A Study of Mapping Technique for Air Blast Modeling

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Abstract

Since LS-DYNA® v971 r4, a new 2D ALE method with an associated Mapping technique is available. Mapping enables the decomposition of a calculation in several steps: at the end of a 2D ALE calculation, data from the last cycle can be mapped into another 2D or 3D mesh. Several finite element studies of Air Blast were modeled to evaluate efficiency and potential of this new LS-DYNA feature.

First, an influence study was performed to evaluate the impact of the mesh characteristic length variation during the Mapping on shock wave both on pressure peaks and impulses. The analysis is focused on the evaluation of the loss due to the Mapping technique.

Then, a comparison with experimental data on a simple 2D study of air blast using Mapping technique was performed. The very good precision obtained with the 2D ALE method and its ability to represent air blast phenomena will be shown.

Introduction

Since 1993, an Arbitrarian Lagrangian Eulerian method has been developed in LS-DYNA®. A lot of developments were realized to obtain an efficient 3D multi-material ALE formulation with very powerful coupling methods. To complete these capabilities, LSTC recently implemented a 2D ALE formulation available since the R4 version.

The 2D ALE method is available for two types of shells (axisymmetric and plane strain elements) and three types of ALE formulations (mono and multi-materials). The Lagrangian step is solved by routines similar to the one called by *SECTION_SHELL with elform=13 and 14. The Eulerian step is solved by algorithms similar to 3D ALE code. As a consequence this new 2D ALE code provides the same functionalities as 3D such as pure Euler, ALE with grid motion and Fluid-Structure Interaction (FSI).

A new technique named “Mapping” has also been developed to allow the decomposition of a calculation in several steps. The last cycle of a 2D or 3D ALE model can be mapped into another 2D or 3D ALE model. This technique offers very large possibilities since it enables to change the mesh length or the model size, to add Lagrangian or Eulerian parts...

This paper presents a study of Mapping technique using 2D and 3D ALE models for Air Blast Modeling. After a brief introduction on blast waves theory, we will present advantages and drawbacks of this technique. Then, a comparison with experimental data will show the real interest of this method.

Modeling of blast waves

An explosion in air with a perfect detonation creates a spherical shock wave with a peak incident pressure and then a depression area. The peak pressure and the propagating velocity diminish with the load distance.

The well known Friedlander wave equation defines the rise and fall of the static overpressure :

$$Ps(t) = Psmax\left(1 - \frac{t}{Ts}\right)e^{\frac{-bt}{Ts}}$$

Psmax defines the pressure peak, ***b*** is the parameter controlling the rate of wave amplitude decay and ***Ts*** is the parameter characterizing the duration of the blast pulse (see Figure 1).

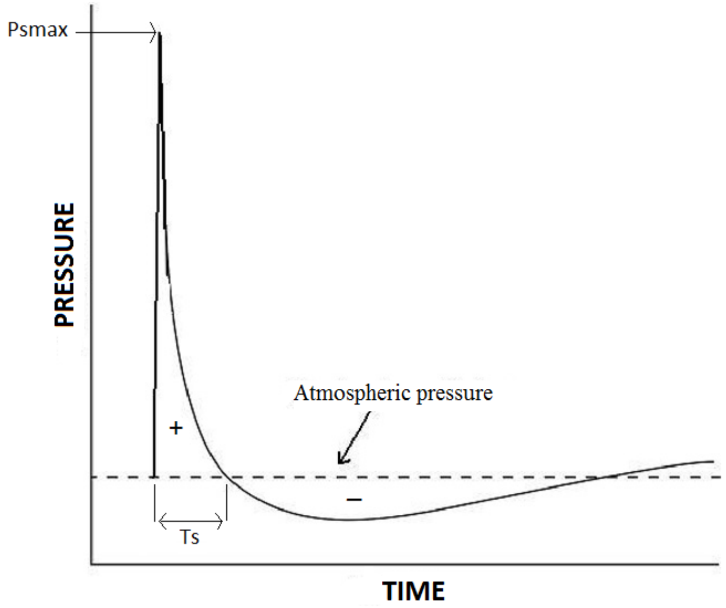

Figure 1 : Friedlander blast model

The Friedlander equation is valid if the blast wave is at a bigger distance than ten charge radii. Moreover, the negative phase of the blast wave (depression area) can only be present in a free air explosion. In fact, during an internal explosion, we don't have enough air to obtain a dilatation after compression.

A study of Mapping technique

Due to its specificities, Mapping technique is a perfect method to study such problems where the quality of initiation is a determining parameter. Indeed, starting with a very fine mesh is the crucial point, because having the right initial energy guarantees a good final % Error with experimental data. Mapping enables to combine a good accuracy in a first very fine mesh with a reasonable CPU time with a second larger mesh. That's why it is a suitable method to perform explosives studies, where initial detonation and the start of the propagation is essential for the rest of calculation.

In this paper, we use this Mapping technique to perform a TNT sphere blast in air. Ignition is done on a first very fine 2D ALE axisymmetric model to be continued in a second larger 2D ALE axisymmetric model. The first model is a butterfly mesh to ensure a good spherical shape of the shock wave (and to be able to capture exactly the explosive shape), the second one is a simple cartesian mesh. A focus on the butterfly mesh is presented in Figure 2.

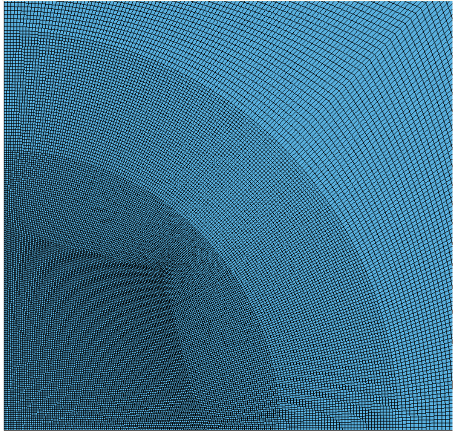

Figure 2 : View of a butterfly Mesh

Figure 3 presents initial configuration of the first LS-DYNA Model.

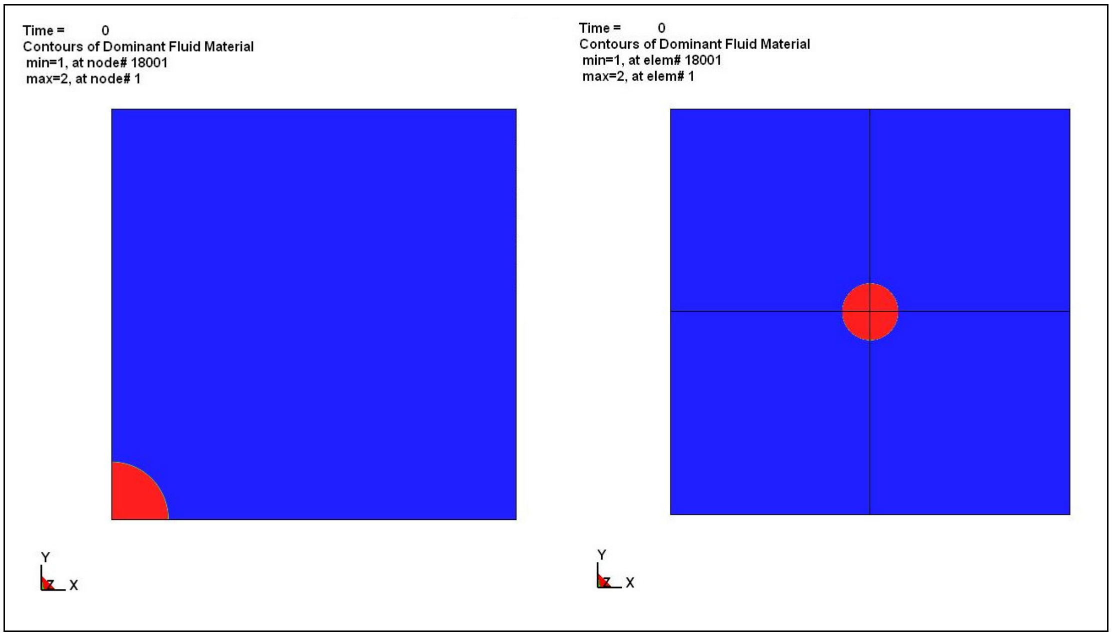

Figure 3 : Views of initial LS-DYNA model configuration

TNT has a constitutive model *MAT_HIGH_EXPLOSIVE_BURN and an equation of state *EOS_JWL to model a perfect detonation of the explosive charge. Air has *MAT_NULL and *EOS_LINEAR_POLYNOMIAL to model a γ-law behavior.

During ignition, a detonation wave travels across the charge. When explosive is fully detonated, a shock wave is generated by the sudden expansion of reaction gases. Then, this spherical shock wave spread over the air. Figure 4 provides views of LS-DYNA simulation before Mapping whereas Figure 5 provides views of LS-DYNA simulation after Mapping.

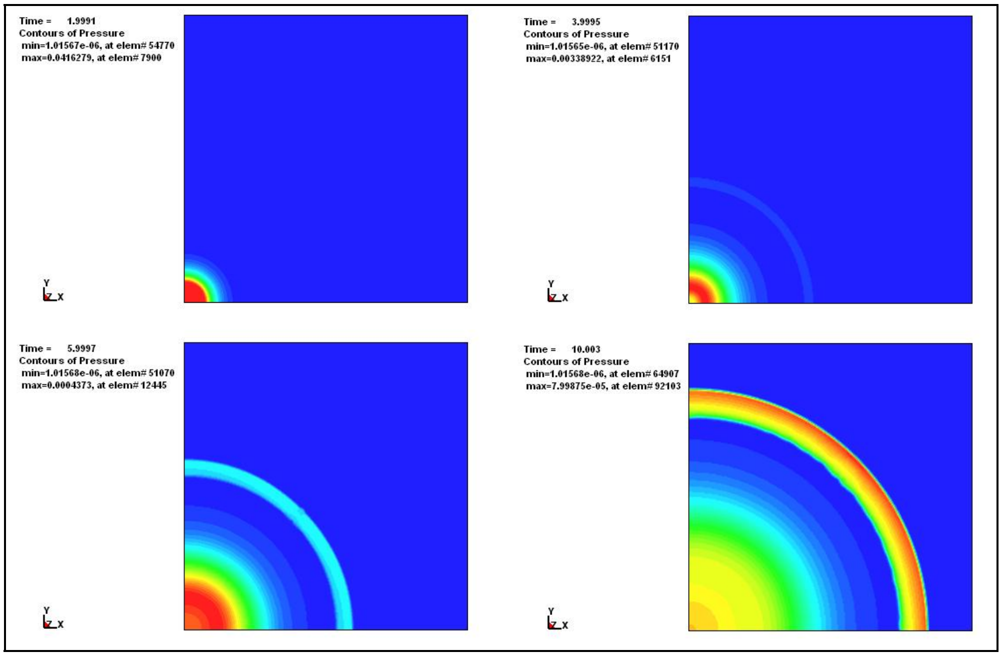

Figure 4 : Views of Pressure at different plots (before Mapping)

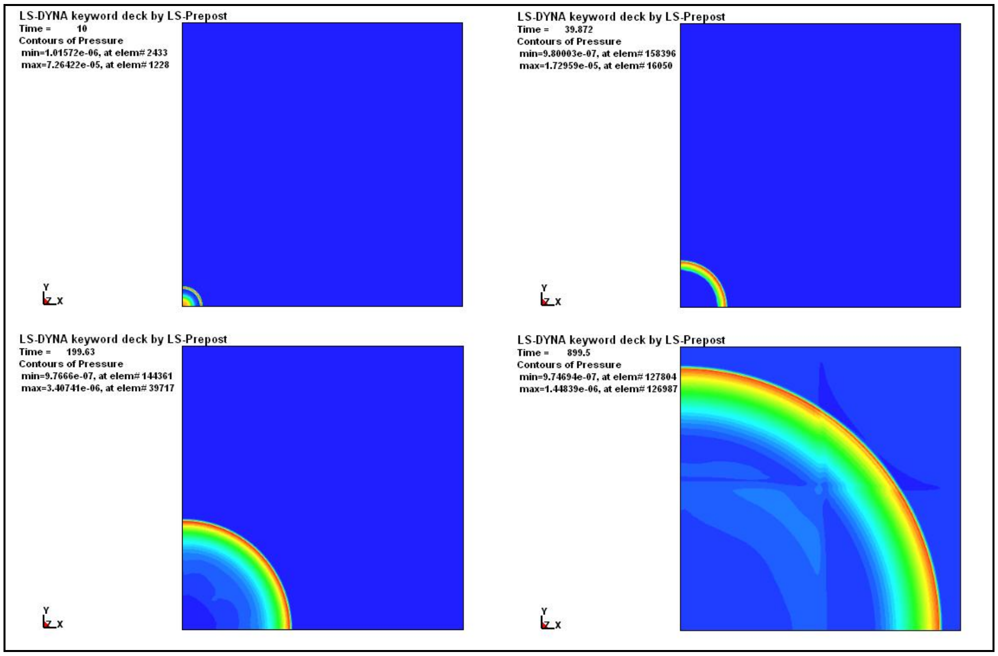

Figure 5 : Views of Pressure at different plots (after Mapping)

Concerning results, we did first a comparison between simulation and theory on static pressure at a distance greater than ten radii. We obtained this pressure with a static *DATABASE_TRACER in the LS-DYNA model. Figure 6 presents a plot of overpressure given by simulation.

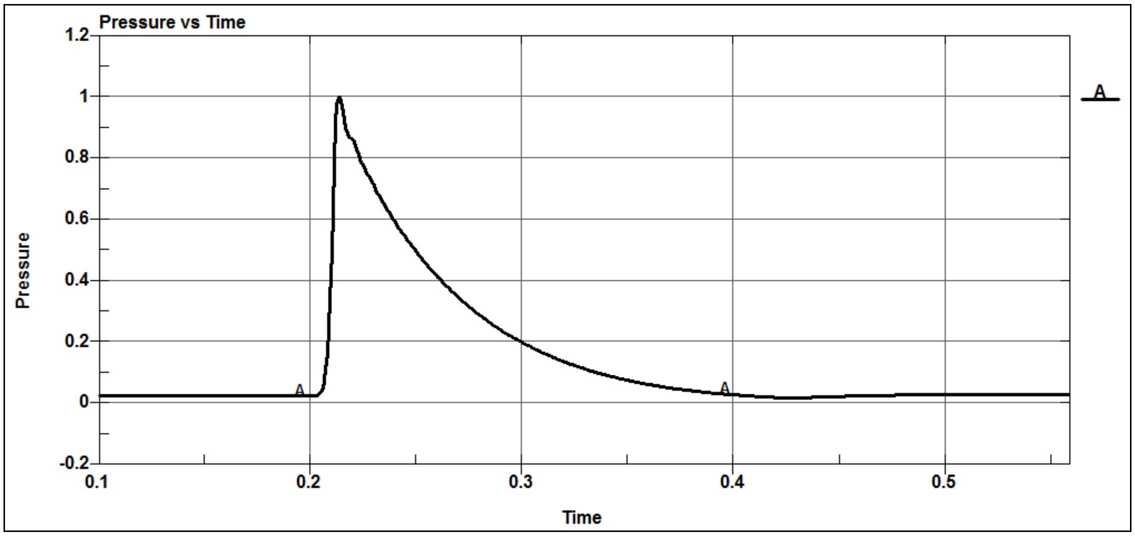

Figure 6 : Pressure curve given by LS-DYNA

This curve shows that LS-DYNA simulation obtains a good shape for the shock wave. However, if we compare with the Friedlander blast model, we don't have the negative phase after the pressure peak. This is probably due to the simulation inability to consider enough air to simulate the air dilatation.

In a second time, we performed a study concerning the influence of mesh length variation ratio during Mapping (mesh variation ratio = mesh length before Mapping model under mesh length after Mapping model). We did this study since this ratio has a real influence on the static pressure of the shock wave. Figure 7 shows the comparison of overpressure given by LS-DYNA simulation according to different ratios.

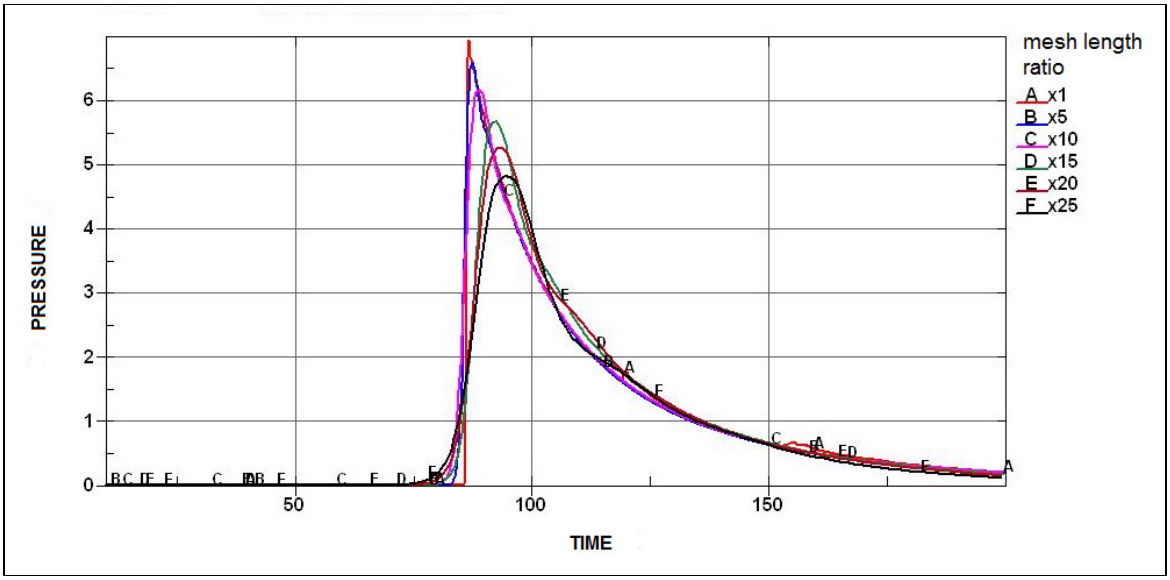

Figure 7 : Pressure curves for different mesh variation ratio during Mapping

We can effectively see that a Mapping with a ratio greater than unity induces a peak reduction and a spreading of the initial shock front. If we want an acceptable overpressure loss (arbitrary fixed at 10 % loss), ratio during Mapping must not exceed 10. Indeed, if it is not the case, maximum overpressure can drop rapidly by 30% with a ratio of 25.

However, there are sometimes cases where Mapping with ratio exceeding 10 is absolutely necessary because of a model size constraint for example. In this case, it is interesting to see if the peak smoothing induces an energy loss. Figure 8 shows an Impulse comparison (representative of transported energy) for different mesh length ratio.

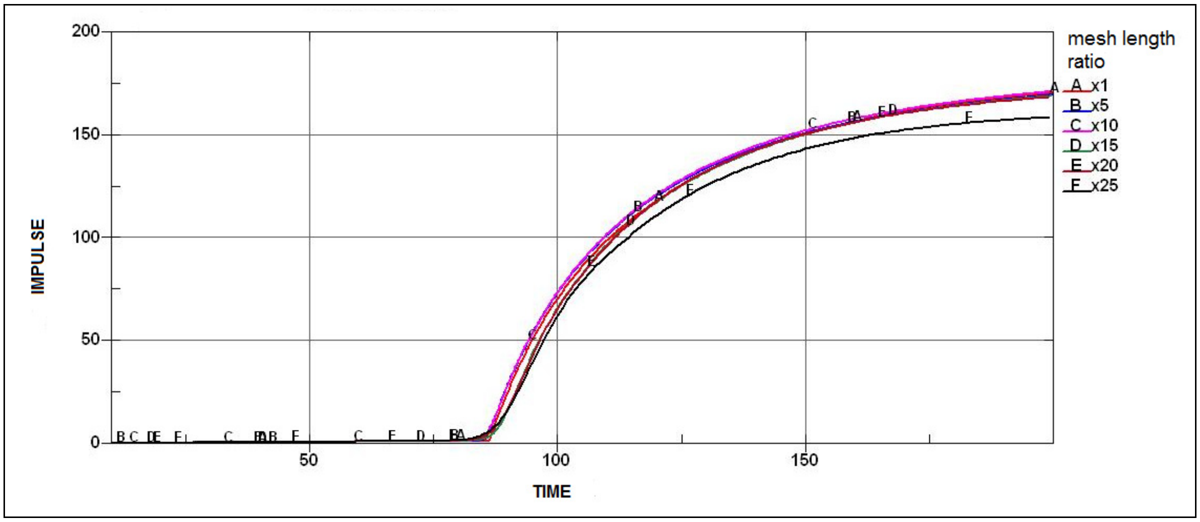

Figure 8 : Impulse curves for different mesh length ratio during Mapping

These curves highlight that without exceeding a ratio of 20, there is virtually no energy loss. Moreover, a ratio of 25 gives a very smoothed peak but with an energy attenuation of about 10%. To conclude, if we want to maintain an acceptable peak overpressure during Mapping, we have to keep the mesh length ratio smaller than 10. But if we need to use a larger ratio, energy conservation is only guaranteed until a ratio value of 20.

Comparison with Experimental Data

In this part, a simulation of a TNT sphere blast in air is presented. This model was created to compare simulation results with experimental data provided by IRSN (Institut de Radioprotection et de Sûreté Nucléaire = French nuclear safety institute). These data are measurements of pressure sensors placed at different locations.

Different ratios of mesh size were tested to evaluate two things:

- Is it possible to obtain less than 10% Error with experiment?
- In this case, what is the maximum size mesh needed to achieve this accuracy?

First, we want to see if a model with a low ratio (ratio = 5) is able to provide the desired accuracy. Figure 9 shows a comparison between pressure results from LS-DYNA simulation and experimental results.

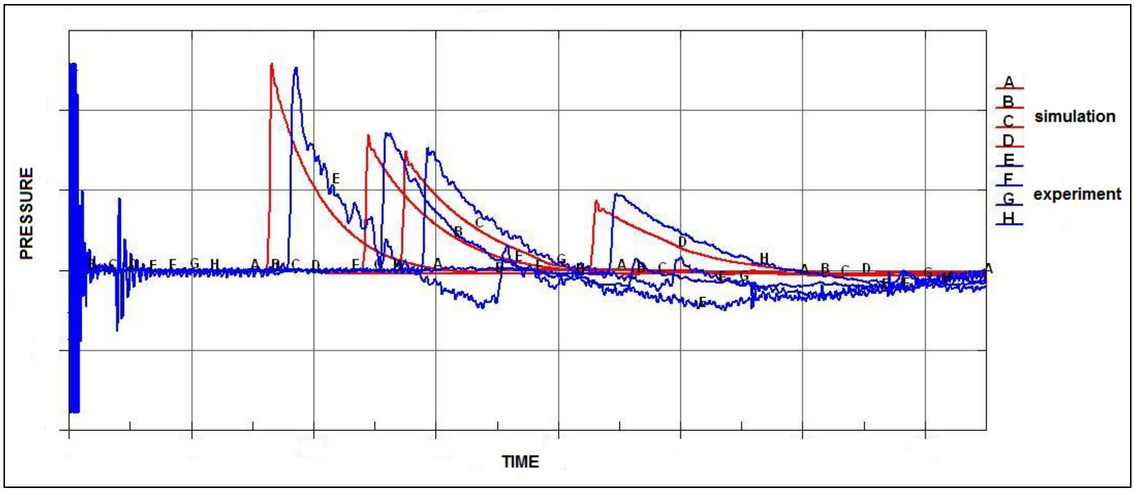

Figure 9 : Comparison of Pressure signals for all sensors

With the finest model (ratio = 5), % Error for the peak overpressure seems to be below 10% for all pressure sensors. In addition, we notice the same delay between simulation and experiment for all signals (probably due to the noise at the beginning of experimental curve). Consequently it means that the propagation wave velocity is nearly the same in LS-DYNA simulation and in experiment.

Figures 10 and 11 show a comparison at the first sensor of overpressure and impulsion after an appropriate time shift.

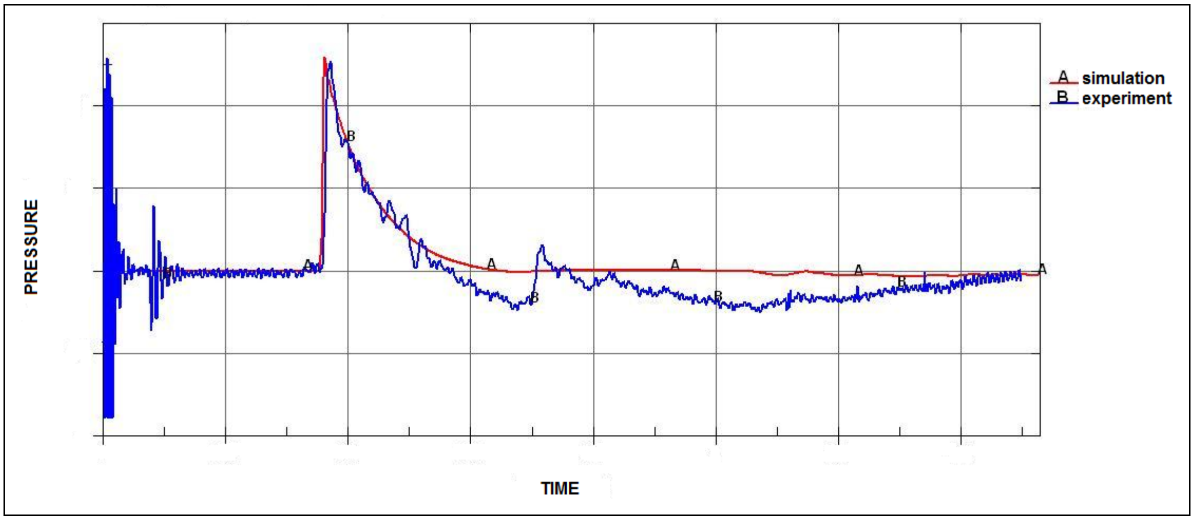

Figure 10 : Comparison of Pressure signals for the first sensor

This plot confirms the very good results given by Mapping technique in simulating Air blast problems. Indeed, for the first sensor, % Error between simulation and experiment is below 5%.

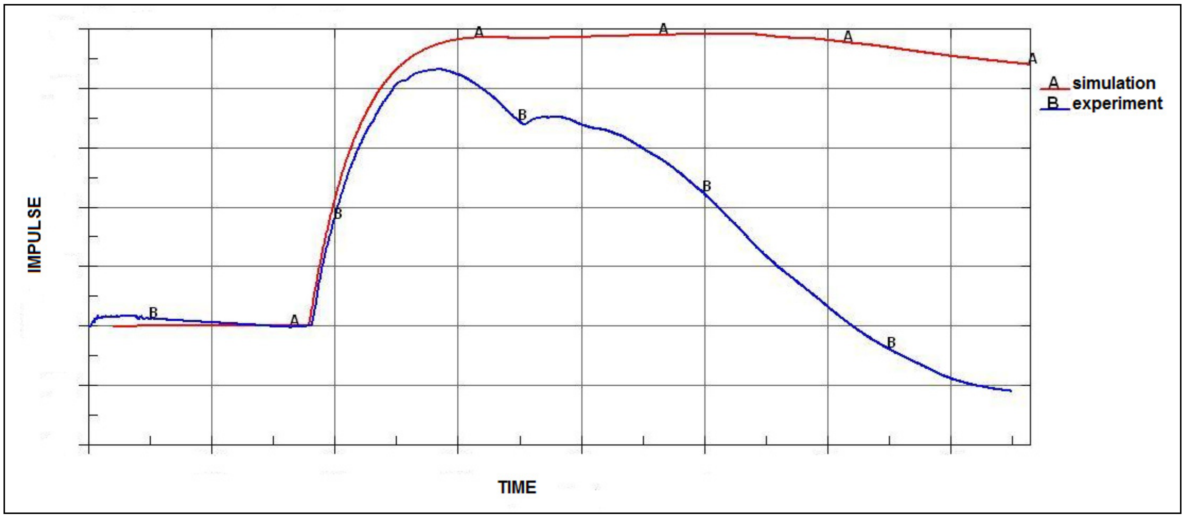

Figure 11 : Comparison of Impulse signals for the first sensor

The increasing error between simulation and experiment is mainly due to the absence of negative pressure phase in the simulation. However, if we consider the maximum impulse, we obtain a quite good accuracy with a % Error lower than 20%.
Then, we evaluate ratio influence on results. Table 1 presents results obtained with 4 different ratios (5, 7.5, 12.5 and 25). In this table, the CPU time of simulation for these ratios is also given (using one core of a 5400 Xeon – 3.2 GHz).

Parameter	**ratio 5**	**ratio 7.5**	**ratio 12.5**	**ratio 25**
% Error Overpressure	1.75	1.67	2.87	6.94
CPU Time	1 h 1 min	17 min	4 min	< 1 min

Tableau 1 : Results obtained for each ratio

We note that with a much higher ratio (12.5), simulation is still very accurate (2.87 % Error). Moreover, even with a ratio of 25, we have very good results with a CPU Time more than reasonable.

These results show a real capacity of ALE method and Mapping to simulate an Air blast Study. With these techniques, in most of cases, we are able to ensure a maximum of 10 % Error for overpressure and 20 % Error for impulse.

Conclusion

To summarize, 2D and 3D ALE associated with Mapping technique seems to be a suitable method to perform Air blast studies. Doing the charge ignition in a fine 2D model with a butterfly mesh ensures a very important accuracy for the first part of calculation. Using Mapping to increase mesh size leads to a very small % Error between simulation and experiment with a reasonable CPU Time.

The other real interest of this technique for Air blast studies is to perform multiple Mapping in order to simulate the shock wave interaction with a 3D structure. Thus, we could do the ignition and propagation in air of shock wave with several 2D ALE models, to finally do a 2D to 3D Mapping to realize a 3D ALE/FSI interaction. This method should be a real alternative to *LOAD_BLAST_ENHANCED for modeling Air blast far from the charge.

This paper shows an application of Mapping technique, with a real success. But there are a lot of other potential application cases. In the future, there is no doubt that the use of Mapping will increased in ALE studies.

Acknowledgement

Dr. Nicolas AQUELET and Dr. Ian DO of LSTC are acknowledged for providing a high level support and for their reactivity in new options implementation.

IRSN is acknowledge for providing experimental pressure signals which make possible this study and this paper.

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