HERA: A Hydrodynamic AMR Platform for Multi-Physics Simulations

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Summary. The development at CEA/DAM of a new AMR multi-physics hydrocode platform led to convincing results on a wide range of applications, from interface instabilities to charge computations in detonics.

In this paper, we focus on:

1. A selection of numerical results illustrating gains to be expected from AMR in such fields, including precise comparisons between AMR and uniform grids (up to 100 millions cells in 2D using CEA's teraflops machine TERA-1).

2. An introduction to the hyperbolic framework and resulting suite of consistent multi-material compressible flow solvers (hydrodynamics, hypo-elasticity, nT hydro and nT MHD).

3. A presentation of an innovative hydrocode architecture, allowing three different parallel modes at runtime: (i) a MPI mode for uniform or well-balanced AMR grids, (ii) a multithread mode on SMPs and (iii) a hybrid MPI/multithread mode on clusters of SMPs. Multithreading is used there to diminish grain sizes, to control memory cache effects and dynamic load balancing.

4. Finally, an overview of the user-model API is given, in both C++ and Python vector modes, for platform extensions using Strang-type operator splitting.

1 Multifluid hydrodynamics

For many users of traditional Lagrangian, ALE or Eulerian hydrocodes, one of the first objections to AMR is usually that “soon or later, AMR grids have to be refined everywhere to capture the growing complexity of most unsteady flows”. Detailed numerical comparisons between AMR and uniform grids of same finest resolutions are then quite helpful. Up to now, such comparisons are not widely available in the literature. The next two examples have been used for a number of years, among others, to get support for the HERA¹ project. The third example involves a more complex flow, making use of CEA’s teraflops machine TERA-1 to get a reference uniform grid result, for comparison to AMR in 2D.

¹French acronym for Hydrodynamique Euler Raffinement Adaptatif.
Single-mode Richtmyer-Meshkov

The goal of the first test problem is to illustrate that cell-by-cell AMR, pioneered more than a decade ago in multifluid context using interface tracking [3] or concentration equation [5], may reveal surprisingly efficient when used with interface reconstruction and elementary grid strategies.

As illustrated Fig. 1, the finest level of 2x2 AMR refinement is applied on the incident shock, on the transmitted shock during the first instants, and on the interface during the whole computation. The comparison of AMR and uniform grid results clearly indicates that the interface instability is well-reproduced using such a simple AMR strategy, leading to a substantial reduction of the total number of cells and CPU time.

Fig. 1. Single-mode Richtmyer-Meshkov instability using a cell-by-cell 2D/AMR grid with interface reconstruction (StonyBrook #1 benchmark, 96 cells per wavelength). The AMR computation is about 7 times cheaper than the uniform grid one, without any significant difference on the development of the interface instability.

Shaped charge computation

In a different context – armor-anti armor – but with a very same AMR strategy, the finest 3x3 refinement level is here imposed on the detonation wave treated by a programmed burn approach, on the reflected shock in the detonation products, and on the liner during all the computation.