Science & Technology REVIEW

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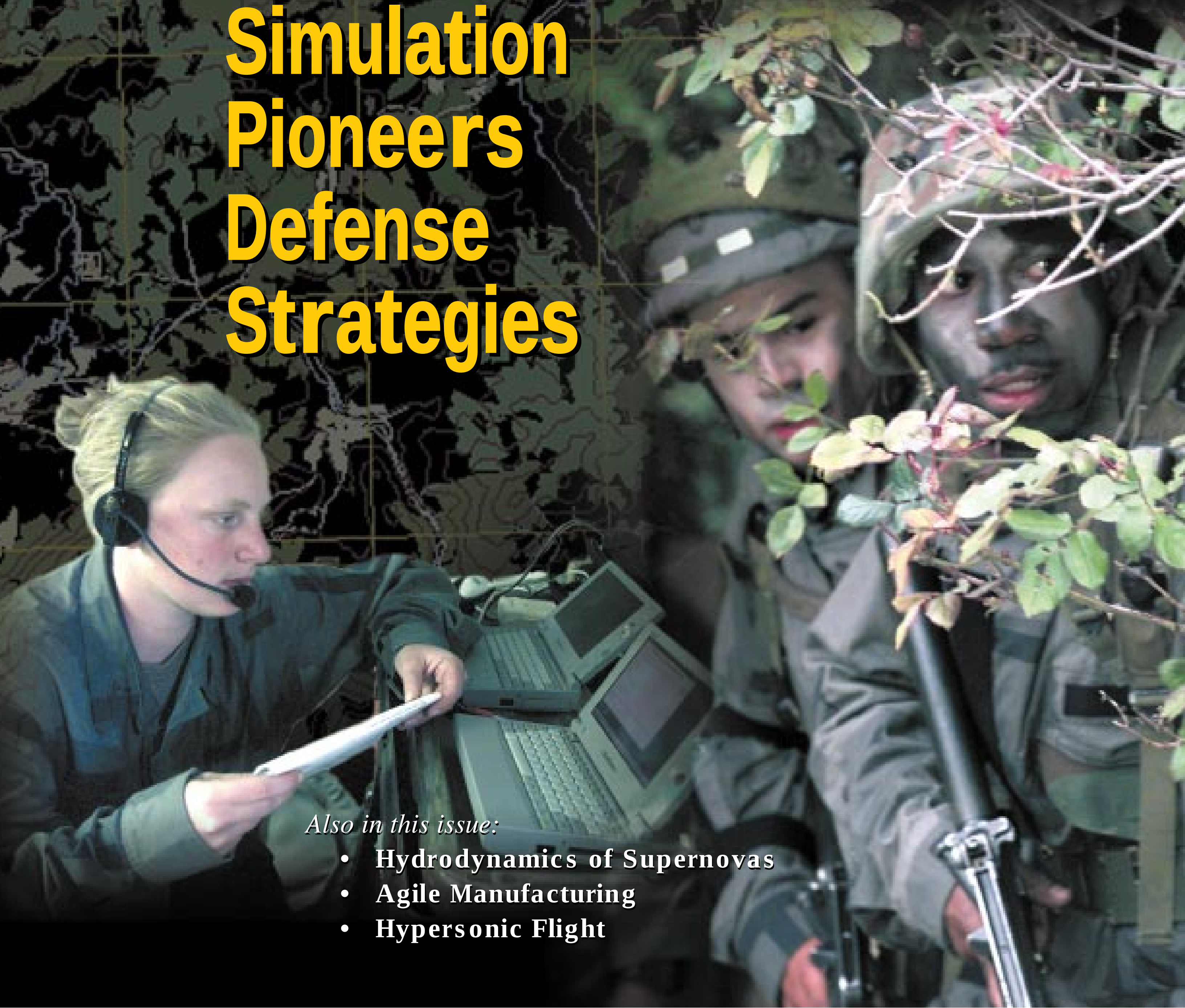
U.S. Department of Energy's
Lawrence Livermore
National Laboratory

Conflict Simulation Pioneers Defense Strategies



Also in this issue:

- **Hydrodynamics of Supernovas**
- **Agile Manufacturing**
- **Hypersonic Flight**

About the Cover

Lawrence Livermore has long been a leader in developing conflict simulation models for defense and emergency response training and planning. This issue's lead article reports on the capabilities of Livermore's JCATS (Joint Conflict and Tactical Simulation), an extremely powerful and detailed conflict simulation program. The article also describes how JCATS was used successfully in March 1999 during Operation Urban Warrior, a U.S. Navy–Marine Corps exercise in the San Francisco Bay Area designed to test new combat concepts, tactics, and technologies in an urban setting. Images from that exercise comprise this issue's cover. The JCATS story begins on p. 4.

Photos: PH3 Eric Logsdon and PH2 Michelle Hammond, FLEETCOMCAMGRUPAC

About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy. At Livermore, we focus science and technology on assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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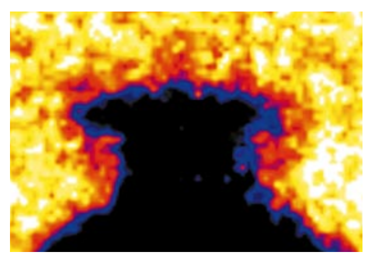

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Photo: PH1 Chris Desmond, FLEETCOMCAMGRUPAC

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Lab's ASCI supercomputer comes of age

On October 28, 1999, Lawrence Livermore and IBM celebrated the "coming of age" of their Blue Pacific supercomputer with a special ceremony at the Laboratory. This machine, part of the Department of Energy's Accelerated Strategic Computing Initiative (ASCI) has been developed and delivered in several stages over the past three years. It has become a mature and powerful tool for maintaining the safety, reliability, and performance of the nation's nuclear stockpile.

Created by IBM, Blue Pacific performs at nearly 4 trillion operations per second, applying all of its 5,856 processors in parallel to a single computational problem. The massive supercomputer is connected by nearly 8 kilometers (5 miles) of cable and occupies an area covering some 750 square meters (8,000 square feet).

With all of the critical elements—software and code development, a functional problem-solving environment, interconnect and communication capabilities, data storage facilities—now in place, ASCI's Blue Pacific has emerged as a fully functional supercomputer to help fulfill the requirements of DOE's Stockpile Stewardship Program.

The October ceremony included presentations by Laboratory Director Bruce Tarter, DOE Deputy Assistant Secretary for Research, Development, and Simulation Gilbert G. Weigand, and IBM Senior Vice President for Technology and Manufacturing Nicholas M. Donofrio. A sampling of breakthrough research calculations performed on the new computer was highlighted.

The ceremony also included a preview of Option White, currently being built by IBM as an extension of Blue Pacific. Able to perform 10 trillion operations per second, Option White has three times the capacity and capabilities of Blue Pacific. It is scheduled for demonstration in March 2000, with delivery to Lawrence Livermore planned for the summer of 2000.

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Lab studies smoking effects on newborns

A team led by James Tucker from Livermore's Biology and Biotechnology Research Program Directorate has been awarded a $1.8-million grant from the California Tobacco Related Disease Research Program to study the effects of smoking on newborns. In particular, the team wants to know if babies born to mothers who smoked during pregnancy have more chromosome damage than babies born to nonsmokers.

Tucker and team members Marilyn Ramsey and Dave Nelson will study blood samples taken from 300 mothers and from the fetal side of the placentas of their newborn babies.

This research grows out of the team's earlier investigation of the theory that as people age, the amount of chromosome damage increases. For part of its work, the team analyzed umbilical cord blood from newborns delivered at a local hospital, and according to Tucker, it saw a significantly high amount of genetic damage in babies of smokers.

Tucker explained further, "We know that tobacco causes cancer. This is a special case of second-hand tobacco exposure. Unborn babies are at a very vulnerable stage of development. They have no choice about being exposed to tobacco carcinogens. [Now] we also want to look at susceptibility. Are some mothers or newborns more susceptible to chromosome damage? The answer to this question may tell us whether some people are at greater-than-average risk of getting cancer as a result of tobacco exposure."

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Potential for improving gene therapy reported

In the October 1999 issue of *Science*, a Laboratory team reported that it has developed a possible method to make gene therapy more effective. The team also announced the discovery of a key step in fertility.

The researchers analyzed the interactions of a single molecule of DNA and a protamine, a small protein with positive charges that allow it to bind to DNA.

One problem of gene therapy—the introduction of new genes into the body to replace defective genes that may cause a disease—is incorporating the genes into cells without damaging the genes. Typically, enzymes in the body destroy foreign genes or DNA.

"We believe we've learned how to design a protamine-like molecule to optimize the success of incorporating genes into the cells in gene therapy," says team member Rod Balhorn. "Protamines bind too tightly to genes to be effective in protecting against enzymes that might destroy the genes. But we have learned that we can . . . possibly improve gene therapy . . . by designing a protamine that has fewer positive charges."

The Livermore team has also made a new discovery about a key step in the fertility process. Balhorn explains that for embryo development to be initiated, a protein in the egg must remove all the protamine bound to the sperm DNA within 5 to 10 minutes after the sperm fertilizes the egg.

Using a two-sided miniature flow cell designed by a team member, the Livermore scientists mimicked the embryo development initiation process and studied the interactions between DNA and the protamine. Viewing the process through a video camera, they saw the speed at which the protein bound to and released from the DNA.

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Tapping the Full Power of Conflict Simulation

WITH the closure of many overseas military bases and the move away from large standing armies and navies, the U.S. military is placing a premium on the use of advanced technology for precision operations that allow U.S. troops to deploy rapidly and win decisively. Lawrence Livermore has a long-standing relationship with the Department of Defense for research and development for advanced defense technologies, and conflict simulation is one area in which we are recognized as among the best in the world. The article beginning on p. 4 describes JCATS (Joint Conflict and Tactical Simulation), the latest advance in decades of effort to create accurate and realistic conflict simulation models.

JCATS is unique in the breadth and depth of the information it integrates and the variety of conflict situations it can simulate. It offers an unprecedented level of detail, operational complexity, and accuracy of simulation. In describing JCATS, it is easy to be swept into the technical details of the model—entity level, aggregation/deaggregation, 660- by 660-kilometer "playbox," and so forth—and lose sight of its wide range of applications and its potential for truly understanding modern combat operations.

The U.S. military uses JCATS primarily for training individual commanders in battlefield operations and tactics. Training, other than "on the job" in actual combat, is difficult to make realistic. Live exercises, which are themselves simulations, are limited by logistics to a relatively small number of participants, and the need for safety limits the use of real weapons. With JCATS, war games can be set up to simulate combat situations, with teams of officers playing the various forces. As the article describes, these war games are extremely accurate and thus provide directly applicable and credible training.

But the program is also useful for mission planning, assessment of military strategy, evaluation of new or proposed technologies, after-action analysis, and even site security assessment.

For example, military doctrine and strategy developed in the large-scale conflicts of the first half of the century are of questionable applicability to current operations, which focus increasingly on limited-scope engagements and peacekeeping. JCATS can be used by military planners to test new doctrines and strategies. It can also be used to evaluate the utility of new technologies, such as alternatives to antipersonnel land mines, or different applications of existing technologies. Once the program's databases are loaded with the desired information (for example, terrain maps, troops, weaponry), simulations can be run over and over again, changing one set of variables at a time. Because JCATS tracks the action at the level of individual items, after-action analyses are extremely detailed, and statistics can be assembled to provide an accurate systems-level view of the pros and cons of different approaches to military operations.

JCATS is also extremely useful for evaluating and improving physical security. Site security at the national laboratories is receiving considerable attention these days. Just as with military training, live exercises to test physical security are expensive and limited in scope. However, JCATS, with its ability to accurately model individual buildings, obstructed lines of sight, the time required to cut through walls or penetrate barriers, and so forth, is ideally suited to this application. Site security has used the program to evaluate the effectiveness of existing physical defenses and response actions against different threats. After-action analyses and statistics, assembled from a large number of runs, provide a credible basis for decisions to alter response tactics or modify physical security features.

Even as the JCATS developers continue to upgrade the model's capabilities, with improvements seemingly limited solely by imagination and technical creativity, the U.S. military and other users are striving to exploit the program's full potential. As new conflict simulation needs arise in both the defense and civil sectors, users will find that the ideal tool is already sitting on their shelves.

■ Wayne Shotts is Associate Director, Nonproliferation, Arms Control, and International Security.

Simulating Warfare Is No Video Game

Livermore's JCATS combat simulation program proves invaluable for training officers and rehearsing missions.

Photo: PH2 Jon Gesch, FLEETCOMCAMGRUPAC

WITH whirling helicopters, grinding tanks, and screaming soldiers, computer war games have become some of the most popular software programs for video arcades and personal computers in recent years. Long before computers became a household item, however, the nation's armed forces were taking advantage of computer-driven combat simulations to train officers, rehearse missions, and explore tactics.

Since the mid-1970s, Lawrence Livermore computer scientists, working at the Conflict Simulation Laboratory, have pioneered increasingly realistic software for the Department of Defense. The Laboratory's landmark Janus program, developed in the late 1970s, was the first conflict simulation to use a graphical user interface. Since then, Livermore experts have remained at the forefront of combat simulation development by taking advantage of steady advances in hardware and software and by working closely with military officers to understand their needs.

By all accounts, the Livermore simulations have proved highly valuable to the military. They have been employed in Operation Just Cause in Panama and Operation Desert Storm in the Mideast, as well as for combat planning in Somalia, Bosnia, and other international trouble spots.

Photo: PH1 Chris Desmond, FLEETCOMCAMGRUPAC

In 1997, a team of computer scientists from the Laboratory's Nonproliferation, Arms Control, and International Security (NAI) Directorate unveiled Livermore's most powerful combat program. JCATS (Joint Conflict and Tactical Simulation) merged and upgraded the capabilities of two earlier programs, the Joint Conflict Model, an advanced version of Janus, and the Joint Tactical Simulation, an urban conflict model. (See *S&TR*, November 1996, pp. 4–11). Significantly, the program also incorporated important new features requested by its DoD sponsor, the Joint Warfighting Center in Fort Monroe, Virginia, that conferred greater fidelity to the simulations.

JCATS was used to rehearse possible combat options in support of the 1999 Kosovo conflict. It was also used by the Marine Corps and the Navy to plan for and participate in an exercise in the San Francisco Bay Area. During the exercise, JCATS tracked the live participants and tested in real time the effects of virtual air and artillery attacks on the participants.

Taking Physics into Account

Livermore computer scientist Faith Shimamoto, JCATS project leader, notes that every aspect of the program takes physics into account. Typical computer games may look impressive with flashy three-dimensional effects, she says, but they don't always observe the laws of physics.

A typical PC game soldier can jump off a 15-meter cliff without a scratch, but a soldier in JCATS doing the same thing will be badly injured. Neither do commercial games take into account such seemingly mundane but crucial factors as fatigue, inclement weather, low food supplies, or poor visibility. "JCATS realistically simulates the capabilities and limitations of armaments, people, and the environment," she says.

Tom McGrann, deputy leader of the tactical systems section in the Laboratory's Conflict Simulation Laboratory, notes that JCATS is a direct descendant of Janus, building on more than two decades of computer-driven mission analysis and rehearsal experience. "We want to help DoD with software that gives commanders a realistic, cost-effective, and operator-friendly training tool," he says. "Our programs give officers a detailed feel for how combat operations will go, from the deployment of an aircraft carrier to an individual soldier."

The program is currently used for training both individuals and command staffs in tactics and deployment of resources, analyzing the effectiveness of weapons and different force structures, and planning and rehearsing missions. Besides warfighting scenarios, JCATS can also simulate exercises for drug interdiction, disaster relief, peacekeeping, counterterrorism, hostage rescue, and site security. Current users include the Army, Air Force Security Forces, Special Operations Command, Marine Corps, Naval Post Graduate School, U.S. Southern Command, U.S. Army Europe, Department of Energy, and Secret Service.

Program Controls 60,000 Elements

An enhanced version of JCATS released in October 1999 can simulate up to 60,000 individual elements, from soldiers to planes to mob participants. What's more, the new version can run on a workstation as well as on a laptop computer, making it feasible for use in the field.

The new program typically simulates a battle between two opposing sides (often called red and blue forces), but it can accommodate up to 10 sides with friendly, enemy, and neutral relationships. Depending on the rules of engagement established for the conflict, a soldier can be programmed to shoot at the first sign of an opposing force, hide, dig a foxhole, fire only upon positive identification, or take other action. The rules of engagement may change during the simulation as political alliances shift or when civilians become involved.

Players see only their respective forces and whatever intelligence they acquire about opposing forces by visual or auditory means, including forward scouts, spotter planes, radar, and sensors. A large hill, for example, can prevent a soldier from visually spotting enemy forces massing on the other side. Tanks generate noise that can be "heard" by nearby opposing forces.

Typically, a controller at a master workstation has a bird's-eye view and can observe the movement of forces on all sides. To test players' responses to the unexpected, the controller can resurrect fallen troops, change the weather, provide more fuel, speed up the clock, release a biological weapon, and the like.

Games Can Last Weeks

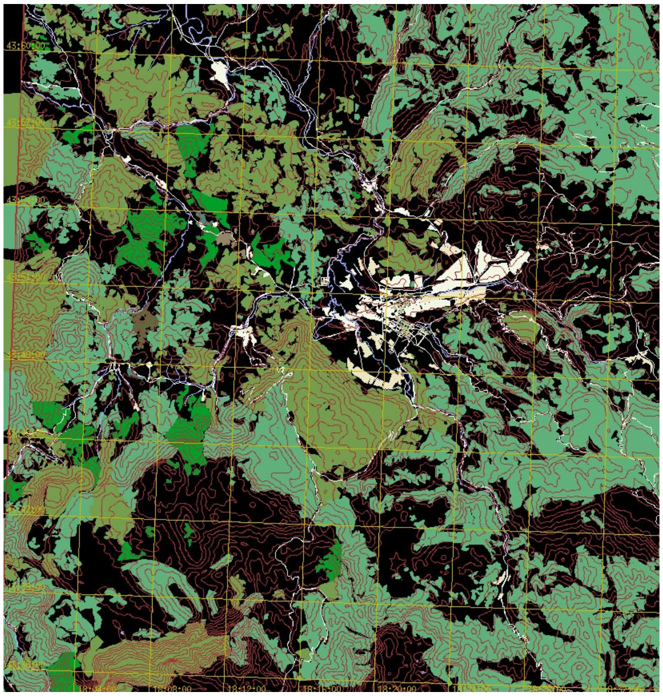
The duration of games varies from 20 minutes for a brief site security exercise involving a few people to two weeks for a complex drug interdiction rehearsal involving different agencies. Sometimes a short game is run dozens of times so that statistical sampling can be used to evaluate a particular tactic or weapon system.

Setting up a JCATS exercise takes one to two weeks depending on the number and kinds of combat forces and, especially, the kinds of topography to be modeled. Terrain is modeled with extraordinary fidelity. Rivers, for example, can be characterized by their current, depth, and underwater obstacles. Players can enter terrain data, including correct elevation and geographical features, from standard DoD maps of the world (such as the one below at the left) and from DoD digitized terrain data.

Players can also import blueprints of specific buildings (below right) for urban warfare and site security exercises. Or users can create their own town or building, as is often done for drug interdiction training. In these cases, JCATS offers a palette of menus to create everything from windows and doors to streets and parks.

Shimamoto points out that terrain significantly affects movement of troops, aircraft, tanks, and maritime operations. A rescue helicopter cannot safely land in a forest, amphibious landing craft must negotiate rocky shores, vehicles move slowly through swamps, and soldiers slow considerably when marching uphill. Environmental factors such as adverse weather, nightfall, and smoke from combat also affect mobility.

JCATS is unusually flexible in the sheer scale of battle, from the defense of a nation involving thousands of



Before a JCATS simulation begins, terrain features are laid out (in this case of the greater Sarajevo area) from standard Department of Defense maps.

Buildings and other urban features are added onto terrain maps. In this example (again of Sarajevo but at a smaller scale), individual buildings can be seen.

soldiers, planes, ships, and vehicles, to the rescue of a hostage in an underground compound by a handful of special operations personnel. Typically, the maximum simulation area, or playbox, is 660 by 660 kilometers, but it can be expanded under special conditions. Even at this enormous scale, a player can zoom in on a city to view details such as roads, rivers, and buildings, and then select an individual building and examine its floor plans.

Depending on the exercise, players have at their disposal a vast range of weapons, including tracked and wheeled vehicles, aircraft and helicopters, ships and submarines, and even systems that are in the development or conceptual stage. Infantry soldiers may have machine guns, rifles, antitank weapons, mortars, and other munitions. Nonlethal weapons, increasingly important as the military assumes peacekeeping duties around the world, include rubber bullets, clubs, tear gas, pepper spray, stinger grenades, rocks, foam, and fists.

Simulations Strengthen Livermore Site Security

The realism of JCATS simulations in urban settings makes it extremely valuable for assessing and strengthening site security at a range of government facilities, including the very institution that created the program. For the past several months, security managers at Lawrence Livermore have been using JCATS to test established interdiction measures against a variety of adversary scenarios. The work has helped to sharpen security strategies, identify vulnerabilities, and train officers for different kinds of threats, even those deemed highly improbable.

Livermore security managers have conducted more than 200 exercises with JCATS, with each exercise repeated about 10 times. According to Stuart Jossey, security administrator with Livermore's Safeguards and Security Department, most of the scenarios involve attempts to gain entry to the Laboratory's heavily guarded Superblock area that houses special nuclear material. Jossey says that JCATS is invaluable for simulating the close-combat, interior fighting conditions a real incursion might involve.

Currently, a small corps of people including Special Response Team members, Protective Force supervisors, and security administrators participate in JCATS exercises at Livermore. The department's long-range goal is to integrate JCATS into the development of site security tactics and training. Operator proficiency requires between two and three weeks of training. "The scenarios involve a lot of mouse clicks under pressure," Jossey notes.

The exercises are performed at adjoining computer stations by operators controlling a designated number of virtual security personnel driving in patrol cars or patrolling on foot. The operators wear headphones to communicate with each other about what their forces see and hear. Their computer screens display buildings comprising the Superblock area and adjoining facilities as well as the location and health of people under their command.

In a nearby room, another operator controls a number of "bad guys" intent, for example, on breaking into a facility containing special nuclear material. This monitor shows only the intruders and any Lawrence Livermore security members they detect. Jossey, meanwhile, operates a station that depicts the locations of all the participants. He can change the makeup of each opposing force, as well as their weapons, on the fly.

Jossey says the simulations are a powerful supplement to real drills involving players with laser-tag-like weapons that are staged regularly in and around the Superblock area. "It's expensive doing actual exercises," he says. "We also run a safety risk because many of our exercises are done at night with people running on roofs, climbing fences, and responding tactically in patrol cars." JCATS allows the department to test security strategies to help decide what scenarios the actual exercises should focus on.

The completed simulations are saved on disk and then replayed for the participants on a large-screen monitor. Jossey invites comments from participants about the exercise, especially how things might have gone better. He also uses the program's Analyst Workstation feature to obtain statistical data such as casualties and ammunition used.

"We get a lot of good statistical information," he says. "The whole point is to make sure we have designed a strategy that denies unauthorized entry to our critical facilities."

Livermore site security exercises use JCATS to strengthen security and help train security personnel for what-if scenarios. Here, Jason Dufour (left) and Raymond Harvey train using JCATS.

Model's Power Is in the Details

Military operations include clearing barriers; aircraft takeoff and landing; bombing runs; naval gunfire; building foxholes, vehicle holes, and fortifications; sandbagging; looking around, standing, and crouching; recovering weapons and ammunitions; resupplying food, fuel, and ammunition; and mounting onto or dismounting from vehicles, ships, airplanes, and helicopters.

The command ship USS *Coronado* docked at a San Francisco pier and served as the command center for both the Navy's and Marine Corps's exercises.

With a feature unique to JCATS, a player may aggregate entities (soldiers, tanks, or other individual units) into a group such as a formation, convoy, squad, or battalion that is then viewed and controlled as one icon. In this way, large formations are more easily viewed and controlled while the program tracks and records activity at the individual entity level. At any moment, a player can zoom in on a squad and examine events involving just a few soldiers, each uniquely outfitted and trained.

The effectiveness of every weapon, from a laser-guided missile to a single bullet, is determined by probability-of-hit and probability-of-kill statistics compiled by DoD. Using these data, JCATS calculates, for example, the blast area and resulting casualties from tripping a land mine. Just as easily, the program calculates if a launched antitank weapon misses the tank, destroys it, incapacitates the tank's movement but leaves its gun free to fire, or destroys the gun but leaves the tank's mobility intact.

Virtual soldiers face hazards from fatigue, enemy and friendly fire, poor health, and inadequate training. Every soldier begins with a certain amount of energy, which is expended more quickly during running or walking uphill. Players can bring in medical assets to attend to the sick or wounded.

In recognition of possible modern enemy capabilities, JCATS can simulate the release of chemical or biological warfare agents as well as other substances that might by employed as poisons during acts of terrorism or warfare. For example, the program can display how exposure to an atmospheric release of a nerve agent can affect personnel. Such capabilities make it useful for developing both military and civilian preparedness and responses.

Many Options to Review a Game

Players can choose from several options to review a completed game. The entire exercise can be replayed at different speeds. The Analyst Workstation, a feature that conducts rapid analyses of exercise data, can also be employed. This capability is especially useful, says Shimamoto, because in combat simulation, only a small fraction of the data is important to any specific factor under scrutiny.

One of JCATS's most significant enhancements is modeling the urban environment for such missions as hostage rescue, disaster relief, mob control, or protecting heads of state along a motor route. In urban settings, players can view

A modular building on the pier housed Marine officers using JCATS to track the action in the Oakland Hills between opposing blue and red forces. The Marines were tied to the command and communication systems headquartered on the nearby USS *Coronado*.

groups of buildings as well as individual building floors and their features—including glass and solid walls, windows, doors, and stairwells—roofs, and underground features, such as tunnels, sewers, and garages. Virtual forces fighting inside buildings are hampered by limited lines of sight, poor lighting, and the risk of injury to civilians.

The program's superb urban simulation capabilities led the U.S. Navy and Marine Corps to give JCATS an important role in exercises conducted last March in the San Francisco Bay Area. The Marine Corps exercise was dubbed Urban Warrior Advanced Warfighting Experiment. Its objective was to develop and test new concepts, tactics, and technologies to prepare Marines for combat in the next century, especially activities in urban areas. The Navy's companion exercise, Fleet Battle Experiment–Echo, also took advantage of JCATS. (See *S&TR*, June 1999, pp. 4–11.)

The exercises were run from the Navy command ship USS *Coronado*, which was docked at a pier in San Francisco. A small building inside the pier housed Marines running JCATS terminals and other command and communications systems. All data were fed to the command ship. Livermore computer scientist Mike Uzelac, director of operations for JCATS, monitored the exercise from the building.

According to McGrann, the Marines focused on an urban exercise because its studies show that by 2020, about 70 percent of the world's population will live in cities and at least 80 percent of those cities will be located within 300 miles of the coastline. Fighting in urban areas, says McGrann, is particularly treacherous because of the danger to the civilian population and because of the numerous hiding places for opponents.

Enemies Eye Urban Warfare

A recent statement by Col. Mark Thiffault, Director, Joint Information Bureau, Urban Warrior, underscores the Marines' commitment to winning urban battles: "Our enemies, having watched Desert Storm on CNN, know they cannot engage the United States with conventional methods. These potential foes view cities as a way to limit the technological advantages of our military. They know that cities, with their narrow streets, confusing layout and large number of civilian noncombatants, place limits on our technological superiority and especially our use of firepower. We have to develop technologies that allow us to win while minimizing collateral damage."

McGrann says that the Marines are concerned about the performance degradation that occurs in standard command, control, communications, computer, and intelligence systems because of cities' concrete buildings, phone lines, and other electronic devices. As a result, Urban Warrior Marines experimented with wireless communications devices, satellite links, remotely piloted reconnaissance aircraft, and global positioning system links.

The focus of the exercise was an intense battle between some 700 battle-dressed Marines, divided into red and blue forces, at the former Oak Knoll Naval Hospital in the Oakland Hills. Both sides wore Multiple Integrated Laser Engagement System gear similar


(a)

Photo: PH2 Michelle Hammond, FLEETCOMCAMGRUPAC

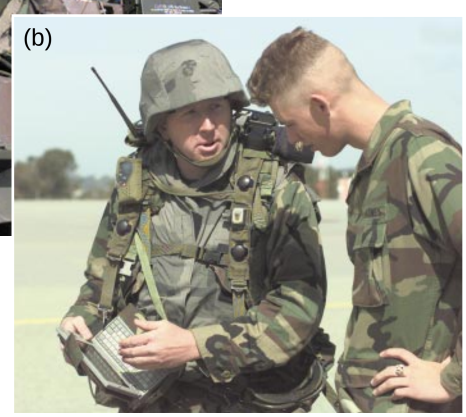

(b)

Photo: PH3 Eric Logsdon, FLEETCOMCAMGRUPAC

(a) The former Oak Knoll Naval Hospital and adjacent buildings in the Oakland Hills formed the setting for the Urban Warrior Advanced Warfighting Experiment. (b) One Marine demonstrates to another a handheld computer used in the Urban Warrior exercise.

to that used in laser-tag games. Red forces, holed up in the hospital, barricaded stairwells with anything they could find as they tried to fight off blue forces intent on taking over the building.

The fierce battle was set against a backdrop of civil unrest taking place in more than 30 small, adjoining buildings. In this outlying area, additional blue forces kept order among noisy reporters, milling civilians, and rock-throwing agitators, all played by paid actors. (Actual video footage of the exercise can be viewed on the Marine Corps's Urban Warrior Web page at www.defenselink.mil/special/urbanwarrior/.)

Prior to the exercise, Marine Corps personnel, who had previously trained on JCATS, modeled the interiors of the buildings (including the hospital's 9 stories and 500 rooms) by digitizing construction blueprints and entering the data into the program's "terrain editor." The Marines' Integrated Global Positioning System Radio System provided updates every 30 seconds on the position of vehicles and soldiers outside buildings. Because the radio system is ineffective inside buildings, every hospital room was wired with the Inside Building Instrumentation System to keep track of each Marine's location and health status (healthy, wounded, or killed) when they were inside.

The ever-changing data on the Marines' locations were broadcast from the Oakland Hills on secure communication links and fed into JCATS for viewing on screen. In this way, command personnel on the pier and aboard the USS *Coronado* were provided unprecedented, real-time details about the location of their Oakland forces, including the whereabouts of combatants on every floor of the hospital.

Virtual Strikes Complete Exercise

JCATS also simulated the effects of artillery and tactical air strikes that obviously could not be used in the Oakland area. Computer-generated weapons even included systems that currently exist only in concept. The virtual strikes were executed by a Marine JCATS operator in San Francisco, acting on request by an officer at the battle and approved by an operation commander.

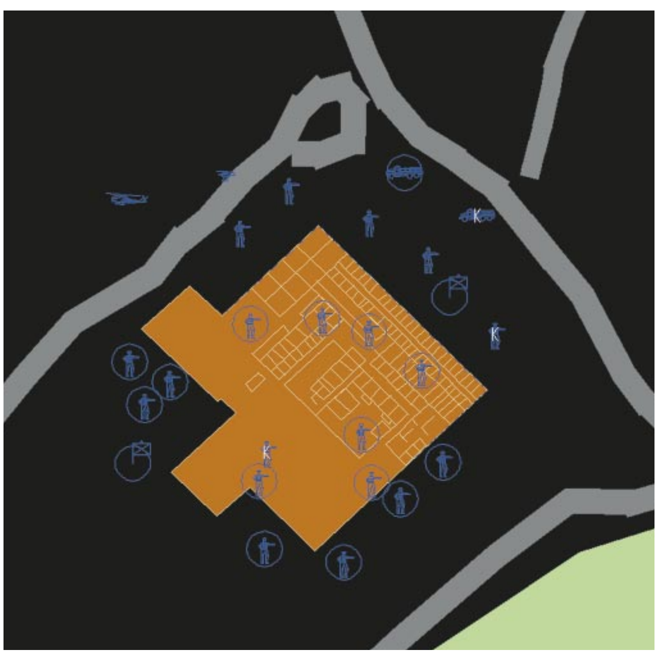
The program calculated the time of flight and the effects based on the impact of the virtual strike and the reported location of the live participants. In this way, commanders learned within seconds the effects of using these weapons. Back in Oakland, both red and blue participants were quickly informed through their laser tag and radio gear if they had been wounded or killed by the virtual strikes.

While the battle for control of the hospital raged, JCATS simulated combat on Treasure Island in San Francisco Bay and on the San Francisco–Oakland Bay Bridge. Red forces driving toward Oakland were attacked by blue virtual aircraft. Simulated Navy ships just off the coast were also included in the overall conflict.

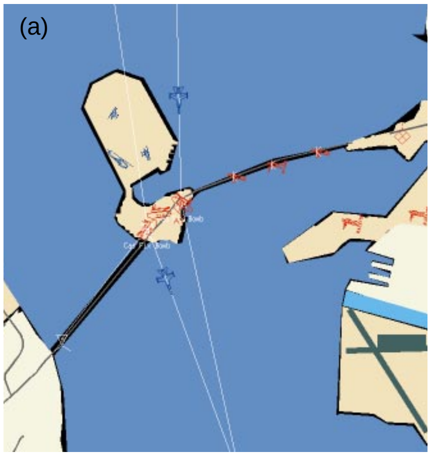
Following the exercise, the program provided a thorough review for the command officers. The review showed who was killed and how and when they became casualties, thereby removing much of the uncertainty that often surrounds the lessons-learned process following an exercise.

Uzelac says that the Marines were pleased with the usefulness of JCATS. In particular, "They recognize that combining simulated firepower with live participants allows the Marines to significantly broaden their training missions," especially when environmental or safety restrictions prevent the actual use of weapons. Uzelac adds that the Marines plan to use the program in their next urban exercise, which will incorporate more buildings than were used in Oakland.

The Livermore team is already working on enhancements to JCATS that have been requested by the Joint Warfighting Center. These enhancements will include an



This JCATS image depicts the location of blue forces outside the Oak Knoll Hospital as well as inside one of its nine floors. (K stands for kill or destroyed target.)



JCATS also simulated combat on Treasure Island in San Francisco Bay and on the San Francisco–Oakland Bay Bridge. (a) Red forces heading toward Oakland were attacked by blue virtual aircraft and Navy ships. (b) Detail of Treasure Island combat. The yellow sunbursts and star shapes depict the effects from naval gunfire and air strikes, respectively. (K stands for kill or destroyed target; S stands for suppressed.)

information warfare capability, a terrain-generation capability using computer-aided design building files and satellite imagery, and better integration with military communication systems.

Shimamoto notes that one of JCATS's most important advantages is its applicability to all the military services. Although each military service has its own weapons, its own methods of combat operations, and even its own specialized simulation programs, JCATS is a powerful resource for all of them. Because it models all of the services' forces, as well as those of other security organizations, it also encourages better coordination among agencies, both in planning missions and in training officers. "We've made JCATS as powerful and flexible as we know how to help the nation prepare for conflicts in the new century," she says.

—Arnie Heller

Key Words: combat simulation, Conflict Simulation Laboratory, Fleet Battle Experiment–Echo, Janus, JCATS (Joint Conflict and Tactical Simulation), Joint Conflict Model, Joint Tactical Simulation, Joint Warfighting Center, U.S. Marine Corps, Special Response Team, U.S. Navy, Urban Warrior Advanced Warfighting Experiment.

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About the Scientist

FAITH SHIMAMOTO joined Lawrence Livermore in 1975 while working on her master's thesis in electronics engineering at the University of California at Davis, where she also earned a B.S. in electronics engineering. She has provided computational capabilities development and management support to numerous departments in the Engineering and Computation directorates, recently managing teams in the development of miniature sensor technology for low-Earth and suborbital satellite experiments.

Currently, she is the project leader of the Joint Conflict and Tactical Simulation (JCATS) Conflict Simulation Laboratory in the Nonproliferation, Arms Control, and International Security Directorate. She is responsible for leading the development of JCATS, a real-time simulation program used by the departments of Energy, Defense, and Transportation for training, analysis, and mission planning, particularly in an urban environment. Her responsibilities have included software development and testing and coordination of deliverables with JCATS's primary proponent, the Joint Warfighting Center. She has also developed JCATS for and demonstrated it to other potential users and sponsors.

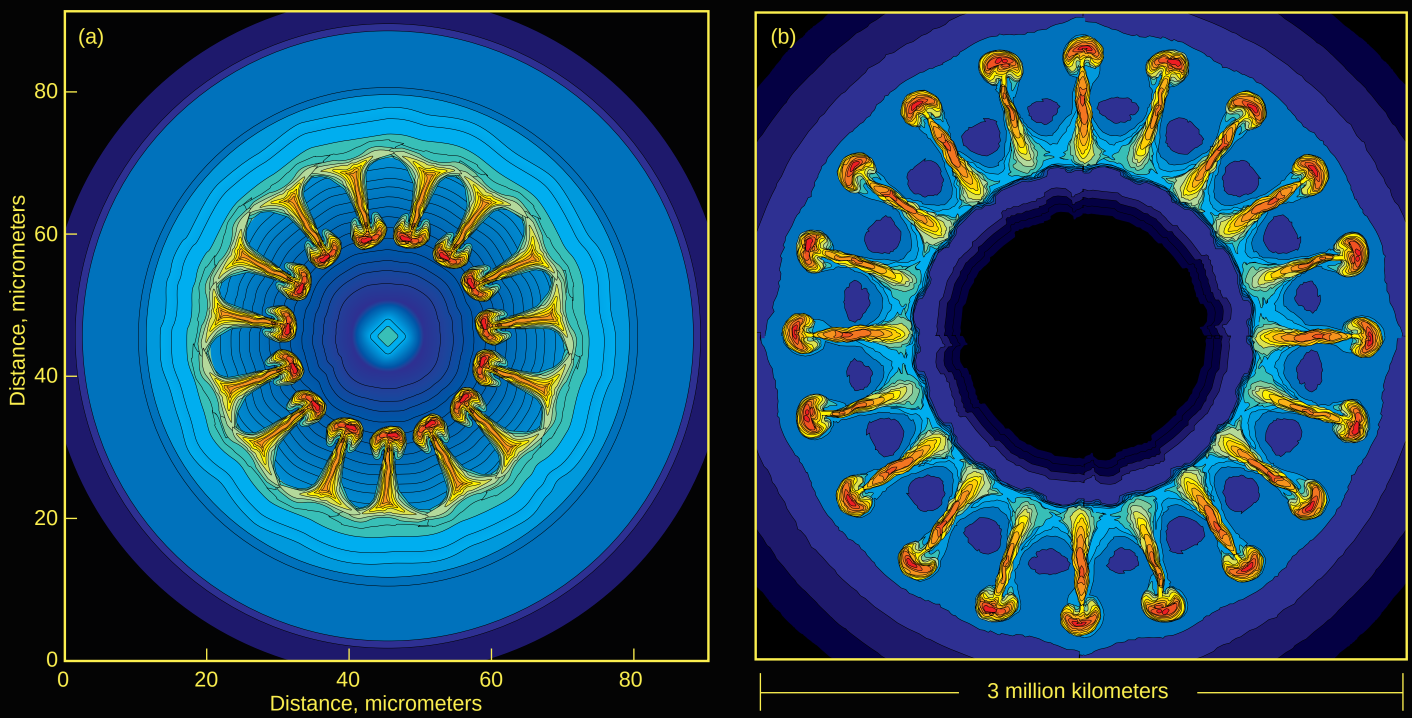
Supernova Hydrodynamics Up Close

Scientists thought they understood supernova behavior until they saw one up close in 1987. Today, ingenious laser experiments and advanced modeling are coming closer to mimicking the complex hydrodynamics of a star's death.

LIVERMORE'S Bruce Remington is no stranger to hydrodynamics. As leader of experimental hydrodynamic work on Nova and other lasers, he has participated in years of experiments related to inertial confinement fusion and high-energy-density physics. One day in 1995, he noticed the similarity between two images (shown on p. 13) in different scientific journals. One showed simulations of the turbulent splashing and mixing of plasma as a fusion capsule was hit by the powerful beams of an intense laser. The other depicted a computer model of gases mixing during a supernova explosion. Although the first picture was of an event less than a tenth of a millimeter across and the second involved millions of kilometers, the fluid behavior of the materials appeared to be virtually identical.

Remington reasoned that laser experiments might be able to mimic the behavior of the phenomenal blast of a supernova. The timing of his ruminations proved to be perfect because a way of doing supernova experiments to quantitatively test observations and models was vitally needed.

Astrophysical research has traditionally been divided into observations and theoretical modeling or a combination of both. But scientists had discovered that existing models did not explain their observations of the great supernova of 1987. That event, known as Supernova 1987A, gave astronomers their first close-up view since 1604 of a star's cataclysmic death. Although supernovas take place fairly frequently all over the universe, they are usually too far away and too dim to be



Striking similarities exist between hydrodynamic instabilities in (a) inertial confinement fusion capsule implosions and (b) core-collapse supernova explosions. [Image (a) is from Sakagami and Nishihara, *Physics of Fluids B* **2**, 2715 (1990); image (b) is from Hachisu et al., *Astrophysical Journal* **368**, L27 (1991).]

viewed with much clarity from Earth. This one was a mere 165,000 light years away in the Large Magellanic Cloud, a satellite galaxy of our own.

Supernova 1987A is a type II supernova, which heralds the demise of a particularly massive star. Toward the end of its life, the star's supply of hydrogen for fusion began to wane. Its central regions began to contract, bringing higher core densities and temperatures. As core temperatures increased, successively heavier nuclear fuels began to ignite—first helium, then carbon and oxygen, and on up through neon, magnesium, sodium, and so on. Each consecutive stage of burning happened more quickly. Helium burned for nearly a million years, carbon took about 12,000 years, and neon burned for perhaps 12 years. Toward the end, silicon took just a week. Iron and its cohorts (nickel, chromium, titanium, vanadium, cobalt, and manganese) lie at the bottom of the curve of binding energy because energy must be added to fuse them into heavier elements or to split them into lighter ones. Fusion could go no further.

As ignition of successively heavier fuels took place in the center of the star, previous fuels continued to burn in the overlying regions, so that in its final moments, the star resembled an enormous layered onion. Ultimately, however, gravity won. In a few tenths of a second, the core collapsed, and almost immediately, its center rebounded, smashing into the still-collapsing outer core and giving birth to a shock wave that burst through the matter at the outer edges of the "onion."

Supernova models in place at the time of the spectacular 1987A event predicted that the onion structure would be preserved in the explosion and that the material in the various layers would gradually dissipate. But, in fact, some of the debris moved much faster than expected, as if fingers of fast-moving gas were poking through the rest of the material. Gamma rays from cobalt-56, generated deep in the star during the explosion, became visible six months earlier than expected. The tidy onion model had to be discarded for a messier one that incorporated more turbulence and mixing (see p. 15, lower left).

Turbulence Up Close

It was this turbulence—in a Nova inertial confinement fusion experiment and in models of 1987A—that

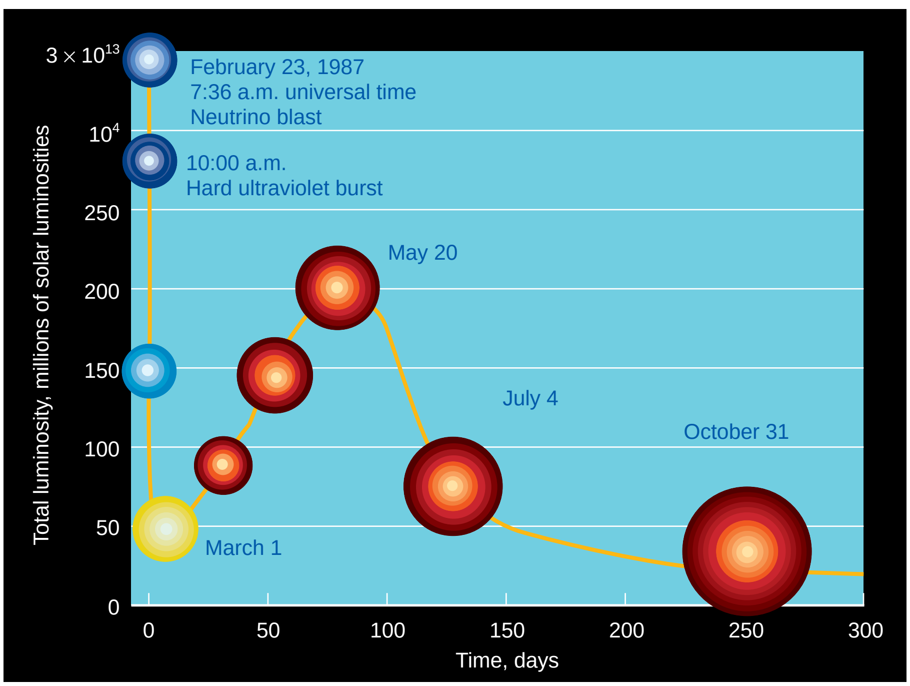
Remington saw in 1995. When fluids or fluidlike matter of different densities is oriented such that the heavier fluid sits on top of the lighter fluid, the system is unstable and tends to mix. At the interface between the two surfaces, the heavier fluid always sinks downward into the lighter one in fingers. This basic fluid dynamic process is known as the Rayleigh–Taylor instability. A related type of hydrodynamic instability, known as the Richtmyer–Meshkov instability, also occurs when there is a shock wave, as in a supernova.

Dozens of laser experiments with Nova tried to simulate the behavior of Supernova 1987A. Early one-dimensional simulations used a tiny, flat stacked target of metal, plastic, and foam to represent the composition and densities of various parts of the supernova. As Nova's laser light hit the hohlraum surrounding the target, a flood of x rays ensued that bathed the target in radiation. The x rays rapidly heated the metal and sent a powerful shock through it, mimicking a supernova blast wave passing through a layer of the star. One-dimensional modeling and laser simulations are useful for determining when the shock wave hit the various shells of the supernova. But one-dimensional work cannot examine the mixing that was obviously taking place.

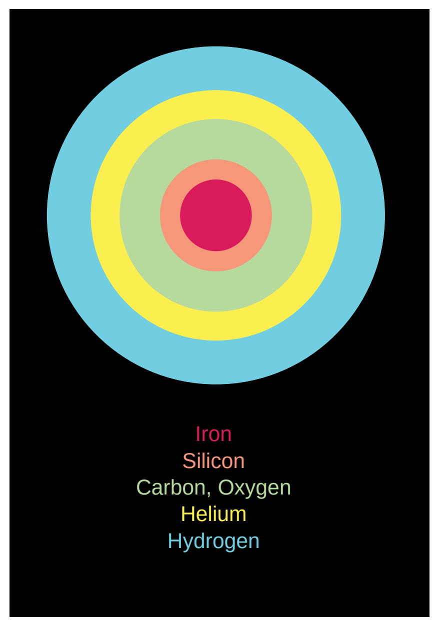
To examine mixing between the helium and hydrogen layers of Supernova 1987A, the most hydrodynamically unstable region of the exploding star, scientists have performed modeling studies using PROMETHEUS, a multidimensional hydrodynamics code, and the two-dimensional code CALE. They compared these simulation results with data from laser experiments that use planar foils with a tin-roof-like sinusoidal ripple to examine in two dimensions a localized region of activity. As shown in the figure on p. 15 (bottom right), the two codes give similar results, both of which agree well with experimental results.

But two-dimensional models predict maximum velocities of only about 2,000 kilometers per second for radioactive materials moving outward from the core, whereas observed velocities for these materials were actually more than 3,000 kilometers per second in Supernova 1987A. Three-dimensional hydrodynamic effects must be considered to explain these and other discrepancies between models and observations.

Laser targets for examining hydrodynamic behavior in three dimensions incorporate a miniscule dimple, invisible to the naked eye, that follows the same laws of hydrodynamics as 1987A. The figure on p. 16 compares a Nova radiograph of a dimpled experiment with a two-dimensional model. (Three-



Supernova 1987A, like other type II supernovas, occurred when the star's iron core collapsed.



In its death throes, Supernova 1987A resembled an enormous, many-layered onion as successively heavier layers of fuel ignited and burned.

dimensional supernova hydrodynamics are unfortunately prohibitively expensive to calculate, but three-dimensional laser experiments are no more expensive to run than two-dimensional ones.)

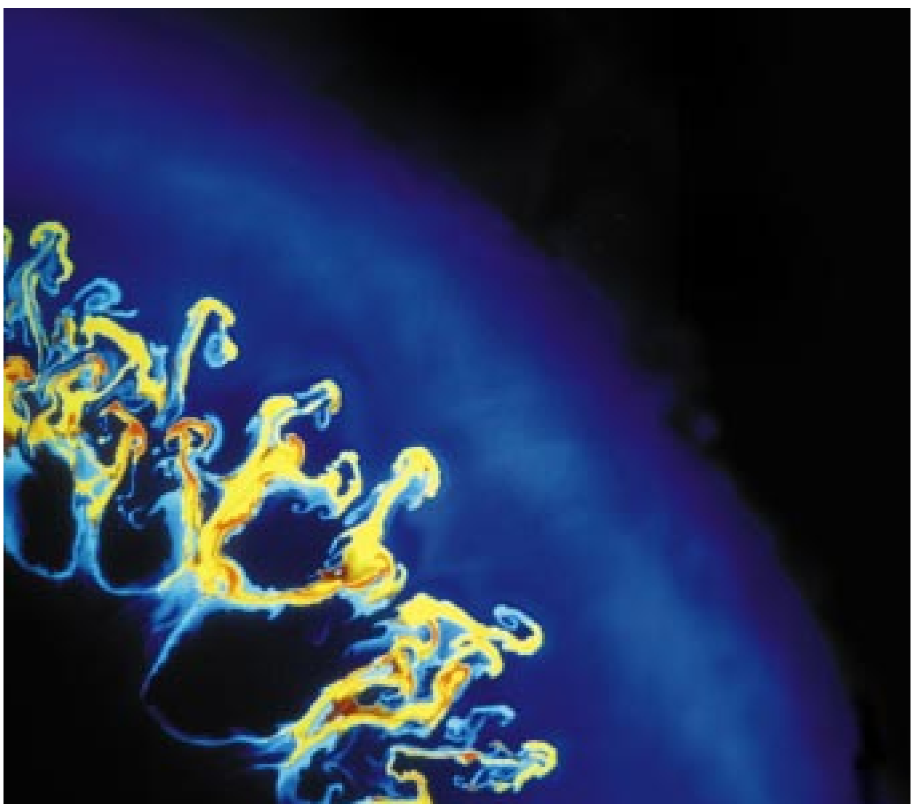
Laser experimentation for supernovas is becoming more complex all the time in an effort to incorporate as many features of supernovas as possible. Remington's team has begun to use multilayer targets in supernova experiments on the Omega laser at the University of Rochester (currently the world's largest operating laser), because an actual supernova does not have just two layers but many. The team is also considering creating density gradients in laser targets because the density within each layer of a supernova is not constant but rather drops smoothly with distance from the core. This density gradient would allow the shock wave to speed up with distance. An actual supernova is also spherical, not planar. Spherical geometry would cause the shock wave to expand, weaken, and slow, which is precisely the opposite of the effect due to the density gradients.

Initial spherical experiments have also been done on Omega. Consideration of the many factors involved will, over time, bring Livermore's laser experiments more in line with actual supernova behavior.

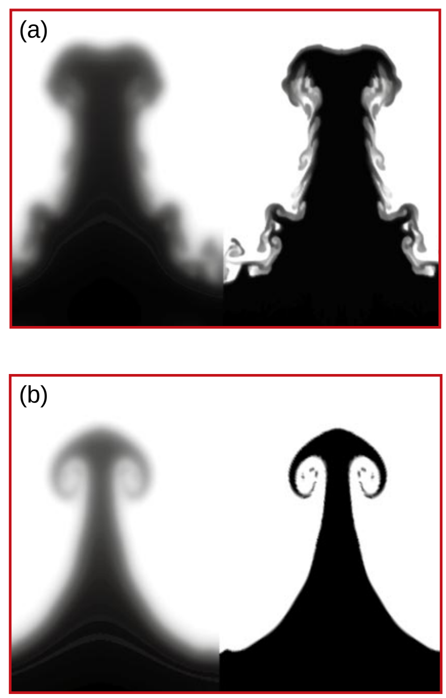
The Issue of Scale

The Euler equations, which describe the conservation of mass, momentum, and energy for fluids, do not know the difference between a tiny laser experiment and a huge supernova. At first, though, not all scientists were convinced that a laser simulation could be considered an accurate representation of the much larger event. Supernova 1987A is about 100 trillion times larger than a laser experiment. Its initial radius equals 20 million kilometers versus 0.2 millimeters for the laser experiment.

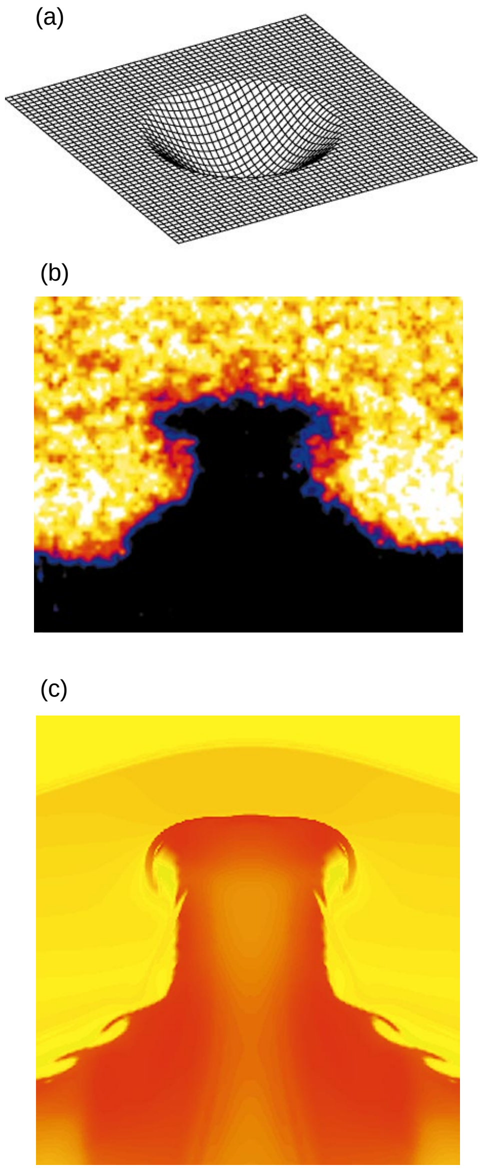
Remington notes that he and others spent a year and a half studying the scaling issue, performing laser experiments and innumerable calculations. Ultimately, they



Supernova 1987A provided strong evidence of turbulence emanating from the core of the exploded star because core materials were observed well before they were predicted. The turbulence caused mixing among the layers and greatly complicated the tidy "onion" model of dying stars. [Image reproduced from Muller, Fryxell, and Arnett, *Astronomy & Astrophysics* **251**, 505 (1991).]



The hydrodynamic mixing of the most unstable region (the hydrogen and helium layers) of Supernova 1987A has been modeled using (a) the multidimensional PROMETHEUS code and (b) the two-dimensional CALE code.



Using (a) "dimpled" targets, Nova experiments yielded (b) three-dimensional radiograph data of a laser implosion's hydrodynamics that show strong similarities to (c) a two-dimensional model of supernova hydrodynamics.

concluded that for the "intermediate" time frame of a supernova explosion, the hydrodynamics can be transformed from the microscopic to the astronomical scale. The intermediate time frame for the laser experiment is in the range of 20 nanoseconds after the initial shock, which, as it happens, is when bubble and spike growth typically occurs. The equivalent time for the supernova is roughly 2,000 seconds, that is, 11 orders of magnitude longer.

The Challenge Continues

The decommissioning of the Nova laser last year ended a four-year program of groundbreaking supernova hydrodynamics experiments at Livermore. With the Nova experiments, Remington and his team demonstrated the value of laser experiments to validate astrophysics codes and study hydrodynamics issues that are difficult to simulate. Nova also helped put to rest the issue of scale. Increasingly complex experiments continue on the Omega laser.

The spectacle of 1987A may not be over yet. Even before the star exploded in 1987, it had what appear to be gaseous rings around it. Those rings are still there, at an estimated distance of about a half light year (5 trillion kilometers) from the supernova's core. Late last year, the shock wave launched by the expanding debris from the supernova began to collide with the rings. Scientists predict that over the next decade, the collision should heat the rings, brightening the supernova again to produce another spectacular light show. Livermore's models and laser experiments will again be put to the test.

—*Katie Walter*

Key Words: hydrodynamics, modeling, Nova laser, Omega laser, Supernova 1987A, supernovas, turbulence.

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About the Scientist

BRUCE REMINGTON received a B.S. in mathematics from Northern Michigan University in 1975 and a Ph.D. in physics from Michigan State University in 1986. He joined the Laboratory as a postdoctoral associate in 1986 doing nuclear physics research and became a permanent staff physicist in the Laser Programs Directorate in 1988. As leader of the hydrodynamics group of the Inertial Confinement Fusion Program, he initiated and managed direct- and indirect-drive hydrodynamics experiments on the Nova laser related to high-energy-density regimes, compressed solid-state regimes, fluid dynamics, and astrophysics, work that continues on the Omega laser at the University of Rochester since Nova laser operations were discontinued. He is currently chair of the American Physical Society's Topical Group on Plasma Astrophysics.

Agile Manufacturing:
Gearing Up to Meet Demand

War has broken out somewhere in the world, and the U.S. becomes involved. Suddenly, all branches of our armed forces need more conventional munitions—and they need them immediately. How can suppliers meet this kind of unpredictable, high-volume demand?

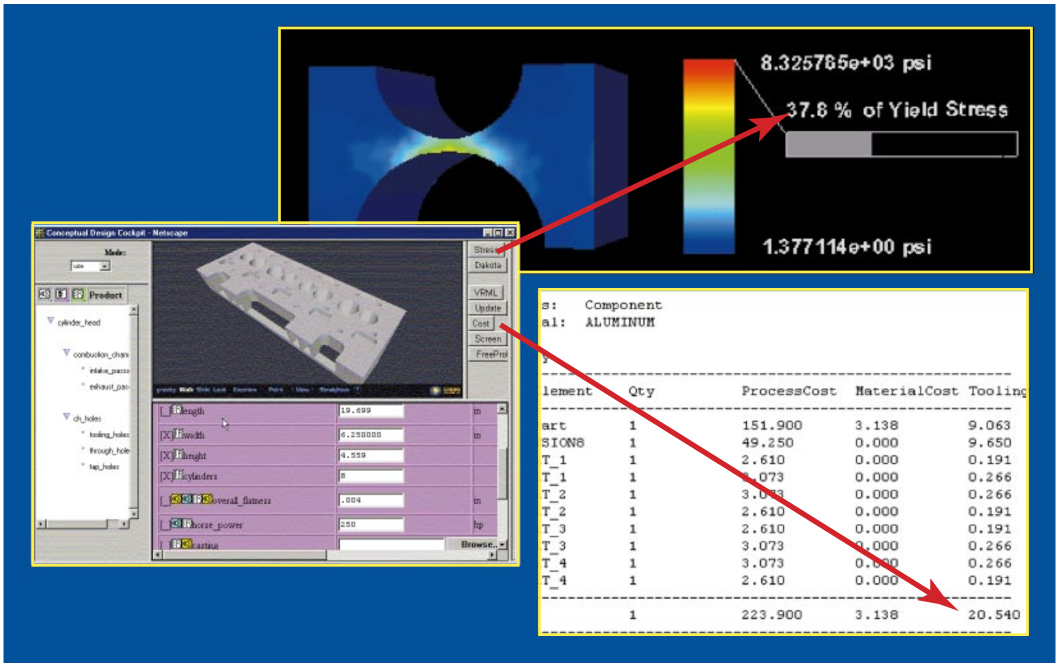
A project under way at Lawrence Livermore aims to help manufacturing companies do just that. Known as Totally Integrated Munitions Enterprise (TIME), it is being funded by the U.S. Army to handle several munitions manufacturing issues. Not only does the Army need to obtain munitions quickly in national emergencies, but munitions productions facilities are being downsized at the same time that a variety of highly complex, "smart" munitions are becoming available. Supplying these munitions on a timely basis while keeping them affordable has become a challenge.

Livermore is one of eight participants in the TIME project. Most other participants, including Raytheon, General Motors Powertrain, Aerojet, and Primex, are in the private sector. Together, project participants are developing and demonstrating a distributed, flexible manufacturing capability that is cost-effective and can be rapidly reconfigured as needs change.

Implementing an integrated manufacturing base means changing a basic practice that is pervasive in manufacturing today. Contractors use subcontractors, who in turn use other subcontractors, and minimal information is shared among them. A contractor typically shares with subcontractors only enough information for the subs to get their job done. But if knowledge, experience, and risk are commonly shared among all partners, so that the manufacturing process can be more widely viewed as a total, integrated process from concept to delivery, then money and time can be saved as quality increases.

Changing the Entire Process

To support this fundamental change, TIME addresses the entire process—from concept to finished product—as a system, integrating design, engineering, manufacturing, administration, and logistics. In the manufacturing industry, this process is called product realization. To facilitate the flow of information



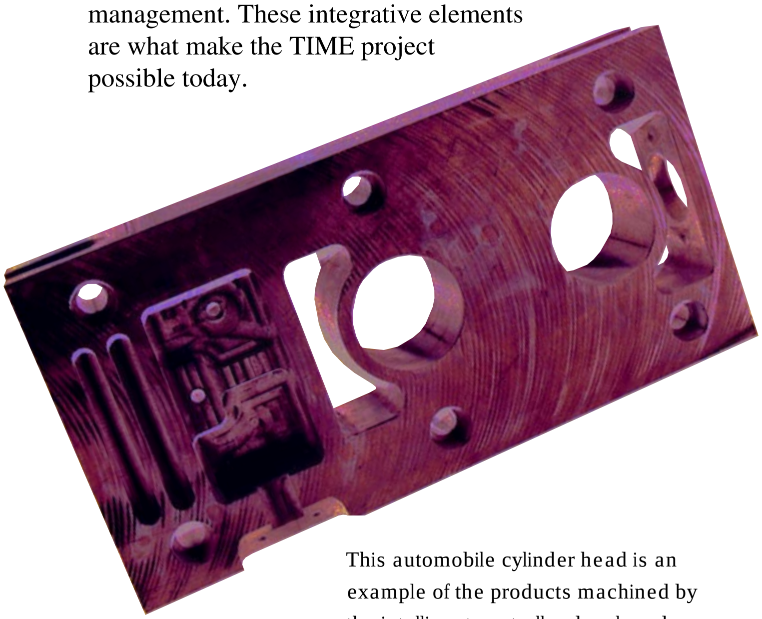
Using Web-based integration manager tools developed by TEAM (Technologies Enabling Agile Manufacturing), a nonspecialist can transparently modify a product design, run cost and product simulations, and produce a tradeoff study.

among various functions, TIME is using a host of Internet-based software tools. Many of these tools were developed during an earlier Department of Energy project known as Technologies Enabling Agile Manufacturing (TEAM). Livermore engineer Bob Burleson was technical manager for TEAM, which started in 1994 and wrapped up work in late 1998. Burleson is technical manager for the TIME project as well.

TEAM's 40 participants were remarkably diverse. Participants from the private sector represented many industries, including aerospace and defense, automotive, machine tools, robotics, consumer electronics, and software. Federal facilities and agencies included Lawrence Livermore, Los Alamos, and Sandia national laboratories, the Oak Ridge Centers for Manufacturing Technology, and the AlliedSignal Kansas City Plant.

The Internet-based software tools developed by TEAM support not only an open flow of information but also modeling of all phases of the work, communication among computing systems for geographically distributed facilities, concurrent engineering and production for teams that may be using different standards, and state-of-the-art methods for controlling manufacturing processes. An integration manager on the World Wide Web pulls together all product realization functions, including product design, process planning, process simulation, and fabrication controls.

Other activities, equal in importance to these software tools, support a generic infrastructure and overall planning and management. These integrative elements are what make the TIME project possible today.



This automobile cylinder head is an example of the products machined by the intelligent controller developed under Lawrence Livermore's leadership.

Manufacturing facilities of TEAM partners served as the proving ground for these models and software tools. The Internet-based tools allowed a large number of facilities to work together quickly and easily. In one instance, project requirements were analyzed at GM in Pontiac, Michigan; design was done collaboratively between a DOE site in Kansas City, Missouri, and Raytheon in Tucson, Arizona; the product analysis was performed at Livermore and ISX Corp in Atlanta, Georgia; DOE sites in Oak Ridge, Tennessee, and Kansas City completed process design; and process simulation was performed by the University of Illinois and a DOE site in Los Alamos, New Mexico. Tradeoff studies between product, process, and resources were performed wherever the product manager happened to be. Then parts were manufactured at GM in Pontiac and inspected at Ford in Dearborn, Michigan.

The real payoff for bringing together these Internet-based tools was in the way they enabled real change. In one instance, a critical machine was down, and the other available machine wasn't as accurate—and even if it were, the entire process design, process simulation, and tradeoff studies would have to be redone. The TEAM project worked across 10 different facilities, making the changeover in less than an hour instead of days or even weeks. That is truly integrated product realization.

Livermore was the leader for development of an intelligent controller for machining products such as the part shown at the left. Machine tools and robots that cut and shape parts for everything from safety pins to computers receive their instructions from a device known as a controller. The controller is programmed to know where to cut, drill, and turn on a particular part and typically serves the machine tool for its entire life. But if a part comes down the conveyor belt slightly crooked, then holes will be drilled at the wrong angle, forcing an inspector to throw that part away. In contrast, an intelligent controller can sense the angle of the part and correct the angle of drilling, reducing waste and saving time and money. An intelligent controller can also be reprogrammed quickly for production of different parts, making it a key player in an agile manufacturing setting. (See also *S&TR*, April 1996, pp. 22–23.)

Meeting Surge Rates and Retrofitting Weapons

The Army was so impressed with the results of the TEAM project and the controller effort that it wanted this collection of tools put to work at its munitions manufacturing facilities. Currently, after having produced a stockpile of m2munitions for potential conflicts, all of these facilities produce munitions at a sustaining rate that just keeps up with the Army's ordinary needs. But the Army also needs facilities to be able to produce at a surge rate, without the necessity of creating a larger stockpile. With agile manufacturing, private companies that manufacture other products could be put to work to produce munitions on short notice. And with agile manufacturing, existing plants could quickly produce entirely new munitions or retrofit “dumb” weapons with new, “smart” features.

Integrated production had already been demonstrated generically, but a demonstration at a munitions manufacturing site was in order. Last fall, the TIME team went to the Scranton Army Munitions Plant in Pennsylvania to show how quickly and easily a manufacturing facility could begin to make something entirely new. There, in just a few days, they were able to produce the part shown on p. 18.

In 2000, another type of demonstration will take place in which production data from a munitions production plant will be used to almost immediately begin production at a nonweapons manufacturing company. The plan is for GM to manufacture components for small grenades using data from Primex, which routinely manufactures these and other conventional weapons. Burleson notes, “This is an almost unheard-of event in the manufacturing world, where proprietary data are zealously protected.”

Work on agile manufacturing to date has focused on material removal processes—milling, drilling, turning, and so on—but agile manufacturing can easily be extended to assembly and other repetitive manufacturing activities.

Tom McWilliams, program leader for the TIME project for the U.S. Army in Picatinny, New Jersey, is enthusiastic about successes to date. “These new control systems could allow existing facilities to change production modes quickly. They could, for example, switch back and forth between ‘dumb’ bullets and ‘smart’ ones, even on a day-to-day basis. Agile manufacturing will give us a flexibility we have not had before.”

—Katie Walter

Key Words: agile manufacturing, machine controller, munitions manufacturing, product realization process, U.S. Army.

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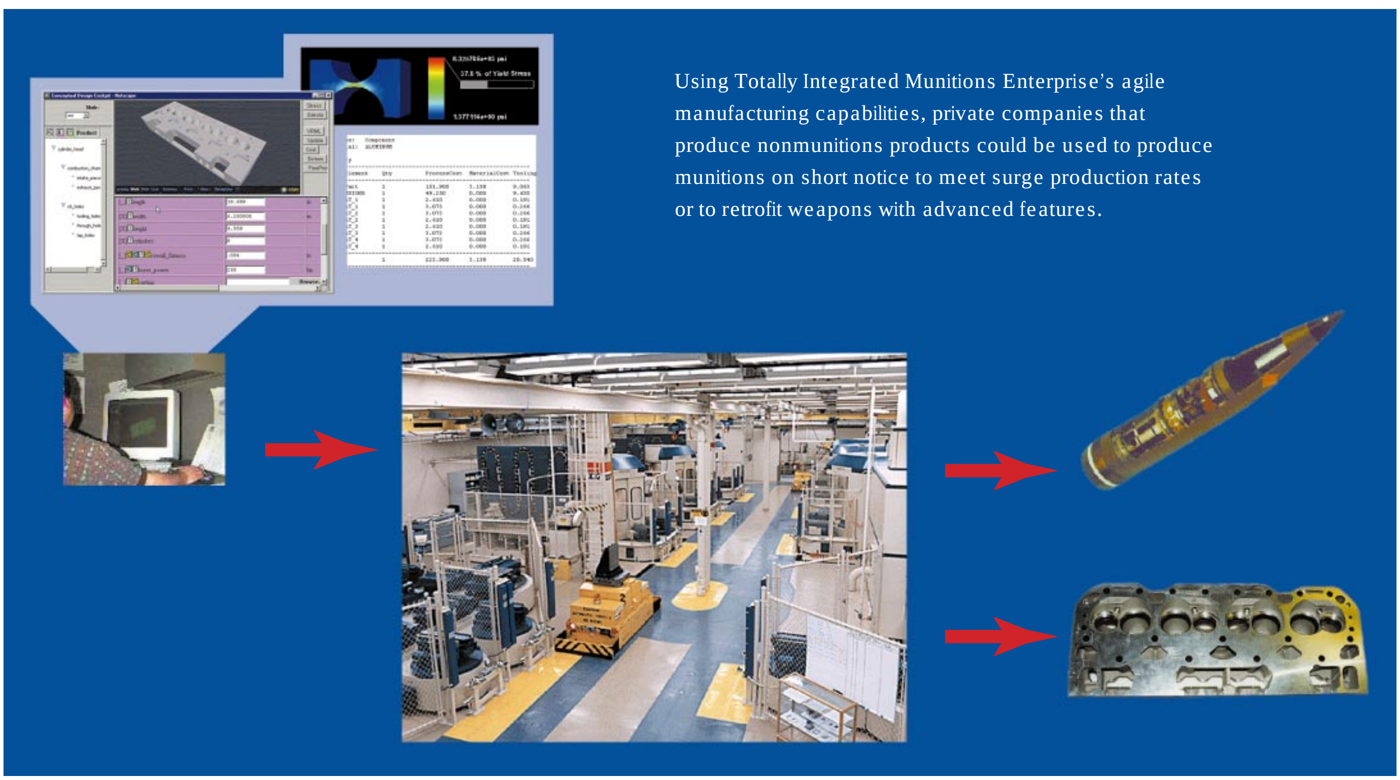


Using Totally Integrated Munitions Enterprise’s agile manufacturing capabilities, private companies that produce nonmunitions products could be used to produce munitions on short notice to meet surge production rates or to retrofit weapons with advanced features.

Bringing Hypersonic Flight Down to Earth

From the doodlings of daVinci and the penned fantasies of Jules Verne to the tangible accomplishments of the Wright brothers and other aviation pioneers, mechanized flight has captured the imagination of humanity through the centuries. Even today, with atmospheric and space flight a reality, there are still aviatory realms to dream about and conquer. Hypersonic flight at speeds 5 to 12 times the speed of sound (Mach 5 to Mach 12) is one such area of interest to the commercial and defense communities.

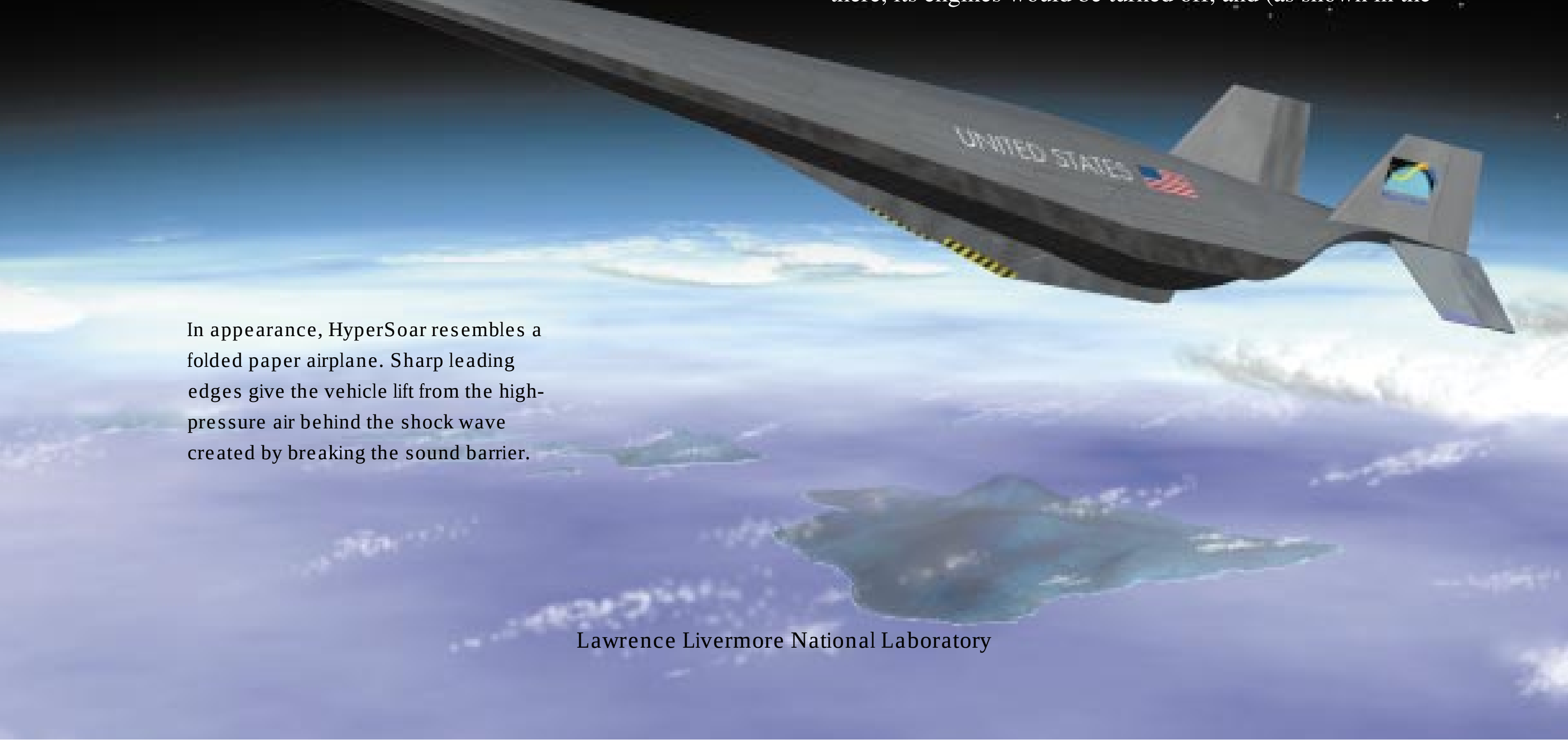
At Lawrence Livermore National Laboratory, aerospace engineer Preston Carter has invented a concept for a next-generation hypersonic aircraft, dubbed HyperSoar, that could fly efficiently, economically, and cleanly.

Flying at Mach 10 (3 kilometers per second), HyperSoar could reach any point on the globe within two hours. (The fastest military plane, the SR-71, flies between Mach 3 and Mach 4, while the commercial Concorde only reaches Mach 2.) HyperSoar would also have twice the fuel efficiency of commercial airliners, be three to five times more efficient in putting satellites in space than today's launch systems, and use liquid hydrogen fuel, which produces simple water vapor when burned.

HyperSoar—a concept-development project funded through Livermore's Physics Directorate and the Laboratory Directed Research and Development Program—could transport people or cargo, strike enemy targets, or help put satellites into space. "The fact that HyperSoar has many potential uses is key," says Carter. "Developing an entirely new aircraft is expensive. However, if there is a large market for such an aircraft, the cost per plane goes down. It's like the difference between a 747 and the Stealth bomber. There are hundreds of Boeing 747s being used by commercial airline companies, airfreight companies, and so on. But the only market for the Stealth is the military, which only needs a few. That's why you'll never see a Stealth being built for much less than they cost today."

Skipping on the Atmosphere

A 25-meter-long HyperSoar aircraft (about as long as the wingspan of a large business jet) could make a conventional takeoff from a standard runway. Using special air-breathing, rocket-based, combined-cycle engines, it would ascend to 40 kilometers—at the outer limit of Earth's atmosphere. Once there, its engines would be turned off, and (as shown in the



In appearance, HyperSoar resembles a folded paper airplane. Sharp leading edges give the vehicle lift from the high-pressure air behind the shock wave created by breaking the sound barrier.

figure below) it would coast up to a high point of 60 kilometers before beginning to fall back down to about 35 kilometers—well inside the atmosphere's upper level. As it descends into denser air, the aircraft would be pushed up by the increased aerodynamic lift. The engines would fire briefly, propelling the plane back into space. Outside the atmosphere, the engines shut off and the process repeats. In this way, HyperSoar would skip off the top layer of the atmosphere every two or so minutes, like a flat rock skittering in slow motion across the surface of a pond.

Inclusive of the time taken and distances covered by the ascent and descent portions of a flight, a trip from Chicago to Tokyo (10,123 kilometers) would involve about 18 skips and 72 minutes, and to travel from Los Angeles to New York (3,978 kilometers) would involve about 5 skips and take 35 minutes. (Both flights require a total of about 2,450 kilometers and 27 minutes for take off and landing.)

By popping regularly out of the atmosphere and using the engines intermittently, HyperSoar would use less fuel and solve a critical problem that plagues other hypersonic aircraft designs—heat.

Beating the Heat

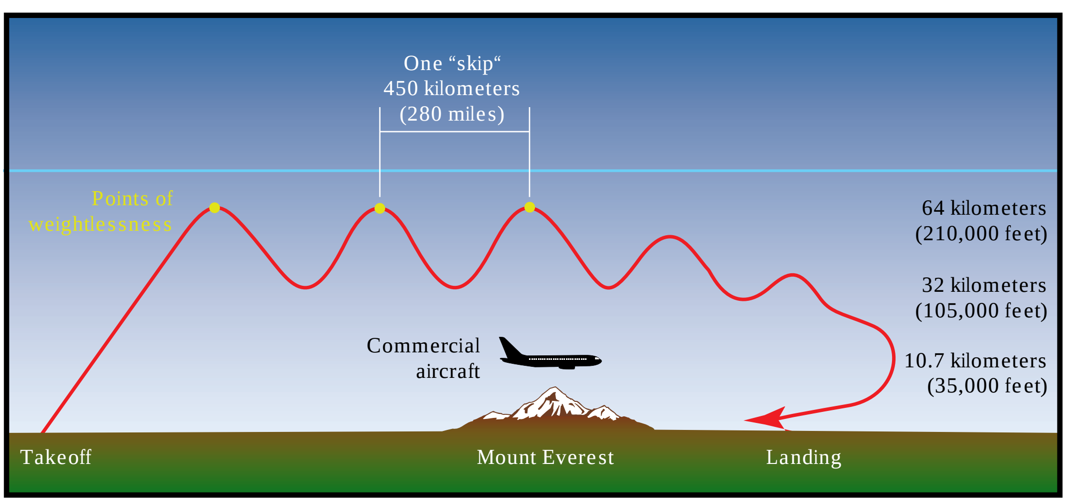
Any object—airplane, spacecraft, asteroid—speeding through the atmosphere will compress and heat the air in front of it. This heat is inevitably absorbed by the surface of the object. "Heat buildup just kills most designs for hypersonic aircraft," Carter said. "The hotter the craft gets, the more material engineers add to the airframe to strengthen and shield it. Also, most other hypersonic concepts have trajectories that are strictly atmospheric, and the only way to get rid of the heat is to dump it into the fuel and then burn the fuel in the engines. The problem is, the faster you fly, the more fuel you must carry as a heat sink. Eventually, you end up carrying a significant amount of fuel just as a heat sink, and the engines end up running fuel-rich, that is, burning up more fuel than they really need. That's wasteful in and of itself. Also, more material and more fuel translate to more weight. After a while, the aircraft can no longer carry a decent cargo."

Because HyperSoar spends nearly two-thirds of its time out of the atmosphere, it can radiate the heat into space. Carter and colleagues at the University of Maryland have analyzed HyperSoar, compared it to other concepts, and found that—thanks to its trajectory and shape—HyperSoar has less heat load on its airframe and consumes less fuel.

From Express Mail to Satellites

"The way HyperSoar blends flight and space access is revolutionary, opening up a world of potential applications," says Carter. Possibilities include using HyperSoar as a freighter, military aircraft, low-cost launcher, and, eventually, a passenger aircraft. According to Carter, HyperSoar would be capable of carrying more weight over longer distances than planes of similar size and mass.

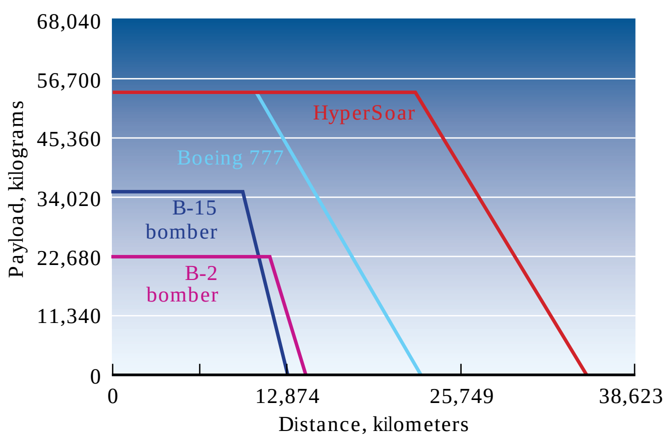
As a freighter, it could make four round-trips to Tokyo daily versus one or less for today's aircraft. This speed would be a boon to the $4-billion-per-year commercial intercontinental package delivery market. "The speed of today's aircraft has limited the growth of this market," says Carter. "The express delivery industry requires central intracontinental hubs that are about two hours' flying time apart. Current technology allows express mail, for instance, to move between these hubs in close to that time. Now, imagine the possibilities if you could fly between Memphis and Singapore in close to two hours." Carter estimates that a HyperSoar aircraft flying express mail between Los Angeles and Tokyo could generate ten times the daily revenue of a similar-size subsonic cargo plane.



HyperSoar's trajectory follows a skipping pattern. Passengers would feel 1.5 times the force of gravity at the bottom of each skip, and weightlessness out in space. The experience would be comparable to being on a swing, although HyperSoar's motion would be 100 times slower.

As a military aircraft, a HyperSoar bomber the size of an F-22 could take off from the U.S. and deliver its payload from an altitude and at a speed that would defy all current defensive measures. It could then return directly to the continental U.S. without refueling and without the need to land at forward bases on foreign soil.

HyperSoar could also be employed as the first stage of a two-stage-to-orbit space launch system. This approach would allow approximately twice the payload-to-orbit as today's expendable launch systems for a given gross takeoff weight. At the high point of its skip, HyperSoar could eject an upper-stage vehicle and its payload into low-Earth orbit. A larger HyperSoar vehicle, the size of a Boeing 777 for example, could handle a 13,700-kilogram payload in addition to the weight of a typical second-stage launcher. At a 255,000-kilogram gross vehicle weight, the HyperSoar would weigh about half as much as the largest Ariane 4 expendable launch vehicle but could carry about 40 percent more payload. Of course, these lower weight-to-payload requirements mean that HyperSoar vehicles will not need to be built as large vehicles but rather as smaller, less expensive ones.



According to its designers, HyperSoar would be capable of carrying more weight over a greater distance than planes of similar size and mass.

Flying the Paper Plane

Even though HyperSoar is still in the "paper airplane" stage, it has garnered interest from organizations as diverse as Federal Express and STRATCOM (the U.S. Air Force Strategic Air Command). HyperSoar has appeared in *Jane's Defence Weekly*, *Aviation Week and Space Technology*, *Scholastic's Weekly Reader*, and daily papers from the *Los Angeles Times* to the *Washington Times* to local newspapers such as the *Valley Times*.

Passenger flight would be one of the last applications to become reality, but it is the one that the media and the public are most interested in. "The public gets very excited about space and air travel," said Carter. "To the general public, HyperSoar looks doable. The technology is nearly there, the concept is proven on paper. The thing now is to make it economically feasible to the defense and commercial communities so HyperSoar can get the funding it needs to take the next step in development."

Carter estimates that about $500 million would be needed to develop the technologies needed and build and test a 16-meter-long flyable unmanned prototype. Lawrence Livermore is positioned to help bring HyperSoar into reality because of its expertise in thermal protection materials, large-scale computational fluid dynamics, ultrahigh pressure testing design, and modeling the environmental effects of high-speed supersonic aircraft.

The question of funding aside, the day when passengers can hop a HyperSoar to London is still a ways off.

"When most people hear about HyperSoar," Carter added, "they immediately think big—building big airplanes to carry lots of passengers or cargo. But that's not economically feasible. I propose building small airplanes to justify the market and then building up from there, according to the need. That's how all the different flight technologies—airplanes, jets, helicopters—got started. It's the way that fledgling technologies like HyperSoar take wing."

—*Ann Parker*

Key Words: HyperSoar, hypersonic aircraft.

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Patents and Awards

Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
William Bennett Peter Celliers Luiz Da Silva Michael Glinsky Richard London Duncan Maitland Dennis Matthews Peter Krulevich Abraham Lee	**Opto-Acoustic Transducer for Medical Applications** U.S. Patent 5,944,687 August 31, 1999	An optically activated transducer for generating acoustic vibrations in a biological medium. The transducer is located at the end of an optical fiber, which may be located within a catheter. Energy for operating the transducer is provided optically by laser light transmitted through the optical fiber to the transducer. Pulsed laser light is absorbed in the working fluid of the transducer to generate a thermal pressure and consequent adiabatic expansion of the transducer head such that it does work against the ambient medium. The transducer returns to its original state by a process of thermal cooling. The motion of the transducer within the ambient medium couples acoustic energy into the medium. By pulsing the laser at a high repetition rate (continuous wave to 100 kilohertz), an ultrasonic radiation field can be established locally in the medium. This method of producing ultrasonic vibrations can be used in vivo for the treatment of stroke-related conditions in humans, particularly for dissolving thrombi. The catheter may also incorporate antithrombolytic drug treatments as an adjunct therapy, and it may be operated in conjunction with ultrasonic detection equipment for imaging and feedback control.
Frank J. Weber Eberhard A. Spiller	**Cleaning Process for EUV Optical Substrates** U.S. Patent 5,958,143 September 28, 1999	A cleaning process for surfaces with demanding cleanliness requirements, such as extreme ultraviolet (EUV) optical substrates. Proper cleaning of optical substrates prior to applying reflective coatings thereon is critical in the fabrication of the reflective optics used in EUV lithographic systems. The cleaning process involves ultrasonic cleaning in acetone, methanol, and a pH-neutral soap, such as FL-70, followed by rinsing in deionized water and drying with dry filtered nitrogen in conjunction with a spin rinse.
John W. Kury Brian L. Anderson	**Explosive Simulants for Testing Explosive Detection Systems** U.S. Patent 5,958,299 September 28, 1999	Explosives simulants that include nonexplosive components that facilitate testing of equipment designed to remotely detect explosives. The simulants are nonexplosive, nonhazardous materials that can be safely handled without any significant precautions. The simulants imitate real explosives in terms of mass density, effective atomic number, x-ray transmission properties, and physical form, including moldable plastics and emulsions/gels.
Paul R. Coronado	**Method for Making Monolithic Metal Oxide Aerogels** U.S. Patent 5,958,363 September 28, 1999	A method for producing transparent, monolithic metal oxide aerogels of varying densities by preparing separately and then reacting a metal alkoxide solution with a catalyst solution. The resulting hydrolyzed-condensed colloidal solution is gelled, and the wet gel is contained within a sealed but gas-permeable containment vessel during supercritical extraction of the solvent. The containment vessel is enclosed within an aqueous atmosphere that is above the supercritical temperature and pressure of the solvent of the metal alkoxide solution.
Claude Montcalm Daniel G. Stearns Stephen P. Vernon	**Passivating Overcoat Bilayer for Multilayer Reflective Coatings for Extreme Ultraviolet Lithography** U.S. Patent 5,958,605 September 28, 1999	A passivating overcoat bilayer for multilayer reflective coatings for extreme ultraviolet (EUV) or soft x-ray applications to prevent oxidation and corrosion of the multilayer coating, thereby improving the EUV optical performance. The overcoat bilayer is composed of a layer of silicon or beryllium underneath at least one top layer of an elemental or a compound material that resists oxidation and corrosion. Materials for the top layer include carbon, palladium, carbides, borides, nitrides, and oxides. The thicknesses of the two layers that make up the overcoat bilayer are optimized to produce the highest reflectance at the wavelength range of operation. Protective overcoat systems composed of three or more layers are also possible.

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
Michael D. Perry Paul S. Banks Brent C. Stuart Scott N. Fochs	**Aberration-Free, All-Reflective Laser Pulse Stretcher** U.S. Patent 5,906,016 September 28, 1999	An all-reflective pulse stretcher for laser systems employing chirped-pulse amplification enables on-axis use of the focusing mirror, thus allowing ease of use, significantly decreased sensitivity to alignment, and near aberration-free performance. By using a new type of diffraction grating that contains a mirror incorporated into the grating, the stretcher contains only three elements: (1) the grating, (2) a spherical and parabolic focusing mirror, and (3) a flat mirror. Addition of a fourth component, a retroreflector, enables multiple passes of the same stretcher, resulting in stretching ratios beyond the current state of the art in a simple compact design. The pulse stretcher has been used to stretch pulses from 20 femtoseconds to over 600 picoseconds (a stretching ratio in excess of 30,000).

Awards

A poster presentation created by a team of Livermore biomedical scientists recently garnered top honors at the California Breast Cancer Research Symposium in Los Angeles. The scientists are **Kristen Kulp** (lead author), **Mark Knize**, **Mike Malfatti**, **Cyndy Salmon**, and **Jim Felton**.

The poster, which focused on diet and how individuals differ in their susceptibility to breast cancer, won the **Cornelius L. Hopper Scientific Achievement Award**. Presented for the poster with the “Highest Impact on Breast Cancer,” the Hopper award recognizes the University of California’s recently retired Vice President for Health Affairs.

The Livermore scientists’ poster analyzed the link between the presence of certain metabolites—the excretion products of carcinogens—and an individual’s susceptibility to breast cancer. Specifically, the Livermore team examined whether the speed at which people excrete the metabolites and the relative amounts are related to the risk of developing breast cancer.

During their study, the Livermore researchers became the first scientists to develop a technique using mass spectrometry to detect phenylimidazo pyridine (PhIP) metabolites in human urine.

Simulating Warfare Is No Video Game

For more than two decades, Lawrence Livermore conflict simulations have proved highly valuable to the military services for training officers, rehearsing missions, and evaluating new tactics. A team of computer scientists has developed Livermore's most powerful conflict model, JCATS (Joint Conflict and Tactical Simulation). The program realistically simulates the capabilities and limitations of combatants, weapon systems, and the environment. The model was used to rehearse possible combat options in support of the 1999 Kosovo conflict. It was also used by the Marine Corps and the Navy to plan for and participate in an exercise in the San Francisco Bay Area. During the exercise, JCATS tracked the live participants and tested the real-time effects of virtual air and artillery attacks. An enhanced version of JCATS released in October 1999 that can simulate up to 60,000 individual elements and can run on a workstation computer as well as a laptop, making it feasible for use in the field.

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Supernova Hydrodynamics Up Close

A group of Livermore scientists has conducted a series of laser experiments to deepen and refine understanding of the hydrodynamics of dying stars. Using Livermore's Nova laser (and more recently, the Omega laser at the University of Rochester), the group has simulated on a near-microscopic scale the hydrodynamic turbulence and mixing of Supernova 1987A, the great supernova of 1987 that marked the demise of a particularly massive star. The Livermore scientists are using the results of multidimensional laser experiments to refine existing one- and two-dimensional models of supernovas, to stand in for prohibitively expensive three-dimensional supernova hydrodynamics modeling, and to bring the supernova models into closer agreement with astrophysical observations. Their work has also helped resolve the issue of the difference in scale between a supernova event and a laser experiment, thereby allowing the cosmically huge supernova to be successfully studied using the vastly smaller laser medium.

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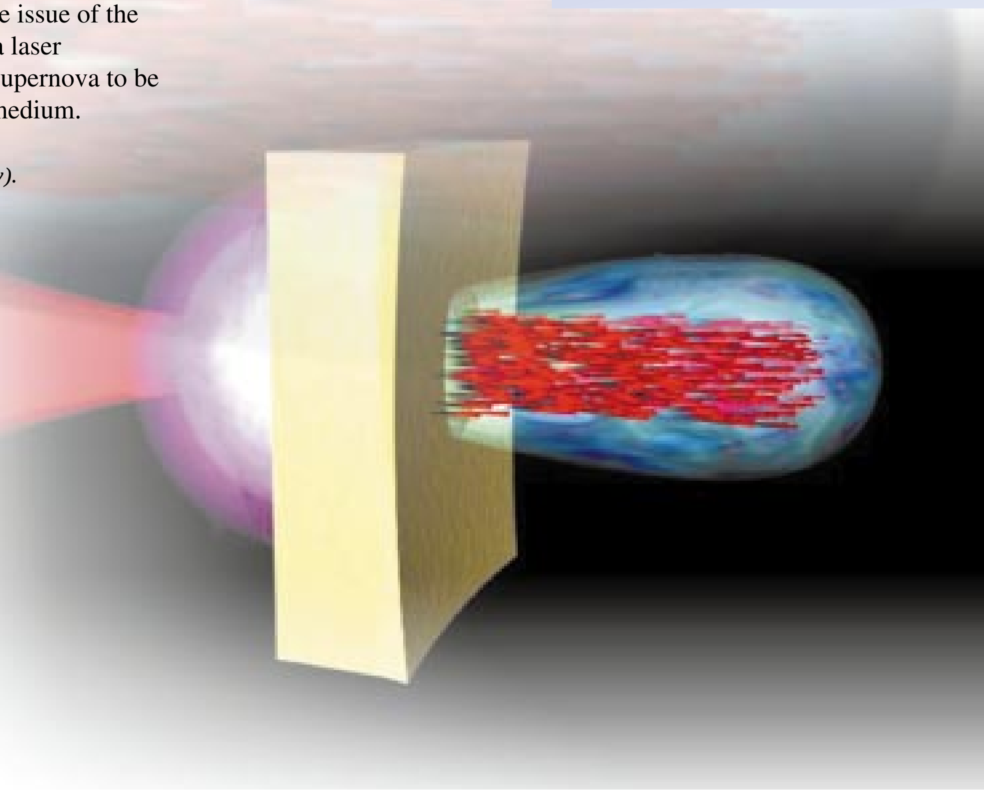
Coming Next Month

The Amazing Power of the Petawatt

Livermore's latest record-breaking laser, the Petawatt, fired its last shot in May 1999, leaving a legacy of information and new ways to delve into high-energy-density physics, astrophysics, and medical diagnostics.

Also in March

- *Simulations predict nuclear repository safety eons into the future.*
- *The design of the Next Linear Collider pushes the frontiers of particle physics and cosmology.*
- *Underwater explosions in Israel serve the nuclear test ban, improve earthquake safety, and foster political cooperation.*



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