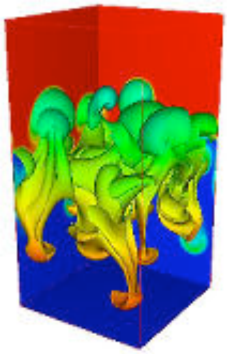
Fusion Accomplished

Success of $1.2-billion fusion-ignition experiment hinges on accuracy of visualization software to preview the unimaginable

by Leah Thayer

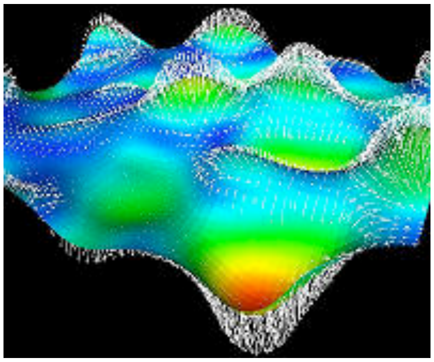
When the world's most powerful laser slices through the California air in 2003, its target – a fusion capsule the size of a BB – will await suspended in an aluminum-alloy chamber less than 100 yards away. Within three billionths of a second, according to plan, the laser's 192 beams will strike the capsule, delivering 500-trillion watts of laser energy that compress it to a small fraction of its original size, heat it to 100-million degrees, and cause it to implode, igniting a fusion reaction and creating a tiny star.



This ambitious experiment is the centerpiece of the Department of Energy's National Ignition Facility (NIF), a $1.2-billion facility being constructed at Lawrence Livermore National Laboratory as part of the Department of Energy's Stockpile Stewardship Program. The aim of this program is to certify the safety and reliability of America's nuclear weapons without testing.

For most scientists involved, the success of the laser and of NIF in general will create a simulated environment for visualizing phenomena never before accessible in the laboratory.

Weapons scientists, for instance, will be able to visualize the conditions inside the nation’s aging stockpile of nuclear weapons. Astrophysicists will gain greater understanding of the inner workings of stars, including the relationship between hydrodynamic instabilities and formation of heavy elements inside supernovae.



Perhaps most notably, at least in a commercial sense, fusion ignition will create conditions in which scientists can explore the wide-scale feasibility of fusion energy, an inexhaustible and non-polluting alternative to fossil fuels.

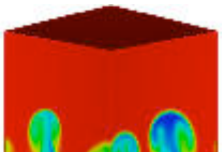
Before exploring these possibilities, however, scientists must accurately simulate and visualize the complex implosion process.

Anatomy of an Explosion

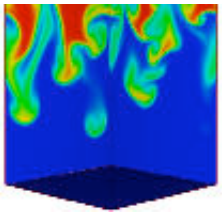
A major concern in the design of the NIF target is the mixing of the capsule shell with the interior fuel. Scientists must maintain an almost incomprehensible degree of control over this process for the laser to implode the capsule in the exact manner necessary to achieve fusion ignition.

Two particular types of mixing – hydrodynamic instabilities and turbulent mixing – are a prime interest of Andrew Cook, a physicist in Lawrence Livermore's Defense and Nuclear Technology Directorate.

Cook, 33, works as part of the Department of Energy's Accelerated Strategic Computing Initiative, which uses large-scale computer simulations to support stockpile-stewardship efforts. He simulates turbulent flows containing a wide range of scales, focusing especially on Rayleigh-Taylor (R-T) instability because of its relevance to NIF.



Discovered in the 1880s by a British physicist named Lord Rayleigh, R-T instability occurs whenever a lighter-weight fluid (liquid or gas) pushes against a heavier fluid. The "pushing" is caused by gravity or by accelerating the fluids. "The acceleration causes the perturbed interface to become unstable and the



fluids to begin to interpenetrate and mix," explains Cook. This is what happens when you overturn a bottle of oil-and-vinegar salad dressing. The denser vinegar spikes into the oil below, as the lighter oil rises into the vinegar above.

R-T instability can have both positive and negative effects. "The relative abundance of chemical elements in the universe depends on the details of Rayleigh-Taylor mixing in supernovae," says Cook. "The fact that there is life on earth means that long ago the right elements were formed in the right amounts inside exploding stars. In this case, R-T instability is arguably a good thing."

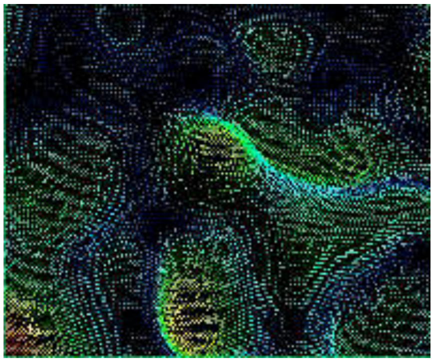
Rayleigh-Taylor mixing at the pusher-fuel interface in NIF capsules is definitely not a good thing. It degrades the capsules' thermonuclear yield. And, if the fingers of fluid penetrate the shell, causing it to break up, ignition might not occur at all.

So you could say that $1.2 billion rests on minimizing R-T instability inside the NIF target capsule.

Previewing the Future

For more than three years, Cook has visualized R-T instability using CEI's EnSight graphics software.

Traditionally, scientists have looked at R-T instability by, among other approaches, accelerating fluid containers downward and snapping photographs. Visualization software, by comparison, "lets you see how mixed fluid is transported within the mixing layer," Cook explains. "It's also very useful in observing the onset of a secondary instability, Kelvin-Helmholtz, which occurs along the sides of the R-T bubbles and spikes. Furthermore, it allows you to see where the high-density gradients are, and hence, where most of the mixing is occurring."



One of EnSight's most valuable benefits is its ability to handle large and time-dependent models. Because Cook is performing direct numerical simulations, he must manipulate very large data sets that do not fit on a workstation. These include 3-D fields of density, pressure, temperature and velocity vectors. "By operating EnSight in client/server mode," says Cook, "we can use a Silicon Graphics Origin 2000 server for manipulating the data."

EnSight also offers the flexibility to visualize many effects at once. "One thing we're very interested in is the sensitivity of instability to different initial conditions, and how long it remains sensitive," says Cook. He uses the EnSight animations to visualize how the interface changes over time – anywhere from a few nanoseconds to several years.

Some of these results are surprising. For instance, when Cook used EnSight to create a pattern in the perturbations representing R-T instability, "I initially assumed it would go away fairly quickly." In fact, "when I first plotted the isosurface, I saw that the pattern persisted for a fairly long time.

"That's something you can't see just from crunching the numbers," he adds. "You have to visualize it."

In the context of the NIF laser, revelations such as these could be critical. History has shown that changes or disturbances that initially seemed insignificant can have a dramatic impact on weapon performance and reliability. By using computer visualization to predict experimental results, scientists are not merely building confidence in the nation's nuclear arsenal. They're also establishing the foundation for vast advances – including many commercial spinoffs – that benefit science and industry alike.

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CEI Press contact: Amanda Baley, 919-363-0883