A Review of S-ALE Solver for Blast Simulations

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Abstract

Blast modeling and simulation is a very important field in the military land vehicle industry. Increasing demands for higher protection levels leads the engineers to more challenging design and simulation cases. In most situations, Arbitrary Lagrange Euler (ALE) method is the most well-known method for blast simulations and also for determining the effects of blast loads on structures. Various studies are performed for the effect of mesh size and the domain shape for traditional ALE solver of LS-DYNA. The newly implemented S-ALE solver is stated to give shorter simulation times and also less memory requirements using the advantage of structured mesh. In this work, the S-ALE solver is compared to the traditional ALE solver for mine blast in steel pod. Different mesh sizes and advection methods are used for comparison. In addition to the displacement, momentum and deformation pattern, the solution times and memory requirements are also examined. Fluid-structure interaction (FSI) performance for solid interfaces is reviewed, as well.

1 General Introduction

Blast simulations take a great portion of the design of armored military vehicles. Determining the deformations on the main structure and the human response are critical issues in military industry. Previous studies are performed for comparison of simulations with the field tests and increasing the accuracy in the simulations [1-2]. In those studies, small scale models are used both in simulations and tests. For the full scale vehicle simulations, larger ALE domain and finer ALE mesh are needed in order to capture the interface forces and hence estimating the impulse more accurately. Larger ALE domain means higher computation times and higher memory requirements. This brings challenges in supporting the projects within the schedule and also hardware investment.

The S-ALE solver implemented recently is stated to reduce the solution time and the memory requirements [3]. It also brings simplicity in defining the ALE domain with a couple of keywords. Since there is no external mesh generation requirement, it also reduces the keyword sizes of ALE domain from gigabytes to a few kilobytes.

2 Blast in Steel Pod

The validation of military vehicles against mine blast is defined in relevant standard [4]. In this document, two alternative blast testing methodologies are defined. The one that is used in this work is the steel pod case, where the soil effects are eliminated and only the effect of explosive plays role in the deformation of structure. The pod geometry is shown in figure below.

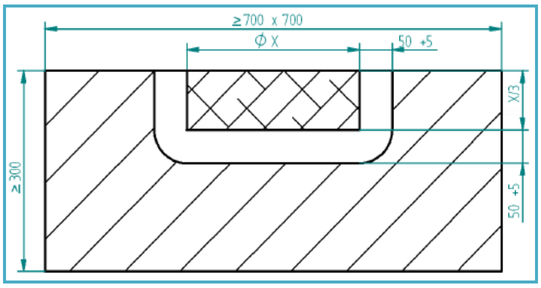


Fig.1: Steel pod specifications [4].

For buried charge, the reference explosive is stated as TNT [4]. However, for blast in steel pod, the explosive is stated as PETN or C4 with their TNT equivalents. In this study, 6 kg TNT equivalent PETN is used and mass of the explosive is given as 5.04 kg [4]. The explosive parameters are taken from literature [5].

3 Model Information

For the impulse comparison of traditional ALE solver and S-ALE solver, the impulse on a rigid plate is examined with different mesh sizes of ALE domain. For consistency of the fluid structure interaction, the rigid plate is also meshed with the same size of elements as the ALE domain. The general view of the model is shown in figure below.

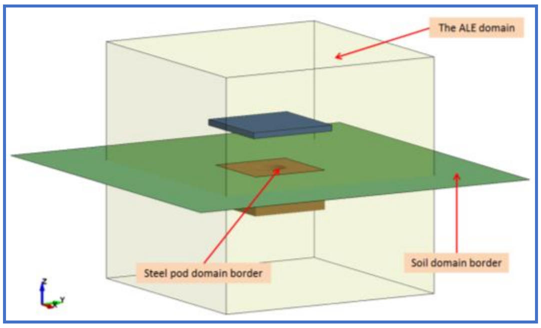
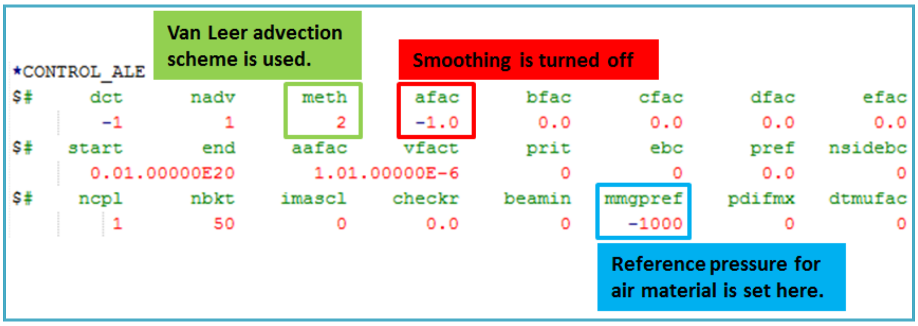


Fig.2: General model view.

The materials in the ALE domain if filled with **`*INITIAL_VOLUME_FRACTION_GEOMETRY`** keyword using appropriate parameters. The domain is fixed from the bottom in the Z direction with the keyword **`*BOUNDARY_SPC_SET`** and this set is generated by using **`*SET_NODE_GENERAL`**. The coupling of ALE domain with the structure is established with **`*CONSTRAINED_LAGRANGE_IN_SOLID`** keyword. Before doing the final simulations, some trials are performed to optimize the coupling parameters in order to prevent leakage.

For S-ALE solver, the new keywords, which are implemented in R9 release of LS-DYNA®, **`*ALE_STRUCTURED_MESH`** and **`*ALE_STRUCTURED_MESH_CONTROL_POINTS`** are used [3]. It is stated that the current implementation of S-ALE solver supports only the Donor Cell (1st order) and Van Leer (2nd order) advection methods. For rigid plate impulse comparison and deformable plate impulse comparison, only Van Leer advection scheme is used. For the simulations without a target plate, hence no fluid structure interaction, both methods are examined.

The air is modeled with **`*MAT_NULL`** and **`*EOS_LINEAR_POLYNOMIAL`** with the values that can be found easily in the literature and also from previous blast simulation studies. The explosive is modeled with **`*MAT_HIGH_EXPLOSIVE_BURN`** and **`*EOS_JWL`**. The necessary parameters are taken from [5]. The steel pod is modeled with **`*MAT_SIMPLIFIED_JOHNSON_COOK`** but there is no deformation on the pod as it expected by the experience from observations in field tests. The **`*CONTROL_ALE`** card used in the simulations is shown below.



Van Leer advection scheme is used.

Smoothing is turned off

```
*CONTROL_ALE
$#       dct      nadv      meth      afac      bfac      cfac      dfac      efac
          -1         1         2      -1.0       0.0       0.0       0.0       0.0
$#     start       end     aafac     vfact      prit       ebc      pref   nsidebc
         0.01.00000E20         1.01.00000E-6         0         0       0.0         0
$#      ncpl      nbkt    imascl    checkr    beamin   mmgpref    pdifmx   dtmufac
           1        50         0       0.0         0     -1000         0         0
```

Reference pressure for air material is set here.

Fig.3: ALE parameters used in the simulations.

All the simulations are performed with LS-DYNA® R9.1 (SVN 113698) MPP version. Intel® MPI is used in the studies and 40 cores are used in all simulations. In one case, which is 10 mm meshed ALE domain, the memory requirements of traditional ALE solution made us to use double precision version. In the rest of the simulations single precision version of LS-DYNA® is used.

4 Simulation Results for Rigid Plate

The interface forces comparisons of traditional ALE solver and S-ALE solver for different mesh sizes are shown in figure below.

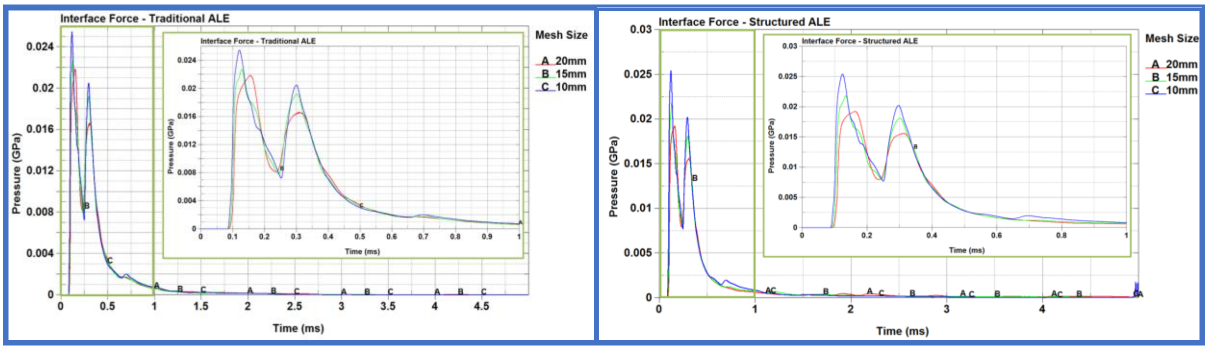


Fig.4: Interface pressures for traditional ALE solver and S-ALE solver.

By looking at the figure one can conclude that as the mesh size decreases, the interface pressure converges to a peak value and the sharpness of the peak is also increasing. The total comparison of the two methods is shown in the figure below.

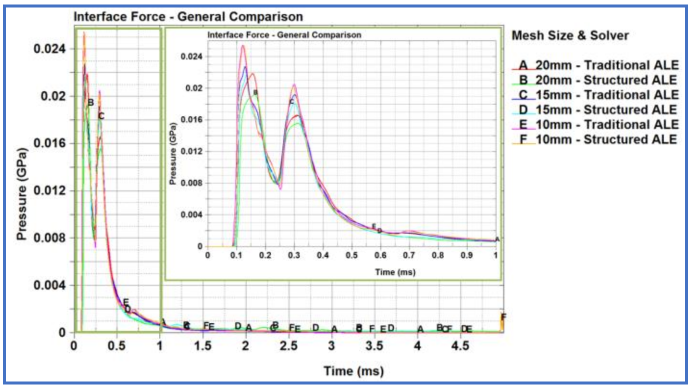


Fig.5: Comparison of the two methods.

When the figure above is examined, it can be seen that as the mesh size decreases, the interface forces become closer between to methods. When the mesh size is higher, traditional ALE gives higher interface forces. This situation also affects the momentum transferred to the target plate. Only when 10mm mesh size is used, the momentum results are close for traditional ALE and S-ALE which is shown below.

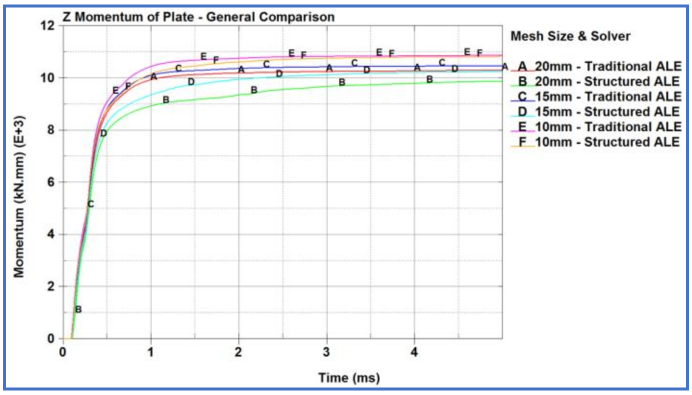


Fig.6: Momentum comparison for the target plate.

It is stated that the S-ALE solver reduces the completion time of the simulation when compared to the traditional ALE method [3]. However, when the simulation times are compared, as the mesh size is decreasing the traditional ALE gives smaller simulation time than the S-ALE.

Mesh Size	Traditional ALE	S-ALE	Ratio
20mm	8540s	7242s	0.848
15mm	18959s	20802s	1.097
10mm*	82582s	144149s	1.745

Table 1: Elapsed time comparison (double precision is used).*

The memory requirements (memory required to complete solution reported in d3hsp file) are also compared and the results are presented in the table below.

Mesh Size	Traditional ALE		S-ALE		Ratio	
	memory	***memory2***	***memory***	***memory2***	***memory***	***memory2***
20mm	329M	23M	74M	21M	0.225	0.913
15mm	762M	50M	164M	44M	0.215	0.880
10mm*	2494M	149M	533M	132M	0.213	0.885

Table 2: Memory requirements for simulations (double precision is used).*

When the solution time steps are investigated in detail, it is found that the S-ALE solver time steps are decreasing during the simulation. For all cases, the time step is defined with LCTM parameter in **`*CONTROL_TIMESTEP`** keyword as 0.1 microseconds. The TSSFAC parameter in the same keyword is taken as 0.5. The time step comparison is shown in figure below.

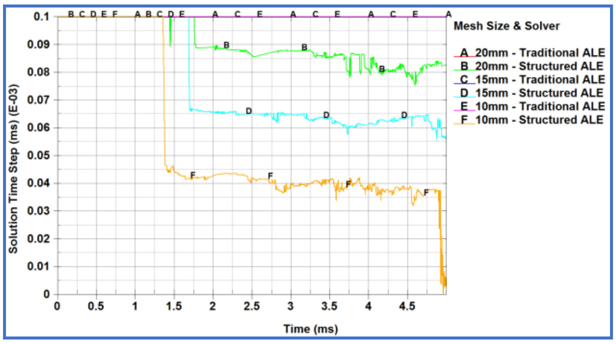


Fig.7: Time steps during the simulations.

After observing this situation, the air internal energy in all simulations is compared to check if there is an abnormality in the trend of energy. By experience it is known that, having very low density and high compressibility, air is a challenging material in blast simulations especially when there is a structure coupling with air.

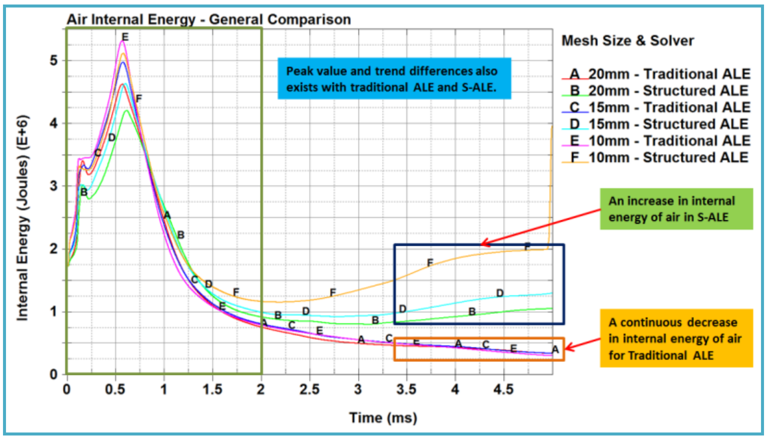


Fig.8: Internal energy comparison of Air material.

Although exactly the same parameters are used for traditional ALE and S-ALE, there is a significant difference in the internal energy trend of the air. Several trials on different parameters were made to eliminate this difference but it still remains. When the volume fraction of the explosive is examined, the difference can be observed. The volume fraction for the explosive are shown in the table below.

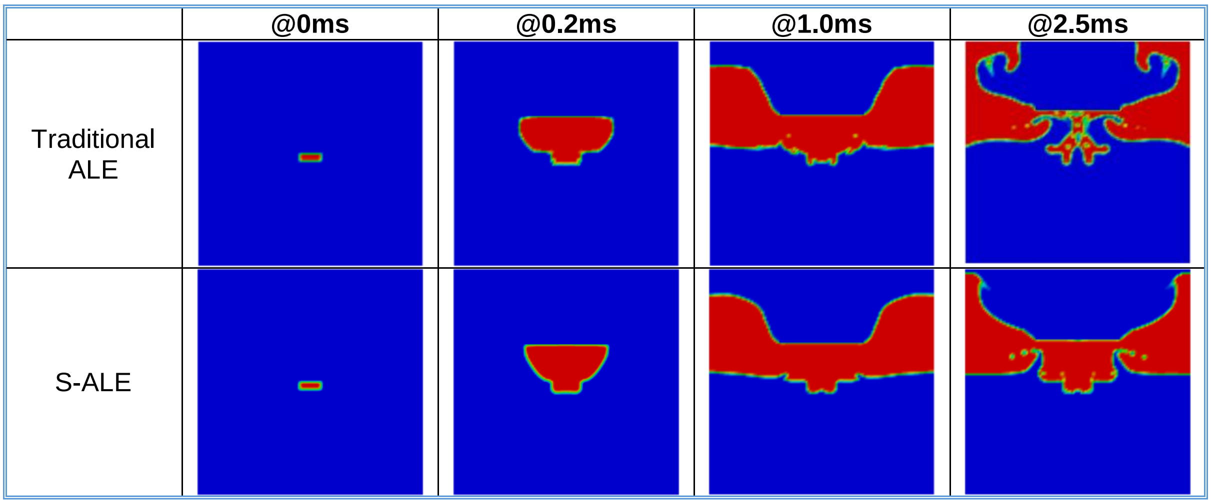


Fig.9: Volume fraction of explosive.

5 Simulation Results for Deformable Plate

The deformable plate simulations are only performed with 20mm mesh to see the difference between traditional ALE and S-ALE. The behavior is very similar to the simulations performed with rigid plate. The time step in the traditional ALE solution seems to be constant, but in S-ALE solution after some time it starts to decrease. This situation eliminates the advantage of S-ALE solver from the point of solution time. The momentum results are also different in deformable plate simulations.

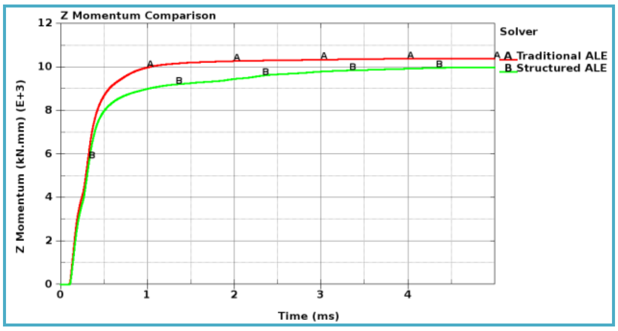


Fig.10: Z momentum in deformable plate.

The distribution of volume fraction of explosive is very similar with the one shown for rigid plate simulations. For this purpose, the pressure distributions are compared for the deformable plate case and shown in figure below.

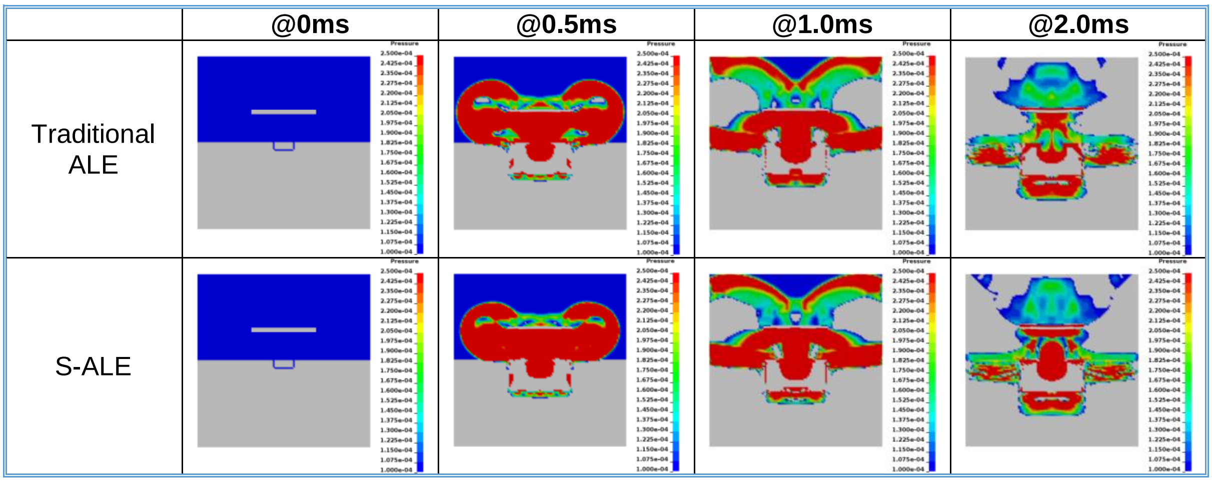


Fig.11: Pressure distributions for simulations with deformable plate.

6 Simulation without Target Plate

After the findings in previous sections, two successive simulations are performed with both methods without using the target plate, hence eliminating the effects of FSI. In these simulations, both Donor Cell and Van Leer advection methods are tested. For all simulations, 20mm meshed model is used. The total energy comparison of the simulations is shown in the figure below.

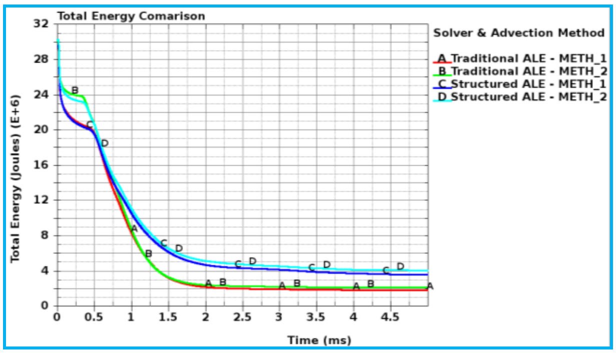


Fig.12: Total energy comparison

As it can be seen from the figure above, there some differences in the trend of the total energy and in the final value, as well. The different advection methods seem to have similar trend for both traditional ALE and S-ALE. For a detailed investigation, the explosive kinetic energy, steel pod internal energy and air internal energy are also compared, respectively. Comparisons are shown in the figures below.

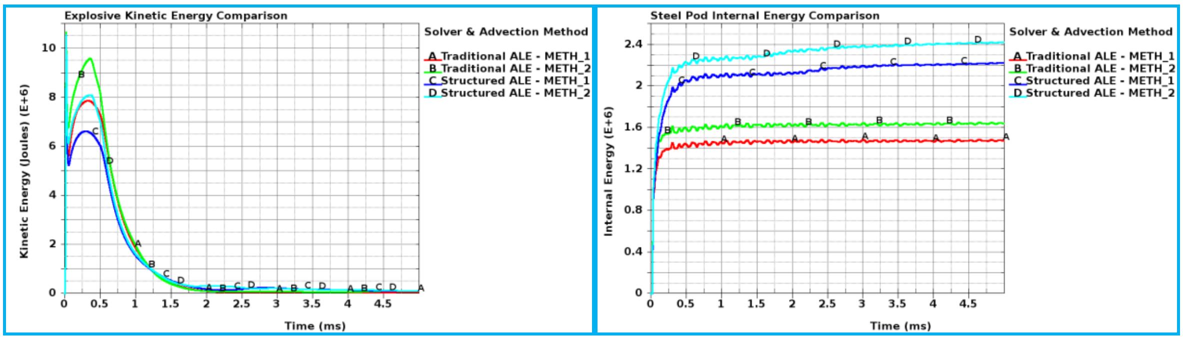


Fig.13: Explosive kinetic energy and steel pod internal energy comparison.

In the figure above, one can note that the kinetic energy of the explosive has similar trends when traditional ALE and S-ALE are compared. Also, the trend in the difference between advection methods are again similar. However, when the same advection method is compared for traditional ALE and S-ALE, the peaks are different although the trends seem to be similar. A similar behavior is also observed in the internal energy for the steel pod. The air internal energy trend has also some differences as shown in figure below.

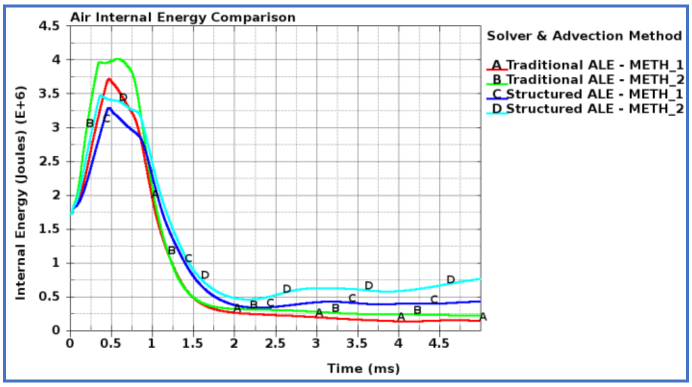


Fig.14: The air internal energy comparison.

Pressure distribution and the volume fraction of the explosive are also investigated and some differences are observed between traditional ALE and S-ALE. The pressure distributions and volume fractions are shown in figures below.

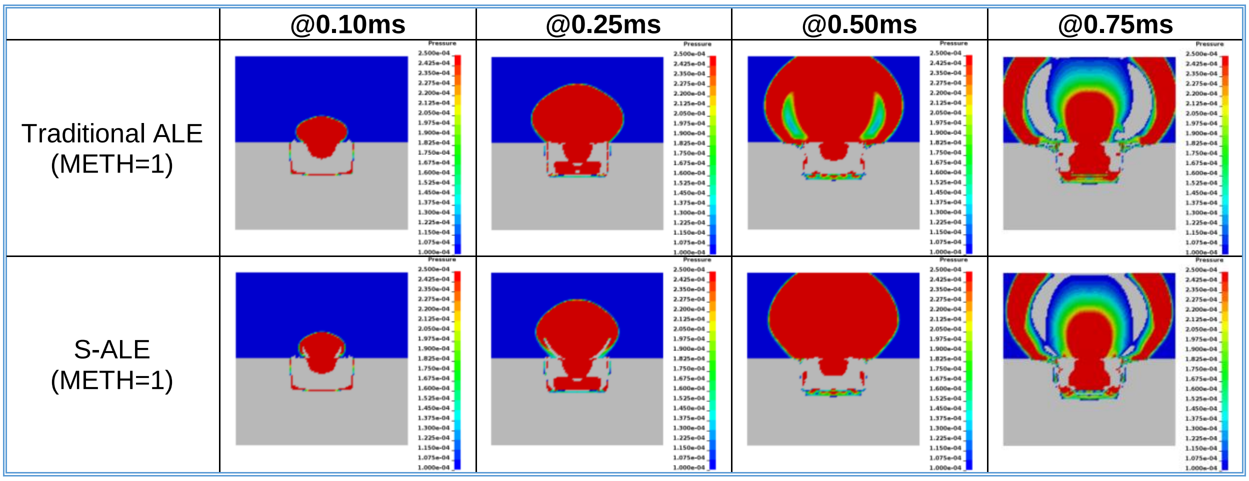


Fig.15: Pressure distribution for Donor Cell advection scheme.

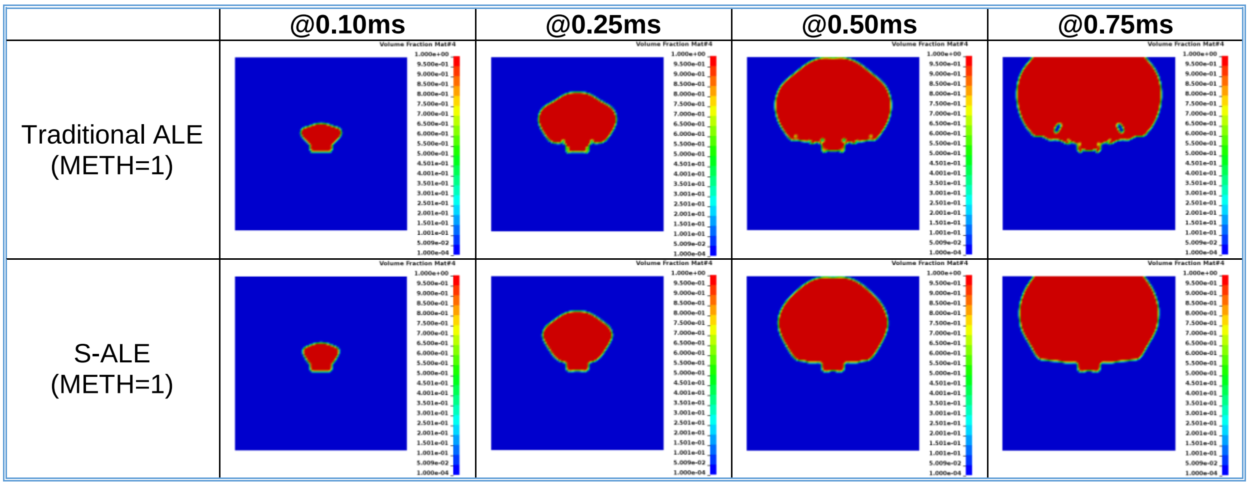


Fig.16: Volume fraction of explosive for Donor Cell advection scheme.

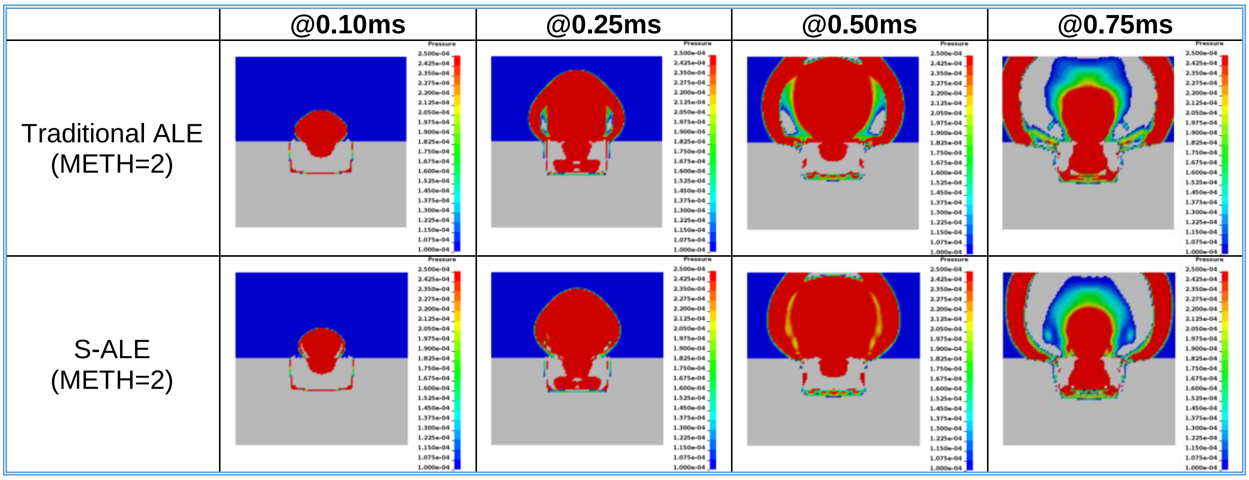


Fig.17: Pressure distribution for Van Leer advection scheme.

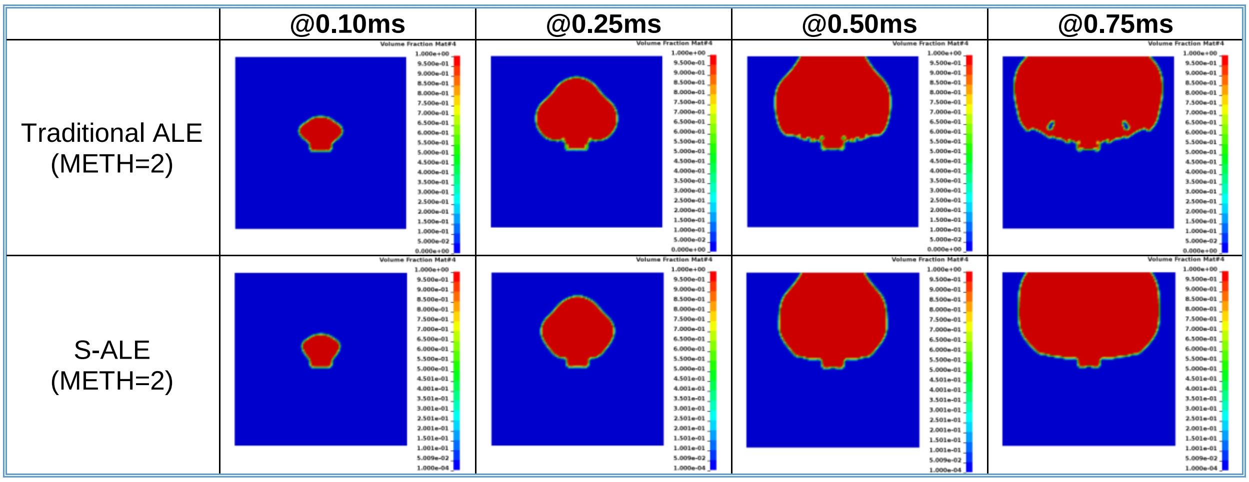


Fig.18: Volume fraction of explosive for Van Leer advection scheme.

7 Summary

In this work, a comparison between the traditional ALE method and recently implemented S-ALE method is performed for mine blast in steel pod case. It is stated that S-ALE solver has much less memory requirements than the traditional ALE and also have smaller simulation times in the identical models. However, due to the differences in advection, air and explosive behavior, the time step decreases during the simulation with S-ALE and this cause the extension of total simulation time except 20mm mesh configuration. When the memory requirements are compared, it is definitely obvious that the S-ALE requires less memory than the traditional ALE since there is no ALE mesh and hence no keyword to read and process.

The reason for time step decrease cannot be determined for S-ALE. When the pressure distribution and volume fractions are examined, differences between traditional ALE and S-ALE can be seen easily. For convenience, the traditional ALE model is tried to be solved by LS-DYNA® R7.1.3 (SVN 107967) version but the time step suddenly decreased after the explosion and the simulation is terminated with error. Hence, no comparison can be made between the versions R9.1 and R7.1.3 for traditional ALE.

In general, METH=-2 is used in blast simulations and METH=3 is also tried. However, since the S-ALE is only implemented currently for Donor Cell (METH=1) and Van Leer (METH=2) advection schemes, no comparison can be made using the former advection methods.

8 Literature

[1] Kurtoğlu İ., Salihoğlu B., Tekin G., Taşan C., Validation of Mine Blast Simulations with Field Tests, 9th European LS-DYNA Users Conference, Manchester, UK, 2013.

[2] Kurtoğlu İ., An Assessment of ALE Mapping Technique for Buried Charge Simulations, 10th European LS-DYNA Users Conference, Wurzburg, GERMANY, 2015.

[3] Chen H., LS-DYNA® Structured ALE (S-ALE) Solver, 14th LS-DYNA International Users Conference, Detroit, MI, USA, 2016

[4] AEP-55, Procedures for Evaluating the Protection Level of Armoured Vehicles Volume 2. November 2010.

[5] Dobratz P.M., Crawford P. C., LNLL Explosives Handbook – Properties of Chemical Explosives and Explosive Stimulants, 1985, Lawrence Livermore National Laboratory.

[6] LS-DYNA® Keyword User’s Manual Vol. I (R9.0), Livermore Software Technology Corporation, 2016.