Fluid-Structure Interaction in LS-DYNA:

Industrial Applications

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Summary:

A new Fluid Sructure coulping algorithms basesd on the penalty method is dpresented in thi spaper. The coupling algorithm and improved multi-material ALE-capabilities have made LS-DYNA an efficient tool for analyzing large deformation processes, such as bird strike events, forging operations and penetration problems and airbag simumations. This paper contains five example problems that illustrate the current features of the code.

Keywords:
Fluid-structure Interaction, ALE algorithms, Eulerian Airbag

1   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 a 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. The idea is visualized in Figure 1.
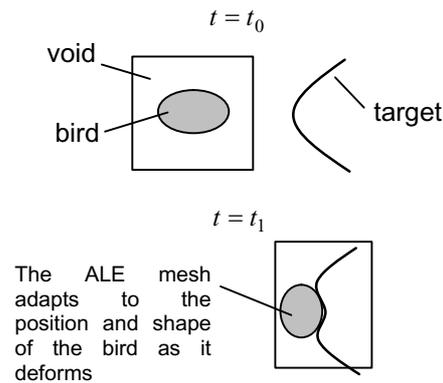

Figure 1. Moving ALE-mesh in impact simulation

2   Fluid-structure coupling

A new Eulerian-Lagrangian coupling algorithm was implemented in the 950 version of LS-DYNA. It is penalty-based and it 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 coupled Lagrangian nodes and the fluid. The coupling forces are defined to be proportional to these displacements.

3   Backward facing step flow

This problem has been selected since a large number of numerical and experimental results are available. Experimental tests [2] show that for a higher aspect ratio of the test section, and at low and moderate Reynolds numbers, the flow is two-dimensional and fully developed at the outflow section.

For the boundary conditions, we assume:
- Poiseuille flow at the inflow boundary (Parabolic form)
- Free outflow boundary
- No-slip conditions at the wall

The computational domain is a rectangle [0,2] x [-0.4, +0.4], with a step of height 0.4m, placed at the lower left corner; the units are m, kg, and sec.

The Reynolds number based on the inflow velocity and the step height is Re=500.

To show the validity of the LS-DYNA results, we compared the numerical reattachment length (recirculation zone) to the experimental ones given in [2]. The reattachment length is determined by the location at the lower wall, in which the shear stress changes sign.

The LS-DYNA results are compared to experimental results for the reattachment length L, for different values of the Reynolds numbers
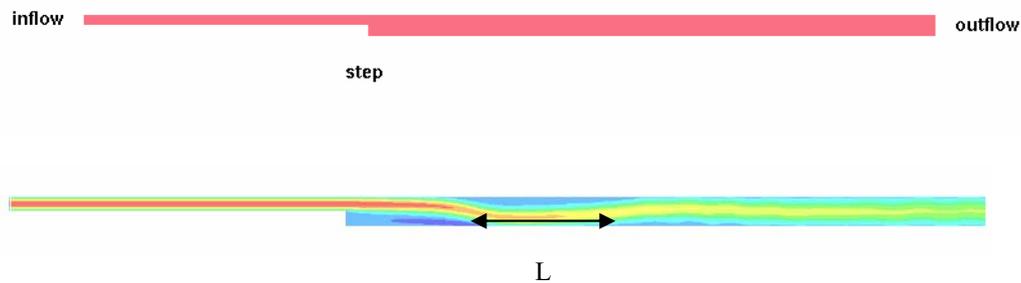

L

Figure 2 Flow velocity profile at steady state

	Experimental	LS-DYNA
Re = 250	L = 6.	L = 5.96
Re = 500	L = 10.15	L = 10.5

4   Forging model

A small forging problem was solved with the purpose of comparing the results from the multi-material approach with those obtained with a purely Lagrangian formulation. Due to element distortions, the Lagrangian model failed in running to completion and the results are compared at a relatively early stage of the process.

Figure 3 shows the Lagrangian and Eulerian models. The work-piece is elastic, ideally plastic with the properties

$$\rho = 7800 \, kg \, / \, m^3$$
$$E = 205 \, GPa$$
$$v = 0.3$$
$$\sigma_y = 500 \, MPa$$

Figure 4 shows the cross section of the Eulerian work-piece at different stages of the process. The effective plastic strain distribution along a line cutting through the work-piece is presented in Figure 8
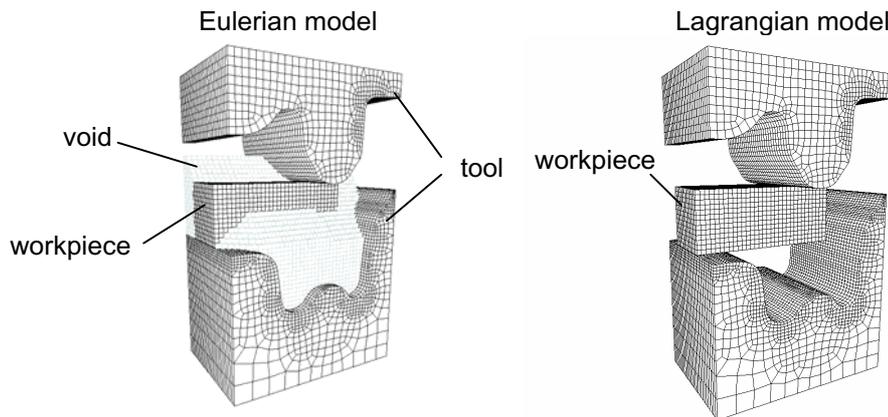

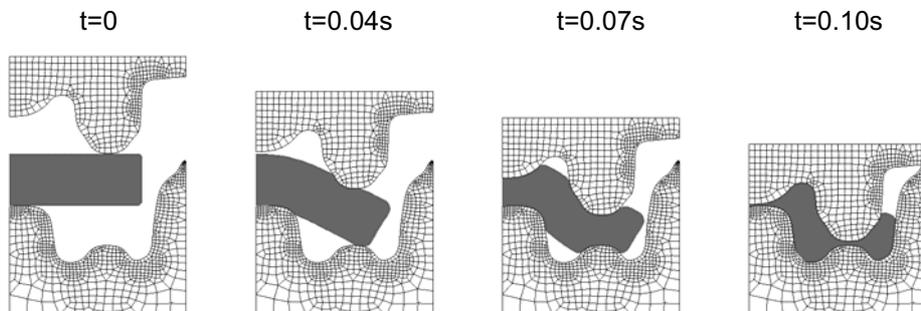Figure 3. Eulerian and Lagrangian forging models

Figure 4. Cross section of Eulerian work-piece at different stages of the process
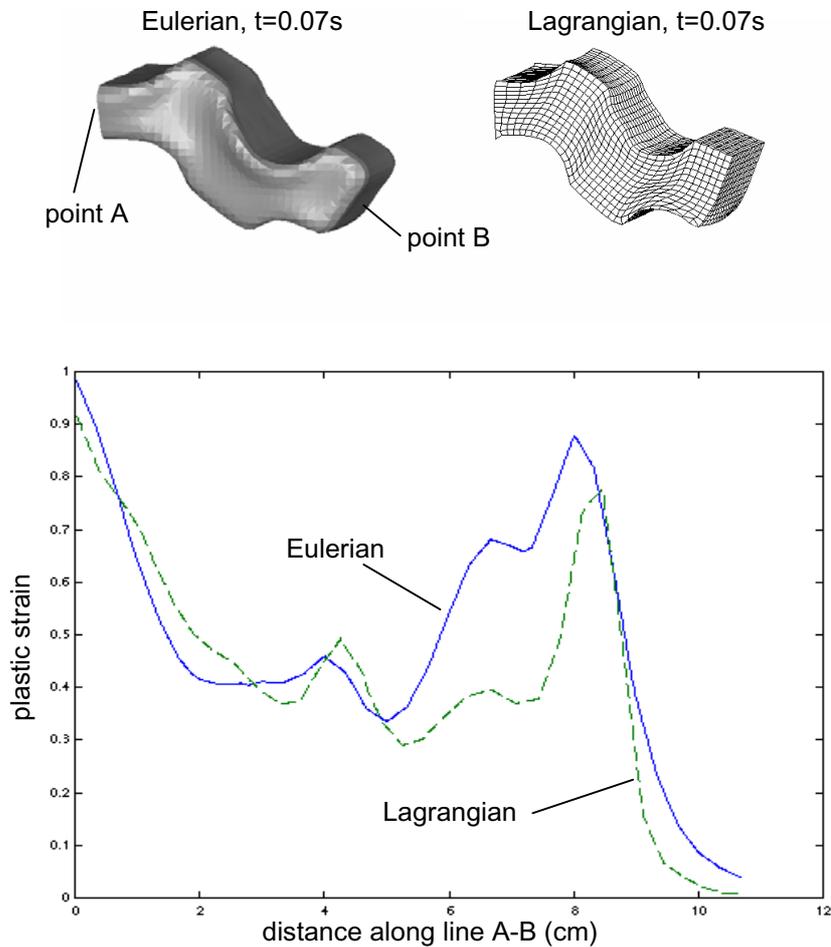
Eulerian, t=0.07s   Lagrangian, t=0.07s

Figure 5. Effective plastic strain level at t=0.07s

5   Elastic ball Impact

This problem demonstrates the capabilities of the LS-DYNA Euler-Lagrange coupling algorithm in impact problems. A cylindrical elastic ball with initial velocity is impacting a rigid wall.

In the multi-material ALE simulation the ball is surrounded by air, into which the elastic material is allowed to move. The Euler-Lagrange coupling is defined between the rigid wall and the two ALE materials, elastic ball and air. The ALE simulation is compared to a Lagrangian one, where a surface to surface contact is defined for the impact; the Lagrangian results are takes as reference.

Figure 8 shows the ALE and Lagrangian balls before and after impact. For the Lagrangian simulation, the material contour is defined by the mesh contour, whereas in the ALE simulation, the material contour is defined by the volume fraction of the elastic material.
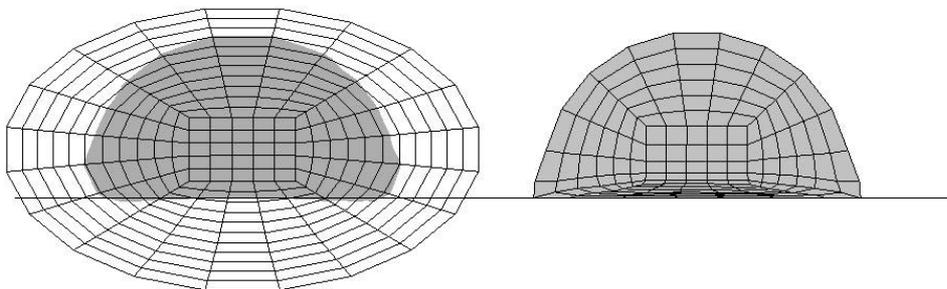
Balls before impact
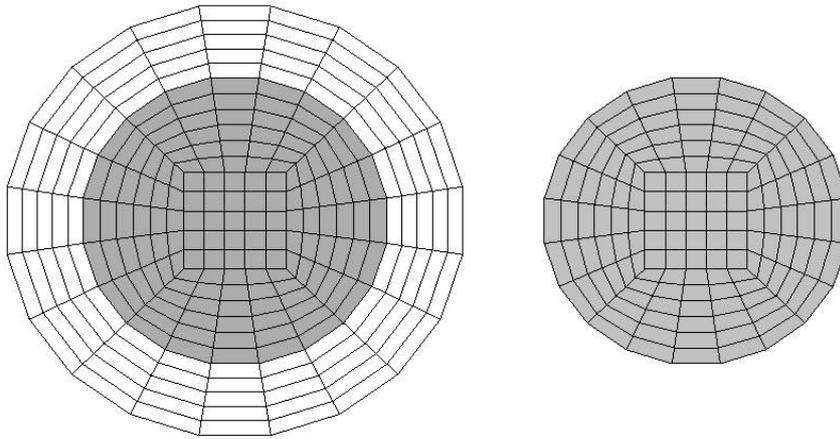
Balls after impact

Figure 8. Material contours of impacting balls.

7 Airbag Simulation

The Euler Lagrange Coupling in Lsdyna has been used to solve the Eulerian airbag problem. In this method the gas flowing to inflate the airbag is considered; a fluid mesh covering the airbag elements is used. 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 can also be used to solve the problem, at each time the fluid mesh will be extended in different directions to fill the volume occupied by the fabric material.
Figure 9 shows the airbag deployment at different times

Time t = 0.

Time t = 30 ms

Time t =40ms

Time t = 50 ms

Figure 9
Airbag with Eulerian mesh
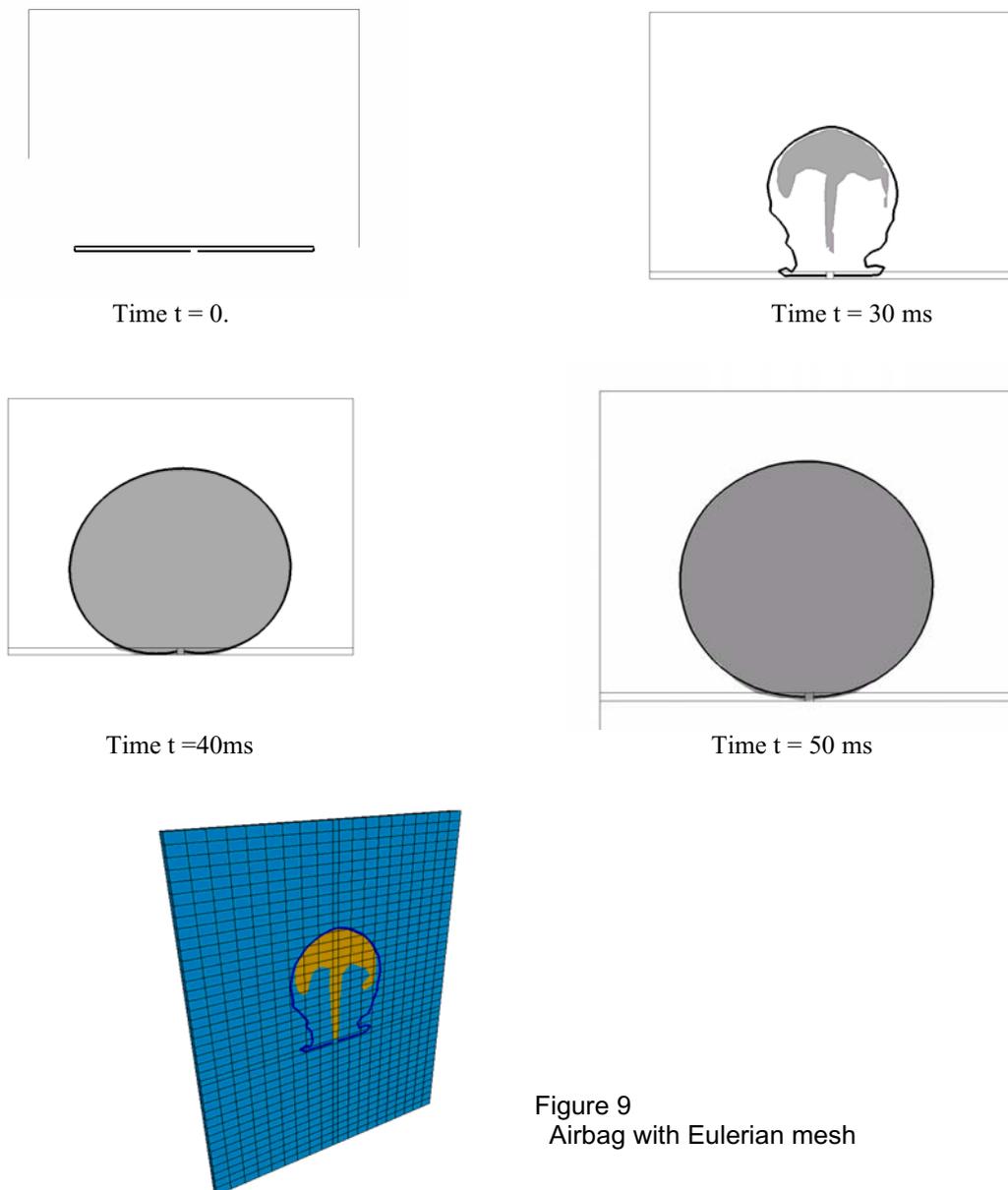
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