

LS-DYNA[®] ALE/FSI Recent Developments

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Abstract

LS-DYNA ALE(Arbitrary Lagrange-Eulerian Method), equipped with its own 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.

*LS-DYNA ALE multi-material formulation solves multiple species of fluids in one ALE mesh. The fluid interfaces are tracked internally by our interface reconstruction algorithms at each of the advection cycle. Then our fluid-structure interaction algorithm is used to study the interactions between structures and those individual fluids. The FSI solver, invoked by the *CONSTRAINED_LAGRANGE_IN_SOLID card, is to couple between ALE fluid elements and Lagrange structure segments.*

The multi-material capability, together with its embedded coupling to structures, have been utilized by users from various engineering application areas such as tank sloshing, tire hydroplaning, bottle dropping, high explosive blasting, etc.

Several recent developments and their engineering applications in LS-DYNA ALE/FSI package are presented here.

Introduction to LS-DYNA ALE/FSI

ALE solid elements can either be of element form 11 or element form 12. While element form 12 assumes only 1 material exist in the ALE mesh, element form 11 allows for multiple materials co-exist in the same ALE mesh.

The volume taken by each individual multi-material group in an ALE element is recorded by volume fraction. The volumes of Fluids flowing through faces of each element are calculated to update the volume fraction at each timestep. We then use those data to generated the new fluid interfaces. These two processes are named advection and interface reconstruction, respectively.

Once we determine where the fluid interface is at, we compare the interface with the structure interface user defined to check for penetrations. Historically, the Lagrange structure is represented by a set of coupling segments. Coupling points, at where we measure penetrations, are generated at each segment as a N by N grid. As the structure geometry is represented by a set of segments, we call this coupling algorithm segment-based.

Meshless and Discrete Formulations in LS-DYNA

LS-DYNA contains several discrete element formulations. Smoothed-particle Hydrodynamics (SPH) are widely used to model objects under severe deformations. The LS-DYNA Discrete Elements recently developed successfully simulated soil and sand undertaking explosion shockwaves from land mine detonations. In the above element formulations, material interface is no longer represented by set of segments. Hence segment-based FSI coupling can not be applied to structured modeled by these formulations.

ALE Nodal Coupling

To deal with cases where Lagrange structures are of meshless or discrete element formulations, we developed a new node-based ALE coupling algorithm. The coupling points are now chosen at nodes instead of the N by N grid on segments.

There are two approaches to construct couplings between fluids and structures. One is constraint-based; another penalty-based. Constraint based nodal coupling was developed to capture the large momentum transfer between high explosives and soil at the early stage of detonation. The development was done nearly two years ago. The keyword is *ALE_COUPLING_NODAL_CONSTRAINT.

Meshless methods such as EFG and SPH don't satisfy Dirac-delta conditions for velocities and displacements at nodes. So constraining nodal velocities and accelerations will violate essential boundary conditions. We developed a penalty version of nodal coupling recently to enable the coupling between ALE fluids and Meshless methods. The keyword is called *ALE_COUPLING_NODAL_PENALTY.

ALE Essential Boundary

We developed *ALE_ESSENTIAL_BOUNDARY keyword to allow users conveniently prescribe velocity boundary conditions along the ALE mesh boundary. ALE does have a legacy version which is invoked by setting EBC=1 or 2 in *CONTROL_ALE card. The implementation was correct for EBC=1, which means all the boundary nodes are fixed at all directions. But the EBC=2 option, which allows for free tangential motion at the surface, had fundamental logic flaws and beyond repair.

ALE Rigid Body Coupling

Certain engineering problems requires resolving interactions between ALE fluids and Lagrange structure modeled as rigid body. For example, a shaker mixing fluids. Bottle deformation would not be a problem here. The fluid motion is the only thing matters here. A full scale modeling of this problem can be very time consuming as the ALE penalty coupling is costly. Another modeling technique would be make the ALE mesh conform to the Lagrange bottle then either make those boundary nodes shared or construct a tied contact between the ALE boundary nodes

and Lagrange boundary nodes. Problem with this approach is that the tangential relative motion between the fluid and bottle are killed by the shared nodes or constraints. We would find much less spillage as the water is going to be significantly quieter.

The new ALE rigid body coupling currently under test aims to solve the fluid-rigid body interaction with minimum overhead. It is an extension to ALE essential boundary. We require the ALE mesh shape conforms to the Lagrange structure. However, we still conserve the tangential relative motion between the two. The time spent on the FSI would be trivial compared to the full scale ALE/FSI.