Assessment of the multi-material ALE formulation with FSI

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Abstract:

This paper presents LS-DYNA 970.5434a simulations for the multi-material arbitrary Lagrangian Eulerian (ALE or MMALE) formulation (solid `ELFORM=11`). The objective is to shed light on the dependence of the results on the count of advection cycles that has been found in former investigations of fluid-structure interaction (FSI) with soft, highly deformable structures [1,2]. The advection cycle count is determined by the `NADV` parameter on `*CONTROL_ALE`, the `TSSFAC` on `*CONTROL_TIMESTEP` and the penalty stiffness of the `*CONSTRAINED_LAGRANGE_IN_SOLID` interface.
For an airbag example a strong random spread of the results on a dual CPU system is found. This spread is estimated to be inevitable. Other, more academic FSI examples are assessed then. The difference of the total energy and sliding interface energy between choosing `TSSFAC=0.4` and `TSSFAC` default is usually bigger than that between the advection schemes alternatives: the now default van Leer scheme `METH=2` and the first order donor cell scheme `METH=1`. Therefore, the dissipative properties of the schemes do not suffice to explain this difference. Furthermore, the influence of explicitly scaling down the default hourglass control in the MMALE elements for fluid and gas materials is smaller than the found difference. The strong influence of the parameters on the `*CONSTRAINED_LAGRANGE_IN_SOLID` card in conjunction with the advection count on the creation of non-physical interface energy proves to be responsible for non-robustness of the solution in some situations.
The paper highlights some of the difficulties encountered and the solutions found. Input decks may be downloaded from www.rudolf-boetticher.de.

Keywords:

multi-material ALE, advection, time step, robustness, FSI, `*CONSTRAINED_LAGRANGE_IN_SOLID`, random spread

1 Introduction

The vision of LS-DYNA is to become multiphysics. So it is worth to evaluate novel features of LS-DYNA to assess what is already accomplished. This paper presents LS-DYNA 970.5434a simulations for the multi-material arbitrary Lagrangian Eulerian (ALE or MMALE) formulation (solid `ELFORM=11`). The objective is to shed light on the dependence of the results on the count of advection cycles that has been found in former investigations of fluid-structure interaction (FSI) with soft, highly deformable structures [1,2]. Fluid-structure interaction models are beneficial for the design process of bioprosthetic heart valves [3] and investigation of the interaction of brain and skull [4]
The paper is organized as following. In Section 2 the inevitable spread of results with multi-processor ALE calculations is illustrated with a close to reality airbag deployment example. In the Section 3 this phenomenon is assessed with a focus on more academic examples. Then some concluding remarks are given.

2 Illustration of spread in results

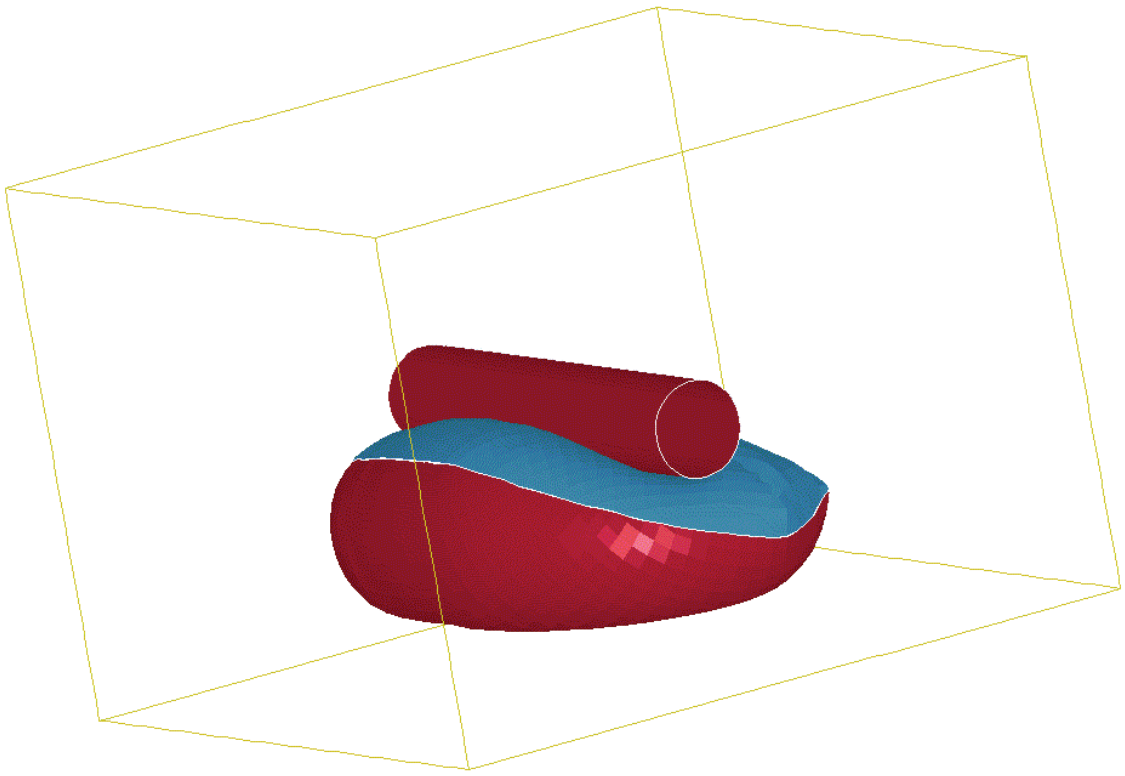


Figure 1: ALE airbag hits an impactor. The rectangular solid indicates the region of the ALE background mesh.

A deck for an `*AIRBAG_ALE` airbag [9] hitting an impactor (figure 1) was run with a single precision 32 bit SMP 5434a executable for Windows on a dual Opteron computer with Windows XP x64. At first, to mimic an uniform pressure (UP) airbag, the switching time was set to zero and no ALE phase was simulated. The deck was rerun five times for two setting of the time step via `TSSFAC`. Figure 2 shows the courses of the airbag pressure.
When multiple CPUs are utilized there is usually a spread of the results observable, if identical decks are executed several times. This reflects the stochastic nature of the underlying physical process rather than a code deficiency. In the SMP version the user can attempt to battle this spread by using the consistency flag on `*CONTROL_PARALLEL` or the command line. This flag, however, does not apply to the MPP version which is going to dominate in the future. (MPP contact consolidation is a hot issue now.) The consistency flag was, therefore, not set. An influence of the time step can be seen during the airbag's pressure unloading phase in figure 2.

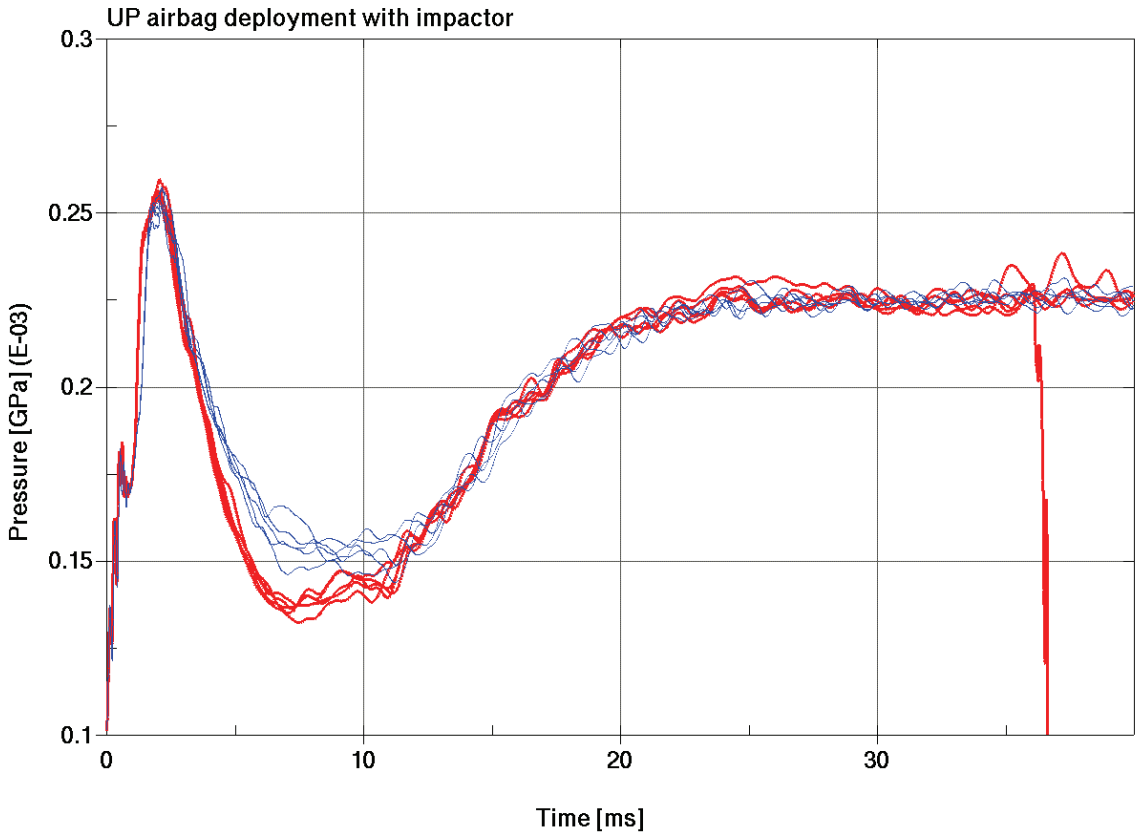


Figure 2: Pressure during an airbag deployment of an UP airbag against an impactor. Identical decks are rerun five times each. The thicker red lines show the course of the airbag pressures for `TSSFAC=0.5` and the thinner blue lines show those for default time step. One run aborted.

Next the switching time was set to 18 ms, during which an MMALE simulation (`ELFORM=11`) with FSI via a `*CONSTRAINED_LAGRANGE_IN_SOLID` is performed. Figures 2 and 3 show pressure courses for the two advection schemes and two choices of `TSSFAC`; the scatter is obvious.
Comparison of figures 1-3 shows that the ALE method predicts a first pressure peak of twice the value the UP method delivers. Until this peak value the results of the both ALE advection schemes are comparable. In the following unloading phase with respect to airbag pressure a big spread in the results is obvious. For `TSSFAC=0.5` the simulations become unstable and abort. The shortening of the stable time step may alter the results or even cause instabilities and abortion of the solution run. As the maximum stable time step size is dependent on the bulk moduli of the materials and element sizes a strong mesh dependence of the ALE results may be seen. The difference between the first order donor cell (`METH=1`) and the van Leer advection scheme (`METH=2`) is not clearly detectable in the noise coming from these effects.
There is no clear prediction for the relative pressure minimum. When for the ALE method the airbag's model is switched to UP at 18 ms a sharp pressure peak appears. This peak's height shows a considerable spread. Towards the simulation end time at 40 ms all curves thrive towards an equal value.
An additional finding is that the `*AIRBAG_ALE` generates `*MAT_GAS_MIXTURE` parts which don't output hourglass energy for post-processing. There is a parameter on `*AIRBAG_ALE` to explicitly downscale the hourglass type 1 control parameter which is appropriate for fluids and gases. To track down the effect of this parameter, which may be a non-issue, the information on hourglass energy is missing in the output. The same is true for `*MAT_FABRIC`.
An ongoing nuisance with LS-PREPOST on Windows is the typically low resolution of xy-plots when they are saved in a graphic format like *.gif for bw hardcopy documentation. Typically, because LS-PREPOST behaves differently on different boards with different graphic adapters and different XPs. On a x64 the system reboots when a graphic is plotted! The reader may forgive the quality of the graphics and is referred to the CD and [8] for a more comprehensive documentation in color.

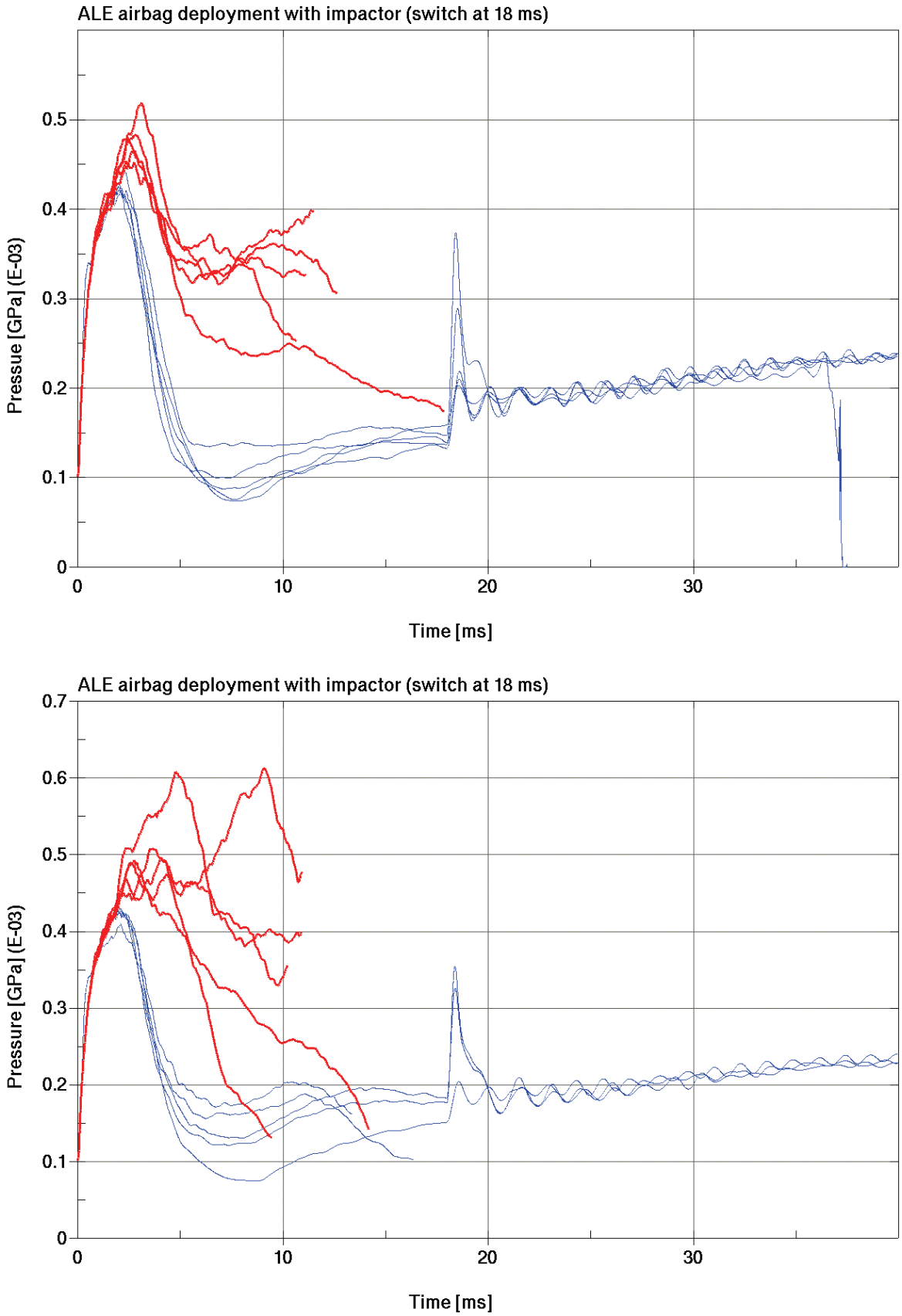
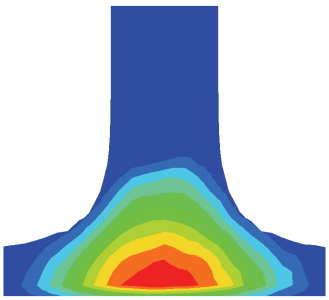


Figure 3: Pressure during an airbag deployment against an impactor. ALE was switched to UP simulation at 18 ms. Above advection `METH=1` and below `METH=2`. The thicker red lines represent the runs with `TSSFAC=0.5` which all aborted. The count of cycles for the default time step is about 9500 and varies by about 20%!

3 Assessment by monitoring of the mass transport



For this section the mass conversation was tested in an example with and without FSI interface. A fluid jet impacts a surface and is turned round to both sides. The example, which is a variation of an example found in [6], may be downloaded from [8]. The impacted surface is modeled in two ways: by SPC constraints of the ALE mesh and by a FSI interface for a shell surface. The outflows, modeled by missing SPC constraints on the ALE mesh, are monitored by dummy interfaces: they are covered with a segment set and creation of a dbfsi file is invoked without a `*CONSTRAINED_LAGRANGE_IN_SOLID` card present. Nevertheless, useful information about the mass flow is output in dbfsi!

The generation of the segments with `*SET_SEGMENT_GENERAL` fails. Details were posted in the LS-DYNA yahoo group [5]. This group proves pretty valuable for LS-DYNA knowledge swarming.
Figure 4 shows the mass outflow on the left side for the example with FSI. The `TSSFAC` parameter has no and the advection method only a small influence. There is a small delay seen at the outflow for `METH=1`. The results without FSI are similar and documented at [8]. Comparable values of the stagnation pressure were found.

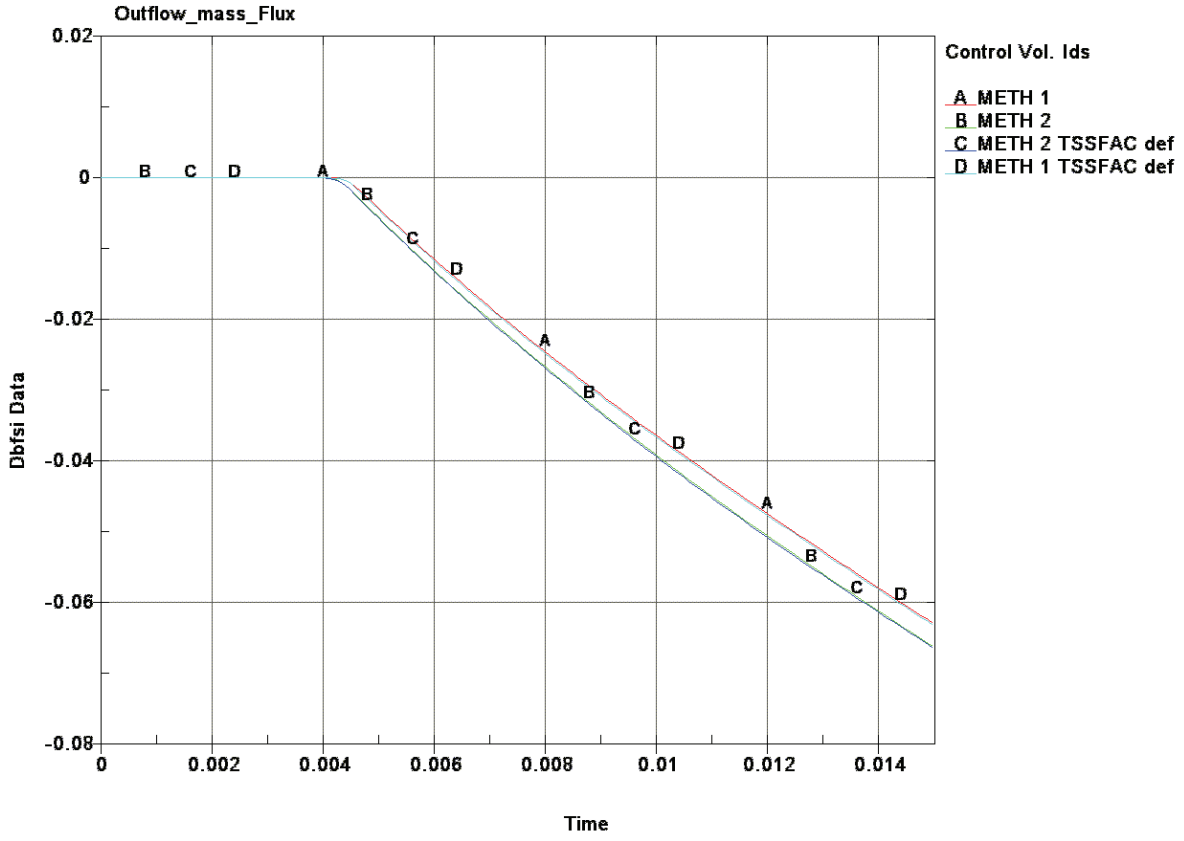


Figure 4: Mass outflow on the right side. `TSSFAC` has no and the advection method little influence.

Figure 5 shows the interface energy of the FSI interface with default penalty stiffness, the work done by the array of penalty springs, as retrieved from the glstat file. This energy is non-physical. Shortening of the stable time step via the `TSSFAC` parameter on `*CONTROL_TIMESTEP` has a beneficial influence on the error. Note, that the now default (there is an error in the manual) v.Leer advection scheme, which is costlier CPU wise, may show a bigger error. Therefore, the higher energy dissipation properties of `METH=1` does not suffice to explain this difference. Furthermore, the influence of explicitly scaling down the default hourglass control in the MMALE elements for fluid and gas materials is smaller than the found difference [8].

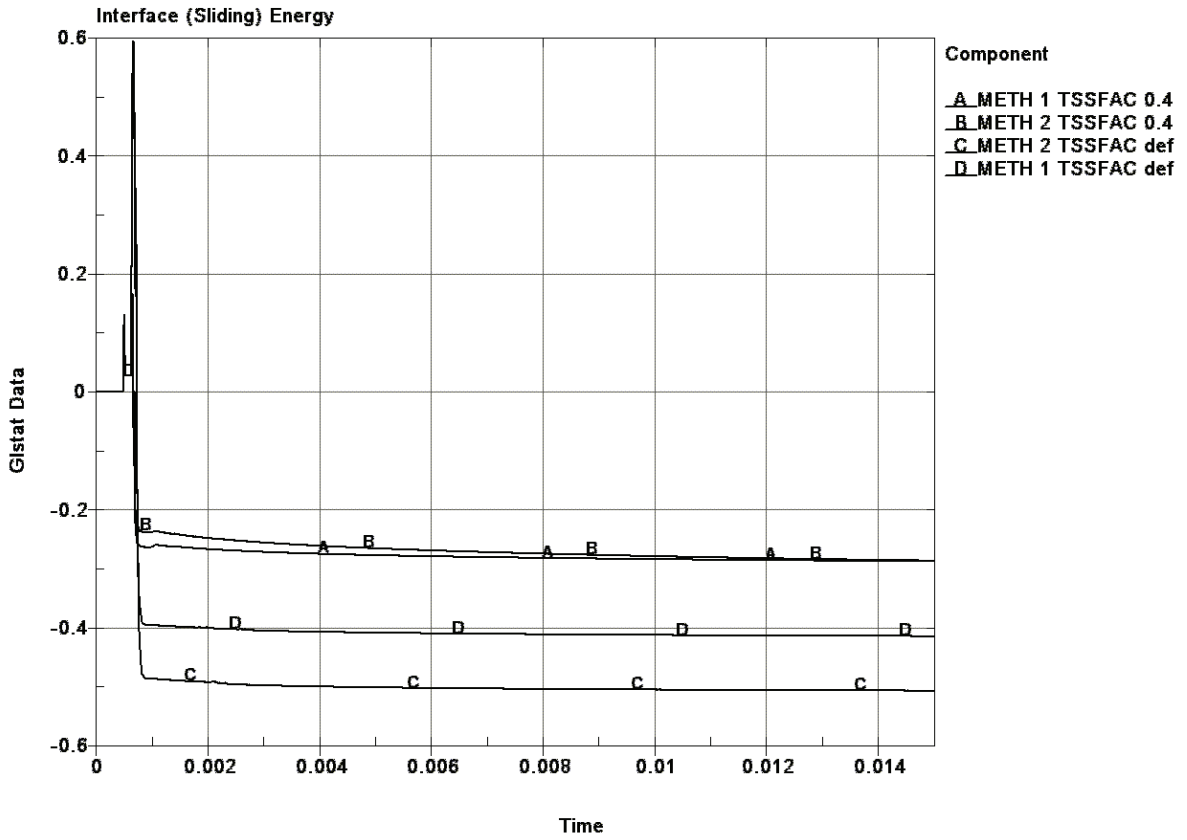


Figure 5: The (sliding) interface energy for default penalty stiffness depends on TSSFAC. The costlier advection scheme METH=2 may have a higher error than METH=1.

It is possible to prescribe the penalty stiffness on the *CONSTRAINED_LAGRANGE_IN_SOLID card (sample input deck [8]). This proves to be helpful for better transient development of the interface energy shown in figure 6, which does not show time step dependence any more; nor it is dependent on the advection method. Invoking different algorithms for the leakage control by the ILEAK parameter generates higher interface energies. The delay of the mass flow out differs for the three schemes for leakage control. This difference is more likely bigger than the difference between the two advection schemes.

4 Concluding remarks

In LS-DYNA the v.Leer scheme is the default advection scheme in ALE simulations. The first order accurate donor scheme is faster by is classed as strongly dissipative. The take-away of this paper is that this difference is typically of less importance, if FSI interfaces are present, because the choice of the FSI parameters induces a larger spread of results than the advection scheme.
The non-physical interface (sliding) energy lost or gained in the *CONSTRAINED_LAGRANGE_IN_SOLID interface is dependent on the penalty stiffness, the leakage control and the time step (TSSFAC) concurrently. With multiple CPUs repeated simulations show a spread of the results. This generates an additional source of random error. Assessing this fuzziness the user may become convinced that there is a problem dependent upper limit of accuracy of the material properties above which the simulation does not become more predictive any more.
During the progress of the work several malfunctions of the programs and inconsistencies of the documentation were found. They were reported and documented in the LS-DYNA group [5], which has a vivid messaging. Downloads of input decks are available at [8].

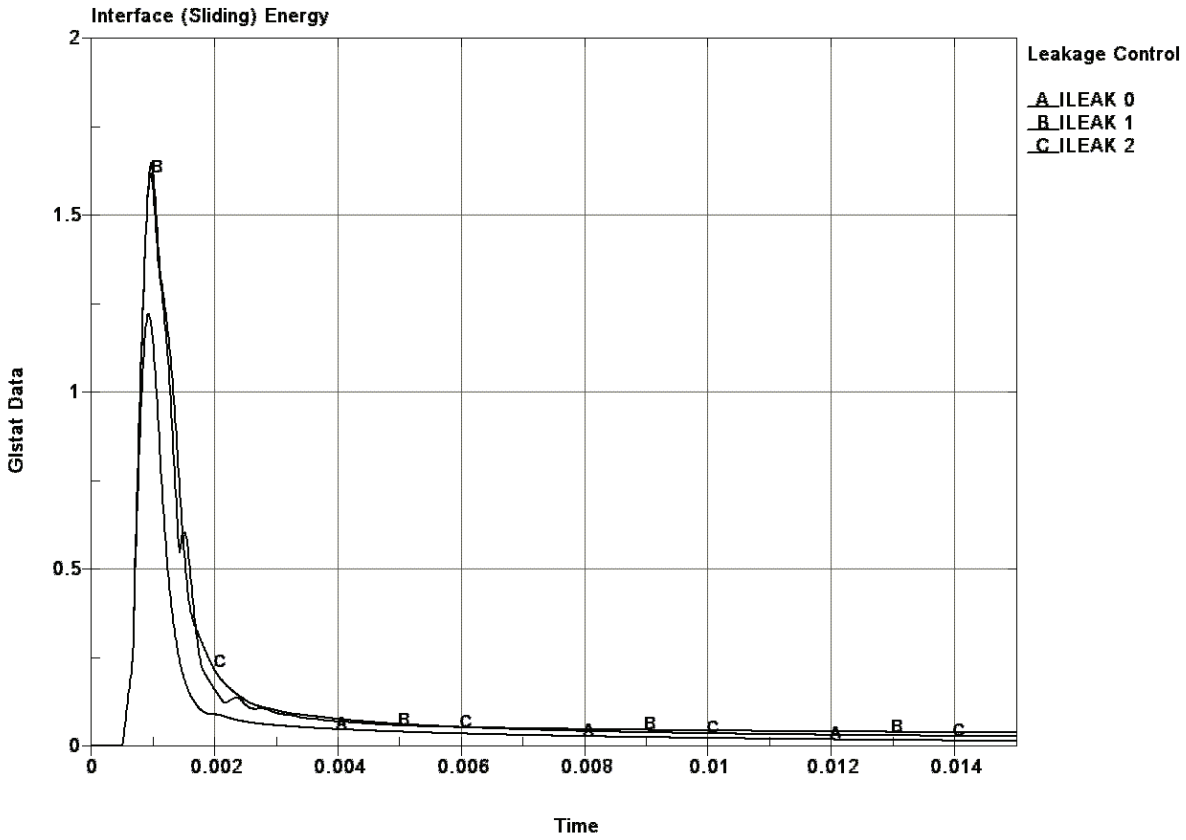


Figure 6: The (sliding) interface energy with prescribed penalty stiffness for the three alternatives of the leakage control. Negative energies are now avoided.

5 References

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