

LOS ALAMOS SCIENCE AND TECHNOLOGY MAGAZINE

DECEMBER 2009

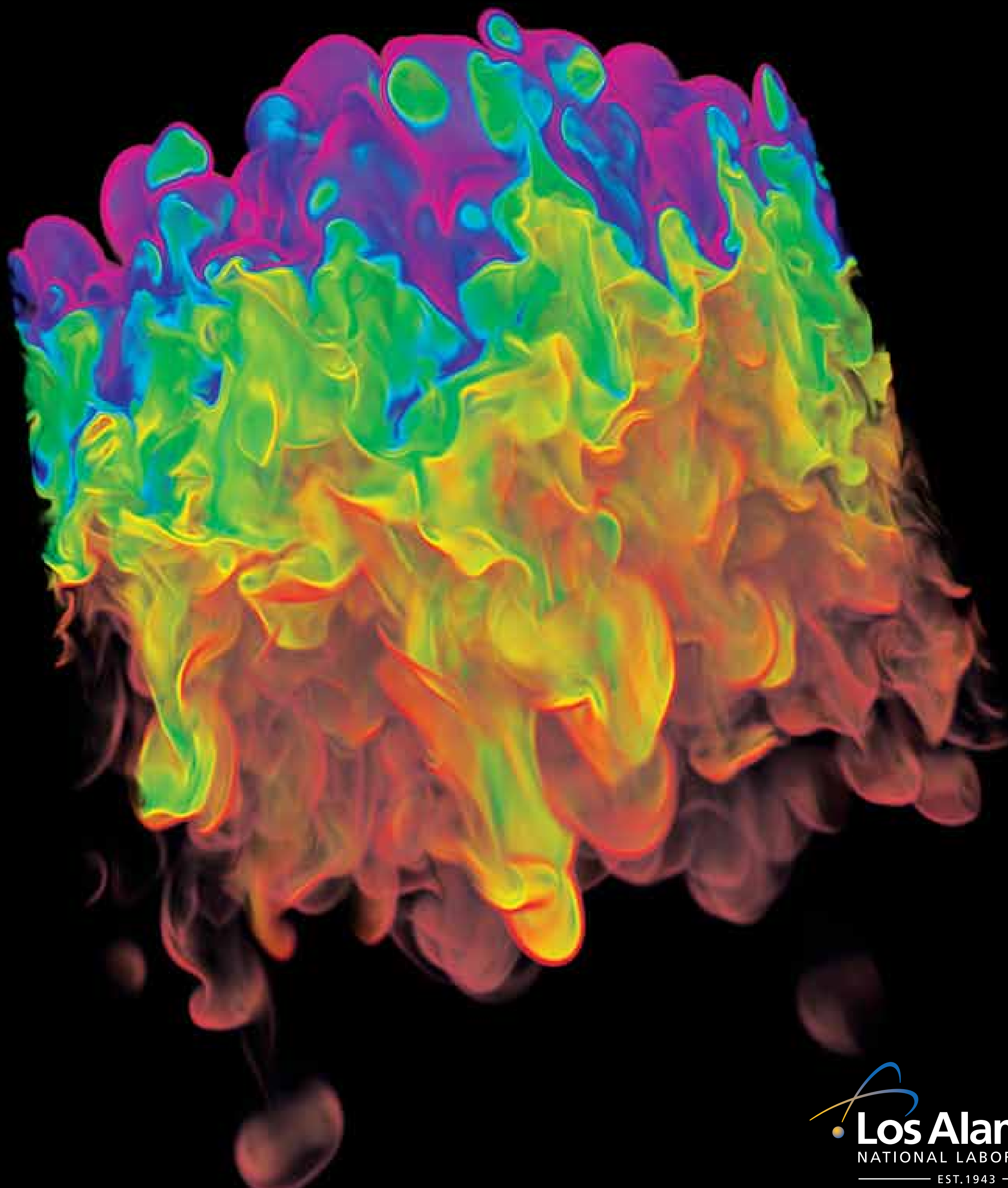
1663

Questions about Influenza

Designing Turbulence

Los Alamos Institutes

Atoms from Nothingness



Los Alamos
NATIONAL LABORATORY
EST. 1943

1663

About Our Name: During World War II, all that the outside world knew of Los Alamos and its top-secret laboratory was the mailing address—P. O. Box 1663, Santa Fe, New Mexico. That box number, still part of our address, symbolizes our historic role in the nation's service.

Located on the high mesas of northern New Mexico, Los Alamos National Laboratory was founded in 1943 to build the first atomic bomb. It remains a premier scientific laboratory, dedicated to national security in its broadest sense. The Laboratory is operated by Los Alamos National Security, LLC, for the Department of Energy's National Nuclear Security Administration.

About the Cover: The largest direct-numerical simulation to date of Rayleigh-Taylor turbulent mixing shows spikes of heavy fluid falling and bubbles of light fluid rising. The first simulation to reproduce realistic mixing layer growth rates, it was performed by Daniel Livescu and Mark Petersen, with the visualization by Steve Martin and Patrick McCormick, all members of the Computer, Computational, and Statistical Sciences Division at Los Alamos.

LOS ALAMOS ARCHIVE

John von Neumann, Richard Feynman, and Stanislaw Ulam (left to right) played important roles in developing the early computers used at Los Alamos.
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From Terry Wallace

Science for the Future

The United States government looks to science and technology to provide solutions to complex national problems, spur innovation, and promote discovery, but that was not always the case. When our country was born, science was largely viewed as a gentleman's pursuit, not as a means to address problems facing the new republic.

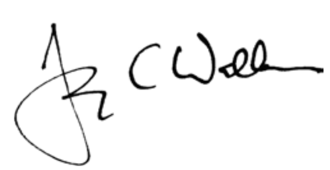
One of the first examples of government funding for science was the Lewis and Clark expedition (1804 –1806). Dispatched to establish a route of communication from the Missouri River to the Pacific coast, the expedition also had the stated purpose of studying the geology, terrain, and wildlife of the West. Public appreciation for science grew during the 19th century as scientific ideas and science-based technology began to influence all aspects of society. (In the 1860s, the government even called on the elite of American scientists to speed the end of the Civil War.) By the early part of the 20th century, the government had begun funding research at universities, but only on an "as needed basis."

World War II and the Manhattan Project changed everything. The enormous project cost about $2 billion but produced atomic weapons that helped end the war in the Pacific. To many, science had proved itself, so government continued to invest in it as the cold war heated up. The national laboratories were created, and today work with universities, industry, and each other to solve a very broad range of national problems.

This issue of 1663 highlights several areas of research at Los Alamos that have the potential to make for a brighter future.

The lead article on influenza discusses Laboratory research into the virus's interactions with its host to try to understand influenza better, and to assess the "pandemic potential" of any influenza virus. The article on turbulence describes how Los Alamos scientists, by manipulating the initial conditions under which two fluids mix, hope to control the turbulence that follows. Turbulence affects everything from the stability of airplanes to the efficiency of a gasoline engine, so the research could have important implications. The dialogue section then introduces the Los Alamos institutes, which initiate and coordinate numerous university partnerships in which university students train at Los Alamos in new disciplines vital to the expanded national-security mission of the Laboratory.

The entire world is turning to science to alleviate the global challenges of the 21st century. Los Alamos, as the premier national-security science laboratory, will help lead the way.



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Can we understand INFLUENZA?

Hippocrates of Cos, the Father of Medicine, was writing about flu in 412 BC, but people still don't fully understand the virus that causes the disease. Los Alamos is marshaling its capabilities in detection, analysis, modeling, and genomic sequencing to learn how to preempt one of the most infectious human diseases.

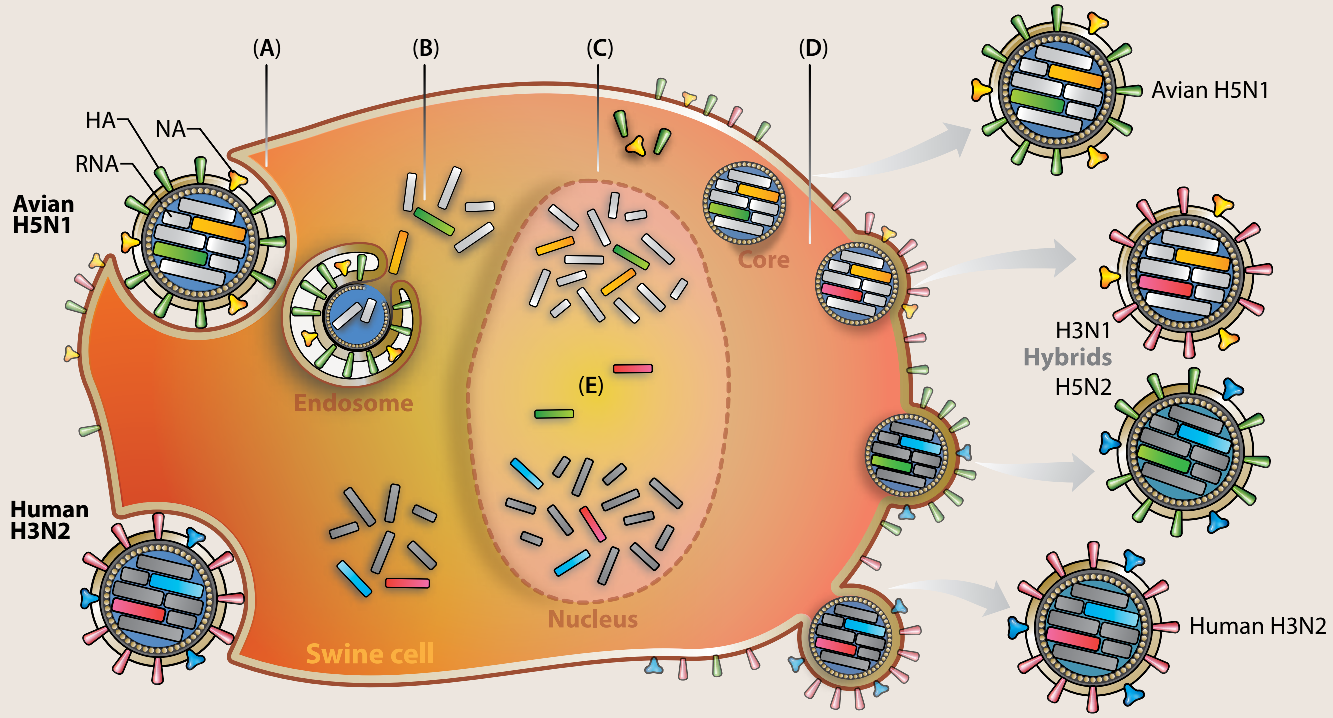
On April 1, 2009, a 10-year-old boy was admitted to an urgent care clinic in San Diego County, California, with flu-like symptoms: fever, cough, and vomiting. By chance, the clinic was participating in trials aimed at developing a new influenza diagnostic, so once a sample had been taken, it was immediately analyzed.

Sure enough, the boy tested positive for influenza A, the virus that gives rise to the flu, but the test could not identify the virus's subtype. Influenza A is actually a large family of viruses, with a family tree consisting of dozens of major branches (the viral subtypes) and each branch splitting into thousands of twigs (genetically distinct viral strains). Knowing the subtype would have given clinicians some insight into what to expect from the virus, much the way that knowing an apple is a granny smith conjures up expectations for the apple's taste, color, and texture.

After a local laboratory also failed to identify the virus, a sample was sent to the Center for Disease Control and Prevention (CDC) in Atlanta, Georgia, arriving on April 15. The CDC quickly concluded that the boy had contracted a new virus that had never circulated through the human population before. Two days later, the CDC received a sample taken on March 30 from a 9-year-old girl from Imperial County, right next door to San Diego County. The girl had caught essentially the same virus.

Those first two cases of what is now called the swine flu immediately raised red flags within the CDC. The new virus was identified as a unique variant of an H1N1 subtype, a "novel H1N1 influenza A virus." Because humans had not been exposed to this H1N1 strain, it would go unrecognized by our immune systems. Thus, it was reminiscent of another H1N1 virus, the infamous Spanish flu virus, which from 1918 to 1920 infected approximately one-third of the planet's 1.6 billion people and killed as many as 50 to 100 million, according to modern estimates.

Year	Name	Virus Subtype	Comments
1918–1919	Spanish flu	H1N1	Estimated 500 million infected, estimated 50–100 million deaths
1957–1958	Asian flu	H2N2	Estimated 2 million deaths worldwide
1968–1969	Hong Kong flu	H3N2	Estimated 1 million deaths worldwide
1977–1978	Russian flu	H1N1	Reintroduction of H1N1 subtype
2009	Mexican flu (swine flu)	H1N1	New H1N1 strain



Creating a Hybrid Virus

New strains of influenza A can emerge from genetic reassortment, which happens only when two or more viral strains infect the same host cell.

(A) The infection starts when HA proteins on the virus's surface bind to the cell surface. The cell engulfs the virus, trapping it inside an endosome. (B) As discussed in the main text, HA causes a channel to open in the endosome, which lets the viral RNA enter the cell's interior. (C) Inside the cell nucleus, each RNA segment is copied, while viral proteins are made outside the nucleus. Newly made HA and NA proteins are transported to the cell membrane and protrude from it. Other proteins (not shown) return to the nucleus, where they and the RNA segments self-assemble into new viral cores. (D) The core migrates to the cell surface and gets coated with membrane as it leaves the cell.

The lower half of the figure shows a second virus infecting the cell. (E) The two sets of RNA segments can mix in the nucleus (get reassorted), as represented by the exchange of two HA segments. The result is two hybrid viruses with their own traits and behaviors.

(Right) In this graph, each horizontal line corresponds to one of influenza's eight RNA segments and groups of eight correspond to a viral subtype. Through reassortments, three subtypes evolved into six. The 2009 H1N1 swine flu virus resulted from a series of reassortments. It contains two RNA segments from H1N1 avian virus, one from H3N2 seasonal human virus, and five from pigs (H1N1 Classical swine virus and the Triple reassortant swine).

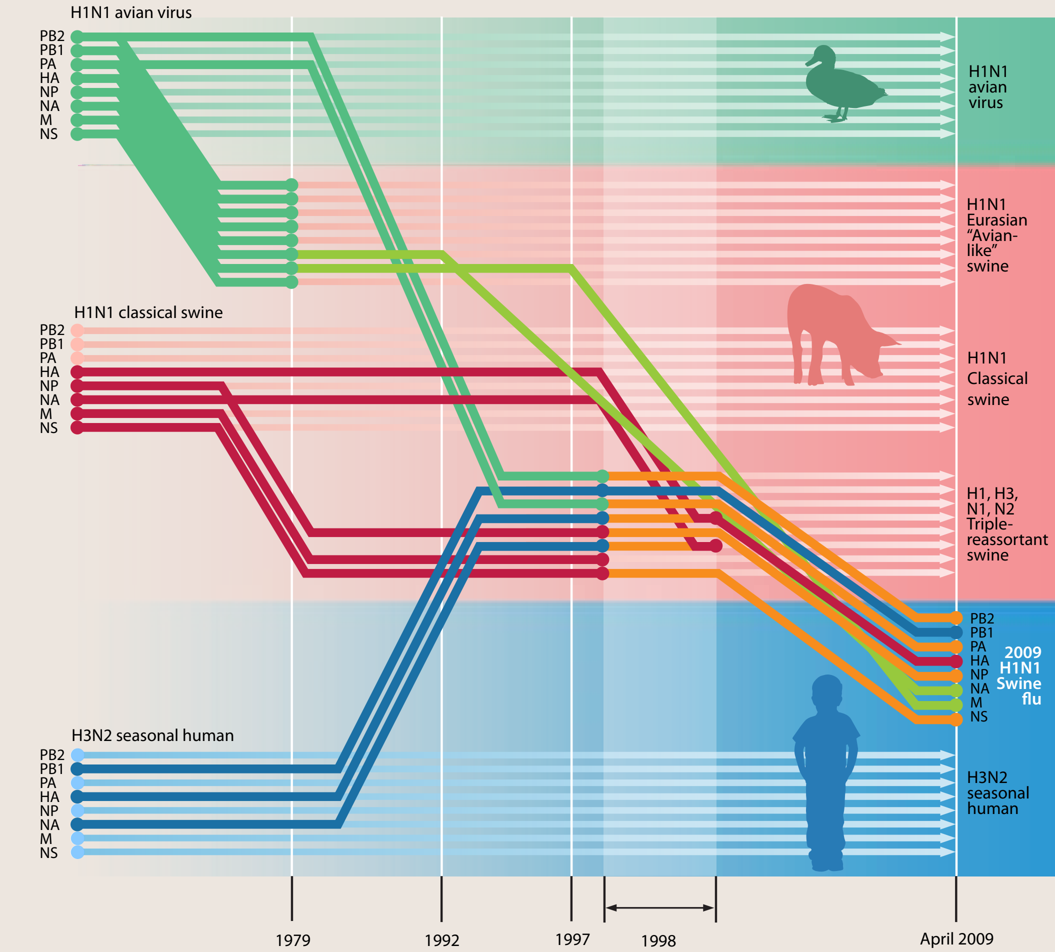


Figure adapted from Smith et al. Nature, (25 June 2009), copyright S.J. Lycett and A. Rambaut.

Fortunately, the 2009 H1N1 strain appears to be much kinder than the 1918 version. This is apparent from the case-fatality rate (CFR), loosely defined as the number of people who die from a disease (and not from secondary causes) divided by the number of people who contract the disease. The Spanish flu's CFR was about 2.5 percent, which is at least 50 times greater than what is observed for the swine flu.

Ruy Ribeiro, an influenza expert with Los Alamos National Laboratory's Theoretical Division emphasizes how huge the difference is. "It's the difference between 50 deaths versus 2,500 deaths per 100,000 cases."

Ribeiro points out that the situation could be far worse. Influenza A is nothing short of remarkable in its ability to infect different species, including humans, chickens, pigs, bats and cats, whales and quails, ferrets, seals, horses, and ducks. Each species typically is susceptible to a small number of viral subtypes, but mutations will always produce new strains that can cross over to other species. The H5N1 avian flu virus (bird flu) jumped from wild birds to humans in 2003. The virus doesn't pass from one person to another, but heaven help us if it ever mutates into one that does—its CFR is greater than 60 percent.

Can Los Alamos Find Answers?

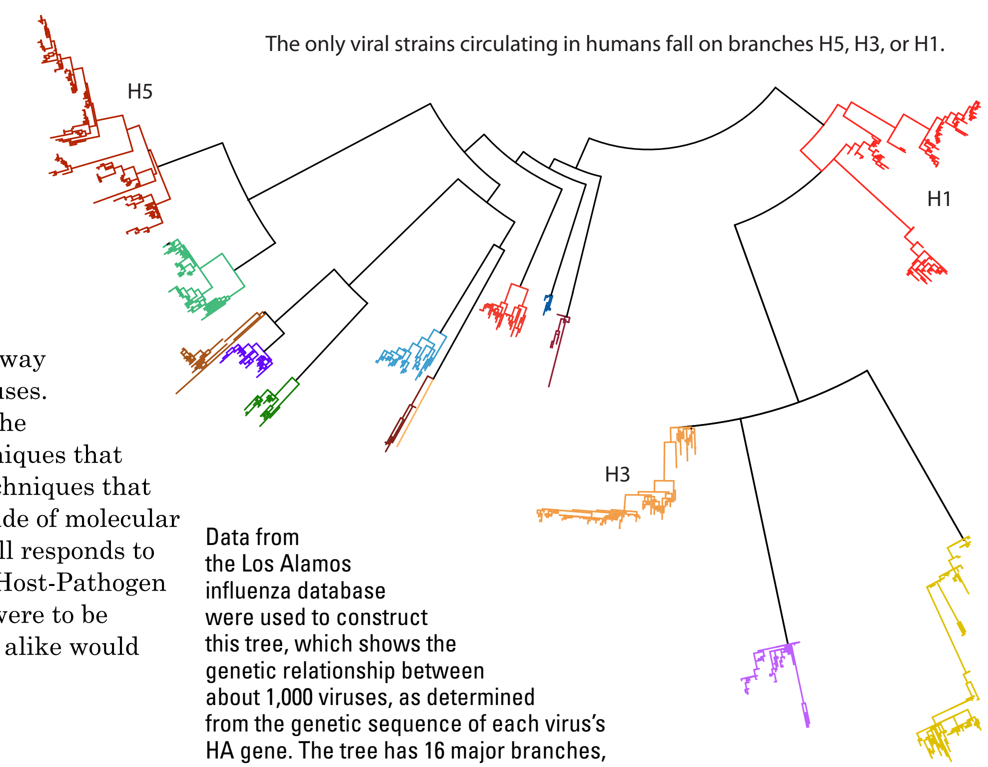
Both the swine flu and Spanish flu viruses spread easily among people and are virulent (able to cause disease), but the former is not very deadly, while the latter was. The bird flu virus is both virulent and very deadly but doesn't spread from person to person. Structurally and genetically, the three viruses are nearly identical. Why do they affect people so differently?

"There's no simple answer," says Ribeiro, "other than to say it's in the details of how the virus and host organism interact with each other. Unfortunately, those host-pathogen interactions are not well understood."

Ribeiro and Murray Wolinsky from the Laboratory's Bioscience Division head a 16-person cross-disciplinary team composed of scientists from the Theoretical and Bioscience Divisions, along with the Computer, Computation, and Statistical Sciences Division. The team is focusing on the host side of those interactions, trying to find genes within a cell that respond one way when the cell is infected with a high-virulence influenza virus, but a different way with a low-virulence virus. If successful, the team could have a way to assess the virulence of new viruses.

More important, however, are the experimental and analytical techniques that team members are developing, techniques that could help them unravel the cascade of molecular interactions that result when a cell responds to a stimulus. (See "Unraveling the Host-Pathogen Interaction" on p. 6.) If that goal were to be achieved, doctors and researchers alike would

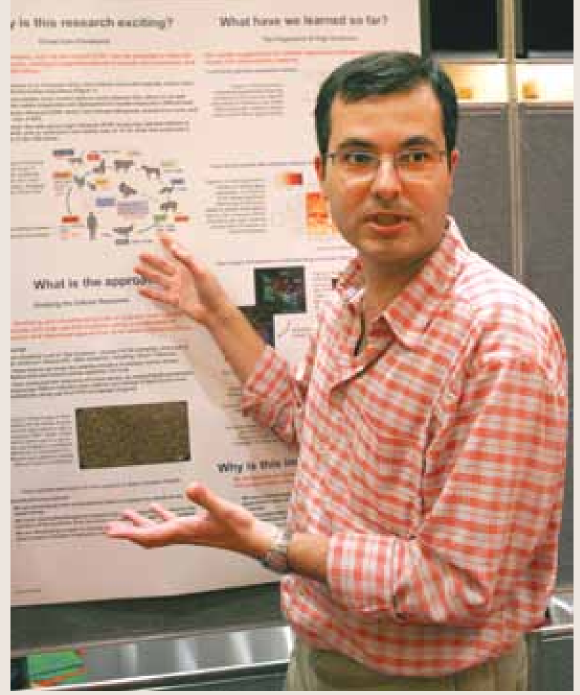
Seasonal influenza A viruses.
Credit: Yoshi Kawaoka



Data from the Los Alamos influenza database were used to construct this tree, which shows the genetic relationship between about 1,000 viruses, as determined from the genetic sequence of each virus's HA gene. The tree has 16 major branches, corresponding to 16 varieties of HA.

Courtesy: Ben McMahon, Los Alamos

Unraveling the Host-Pathogen Interaction



Ruy Ribeiro (right) is the principal investigator on a project funded by the Laboratory Directed Research and Development program to find genetic markers, in both influenza and humans, that correlate with high- and low-virulence viruses. Says Ribeiro, "Our goal is to develop the knowledge and tools necessary to predict the pandemic potential of any influenza virus."

Figure A shows one approach—whole-genome microarray experiments. Each of the more than 30,000 spots in the microarray image corresponds to a human gene, and the spot brightness indicates the degree to which that gene was turned on 24 hours after a cell was infected with a high-virulence strain of influenza. The "hit" pattern changes with virus strain, type of cell, and time after infection. Through pattern comparison, a set of genes might be found that would correlate with virulent viruses, but it takes sophisticated tools to extract information from the complex images.

One of those techniques is shown in Figure B on the facing page. Numerous experiments similar to those described in Figure A were conducted, and pairwise comparisons of the results were reduced by an algorithm to a single value. The values are plotted as a "tree." Each experiment, represented by a color, was repeated three times. Data were taken after 8 hours (open circles) and 24 hours (closed circles). A short line between two dots indicates the two experimental resuls are very similar, a longer line less similar. The "tree" suggests that the cellular response to different strains of influenza cluster into characteristic patterns; for example, the high-virulence strains (red) and low-virulence strains (yellow) form distinct groups.

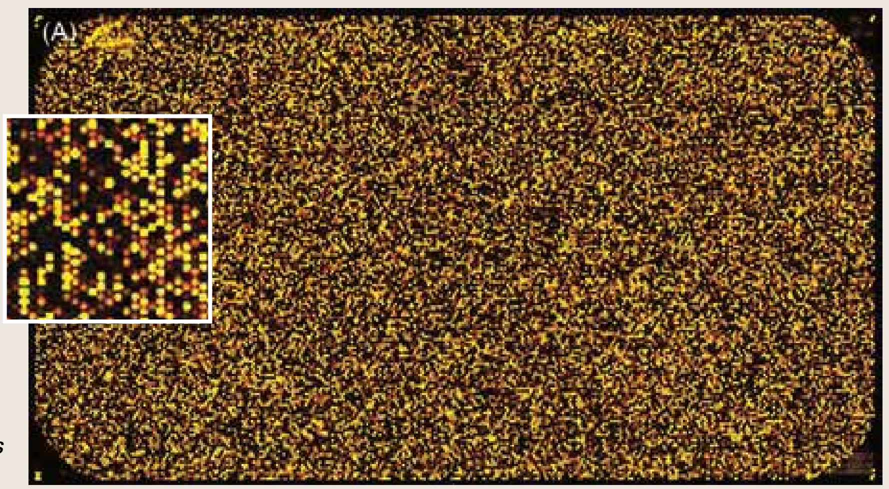
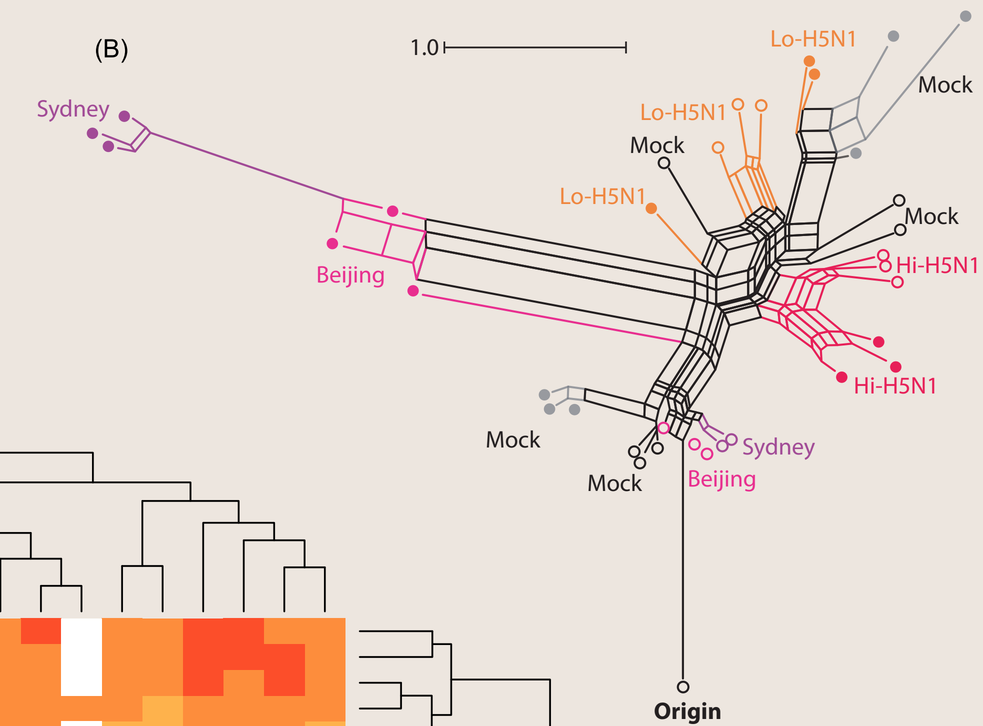
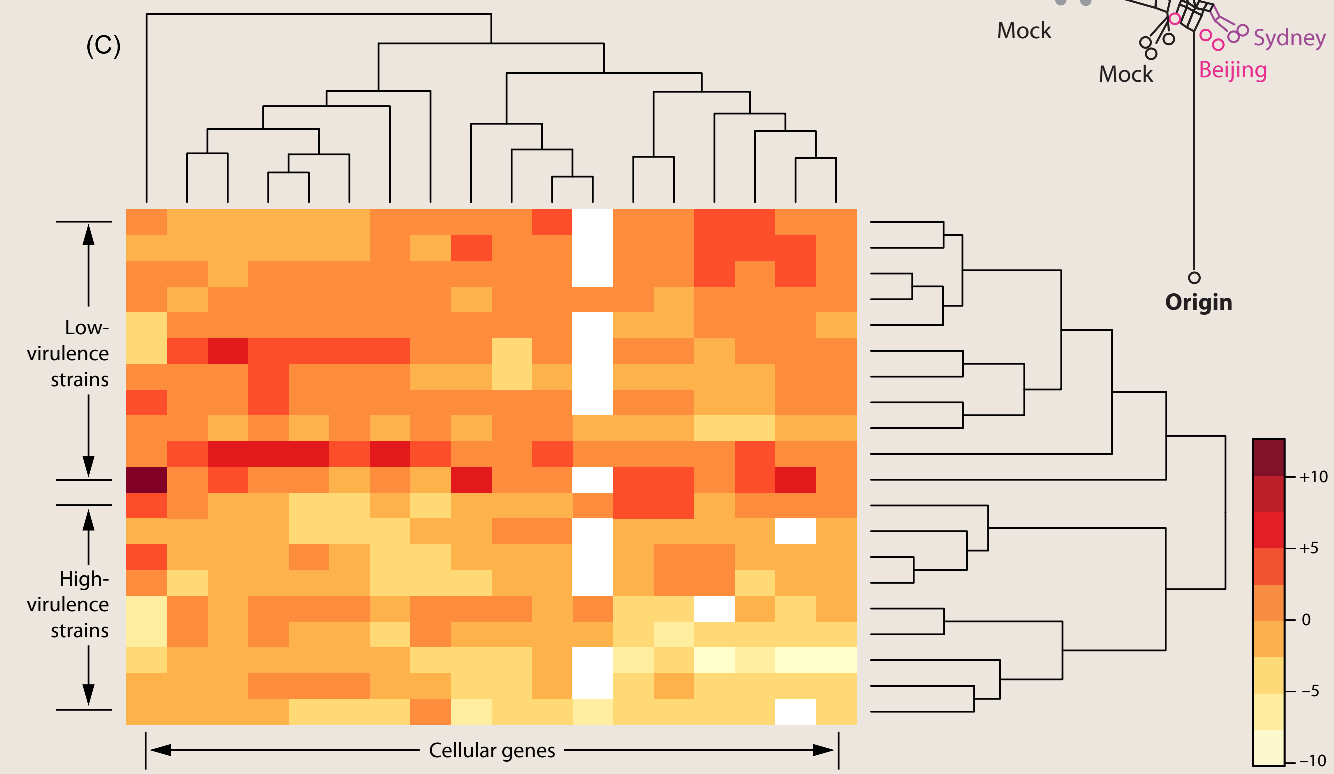


Figure C shows a more quantitative assay. A matrix is constructed with cellular or immune-system genes as column elements and viral strains as row elements. The color of each matrix element shows the degree to which that gene turned on or off when the cell was infected with that virus. The matrix was analyzed and rearranged as per the two "trees" on the right and top of the matrix. There is a clear distinction between high- and low-virulence strains; namely, the gene expression for high-virulence strains was greatly reduced, which may be related to the ability of those strains to minimize the immune response.





gain tremendous insight into many areas of biology, medicine, and health.

Another large team of Los Alamos researchers, now headed by Chris Detter of Bioscience Division, is attacking the pathogen side. In a joint effort with the University of California, Los Angeles (UCLA), Detter's team is helping to establish a global network of organizations that will continually monitor influenza and other infectious agents by gathering samples from critical sources. (For influenza, those sources are birds, pigs, and flu-struck humans). The samples will be sent to any of several automated, high-throughput sequencing laboratories, where researchers will obtain the genetic sequences of the pathogens in the samples. (See "The High-Throughput Laboratory Network" on p. 8.) Estimates are that the entire genome of any influenza virus can be sequenced in less than half a day.

Having sequence data is equivalent to having the keys to the city because those data open so many research doors. Scientists have access to nearly every influenza sequence through the Influenza Sequence Database, developed and maintained by Los Alamos and managed for over a decade by scientist Catherine Macken. Los Alamos scientists use such data, for example, to understand the structure of influenza's proteins, to follow the course of a pandemic, to develop new influenza detectors, and increasingly, to understand why some strains are more virulent than others.

Influenza Basics

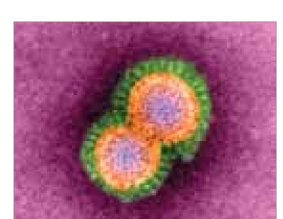
Influenza A is a severely stripped-down biological entity about a million times smaller in volume than a cell. It consists of a core of genetic material (single-stranded RNA instead of double-stranded DNA) packed tightly together with proteins. A protein matrix protects the core, while a protein-studded lipid membrane surrounds and protects everything. The virus is atypical in that its RNA comes in eight separate segments rather then the one long strand that is common for RNA viruses. Each segment contains a single gene that codes for 1 of 11 different proteins, with three of the genes each coding for two proteins.

Influenza's sole purpose is to make copies of itself, but it lacks almost all of the resources to do so. The virus must infect a cell and use the cell's resources to make proteins and help copy its genome. In addition, the virus must circumvent cellular defenses and avoid alerting the host's immune system.

The latter task is complicated by two viral proteins, hemagglutinin (HA) and neuraminidase (NA), both of which protrude from the surface of the virus. HA anchors the virus to the host cell by binding to sialic acid, a type of sugar that graces the surface of cells in the upper respiratory system of mammals (or the intestines of birds). NA is important for helping newly made viruses exit the cell. Both proteins are antigens, meaning they can trigger the immune system to produce antibodies that will stick to the proteins and prevent them from functioning.

The virus counters this vulnerability by relying on antigenic drift—random mutations of the HA and NA genes that make the corresponding proteins unrecognizable to the immune system. How does that happen? Packed into the virus's core is a protein complex that makes the complementary strand to a single-stranded RNA segment, which can be used to manufacture the protein that's encoded within the

Two H5N1 avian flu viruses.
Credit: AP/Reporters



High-Throughput Laboratory Network

Every influenza virus has the potential to mutate its way past molecular defenses such as vaccines, so the key to having control over influenza is to understand how it evolves. "Rendering a virus harmless means honing in on the exact sequences that are being changed though mutations," says Gary Resnick, the Bioscience Division leader.

Honing in requires lots of viral sequence information. That's one reason Los Alamos, in collaboration with UCLA, is advocating a globally distributed network of high-throughput sequencing laboratories that would rapidly obtain and catalogue genomic sequences and phenotypic information (for example, level of virulence, transmissibility, etc.) for influenza and other pathogens.

The High-Throughput Laboratory Network project's sequencing team leader Lance Green.

The first node of that network will be UCLA's Global Bio Laboratory. Nearly operational, the lab will consist of several automated or semiautomated stations for inventorying samples gathered from influenza hot spots, preparing the samples for analysis, and screening them to make sure they contain influenza A.

An influenza sample will typically contain anywhere from a thousand to 100 million viruses per milliliter, not enough to sequence the whole genome. In the past, researchers would infect embryonated chicken eggs with the virus, let the virus reproduce, then harvest their RNA—a rather cumbersome and limiting technique. The project is already moving toward harvesting viral RNA using next-generation cultured cell lines to grow the viruses. After being harvested, the viral RNA will be sequenced at the genotyping station.

Built to Los Alamos specifications by Agilent Technologies and about the size of a compact car, each automated genotyping station will perform "all the functions needed to first amplify then sequence viral gene segments," says Lance Green, leader of the project's sequencing team. The data will then be analyzed and pieced together to obtain the sequence of all 13,588 RNA bases of influenza's genome, which will be accessible to researchers anywhere in the world. Finally, interesting samples will be sent to a refrigerated archive that can hold up to a million strains, which will be available for further studies.

Technologist Cheryl Gleasner attends to matters in the Los Alamos–designed automated genotyping station.

Once it becomes fully operational at UCLA, the high-throughput genotyping station can begin sequencing up to 160 samples per 11-hour run. In an emergency mode, up to 10,000 samples per day will be processed to obtain enough identifying information to follow the course of an outbreak.

"Just imagine that you have 10,000 influenza strains come into the system a year," says Resnick. "After screening them, you sequence the ones that are interesting and archive the ones that are still interesting to you after you sequence. So now you're starting to have this temporal, spatial archive of strains from all around the world. You'll have a huge capability to do comparative studies, get to the heart of host-pathogen interactions, and generate knowledge that can be readily applied to designing more-efficacious medical countermeasures."

segment's gene. But the complex can also make a complement of the complement, that is, a copy of the original RNA segment.

The protein complex is error prone, however, and makes, on average, one mistake (mutation) every time the virus's genome gets copied. The upshot is that the strain that infects a cell is often not the strain that leaves it. A new virus with, say, a mutated HA gene can have the mutated HA antigen already expressed on its surface by the time it leaves the cell and therefore go at least partially unrecognized by the host's immune system. The seasonal flu viruses that plague us each winter typically are new strains that have antigenically drifted away from strains already circulating within the human population.

As an aside, over thousands of years, antigenic drift helped HA evolve into 16 separate varieties (H1 through H16) and NA into 9 (N1 through N9). A virus's subtype is a particular combination of HA and NA, for example, H1N1.

Another of the virus's survival strategies takes advantage of the segmented genome. Two viruses from different species, say duck and human, infect the same host, typically a pig, and produce a duck/human hybrid virus by exchanging RNA segments. The hybrid can gain the ability to cross species, say from pig to human, as was the case with the swine flu virus. (See "Creating a Hybrid" on p. 4.)

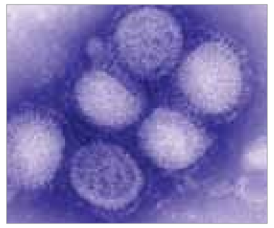
A Glimpse of Virulence

While every influenza A virus uses the same tactics to survive, logic dictates that high-virulence strains with the potential to cause severe illness must interact with cells differently than low-virulence strains do. "Our research shows that there is a clear distinction in the body's response to high- versus low-virulence strains," says Ribeiro.

For example, one of the better-known factors that influence a strain's virulence is the length of a chain of amino acids that runs between two fragments of the HA molecule. This chain must be cut if the virus is to get its RNA into a host cell.

What happens is that the virus, bound to the cell surface by HA proteins, enters the cell by endocytosis: the cell membrane binding the virus craters and then deepens into a pocket with the virus attached to its inside. The pocket pinches off from the membrane, so that the virus is in the cell but trapped within the enclosure (called an endosome).

The newly identified H1N1 influenza virus.
Credit: CDC Influenza Laboratory.



The cell begins to make the interior of the endosome acidic in an effort to break down whatever is inside. Under acidic conditions, however, HA changes its shape, which causes the virus's outer membrane to fuse with the endosome's. A pore then opens in the fused region, establishing a channel through which the viral RNA enters the cell.

RNA cannot enter the cell unless HA changes shape, and HA can't change its shape unless the amino-acid chain gets cut. Researchers speculate that if the chain is "long," it will protrude a bit outside the body of the protein. Shortly after HA is made, the chain can be cut by a wide variety of enzymes found in most cells. If the chain is "short," however, it will run closer to the protein, and the cellular enzymes can't cut it. The protein gets attached to the virus intact (see figure on p. 4), and is cut by only a few types of small enzymes found outside cells in the nose, throat, and upper part of the lungs. Viruses with short-chain HA proteins therefore tend to be less virulent than those with long-chain HA proteins because the latter can infect many more types of cells.

"The length of the amino-acid chain is a strong virulence factor, but there are dozens of others," says Ribeiro. "We hope our research will help the influenza community understand the complex interactions."

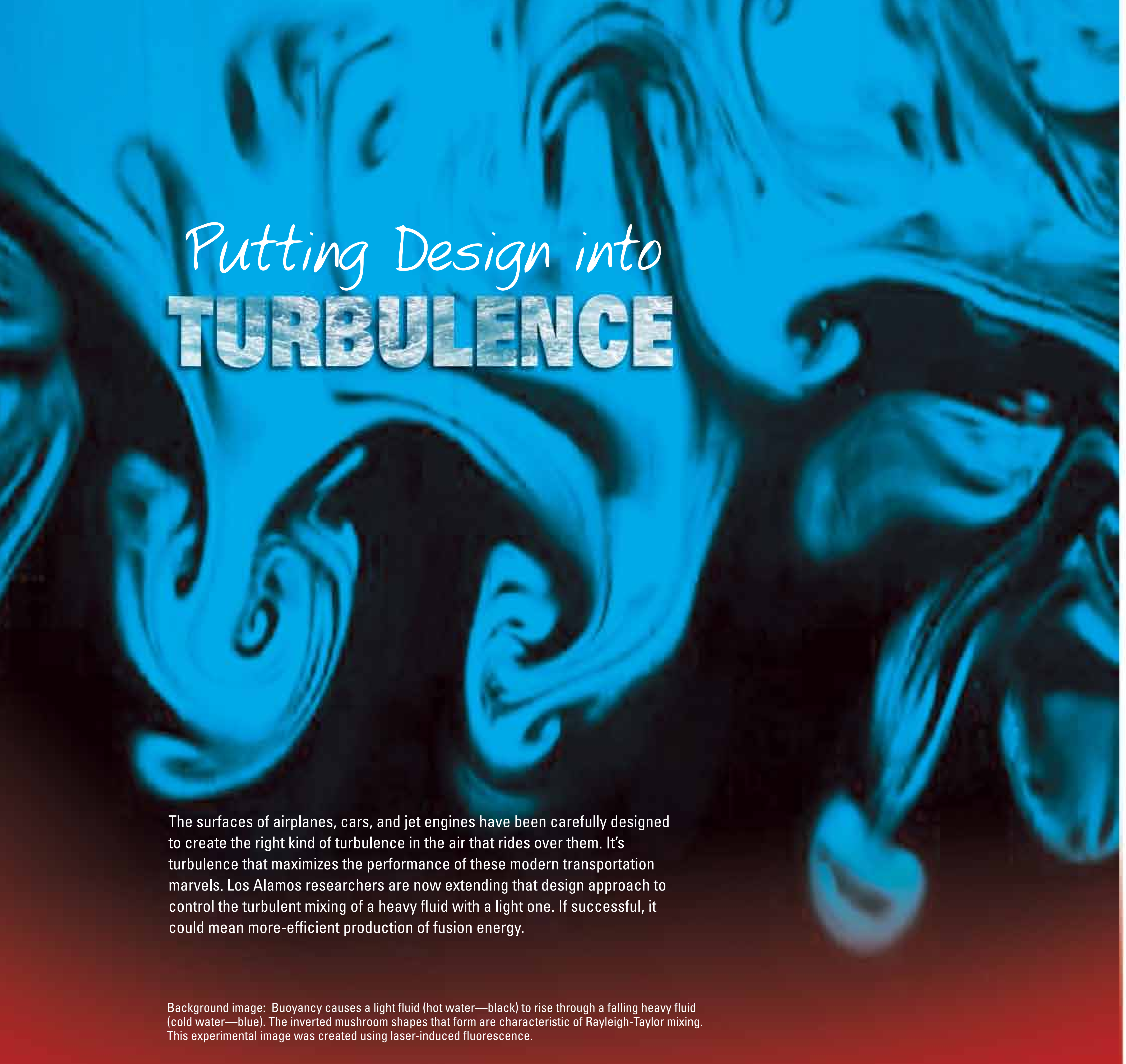
The Big Picture

Sometime during the 2008–2009 flu season, the novel H1N1 virus gained the ability to jump ship from pigs to humans. It circulated in Mexico for several months before it encountered a little American boy, then spread across every continent in less than two months. It was a remarkable evolutionary accomplishment for the new strain on the block.

Any influenza pandemic, however, is but one battle in an epic conflict between man and microbe, a battle in which the evolutionary power of a short generation time, a mere 20–30 minutes in some bacteria, gives the microbe a distinct advantage. While it's naïve to think of winning that war, humanity hopes to achieve a détente that will allow civilization to prosper. The steps taken by Los Alamos and researchers around the world to understand influenza and its interactions will have an effect. Not this flu season, and maybe not the next, but soon we may understand the enemy well enough to reach and sustain that détente. ❖

—Jay Schecker

This article is dedicated to Tony Beugelsdijk, former leader of the Los Alamos High-Throughput Laboratory project, who passed away August 23, 2009.



Putting Design into TURBULENCE

The surfaces of airplanes, cars, and jet engines have been carefully designed to create the right kind of turbulence in the air that rides over them. It's turbulence that maximizes the performance of these modern transportation marvels. Los Alamos researchers are now extending that design approach to control the turbulent mixing of a heavy fluid with a light one. If successful, it could mean more-efficient production of fusion energy.

Background image: Buoyancy causes a light fluid (hot water—black) to rise through a falling heavy fluid (cold water—blue). The inverted mushroom shapes that form are characteristic of Rayleigh-Taylor mixing. This experimental image was created using laser-induced fluorescence.

We recognize and experience turbulence in many forms. The swirling eddies and energetic froth of turbulence are seen in white water rapids, volcanic eruptions, and speedboat wakes. The unpredictable nature of turbulence is experienced by anyone who's taken a plane ride through a storm and felt the sudden bumps, rolls, and shudders caused by turbulent air. But while turbulence can be seen, felt, and experienced, can it also be controlled?

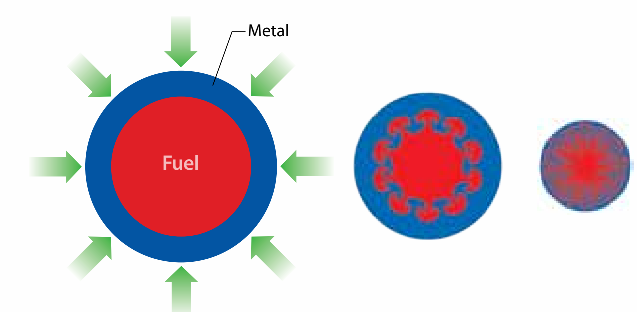
Of particular interest at Los Alamos is the turbulence that arises spontaneously as two fluids mix, say, when a layer of rising warm fluid (air or water) pushes through a layer of sinking cool fluid—called Rayleigh-Taylor, or buoyancy-driven, mixing—or when a high-pressure front in the atmosphere slides across a low-pressure one—called Kelvin-Helmholtz, or shear-driven, mixing. The interface between the two fluid layers may initially be smooth or laminar, but tiny variations in that smoothness will initiate the curling motions of turbulence, in which one fluid curls around and entrains the other (as in the image at left). Very quickly these circulating eddies merge and/or break up across a broad, cascading spectrum of length scales that differ by factors of thousands or millions.

Because it mixes two fluids on many length scales all the way down to the atomic scale, turbulence works efficiently to transport heat, mass, and momentum from one fluid layer to another, often to good effect. In home heating, for example, it causes hot air near a radiator to be rapidly transported to the rest of the room. In an internal combustion engine, it causes the split-second mixing of air with fuel to produce cleaner, more-efficient burning.

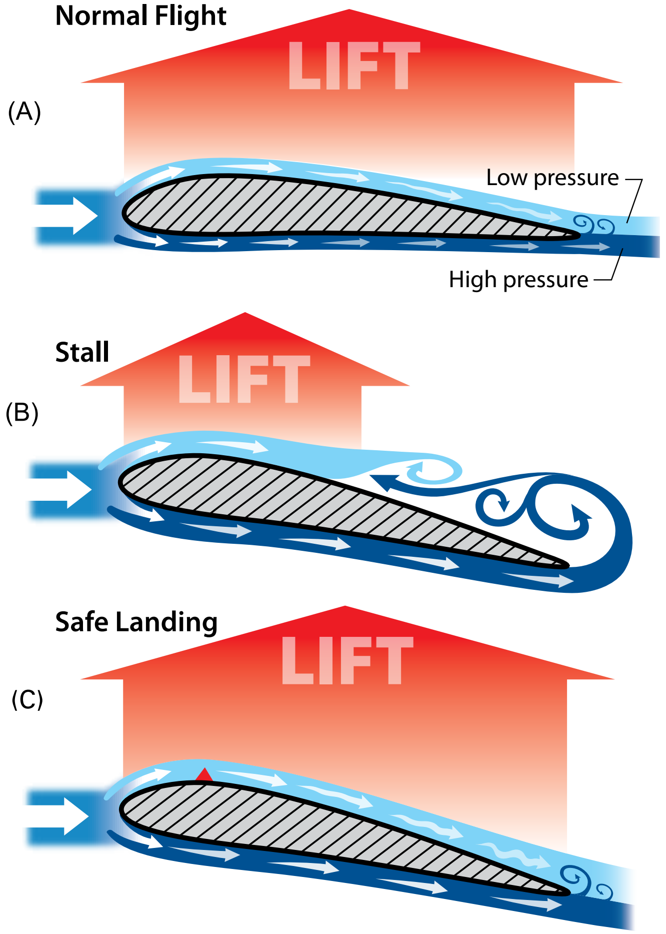
But turbulent mixing is a hindrance in one particular system, namely inertial confinement fusion (ICF). ICF is a laser-driven system for creating fusion energy. In ICF a strong shock wave (high-pressure pulse) implodes (collapses) a millimeter-size spherical metal capsule to about a thousandth of its original volume. Deuterium-tritium (DT) gas within the capsule gets so compressed and hot that its nuclei begin to fuse into helium nuclei, releasing large amounts of nuclear energy. That energy, in turn, provides the heat to sustain additional fusion reactions. But there's a fly in the ointment. Any small bumps or imperfections that develop during the implosion will rapidly grow and cause metal to mix with fuel, damping the heating process and perhaps even quenching the fusion burn (see figure below).

Los Alamos' Malcolm Andrews, E.O. Lawrence Award winner for his work on turbulent mixing, sees a way around this problem. "It may be possible," says Andrews, "to control the turbulent mixing down to acceptable levels, not by removing all bumps—that's unrealistic—but rather by creating very subtle, very long wavelength ripples at the interface between the metal and the fuel."

Andrews and Los Alamos colleagues are pursuing this counterintuitive idea



In inertial confinement fusion, a spherically converging shock (arrows) compresses a millimeter-size metal capsule (blue) filled with deuterium-tritium (DT) gas (red). With sufficient compression, the pressure and temperature ignite the DT fuel, forming a self-sustaining fusion reaction (fusion burn). However, any small bumps or imperfections in the spherical implosion will cause the capsule material, melted by the shock, to grow fingerlike projections that mix with the fuel and rob it of its heat.



through the Turbulence by Design project, sponsored by the Laboratory Directed Research and Development program. This project aims to design turbulence not just in ICF but in all cases in which two fluids (gas or liquid) of different density are driven past each other by buoyancy forces and mix far from the influence of solid walls and boundaries.

Turbulence by Design

The inspiration for Andrews' idea comes from technology's brilliant successes over the last half-century in designing and controlling "wall" turbulence: turbulent flow around the solid boundaries of airplanes, cars, turbine blades, and even golf balls. By reshaping these boundaries, engineers purposely create turbulence—of the right kind and in the right place—to dramatically control the adjacent airflow, thereby reducing the drag and/or increasing the maneuverability and efficiency of these objects.

A case in point is turbulators, the small, fixed vanes of metal that poke up from the top surface of an airplane wing and are designed to help during slow flight. As seen in the illustration above, in normal flight (A), the thin layer of turbulent air flowing along the top surface of the wing has lower pressure than the layer flowing along the wing's underside, and the vertical pressure difference between the two provides the lift that keeps the plane aloft. To slow the plane for landing, a pilot may raise the craft's nose, which tilts the wings upward. Without turbulators (B), the wing tilt can cause the low-pressure layer (light blue) to separate from the aft section of the wing's top surface, allowing high-pressure air from behind to move in under that layer and press down. The result would be a sudden loss in lift, causing the plane to stall and crash.

Enter the turbulators (C). Their effect is to produce turbulent eddies that entrain fast-moving air from above into the low-pressure layer, thereby increasing the top layer's thickness and momentum. That extra momentum pushes back on invading high-pressure air and keeps the low-pressure layer flowing on the wing surface even when the wings tilt up. So the lift stays steady during the plane's descent.

Such designed turbulence has typically been limited to wall turbulence, in which the flow past the fixed shape of a solid boundary continuously drives the formation of the desired eddies. In the turbulent mixing of ICF, there are no solid boundaries; instead, buoyancy drives bubbles of the light DT fuel to rise through heavy fingers of molten metal. The shear generated as the rising and falling fluids slide past one another causes curling eddies to mingle the two fluids. This turbulent mixing layer increases in width as the two materials interpenetrate and mingle, releasing potential energy as the heavy fluid falls. That energy drives a cascade of smaller and smaller eddies until the two fluids are combined at the atomic level.

On the face of it, there seems little opportunity for external control of this unbounded mixing layer. However, just as turbulators design large-scale turbulence and momentum entrainment on a wing, Andrews suggests that large-scale (long-wavelength) but very small amplitude ripples in the initial interface between a heavy and light fluid can control the overall growth of the mixing layer. If Andrews is right and long-wavelength ripples control mixing, then turbulence must somehow store a "memory" of the rippling interface where the turbulence originated.

Breaking with Tradition

Turbulence with memory is a somewhat heretical, almost contradictory, viewpoint. Most scientists assume that turbulent mixing involves rapid loss of memory, the random formation and breakup of eddies erasing information about the initial shape of an interface between two fluids just as effectively as random changes of direction would erase a hiker's memory of the direction back to his or her starting point. Scientists have built mathematical descriptions of turbulence—turbulence models—that are based on the assumption of memory loss and therefore predict certain universal properties. In particular, in these models, energy flows equally through all scales (sizes of eddies), from the largest to the smallest, for a given problem, keeping the turbulence in balance (equilibrium) across the scales.

Counter to that orthodox view, Andrews emphasizes that equilibrium flows are hard to find in reality. "Fluid mixing in ICF, for example, is far from equilibrium, and it is this intrinsic out-of-balance flow that makes mathematical models describing the development of turbulence difficult to formulate and solve," he explains. "But what if memory of the starting configuration simply persists and dominates at 'late time,' when the flow is seemingly turbulent? Then these same, already-complex mathematical models must also include knowledge of the starting conditions and must account for late-time effects."

Andrew's team has already gathered experimental evidence showing that memory of long-wavelength ripples in the initial interface between two fluids does indeed persist during mixing (see figure above).

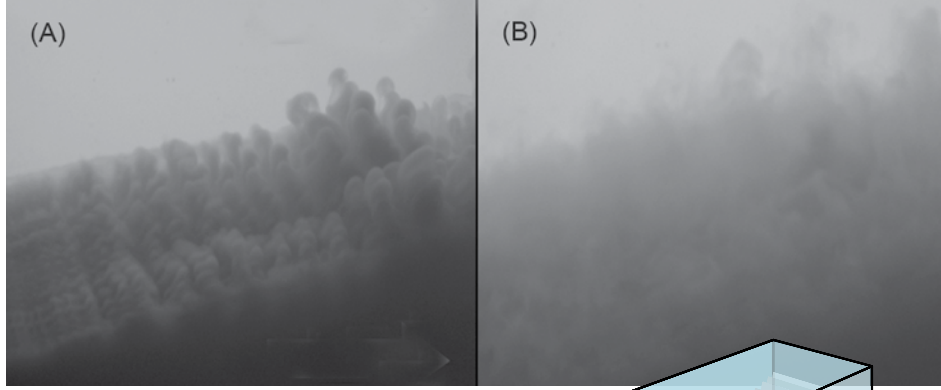
To turn that evidence into a design tool for ICF fusion capsules or other technological applications such as internal combustion, climate prediction, and free-flowing jets and plumes, the Turbulence by Design team must first understand how those initial ripples in density or velocity propagate in time. They need to learn from experiment (actual and numerical) how different interfacial shapes alter the development of the mixing layer. Then they must translate that behavior into a predictive foundation for use in turbulence models, which can be put on a high-performance computer to predict or design the outcome of many different initial conditions that occur in experiments for ICF and other fluid-based applications.

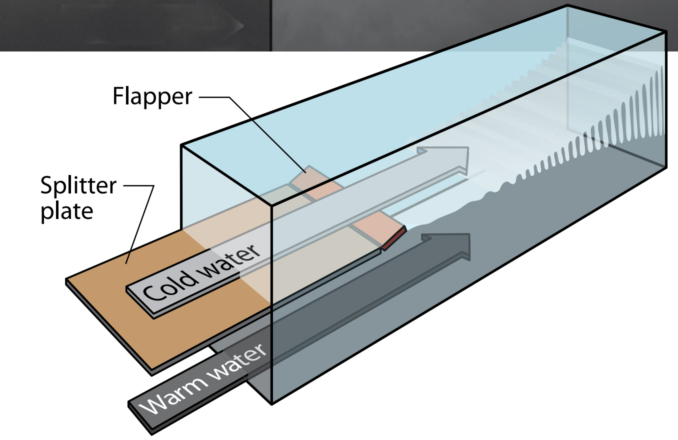
Discovering the Effects of Initial Conditions

Just 10 years ago it would have been impossible to achieve the level of knowledge required to carry out this program. Neither the experimental diagnostics nor the high-performance computing capabilities were up to the task. Today, those capabilities are in hand at the Laboratory, and researchers are gung-ho about pursuing this new adventure in turbulence research.

The game plan is to gather data from turbulent mixing experiments at Los Alamos (the shock-tube experiment) and at the water channel facility (represented above) at Texas A&M University. Both have a proven capability to control the shape of the initial interface between the fluids and to track how the perturbations from a smooth, uniform interface affect the mixing over time. The choice of initial interfaces will be guided by results from direct numerical simulations of turbulence performed on the highest-speed (petaflop) computers, including Roadrunner at Los Alamos. The measured effects of those initial interfaces will then guide how turbulence models are adapted to capture the realistic influence of initial conditions on turbulent mixing. State-of-the-art capabilities and close coupling of experiment, computation, and theory make Los Alamos a perfect location for the Turbulence by Design project.

The Shock-Tube Experiment. The Laboratory's Kathy Prestridge and her team use a unique shock tube to study the mixing induced when a shock hits the interface between air and a higher-density gas. This setup mimics, in part, the shock-induced mixing between DT fuel and capsule material in ICF experiments. For the initial condition, the team can successfully create a very-stable and reproducible wavy curtain of high-density gas and can alter the initial shape of the curtain to study the effects of different initial interfaces. As a flat shock passes through the long-wavelength ripples of the interface between the air and the curtain, those ripples grow more pronounced,

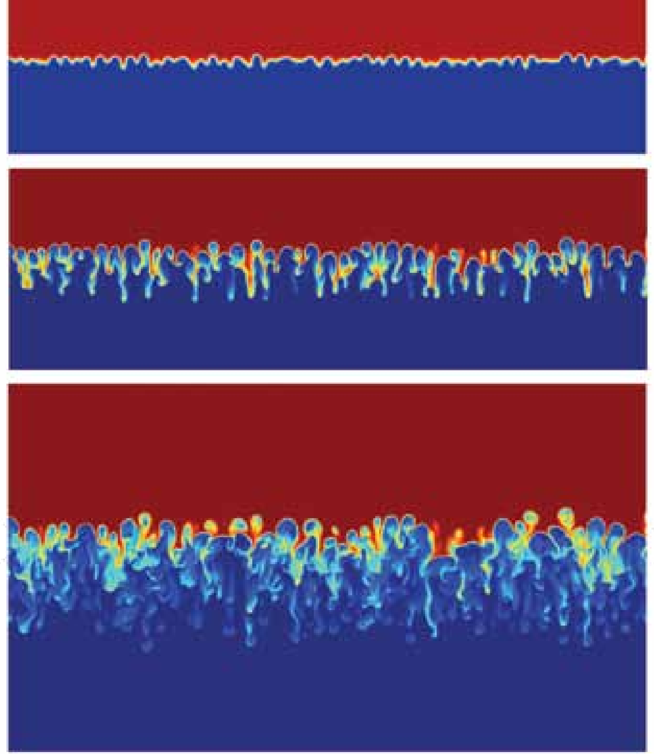




Above: The schematic shows the Texas A&M water channel facility where cold, heavy water (top) and warm, light water (bottom), with milk added to show the interface, flow left to right past a splitter plate. The flapper at the end is moved up and down to create a wavy interface between the two fluids as they flow past. The experimental result in A shows that long-wavelength ripples in the interface (introduced by moving the flapper slowly) maintain their shape, while buoyancy forces drive the cold and hot fluids to mix. In contrast, the result in B shows that short-wavelength ripples (introduced by rapid flapper motion) lead to mixing on very-small scales and wash out any memory of the initial ripples.

curl to form eddies, entrain the air around them, and eventually develop into a turbulent mixing layer that travels down the shock tube (see the figure below).

Prestridge describes the team's goals. "We're gathering enough data to simultaneously determine the mean velocity and mean density at every point in the flow, down to the 50-micron scale, as well as the fluctuations. With that we can measure the effects of initial conditions and provide the necessary statistical data for the development of a 'memory' turbulence model."



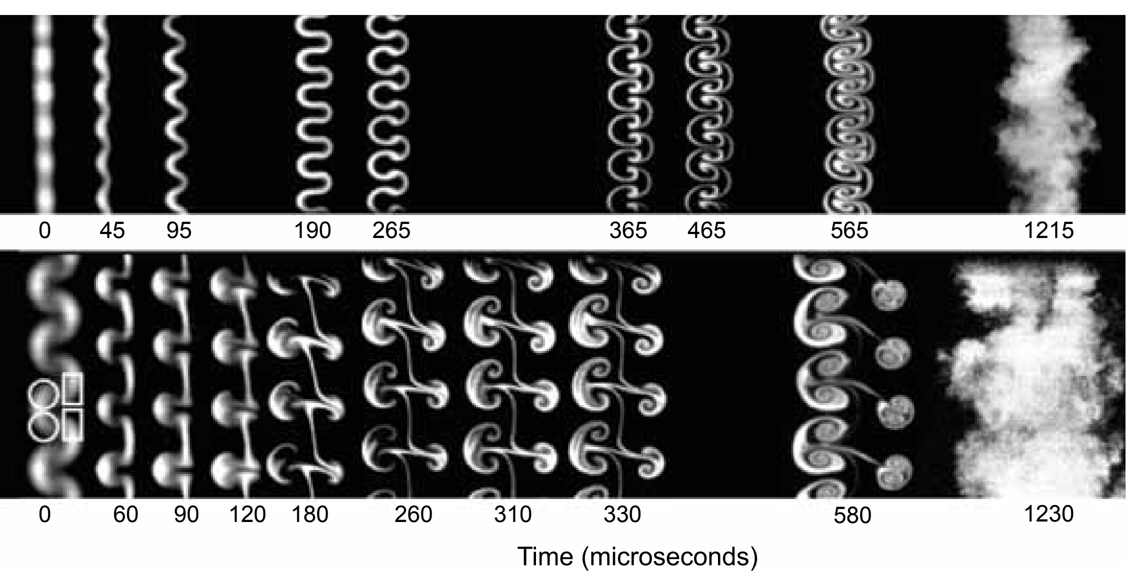
In the highest-resolution DNS simulation thus far of Rayleigh-Taylor mixing, tiny initial perturbations in a flat surface (top) grew large, entrained fluid, merged, and led to turbulence at growth rates seen in experiments.

Prestridge will investigate initial interfaces that numerical experiments and analytical studies suggest might be promising for producing late-time effects.

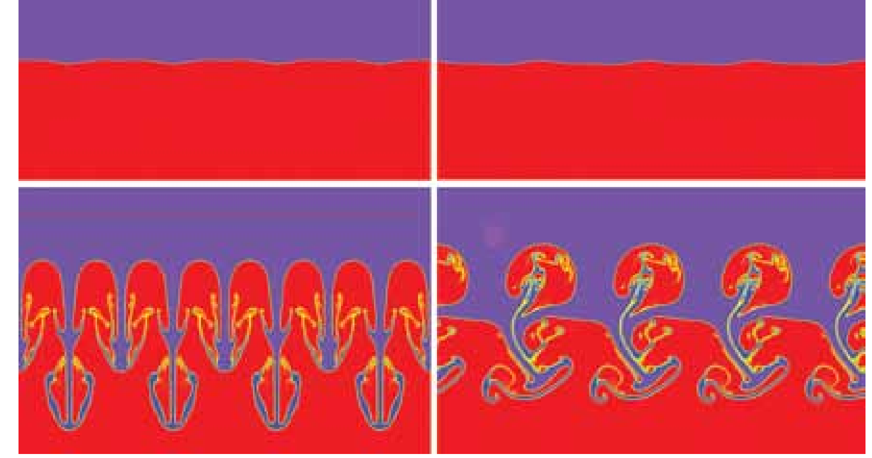
Numerical Experiments. The modern toolkit for high-performance computers now includes programs to perform high-resolution direct-numerical simulation (DNS) of turbulent flows. The quality of the latest DNS results is on a par with, or in some cases even supersedes, experimental data. How can that be? First, DNS uses the fundamental equations of fluid flow to calculate pressures, densities, and velocities in turbulent flows. Second, the petaflop computing power of today allows those values to be calculated for a very-fine lattice of time and space points, fine enough to calculate the smallest eddies in the turbulent flow. Those two features make DNS results as real as experimental data.

Daniel Livescu, leader of the fluid-mixing DNS effort at Los Alamos, explains why DNS data can be better than experimental data. "We have the freedom to set up the boundary and initial conditions of the flow as we want them or to focus on particular types of flow, such as those in the turbulent mixing experiments of Texas A&M or in the Prestridge shock-tube experiment. That freedom sets up a complementary discovery path between actual and numerical experiments: DNS points the way for actual experiments, and unexpected experimental results can be explored in detail by DNS."

Livescu and collaborator Mark Petersen recently used DNS to perform the largest simulation to date of Rayleigh-Taylor mixing (heavy fluid falling through and mixing with a light fluid). By selecting the appropriate set of initial conditions, they became the first researchers to simulate mixing-layer growth rates comparable to those seen in experiments. Next, the Livescu team will vary the initial conditions to identify perturbations that have long-lasting influence on the growth rate.



Each set of sequential photographic images from the Los Alamos shock-tube experiment shows horizontal slices through a high-density gas curtain (white) that when shocked develops into a turbulent mixing layer as it moves down the tube. The surrounding air is black. The different initial shapes of the gas curtains give rise to quite-different mixing layers at late times. A high-intensity, very-short laser pulse serves to freeze the flow's high-speed motion, allowing cameras to capture an image.



Computations by Ray Ristorcelli show that slightly different initial ripples in the interface made from two wavelengths (top figures) produce very-different Rayleigh-Taylor growth (bottom figures). The purple fluid is four times denser than the red fluid. In the left example, the two wavelengths are 180 degrees out of phase, and the ripples grow into rising bubbles in red and falling spikes in blue. In the right example, the same two wavelengths have been phase shifted by 45 degrees, and the resultant mixing has noticeably different penetration and morphology.

Retooling Turbulence Models—The Central Idea of Design

So the team's strategy is shaping up. The researchers have established that initial conditions affect the development of turbulence, and now the goal is to translate that behavior into mathematical turbulence models that can predict experimental outcomes.

Andrews explains, "Right now we don't formally know how to set initial conditions in our turbulence models, and neither do we know the best conditions to choose for a given purpose. It's like walking onto a new continent—we know how big it is, but we don't know what we're going to find. We may find some places where very-special things happen."

The examples above show two Rayleigh-Taylor mix configurations, computed by Ray Ristorcelli, in which the heavy fluid (purple) is four times denser than the light fluid (red) beneath it. In both examples, the interface between the heavy and light fluids contains ripples made from the same two wavelengths, but in the second example, a deliberate misalignment (a 45-degree phase shift) exists between the two wavelengths. The late-time configurations are strikingly different. If this were not a computation, one might guess that the "lean" in the second configuration was caused by shear, but there was none. Says Andrews, "This is a surprising result for such a simple change. It shows that deliberate perturbations, designed either from experiment, DNS, or theory, can affect late-time turbulence, perhaps minimizing (or maximizing) mixing. The ability to reproduce these 'designs,' from initial conditions to late-time behavior, then becomes a test for setting the right initial conditions in our turbulence models, conditions that are necessary for accurate predictive capabilities for these models."

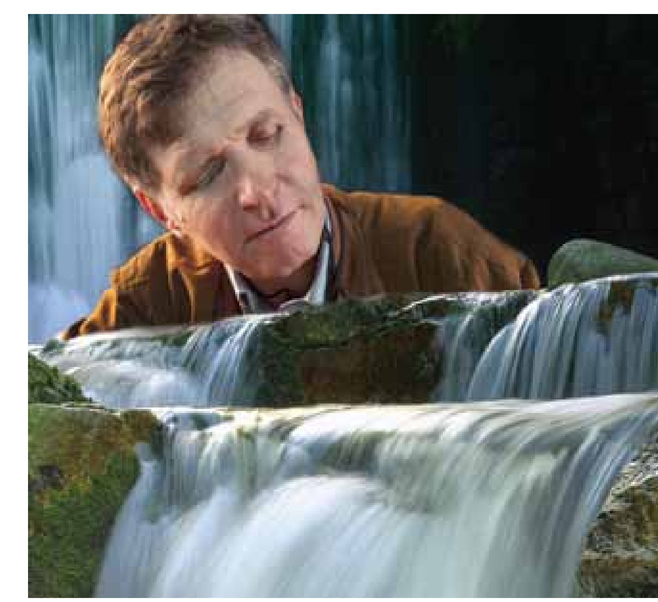
Once the team can understand, control, and predict the flow from initial conditions to late-time turbulent mix, it will have a complete design route, which will then open the possibility of inverse design. In other words, one could start from a desired result and provide or predict an initial condition (the size and location of a turbulator or the initial ripple of the density interface) that would produce that result.

Reconciling Experiment and Theory

Turbulence research is often a humbling experience because it usually involves discovering how little the researcher knows or understands about turbulence. However, Andrews predicts that understanding initial conditions and their influence on turbulence will likely lead to efficient energy-production designs for ICF, high-speed trains, and more-efficient internal combustion engines. That understanding may also resolve a host of outstanding inconsistencies between experiment and theory, a possibility that intrigues turbulence researchers as they struggle to understand and control one of the great unsolved problems of physics.

Andrews sums up the vision for the Turbulence by Design project this way: "We can't provide a complete theory of turbulence because turbulence tends to reflect its drivers, and these can be very disparate. However, just as the physicist Richard Feynman pointed to 'space at the bottom'—room for exploration at the smallest scales—and thus stimulated the development of nanoscience, perhaps Los Alamos, through its variable-density turbulence problems, can point to 'memory within turbulence' as a new field waiting to be explored and developed." ❖

—*Necia Grant Cooper*



Malcolm Andrews gets a new take on turbulence.

Los Alamos Institutes

Strategic Outreach for Renewal and Competitiveness

The National Security Education Center sits at the edge of the Laboratory campus in the Los Alamos Research Park, a building marked UCSD and UCSB for two University of California campuses. The center bustles with students, visiting professors from the University of California, and Laboratory technical staff. They're all there to participate in distance-learning classes and exciting projects on everything from the structural health of wind-turbine blades to new computer architectures for handling gigantic datasets. 1663 *recently sat down with Nan Sauer, the center's director.*

1663: What is the National Security Education Center all about?

Los Alamos Research Park, home to the institutes.

Nan Sauer: The center is home to five educational institutes, three innovation centers, and the Institute for Geophysics and Planetary Physics. It's the Laboratory's response to change, and it's a way to develop the technical workforce and the science for our expanded national security mission.

1663: By national security mission, do you mean the Nuclear Weapons Program?

Nan Sauer: Well, that's the Lab's central mission. As long as nuclear weapons remain extant, Los Alamos has to maintain preeminence in nuclear weapons science. But that's only part of the story. There's much more to the national security science mission. Los Alamos is also becoming a nexus for many new technological challenges—energy security, health and infrastructure security, global security, and more. Both the institutes and the innovation centers are focusing on the science associated with all elements of the extended mission. But the institutes have the special purpose of developing the workforce, and they're doing that by building partnerships.

1663: Partnerships with whom?

Nan Sauer: Each educational institute at the center is a strategic long-term partnership with a specific University of California (UC) campus or with universities in the New Mexico Consortium (New Mexico State University, the University of New Mexico, and the New Mexico School of Mining and Technology). The goal of each is to educate both undergraduate and graduate students in some specialized area important to the Laboratory.

1663: Are these institutes a new thing?

Nan Sauer: When LANS (Los Alamos National Security, LLC) took over management of the Laboratory from UC, it established the institutes to address two big concerns. One is replenishing the DOE/National Nuclear Security Administration (NNSA) workforce. The other is competitiveness—maintaining technical competitiveness in a rapidly changing world.

1663: So the institutes are to create a pipeline for new young scientists to enter mission-oriented programs.

Nan Sauer: Yes, and also to help retain and revitalize existing staff. Their origin really goes back to the late 1990s. At that time the Nuclear Weapons Program was facing the problems of assessing aging weapons, and it needed new staff. But there was no targeted program in place to attract the best and brightest in engineering. In 2000 Los Alamos' Chuck Farrar and his division (the Laboratory's Engineering Division at that time) responded by starting the Los Alamos Dynamic Summer School, and by 2003 it had evolved into a joint institute with UC San Diego: the Engineering Institute. This institute has a graduate degree program that focuses on damage prognosis—a new field concerned with assessing structural integrity and also developing models to predict the useful life of a given component.

1663: Is the Engineering Institute still a summer school?

Nan Sauer: It still holds summer schools for undergraduate and graduate students, but it also sponsors a unique distance-learning program in which Lab technical staffers pursue advanced degrees in engineering from UC San Diego while staying employed here in Los Alamos. Graduate students at UC San Diego participate as well.

1663: Are Engineering Institute graduates joining Los Alamos?

Nan Sauer: Some are joining, but many graduates are already part of the staff. They can apply their new skills within the Nuclear Weapons Program, or they can join one of several Laboratory divisions that provide engineering solutions in energy, defense, and global security.

Kevin Farinholt (left) and Stuart Taylor show Center Director Nan Sauer the wireless sensor network they've created for wind turbines. The piezoelectric transducer sensors (not visible) mounted on the surface of of the turbine blades measure changes in electromechanical impedance, a useful indicator of local structural damage formation. On the hub of the wind turbine is a wireless device that collects these impedance measurements and either transmits them for immediate analysis or stores them for later retrieval.

Kevin Farinholt and Stuart Taylor are wonderful examples. They've been working on advanced wireless sensing systems for wind-turbine blades, bridges, and other structures. The sensors are designed to detect signs of material fatigue and transmit measurements for offsite analysis. On wind turbines, these sensors will help us understand how detrimental wind loads are causing damage to sensitive internal components. Stuart started in our Engineering Institute summer school on structural health monitoring as an undergraduate and is now earning his Ph.D. from UC San Diego through the Engineering Institute. He hopes to remain as a postdoctoral fellow working on institute-related projects. Kevin came to the institute from industry to be a postdoc and is now a staff member in our Applied Engineering and Technology Division.

Institute graduates learn a multidisciplinary approach to damage assessment and prognosis that involves modern robotics, information technology, advanced sensing technology, and theory and simulation. And the approach is applicable to everything you can imagine, including energy systems, bridges, manufacturing infrastructures—even biomedical devices like artificial joints and limbs.

1663: The program sounds very innovative.

Nan Sauer: It is, and it's been a model for three other joint institutes with UC campuses: the Information, Science, and Technology Institute with UC Santa Cruz; the Materials Design Institute with UC Davis; and the Institute for Multiscale Materials Studies with UC Santa Barbara. Now there's a fifth institute, the Institute for Advanced Studies, which partners with universities in the New Mexico Consortium. This institute has a broader scope than the others. It's promoting cutting-edge research projects on topics aligned with the New Mexico universities' interests: materials science and nanotechnology, energy and environment, and information science and technology. For example, there are institute collaborations on medical radioisotopes, biofuels, and a prototype green grid for New Mexico.

1663: Health and energy projects must draw new people to Los Alamos, but in terms of revitalizing existing staff, how popular are the graduate courses at the institutes?

Nan Sauer: About 100 Lab staff members have enrolled in the formal graduate courses each year. Some are working toward advanced degrees. Others are getting more knowledge and training in nontraditional disciplines. Take the course in bioinformatics from UC Santa Cruz that was offered this past spring. It was quite popular; some people wanted to update their skills and others wanted to learn the fundamentals.

In the 2008–2009 academic year, we ran 22 graduate courses. The campuses are gracious about offering a list of classes each quarter and seeing which of them fill up and which don't. Some faculty come from the Lab, but many more are UC professors. If a UC professor is giving the class, students here participate via Polycom video-conferencing. The students see three screens—one showing the notes on the whiteboard, one showing the instructor, and one showing the class on the university campus. It's like being in the classroom. We have Lab staff who are taking courses, but we also have students from the campuses who are doing their graduate work here and need to fulfill their coursework requirements.

Charlene Dvoracek, a student from the Materials Design Institute, explains a poster about her work to Lab Director Mike Anastasio.

1663: Why are most institutes associated with a single campus?

Nan Sauer, director of the National Security Education Center.

Nan Sauer: People seeking a degree have to have a home campus. When the Engineering Institute was formed back in 2003, advanced degrees through distance learning were not that common, and we needed to partner with a specific university. The Jacobs School of Engineering at UC San Diego was willing to offer a unique degree in damage prognosis, and Chuck Farrar teamed with them.

Now our Information, Science, and Technology (IST) Institute with UC Santa Cruz—led by Gary Grider and Carolyn Connor of the High Performance Computing (HPC) Division—has branched out to multiple schools, including MIT, Carnegie-Mellon, and Ohio State. Several of these relationships grew naturally from collaborations that the IST innovation center and its leader Frank Alexander had initiated. Frank, Gary, and Carolyn work closely to coordinate IST activities.

Of the schools involved, only UC Santa Cruz offers classes, but the others are participating in specific research areas. Santa Cruz is focused on data storage for the huge datasets from computer simulations and from observations in space, in the environment, in medicine, and so on. Carnegie Mellon is looking at the resiliency of high-performance computing systems. Ohio State is focused on sensors, sensor systems, and data fusion—bringing together different data streams. MIT is focused on machine learning.

Undergraduate students in the IST summer school with a new computer cluster they built during their stay.

All these avenues can contribute to solving complex problems such as situational awareness, that is, the ability to measure environmental elements, interpret them, and predict their status in the future. For example, you might like to monitor greenhouse gases over the globe, but how do you handle and interpret all that data? How do you turn data into knowledge? That's an overarching focus for the IST innovation center as well as the IST Institute.

1663: Can you describe a project of this kind?

Nan Sauer: One we're very proud of is a pilot project to introduce data-intensive supercomputing (DISC) to the Laboratory. Gary has told me that giants like Google, IBM, Yahoo, and Microsoft have already developed the DISC software and hardware to manage massive indexes of files and images, and those tools might be very useful to us for analyzing the massive datasets you get in cosmology, bioinformatics, genomics, environmental monitoring, and cybersecurity.

To try this out on a shoestring budget, HPC Division and the IST innovation center donated the hardware components for a DISC computer cluster, and then the IST Institute and HPC Division brought in summer students (Ph.D. graduate students) to help. As part of their summer work, they were given the task of building the DISC computer cluster, programming the cluster using software similar to that used by Google, and testing its ability to do simple tasks on different kinds of datasets. That's the kind of experience students have when they come to one of the institute summer schools. They're thrown into situations that require them to work in teams to solve multidisciplinary problems. Gary likes to point out that DISC is a trailblazing project—not only does it introduce the Lab to a new way of thinking, but it also pulls people together from across the Lab to get things done.

1663: The Laboratory's Postdoctoral Program brings in a large fraction of our new hires. How would you compare the institutes with that program?

Nan Sauer: Postdocs are very common in chemistry, physics, and theoretical work, but for computer science, engineering, and high-performance computing systems, people earning a Ph.D. are typically picked up by industry even before they graduate—so these Ph.D. students don't take a postdoctoral position. That's why we're targeting undergraduates and graduates in these areas and introducing them to the Lab's mission-critical problems.

One of the goals is to influence the types of topics that are taught in graduate schools. We're focusing on specific niche areas where we need to be competitive, and we're working on getting really good people to come here. Dan Rees of Accelerator Operations Technology (AOT) Division is now developing a graduate program with UC San Diego on radio-frequency engineering to support the accelerator work that goes on at LANSCE, our neutron science center, and the work that will be done in the future at MaRIE, the Lab's planned Matter and Radiation In Extremes signature facility for studies of materials under extreme conditions. Dan wants students to do their graduate work here and learn how accelerators work because the academic programs don't adequately prepare engineers in many of the technical areas required to support accelerator design and engineering.

UC San Diego Engineering Institute students (above) test the capabilities of their fledgling wireless plume-tracking system on an engineered smoke plume (right). This system will eventually use up to six remote-controlled, sensor-equipped planes (bottom right) to map out the distribution of contaminant concentrations and wind velocities in a plume—enough data to predict the likely course of dispersal.

Another example is the the degree program in energy to be started at UC Davis. Dan Thoma, who leads the Materials Design Institute, is working with the office of the vice chancellor of research at UC Davis to create two new cross-disciplinary degree programs in energy: one in management and policy and the other in science and engineering. Materials science, mechanical engineering, physics, chemistry—basically any science discipline—would have an overlap with these programs.

And recently Larry Ussery in the Nuclear Nonproliferation (N) Division has suggested we start a university program in nuclear engineering and criticality safety. Larry wants to sponsor interns who would do their research at the Laboratory. N Division is known internationally for nuclear criticality expertise, an area that's crucial to handling nuclear materials safely, but not many people are going into it, resulting in a chronic shortage of this expertise at the Laboratory and across the NNSA.

Tutorials are another important educational tool that we use. For those, people don't need to be formally enrolled in graduate school. They can take a tutorial in an area that's important to their research. A good example is the distinguished lecture series held in the Institute for Multiscale Materials Studies, which focuses on soft materials (foams, gels, liquids, colloids, polymers, granular materials, and some biological materials) and materials modeling.

1663: It sounds like the institutes approach is an exciting one—for students and Los Alamos staff.

Nan Sauer: For students, it's an eye-opening experience, much like when I first joined Los Alamos as a postdoc. I was in the Isotope and Nuclear Chemistry Division, and I saw inorganic chemists and spectroscopists and biologists all working side by side on topics ranging from hydrogen activation to medical radioisotopes. And today I find it very gratifying to see bright young students having a similar experience when they walk through the institutes' doors. They're invariably struck by the range of work and the way Los Alamos staff from different disciplines are working together. It's an experience that makes many of them want to stay. ❖

—*Necia Grant Cooper and Eileen Patterson*

SPOTLIGHT

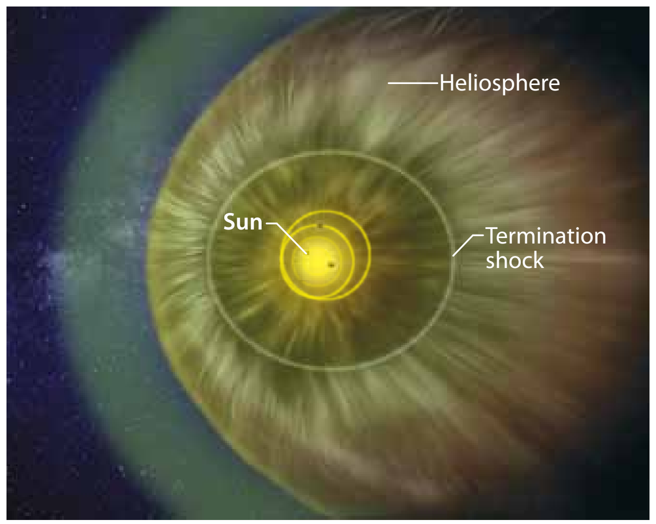
Something from Nothing

Billions of miles beyond the orbit of Pluto, in the so-called interstellar boundary region where the Sun's territory gradually gives way to interstellar space, there's a whole lot of surprising physics going on.

Data taken by the Los Alamos–built particle imager aboard NASA's IBEX (Interstellar Boundary Experiment) satellite revealed an unexpected "ridge" of atoms running through most of the boundary region. With no explanation for why this band of matter exists, mission scientists are as perplexed about it as they are excited.

"This band was not predicted by any of our models or theories—not even hinted at," says the Laboratory's Herbert Funsten, leader of the collaboration that designed, built, and tested the imager. "It speaks to how much more there is to learn about our own little corner of space."

To their credit, scientists have learned a tremendous amount about the galactic neighborhood. They know that the space between the nearby stars, the local interstellar medium (LISM), is filled with protons and neutral hydrogen atoms in the form of a moderately hot (6000°K) "cloud" some 30 light-years across. The LISM also sports cosmic rays, magnetic fields, and a smidgen of heavy elements, molecules, and dust. But with a density of only 0.1 atom per cubic centimeter, the LISM is rightly said to be filled with next to nothing.

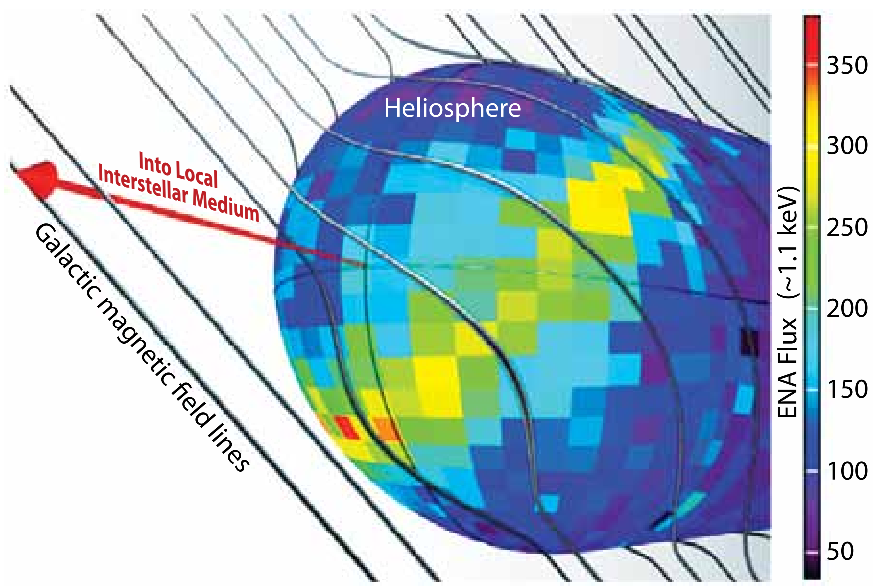


The solar wind from the Sun carves out a region of space—the heliosphere—that keeps cosmic rays and the interstellar gases at bay. The Sun is moving into the local interstellar medium, so the heliosphere is compressed in the direction of travel, and lengthened behind.
Credit: NASA/IBEX/Adler Planetarium

Our Sun and solar system are cruising through the LISM at a respectable 10 miles per second. However, the so-called solar wind, composed of highly energetic hydrogen ions that race outwards from the Sun in all directions at well over a million miles an hour, pushes the LISM out of the way. Thus the wind creates an immense bubble within the LISM known as the heliosphere. Aside from delineating the Sun's domain, the heliosphere helps protect Earth and the rest of the solar system from dangerous cosmic rays.

The heliosphere has structure, however. As the solar wind spreads outward, it becomes less dense, and at about 9 billion miles from the Sun, its density becomes roughly equal to the LISM's. At that distant boundary, called the termination shock, fast-moving solar wind ions occasionally collide with LISM particles, with the net result that the solar wind slows down and heats up as it transitions from a supersonic gale into a subsonic breeze. Beyond the termination shock lies a thick interaction region, perhaps 3–4 billion miles across, where the ions finally come to rest—the edge of the heliosphere.

Scientists knew very little about the termination shock or the interaction region. After all, no light or radiation emanates from either location. Yet scientists were able to gather data from and map those regions by cleverly exploiting a neat piece of physics. During a collision, an energetic hydrogen ion can steal the electron from a slow LISM hydrogen atom and become an energetic *neutral* atom—an ENA. The neutral atoms can be detected by one of two particle imagers aboard IBEX: IBEX-Hi, built by Funsten's team, and IBEX-Lo. The two detect high- or low-energy ENAs, respectively.



The ENA flux, as measured by the IBEX-Hi ENA imager, painted on the heliosphere. The black lines are a possible configuration of the galaxy's magnetic field lines.
Credit: Adler Planetarium/Southwest Research Institute.

The IBEX-Hi ENA imager in the Los Alamos calibration chamber, with instrument manager Arthur Guthrie (left) and IBEX scientist Paul Janzen, formerly of Los Alamos and now at the University of Montana.

"The ENAs go in whatever direction the ions were heading the instant before the collision," explains Funsten. "As ions, they were forced to spiral around and follow the Sun's magnetic field lines, and if you trace out an ion's trajectory after it is heated at the termination shock, you'll see that it frequently points back to Earth. A tiny fraction of ions becomes neutral at just the right instant to travel straight into our imager."

As IBEX circles Earth in a highly elliptical orbit that extends nearly to the moon, the two imagers get a direct view of a small slice of the heliosphere. Each records the number of ENAs with a specific energy that come from that slice. Then as Earth orbits the Sun, more of the heliosphere gets sampled, allowing mission scientists to construct a contour map showing the source of the ENAs.

As summarized in one of five papers recently published online by *Science* magazine, IBEX-Hi recorded a factor of 2–3 times more ENAs than expected coming from a circular band that runs most of the way around the heliosphere but that is not centered about the Sun's direction of travel. Many believe the galaxy's magnetic field somehow shifts the ENA distribution, but much work awaits scientists as they try to understand how a band of something emerges from nothing.

—*Jay Schecker*

Harvesting Oil

We're used to the idea of pumping fuel from the ground, but how about growing it in water? It could happen if we tap into a new fuel source, one we generally think of as . . . well, pond scum: algae.

Algae contain a high concentration of fatty, energy-rich molecules called lipids that can be refined into biofuel. The trick is to extract the lipids in industrial-scale amounts and at a reasonable cost. The Laboratory's Greg Goddard has a technique for doing that, and it just needs a little noise, that is, sound waves.

The technology is adapted from the award-winning Los Alamos Acoustic Flow Cytometer, which uses an ultrasonic field (a sound wave) to force fluid-borne cells into single file to be counted or analyzed. With Colorado's Solix Biofuels, Inc., Goddard is developing a harvesting device in which sound waves exert their force on algae to separate it from the water it grows in, lyse (rupture) it, and extract its lipids. And this all happens in a single chamber only a few inches long.

"For industry, it's not size that's important," says Goddard. "It's throughput."

He gets high throughput by simultaneously sending multiple streams of algae-laden water into the chamber, where the sound waves lyse the algal cells and create distinct layers of lipids, water, and leftover cellular proteins. The water is left pure enough for reuse, and the proteins can serve a new purpose as animal feed (especially in fish farming) or organic fertilizer.

Other methods of processing the algae are costly and hard on the environment because they depend on power-hungry centrifuges and/or hazardous solvents. Such problems have kept the biofuel industry from flocking to algae, even though using it for biofuel, instead of crops like corn, would keep power needs from conflicting with food production and potentially offer greater fuel yield per acre. By replacing both centrifuges and solvents with sound waves, the Laboratory's acoustic technology could reduce production costs by a factor of 100 and make the production of algae fuel as green as the organisms it uses.

The right technology could make algae a new fuel source.

Solix's goal is be producing 1.4 million liters of oil a day from algae two years from now; that's something over 8,000 barrels of oil. Goddard hopes to have the technology pumping out 100 liters a minute in the first half of 2010. He'll then turn it over entirely to Solix for the final push. If all goes as planned, acoustics may be the enabling technology for the next big thing in fuel.

—*Eileen Patterson*

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Matt Romero of Dixon, New Mexico, displays his late-summer harvest.

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