

## Effects of the irradiation of a finite number of laser beams on the implosion of a cone-guided target

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**Abstract.** In direct drive laser fusion, the non-uniformity of the laser absorption on the target surface caused by the irradiation of a finite number of laser beams is a severe problem. GekkoXII laser at Osaka University has twelve laser beams and is irradiated to the target with a dodecahedron orientation, in which the distribution of the laser absorption on the target surface becomes non-uniform. Furthermore, in the case of a cone-guided target, the laser irradiation orientation is more limited. In this paper, we conducted implosion simulations of the cone-guided target based on GekkoXII irradiation orientation and compared the case of using the twelve beams and nine beams where the three beams irradiating the cone region are cut. The implosion simulations were conducted by a three-dimensional pure hydro code.

### 1. Introduction

In laser fusion, a fuel capsule is irradiated by many high intense lasers and imploded to so high density and temperature that nuclear fusion reactions occur. To achieve both high density and temperature at the same instant is very difficult and requires the high uniformity of the implosion. Thus, in fast ignition (FI) scheme [1], that is one of the schemes to achieve laser fusion, the implosion process is used only for the compression of the target, and then, the target is heated by an external source. In Fast Ignition Realization EXperiment (FIREX) at Osaka University, a hollow Au cone is inserted to the target and a heating laser is irradiated into the cone [2]. In this scheme, the laser light interacts the tip of the Au cone, which generates many high energetic electrons and then, these high energetic electrons heat the compressed fuel core. A FI experiment at 2002 showed 1000-fold increase in neutron yield compared with the case without heating, which also showed that the temperature is raised by the heating laser [3].

The fuel core is efficiently heated by using the cone-guided target, but there are some problems in the implosion process due to the presence of the cone. One problem is about the irradiation orientation of the implosion laser. The laser orientation is restricted so that the cone may not be irradiated and



ablated. In FIREX, GekkoXII is used for the implosion, which has twelve laser beams designed to irradiate into the target with a dodecahedron orientation, but in many case, the three beams that have the possibility to irradiate the cone surface are not used (called as nine-beam implosion) [4]. In the case of the nine-beam implosion, the target is imploded more asymmetrically, which leads to the inefficient compression of the fuel.

So far many implosion experiments and simulations of the cone-guided target have been conducted, where the position of the fuel core formed by the asymmetric implosion, the interaction with the Au cone and core, and the collapse of the cone are investigated [5-7]. In this paper, focusing on the effects of the irradiation orientation of GekkoXII, the density decrease and implosion dynamics in the case of the nine-beam implosion are investigated and discussed comparing with a twelve-beam implosion case that uses all laser beams of GekkoXII; it is more symmetric implosion than the nine-beam case.

## 2. Simulation conditions

In order to investigate the effects of GekkoXII irradiation orientation on the cone-guided implosion, we used a pure hydro code IMPACT-3D [8]. IMPACT-3D is Eulerian code and solves compressible and inviscid hydro equations in three-dimensional Cartesian coordinates. The target is assumed as a simple two-layer target that consists of a shell and fuel as shown in figure 1. The inner radius and outer radius are  $130\text{ }\mu\text{m}$  and  $180\text{ }\mu\text{m}$  respectively. The cone is set as the full opening angle is  $30^\circ$ , the apex is located on the target center, and the distance between the tip and the target center is  $20\text{ }\mu\text{m}$ . The cone is treated as a solid boundary in this simulation, which means that the cone never deformed. To compute the fluid with the cone boundary embedded, immersed boundary (IB) method is introduced into IMPACT-3D. The IB method was developed by Peskin and has received many attentions in computational fluid dynamics [9, 10]. This method allows computing flow around the embedded boundary without using the boundary fitted coordinate.

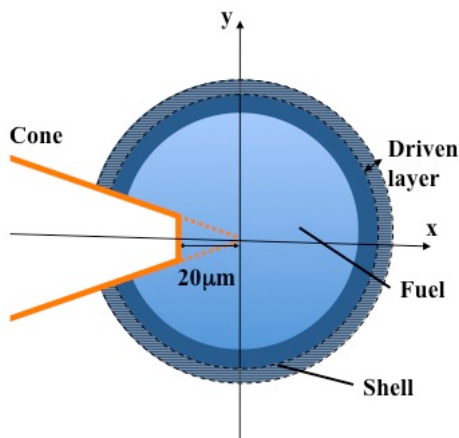


Figure 1. The schematic of the target. The inner radius and outer radius are  $130\text{ }\mu\text{m}$  and  $180\text{ }\mu\text{m}$  respectively. The cone is set as the full opening angle is  $30^\circ$ , the apex is located on the target center, and the distance from the tip to the target center is  $20\text{ }\mu\text{m}$ . The shaded area in the shell is a driven layer.

IMPACT-3D is pure hydro code that does not include laser absorption. Therefore, the implosion is mimicked by pressure drive. A high-pressure region of  $20\text{ }\mu\text{m}$  width called as driven layer (*see also figure 1*) is imposed in the shell, which accelerates the shell inward. Adding the pressure distribution on the driven layer, we simulate the cone-guided implosion with the GekkoXII irradiation orientation. The pressure distribution is defined as proportional to the laser absorption distribution that is computed by three-dimensional raytracing, in which we assume the target as plasma and absorption process as inverse bremsstrahlung. The laser beam diameter is the same size to the target diameter, the f-number is infinite, and the profile in space is uniform. Figure 2(a) and 2(b) are the pressure distribution of the driven layer in the case of the twelve-beam and nine-beam without the cone respectively. The cone is inserted into the “cone area” as shown in figure 2. The initial density of the fuel and shell are  $1\text{ g/cc}$  and  $45\text{ g/cc}$ , and the pressure of the fuel and shell except the driven layer are  $1\text{ Mbar}$ . This initial profile is set so that the radial convergence ratio is achieved as approximately 3.5.

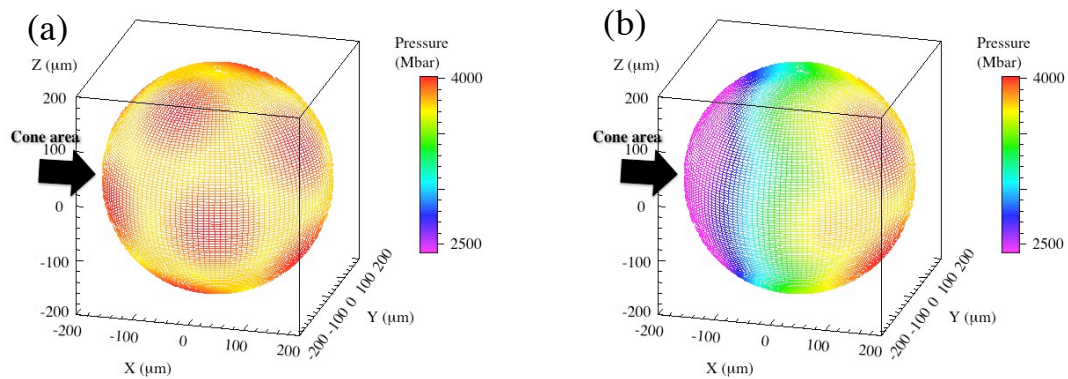


Figure 2. The pressure distribution on the driven layer.

(a) Twelve-beam case. (b) Nine-beam case.

### 3. Results and discussion

Figure 3(a) and 3(b) show the density iso-surface corresponding to the fuel-shell interface near the maximum compression time in the case of the twelve-beam and nine-beam respectively. It is found that the irregularity of the target surface caused by the irradiation non-uniformity of the implosion laser is emphasized by Rayleigh-Taylor (RT) instability in the twelve-beam case. On the other hand, in the case of the nine-beam, the target is crushed in toward the cone, which means that the fuel flow toward the cone side occurs. Figure 4 shows the time evolution of the gravity point of the fuel region. The red and blue lines are in the case of the twelve-beam and nine-beam respectively. In the case of the nine-beam, the gravity point moves toward the minus direction of the x-axis, which is corresponding to the direction toward the cone side, unlike the twelve-beam case where the gravity point keeps at the same position. It is found that the strong fuel flow toward the cone side occurs in the case of the nine-beam. In the iso-surface figure of the nine-beam case, a tumor like shape appears in front of the cone tip. This tumor like shape was formed even in the case without the cone. Furtherer analysis is required to explain the mechanism to form such a tumor. However, the tumor size is very small and it has little effect on the implosion.

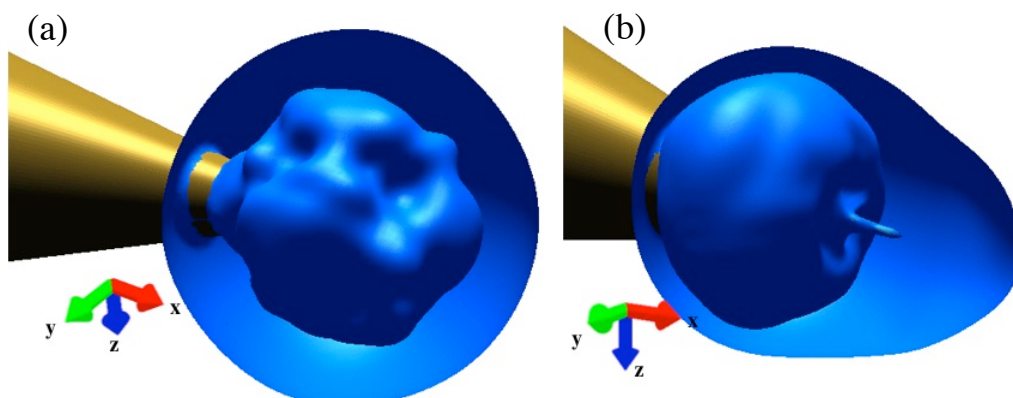


Figure 3. The density iso-surface corresponding to the fuel-shell interface.

(a) Twelve-beam case. (b) Nine-beam case.

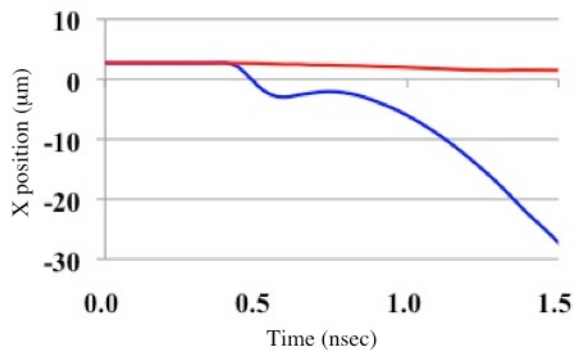


Figure 4. The time evolution of the gravity point of the fuel region. The red and blue lines indicate the twelve-beam and nine-beam case respectively.

Figure 5 shows the time evolution of the average density in the fuel region with the trajectory of the fuel-shell interface in the case of a spherical implosion that is simulated as the pressure of the driven layer is defined by the average pressure of the driven layer of the twelve-beam case. The black, red, and blue lines indicate the density of the spherical, twelve-beam and nine-beam case respectively. The dashed line indicates the trajectory of the fuel-shell interface in the case of the spherical implosion. Comparing the twelve-beam and the nine-beam case, the maximum density of the fuel region decreases by approximately 30 % in the case of the nine-beam. On the other hand, the density decrease between the twelve-beam and spherical case is very small, that is approximately 1%. Therefore, it is considered that the density decrease is due to the strong asymmetric flow.

In this simulation, the cone was treated as the solid boundary. In reality, it is important matter whether the cone tip could tolerate such a strong asymmetric flow due to the GekkoXII nine-beam implosion. In next step, it is required to estimate the effect of the asymmetric implosion on the cone tip.

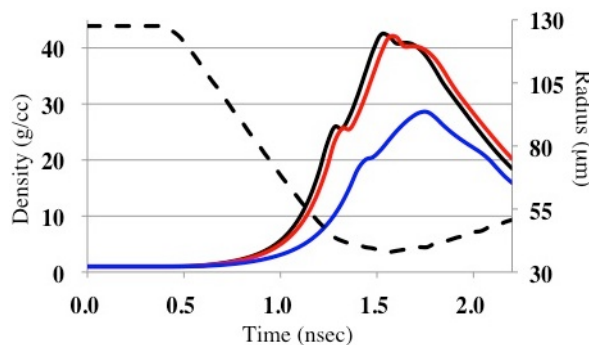


Figure 5. The time evolution of the average density in the fuel region and the trajectory of the fuel-shell interface of the spherical implosion case. The black, red and blue lines indicate the spherical, twelve-beam and nine-beam case. The dashed line indicates the trajectory.

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