Application of a CFD Modeling Framework to High Energy Density Regimes

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Abstract: High Energy Density (HED) experiments provide an excellent platform for modeling and validation of CFD codes in the plasma-fluid regime. We describe the adaptation of a CFD framework to model HED regimes in the fluid limit. Experiments that can be modeled and visualized with the code provide a means for testing advanced computational algorithms for multiphase flows. Particular attention is given to methodology to model droplet targets heated by a high repetition rate x-ray free electron laser (XFEL). This application exercises parts of a more generic CFD framework that also has a variety of more traditional CFD applications such as hypersonic flight.

Keywords: CFD, HED, Droplet Formation and Interaction, high speed flows

1 Introduction

Material in HED regimes are at very high pressures and temperatures but can often still be modeled in the plasma-fluid approximation. Historically HED regimes were created using large laser/ion-beam drivers heating solid targets. Exciting data was obtained from these single shot experiments. In recent years there has been a shift to obtain HED related data from a large number of shots by using high-repetition-rate drivers. For high-repetition-rate experiments a series of droplet targets are often used to have a fresh target/droplet for each shot. However, one must make sure that target debris from the previous shot does not degrade the target for subsequent shots. This is a challenging CFD problem as one needs to model the initial dynamics of the heated droplet and the subsequent interaction with the following droplet. We discuss results for liquid hydrogen droplets heated by an XFEL.

2 Initial Results

The energy deposition from an XFEL pulse is nearly uniform through a 5 micron diameter hydrogen droplet and can be modeled in PISALE (https://pisale.bitbucket.io/) by imposing an initial temperature. We use axial symmetry to model a single droplet in 2D with the XFEL beam on the z axis. The initial conditions are shown in Figure 1. Because of symmetry it is only necessary to model 1/4 of the droplet. The evolution of the droplet density is shown in Figure 2. Note that the density scale is changing with time. The y-axis in this figure extends out to 10 microns, which is the approximately location of the edge of the following droplet.

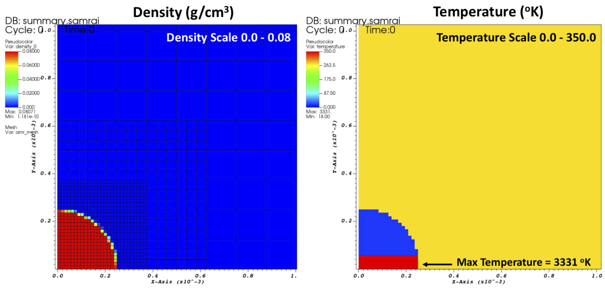

Figure 1: Initial conditions for a 5 micron hydrogen droplet heated by an XFEL beam. Left image shows the density and the AMR mesh. Right image shows the initial temperature.

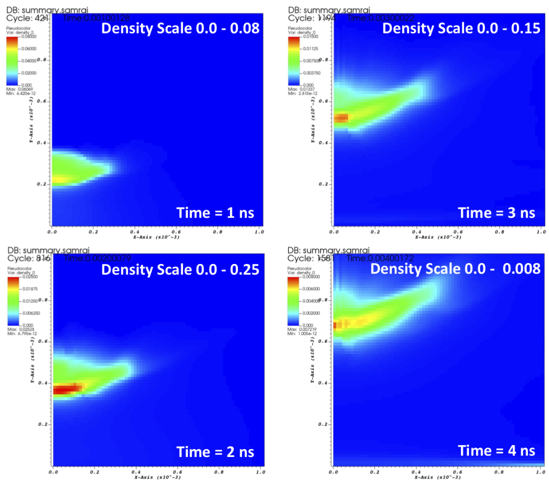

Figure 2: Density of the hydrogen droplet at 1, 2, 3, and 4 ns.

3 Current Simulations

We model multiple droplets in 3D simulations including up to three hydrogen droplets. If the following droplet is impacted too much, it is possible to hit every other droplet but causes a reduction in data quantity. We plan to model three droplets because the data on water droplet fratricide shows that even the second following droplet can be impacted [1]. In addition to hydrogen droplets, we plan to model water droplets heated by XFEL beams and compared with this experimental data. For both hydrogen and water droplets, the effect of surface tension on the dynamics of the droplet heated by the XFEL beam is generally very small but is important for the following droplets. While the surface tension coefficient for hydrogen is significantly smaller than the coefficient of other materials we have modeled previously, we have not found any reason that the height function approach that we use in PISALE would not be an appropriate choice for both hydrogen and water. Results are relevant to ongoing modeling of rain droplets interacting with hypersonic vehicles.

References

[1] C.A. Stan, et al. Liquid explosions induced by x-ray laser pulses. *Int. Nature Physics,* 12(5):966–971, 2016.