Influence of HE shape on blast profile

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Abstract

This paper is concerned by the effect of HE geometry on the shape of the blast wave. The aim of this work is to increase the knowledge on pressure profile generated by blast wave so as to optimize the design of explosion chambers. These facilities are commonly designed for spherical HE but most of the customer charges have other geometry (line, plate, cylinder …). Numerical simulations performed with Multi Materials Arbitrary Eulerian solver in LSDYNA were used to simulate hemispherical and rectangular shape HE events detonated on the ground. Pressure records in front of the charge (reflected pressure) and on lateral positions at different locations (incident pressure) are compared to experiments performed at CEA / Gramat. High speed video has also been used to visualize the shape of the fireball and the shock wave in air. It is confirmed numerically that the shape of explosive generates different shape of blast wave and so will change the way of designing new chambers.

Keywords: High Explosive, LSDYNA computational method, MMALE, High speed Framing Camera

1. Introduction

Most of the studies of explosion chambers are only based on spherical explosive geometry. In fact, the optimization of these containment chambers is directly depending on the energetic term and the way in which pressure waves act on their internal faces. Knowledge of the peak pressures, pressure shapes and arrival times in all the directions is a mandatory to reinforce the structure in high stressed areas and weaken it where low pressure levels are expected.

For that purpose, a small scale blast experimental work has been done to determine the influence of high explosive plates with various dimensions and ignition point on blast in comparison with a hemispherical charge.

The first part describes rapidly the experimental work with the initial set-up, the various studied configuration and instrumentation associated.

The second part is focused on the description of the numerical simulation with the principal assumptions (geometries, meshing, materials, configurations studied …).

Finally, experimental and simulation results are compared simultaneously to characterize the effect of the shape of the charge on the generated blast. The objective is also to confirm the ability of LSDYNA MMALE computation method to reproduce blast effects whatever the explosive shape is.

2. Experimental work

The experimental set-up is described here under on **Figure 1** and **Figure 2** (a detailed description of the experiments is given in [1]). The experiment consists of two heavy concrete walls (2 m x 2 m) with a Formex explosive charge placed in the center of the incident pressure wall. The position of the reflected pressure wall in front of the side-on pressure wall depends on the charge weight (0.57 m for the small charges weight and 0.95 m for the heavy one).

Three configurations have been tested:

- Configuration # 1: 14.2 g hemisphere with central initiation,
- Configuration # 2: 15 g plate (120mm x 60mm x 1.5mm) with half-width initiation,
- Configuration # 3: 66.6 g plate (200mm x 10mm x 2.5mm) with half-width initiation.

PCB piezoelectric pressure gauges were set-up on both walls (4 on the side-on wall and 2 on the reflected wall) and a 30 000 frames/s Photron high speed video camera was implanted to show the fire ball evolution and the blast effects. **Figure 3** shows examples of high-speed camera records.

Figure 1: Hemispherical and plate charge with side-on pressure gages 1 to 4 on side-on wall [1]

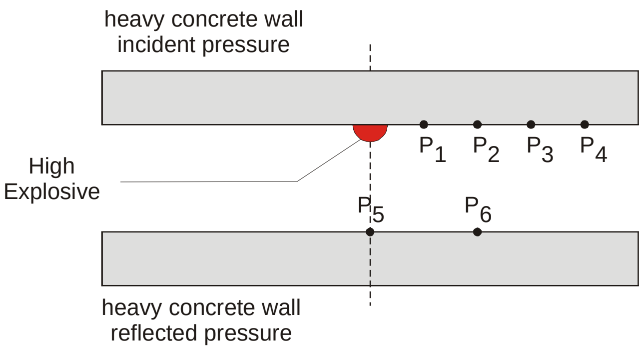

Figure 2: Schematic of the experimental set-up (upper view of the side-on wall) [1]

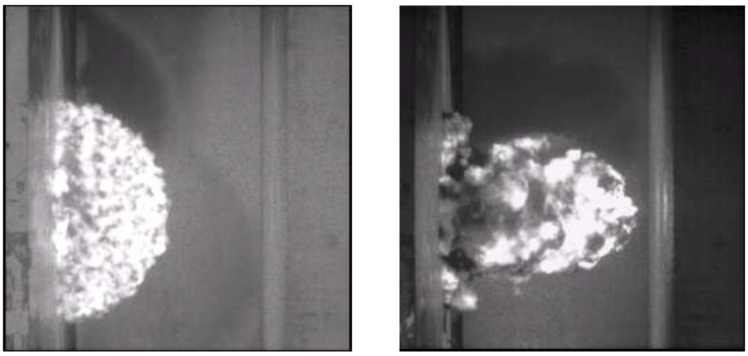

Figure 3 : Examples of high-speed camera records at t = 167 µs (hemisphere on the left, plate on the right)

3. Numerical simulations

The Multi-Materials Arbitrary-Lagrangian-Eulerian solver of LSDYNA has been chosen to reproduce the experimental configurations. The very small thickness of the two explosive plates compare to the other dimensions allows treating them like disks. Thanks to this assumption, all the simulations have been done with 2D-axisymmetry and then with solid shell element n°14. Three numerical configurations have been investigated: #1 for the 14.2 g hemisphere, #2 for the 15 g plate and #3 for the 66.6 g.

The geometry consists of a 2 m diameter air cylinder (Y main axis) with two different heights: 0.57 m for configuration #1 and 2 and 0.95 m for #3 (same dimensions as the experimental work). The geometry for the hemispherical charge is presented in **Figure 4-left**, closed views of the hemispherical and the 15 g plate configuration are shown in **Figure 4-middle**.

Meshing of the three configurations has been done with Hypermesh™ from ALTAIR ENGINEERING. All the meshing are composed of 4 nodes shells elements with 200000 elements with configuration #1 and 2 and 300000 elements for the configuration #3. The characteristic length of the edges in the explosive is 0.2 mm and 2 mm in the surrounding air. A detailed view of the mesh of the hemispherical charge is given in **Figure 4-right**.

Air is treated with MAT_NULL material model and POLYNOMIAL_EOS. TNT has been chosen as the energetic material because it has a one to one weight equivalence with Formex for pressure effect. The behavior of the TNT products is approximated by using a JWL_EOS with parameters from *Dobratz* [2] and MAT_HIGH_EXPLOSIVE_BURN material model.

The ignition point is located in the axis of symmetry at the intersection with the side–on wall. Finally, nodes on the side-on and the reflected walls are fixed along the Y-direction to allow reflections. The pressure versus time history of 6 shells at the same position than the PCB pressure gauges in the experiments have been recorded with 1 µs time step.

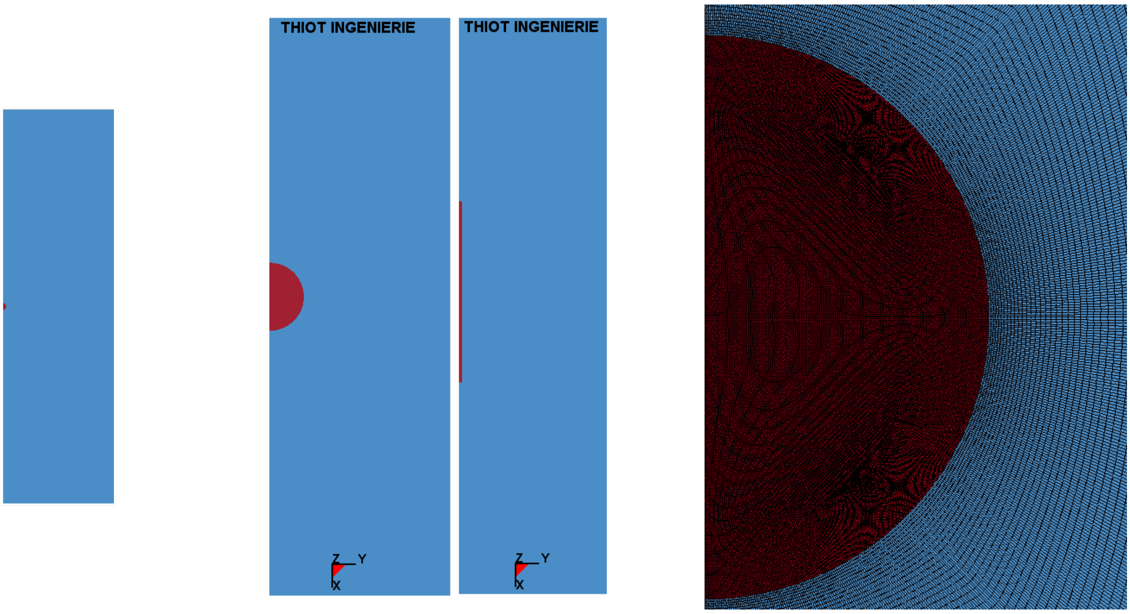

Figure 4: Geometry of the hemispherical configuration (left), closed views of the hemispherical and the 15g configurations (middle) and closed view of meshing (right)

4. Results

4.1. Comparison with high speed camera records

The behavior of the two explosive shapes is presented here under with the high speed camera records (**Figure 5**) and the pressure at various times for the numerical results (**Figure 6**.). For the numerical results, a half view of the pressure field is given with the hemispherical charge on the top and with the 15 g plate charge at the bottom. The pressure range is modified between two times to highlight the difference between the two configurations but the pressure range is the same for the two cases at a given time.

The simulation results are consistent with the experiments which show that the shape of explosive generates different shape of blast wave. After ignition, the hemispherical charge generates a homogeneous shock wave in the surrounding air and the expansion of the pressure wave is of course hemispherical. With the plate charge, the expansion velocity is not uniform in all the direction: it is faster perpendicular to the explosive main surface and it is slower in the lateral directions. An analysis of the fire ball velocity which has been investigated in [1] confirms those results.

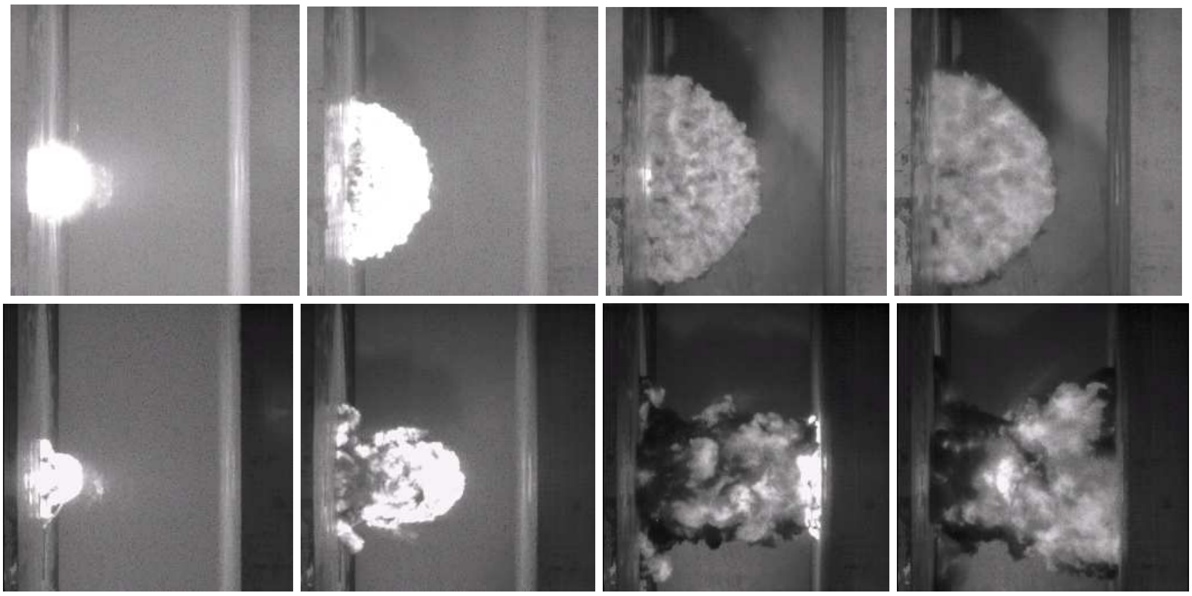

Figure 5: High speed framing camera records at t = 0, 100 and 300 and 633µs (top: hemisphere, bottom: plate)

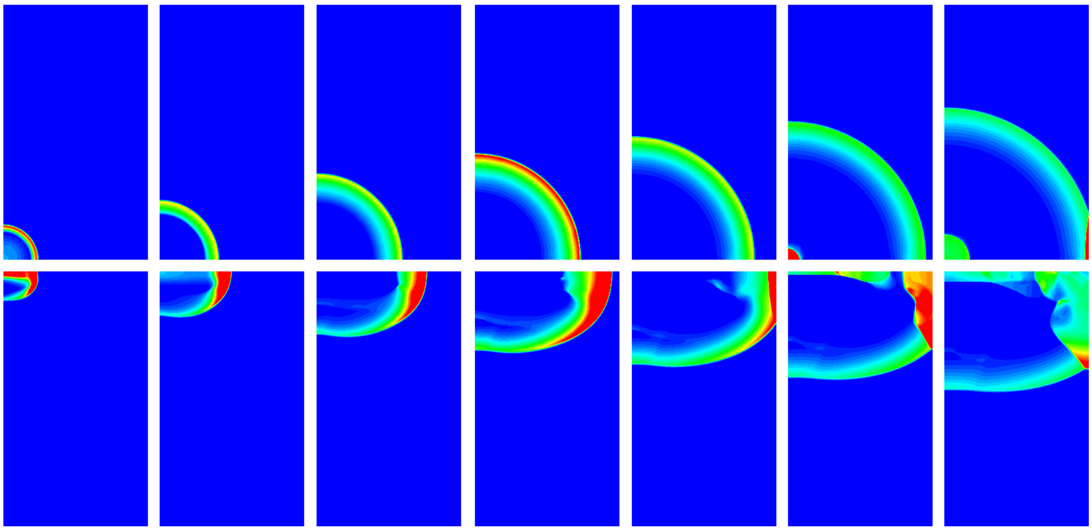

Figure 6: Comparison of pressure fields for numerical simulations case #1 and #2 at t = 40 µs and between 100 and 600 µs with 100 µs time step (top: hemisphere, bottom: plate)

4.2. Comparison with pressure gages records

Hemispherical configuration #1:

The experimental pressure records and the pressure obtained with LSDYNA are presented in **Figure 7** for the hemispherical configuration #1. Pressure profiles are quite similar in terms of peak pressure, arrival time and shapes for the four side-on records position (P_1 to P_4) and the two reflected positions (P_5 and P_6).

A comparison of the side-on parameters (pressure, impulse, time of arrival and positive duration time) versus scaled distance (distance divided by the cube root of the weight of the charge) is given in **Figure 8**. US Army TM5-1300 data [3] and numerical results given in [1] are also compared with the experimental work and the LSDYNA simulation results. These diagrams show that the LSDYNA simulations give quite good results compare to the experimental data and the other reference for the peak pressure and the time of arrival. The scaled impulse and the positive time duration are also very closed except with the TM5-1300 reference that gives higher value.

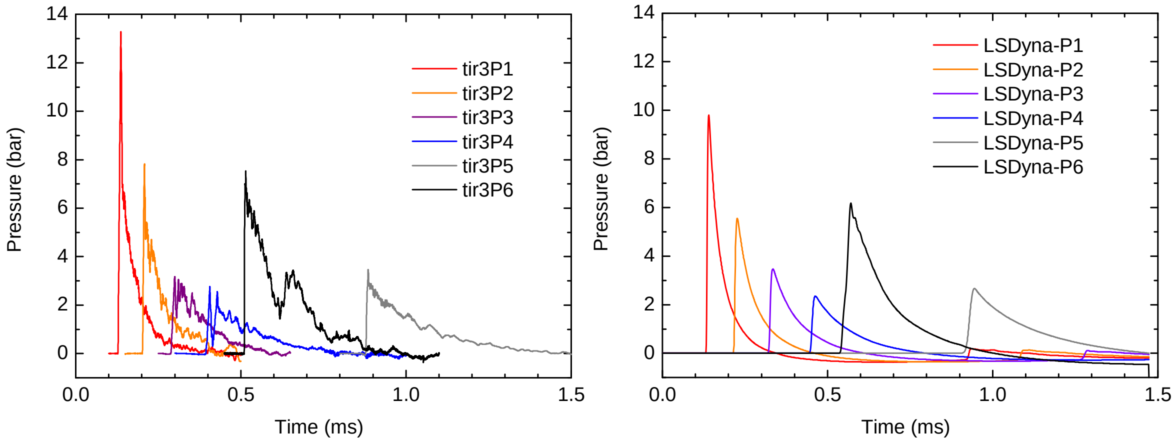

Figure 7: Hemisphere comparison between experimental pressure records (left) and LSDYNA simulation (right)

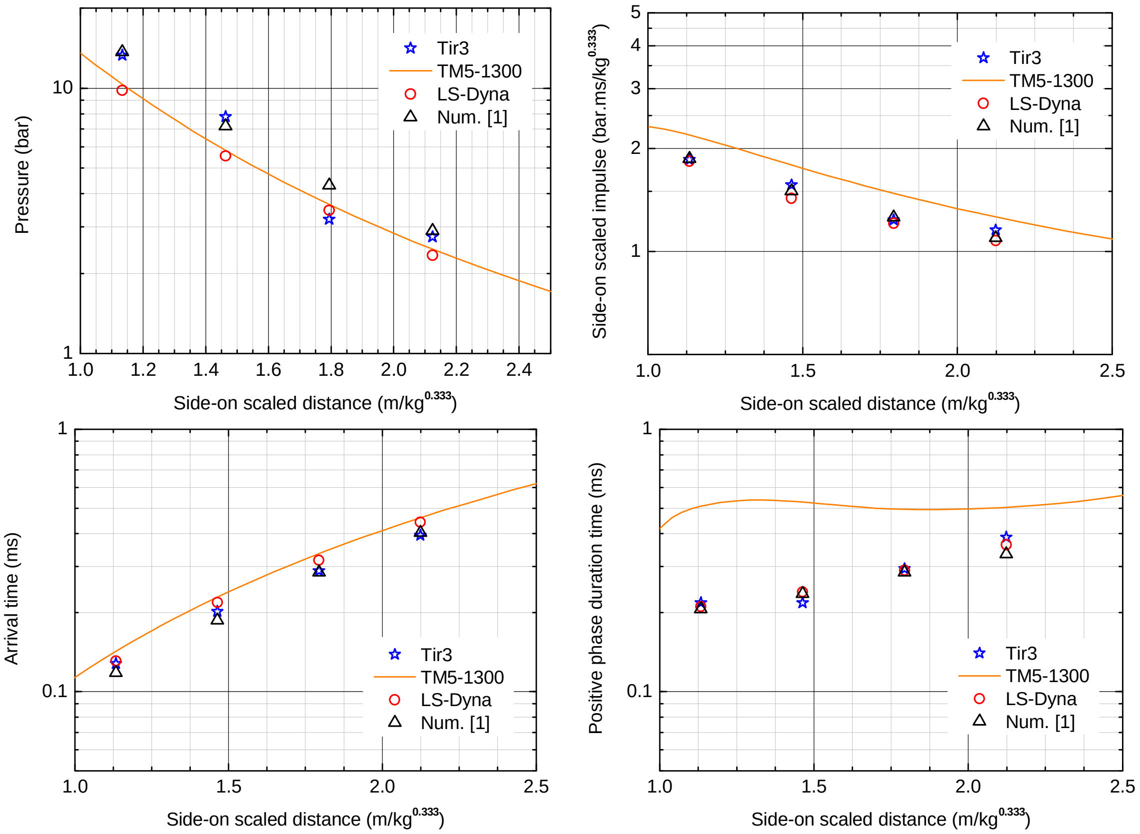

Figure 8: Comparison of side-on results between experimental, TM5-1300, LSDYNA and numerical work [1]

Plate shape configuration #2 and #3:

The experimental pressure records and the pressure obtained with LSDYNA with the two plate configurations are presented from **Figure 9** to **Figure 12**. The two first figures show the experimental and simulation results for the 15 g configuration and the two others for the 66.6 g plate.

The pressure profiles for gauges P1 to P5 are quite similar for the two weights in terms of peak pressures, shapes and positive phase duration but the simulation gives a very smaller peak pressure than the experimental record for the P6 reflected pressure gauges in front of the explosive plate.

The pressure waves arrival time for all the gauges are shorter in the experimental work. The simulation is especially not able to reproduce the very fast expansion of the fire ball in the direction of the reflected wall even if it shows an increase of the peak pressure in this direction.

A comparison of the side-on pressure and side-on impulse in function of the scaled distance is given in **Figure 13**. Experimental data and LSDYNA results for the two shapes configurations results are plotted to highlight the effect of the explosive shape on the generated blast.

The analysis of the pressure profiles of both the experimental works and the simulation confirm that the shape of explosive generates different shape of blast wave. Unfortunately, the simulation cannot reproduce yet the entire phenomenon but more investigations will decrease the gap between experiment and simulation.

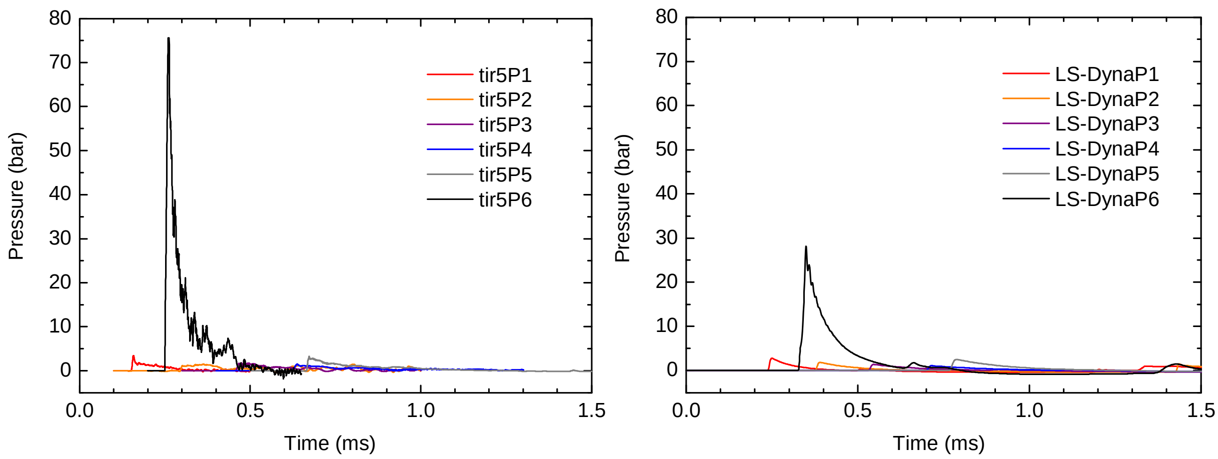

Figure 9: Plate configuration #2 (15 g) comparison between experimental pressure records (left) and LSDYNA simulation (right) (large view)

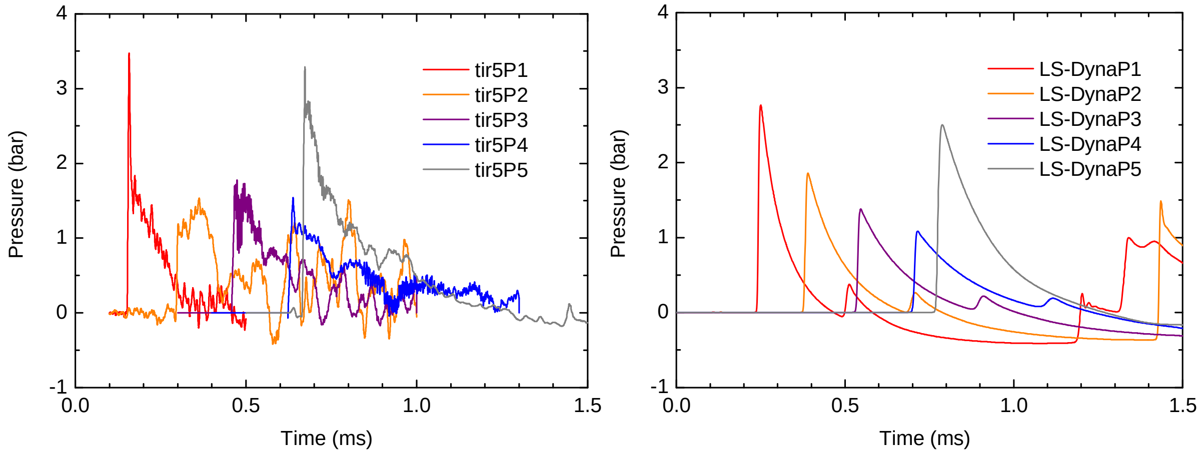

Figure 10: Plate configuration #2 (15 g) comparison between experimental pressure records (left) and LSDYNA simulation (right) (closed view)

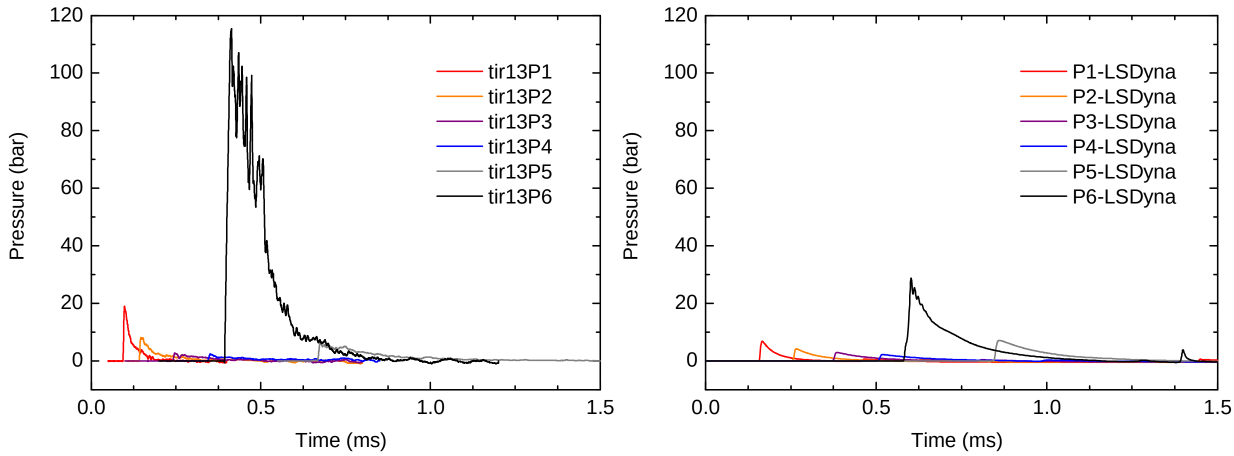

Figure 11: Plate configuration #3 (66.6 g) comparison between experimental pressure records (left) and LSDYNA simulation (right) (large view)

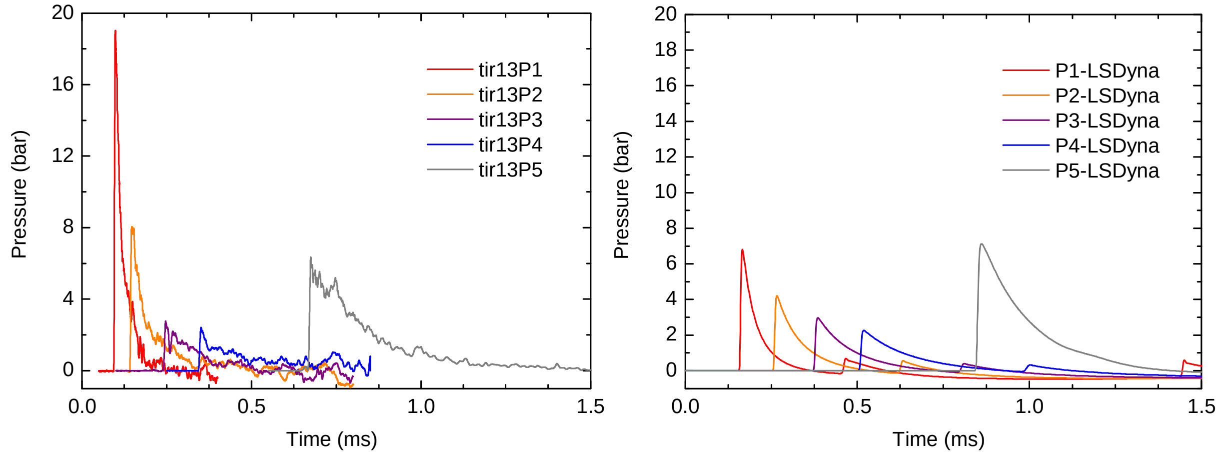

Figure 12: Plate configuration #3 (66.6 g) comparison between experimental pressure records (left) and LSDYNA simulation (right) (closed view)

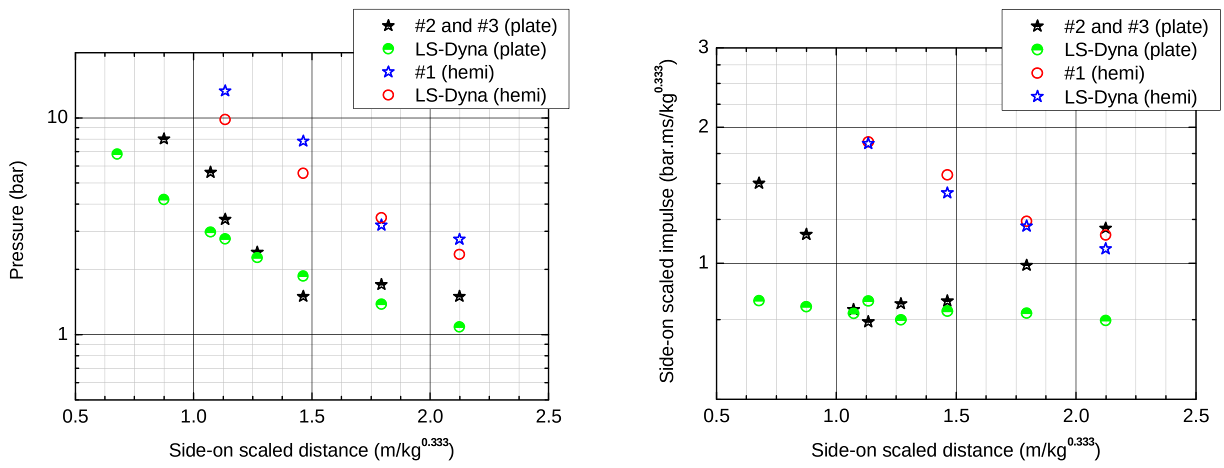

Figure 13: Comparison of side-on results (pressure on the left and impulse on the right) between experimental and numerical works [1]

5. Conclusion – Future works

This study highlights the effect of the explosive shape on pressure waves. Experimental works and simulations have simultaneously shown an increase of the blast effect above the plate configuration compared to the hemispherical configuration. On the opposite the lateral blast is much lower. Even if simulations reproduce globally the experimental results, more investigations must be done in this field.

Further experimental works will characterize the influence of the position of the initiation point on the pressure waves: half-width, half length and central initiation.

Many numerical investigations will be done on the material models and the MMALE advection methods to make simulation results closer to the experiments.

3D MMALE will be used to simulate the rectangular shapes of the explosive and evaluate the influence of the position of ignition point and the orientation of the plate on the side-on and the reflected pressure signals.

6. References

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[2] Dobratz, B.M., "LLNL Handbook of explosives" UCRL-52997, Lawrence Livermore National Laboratory, 1981

[3] "Structures to resist the effects of accidental explosions", US Army technical manual TM5-1300