Computational Physics and Methods

Coupled ALE-AMR for 3D Unstructured Grids

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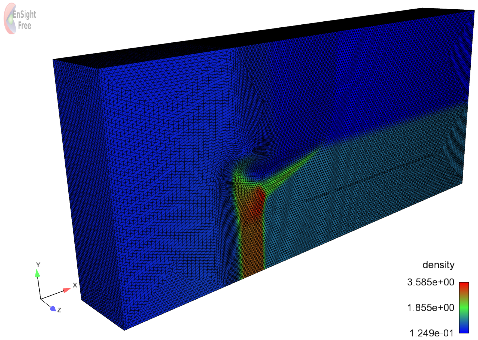
We are developing a numerical method that couples Arbitrary Lagrangian-Eulerian (ALE) and Adaptive Mesh Refinement (AMR) algorithms for shock hydrodynamics on 3D unstructured grids. ALE and AMR methods are widely used at LANL and other laboratories for shock hydrodynamics simulation. However, despite their individual success, very few examples of coupled ALE-AMR methods can be found in the literature and none address unstructured grids, which is a core technology in production ALE codes at LANL. A coupled ALE-AMR capability for unstructured grids is therefore a breakthrough technology that enables new classes of problems.

An ALE-AMR method may appear to simply require that both are implemented in the same code and compatible at the software level. However, this is a necessary but not sufficient condition. A useful analogy is multi-physics simulation: different physics packages must not only be implemented in the same code but also coupled in a physically correct manner. We couple ALE and AMR in a mathematically correct manner. This involves a number of questions that remain unanswered or even unasked: (1) Can an ALE mesh motion strategy be devised that preserves the mesh anisotropy introduced by AMR? (2) Can an ALE-AMR method satisfy the Geometric Conservation Law (GCL)? (3) Can error indicators for AMR be designed that account for the variations in mesh size produced by ALE? (4) Can an ALE-AMR method be demonstrated to converge? (5) Can an ALE-AMR method actually provide improved simulation quality?

A component of the coupled ALE-AMR method is to develop a theory and implement mathematical techniques to compute a physics-based motion of the mesh. Current mesh motion approaches either smooth local variations in mesh size or require mesh-dependent iterative smoothing. We instead set the mesh velocity equal to the irrotational component of the fluid velocity computed from a Helmholtz decomposition. This eliminates vortical mesh motion that can lead to tangling, yielding a unique mesh velocity for a given fluid velocity, independent of local variations in cell size. Another component of our mesh motion strategy is a spring-force model that increases the strength of a hypothetical spring, via a pressure-force, only in cells under compression, which prevents mesh cells from collapsing.

The combined capabilities of removing (some or all) mesh vorticity and compression increase the accuracy of numerical modeling of high-speed material flows, reduces uncertainty in simulation-based reponses to programmatic issues, and increases scientific insight.



Density field in a gasdynamics problem with shocks yielding a vortex. Such problems computed with Lagrangian or ALE methods are problematic due to the vorticity field which eventually tangles the mesh. In our new ALE method, we can locally remove part or the full voritcity from the mesh velocity and thus can run the problem farther in time compared to other ALE methods.

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