TERMINAL DIAGNOSTICS AT SEA

As Livermore's LLNL Independent Diagnostic Scoring System (LIDSS) rafts collect weapons data, the LIDSS team can watch from afar. This photograph, captured in 2017 during a GT 221 Minuteman III missile test, shows three warheads that are part of the Multiple Independent Re-Entry Vehicle (MIRV) system test over the ocean. The flash above the clouds is the separation of warheads from the bus as they go to distinct locations. One warhead, a HiFi, detonates while the other two are instrumented and do not detonate. LIDSS continues to support MIRV missions.

A warhead detonates in the ocean as a fleet of carefully stationed rafts carrying diagnostic instrumentation measure the warhead's performance just before, during, and after detonation. The rafts, part of the Laboratory's LLNL Independent Diagnostic Scoring System (LIDSS) Program, are uniquely capable of evaluating the accuracy and efficacy of the nation's defense deterrent for in-development and deployed nuclear and conventional systems, many of which are over four decades old. These systems include intercontinental ballistic missiles (ICBMs), conventional prompt strike (CPS) missiles, and other delivery systems used for national defense. "Very few things in our lives are 40 years old. Phones don't last 40 years, cars don't last 40 years," says Steve Jensen, the director of the LIDSS team. "We have to assess how well our stockpile ages."

If assessment scores indicate an issue, researchers determine how pervasive the problems are to understand whether the entire stockpile is affected or if the problem is a more localized concern. "It's no different from going to the doctor: As we age, we don't have the same metabolism. We're not as energetic. We go to the doctor more frequently because the body is breaking down," says Jensen. "Flight testing is an end-to-end health check of our aging stockpile that occurs annually on all enduring systems to ensure they are still viable defense assets."

After arriving at the target destination, the deployment team delivers a set of rafts equipped with the appropriate instrumentation for the test, and they depart to a distant location to monitor the warhead and collect the data. From afar, the rafts measure the terminal event conditions, including trajectory, accuracy, and miss distance; velocity; height of burst; detonation timing; neutron detection; and dive angle in real time. The team then combines these physics parameters into a score that is compared against expectations for the system for an indicator of the warhead's health.

Earlier versions of LIDSS rafts were equipped with neutron detectors, cameras, and a hydrophone system (see *S&TR,* June 2019, pp. 20–23). Following LIDSS's success in recent years, the program has grown rapidly, incorporating emerging technologies including telemetry, Radar on a Raft (ROAR), drones, Smoke-and-Mirror (SAM) camera systems, and infrared cameras. As a result, the LIDSS team has expanded its workforce and upgraded its workspaces at Lawrence Livermore.

Rafts, Drones, and Better Capabilities

LIDSS's growth has presented the team with a challenge—as the program's capabilities expand, its customer base and their requirements expand in tandem. LIDSS is a unique program with a unique set of terminal diagnostic assets, and many agencies have a growing demand for the program's capabilities. Once exclusively used for missions for the United States Air Force and National Nuclear Security Administration, LIDSS now includes the U.S. Navy, the U.S. Army, the Office of the Secretary of Defense, and the Test Resource Management Center among its customers. Although each of these customers has a different delivery system, each agency has the same overall goal of obtaining terminal scoring of a weapon.

For each deployment, LIDSS rafts are transported via boat to the testing location (top). After arriving at the target destination, the LIDSS crew unloads the rafts into the ocean (bottom) before departing to a distant location to monitor the test.

The rafts themselves have undergone significant upgrades in recent years. They now feature a new dynamic positioning system, new glass windows, and satellite systems that can be controlled from anywhere in the world, along with support for different types of sensors on board. The electronics loaded onto the rafts are increasingly sophisticated. For example, what was once a set of 10 separate circuit boards, each in charge of a different task, has been redesigned into one purpose-built control of raft electronics (CORE) board that can be used for multiple applications. The CORE board is the nucleus of LIDSS, enabling tasks such as controlling messaging, monitoring the camera trigger, tracking the raft's GPS location, and storing data, among others.

Paul Nyholm, LIDSS system design and integration lead, says, "We've undergone significant growth in the scope of our work.

The Livermore deployment team watches as one of the LIDSS rafts navigates to its position carrying a complementary diagnostic drone ready for deployment.

When we needed to add more features, we added more circuit boards.” The circuitry previously siloed on older boards—a product of the program’s rapid expansion—was limited in its inputs, and modernizing the system was necessary not only to improve maintenance and debug the system, but also to allow room for further growth. In addition to improved raft-circuit design, construction of a new generation of rafts is underway. The LIDSS team recently completed nine rafts for use by the U.S. Navy and U.S. Army on the east coast and two for the U.S. Air Force on the west coast, with seven more planned.

The LIDSS program has added a fleet of drones that can be equipped with different data collection packages. These drones autonomously launch from the LIDSS rafts to collect data and return to their home. “Nobody else has mission drones that take off and land autonomously in the middle of the ocean,” says Jensen. “That is unique to LIDSS.” In the early stages, Nyholm helped develop the first two LIDSS prototype drones, one hydrophone fiducial drone that uses underwater microphones as points of reference to calculate where the reentry splash occurs, and one camera drone. Initially working on one-off research projects, the LIDSS team will conduct additional environmental, water, and parts testing to build more robust, production-ready versions now that the technology has been proven.

For LIDSS systems, thermal measurements are another important diagnostic. Objects that move very rapidly through the Earth’s atmosphere can heat up enough that they burn off some of their shell, a process called ablation. From a manufacturing perspective, the need for thermal diagnostics is critical to ensure the vehicle is stable enough to withstand its speed and acceleration at high temperature. If the vehicle’s nose tip erodes away too much, or irregularly, its aim can become inaccurate. “If the material isn’t structurally sound, it will completely disintegrate,” says Jensen.

LIDSS developed a series of new cameras to help with temperature assessment. LIDSS deploys a unique patent-pending SAM camera system that produces the highest-resolution ICBM images yet. SAM relies on a gray, smoky-colored neutral density filter that filters the bright light of the ICBM’s hot glow, enabling the desired wavelengths to be seen more clearly. SAM also uses a set of turning mirrors that work alongside beam splitters to bend and move light to increase the camera’s field of view fourfold, from about 5 to 20 degrees. These capabilities ensure the ICBM's detonation will be captured without adding multiple cameras. LIDSS has a total of three SAM assemblies, which together cover 12 standard cameras' frames from a raft.

To complement the SAM system and its temperature assessment data, the team developed and recently deployed the program's first infrared (IR) camera, which measures the temperature of the ICBM warhead and its surroundings. After developing significant new software to provide the IR camera with a remote trigger and interface with it through radio or satellite signals, the team captured their first IR images in May 2023. Together, these improvements enable the team to obtain data that was not previously possible in the open ocean, including nose tip ablation measurements and thermal imaging of the warhead prior to detonation.

The newly upgraded LIDSS facilities include a high bay, where the team can work on instrumentation maintenance and upgrades.

New Opportunities

Managing so many different components makes preparing for a deployment a careful balancing act between technical and logistical planning. In the past, the LIDSS team conducted approximately three or four test missions per year, but in 2023, they completed nine. Nyholm, Jensen, and mission execution group leader Rob Golden ensure the instrumentation is ready at Livermore before deployment, and they determine which members of the team should provide electronic and mechanical support, as well as general equipment expertise on the boat. Problem-solving abilities are key—if the team encounters a problem at sea, they can only use the tools at hand to find a solution. "These trips have an exciting adventure aspect to them but also an unknown aspect. Every mission is resource-limited—we only have what we bring with us," says Nyholm.

In spring 2023, the team worked at Cape Canaveral on a 29-day deployment. After the team drove the equipment to its predetermined location and sailed away to observe the test, the autonomous rafts positioned themselves on the ocean to best capture the diagnostic data. Following so much work to conduct the tests, the event can be a little bittersweet. "We put a lot of time and effort into designing and maintaining the assets, and then they're placed in harm's way near the test site," says Samuel Maddren, a recent addition to the LIDSS team. "Everything culminates in this one moment, and then we pick it up and go home."

Due to demands for new technology and more tests, the LIDSS team has grown from 15 to over 50 individuals within the past few years and has moved into a new workspace. Once scattered across multiple locations throughout the Laboratory, the team took ownership of a pair of buildings that had been planned for decommissioning but could be brought back to life by the LIDSS program. Accustomed to rough facilities in the Marshall Islands, the buildings at Livermore provided an opportunity to develop the type of workspace the LIDSS program needs to expand. Jensen has spearheaded efforts to transform the buildings into a modern space, adding a high bay in one building where the team can work on the rafts.

In addition to its support of the nuclear stockpile, the LIDSS team also plays a key role to support Department of Defense hypersonics. As the demand for LIDSS continues to grow and the team prepares for upcoming deployments to serve their expanding customer base, Nyholm emphasizes that warheads are more often a deterrent than an offensive. "Our work has real, lasting implications on the defense of our country, and we take that pretty seriously," says Nyholm.

—Anashe Bandari

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