NIF Rugby High Foot Campaign from the design side

J-P Leidinger¹, D A Callahan², L F Berzak-Hopkins², J E Ralph², P Amendt², D E Hinkel², P Michel¹, J D Moody², J S Ross², J R Rygg², P Celliers², J-F Clouët¹, E L Dewald², P Kaiser¹, S Khan¹, A L Kritcher³, S Liberatore¹, D Marion¹, P-E Masson-Laborde¹, J L Milovich², O Morice¹, A E Pak², O Poujade¹, D Strozzi² and O A Hurricane²

¹ CEA-DAM, DIF, F-91297 Arpajon, France
² Lawrence Livermore National Laboratory, Livermore, CA-94551, USA

E-mail: jean-pierre.leidinger@cea.fr

Abstract. The NIF Rugby High Foot campaign results, with 8 shots to date, are compared with the 2D FCI² design simulations. A special emphasis is placed on the predictive features and on those areas where some work is still required to achieve the best possible modelling of these MJ-class experiments.

1. Introduction
Part of the NIF 2014-2015 High Foot Campaign was carried out with the same “Rugby 700” hohlraum (figure 1, waist diameter 7.0 mm) used in 2013 for 3 Low Foot shots [1]. Due to the high neutron yield obtained with the high foot pulse in a cylindrical hohlraum [2], it was of interest to test this laser pulse in a parabolic hohlraum geometry such as the rugby one.

Figure 1. “Rugby 700” hohlraum with higher case-to-capsule ratio than “cylinder 575” but 10% larger surface.

Figure 2. N131011 Rugby Low Foot shot (SymCap) GXD hot spot. The Legendre mode 2 (P2/P0) is 6% and P0 = 55 µm, achieved by repointing outer cones.
Moreover the last low foot rugby shot, N131011, which was the first shot in the CEA/LLNL rugby collaboration, showed that repointing the outer cones inwards by 500 µm could effectively achieve a round hot spot (figure 2) in a 1.2 mg/cc He filled rugby hohlraum. The same pointing was then selected for the high foot campaign, with a higher fill density of 1.6 mg/cc to counteract the faster outer gold bubble expansion.

The campaign started with 2 Keyholes shots followed with a Reemit and 3 2dConAs. Finally 2 additional Keyholes were shot in August 15. We detail the whole campaign hereafter.

2. First Keyholes N140822 (0.75 MJ) and N141102 (1.1 MJ)
The NIF Keyhole platform’s main goal is to allow precise shock-timing using a Visar diagnostic and to tune the laser pulse for an optimal DT adiabat. The high foot pulse is characterised by 3 shocks. Figure 3 shows the shocks inside the ablator (top) and the surrogate liquid deuterium (center) in a Lagrangian plot. 

The pulse was calculated with the CEA FCI2 rad-hydro code in order to allow the first and second shocks to coalesce at a depth from the ablator/deuterium interface of about 80 µm. The capsule is the regular LLNL “T-1” with 175 µm ablator thickness. Some power multipliers [3] are taken into account to simulate laser losses. For instance, the first shock is computed with a multiplier of 0.9 (same value used in the LLNL cylinder simulations) applied to the laser foot in order to fit the data.

The N140822 Visar shock speeds are within 1% of the FCI2 prediction, but the 2nd shock arrived 700 ps earlier than predicted (figure 4).

The likely explanation for this delay was inferred from the post-shot calculations using a new NLTE model for the wall and especially the ablator. With the CEA standard ablator LTE model, the 2nd shock is created by the coalescence of two separate shocks. The extra shock forms around 100 µm in front of the main ablation front and is due to K-shell C opacity at 300 eV. Launching the shock 100 µm outside the main ablation front causes a 700 ps delay in the 2nd shock arrival time [4].

Modeling the ablator in NLTE using Nohel [5], the fully ionized ablator no longer absorbs the 300 eV photons, allowing them to reach the main ablation front and launching a single shock that arrives 700 ps earlier than for the LTE calculation, thus matching the data.

N141102 then used a delayed 2nd picket and validated the full high foot shock-timing.
3. Reemit N150104
The aim of the Reemit platform is to measure the early-time flux symmetry around the capsule. The design picket cone fraction at 0 Å of 0.5 is very different from the NIF high foot cylinder shots, which rely on cross-beam energy transfer (CBET) to achieve hot spot symmetry.

This shot measured a pole-hot flux (mode 2 +5.6%) inside the 7.5% specification. A slight discrepancy was found with the simulations predicting rather a waist-hot flux at early time. One post-shot way to close the gap calls for extra outwards refraction in the hohlraum: with a 400 µm refraction for all cones, the calculated mode 2 evolution becomes similar to the measured one but the physical cause behind this extra-refraction, if true, is still unknown.

4. 2dConAs N150127, N150329 and N150504
The 3 ConAs shots, all done at 1.3 MJ, differed from each other by the peak cone fraction (0.33 vs 0.4 resp. for N150127 and N150329) and the cone colors. N150504 was a “3-color” shot that used a 2 Å separation for the 23.5° cone and a 5 Å separation for the 30° cone relative to the outer cones.

The first shot N150127 hot spot came out 34% pancake, despite the prediction stating a close-to-round hot spot (P2/P0 -5%). The initial strategy to mitigate any out-of-round shape was to vary the peak cone fraction, see figure 5. The 2nd 2dConA therefore used a cone fraction of 0.4 instead of 0.33 previously (inner energy +20%, outer energy -10%). The hot spot shape result was unfortunately unchanged, both SXIs showing the same relative outer/inner intensities (figure 6). The most likely explanation for this surprising outcome is that a higher inner cone SRS and a lower outer cone SBS compensated for the cone fraction change, the useful laser energy deposited in the wall being the same.

![Figure 5. 2dConA mode 2 FCI2 prediction as a function of the inner cone power change. Black squares are N150127 (center) and N150329 (right) results.](image)

![Figure 6. Comparison of N150127 (right) and N150329 (left) SXI images. Inner cones are on top and outer cones are the main bright coronal areas.](image)

The third 2dConA N150504 used the 3-color approach to see a drastic hot spot change, maximising the laser energy absorbed at the hohlraum waist with a designed high CBET towards the 30° cone, the closest one to the equator. The transfer prediction, using either P. Michel’s script [6] or the FCI2 CBET model (figure 7 (a)), was +80% laser energy applied to the 30° cone from the 44.5° one mainly and no change on the other 23.5° inner cone.

The shot result was more satisfactory than the previous one, achieving a “sausage” hot spot shape (mode 2 +30%) and demonstrating that round symmetry can be obtained with a high foot pulse in this...
rugby hohlraum. However we obtained a waist-high flux because the CBET was likely higher than calculated, possibly doubled according to the in-flight radiography analysis (figure 7 (b), (c)).

![Figure 7](image)

**Figure 7.** (a) Cone to cone CBET FCI2 prediction with the laser pulse (black). Negative values (red curve for instance) mean the transfer goes from 23 to 30°. (b) FCI2 synthetic radio with +160% energy on 30° cone. (c) N150504 radio at the same time showing the same P2 as the FCI2 picture.

5. **Keyholes N150810 (1.1 MJ) and N150823 (0.8 MJ)**

The campaign ended with 2 new Keyholes due to platform availability, the first one still using a 3-color scheme with half-N150504 wavelengths (1 Å and 2.5 Å) and the last one testing a quad unsplitting + repointing proposal to draw closer to the 2D modelling for the 44° cone.

The best overall coupling was achieved with the 2nd shot, whose shock-timing waist/pole symmetry analysis indicates an effective 400 µm inwards repointing is optimal for hot spot symmetry. N150823 SXI also showed for the first time a bright 44° spot (figure 8). A future 2dConA shot should allow us to check for a symmetric hot spot shape with this new 44° cone configuration.

![Figure 8](image)

**Figure 8.** SXI pictures from N140822 (left) and N150823 (right) showing new 44° cone.

**Acknowledgments**

We thank the whole NIF staff and operations people who made this LLNL/CEA rugby campaign possible.

[1] Amendt P et al 2014 *Phys. Plasmas* **21** 112703
[2] Hurricane O A et al 2014 *Phys. Plasmas* **21** 056314
[3] Jones O S et al 2013 *EPJ Conf.* **59** 02009
[4] Poujade O, Bonnefille M and Vandenboomgaerde M 2015 *Phys. Rev. E* **92** 053105
[5] Decoster A, in 2003 *JQSRT* **81** 71-84
[6] Michel P et al 2009 *Phys. Rev. Lett.* **102** 025004