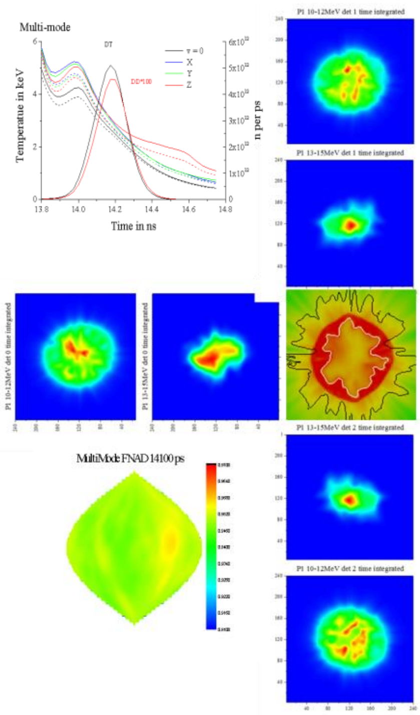
Understanding limitations to hotspot confinement by exploiting multiple synthetic diagnostic methods
PhD Project proposal for October 2016: Supervisor Prof. J. Chittenden

Three-dimensional asymmetry is thought to be one of the principle causes of fusion performance degradation in indirect drive capsule implosions on NIF. Such asymmetries can arise from non-spherical components of the target structure such as the capsule support tents or the cryogenic fill tube or from non-uniformity in the radiation intensity reaching the surface of the capsule. Departures from spherical symmetry can result in strong variations in the areal density and velocity of the dense fuel layer converging on the axis. Such asymmetries can mean that not all of the momentum of the dense fuel is extinguished at stagnation and thus there is a reduction in the efficiency with which the kinetic energy is thermalized and hence a reduction in the pressure of the hotspot material. Departures from symmetry at stagnation produce an increased surface area of the hotspot/dense fuel interface which leads to enhanced thermal conduction and radiation losses which quench the hotspot[1]. Variations in the areal density of the dense fuel layer introduce weak points in the inertia required to confine the thermal pressure of the hotspot and lead to truncation of the burn phase[2]. This problem becomes particularly acute should finite alpha heating begin to initiate the ignition process and raises the pressure of the hotpot.

Diagnosis of the magnitude and the nature of asymmetry in the stagnating hotspot is problematic and in particular, linking the observed asymmetry to original perturbations in the capsule structure or radiation drive remains very challenging. One of the principle approaches to diagnosing asymmetry at stagnation is the use of neutron diagnostics such as energy spectra deconvolved from time of flight measurements, primary or scattered neutron images and fNAD activation detectors. These diagnostics are particular useful where the perturbation is not periodic, but is either incoherent or one-sided, such that a significant residual bulk velocity of the dense fuel layer and the hot spot can result. If the residual bulk motion of the hotspot material has a coherent centre of mass velocity this results in a measureable Doppler shift of the thermonuclear neutrons that are emitted[3]. Where this motion is not coherent, the variance of the fluid velocity broadens the Doppler width of the neutron pulse, giving a false signature of high ion temperatures[4].



At the recent IFSA 2015 conference our group presented results from 3D radiation hydrodynamics simulations of capsule implosions on NIF which were post processed using a new semi-deterministic model for creating primary and scattered neutron images and spectra. This processing tool bypasses much of the computational expense associated with comprehensive Monte-Carlo simulation of the neutron flux and enables multiple calculations such as time dependent neutron scattering images to be generated. The image on the right shows results from a simulation where a broad range of different perturbations have been applied in order to generate a quasi-turbulent flow in the hotspot[5]. The images show a density slice along with primary and scattered neutron images in three orthogonal directions and the fNAD distribution all at peak neutron output. The graph shows the ion temperatures inferred from the DD and DT neutron spectra widths in the three orthogonal directions as functions of time. These show that whilst the inferred temperatures are fairly isotropic the temperature inferred from DT spectra are consistently higher than those form DD spectra (by about 300eV). This result is similar to that observed in experiment and is consistent with a hotspot with a finite but isotropic velocity variance[5].

In addition to the neutron diagnostics, there are several other diagnostic approaches which can be utilised to constrain our ideas of the magnitude, form and origin of asymmetries at stagnation. Not least of these is X-ray imaging of the emission from the hotspot. The advent of improved temporal resolution through time dilation techniques and improved spatial resolution suing KB or Wolter optics will provide data for far more detailed comparisons between simulations and experiments. Using high Z dopants which provide spectroscopic emission lines in the 10-20keV range can provide a diagnostic of electron temperatures in plasma under similar conditions to the dominant neutron sources and provide a comparison of Ti and Te in surrogate targets. Improved spatial resolution in the X-ray imaging also provides the option for high spatial resolution in X-ray radiographs of the imploding shell between peak velocity and stagnation. The use of curved crystal imaging techniques can provide the spatial resolution to observe higher mode structures than are presently observable. Aside from the enhanced data available from diagnostic development projects, there is additional data which can be further analysed within the existing shot records. This includes data on the post stagnation emission and structure during the late time break-up of the capsule which provides a forensic record of the asymmetry at stagnation and can be used to further constrain 3D computational models.

The project seeks to make use of a comprehensive suite of diagnostic data from NIF to constrain possible sources of 3D perturbation in radiation hydrodynamics simulations of asymmetric implosion and stagnation. The student will make use of the CHIMERA 3D radiation hydrodynamics code recently developed at Imperial College which incorporates a multi-group radiation diffusion model based on CRE tabulated opacities calculated from the SpK model. Data from 3D simulations with different perturbation scenarios will be post-processed using the new semi-deterministic model for creating primary and scattered neutron images and spectra. In addition an off-line solution of the radiative transfer equation at very high spectral resolution will be used to generate synthetic X-ray emission and radiography images. Model development work will include improvements to the representation of spectral sensitivity and other instrument response function within synthetic diagnostics. These synthetic diagnostic data can then be utilised to assess which perturbation scenarios in simulation provide the closest representation of experimental diagnostic data. They can also be used to assess potential sources of ambiguity involved in each diagnostic method such as fluid velocity contributions to neutron spectra measurements of Ti or surrogacy issues involved in inferring Ti by measuring Te. Finally synthetic diagnostics can be used to help constrain the design of diagnostics under development by for example estimating the temporal resolution required by the time dependent magnetic recoil spectrometer, or the spatial resolution required in 2D inflight radiography.

References

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