Central Density and Low-Mode Perturbation Control of Inertial Confinement Fusion Dynamic Shell Targets

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The dynamic shell is a new class of target in inertial confinement fusion (ICF).[1] ICF targets require a high-density outer shell to contain a fusion burn triggered by the ignition of a central low-density fuel. Traditionally, this outer shell is formed during capsule production by the manufacture of a solid, cryogenic deuterium–tritium (DT) layer. In the dynamic shell target, the high-density outer layer is formed dynamically in-flight via a series of laser pulses that compress the target, allow it to rebound, and then decelerate the expanding plasma, forming a shock that develops into the shell. In this summary, we first consider control of the fuel density in the central region, set by the initial profile of the laser pickets. By controlling the central density, it is possible to modify the convergence ratio (CR) of the implosion. Secondly, we consider how best to minimize low-mode perturbation through the choice of beam-port configuration.

In conventional targets, CR is determined mainly by the implosion velocity and shell adiabat. High convergence ratios require high implosion velocities; such implosions are susceptible to hydrodynamic instabilities formed during the acceleration of the shell. However, CR can additionally be controlled by changing the initial density of the central vapor region. In conventional targets this is limited by the operational temperature range of the DT ice. The dynamic shell target can access a broader range of central densities by controlling the laser pickets. Longer pulses allow for longer periods of expansion and therefore lower central densities. This is plotted in Fig. 1, where two pulses are shown to have a central density range of nearly an order of magnitude, 0.1 to 0.8 mg/cm^3.

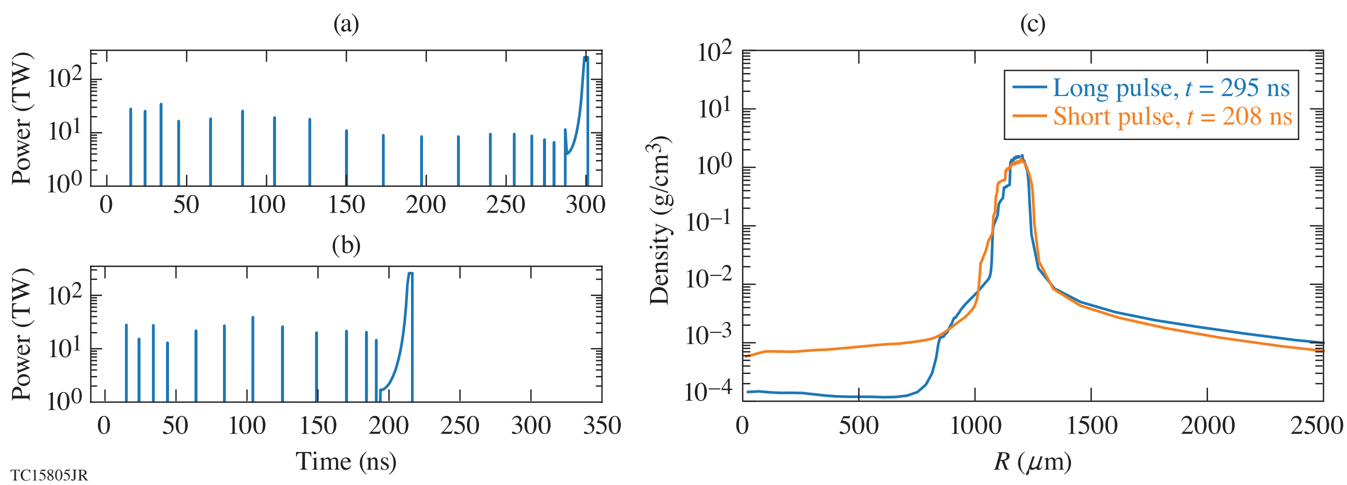

Figure 1
Time profiles of the laser profile for a (a) long- and (b) short-pulse dynamic shell target. (c) The mass-density profiles from a *LILAC* simulation, taken at the point of shell formation.

In the formation of the dynamic shell, there are three sequences of hydrodynamic implosion, expansion, and implosion again. The long periods involved allow ample time for low-mode ($\ell \leq 20$) perturbations to form, threatening the stability of the shell. Beam-port geometry is a major contributor to these perturbations. Previous work by Murakami *et al.*[2] has shown that high-performing configurations can be found using a technique where each port is modeled as a charged particle fixed to the surface of a sphere. In a numerical simulation initialized with a random configuration, the particles are allowed to repel up to the point where they reach a minimum Coulomb potential across the surface of a sphere. Using this technique it was found that configurations with certain beam numbers produced "particularly symmetric" configurations, which are observed as sharp drops in the root-mean-square perturbation in Fig. 2.

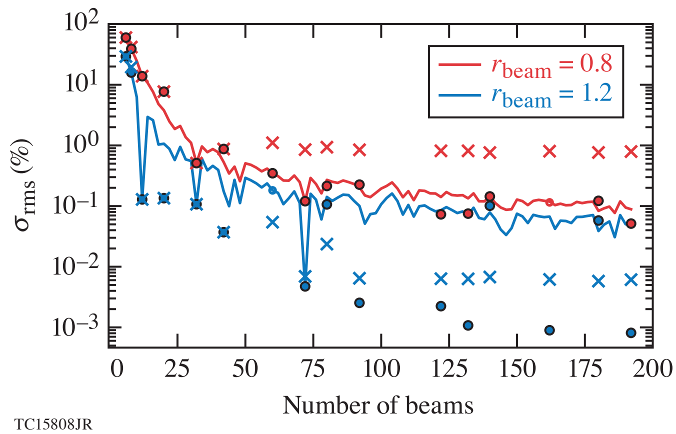

Figure 2
The root-mean-square perturbation as a function of beam number for two sets of super-Gaussian beam parameters. The solid curves show the performance of charged-particle configurations. Icosahedral configurations are shown as ×'s. Icosahedral initialized charged-particle configurations are shown as circles.

In the present work, it is shown that high performance occurs when the charged-simulation naturally tends toward a polyhedral shape, namely the geodesic icosahedron. These icosahedral configurations have a spectral mode structure where the majority of the nonuniformity is supplied by only a select number of modes and all other modes contribute negligible perturbation. This is in contrast to a typical charged-particle configuration that will have similar contributions from all modes up to a dominant beam mode. The main contributing mode in icosahedral configurations is $\ell = 6$; high performance comes when the beam shape suppresses the $\ell = 6$ mode. A further improvement can be made when icosahedral configurations are optimized using a charged-particle simulation. The effect is to reduce the $\ell = 6$ mode while sacrificing increased contribution from other less-significant modes. Different geometries and spectral mode structures of the configurations are shown in Fig. 3. In Fig. 2, it can be seen that the icosahedral configurations optimized with the charged-particle method achieve the lowest nonuniformity of all the configurations.

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1. V. N. Goncharov *et al.*, Phys. Rev. Lett. **125**, 065001 (2020).
2. M. Murakami and D. Nishi, Matter Radiat. Extremes **2**, 55 (2017).

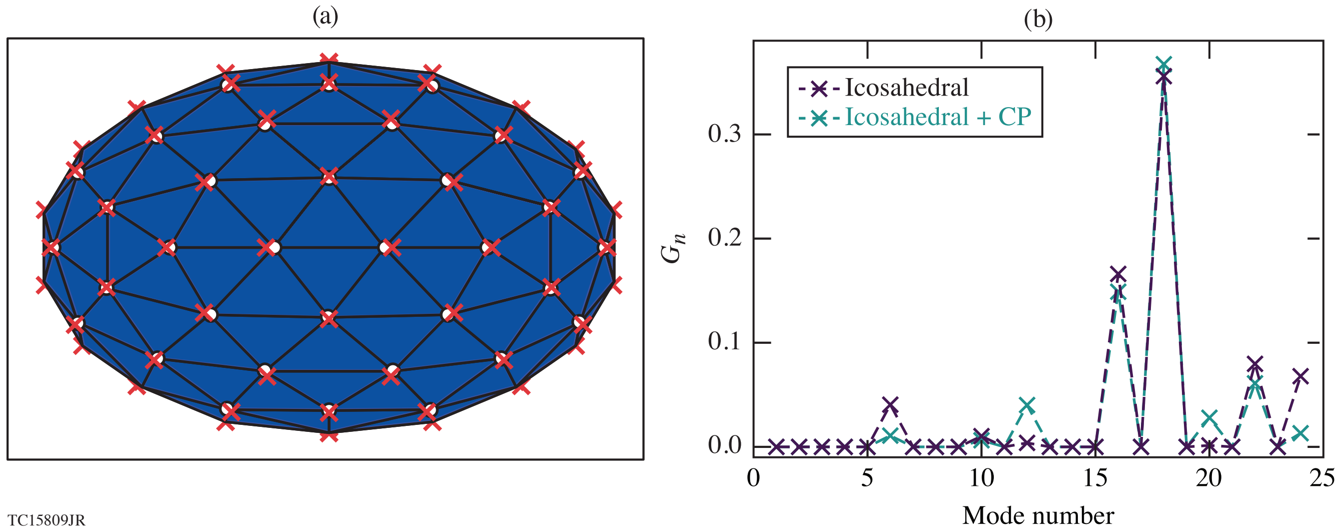

Figure 3
Comparisons between icosahedral and icosahedral initialized, charged-particle configurations. (a) The blue surface and white circles show the position of beam ports for a 92-beam icosahedral configuration, the red ×'s show where the beam ports move under a charged-particle simulation. (b) The change in the geometric factors between the two configurations.