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SUBMITTED TO: 1995 APS Topical Conference on Shock Compression of Matter,
13-18 August, 1995, Seattle, WA

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MODELING CYLINDER TEST

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The dynamic behavior of a copper tube containing high explosive PBX 9502 is studied. The detonation of the explosive propagating along the axis drives the copper tube radially outward. A multi-process reactive model is used to simulate the explosive burn behavior in an Eulerian hydrodynamic code. In addition, an adaptive mesh refinement technique is featured in controlling the computational mesh size as the detonation wave moves in and out of a region. Comparison with experiments is made to show the capability of the new hydrocode.

INTRODUCTION

The high explosive (HE) detonation wave reaction zone affects not only the wave curvature but also the hydrodynamic force close to the detonation wave front. It is recognized that for carbon-rich explosives including TATB, the reaction zone can be as long as 2 mm or even longer for most composite explosives. Inside the reaction zone region, the hydrodynamic behavior is controlled by a partially reacted state, not the final products (1). In a typical engineering system, the explosive energy is transferred to a metal shell, and the initial or early motion of the shell depends on the hydrodynamic effect of the partially reacted explosive. Without taking the reaction zone into account, the early motion of the shell cannot be simulated accurately.

To determine the partially reacted state correctly, we must resolve the reaction zone by having a sufficient number of computational cells in the detonation front region. Away from the front, fine zoning is usually not necessary, and the mesh size should be coarsened to save memory space. However, near the boundary where the HE is bordered with other materials, shock reflection and transmission occur, producing very large gradients in some physical parameters, and so fine zoning is again needed to determine the precise hydrodynamic conditions even though the force field is controlled entirely by the final products alone. Even the interior of a single HE region cannot be always assumed smooth hydrodynamically whenever there are shock or compression wave interactions. All the above considerations also apply to other material regions when strength model is used, for example. A dynamic mesh configuration seems to be a desirable feature in the simulation of explosive system behavior. This paper demonstrates such a feature in simulating cylinder tests.

ADAPTIVE MESH REFINEMENT

An Eulerian hydrocode with an adaptive mesh refinement (AMR) capability has been developed. In the code the adaptive mesh capability anticipates and adapts the mesh to the physics and then automatically nests more refined meshes within coarser meshes. A judicious selection of features which a mesh must exhibit makes the production of an adaptive mesh code possible. Material interfaces are captured on the finest level mesh. Subzonal material interfaces are reconstructed using Youngs' volume fraction technique (2). A zone must refine completely not partially. Coarsening must produce a parent zone. Each mesh level is nested completely within the next coarser mesh level. Boundary zones exist at the same level as their neighbor zones inside the boundary.

Local anticipatory adaptivity is achieved through the use of a "mesh potential." Physical phenomena are "captured" at appropriate mesh levels. The mesh potential is defined by first locating zones which must be refined. A definite sequence is used to determine whether or not a zone is scheduled for refinement. First, material interfaces are captured by
assigning a value to the mesh potential that will ensure that they are captured on the finest mesh level. Next, shocks are captured using White's artificial viscosity (3), and a value of the mesh potential is assigned to ensure that shocks are captured at the finest mesh level or at a user-defined mesh level. The next step involves using either of two possible procedures to capture variations in density and various energy densities. One procedure uses an estimate of the local total-energy error to assign a value to the mesh potential which will ensure that a mesh level is chosen to reduce this error below a specified value. The other procedure compares the minimum local radii of curvature of kinetic energy density, material density, and, gradient scale lengths in velocity to the zone size to assign a value to the mesh potential which ensures that a mesh is chosen to resolve these scales by a specified number of zones.

The mesh potential of a zone is chosen to be the maximum found using interfaces, shocks, and either of the two procedures defined above. For each mesh level starting from the finest level from the positive integers defined by capturing the physics, the mesh potential is decreased by one per zone in every direction away from these capture zones until a mesh level boundary is encountered. Again, the maximum mesh potential found in a zone is retained. If at the boundary a mesh potential greater than zero is encountered, the mesh potential in the coarser zone is raised to a level which will ensure nesting. Zones with zero mesh potential are unchanged while those with negative mesh potential are scheduled for coarsening.

CYLINDER TEST SIMULATION

The objective of cylinder tests is to extract the equation-of-state (EOS) information. A copper tube is filled with explosive, and detonation is initiated at one end. The motion of the copper tube is monitored, and typically the wall displacement is recorded using a streak camera. The wall velocity is sometimes measured that gives more accurate information about the early phase of motion. The explosive diameter is usually 2.54 cm, and the copper tube wall thickness is 0.26 cm. Measurement is taken only at some distance from the initial initiation plane. In this paper, instead of extracting EOS data, we perform a direct simulation of the cylinder test using the hydrocode with the AMR capability. Figure 1 shows the initial mesh configuration with the length scale in cm. The top region is void, the middle copper, and the bottom HE. The bottom boundary is the axis of symmetry. A total of six mesh levels is used, ranging from 0.25 mm to 8 mm. The smallest size is sufficient to resolve the reaction zone thickness of about 2 mm. As we see in the figure, the first consideration in fine zoning is the material interface without any hydrodynamic effect. Instead of a programmed burn model used typically in this type of simulation, a multi-process reaction model is employed to

FIGURE 1. Initial mesh configuration for cylinder test simulation.
simulate the reaction behavior of PBX 9502 (95% TATB, 5% Kel-F) (4). In the model there are four major reaction processes: hotspot, energy transfer, nonequilibrium excitation, and slow reaction. Near the detonation front, the last two reaction steps are dominant; but close to the HE boundary, the first two become the major controlling mechanisms which are sensitive to the local hydrodynamic condition. A JWL EOS with a small adjustment from the documented one (5) to account for the reaction zone effect (6) is used.

After the detonation propagates to some distance, the mesh configuration and the pressure contours near the detonation front are shown in Fig. 2. We can easily see how the mesh conforms to the pressure distribution as the contour spacing varies, even though the pressure itself does not contribute to the mesh potential directly; the closer the space is, the finer the mesh becomes. The curvature of the detonation front near the copper tube is caused by the weakening of the reaction rate through the hotspots and energy transfer processes as the rarefaction wave moves into the region. Furthermore, the flow field is not so homogeneous as expected and is caused by the complexity the wave reflection and interaction. Figure 3 shows
mainly the gradual enlargement of the mesh size inside the HE region farther away from the detonation front.

The wall displacement versus time is shown in Fig. 4, both experimentally and computationally. Overall, the simulation is quite satisfactory, although we notice the slight delay in the early time, but it overtakes in late time. We believe the products EOS needs further improvement because in the original calibration process to obtain the EOS parameters, the reaction zone was not accounted for and the curvature effect was ignored. More on the topics will be reported in the future.

CONCLUSIONS

We have demonstrated the usefulness of the AMR technique to simulate HE behavior in a system such as the cylinder test using a realistic reaction model. This is the first attempt to bring the two very important aspects together in hydrodynamics: reaction and mesh size. The success of this simulation ensures the role of the AMR technique in other hydrodynamic problems with different physics involved.

ACKNOWLEDGMENTS

The work is supported by the United States Department of Energy under contract W-7405-ENG-36.

REFERENCES