Instability modeling for NIF ignition targets and Omega experiments

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Summary: We are continuing to explore hydro instability issues on NIF targets, and verifying modeling with Omega experiments

Specifications are being completed for a variety of indirect drive targets:
Beryllium, polyimide, CH(Ge) ablators
Drive temperatures 250 - 350 eV, spectra for gold or cocktail hohlraum
Scales from 100 kJ to 600 kJ into capsule (NIF energy ~1.8 MJ)

Details such as $^3$He buildup in the core are being analyzed

Modeling of Omega planar polyimide Rayleigh-Taylor foils is close to experiments

A new design for convergent Rayleigh-Taylor experiments on Omega will test other aspects of the modeling
Generically the ignition targets all look the same as for the last 10 years or so
Our current instability modeling is based entirely on explicit full simulations of perturbation growth and its impact on ignition and burn.

- Single shell cryogenic capsules are ablativeley stabilized on outside during acceleration, and on inside during deceleration
- Simulations indicate that modes beyond about 120 do have any appreciable amplitudes at any times of interest
- Experiments have generally been compatible with simulations giving us confidence in them
- Modeling is done in 2D (LASNEX and Hydra) and 3D (HYDRA) for single modes, and for multiple modes over various solid angles
- Biggest uncertainties are considered to be in the input: spectrum of drive radiation, opacities, characterization of initial perturbations
There are three failure modes we see in our simulations

• Acceleration: Modes $l \sim 100$ grow and disrupt the shell
  Especially a problem if shell is too thin
• Deceleration: Modes $l \sim 15$ create spikes that cool the hotspot
  Especially a problem if shell is too thick
• Low modes: If there is much solid angle with $\rho r < 1 \text{ g/cm}^2$, bubbles blow out and yield is reduced

A successful target is optimized to trade off the first two issues, and has enough 1D $\rho r$ to minimize the third. Requires power and energy to have room to trade them off!
This plot summarizes ablator-seeded Rayleigh-Taylor results for the different capsules.

Rms roughness for 50% YOC, nm
All with gold hohlraum spectrum

- 300 eV Be(Cu)
- 300 eV Polymid, both mg/cc
- New CH(Ge) 300eV, 0.5 mg/cc
- Old Dittrich 250eV result w/ graded dopant, 0.3 mg/cc

Be(Cu) is better, and higher $T_R$ helps a lot.

Different calculation details

- 0.3 mg/cc DT gas
- 0.5 mg/cc

Capsule energy, kJ

0 200 400 600 800
0 20 40 60 80 100 120
600 kJ capsules might be constrained in foot length, at a significant energy price

Largest scale might have foot increased in order to keep total pulse length close to 20 ns

If shock-crossing time is fixed, velocity \( \sim S^1 \)
foot level flux \( F \sim S^2 \)
Adiabat \( \beta \sim S^{1.2} \)
Margin \( \sim S^3\beta^{1.5} \sim S^{1.2} \sim E^{0.4} \) instead of \( E^1 \)
Surface roughness specifications are tighter if there is $^1$H or $^3$He in the central gas

- Both are “dead weight” w/ respect to hydro, ignition & burn
- Atom-for-atom, $^3$He is worse—more electrons and ion charge, increases radiative and conductive losses
- But gram-for-gram, $^1$H is slightly worse—3x more atoms/g

Relative ablator roughness requirement (ablator roughness for 50% YOC, normalized)
The calculated NIF cocktail spectrum is intermediate between Planckian and gold.

A (black) typical gold spectrum
B (red) cocktail calculation (Pollaine)
C (blue) Planckian w/ same flux

Need to do simulations of effect on Rayleigh-Taylor of actual cocktail spectrum
With a Planckian drive, baseline polyimide NIF capsule shows 85% more Rayleigh-Taylor growth.

Growth in 2D simulations, very small multi-mode pert on ablator initially.

Complicated interplay of growth on the various interfaces. With doped ablators, may be able to reoptimize with a cocktail wall.
We are doing Rayleigh-Taylor experiments on Omega to verify modeling of polyimide
Peter Amendt has done hohlraum simulations that fit the Dante flux measurement.

Post-process to simulate Dante: almost high enough to fit data (black curve compared to green).

Simulated drive for package is red curve, about 10 eV lower.

There’s a significant geometrical correction (like the old albedo correction, but now in the other direction) that we need to incorporate.
Simulated drive extracted from Peter’s hohlraum calculations makes sideons very close to data.

Simulation using Peter’s simulated drive

Also shown shifted in time, improves fit

Peter’s hohlraum simulations include a foil, its side-on motion agrees with my foil-only simulation.
I have finished one case faceon and sideon from June 00 shots with the new source info

Source was Dante-25eV, with M-band adjusted (by factor of several) to match Dante M-band fraction

Gail says this is the one reliable side-on from this series

This is late and slow, meaning we’ve overcorrected the drive, which is very good news
The simulations I’ve shown previously for the June 00 faceons used this drive profile

Dante:
- Black 19010, 1, 3 (Feb 00)
  (sideons we’ve been trying to fit)
- Red 20154 5 6 (June 00)
  (faceon shots)
- All Dante retimed to go through
  (1.2 ns, 120 eV)
- All plots are with CEA calibration

Black solid to black dashed is geometry correction + ~10 eV that Dante is still high compared to simulations. (Arguably fits sideons)
Same correction to red curves would be “right” profile, compare to green curve.

Red dash is face-on Dante -25eV, shifted 0.1ns to get good time 0 -- best guess at drive for faceons 20154-6. On old green profile, foot was too high, peak not bad
With that profile I had a decent fit, need to revisit now that sideons are more or less sorted out

Better simulations use opacity tables generated from OPAL code

Increases growth slightly, improves agreement at 30 microns

- Simulations using XSN opacities, Dante drive, calculated spectrum (same as above)
- OPAL opacities, drive shown above and calculated spectrum
- OPAL opacities, Planckian spectrum
Recent shots in cocktail hohlraum had this drive

Dante curve
23683, minus 25 eV from “typical” temperature for this series, shifted +200ps for Dante timing -- used as source for foil simulations
At 70 micron wavelength, we see good agreement between simulated and observed perturbation growth.

At 70 µm wavelength there is no difference between Au and cocktail drives in modulation growth. Early shots seemed to show experimental difference, but not more recent data.

70 µm happens to be the wavelength at which experiments have worked to date. Need to get data comparing Au and cocktails at smaller wavelengths!

17eV lower, too low to fit side-ons.

Nominally adjusted Dante, too high to fit side-ons.
We are also planning convergent Rayleigh-Taylor experiments with a mock fuel layer

- On NIF capsules, perturbation ends up growing on interface between ablator and fuel, which becomes increasingly unstable as shells implode

- Converging geometry is a big part of the physics determining densities, plus something we haven’t done enough with yet

CH

Be stays at density > CH
Doped with silver for diagnosis

Impose perturbations, view face-on

Image here may give “side-on” growth measurement

Image here will give “face-on” growth measurement

Similar to experiment calculated by Dittrich for 0.6-scale NIF noncryo
With a beryllium mock fuel layer we do a decent job of mocking up the interface instability.

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<th>Ablator density</th>
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Fuel density vs Ablator density graph:
- Black NIF
- Green CH over Be(Cu)
- Also tried CH(Ge) over CH(Ti) Ge= 0, 1, 2.5, and 4% (red curves)

Interface radius (NIF, mm, scaled for Omega)
We are working on optimizing this experiment

Current thinking: ramp pulse that pushed single shell program developed, they are verifying symmetry

Capsule 210 µm outer radius,
  23 µm CH / 4µm Be+0.5% Ag / 3 µm mandrel

Gives good density profiles, and good images

Simulated image from 1 µm initial amp, 50 µm initial wavelength, 2 1/2 waves at waist cut into ablator