New designs of LMJ targets for early ignition experiments

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Abstract. The LMJ experimental plans include the attempt of ignition and burn of an ICF capsule with 40 laser quads, delivering up to 1.4MJ and 380TW. New targets needing reduced laser energy with only a small decrease in robustness are then designed for this purpose. A first strategy is to use scaled-down cylindrical hohlraums and capsules, taking advantage of our better understanding of the problem, set on theoretical modelling, simulations and experiments. Another strategy is to work specifically on the coupling efficiency parameter, i.e. the ratio of the energy absorbed by the capsule to the laser energy, which is with parametric instabilities a crucial drawback of indirect drive. An alternative design is proposed, made up of the nominal 60 quads capsule, named A1040, in a rugby-shaped hohlraum. Robustness evaluations of these different targets are in progress.

1. Introduction

The Laser Mégajoule (LMJ) facility is located at the Commissariat à l’Energie Atomique center CESTA near Bordeaux in France. It will deliver up to 2MJ and 550TW of $\lambda = 0.35\mu m$ light. The standard approach for achieving ignition on the LMJ relies on the indirect drive scheme. Our nominal point design target A1040 is composed of a graded doped plastic capsule in a gold cylindrical hohlraum [1]. Robustness studies have been done for this design [2], showing that specifications based on current CEA capabilities [3] give reasonable margins. The experimental plans include the attempt of ignition and burn of an ICF capsule with 160 beams in 2 cones ($33.2^\circ$ and $49^\circ$), delivering up to 1.4MJ and 380TW at $3\omega$. New targets needing reduced laser energy with only a small decrease in robustness are then designed for this purpose. A first strategy, illustrated in section 2, is to use scaled-down cylindrical hohlraums and capsules, taking advantage of our better understanding of the problem, set on theoretical modeling, simulations and experiments. Another strategy is to work specifically on the coupling efficiency parameter, i.e. the ratio of the energy absorbed by the capsule to the laser energy, which is with parametric instabilities a crucial drawback of indirect drive. An alternate configuration is proposed in section 3, with a rugby-shaped hohlraum [4] exhibiting a better coupling efficiency and symmetry control of the implosion than a cylindrical one for the specific energy balance of the 160 beams configuration. In the last section we finally describe a novel ablator configuration [5] still under investigation, in order to release the surface roughness specifications of the capsule.
2. Design of scaled-down targets

We have first designed new 300eV capsules which need less energy with a small decrease of robustness compared to our nominal 60 quads capsule A1040. The capsule designs have been first defined by a 0D-model [6], and then confirmed by 1D simulations giving the $T_R$ law optimization. The selected capsules A850 (about 110KJ absorbed) and A943 (about 140KJ absorbed) have the same in flight aspect ratio than the capsule A1040 (about 160kJ absorbed), which is a signature of the shell break-up risk, while the 1D robustness quantified by the excess in kinetic energy above the ignition threshold is decreasing by less than 20%.

Figure 2 shows the capsule thicknesses optimized for an uniformly 0.25% germanium doped plastic ablator, while the LMJ point design is now including gradually doped ablators. As the capsule sensitivity to hydrodynamic instabilities is very dependant on the hohlraum spectrum, the ablator thickness and dopant structure are still optimized in 2D simulations.

Integrated simulations of both capsules have been led with our 2D hydro-radiative code FCI2. The scaling is done for a given ratio of hohlraum equatorial radius over capsule radius, as this parameter is representative of the flux uniformity around the capsule. In this 2 cones configuration, the size of the Laser Entrance Holes is taken equal to 1.5mm for cylindrical hohlraums, to compare to 1.75mm for the 3 cones design. The gas filling, used to limit the wall motion, is a 0.83mg/cc to 1.3mg/cc H$_2$-He mixture, contained by a polyimid window. Controlling the time-dependent symmetry in this specific 1/2-1/2 balance configuration is more difficult than in the nominal 3 cones configuration. The symmetry control can be obtained by increasing the aspect ratio (half-length over equatorial radius) of the cylinder. An alternative way is to break the inner cone in two, which leads back to a configuration close to the nominal one. All A850 integrated simulations corresponding to small design variations produce 11MJ yield with an energy budget of 850kJ and a power laser up to 300TW. LPI evaluations show slightly enhanced risks in these small targets compared to the nominal 60 quads one.

Igniting the A943 capsule in a gold cylindrical hohlraum is still in the budget (1.17MJ, 363TW) and produces 21MJ. Cocktail walls will be an additional ingredient to save energy (approximately 10%), and first 2D robustness calculations are encouraging. LPI evaluations are under progress, but
first insight is given by the plasma profiles along the outer and inner beam paths at maximal laser power, shown in Figure 3.

![Figure 3: Plasma profiles along the outer and inner beam paths at maximal laser power](image)

3. Alternate hohlraums

Rugby-shaped hohlraums have many advantages over cylindrical ones for the 40 quads configuration. First, minimizing the hohlraum wall surface while keeping the equatorial radius constant improves the coupling efficiency, as approximately half the laser energy is used to heat the walls. But the rugby shape has also a significant advantage for the control of the radiation asymmetry on the capsule with a 1/2-1/2 energy balance. Bending the walls toward the center of the hohlraum helps increasing the outer ring contribution near the level of the inner ring and leads to a better drive of the capsule.

![Figure 4: Thermonuclear yield as a function of the maximum laser power. Appended is the value of the maximum implosion velocity of the solid DT shell, in µm/ns. Laser pulse shapes used for simulations are in inset.](image)

Since 2002, the rugby-shaped hohlraum concept has been tested at small scale on Omega [4,7] and has been also studied for non cryogenic ignition capsules [8]. We have performed integrated FCI2 simulations of the nominal A1040 capsule in a gas-filled rugby hohlraum with the same equatorial radius than the nominal 60 quads hohlraum (3.1mm), slightly smaller length (10mm instead of 10.46mm), and smaller LEHs (1.4mm instead of 1.75mm) [4]. Variations on the laser pulses shown in the inset of Figure 4 show that the threshold to ignite the A1040 capsule in a rugby-shaped hohlraum is around 270TW; furthermore the absorbed laser energy and maximal power laser required
to get the implosion velocity of the nominal 60 quads design are around 1.04MJ and 315TW. Refined simulations may lead to slightly higher values, but cocktail walls will be an additional ingredient to reduce the laser energy. Work is now in progress to estimate the sensitivity of this design to parametric instabilities. Anyway, rugby shaped hohlraums appear already as promising candidates for achieving ignition with the 160 beams configuration.

4. Alternate ablators
Both A943 and A850 have been chosen in order to keep approximately the same shell break up risk as the nominal A1040 capsule. This has been comforted numerically by using linear 2D simulations and Haan’s saturation model [9] to estimate the final deformations caused by initial roughness.

A recent analysis of the stabilizing effect of transversal diffusion on the ablative Rayleigh-Taylor instability showed a promising way to reduce the instability growth [5]. Replacing the nominal doped plastic ablator by a material composed of successive layers of different dopant concentrations will generate anisotropic diffusion for indirectly driven capsules without modification of the 1D flow. These theoretical predictions have been confirmed by 2D numerical simulations and will be tested experimentally on the Omega laser facility in February 2008, using planar CH samples periodically doped with 8% germanium.

5. Conclusion
In the context of early Laser Mégajoule experiments with reduced laser energy, scaled down targets and alternative concepts are studied. Robustness evaluations of these different targets are in progress and will lead to the definition of a mature point design for early ignition experiments. The rugby-shaped hohlraum appears as a natural candidate to save energy and achieve ignition with the specific 160 beams configuration. Laser-plasma instabilities stay a major drawback in these small hohlraums, and indicators have been defined to compare the LPI risks between designs. Detailed simulations and specific LPI experiments are mandatory to quantify them, while the definition of a 285eV target is in progress.

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