Investigation of converging ultra-fast jets in cylindrical implosions: A new platform to study complex hydrodynamic effects relevant to inertial confinement fusion

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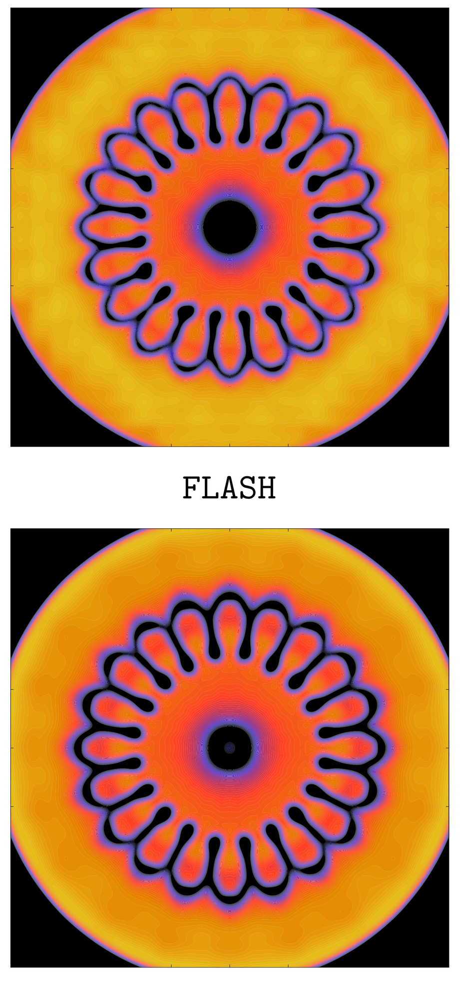
Abstract

We present the results of a computational study investigating an experimental platform that can furnish new insights on the stability of inertial confinement fusion (ICF) implosions. This novel design concept puts particular emphasis on the generation of very-high Mach number jets, which are similar to flows observed in certain ICF target designs. The platform has been designed and modeled using the `FLASH` code,[1] a highly versatile, parallel, adaptive mesh refinement, finite-volume Eulerian, radiation-magnetohydrodynamics code with extended physics capabilities[2]. A directly driven, open-ended cylindrical ablator is manufactured with a series of carefully designed conical protrusions. These jet-generating features give a high degree of control over the characteristics on the inwardly propagating jet flows, their speed, collimation, etc., and the open geometry of the cylinder gives us a clear window to observe the flows over the entire implosion history. The behavior of this kind of converging flow, in the context of ICF, is still not well understood. This platform opens the possibility of studying converging ultra-fast jet propagation over a large parameter space, and it can be used to inform the design of ICF targets that may exhibit jetting phenomena.

Motivation for the Jetted Cylindrical ICF platform

Inertial fusion aims to create very high densities and pressures in the core of a tiny pellet containing DT fuel. This is possible by uniformly driving the target at high velocities and convergence ratios. Nevertheless, as the dimensions of the pellet decrease, undesirable effects arise, such as the Rayleigh-Taylor and Richtmyer-Meshkov instabilities, due to surface perturbations amplified by convergence. The geometry of the spherical pellet and additional features like the fill-tube - which allow the injection of the fuel inside the pellet – make diagnosing the implosion and instabilities challenging. Fill-tube-generated jets that are launched into the hotspot are particularly deleterious and still poorly understood for spherical geometries.[4] Nevertheless, cylindrical platforms can emulate well spherical implosions and provide us with a direct "window" to look inside the compressing system.[3] So far, LANL has deployed such cylindrical platforms at OMEGA and NIF in relation to its ICF program.[5] To design and interpret their laser-driven cylindrical implosions, LANL has been leveraging the `FLASH` code, along with xRAGE,[4] for predictive modeling and post-shot analysis, as well as integrated verification and validation.



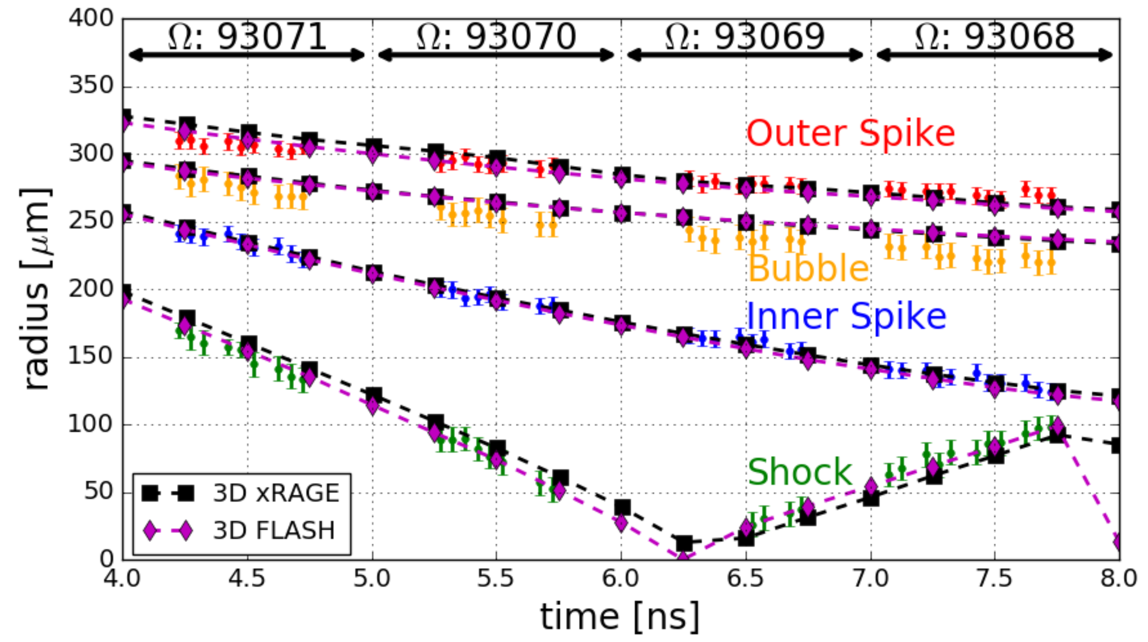


Figure 1.

Left: *Pseudocolor synthetic radiographs on log-scale of low-convergence $m = 20$ cylindrical implosions simulated with `FLASH` and xRAGE.*

Top: *An integrated comparison of the 3-D simulated trajectories with FLASH and xRAGE against the experimental data is also shown.*[4]

Target applications

In this poster, we propose a modification of the cylindrical platform that extends the design to include features that act as surrogates to fill-tubes. The latter are expected to generate fast, implosive flows that are relevant to the fill-tube jetting problem. Controlling such implosive jets can help develop mitigation schemes relevant to LANL's ICF program. Additionally, this experimental platform will help further validate FLASH and increase simulation fidelity when the code is applied to model jetting phenomena pertinent to laboratory astrophysics and Type Ia supernovae.[6,7] The concept will allow us to explore broadly the hydrodynamics needed to generate implosive jets,[9] the properties of such jets (speed, coherence, stability),[11] and survivability of a target with strong surface features. Generating implosive HED jets *by design* has never been attempted before and while past literature on converging flows exists,[10] only few planar studies were done on Nova at LLNL in the 1990's.[12,14]

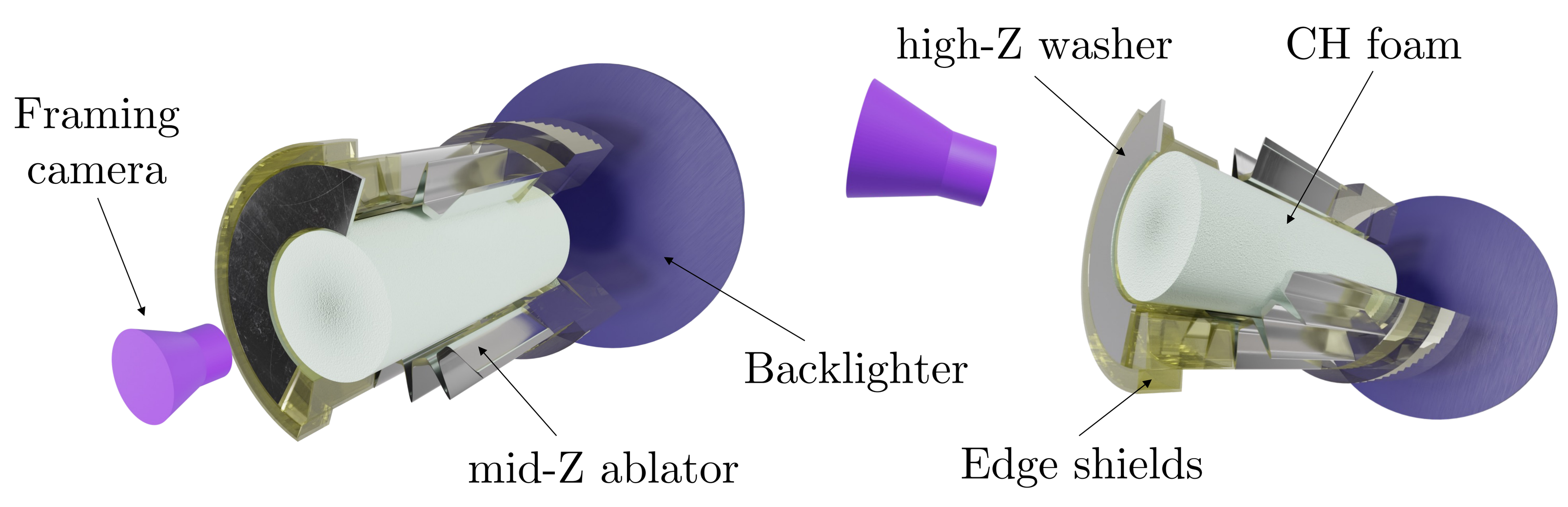


Figure 2. *3-D illustrations showing and the main components of interest for the proposed extension to the cylindrical platform.* Illustrations by Mike Franchot, LLE.

The simulation setup with the FLASH code

Preliminary full-physics FLASH calculations were done on a 2-D Cartesian domain; a quadrant in the positive x- and y-axis. We geared our investigations towards geometries that can take advantage of symmetric boundary conditions to minimize computational time for quick turnaround. All simulations featured a cylindrical cross-section illuminated with the laser pulse shapes employed in standard cylindrical implosions by LANL at OMEGA. The ablator material is aluminum with a standard foam fill.

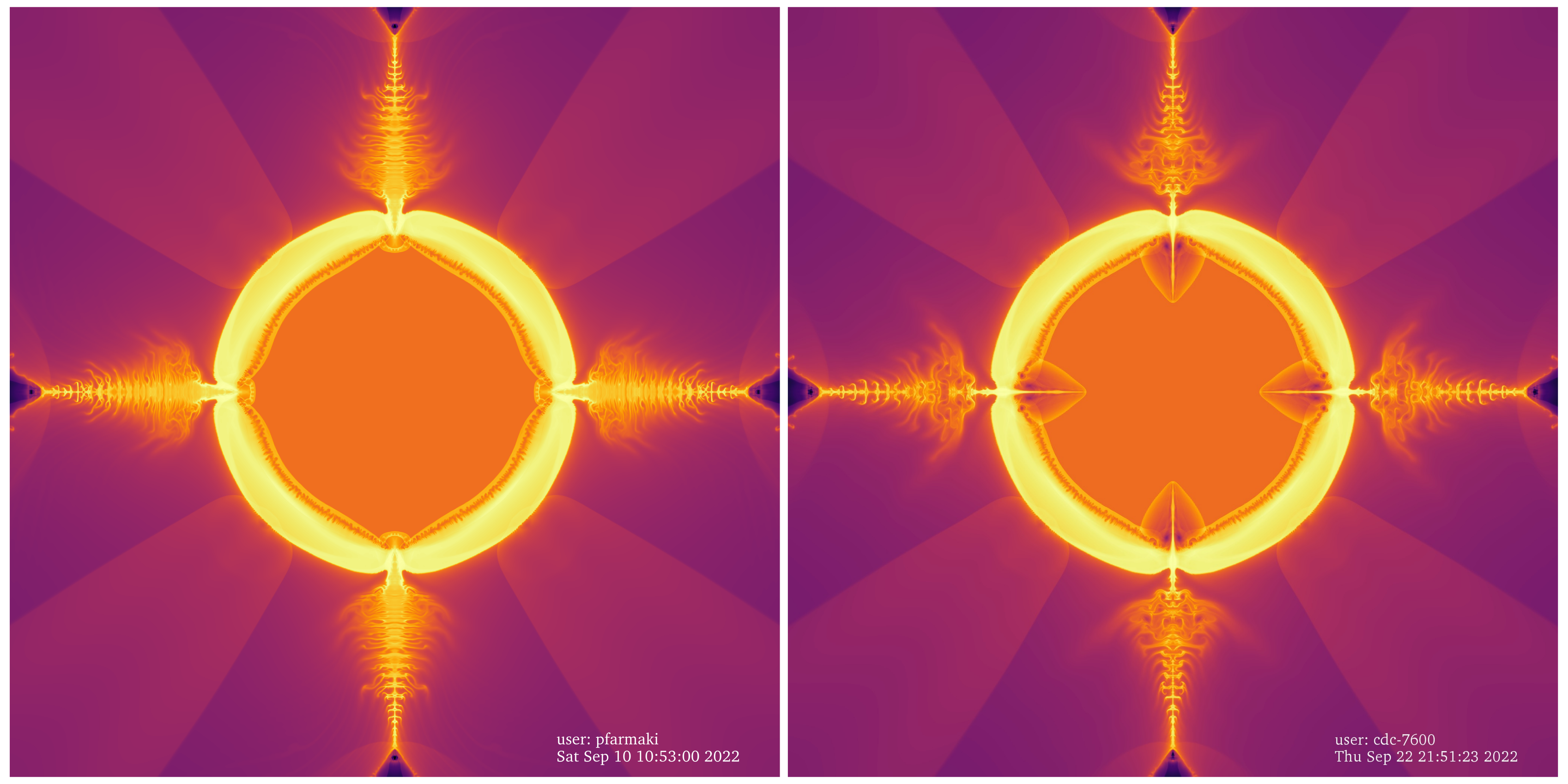


Figure 3. *Pseudocolor log-scale density plots of two 2-D, intermediate convergence, mode 4 implosions in `FLASH` with a Gaussian train of tamped (left) and untamped (right) spikes at 3.3ns. The free jets outrun the imploding shell.*

Preliminary results from `FLASH` simulations

Two main feature geometries (or "spikes") were used. One where the spike is a sharp absolute cosine function, and one sporting a Gaussian shape. The cylinders were perturbed with different mode numbers, varying the number of the spikes. We wanted to examine how the cylinder will implode, as well as the jetting from these spikes, which act as radiatively-driven shaped charges. At the same time, we investigated filling the cavities with a tamp to time the emergence of the jet and its subsequent impact on the foam filler. Our simulations with `FLASH` predict several interesting hydrodynamic effects in these implosions:

- The jets can achieve speeds many times the shell's implosion velocity, agreeing with the analytical approach by Birkhoff.[15]
- The formation of these jets is very sensitive to initial conditions; timing their impact to the foam core is <u>not</u> trivial.

The jet velocity seems to scale well with the relation:

$$v_j \propto \frac{v_i}{\sin \alpha}$$

were α is the conical half-angle of the spike.

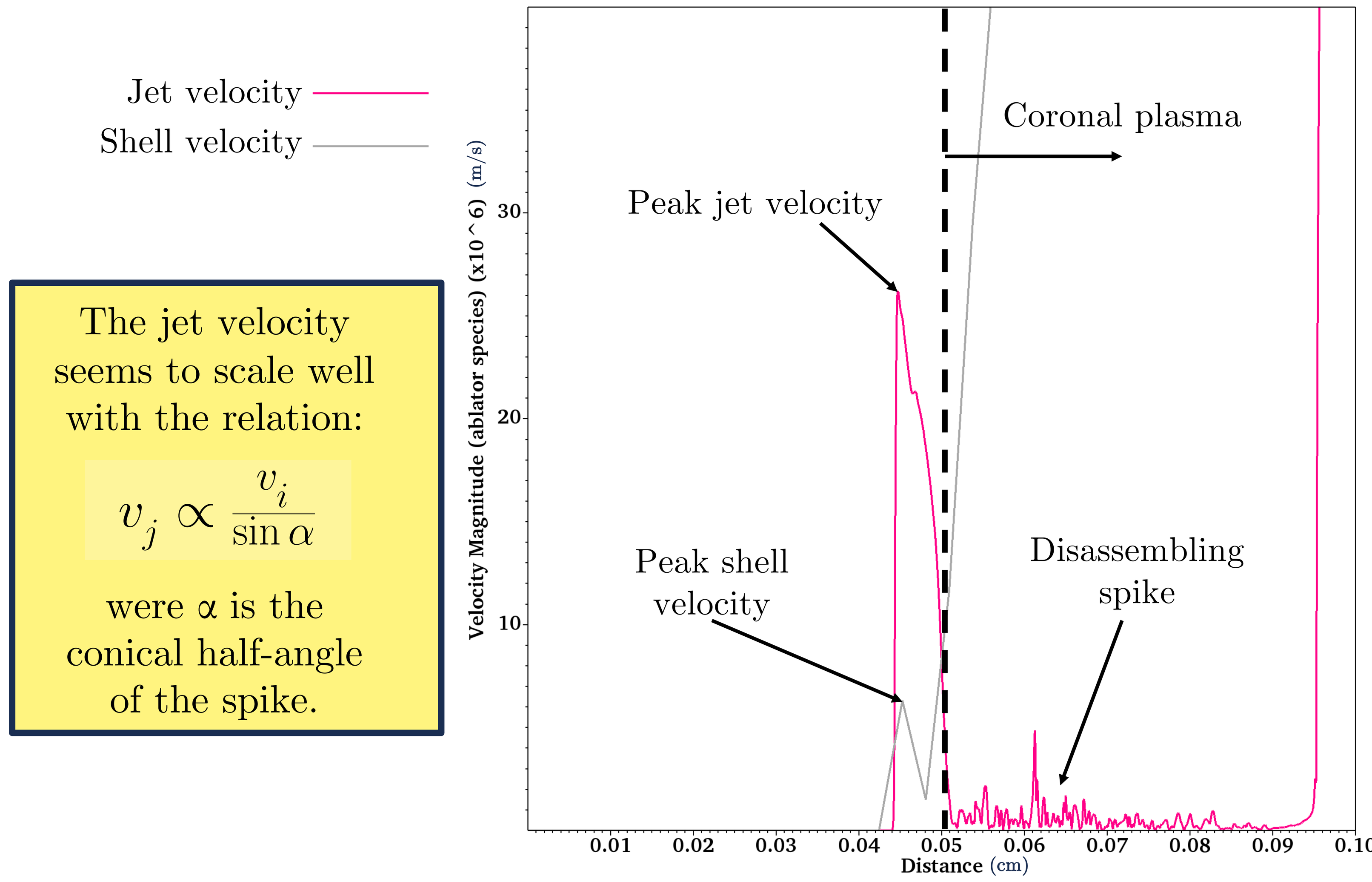


Figure 4. *Velocity magnitude showing the jet (pink) and ablator (grey) around 8 ns, i.e., prior to jet impact to the CH foam, and close to shock breakout).*

The development of this new platform allows the generation of very fast hydrodynamic jets to assist LANL's ICF program by providing new insights on the properties and stability of fill-tube jets and by exploring new implosion degradation mitigation strategies.

Future Work

- New ideas can be tested to time the jet impact better and allow better foam compression. Tamping the jet is far from trivial.
- More realistic simulations accounting for surface roughness are underway.
- The evaluation of the laser ray bending and the potential formation of caustics (including amplification of CBET) will follow.[16,17]

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