Investigation of explosively dispersed glass particles

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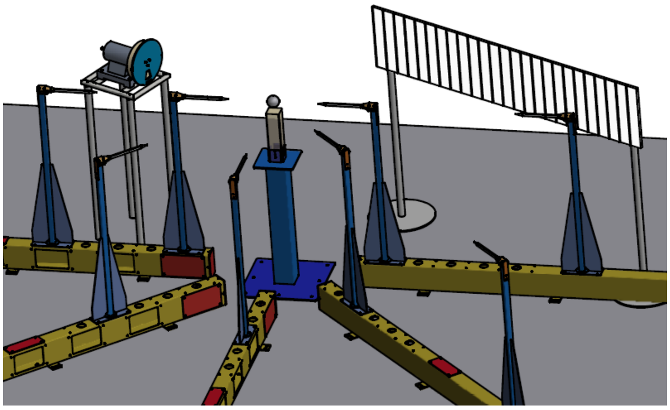
1 Introduction

Heterogeneous blast generated by highly metallized explosive compositions is being investigated at ISL since 2004. The mechanism ruling multiphase explosions is critical to understand thermobaric blast effects based on the delayed combustion reactions of metal particles. Dispersion and ignition of metal particles in explosive charges have already been extensively studied. Frost et al. [1] and Zhang et al. [2] worked on metal particles beds saturated with liquid explosives and compared the results with numerical simulation data to understand the mechanism of these explosions. Neuwald et al. [3] studied the detonation of small charges containing aluminium particles in a micro-calorimeter. Gregoire et al. [4,5] presented results concerning particles dispersed by spherical C4 booster charges. The purpose of the present work is to improve the understanding of the mechanisms of particle dispersion by an explosive. We investigated experimentally and numerically the dispersion of particles generated by the detonation of a spherical charge of homogeneous explosive surrounded by a layer of solid particles in a free field area.

2 Experimental setup



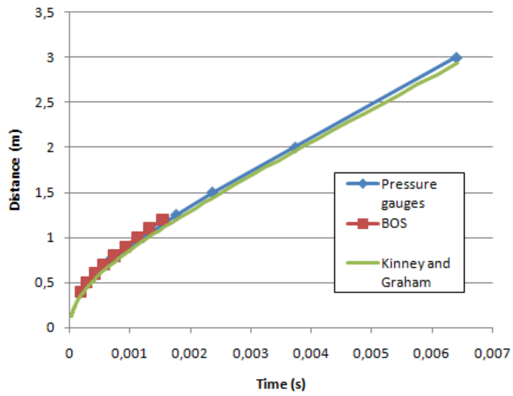


Figure 1. Experimental setup around spherical charge.
Figure 2. Shock propagation for the bare booster charge.

Explosion of unconfined spherical charges was studied in free field (Fig. 1). The experimental configuration was chosen to facilitate comparison between experimental and numerical data. Cast Comp B charges were specifically produced in a spherical shape for this study to ensure

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reproducibility. Ignition was realized by a RP83 high voltage detonator surrounded by 3g of C4 as a relay. A 3cm layer of 550g composed by glass spheres (5-150µm of diameter) was formed around the 31g Comp B booster using 95mm glass bulbs. Each charge is placed 1.5m above the concrete test pad, on a polyurethane block of foam fixed on the top of the central metallic pillar. This configuration helps delaying the interference of the reflected leading shock on the ground surface.

The evolution of the pressure around the charge is recorded by 8 PCB piezo-electric side-on pressure sensors mounted on fixed poles located respectively at 0.5 (2 sensors), 0.75, 1, 1.25, 1.5, 2 and 3m from the charge centre. Sensor positions were chosen to limit their wake influence on each other. The first two sensors placed on both sides of the charge at 0.5m are used to verify the spherical geometry of the explosion.

A bare booster was detonated to provide a reference for the later particle dispersions. Propagation of the leading shock was compared to the Kinney and Graham [6] analytical model (Fig. 2). Experimental results proved to be in good agreement with shock trajectory prediction for shock run distance used in this study (up to 3m).

Each explosion was filmed at 110 000 i/s using a high-speed Phantom V310 camera equipped with a 135mm f2 lens. A white wooden board was placed behind the charge to enhance the image contrast. Vertical black stripes were painted every 10cm to improve the detection of the shock propagation. The resulting field of view covers 1.8m x 0.4m (304 x 64 camera pixels).

Background Oriented Schlieren (BOS) was chosen to enhance the quality of high-speed images showing the dispersion of particles. However another approach proved to be more efficient in the case of particles being projected: the successive images subtraction and contrast increase.

Optical methods developed in former ISL studies [7] provided the position evolution of the leading solid material projected in an orthogonal plane to the camera axis. A time-resolved particle trap was consequently developed [7] to provide the arrival times of the entire particle distribution behind the leading front: a rotating slit precisely synchronized with the explosion and placed in front of an annular block of wax uncovers a progressing sector during the explosion. In this study, the trap was successively placed at 1.2, 0.8 and 0.6m from the charge centre, in order to progressively verify its resistance to the increasing blast effects. By comparing the signal provided by a sensor mounted at the bottom of the disk and the trigger signal, it is possible to determine the angular position of the slit at the booster ignition time. The disk is rotating at 50Hz, providing a recording duration of 20ms: this duration was chosen to be long enough to collect all projected materials during slightly less than a single rotation.

3 Experimental results

We compared the time evolution of pressure between the bare booster and the charge containing the glass particles (Fig. 3). One can see that peak pressures are strongly reduced by the presence of inert particles, especially in close range where the initial pressure raise is completely mitigated and the pressure decay is slowed down by the presence of a high concentration of particles (Fig. 5). For further distances (i.e. more than 1m), classic shock profiles can be observed, as the shock reforms after the passage through the dispersed particles. Arrival time of the leading shock is significantly delayed by the particle layer around the booster. Figure 4 compares the leading shock propagation of the bare booster to the glass particle dispersion. The shock velocity is strongly reduced during the first meter, as it crosses the particle cloud. From 1 to 3m, the delay between the booster shock and the mitigated shock remains steady as no more solid material alters its propagation.

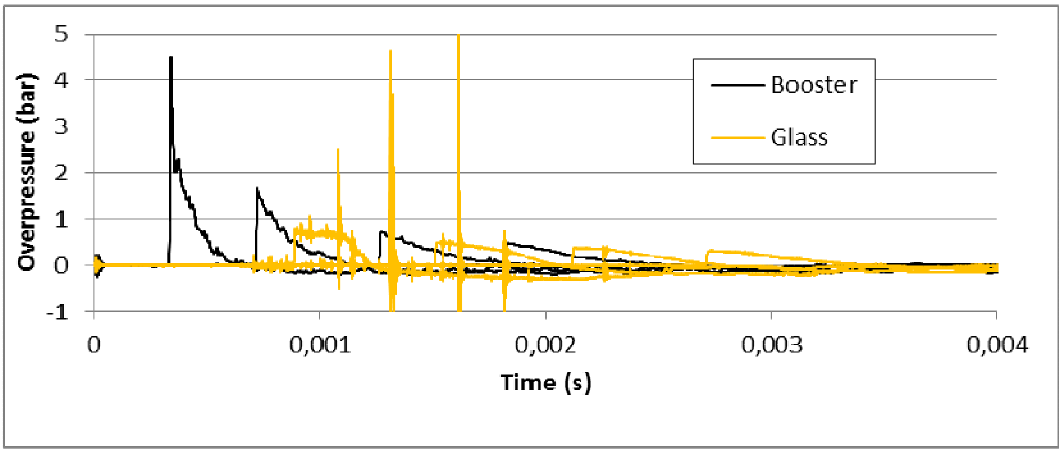

Figure 3. Comparative evolution of pressure for the booster charge and the glass particle dispersion at r=0.5, 0.75, 1 and 1.25m.

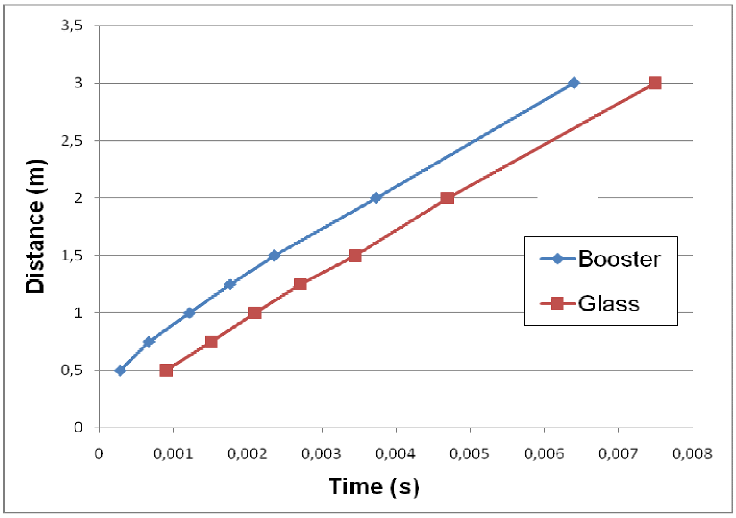

Figure 4. Comparative X-t evolutions of the leading shock for the booster charge and the glass particle dispersion.

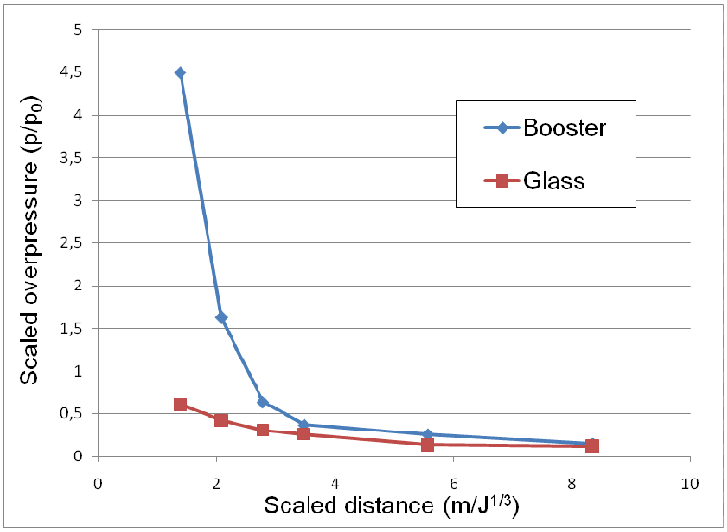

Figure 5. Comparative evolution of scaled pressure for the booster charge and the glass particle dispersion versus scaled distance.

Particles collections successively realized at 1.2, 0.8 and 0.6m provided the synthetic graphic presented on figure 6. Two main types of material were collected:

- agglomerated particles penetrating up to few cm into the wax
- particle dust (dispersed particles) covering the wax trap surface.

Angular collection positions for both types were converted into times of arrival and reported on Figure 6. Dark grey horizontal lines correspond to collection durations of agglomerated particles, whereas light grey lines indicate dispersed particles presence on the trap. Trajectories of the leading shock measured by pressure gauges and BOS techniques are also plotted on the diagram, as well as the propagation of the leading particles identified by BOS. Optical visualization of the leading agglomerates is confirmed by the arrival time of the first collected particles on the traps. A large dust cover is visible in close range (0.6m). This collection corresponds to the large amount of small particles unable to fly to large distances. These particles are either present in the initial particle size distribution or either form during the breaking of the particles under the pressure effects of the leading shock. Larger particles are projected to further distances; they are collected at least up to 1.2m at speed down to 170m/s. In comparison, the leading agglomerates travel at around 300m/s. All projected material remained behind the leading shock in this configuration. Broken particles and agglomerates were observed with a microscope. Up to now, only qualitative information was collected on the shape and size of projected particles. Particle extraction and analysis are yet to be conducted.

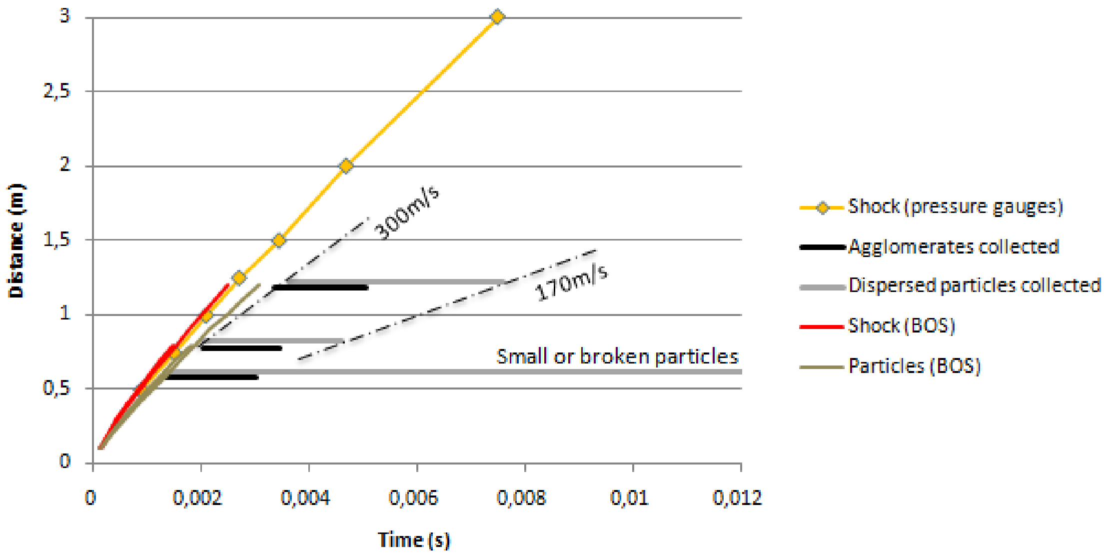

Figure 6. X-t diagram of the glass particle dispersion.

3 Numerical study

Numerical simulations performed with the EFAE code have been compared to experimental results. The EFAE is a computer code for multiphase reactive flows developed by Khasainov to model heterogeneous detonations. It allows to simulate the detonation of the initiator charge of solid explosive, the propagation of shock and combustion waves in reactive heterogeneous mixtures (solid particles in gaseous atmospheres), and the blast wave effects generated in the surrounding field. The model used in this study is an evolution of the model developed by Khasainov and Veyssière [8].

At first, the detonation of the bare booster (31g of Comp B) and its blast effects have been numerically simulated. Previous studies made by Grégoire et al. [4,5] have shown that modeling the explosion with the hypothesis of instantaneous detonation (the homogeneous explosive is replaced by a pressure and temperature jump) provides results in reasonable agreement with experimental data in the far field only. Hence in this study we chose a one-dimensional spherical model, using a modified HOM equation of state of the homogeneous explosive [9] in order to investigate the interaction of the shock wave with the particle layer in the near field. The pressure profile calculated at r=0.75m reasonably agrees with the experimental record shown in Figure 7.

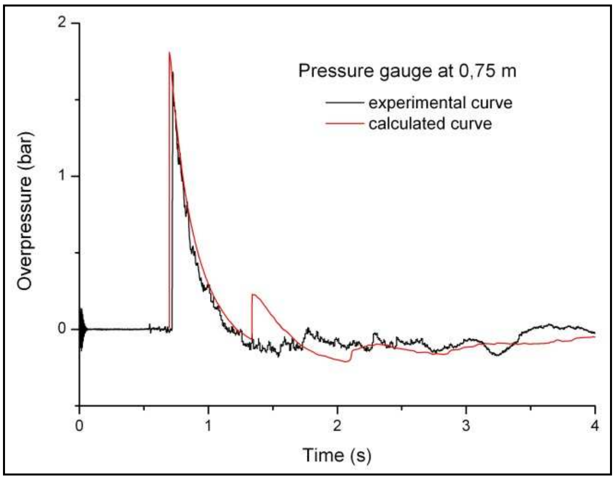

Figure 7. Pressure recorded and calculated at r=0,75m after explosion of bare booster.

Numerical simulations are now conducted for charges involving particles. Preliminary calculations for 120-μm diameter glass particles (Gregoire [5] has shown that particle size has a weak effect on final particle velocity) are compared in Figure 8 with experimental pressure records (mass of particles = 650 g). One can see that the model has to be improved. In general, our first results show that using (i) a hypothesis of instantaneous detonation and (ii) an ideal equation of state for air can introduce noticeable error in arrival time of shock wave to the first pressure gauges. These features of the model will be improved.

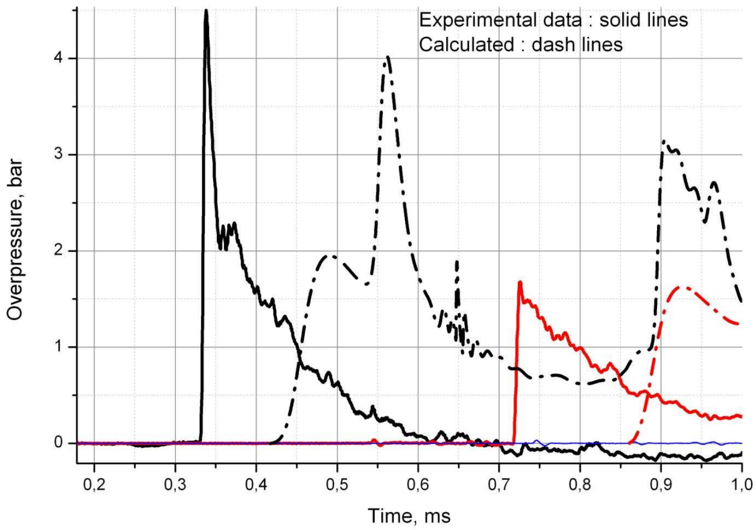

Figure 8. Experimental and calculated pressure records at r=0,5 m and 0,75 m.

4 Concluding remarks

A set of fine and reproducible experimental measurements of shock induced particle dispersion using pressure gauges, particle capturing technique and high speed video was realised. Successive particle collection at decreasing distances from the charge centre provided information on the relative arrival times of the two type of projected material: at first, fast-moving shock-agglomerated glass particles arrive on the wax disk, followed by broken particles aerodynamically decelerated in a significantly shorter distance. Preliminary results obtained with the two-phase reactive flow model agree in general with the experimental results. The work is now conducted on improvement of the model in order to compare the time evolution of the particle layer position to the results recorded by the particle traps.

5 References

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Acknowledgments

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