ALE/FSI AirBlast Modeling: On the Way to One Billion Elements

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1 Introduction

The *Arbitrarian Lagrangian Eulerian* (ALE) method of LS-DYNA® software is the best actual solution to perform AirBlast simulation. Indeed, thanks to its coupling method (ALE/FSI), it allows to the user to model complex blast waves interaction with Lagrangian structures.
Today, due to hardware advances (the computer power highly increased) and LS-DYNA technology enhancement (ALE Mapping, MPP), it becomes possible to consider models with a very large volume of air, while keeping a good accuracy with a small element size. These new possibilities lead to a quantity of elements never reached before, for which LS-DYNA and LS-PrePost® had to adapt.
In this paper, based on work realized with the help of LSTC, we will explain what exactly are the issues of modeling an ALE/FSI model with more than 100 million elements and what solutions were found. We will present some facilities to pre-process such a big model, like the new LS-PrePost “Long Format” or an innovative way to create ALE mesh using a new LS-DYNA keyword. We will also discuss about other important points concerning MPP decomposition, memory needs and post-processing, in order to give LS-DYNA users a complete overview of the ins and outs.

2 Model and Method Description

In the Defense field, people who probably need the most this capacity to reach several hundred millions of elements are the one working on buildings and structures. In fact, when you have to model a blast on a complete building with complex interactions and wave reflexions, if you expect to have an acceptable result, you are obliged to model a huge ALE grid with a very fine mesh.

To be able to perform tests on a realistic case, we modeled a complex ALE/FSI Model with all recent techniques. The case, prepared with the partnership of CEA Gramat (a French Department of Defense Engineering Center), is an air blast simulation with an interaction on a reinforced concrete Lagrangian wall. For confidentiality reasons, we will only present in this paper general information and method used (not all the exact dimensions and no results).

In this chapter, after a presentation of the model, the method (ALE/FSI with 1D to 3D Mapping technique) will be explained.

2.1 Model Description

The test case presented here is composed on two parts:
- An explosive of 50 kg situated at 3.6 meters up to middle of the slab.
- A concrete slab with a thickness of 10 cm, reinforced by two square meshes of longitudinal rebars on each side and transverse rebars.

This test is modeled by a 3D quarter model; the goal is to use two symmetry planes to reach a very good accuracy without forcing a distortion mode.

The blast is modeled in Arbitrarian Lagrangian Eulerian (ALE) using an **`*EOS_JWL`** and a **`*MAT_HIGH_EXPLOSIVE_BURN`**, the rest of the grid is filled by air (**`*MAT_NULL`** and **`*EOS_LINEAR_POLYNOMIAL`**).

Concrete is modeled by under integrated constant stress solid element (one integration point per volume) with a ***MAT_WINFRITH_CONCRETE** law. The slab is blocked all around with *BOUNDARY_SPC and a stiffness hourglass is defined for concrete elements. Reinforcements are modeled by Hugues-Liu with cross section integration beam elements. The mesh ratio between slab and reinforcement element size guarantees a good behavior during the simulation.
The constitutive law of steel elements is a ***MAT_PIECEWISE_LINEAR_PLASTICITY** able to model the behavior of steel with a complex plasticity curve and to include strain rate effects. Engineer values are changed into true values up to striction and then interpolated using a swift law.
Rebars are not merged to the concrete elements; the interaction is modeled by a coupling method based on a constrained approach. Junctions between two longitudinal rebars are merged.

The interaction between the blast wave and the concrete slab is realized by a penalty coupling method using ***CONSTRAINED_LAGRANGE_IN_SOLID**.

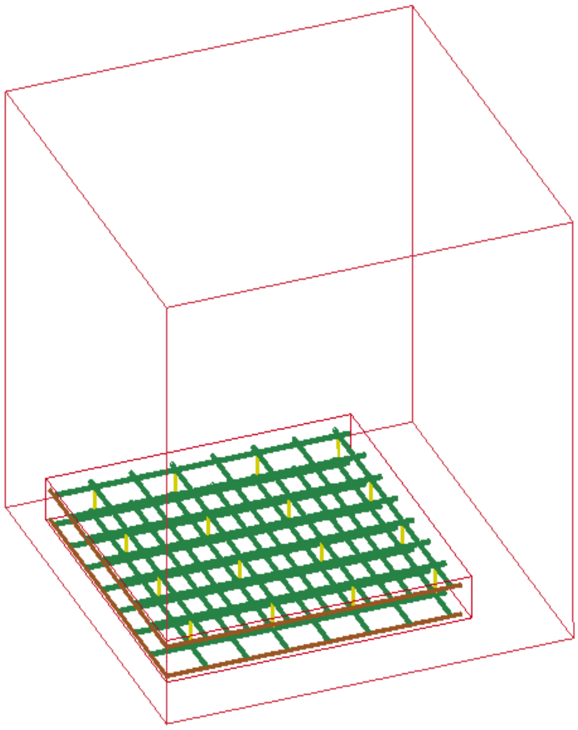

Fig.1: Reinforced concrete slab and ALE Mesh around.

2.2 Method Description

In order to obtain the most accurate result, recent modeling techniques have been performed in this model.
To have a quite perfect spherical blast wave, we chose to model the blast initiation and the propagation of the blast wave until the slab on a 1D pure Eulerian model.

When the blast wave arrived very close to the slab, we realized a mapping 1D to 3D to create a full and well shaped 3D spherical wave. Then this blast wave reflected on the slab, sollicitating it in flexion, and creating cracks.

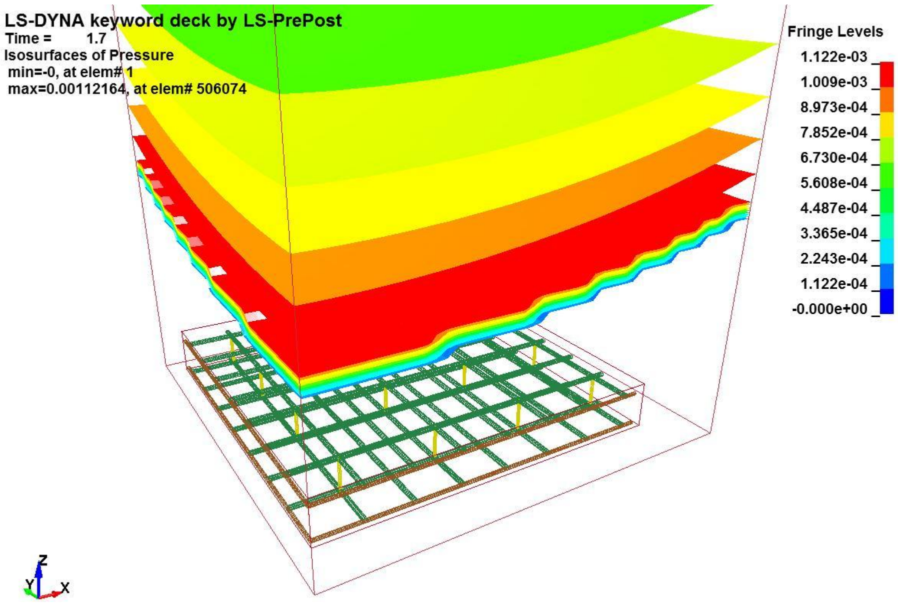

Fig.2: Blast wave before interaction with the concrete slab.

3 Problems and... Solutions

The chosen case would present no major difficulties if we did it with a “normal” quantity of element, but here, we tested it with three different mesh sizes leading to three big models:

- 50 Millions of elements,
- 100 Millions of elements,
- 200 Millions of elements.

The following chapter will explain difficulties encountered in preparing, running and post-treating such big models and what were the solutions found in collaboration with LSTC (some of them are still in discussion).

3.1 Model Creation

The first problem encountered in this study was: How can LS-DYNA users create easily meshes of several millions of elements?

Firstly, we started with the obvious way to create our models, we used LS-PrePost. In 3D, we used the “Shape Mesher” of LS-PrePost to create the 1 m^3 ALE grid able to perform the Fluid / Structure interaction with the concrete slab. So, we created and saved the 50 Millions elements model without problems but when we tried to save 100 Millions elements model, we failed because the element and node IDs were too long.
In fact, if you define a model with more than 100 000 000 of elements, you need a field with more than 8 columns (the max ID with 8 columns is 99 999 999).

```
*NODE
$#   nid               x               y               z      tc      rc
99999999           0.000           0.000           0.000       0       0
```

Fig.3: Maximum ID with 8 columns field is 99 999 999.

LSTC developed a special option in LS-PrePost to allow the user to save an input file with more than 100 Millions elements. This option is called “Long Format” and is available in the “save” panel.
This option has the effect of saving the file with 16 columns per field instead of 8, and LS-DYNA is then able to read and run well the model.

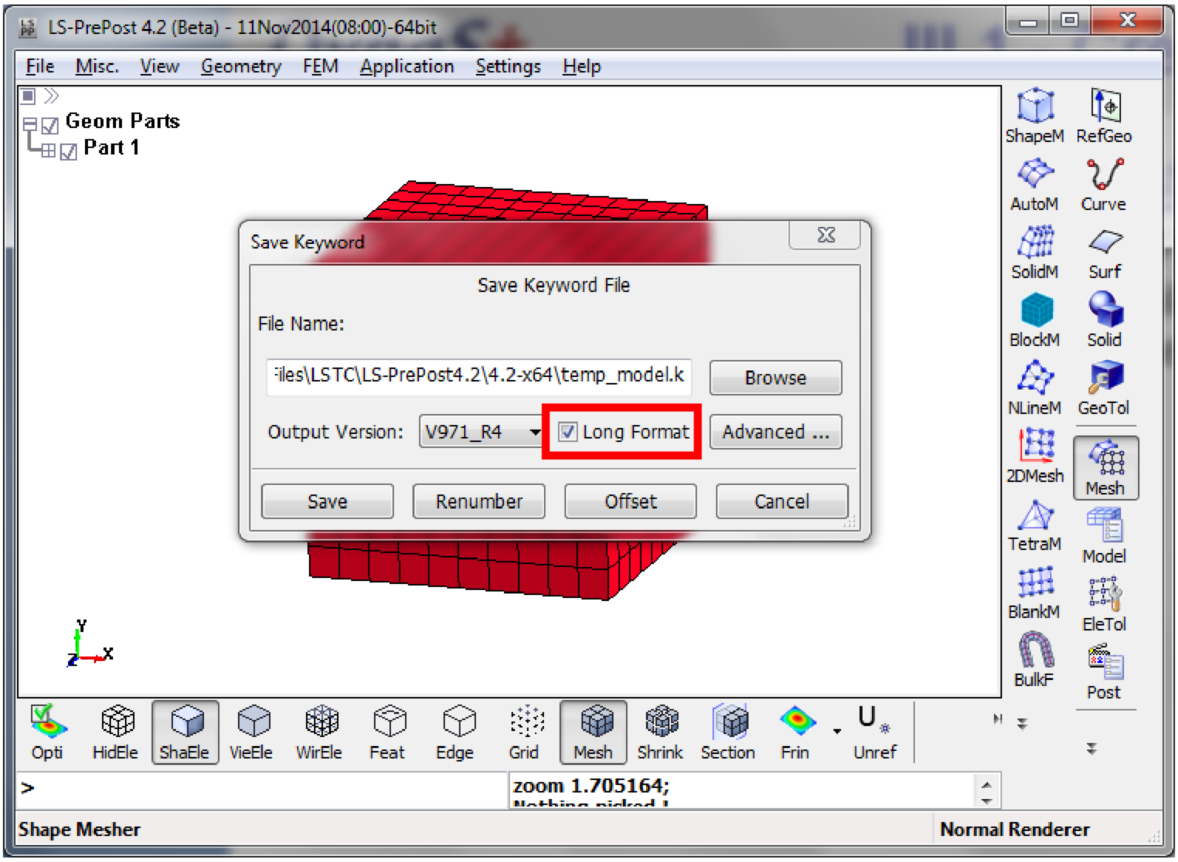

Fig.4: "Long Format" option in LS-PrePost

This option is a good answer to the problems encountered during big model creation, but it remains a major problem: create such a big mesh is very long.

To bring a real answer to this problem, we had the idea to take advantage from the simplicity of ALE Meshes. In fact, in ALE models and especially in blast calculation (pure Euler model), the grid is a box meshed by perfect cubes. Because it is very simple to create such a mesh, LSTC developed a new keyword called **`*DEFINE_MMALE_MESH`**, containing a topology mesher similar to the one in the "BlockMesher" option of LS-PrePost.

***DEFINE_MMALE_MESH**

Purpose: This keyword generates structured 3D mesh for Multi-material ALE (MMALE) solver.

> This keyword requires a 3D ALE formulation. It is, therefore, incompatible with parts defined using *SECTION_ALE2D or *SECTION_ALE1D.

Fig.5: New keyword ***`*DEFINE_MMALE_MESH`***

This new keyword can make LS-DYNA create the ALE grid using index values (i, j, k) and position values. In each direction, the user has to define at least 2 indexes that define a zone; the position of this zone is defined by other position values, and the number of elements in the zone is defined by the difference between index values.

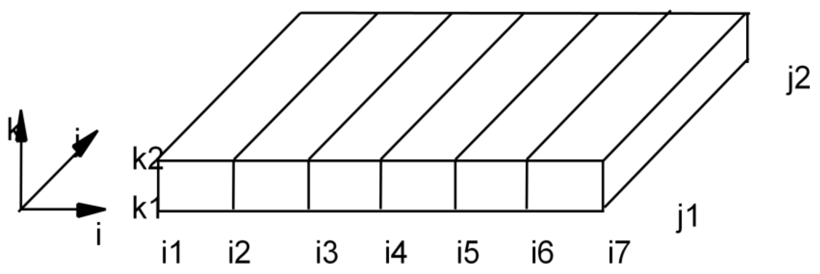

*Fig.6: Index values used in *DEFINE_MMALE_MESH*

This new keyword only creates elements and nodes, the user can choose to which part these elements belong. And of course, the user has to create himself all other keywords necessary to the ALE calculation (**`*PART`**, **`*MAT`**, **`*EOS`** and ***`ALE_MULTI_MATERIAL_GROUP`**).

3.2 Model Running and Post-treatment

After the creation of these three models (50 Millions, 100 Millions and 200 Millions of elements), LSTC ran them using official MPP R7.1.1 LS-DYNA double precision version on a cluster equipped with Intel(R) Xeon(R) CPU E5-2680 0 @ 2.70GHz. Three runs (32, 64 and 128 CPUs) by model were made to test Elapsed Time and scalability. The following table presents results of Elapsed Time for all runs.

Number of Elements	NCPU	Elapsed Time
50M	32	26 h 10 min
50M	64	15 h 22 min
50M	128	9 h 59 min
100M	32	41 h 30 min
100M	64	21 h 26 min
100M	128	11 h 47 min
200M	32	86 h 10 min
200M	64	59 h 59 min
200M	128	35 h 48 min

Table 1: Elapsed Time of all runs

We can see in these results that LS-DYNA is able to perform a 200 Millions model in only 36 hours in 128 CPUs. The scability seems good too because it is close to 1. These results are promising, because it seems possible to make a run with a lot of elements in one week-end.

However, a problem remains at this step: the MPP decomposition. In fact, despite an effort made LSTC in the code, the decomposition of the 200 Millions elements model took more than 300 Go of memory, which is probably too much for an industrial use.

Another problem appears too after the run, it concerns the post-treatment of such a big model. The run of the biggest model created several d3plot of 38 Go each, and find a computer to do the post-treatment of this is not easy.

To face this post-treatment problem, several solutions are considered and discussed with LSTC:

- Improve parallelization of LS-PrePost to facilitate the opening of very big d3plot,
- Create reduced d3plot (or other format) with for example only AMMGs positions and pressure (for blast).
- Create a different output format easier to post-treat with other post software.

At the moment, the only fast solution we have is to use d3part to create a d3plot of the entire model excepted the ALE grid. The post-treatment of ALE parts can be made by lots of tracers put in the model, and d3plots are used to make post-treatment of the Lagrangian parts.

4 Summary

This paper presented the actual ability of LS-DYNA to perform ALE / FSI models of several hundred Millions of elements. Taking the example of a blast calculation with interaction of the blast wave with a concrete wall, we tried to show the possibilities and difficulties of LS-DYNA to make such studies.

For the creation of big ALE models, a lot of improvements have been made by LSTC to help the user. In LS-PrePost, a “Long Format” has been created to be able to save models containing more than 100 Millions of elements. In LS-DYNA, a new keyword has been created to create the ALE mesh at the beginning of the calculation.
Performing some tests in MPP, we showed that LS-DYNA is perfectly able to run these models in a very reasonable time, even if a difficulty remains concerning decomposition (amount of memory too large for the moment). Concerning post-treatment, some work still need to be done on output format to make easier results using.

To conclude, setting up a 1 billion ALE / FSI model is headed in the right direction, LSTC and DynaS+ are hardly working on potential solutions that could resolve all problems, for example doing the mesh and decomposition in the same time and creating reduced output data.

5 Literature

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