Multiphase Flow Approach toward Fluid-Structure Interactions

Xia Ma, Qisu Zou, Duan Z. Zhang, W. Brian VanderHeyden, and Nely Padial-Collins, T-3

Fluid-structure interactions with possible large deformations pose a great challenge to numerical simulations. These types of problems include interactions of solid high explosives (HE) and product gas generated from chemical reactions at the initiation of explosions, projectile-target interactions, etc. In these cases one needs to consider the stress states in both the solid phase and the fluid phase. An Eulerian mesh-based method encounters significant difficulties associated with numerical diffusion. A Lagrangian mesh-based method encounters the mesh-tangling problem. Expensive re-meshing procedures need to be done frequently. To meet these challenges, we represent different materials by different phases and treat the problem as a multiphase flow problem. To take the advantages of both Lagrangian and Eulerian methods, while avoiding their disadvantages, a particle-in-cell (PIC) method is employed to represent the solid phase.

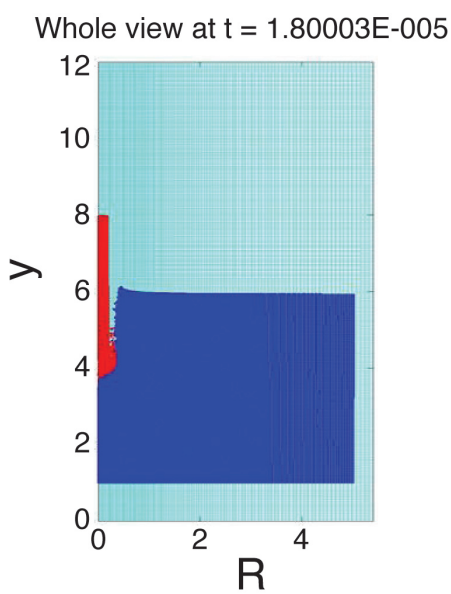

Fig. 1.
The tungsten problem.

In the method the fluid phases are computed on an Eulerian grid only and the solid phase is represented by particles and also represented on the same Eulerian grid. The solid particles are Lagrangian material points. Information like deformation, stress, damage, etc. is carried on the particles. Certain information of the solid phase is interpolated back and forth between particle and the Eulerian grid to account for the interaction with fluids. These ideas are implemented in an award-winning (R&D 100, 2005) computer package called CartaBlanca using the object-oriented language Java. The features of the Java language enable us to easily implement many practical engineering material models and to perform parallel calculations easily.

We also extended the multiphase flow theory by studying a multipressure model. In many calculations of multiphase flows, a single pressure called the equilibrium pressure is used for all phases. However, in some of the continuous multiphase flows, the notion of the equilibrium pressure encounters conceptual difficulties. For instance, the single pressure model cannot be used to study the tension break of a sponge with interconnected pores filled with air because the air can never go into tension. We found that the equilibrium pressure model corresponds to a particular assumption in deriving the multiphase flow equations. Other assumptions are also possible, and one of the assumptions that we propose leads to a multipressure model. This model is also implemented in CartaBlanca.

To validate our implementation of the PIC method, a simulation of tungsten penetrating a steel plate was performed. It is a case with cylindrical symmetry. Figure 1 shows the problem in the middle of penetration, and Fig. 2 is a comparison of the simulation and the experiment for the tungsten tail position and the lowest penetration point. The

agreement with experiment is quite good. To demonstrate the capability of the two-pressure model, we consider a spalling damage case for a porous plate. At time t = 0, a plate of thickness h impacts a thicker plate of the same material of thickness 2h with velocity V. Both plates have a small air volume fraction and are surrounded by air. At the impact time, a compression stress wave with strength σ is generated, travels in both directions, and reflects at the boundaries to become two tensile stress waves. At a certain time, the two waves meet at the middle of the thicker plate to generate a tensile stress of 2σ. If the material strength is between σ and 2σ, the thicker plate breaks at this point. Figure 3 is a sketch of the problem, and Fig. 4 shows the simulation result. The blue part represents both plates together with a black dashed line indicating the interface of the plates; the red color indicates the damaged part. Thus, the breakage indeed occurs at the middle of the thicker plate. The damage time and the impact stress are compared with elastic theory and found to agree with the theory with errors of 5% and 11% respectively. Finally, we apply the code to an HE problem using the multipressure model. Figure 5 shows the case of a drop-skid problem: an HE charge of hemisphere shape is swung into a plate. Ignition depends on the drop height and the property of the plate. Figure. 6 is a plot of the 2-D simulation result when ignition occurs. Simulations for different drop heights and different plates are in agreement with experiments in terms of "go" or "no go," that is, whether or not an explosion occurs.

For more information contact Qisu Zou at qisu@lanl.gov.

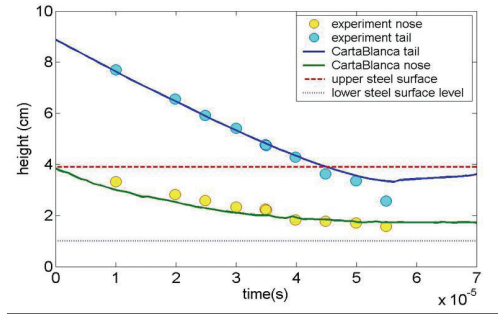

Fig. 2.
Comparison with experiment of the tungsten problem.

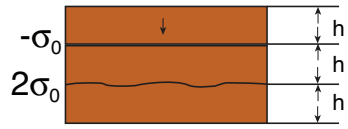

Fig. 3.
The spalling problem.

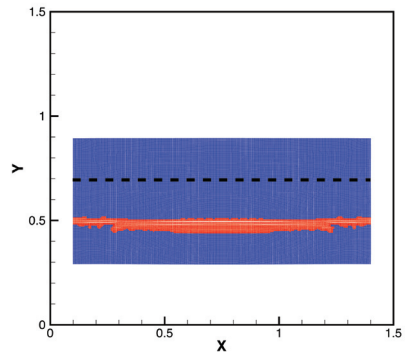

Fig. 4.
Simulation result of the spalling problem.

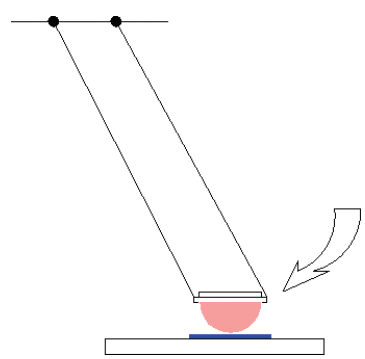

Fig. 5.
The drop-skid problem.

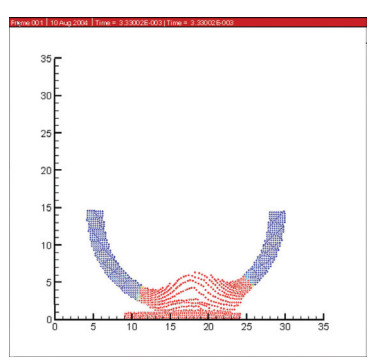

Fig. 6.
A snapshot of the drop-skid simulation.