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Comparative Study Using LS-DYNA ALE & S-ALE Methods for under body Mine Blast Simulations

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Full-vehicle, End-to-End Underbody Blast (UB) simulations with LS-DYNA ALE (Arbitrary Lagrange-Eulerian) method have been common practice at the Tank Automotive Research, Development and Engineering Center (TARDEC) for the last several years to support Program Managers in the Army Acquisition and Science & Technology (S&T) Community of military ground vehicles. Although the method has been applied extensively and successfully, the demand for reducing the simulation time has been very high. Very recently a new method, Structured ALE (S-ALE), was developed in LS-DYNA by taking advantage of structured mesh to speed up the calculation time. In this paper several case studies for underbody mine blast simulations were analyzed by both ALE and S-ALE methods. The comparative results show the new method is very promising in improving the simulation time as well as the Massively Parallel Processing (MPP) scalability.

INTRODUCTION

LS-DYNA [1] ALE (Arbitrary Lagrange-Eulerian) method, coupled with its embedded fluid-structure interaction, aims to solve a series of transient engineering problems characterized by large momentum and energy transfer between Lagrange structures and ALE fluids. It employs a multi-material formulation which models multiple species of fluids in the ALE mesh. Its versatile fluid-structure interactions module couples fluids and structures together and accurately predicts the structure response. The multi-material capability, together with its embedded coupling to structures, has been utilized by users from various engineering application areas such as mine explosions [2-4] missile penetrations in defense industries, tank sloshing, hydroplaning in auto industries and container dropping, bird strikes in other civil/aerospace industries.

The computational Underbody Blast (UB) modeling and simulation with LS-DYNA ALE has been used in military ground vehicle acquisition, design and development for several years and has helped engineers to develop vehicles with improved occupant survivability, and assisted Program Managers to select appropriate technology in its acquisition even before live fire tests. The current UB modeling and simulation processes and tools used in the Department of Defense agencies and its contract industry partners are relevant and effective, but have some limitations. It is not uncommon for a full vehicle model to take from one to several weeks to complete one analysis. Therefore the demand for a quicker solver has been highly desired.

A new method, Structured ALE (S-ALE) [5], was recently developed in LS-DYNA to speed up the calculation time by taking advantage of structured mesh. In this paper, three case studies for underbody mine blast simulations were analyzed by both ALE and S-ALE methods. These include a simple plate, a simplified box and a test fixture for blast tests. The analysis results and CPU time are compared between the two methods. Also the Massively Parallel Processing (MPP) scalability was compared using the test fixture case.

THE NEW S-ALE SOLVER

In the past decade, we have observed the usage of structured mesh as shown in Fig. 1 and non-structured mesh as shown in Fig. 2, developed outside of LS-DYNA solver code in simulating fluid structure interaction problems. By structured mesh, we mean the mesh is of a box shape and all its elements are rectangular. The element spacing is not necessarily the same. The mesh can be finer at specific regions and coarse elsewhere.

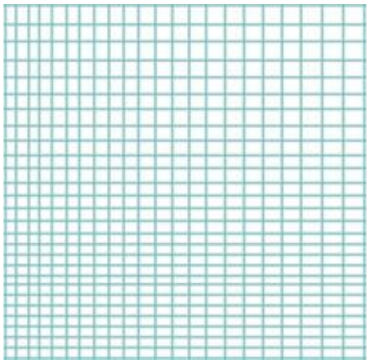

Figure 1: A structured mesh

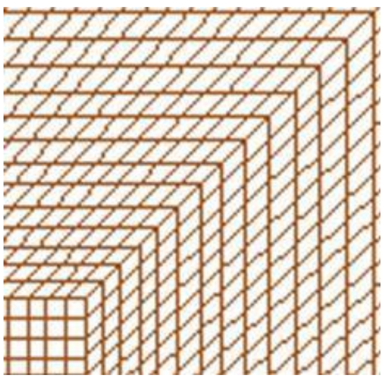

Figure 2: A non-structured mesh

Efforts have been made to develop Structured ALE (S-ALE) method inside of LS-DYNA solver code to take advantage of structured mesh characteristics. The major objective is to utilize the explicit geometry information to achieve speedup in calculation time. Along the way, the search algorithm was completely redesigned and this resulted in a much more compact and refined solver. Furthermore, the new Structured ALE method, with the help of redesigned search algorithm, supports Symmetric Multiprocessing (SMP). Unlike the old ALE method which only has Massively Parallel Processing (MPP) capability. The S-ALE supports all three kinds of parallel scheme: SMP, MPP and MPP hybrid.

The algorithm is tailored to best fit the structured mesh. This enables a much faster solution time and much less memory usage. In additions to that, it generates and stores the structured ALE mesh automatically without explicitly reading all the elements and nodes information. This brings a huge reduction in both the keyword read-in time and input file size. It is also much easier for users to modify the ALE mesh geometry, especially for problems containing large numbers of ALE elements.

The S-ALE method is easy to use, especially for users acquainted to the old generic ALE method. So far, only two new keywords have been introduced to use the new method. They are *ALE_STRUCTURED_MESH and *ALE_STRUCTURED_MESH_CONTROL_POINTS. The former is used to generate the mesh and the latter is to provide mesh spacing information along each local directions in LS-DYNA solver. Most other ALE keywords remain the same.

COMPARISONS BETWEEN ALE AND S-ALE

Three application cases were compared between ALE and S-ALE methods for the simulation results and CPU time. These cases are: a simple flat plate, a simplified box and a test fixture. The LS-Dyna development version 102979 with 32 processors is used for all the analyses. It is noted that although the meshes for charge, air and soil are defined with different keywords in the input files, they are essentially the same between the two methods. The meshes used in ALE method were defined through the keywords: *NODE and *ELEMENT, while the ones used in S-ALE method were defined by the keywords: *ALE_STRUCTURED_MESH and *ALE_STRUCTURED_MESH_CONTROL_POINTS.

In this study the parameters DCT and METH in keyword *CONTROL_ALE are set to -1 and 2, respectively. Also two different MPP decomposition cards are used for ALE method. The first, *CONTROL_MPP_DECOMPOSITION_DISTRIBUTE_ALE_ELEMENT, is the regular one and is referred as “old MPP” herein. The second, *CONTROL_MPP_DECOMPOSITION_TRANSFORMATION, is a newly developed one that takes advantage of the nature of the loading and structural geometry. The idea in this “new MPP” is to distribute the loads and advection calculations evenly among the processors so as to speed up the analysis time. For S-ALE method only the old MPP is used.

Case 1: A flat plate model

A flat plate with two heavy rigid blocks sitting on its top are shown in Fig. 3. The RHA plate has the dimensions of 1.8 x 4.5m and the thickness of 3”. The mass for the two rigid blocks is 36,000kg. The mesh for the plate and blocks is made of around 160,000 nodes and 130,000 3D solid elements. The Double-Sifted (DS) Topsoil with 12% AFV (Air Filled Void) and a certain mass of charge are used. Also 17” of SO (Stand Off) and 4” of DOB (Depth of Burial) are used for the analysis.

The deformation history of the plate center is plotted in Fig. 4 for the S-ALE method. The CPU time and the maximum deformation of the plate center are listed in Table.1. It can be seen that the difference in the deformation result is very small, *i.e.*, 0.97%. For the CPU time S-ALE method is able to speed up by 46.6% (from 11.5 to 6.14 hours) as compared to ALE with old MPP. However, ALE with new MPP is the best, or a 5.53% improvement (from 6.14 to 5.8 hours) from S-ALE method.

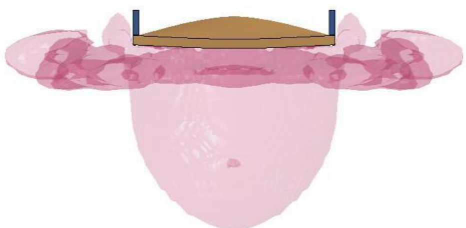

Figure 3: A simple flat plate model

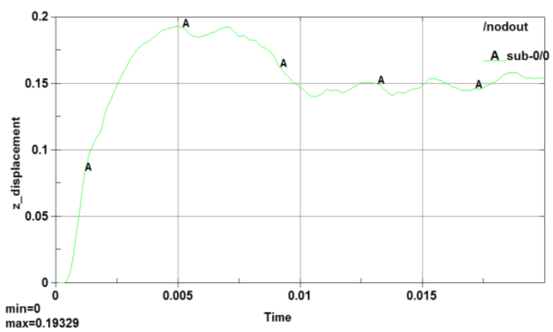

Figure 4: Deformation result for flat plate model

Table 1: Comparisons for flat plate model

	ALE (old MPP)	ALE (new MPP)	S-ALE (old MPP)
CPU Time (hours)	11.5	5.8	6.14
Max. Def (mm)	19.24	19.24	19.33

Case 2: A simplified box model

A box model as shown in Fig. 5 represents a simplified vehicle model. The simplified box has the dimensions of 7.6 x 2.0 x 2.2m. It contains about 200,000 nodes and 200,000 2D shell elements. Some soil and charge are used in this case study. Also 12" of SO and 2" of DOB are used for the analysis.

The velocity histories of the underbody center, roof center and crew floor center are respectively plotted in Figs. 6-8 for the S-ALE method. The CPU time and three resulting maximum velocities are shown in Table. 2 for comparison. It can be seen that the differences in the velocity results are very small, *i.e.*, within 2.4%. For the CPU time S-ALE is able to speed up by 28.5% (from 17.17 to 12.27 hours) as compared to ALE with old MPP. However, ALE with new MPP is the best, or a 23.1% improvement (from 12.27 to 9.43 hours) from S-ALE method.

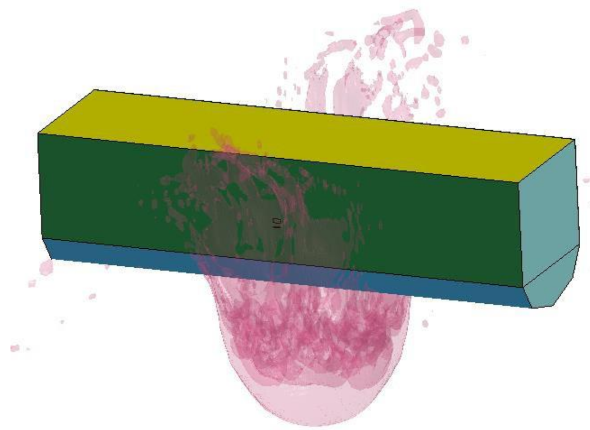

Figure 5: A simplified box model

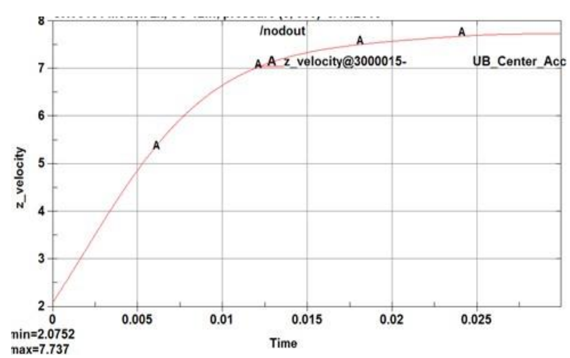

Figure 6: Underbody velocity result for simplified box model

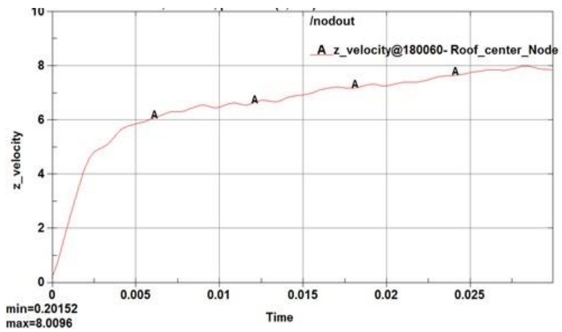

Figure 7: Roof velocity result for simplified box model

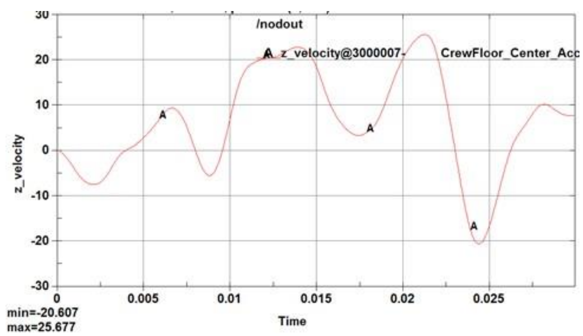

Figure 8: crew floor velocity result for simplified box model

Table 2: Comparisons for simplified box model

	ALE (old MPP)	ALE (new MPP)	S-ALE (old MPP)
CPU Time (hours)	17.17	9.43	12.27
V.ub (m/s)	7.71	7.71	7.74
V.roof (m/s)	7.82	7.84	8.01
V.cfloor (m/s)	25.80	25.76	25.68

Case 3: A test fixture model

A test fixture shown in Fig. 9 is used to hold a specimen, *i.e.*, a composite plate, floor, hull and seat specimens, for a blast test. The dimensions for the fixture are 3.3 x 2.1 x 2.1m. The mesh contains about 300,000 nodes and 250,000 elements that mix with 2D shell and 3D solid elements. The DS Topsoil with 14% AFV and a certain mass of charge are used in this case study, along with 19” of SO and 4” of DOB.

The deformation history of the specimen center is plotted in Fig. 10 for the S-ALE method. The CPU time and the maximum deformation of the specimen center are listed in Table. 3. It can be seen that the difference in the deformation result is 6.02% (from 23.75 to 25.18mm). For the CPU time S-ALE is able to improve by 47.9% (from 28.8 to 15.0 hours) as compared to ALE with old MPP. Compared to ALE with new MPP, S-ALE method also shows 16.7% improvement (from 15.0 to 18.0 hours).

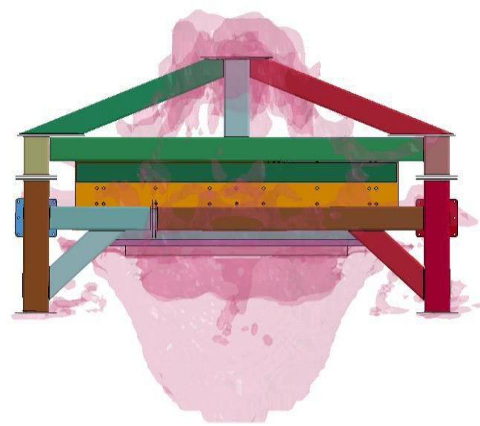

Figure 9: A test fixture model

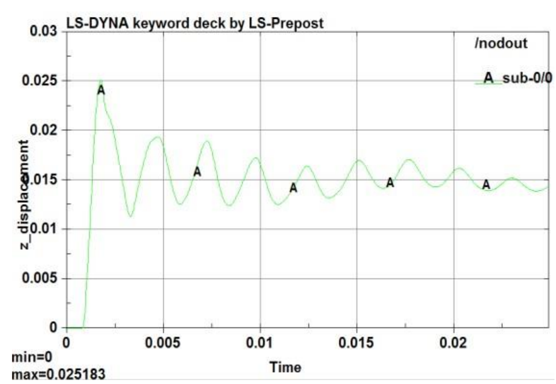

Figure 10: Deformation result for test fixture model

Table 3: Comparisons for test fixture model

	ALE (old MPP)	ALE (new MPP)	S-ALE (old MPP)
CPU Time (hours)	28.8	18.0	15.0
Max. Def (mm)	23.75	23.75	25.18

MPP scalability comparison

To compare the MPP scalability between ALE and S-ALE methods the test fixture model mentioned previously is employed again to be analyzed. Five different processors are used: 32, 64, 128, 256 and 384 for the comparison. The results are shown in Figs. 11 and 12, respectively, for ALE with the old and new MPPs. Through the comparison it clearly shows that S-ALE has excellent scalability since the actual and ideal curves are very close. For ALE with old MPP the resulting scalability is not as good as S-ALE, see Fig. 11. The scalability for ALE with new MPP demonstrates good result for CPU up to 128, and then starts decreasing afterwards, see Fig. 12.

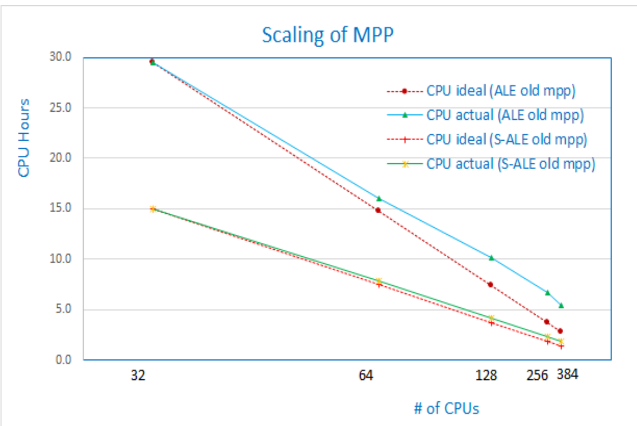

Figure 11: MPP scaling comparison between S-ALE and ALE with old MPP

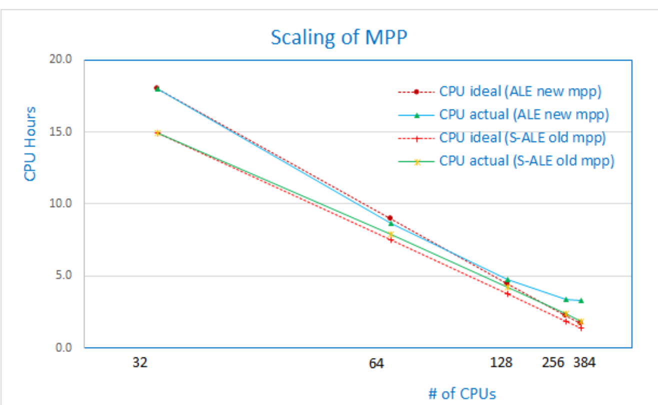

Figure 12: MPP scaling comparison between S-ALE and ALE with new MPP

DISCUSSION AND CONCLUSIONS

The comparisons between LS-Dyna ALE (with the old and new MPPs) and S-ALE (with old MPP only) methods have been presented in this paper through three case studies. These comparisons show:

(1) The differences in the resulting deformations or velocities are all within 6.0%.
(2) S-ALE runs faster than ALE with old MPP by 46.6%, 28.5% and 47.9%, respectively, for all three case studies.
(3) S-ALE runs with about the same speed as ALE with new MPP, more precisely by -5.5%, -23.1% and +16.7%, respectively, for all three case studies.
(4) S-ALE has better MPP scalability than ALE with either new or old MPPs.

From the results described above, the newly developed S-ALE is deemed to be very promising to be used as compared to ALE with old MPP. Also the ALE with the new MPP shows very good computational efficiency. It is worth mentioning that more computational simulations should be performed with S-ALE and ALE with new MPP, particularly for the analysis of full-vehicle with occupant models. Assessments of S-ALE with new MPP option will be conducted when S-ALE with new MPP is available for use.

DISCLAIMER

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