A Contribution to New ALE 2D Method Validation

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Abstract

Since LS-DYNA® v971 r4, a new ALE 2D method is available. Several finite element studies were performed by AS+ to evaluate the precision of this method in pure Multi-Materials Euler studies .

Pure Multi-Materials Euler was tested on Impacts and Explosives studies from Defense and Spatial fields. A High Velocity Impact, a Long Rod Penetration, an Explosively Formed Projectile, a Shaped Charge Jet and an Air Blast were modeled using 2D axisymmetric models. Results were compared to experimental data extracted from reference papers. The very good precision obtained with the 2D ALE method and its ability to represent very dynamic phenomenon 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. This new feature will be discussed more in details at this 11th International LS-DYNA Users Conference in the paper “A study of Mapping technique for Air Blast modeling”.

ALE method is particularly adapted to model fluids and very dynamic phenomenon. But most of ALE applications need a very fine mesh to obtain very good results, and sometimes this necessary very small element size is unreachable with a 3D model. The implementation of 2D ALE makes possible this type of simulation with a mesh size difficult to reach with 3D Eulerian applications in LS-DYNA.

This paper presents six studies as a contribution to the validation of this new 2D ALE method. First, two studies based on an impact issue (Spatial and Defense field) and three using an explosive (Defense field) lead to prove the ability of LS-DYNA to simulate pure Multi-Materials Eulerian problems with a fairly good accuracy. Then a study of a slamming (nautical field) in ALE/FSI will be presented to ensure quality of coupling method in 2D.

Impacts in pure 2D MMALE

High Velocity Impact

The first type of calculation presented here is based on an impact problem. In fact pure Eulerian formulations are particularly adapted to obtain good impact simulations at high velocity range. A study of High Velocity Impact and a study of a Penetration of long-rod into a semi infinite plate were performed to highlight the good abilities of 2D MMALE method to perform pure Euler studies.

The high velocity impact is a study from spatial field; it models the impact of space debris on a structure (satellite, launcher…). As the number of space fragments is more and more important (10 000 cataloged debris and more than 50 000 not listed), spatial structures are increasingly subjected to this kind of impact which can have devastating consequences. Currently the experimental devices hardly allow the study of High Velocity Impact with speeds exceeding 10 km/s. That's why the advantage of numerical simulation is huge: there is no speed limit avoiding us to overtake 10 km/s.

This study of High Velocity Impact is the modeling of a metal sphere (debris) which is impacting a thin plate (wall of a spacecraft) at a speed of about 6 km/s. Experimental results are taken from two papers of *J.M. SIBEAUD, P.L. HEREIL, V. ALBOUYS [1]* and *Andrew PIEKUTOWSKI [2]*. A two-dimensional finite element model LS-DYNA has been developed for the full model with a 2D axisymmetric Eulerian element formulation. This model is shown in Figure 1. Background of the grid is filled with void whereas the sphere and the plate are in Aluminum.

Void is modeled by *MAT_VACUUM. Aluminum is modeled by the association of *EOS_GRUNEISEN equation of state and *MAT_STEINBERG.

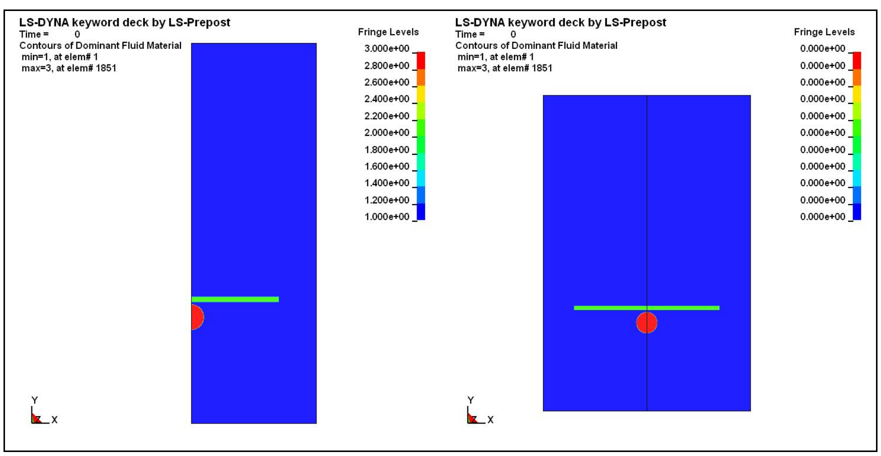


Figure 1 : Initial configuration of LS-DYNA simulation

When the sphere impacts the plate, a shock wave is generated within the two materials. These waves are then reflected on the edges and the rear face. A strong pressure gradient (because the pressure shock is far greater than the external pressure) causes a lateral material motion. Acceleration induces stresses greater than the stress at break and creates what is called the "retro-jet" (jet at rear of the plate). During penetration of the plate, a debris cloud is formed at the front of the plate with a complex evolutionary process.

Figure 2 shows views of the LS-DYNA simulation at various stages of calculation.

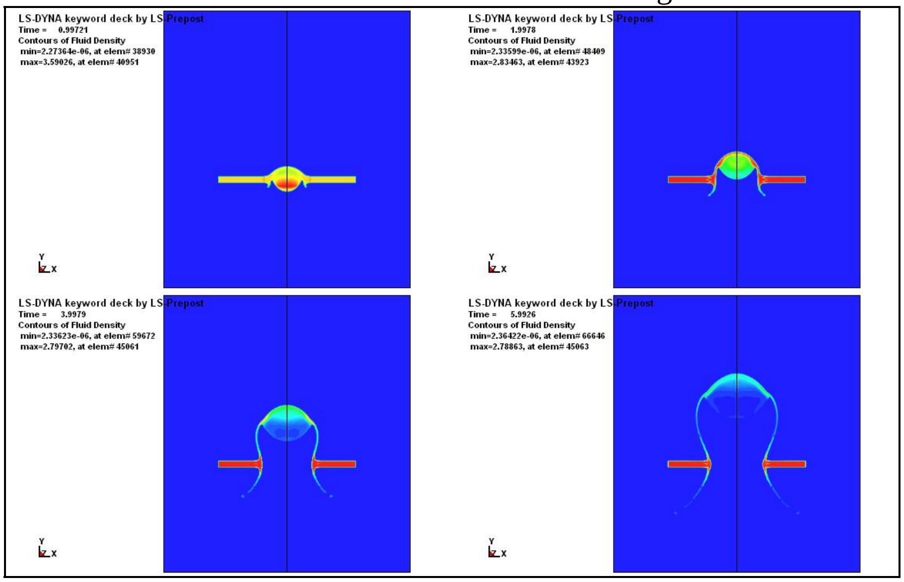


Figure 2 : Views of HVI at various steps of simulation

Debris cloud at 6 µs obtained by simulation is compared to the experimental one (extracted from paper [1]) in Figure 3.

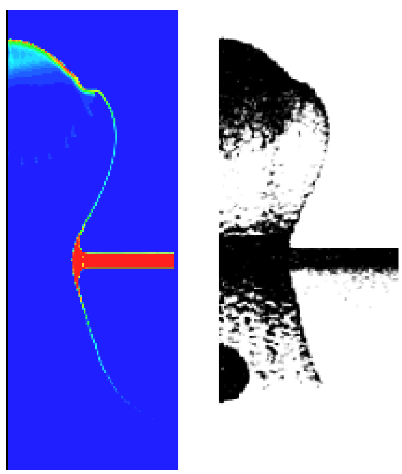
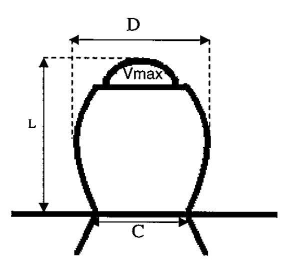


Figure 3 : Views of simulation and experiment final nucleus shape

The cloud shape obtained in the simulation is very close to the experimental one. But this is not enough to conclude on the ability of 2D ALE to perform calculations of hyper velocity impact, we must compare the results from a quantitative point of view. That is why the calculation was extended to 16 µs in order to compare cloud size and penetration velocity with experimental values extracted from the second paper cited before [2].

The comparative measurements carried out are:

- Maximum Penetration Velocity (V_{max})
- Cloud Diameter (D)
- Cloud Length (L)
- Crater Diameter (C)



Results obtained by simulation in % error with experiment are presented in Table 1.

Parameter	% Error
V_{max}	2.5
D	1.1
L	0.4
C	1.1

Table 1 : % Error between simulation and experiment

These results show that we get less than 2.5% error for all parameters. These results confirm the good impression of the qualitative comparison. The 2D ALE method seems to be able to correctly simulate a High Velocity Impact with a reasonable amount of time (4 hours to go up to 16 μs).

Long rod penetration

A long rod penetration into a semi-infinite target is the second study performed. It models a process used in some weapons to pierce thick walls. The rod is a very fine and long cylinder impacting a hard target at high velocity. During penetration, the bar is consumed by piercing the target and creates weaknesses that can be exploited by following explosive charges.

Models presented in this study are all based on two papers from Sandia National Laboratories ([3] and [4]). These papers contain experimental results and numerical results of several cases performed with CTH and ALEGRA Eulerian codes. The goal of our study is to compare results both with experiment data and with results from CTH and ALEGRA.

A two-dimensional finite element LS-DYNA model has been developed for all cases with a 2D axisymmetric Eulerian element formulation. A model is shown in Figure 4, background of the grid is filled with void, long rod is in tungsten and target is in Aluminum. Metals are modeled by the association of *EOS_GRUNEISEN equation of state and *MAT_ELASTIC_PLASTIC_HYDRO. Void is modeled by *MAT_VACUUM.

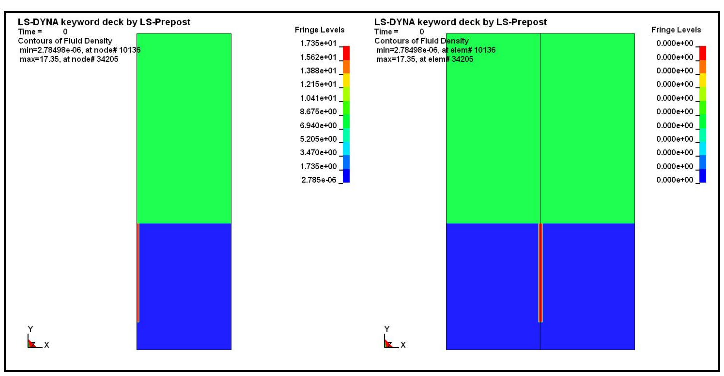


Figure 4 : Initial configuration of LS-DYNA model

The long rod impacts the target with a speed of more than 1 km/s. Piercing target, the long rod creates a crater due to the higher tungsten density. The long rod is consumed during penetration and loses kinetic energy. When the whole rod is consumed, energy is completely dissipated.

Figure 5 shows views of the LS-DYNA simulation at various stages of calculation.

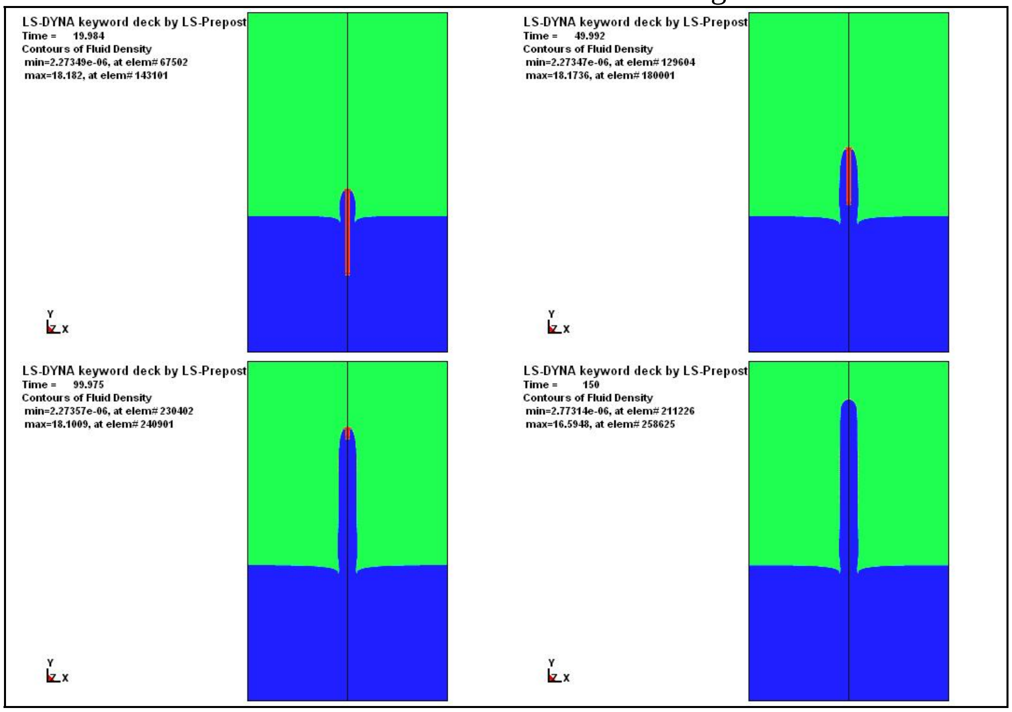
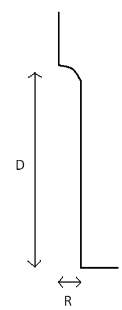


Figure 5 : Views of Long rod penetration at various steps of simulation

Six cases have been tested in this study, the first 5 (1 to 5) are extracted from the first publication and the last one (6) from the second publication. These cases differ in the impact velocity and the long rod dimensions.

The comparable measurements for these test cases are:

- Penetration speed (Vp)
- Crater radius (R)
- Crater depth (D)



The results obtained by simulations are presented in Table 2.

Parameter	% Error Case n°1	% Error Case n°2	% Error Case n°3	% Error Case n°4	% Error Case n°5	% Error Case n°6
Vp	**1.9**	**1.1**	**2.8**	**0.5**	**0.9**	**No data**
R	**0.1**	**3.8**	**1.6**	**5.2**	**3.6**	**6.4**
D	**2.6**	**0.8**	**6.2**	**0.1**	**1.6**	**0.1**

Table 2 : % Error between experiment and simulation

These results confirm the good impression given by HVI study. Maximum percentage error is 6.4%, and lower percentages are less than one percent. The 2D ALE method of LS-DYNA enables very accurate and regular results prediction for this kind of impact simulation.

The second step is now to compare LS-DYNA results with ones given by other Eulerian software CTH and ALEGRA. Figures 6, 7 and 8 are graphs of the error between experimental and numerical results for all software. Mesh size is identical in simulations for LS-DYNA, CTH and ALEGRA.

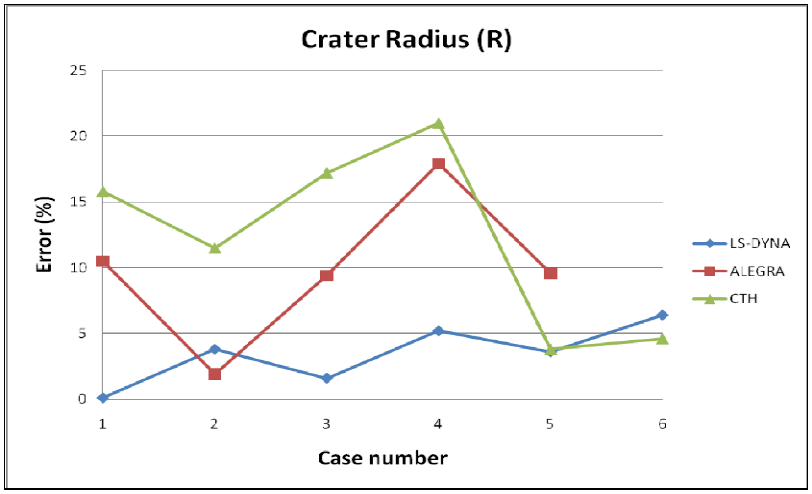


Figure 6 : % Error for Crater Radius

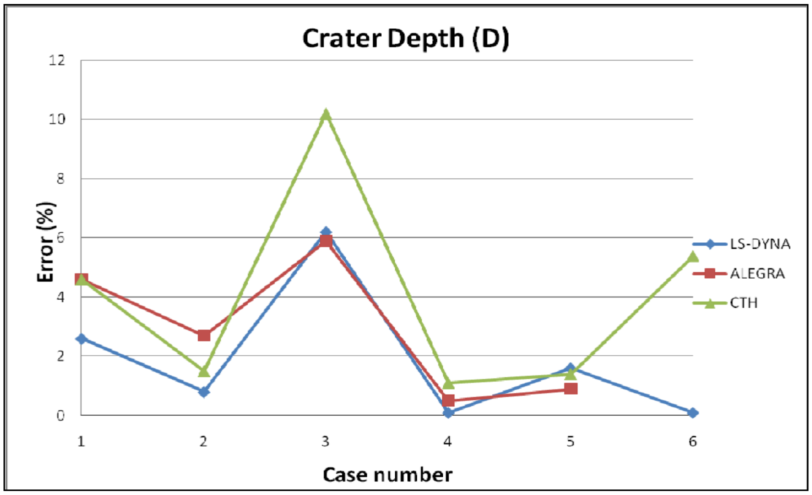


Figure 7 : % Error for Crater Depth

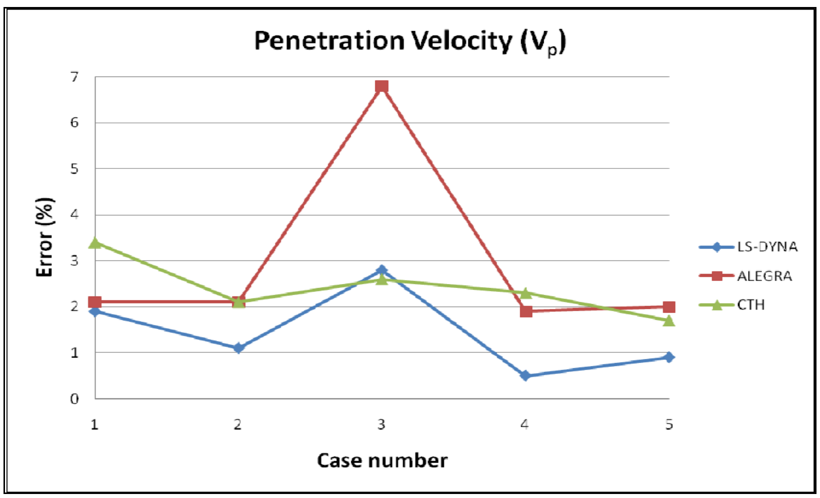


Figure 8 : % Error for Penetration Velocity

For a same simulation with same mesh size and equivalent parameters, LS-DYNA gets the same order accuracy than CTH and ALEGRA and even obtains better results for most parameters. The 2D ALE method of LS-DYNA seems to provide a unique regularity in simulation of long rod penetration.

Explosives in pure 2D MMALE

Explosive issues are more complex problems due to both large and fast deformations and shock waves, therefore it will be a perfect complementary contribution to the validation of this method. An Explosively Formed Projectile, a Shaped Charge Jet and an Air Blast study will be presented in the following part.

Explosively Formed Projectile

A steel case containing the explosive (LX-14) is covered with a copper lens. Explosive detonation leads to the formation of a copper nucleus propelled at very high speed. Figure 9 shows explosive pattern used in this study. LS-DYNA simulation results will be compared to experimental data and CTH results extracted from paper [4].

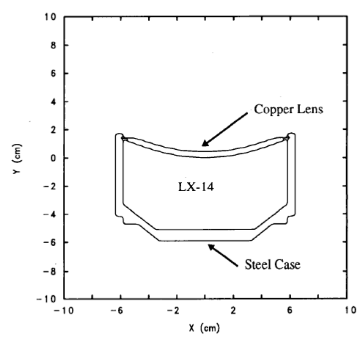


Figure 9 : Initial EFP configuration

A two-dimensional finite element model LS-DYNA has been developed for this EFP with a 2D axisymmetric Eulerian element formulation. This model is shown in Figure 10, background of the grid is filled with void. Void is modeled by *MAT_VACUUM. Metals are modeled by the association of *EOS_GRUNEISEN equation of state and *MAT_JOHNSON_COOK. Explosive is modeled with a JWL equation of state (*EOS_JWL) and a constitutive model *MAT_HIGH_EXPLOSIVE_BURN that were specifically created to reproduce explosive behavior.

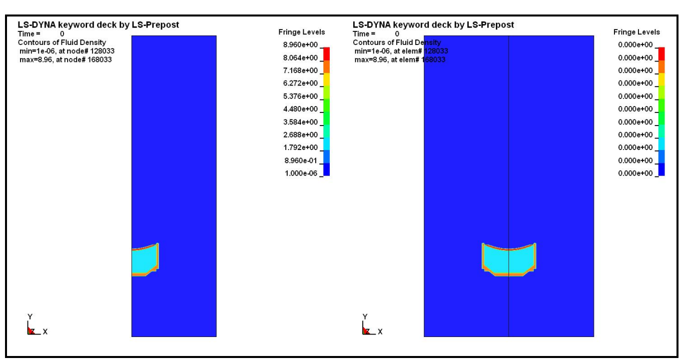


Figure 10 : Initial configuration of LS-DYNA model

After ignition at weapon base, a detonation wave travels the explosive. Steel case (because of its higher density) projects most of detonation energy to the copper lens. Effects are the steel case explosion and a copper lens motion with a speed of several km/s. Because of the initial lens curvature, center is set in motion with a higher speed than edges, leading to a nucleus formation with a very high kinetic energy. Figure 11 shows views of the LS-DYNA simulation at various stages of calculation.

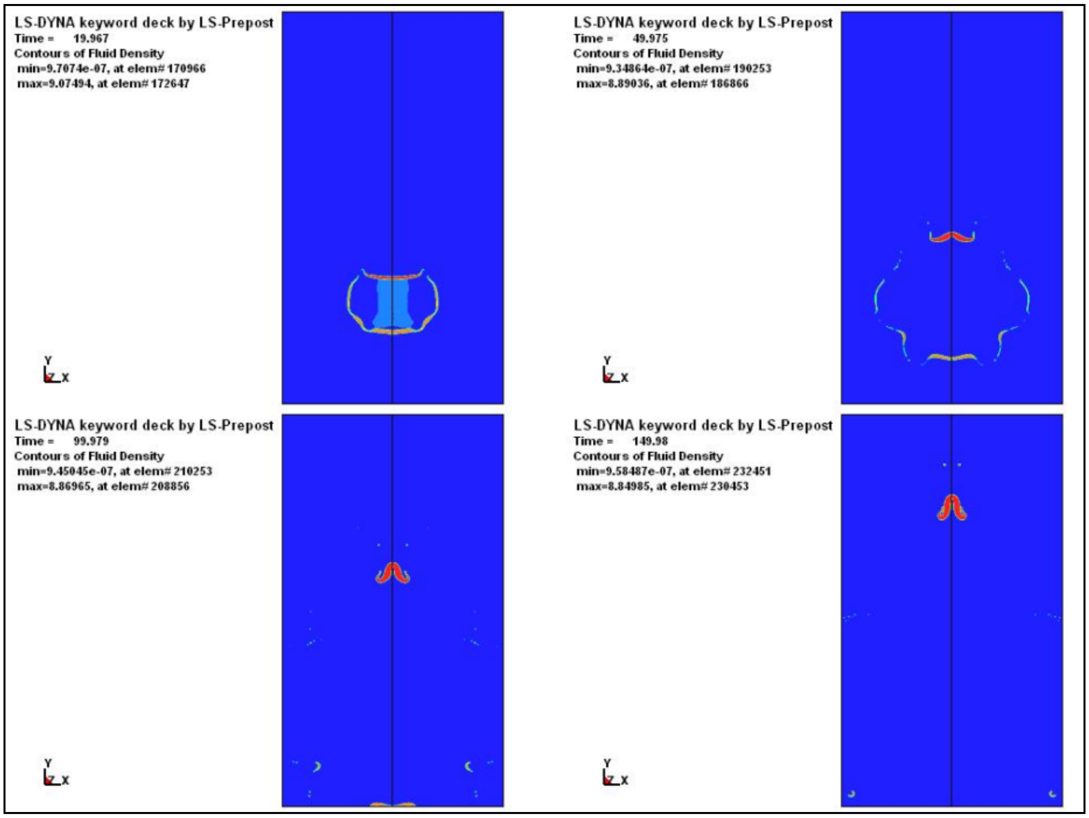


Figure 11 : Views of EFP at various steps of simulation

Firstly a qualitative comparison about nucleus shape at 200 µs is shown in Figure 12. The experimental picture is taken from the publication cited before [4].

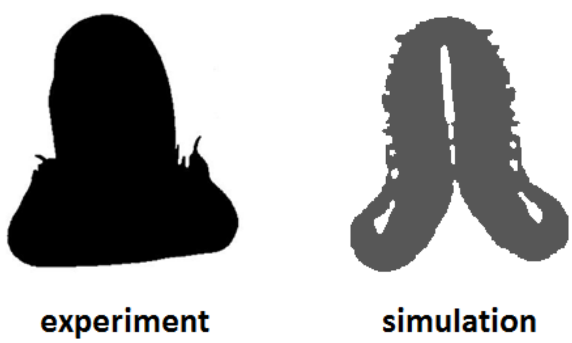


Figure 12 : Views of simulation and experiment final nucleus shape

The deformed shape obtained in the simulation is very close to experimental. But this is not enough to conclude on the ability of 2D ALE to perform EFP calculations, the nucleus size and velocity will also be compared with experimental values.

The comparative measurements carried out are:

- Velocity (V)
- Nucleus diameter (D)
- Nucleus length (L)

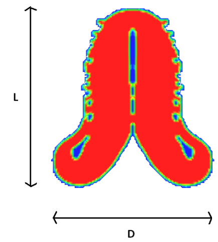


Table 3 presents % error compared to experimental results for the LS-DYNA simulation and CTH simulation.

Parameter	% Error CTH	% Error LS-DYNA
V	8.1	0.9
D	3.1	5.1
L	3.8	4.8

Table 3 : % error between simulations and experiments

Both programs provide acceptable results with errors globally below 10%. LS-DYNA provides really better results for velocity, and CTH gives slightly better results for nucleus geometry. As for impact issues, 2D ALE method of LS-DYNA also seems well suited for doing EFP simulations.

Shaped Charge

After EFP, the last study dealing with confined explosive is Shaped Charge Jet computation. This study requires more accuracy from the software because involved phenomena are more dynamic and metal deformation is faster than previously. Therefore, Shaped Charge Jet will help push a little further with 2D ALE method test in pure Euler.

The model presented in this study is based on a paper from Los Alamos National Laboratories ([5]). This paper contains experimental results and numerical results of a Shaped Charge performed with MESA-2D Eulerian code.

An aluminum case containing the explosive (Octol) is covered with a copper liner. The detonation of the explosive causes the formation of a thin jet of copper propelled to more than 1 km/s. Figure 13 shows initial configuration of the charge.

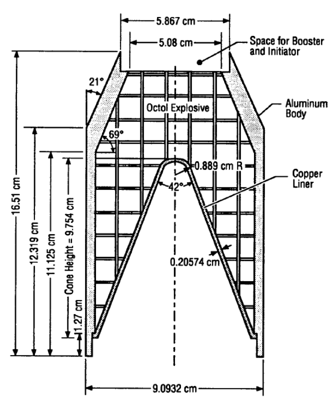


Figure 13 : Initial configuration of Shaped Charge

A two-dimensional finite element model LS-DYNA has been developed for this Shaped Charge with a 2D axisymmetric Eulerian element formulation. This model is shown in Figure 14, background of the grid is filled with void. Void is modeled by *MAT_VACUUM. Metals are modeled by the association of *EOS_GRUNEISEN equation of state and *MAT_JOHNSON_COOK. Explosive is modeled with a JWL equation of state (*EOS_JWL) and a constitutive model *MAT_HIGH_EXPLOSIVE_BURN that were specifically created to reproduce explosive behavior.

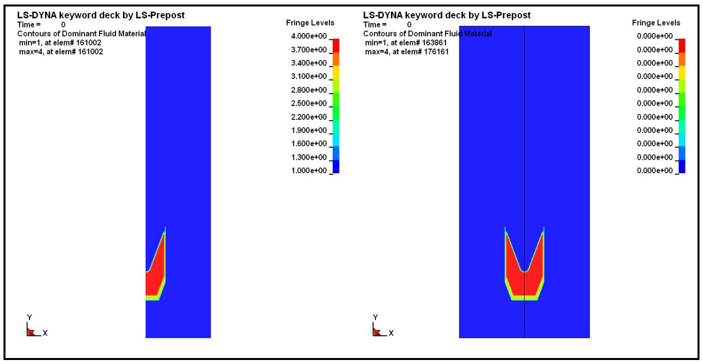


Figure 14 : Initial configuration of LS-DYNA model

After ignition at explosive base, a detonation wave travels the Shaped Charge. Aluminum case (because of its higher density) projects most of detonation energy to the copper liner. Then, the case explodes under detonation effect and the copper liner, due to its V-shape, creates a fine material jet with a speed of more than 1 km/s. Figure 15 shows views of the LS-DYNA simulation at various stages of calculation.

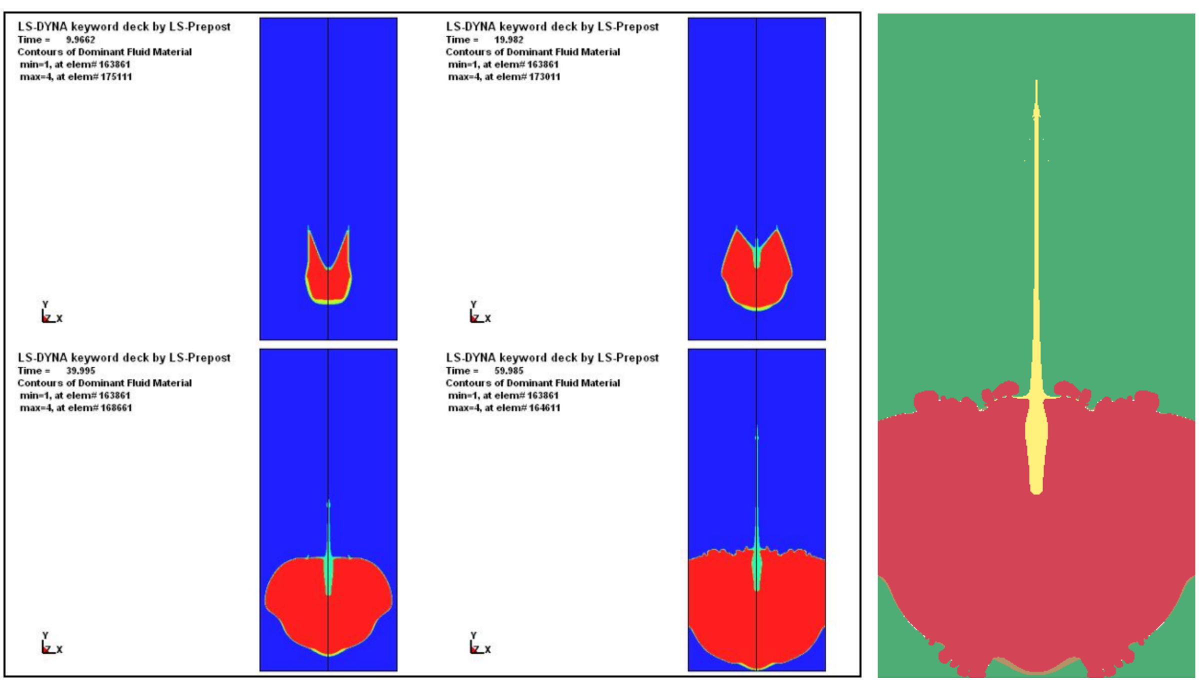


Figure 15 : Views of Shaped Charge Jet at various steps of simulation

From a qualitative standpoint, LS-DYNA gives a good final shape for this Shaped Charge. From a quantitative standpoint, measured parameter is the final velocity (V) at t = 200µs. Table 4 presents a comparison of results for MESA-2D and for LS-DYNA.

Parameter	% Error MESA-2D	% Error LS-DYNA
V	2.0	5.1

Table 4 : % error between simulations and experiment

MESA-2D is able to obtain results closer to the experiment. However, LS-DYNA also gives very good results with an error of about 5%. This value confirms good abilities of new 2D ALE method of LS-DYNA to perform explosive simulations in pure Euler.

Air blast

At last, an Air blast study was performed using Mapping technique from the charge initiation to the shock wave thread in air. This study is more specifically presented in another paper presented at this Conference: " A study of Mapping technique for Air Blast modeling ". Figure 16 presents an overview of this study.

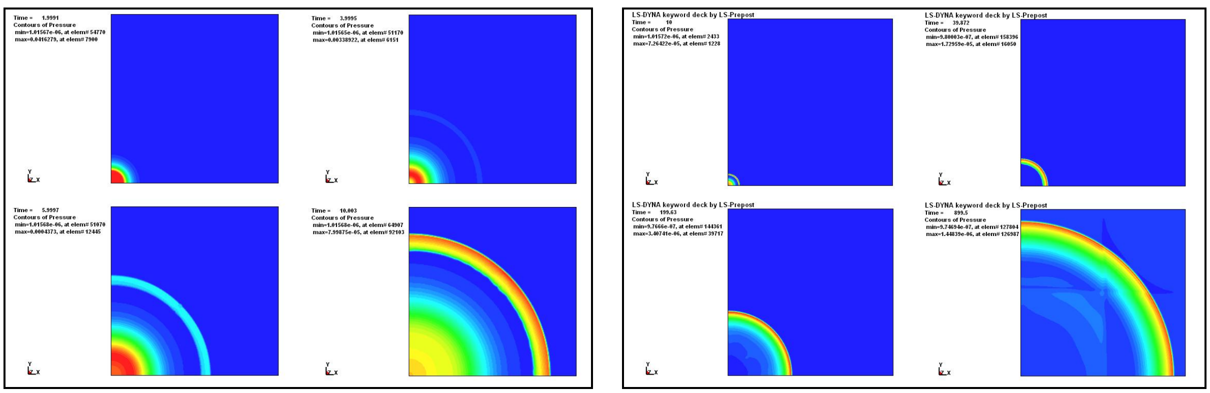


Figure 16 : Overview of Air Blast simulation

In the paper, Mapping technique is studied and LS-DYNA simulation results are compared to experimental data. These results show that we can obtain less than 5% error for the pressure peak with a reasonable CPU time. Another time, 2D ALE method of LS-DYNA seems to provide very good accuracy to do explosive simulations (see Figure 17 below).

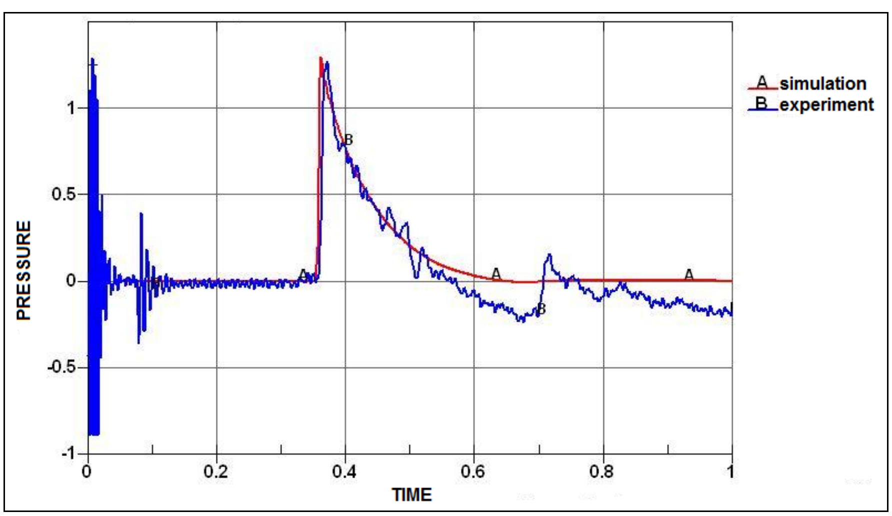


Figure 17 : Result example given by LS-DYNA on Air blast study

Conclusion

The new ALE 2D method of LS-DYNA seems to be particularly adapted to model fluids and very dynamic problems. Studies presented in this paper show that this method can model both impacts and explosive problems with a very good accuracy. Now, pure MMALE studies can be performed with a mesh length rarely reached before. Moreover, results given by LS-DYNA are as good as results obtained by referenced ALE codes such as CTH, ALEGRA and MESA-2D.

Acknowledgement

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