

CHAPTER 1

INTRODUCTION

Today, most scientific researchers are challenged with the pace of the dynamic software and hardware industries. For example, computer scientists are using the C^{++} programming language for object-oriented programming while the large scientific codes are still maintained in Fortran 77 programming language. It is very difficult for a good physicist to write a complex code that solves the pertinent partial differential equations using a modern language like C^{++} . However, the gap between the computer scientist and the physicist can be narrowed down by introducing a better numerical method. This is the hope and the purpose of this book.

For multi-material problems, Lagrangian method is the most accurate tool for tracking the material interfaces, assuming that the material deformation is minimal. As soon as the deformation becomes large, the computational mesh starts to form a long thin zone or slender zone that will terminate the calculation due to an unaffordable small time step.

For the last 35 years, the scientists working on Lagrangian codes spend most of their time trying to fix these mesh tangling problems.

Due to its fixed grid mesh, Eulerian method can handle large deformation. However, the accuracy of calculating the mass, momentum, and energy flux across the zone boundary can be challenging. The other difficulty associated with the Eulerian method is the tracking of the material interface that tends to be smeared and fuzzy. Therefore, most of the code developers using Eulerian equations are battling with the flux or the advection and the material interfacial problems.

The main idea of Arbitrary Lagrangian and Eulerian (ALE) method is to create a code that preserves the advantages of both Lagrangian and Eulerian methods. At the same time, the ALE method aims to avoid the weaknesses of the Lagrangian and Eulerian methods. However, no matter how clever you are, mother nature seems to always work against you. Frequently, the ALE method will end up taking the weaknesses of both the Lagrangian and Eulerian methods. Using the ALE method without falling into the pitfalls is a delicate art.

Free Lagrangian method was first brought into attention at Lawrence Livermore National Laboratory in early 1970. A few years later, two-dimensional free Lagrangian codes were developed and used by many researchers throughout the world. This method becomes very popular during 1985–1990. After 1990, the research work on the free Lagrangian method decreased drastically due to the difficulty in calculating the particles when they are moving too closely. Today, most of the researchers are working on “Smooth Particle Hydrodynamic” that is a subset of the free Lagrangian method.

Free Lagrangian method uses nodes but no grid to represent the fluid and solid material. The advantage is its fast computation that consumes less CPU. The problem of this method arises when the material is squeezed spherically from the outside towards the center. Since too many nodes are confined in a small volume, the calculation starts to lose its accuracy. Also at this moment, the nearest neighborhood searching becomes very confusing.

The Riemann solver, or its family member, such as the Godunov or the Total Variation Diminishing (TVD) methods, is the best numerical scheme for solving one dimensional shock problems. The essence of this method lies in its dividing the original shock problem into two regions using the shock front as the connecting boundary for these two regions which have no discontinuity inside its own domain. The Riemann solver has been used in both Lagrangian and Eulerian coordinates and the results from these two approaches are all excellent. Many researchers are trying to extend this method into multi-dimensional shock wave problems with the real material equation of state.

For shaped charge problems, most of the wave codes use programmed burn for computing the chemical released energy from high explosive. The programmed burn model, although not as accurate as the reactive burn model, is simple and robust. If one would modify the detonation speed while considering the burning front curvature’s effect, then the programmed burn model will become more accurate for the insensitive explosive. In principle, the reactive burn model is more desirable due to its accuracy. However, in the large code calculation, it becomes impractical for the reactive burn approach because it requires an enormous large core memory and CPU.

The performance of the shaped charge jet is mostly dependent on the grade of the liner material and the energy of the high explosive. The pressure wave interactions between the burned explosive gas and the neighboring material, i.e. liner or casing, are so complicated that it is very difficult for the laboratory test to identify these material characteristics. By using the

two- or three-dimensional Eulerian hydro codes, it is possible to design a good shaped charge while specifying the thickness and geometrical shape of the liner and casing quantitatively. The grain size and the uniform density in the high explosive are also important in the formation of the shaped charge jet.

Explosive formed projectile (EFP) is made up of casing, detonator, high explosive and liner. When the projectile hits the target, the EFP speed usually exceeds 2 km/s and the mechanical power can be huge due to its speed and mass. During 1970s, the EFP technology advanced dramatically through the use of 2D and 3D Lagrangian hydro codes. Today, designers use Lagrangian or finite element code exclusively to obtain flared EFP, finned EFP, and long-rod EFP by varying the thickness and the geometrical shape of the liner. A thicker casing may increase the explosive impulse and increase the liner speed as a result. However, there exists an optimal thickness of the casing for any special EFP.

Penetration always involves a penetrator and a target. For example, a tungsten rod penetrates an aluminum plate. Usually, the penetrator will have a relatively high speed as compared with the target. In the first stage of the penetration process, the kinetic energy of the penetrator becomes heat energy which is shared by the penetrator and the target at the contact interface. As the temperature rises, the material of both the penetrator and the target at the interface start to melt and, eventually, a crater forms inside the target.

In Appendix A, the Lagrangian method described in Chapter 2 is extended to include the radiation transport which is solved by using the Variable Eddington (VE) approximation. The VE approximation uses both the Rosseland and Planck mean opacities and is capable of describing the radiation transport in optically thin and thick systems. Energy exchange between the material and the radiation field due to Compton scattering and the attendant spectrum changes are also taken into account.

The numerical method for calculating the thermonuclear burn of deuterium-tritium sphere is described in Appendix B. In this appendix, the couplings between the photon and the electron, and between the electron and the ion, are discussed in a Lagrangian coordinate system which is described in Chapter 2. The logical procedure and the calculation steps for solving the non-homogeneous and non-equilibrium transport equations are also discussed.