Planar hydrodynamic instability computations and experiments with rugby-shaped hohlraums at the Omega laser

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Abstract. Implosion of inertial confinement fusion (ICF) capsule is very sensitive to the growth of sphericity perturbations. The control of the feeding of such perturbations and their transport (“feedthrough”) through the ablator is a key point to reach ignition. Since 2002 [1, 2], experiments have been designed and performed on the Omega laser facility in order to study these phenomena in planar geometry. A new “rugby shaped” hohlraum was used [3,4]. We present experimental results and comparisons with numerical simulations.

1. Introduction
A major goal of inertial confinement fusion (ICF) is to ignite a deuterium-tritium pellet. This pellet is encapsulated within a layer of material, the ablator. This outer shell is ablated by x-rays coming from the hohlraum and the pellet iscompressed until it ignites. CHGe is a potential ablator for the Laser MegaJoule (LMJ) capsule and we have investigated its sensitivity to hydrodynamics instabilities. Rayleigh-Taylor instability (RTI) and feedthrough mechanism are sensitive to radiative drive, spectrum, opacity and the equation of state and provide benchmark to radiation-hydrodynamics code. The OMEGA laser facility enables multiple beam cone irradiations similar to LMJ configuration: LMJ beams can be gathered in 3 illumination cones. On Omega, we have used a new rugby hohlraum with 3 laser cones in order to drive ablator samples mounted on a hole in the midplane of the hohlraum.

2. Set-up
2.1. Experimental
The targets were gold hohlraums with 2760 µm inside length, 1600 µm inside diameter, and with 1200 µm diameter laser entrance hole (LEH). We used rugby-shaped hohlraums in a 3-laser cone configuration consisting of 5, 5, and 10 beams, which enter each LEH at 21.4°, 42°, and 58.9° relative to the symmetry axis. The 21.4° beams heat the opposite wall to their LEH. Each beam delivers 350 J in a 2.6 ns shaped pulse. The hohlraum radiation temperature is diagnosed with the absolutely calibrated, time-resolved, spectrometer Dante [5] but also, more recently, with the spectrometer DMX [6]. Such measurements were done through, either the LEH or a hole in the midplane of the hohlraum wall. Ablator is studied via planar modulated samples mounted on a hole in the midplane of the hohlraum. Sample thickness is 45 µm and perturbations wavelengths are 35, 50 and 70 µm. Modulations are either front-side (in direct view of the x-ray flux from the hohlraum) or rear-side, in order to study RTI or feedthrough, respectively. Face-on and side-on radiographies are realised simultaneously to characterize the instability growth and the sample velocity, respectively. Perturbation growth in optical depth (o.d.) is extracted from Fourier analysis of lineout across the bubble and spike images after removal of the backlighter shape. This analysis gives the time-evolution of the perturbation.
2.2. Numerical
In order to analyze the experimental data, we use the FCI2 code [7] which is a two-dimensional (2D) Lagrangian radiation hydrodynamics code. The atomic physics takes into account nonlocal thermodynamic equilibrium and radiation exchanges. The laser beam is described by a ray-tracing method. Diagnostics are simulated and raw FCI2 results are post-processed via the DIXIM code [8]. It takes into account pinhole effects, spectral attenuation of filters, time and space integration. As experiments are three dimensional due to the sample location, midplane flux is first extracted from a 2D hohlraum simulation without diagnostic or sample holes. Using this extracted flux as a drive, another 2D simulation is run to get the ablator sample acceleration and perturbation growth.

3. Hohlraum energetics
3.1. Radiative temperature through LEH
Radiation drive and flux are described in terms of the equivalent black body radiation temperature, $T_r$. We present comparison between the Dante $T_r$ measurement of one shot and the corresponding simulation which takes into account the back-scattered laser measurement. Figure 1 shows the good agreement between measured and computed time-dependent $T_r$ as seen by Dante through the LEH.

![Figure 1](image1.png)

**Figure 1:** Comparison between numerical and experimental $T_r$ measured through the LEH.

![Figure 2](image2.png)

**Figure 2:** Comparison between $T_r$ measured through the LEH and at the hohlraum midplane. a) experimental data. Inset: set-up of measurements. b) numerical data

3.2. Midplane $T_r$
Since 2002, a strong discrepancy has occurred between the foil velocity computed with the extracted flux in the midplane of the hohlraum and experimental data: experimental velocity is lower than the predicted one and is consistent with a 50% reduction of the computed flux. As a consequence, one shot has been devoted to the measurement of the midplane $T_r$ through a hole in the side of the hohlraum. Figures 2 show the $T_r$ obtained in the experiment and the simulation: the discrepancy is 30eV between LEH and midplane $T_r$ in the experiment (consistent with a 50% flux reduction), and only 5eV in the simulation. First refined simulations seem to show that the 21.4° beams slide out of the hohlraum (~300 µm motion) and that it could reach and heat the border of the sample hole (figure 3).

![Figure 3](image3.png)

**Figure 3:** Isovalues of Log ne at $t = 1.65$ns for a rugby hohlraum. Contours of 21.4° beams are superimposed: plain and dashed shaped are for the coarse and refined simulations, respectively.
This could lead to the closure of the hole and thus, to the apparent drop of the midplane $Tr$. Let us remark that 50% flux reduction corresponds to a hole closure of 100 $\mu$m for an initial 350 $\mu$m radius. We believe that such a displacement of the 21.4° beams could have already occurred without being noticed in Omega experiments (see figure 2 of Ref. [9]). Furthermore, similar discrepancies have already been identified [10] between midplane and LEH $Tr$, and explained by hole closure effects. Other refined simulations and model will be run in order to confirm this explanation and evaluate the time history of the hole closure. Finally, as foil velocity computations with reduced flux are in agreement with the experimental data, hereafter simulations of perturbation growth will use a 50% reduced baseline flux for drive radiation.

4. Perturbation growth

4.1. Single mode perturbation

Since 2002, CHGe and CHBr surrogate ablator are tested with single mode sinusoidal perturbation. The foil velocity is matched by simulations. Two kinds of simulations have been run with and without taking into account the M-band in the radiative spectrum to compute the growth for the fundamental mode. To have good agreement between data, it is necessary to consider the hard x-ray part of the flux (M-band) impelling the foil and not only its black body emission. Good agreement is obtained either for RTI or feedthrough experiments.

4.2. Bi-mode perturbation

4.2.1. Numerical predictions

3 at. % Ge-doped CH foils have been modulated using the combination of two sinusoids with respective wavelengths 35 and 70 $\mu$m. As the first one is the harmonic of the second one, coupling between the two modes is enhanced. We chose two configurations in order to clearly see mode coupling effects. The first one consists in engraving the sinusoids in phase, i.e. $y(x) = \cos(2\pi x/70) + \cos(2\pi x/35)$, where $y(x)$ is the amplitude of the perturbation at the position $x$ (in microns). As shown in figure 4-a, simulations predict a reduction of the 70 $\mu$m mode.

![Figure 4:](image) Simulations of the growth of the perturbations for the bi-mode cases. a) pattern in phase. 2 $\mu$m peak-to-valley (ptv) amplitudes for the 70 and the 35 $\mu$m modes. b) opposite phase pattern. 4 and 2 $\mu$m ptv amplitudes for the 70 and 35 $\mu$m modes, respectively.

The second one consists in an opposite phase pattern, where $y(x) = 2\cos(2\pi x/70) - \cos(2\pi x/35)$. In this case, simulations predict a greater growth of the 70 $\mu$m mode than in the single mode case, and a phase inversion resulting in a delayed growth for the 35 $\mu$m mode (figure 4-b).

4.2.2. Experimental results

For the pattern in phase, figure 5-a shows growths which are qualitatively similar to the predicted one: 35 $\mu$m mode growth is unaffected by the coupling; unfortunately, data are missing to clearly show the expected reduction of the 70 $\mu$m mode due to the coupling.
Figure 5: Experimental data. Comparisons between growths of the perturbations for the single and the bi-mode cases. a) pattern in phase. b) opposite phase pattern for $\lambda=35\ \mu m$. c) opposite phase pattern for $\lambda=70\ \mu m$. For the 35 $\mu m$ mode in the opposite phase pattern, phase inversion could not be seen as the amplitude of the o.d. remains under the detection threshold. But it is clearly seen on data (figure 5-b) that the growth is delayed in the bi-mode case which is consistent with the simulations. On the other hand, experiments show the expected behaviour of the 70 $\mu m$ mode: its growth is slightly enhanced by the coupling effect (figure 5-c). Finally, these comparisons need further data measurements and further simulations to validate the expected mode coupling effects, but these are encouraging results and no inconsistency has been found between experimental and numerical data.

5. Conclusion

Since 2002, experiments have been performed on the Omega laser facility to study the sensitivity of the LMJ CHGe ablator to hydrodynamic instabilities. In order to drive the ablator foil, a novel rugby shaped hohlraum has been designed and used. Radiative temperatures are clearly on the way to be fully understood as numerous clues indicate a midplane hole closure. This would explain the half-baseline flux used to recover the experimental foil velocity and perturbation growths. As a consequence, RTI and feedthrough data are well understood for single mode perturbation with FC12 simulations. Bi-mode perturbations have also been studied and mode coupling effects have been seen. To fully ascertain the agreement between experiments and simulations, new data points are needed. Nevertheless, first comparisons are encouraging and constitute another step to validate further our modelling of plasma physics in the context of indirect drive ICF.

References

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