test were compared to results from tests in a much larger chamber to validate the use of the small chamber for comparing new explosive compositions to assist in down selection prior to scaling up. The small-scale tests displayed lower energy release efficiencies than those conducted at the larger scale, which was attributed to the use of a steel confinement cell. The confinement was needed to avoid issues associated with complete detonation in samples with large critical diameters. The confinement affected the efficiency of each composition differently. However, the small-scale test appears to be a valid tool for ranking relative performance for explosives with similar concentrations of explosive ingredients. Plans to make this test more broadly applicable will address heat losses to the holder.

Acknowledgements
The authors would like to thank Bill Wilson from the Defense Threat Reduction Agency (DTRA) for supporting this work. We thank Kevin Gibson, John LaSala, Robert Hay, Tyrone Pickeral, and John O’Connor of the Energetics Evaluation Division at Indian Head for their technical support.

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