Instability Growth on ICF Capsules Caused by Support and Fill Features


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1LLNL, 2GA
Engineering features, used to support and fill ICF capsules, damage the implosion

- The **tent** imparts a significant perturbation on the capsule – dominant degradation to CH “low-foot” implosions
  - A campaign is underway to replace the tent with a less-damaging support

- Evidence of the **filltube** appears in recent HDC (diamond) implosions
  - Radiographs of the perturbation are more complex than expected
  - Modifications are being considered to reduce the impact
Direct simulations of the tent show it growing into a significant perturbation.

Zoomed in 100x

$\mu m$

100 nm thick

4 μm

$\mu m$

$T = 0 \text{ ns}$

Simulation by B. Hammel

As the tent blows up, it launches a pressure wave that hits the capsule, seeding a perturbation.
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Tent distorts the capsule through baroclinic vorticity deposition

\[
d\omega / dt = \left( \nabla \rho \times \nabla p \right) / \rho^2
\]

\[
\approx |\nabla \rho||\nabla p| / \rho^2 \sin \theta
\]
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\[ \frac{d\omega}{dt} = \frac{(\nabla \rho \times \nabla p)}{\rho^2} \]

\[ \approx \frac{\nabla \rho \| \nabla p \|}{\rho^2 \sin \theta} \]

Larger angle, \( \theta \), is worse

Pressure

\( 0.9 \text{ ns} \)

Tent pressure wave

\( 1.5 \text{ ns} \)

\( t = 0 \text{ ns} \)

\( 300 \text{ } \mu \text{m} \)
The tent perturbation is amplified by the Rayleigh-Taylor instability
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In-flight perturbation agrees reasonably with experimental radiograph.

Zoomed in 100x

Density

Radiographs*

Experiment

Hydra simulation

*Exp is processed to include multiple exposures and remove bkgd. Sim radiograph includes expected blurring

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*Exp is processed to include multiple exposures and remove bkgd. Sim radiograph includes expected blurring
Significant degradation to the hot-spot by peak compression

Zoomed in 100x

- $t = 0$ ns
- 100 nm thick
- Tent

- $t = 22.5$ ns
- 80 µm

Density

- $t = 0$ ns
- 22 ns
- 21 ns
- 1000 µm

Significant degradation to the hot-spot by peak compression
The tent perturbation was measured using backlit radiography.
The tent perturbation improved with the high foot laser pulse, but is still present.
Several possible capsule support alternatives are being evaluated

Original setup

Possible alternatives

- **tent & fill-tube**
- **FT only**
- **supported FT**
- **polar tent**
- **foam shell**
An option to replace the tent is to hold the capsule by the fill tube supported with a perpendicular rod.

- **Supported fill-tube**
  - fill-tube is cantilevered
  - rod perp. to fill-tube

- **Viewed along hohlraum axis**
  - Support rod
  - offset distance
  - fill tube
The imprint of the supported filltube has been quantified in two hydro-growth radiography (HGR) experiments

- 10µm OD fill-tube
- 12µm OD SiC rod
- Rod lengths of 0.75 and 2.0 mm were tested
- Stand-off distances of 100, 200, & 300µm were tested
- To support the capsule, only one filltube and support (spanning the hohlraum width) would be needed
These experiments showed reduced imprint with offset distance & excellent repeatability for 200 µm offset case

- The finite transverse extent of the perturbation in the 200 µm offset case is similar for both 750 µm vs. 2 mm rod lengths, suggesting its full imprint is present.
- The 300 µm offset rod imprints a localized and small-amplitude perturbation.
Experiments are used to validate simulation models

N151115-002

100 μm offset

200 μm offset

750 μm long

600 μm

Δ(OD)

-0.3

-0.15

0.0

+0.15

+0.3

Simulation radiograph

*composite of 2D simulations, fill-tube not included

Optical Depth Modulation

200 μm

100 μm

x (μm)
Simulations show that 200-300 μm standoff distance gives good performance.

**300 μm standoff distance**

**100 μm standoff distance**
Simulations show that 200-300 $\mu$m standoff distance gives good performance

300 $\mu$m standoff distance

100 $\mu$m standoff distance

Yield/Clean = 1.0

0.42 (similar to tent)
The fill-tube has a visible effect on recent HDC implosions.

W-doped HDC DT (N160223)

Undoped HDC symcap (N161205)

Radiograph of filltube used in HDC HGR experiment

N. Rice et al. (GA)

X-ray emission

~B.T. – 100 ps
In simulations, filltube injects mix and forms a bump on the shell

**Initial state**

Jet from fill-tube collapse

Jet runs ahead of main shock, squirting material into the capsule

**Hole in shell \(\rightarrow\) ablator mix**

By early time (CR \(\sim\) 1.4) hole in shell allows ablator material to inject into capsule

**High \(\rho R\) bump**

By CR \(\sim\) 2.4, hole closes up, forming a high \(\rho R\) bump

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X-ray emission from mix

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Lawrence Livermore National Laboratory
LLNL-PRES-725747
The in-flight perturbation was measured with radiography. Unexpected “spokes” were observed.

A radial “spoke” pattern, centered on the fill-tube, is seen on both CH and HDC capsules.
Ray-tracing from individual beams reproduce the spoke pattern

The spoke pattern seems to be from shadows cast by individual laser spots
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The spoke pattern seems to be from shadows cast by individual laser spots
A smaller diameter filltube is being tested. In-flight perturbation is reduced by 5x

A smaller diamater hole was drilled for the 5µm filltube

Standard (10µm) FT

5 µm FT

Amplitude Δ(OD)

N. Rice, et al. (GA)

Recent layered implosion showed ~40% performance improvement with smaller FT. Analysis ongoing
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To reduce the filltube impact, a smaller diameter filltube is being assembled

Simulations predict that a 5 \( \mu \text{m} \) OD filltube will reduce the amount of injected mix.

Standard 10 \( \mu \text{m} \) OD filltube  5 \( \mu \text{m} \) OD filltube

Injected mix is significantly reduced by smaller filltube

rhoR perturbation is relatively unchanged (but shadowing/spokes may reduce – will test with HGR)

Smaller hole-drilling and 5 \( \mu \text{m} \) FT insertion are currently being tested by GA

N. Rice, et al. (GA)
Cantilevered support shows reduced imprint compared with the tent.

Experimental radiographs

Tent

N151115-002

N160229

Simulated density profiles

45 nm tent

100 mm offset

300 mm offset

perturbation is a localized defect

The affected area from the cantilever support is 10x less than the area of the tent perturbation and smaller in amplitude for the larger offset cases.
To model the 3D effect of the cantilevered support, several 2D cross-sections were simulated. This approximates the rod as a ring around the waist of the capsule at various distances.

This approximation misses:

- 3D effects (perturbations in the azimuthal direction)
- The effect of the fill tube
- Shadows from non-uniform radiation
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Density at convergence ratio = 3

100 µm from capsule

200 µm from capsule

300 µm from capsule
Simulations show the early-time blow-up of the cantilevered support, creating a large shadow

- Simulation shows the wire blows up to 50x its original size.
- This casts a shadow on the capsule and causes an imprint.

<table>
<thead>
<tr>
<th>Time (ns)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>200 um SiC wire</td>
</tr>
<tr>
<td>1.8</td>
<td>12um dia.</td>
</tr>
<tr>
<td>3.0</td>
<td>Shadow</td>
</tr>
<tr>
<td>7.5</td>
<td>Shadow</td>
</tr>
</tbody>
</table>
IMC radiation transport is needed to accurately model the shadow

Early-time shadow is larger with IMC transport

Radiation temperature at ablation front

$T_{\text{rad}} (eV)$

$\theta$ (deg.)

Diffusion

IMC

$\log(\rho)$

Material

$t = 1.8$ ns

Producing a 50% larger $\rho R$ perturbation at late times

$\rho R$ perturbation

IMC

Diffusion
The secondary shadow is reproduced in high-resolution hohlraum simulations including a rod.

- Simulation resolved up to mode 600 (0.06° resolution)
- 535 radial zones
- 3 weeks runtime (so far) on 2048 CPU

Modeling by Jose Milovich