ALE and Fluid Structure Interaction in LS-DYNA

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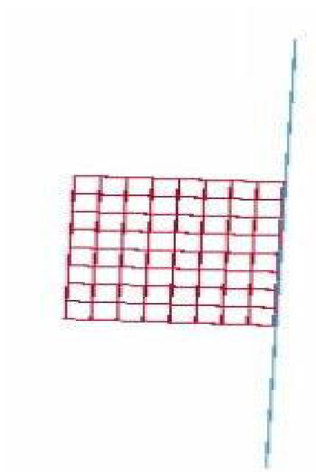
Abstract

Fluid-structure interactions play an important role in many different types of real-world situations and industrial applications involving large structural deformation and material or geometric nonlinearities. Numerical problems due to element distortions limit the applicability of a Lagrangian description of motion when modeling large deformation processes. An alternative technique is the multi-material Eulerian formulation for which the material flows through a mesh, fixed in space and each element is allowed to contain a mixture of different materials. The method completely avoids element distortions. With an Eulerian-Lagrangian (fluid-structure) coupling algorithm, Eulerian parts may interact with Lagrangian parts in the same model. The Eulerian method is limited by dissipation and dispersion problems associated with the fluxing of mass across element boundaries. In addition, the Eulerian mesh must span the whole active space covering all Lagrangian structures and the spatial range of their motions. This requires a large mesh and thus high computing cost. The multi-material arbitrary Lagrangian-Eulerian (MMALE) method improves upon pure Eulerian formulation by allowing the reference fluid mesh(es) to translate, rotate and deform, thus minimize the amount of flux transport, and reduce mesh size of the reference fluid mesh(es).

Introduction

Numerical problems due to element distortions limit the applicability of a Lagrangian description of motion when modeling large deformation processes. An alternative technique is the multi-material Eulerian formulation. It is a method where the material flows through a mesh that is completely fixed in space and where each element is allowed to contain a mixture of different materials. The method completely avoids element distortions and it can, through an Eulerian-Lagrangian coupling algorithm, be combined with a Lagrangian description of motion for parts of the model, see [3] and [4].

The Eulerian formulation is not free from numerical problems. There are dissipation and dispersion problems associated with the flux of mass between elements. In addition, many elements might be needed for the Eulerian mesh to enclose the whole space where the material will be located during the simulated event. This is where the multi-material Arbitrary Lagrangian-Eulerian (ALE) formulation has its advantages. By translating, rotating and deforming the multi-material mesh in a controlled way, the mass flux between elements can be minimized and the mesh size can be kept smaller than in an Eulerian model. An example of the limitation of the Lagrangian method is shown in Figure 1.



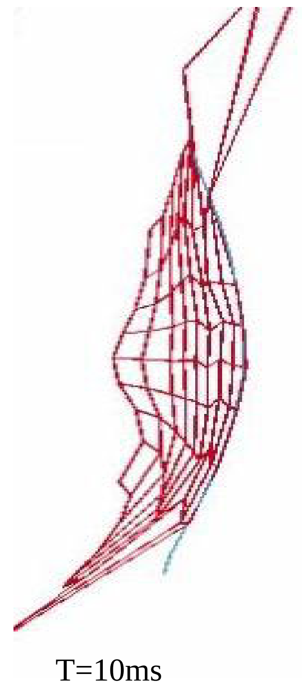


Fig 1 t=0 T=10ms

Fluid Structure Interaction (FSI)

A constrained-based Eulerian-Lagrangian coupling algorithm was first implemented in the 950 version of LS-DYNA. The coupling has been improved in ls960 and ls970 in order to solve complex problems as Airbag inflation, bird strike impact and forging. The new coupling is penalty-based and is defined to preserve the total energy of the system as well as possible. The old constraint based methods consume some kinetic energy, which is a problem in many impact applications.

The basic idea of the penalty formulation is to track the relative displacements between the corresponding coupling points defined on the Lagrangian surface segments and inside the ALE fluid elements. The coupling nodal forces are defined to be proportional to these displacements.
In the next example, we illustrate the water impact problem of figure1, using the coupling technique. Since the fluid is solved on a fixed mesh, a Void material part is used, as a separate part, in order for the fluid to flow outside its initial mesh. The Lagrangian structure made of shell elements, deforms inside the Eulerian fixed mesh. Both fluid and Void parts are considered Eulerian parts. Unlike the Lagrangian formulation with contact algorithm used in figure 1, the Eulerian formulation with coupling algorithm uses fixed mesh for the fluid and prevents mesh distortion.

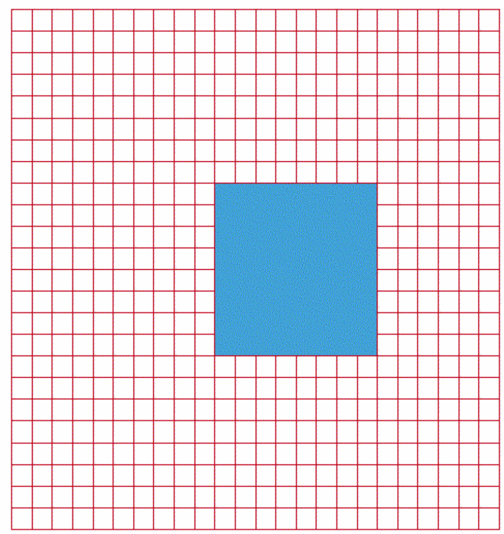


Figure 2.1 Time t=0 ms

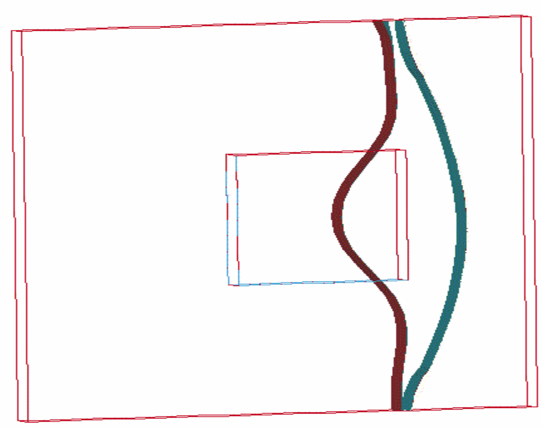
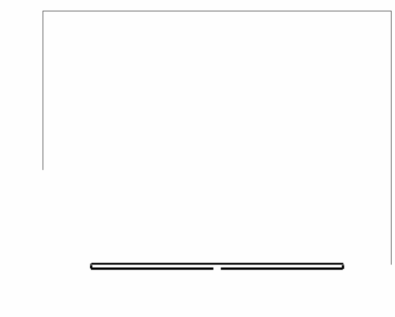


Figure 2.1 Time t=10 ms

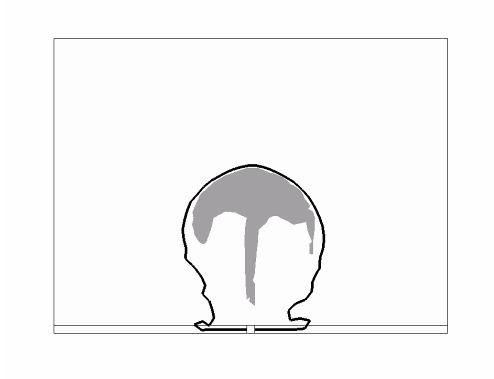
Airbag Simulation

The Euler-Lagrange Coupling method in LS-DYNA has been used to solve the Eulerian airbag problem. With the FSI method, a fluid mesh covering the airbag and its spatial range of motion is defined, and the inflator gas injection is modeled such that the coupling forces will cause the inflation of the Lagrangian airbag. The fluid mesh can be Eulerian or fixed mesh, in this case we need a large fluid domain to cover the volume in space that will be occupied by the fabric material. An ALE moving mesh may be used such that the fluid mesh can expand to follow and envelop the Lagrangian structure (airbag).

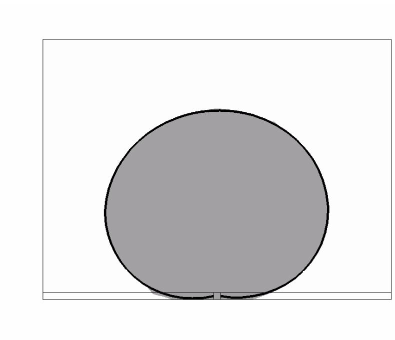
Figure 9 shows the airbag deployment at different times.



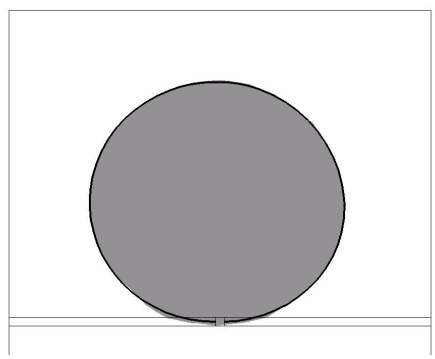
Time t=0 ms



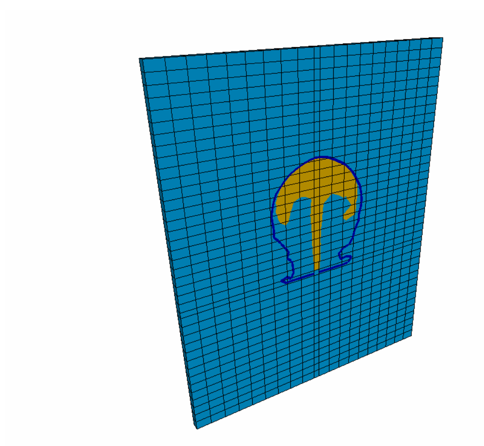
Time t=30 ms



Time t=40ms



Time t= 50 ms



Airbag with Eulerian mesh

***AIRBAG_ALE and Switching time from ALE to Control Volume**

Using a purely ALE method to model airbag inflation process may be computationally intensive. Thus a new method has been developed to run the model via the ALE approach for an initial critical duration, then switching to the traditional control volume method for the rest of the deployment. The user has control of the switching time. A new keyword command AIRBAG_ALE is defined for this purpose simplifying the use of the ALE Airbag features. Using this new option, the user does not have to define for the ALE Parts the following commands:

*MATERIAL_
*EOS_
*ALE_MULTI-MATERIAL_GROUP
*CONSTRAINED_LAGRANGE_IN_SOLID
*SECTION_SOLID
*SECTION_POINT_SOURCE_MIXTURE

All these commands are included in the AIRBAG_ALE Card definition.
A switch time is defined by the user. After this time the ALE calculation stops, and the Control Volume method takes over. From a CPU time point of view this technique is very efficient.

References

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[3] M. Souli, A.Ouahsine, L.Lewin, Arbitrary Lagrangian Eulerian Formulation for Fluid-Structure Interaction Problems. Computer Methods in Applied Mechanics and Engineering 190 (2000) p 659-675
[4] Benson D. 1989,' An efficient accurate, simple ALE method for non linear finite element programs, Computer Methods in Applied Mechanics and Engineering 1989 (33) p 689-723.