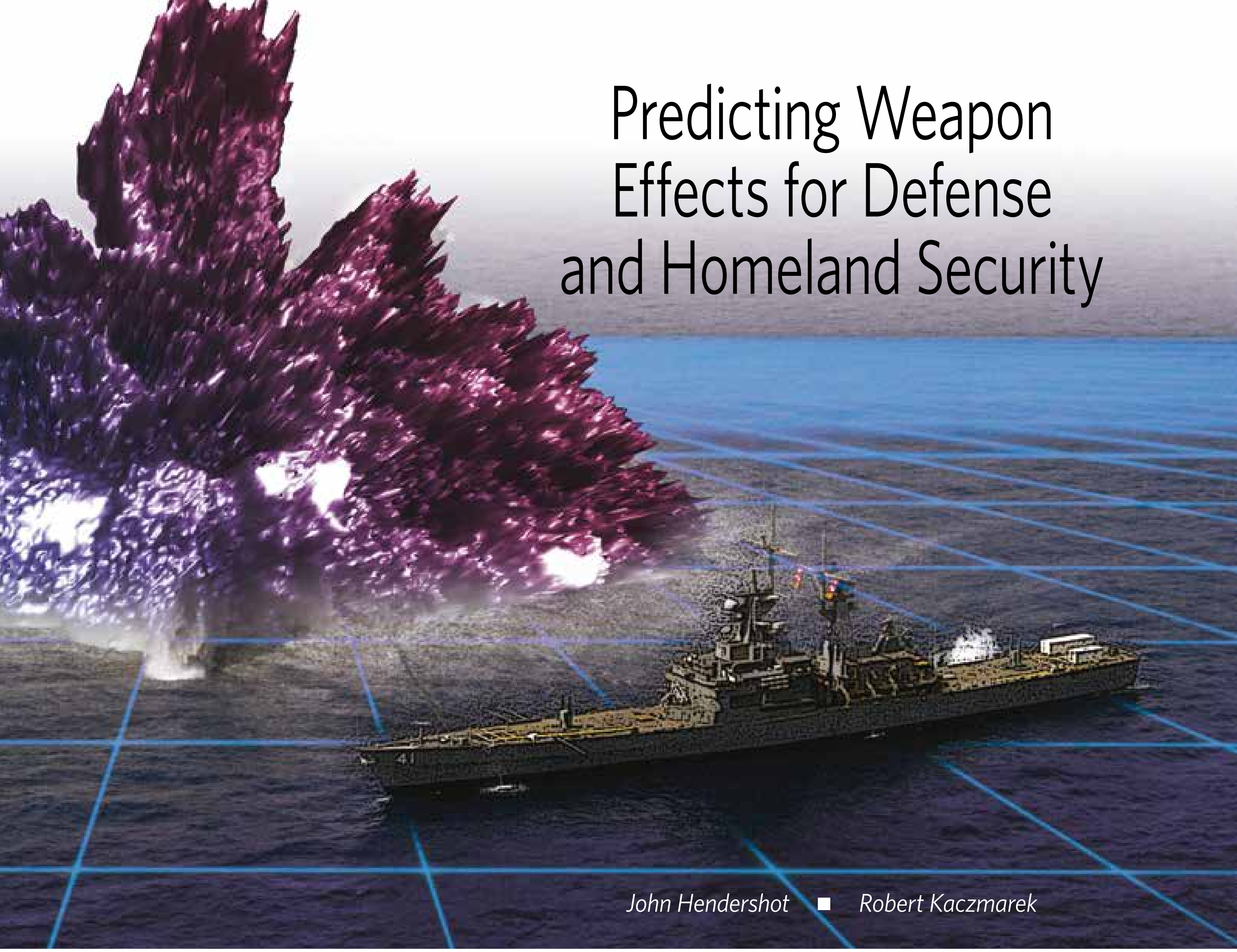
Predicting Weapon Effects for Defense and Homeland Security



John Hendershot ■ Robert Kaczmarek

How well will weapons work? The answer to this question is not simple, but is necessary to develop effective weapons and survivable systems. The fundamental knowledge required to answer this question comes from energetics experts—researchers and developers of warheads, explosives, propellants and pyrotechnics. Ideally, real-world tests are used to determine weapons effects, but they are not always possible, particularly due to cost.

To improve this situation, the Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division (Indian Head), in Maryland, develops high-fidelity simulation tools to serve as an acceptable surrogate for real-world tests. These tools accelerate development and reduce cost, while informing weapons development and systems survivability for defense and homeland security applications. They provide the United States with a strategic advantage today and, with sustained investment, will continue to give the nation a strategic advantage for years to come.

The Quest for a Predictor

Underwater weapons are powerful assets in an arsenal. They can blow holes in a ship's hull, initiate violent whipping motions that can damage the ship and injure the crew, and, under the right circumstances, break

Hendershot *is director of the Energetics Technology Division and* **Kaczmarek** *is a member of the Technical Director staff at the Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division.*

As weapons and vessels grew in complexity, analytical methods became insufficient and high-fidelity computational methods became necessary.

a ship completely in half. Understanding underwater weapons and their effects on targets is critical to U.S. naval superiority, aiding in naval weapons development, as well as in ship design and survivability assessments.

But understanding underwater explosions was long a vexing problem. During World War II, nearby torpedo explosions did more damage to ships than did direct hits. The reason for this was not well understood at the time. Following the war, theoretical developments helped researchers better understand underwater explosions and how ships and submarines respond to them. These theories helped improve undersea weapon lethality and led to more-survivable ship designs. As weapons and vessels grew in complexity, analytical methods became insufficient and high-fidelity computational methods became necessary.

In the late 1980s, undersea weapons researchers recognized the potential of modeling and simulation to aid in weapon design. The goal was to computationally assess new concepts in order to greatly reduce the amount of physical testing needed to field a weapon, thereby saving time, money and personnel.

Emerging computing power made this possible, but weapons effects software was needed. The U.S. Navy evaluated available commercial and government software capabilities. The most promising software was found in Germany. The Dynamic System Mechanics Advanced Simulation, or DYSMAS, software took an innovative approach to predicting underwater explosion effects and the response of naval targets. DYSMAS gained the U.S. Navy's attention, and in 1993, Germany provided the software to the United States for evaluation.

Initial evaluation led to three international project agreements focused on jointly enhancing and validating the software. All of the original software modules have been upgraded or replaced, resulting in a fast, modern software package that harnesses the power of the Department of Defense's largest supercomputers. The U.S.-German collaboration has focused on validating the software against real-world tests. Consequently, DYSMAS is now the most extensively validated full-physics software for predicting underwater explosions and their effects on marine structures.

The capabilities of DYSMAS for predicting weapons effects are not limited to naval applications. DYSMAS enjoys a wide user base spanning multiple government agencies, and it is solving real-world problems affecting sea war, land war and homeland security.

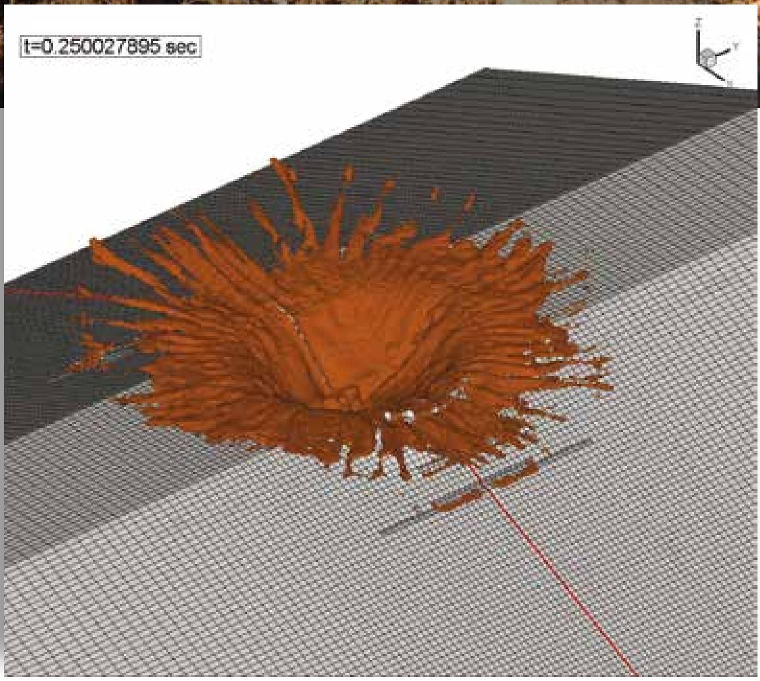
Predicting Weapons Effects from Ship to Shore

In the undersea domain, DYSMAS influences programs ranging from naval weapons development and effectiveness assessments to ship survivability and acquisition. As foreign navies advance their fleets and the geopolitical climate changes, U.S. strategy for naval conflict evolves, and with it the requirements of naval weapons. DYSMAS affects naval weapons development programs throughout the design, assessment and acquisition process.

A major use of DYSMAS is for assessments of undersea warhead lethality against targets such as ships, submarines, torpedoes and mines. For example, DYSMAS was used to optimize the warhead configuration for the Countermeasure, Anti-Torpedo (CAT) System that will be fielded to defend high-value platforms from incoming enemy torpedoes. After the *USS Cole* attack, DYSMAS was used to support the development of weapon concepts to engage and destroy swarms of small boats, a very real threat scenario in the Persian Gulf. DYSMAS currently is being used to assess warhead concepts for next-generation Anti-Submarine Warfare torpedoes, especially in the context of small warheads that can be launched from the air or from undersea autonomous vehicles.

DYSMAS supports amphibious warfare and mine countermeasure programs. It predicted the ballistic penetration of air-released darts through water and sand, determining their ability to neutralize mines in the surf zone. To help Marines prepare for amphibious landings, DYSMAS was used to assess the effectiveness of air-dropped explosive ordnance for obstacle clearance, calculating the trajectories of anti-access obstacles in response to bomb blasts. It currently is being used to assess the vulnerability of moored contact mines to explosions, supporting development of a new mine-countermeasure system.

Another major use of DYSMAS is the protection of U.S. naval forces. Underwater threats to U.S. forces are increasing continuously. Foreign defense contractors estimate that foreign



Above: Indian Head personnel measure the diameter of a blast crater from a replicated IED.
Right: This screenshot from a computer simulation graphs the extent of a blast crater.

torpedo effectiveness has doubled in the past decade, largely due to Russian research and development. Furthermore, 60 foreign navies possess an estimated 1 million sea mines, with more than 300 types; some look like rocks, making them hard to find, and some move, making them hard to neutralize.

DYSMAS is used to assess the vulnerability of new ship designs, including the littoral combat ships and the Zumwalt-class guided missile destroyer, to underwater weapons and to develop protective technologies to improve survivability. It is especially important for new ship missions that require operations in relatively shallow waters, where mines on or near the sea bottom can have additional damaging effects due to the complex blast interaction with the sea bottom. DYSMAS simulations are also improving the design of external structures on vessels to ensure that they are resistant to explosion effects—a concern with increasing numbers of unmanned systems, delivery vehicles and special operations containers.

The full potential of DYSMAS in naval systems development is still being explored. There is potential for DYSMAS to aid in the maturation of ship design beyond the well-established paradigm of using historical data, experimental testing and redesign before the construction process. This capability is being explored for ship survivability applications under the Computational Research & Engineering Acquisition Tools & Environments (CREATE) program sponsored by the Department of Defense High Performance Computing Modernization Office. The CREATE program leverages DYSMAS for the blast physics, fluid dynamics and unique fluid-structure interaction-coupling technology, and leverages the Department of Energy's structural solver codes that have been enhanced for Navy ship-design applications.

Predicting Weapons Effects in Land War

In Iraq, the Marines encountered urban combat that required a novel solution. Insurgent-held buildings were dangerous and difficult to clear, so a portable standoff weapon

Computer simulations reduce the need to conduct real-world tests of explosives, saving money and lessening the environmental impact.

capable of defeating these targets was requested. Indian Head researchers assisted in development of the "novel explosive," or NE, warhead for the Shoulder-launched Multipurpose Assault Weapon (SMAW). The NE warhead produces pressures capable of leveling the intended target. DYSMAS was used to analyze the mechanical behavior of the warhead during penetration, leading to important fuze design modifications.

The punishing effects of improvised explosive devices (IEDs) used against U.S. forces in Iraq and Afghanistan are well documented. Mitigating the IED threat was critical, but the IED signature in Afghanistan differed from that encountered in Iraq. Those in Afghanistan typically use fertilizer-based "homemade" explosives, or HMEs. Researchers at Indian Head performed tests to quantify HME explosion output and provided the data required to develop a computational model of the HME. Once developed, the HME model was validated by both Indian Head and Army researchers for use in DYSMAS and other software packages.

Despite an in-depth understanding of IEDs, efforts to detect IEDs before detonation, and the development of under-body kits and blast-mitigating seats, IED blasts continue to be a major source of casualties today. Better solutions are needed, and modeling and simulation continues to play an important role in the development and assessment process.

In collaboration with Army and Navy researchers, the DYSMAS team is supporting this work. DYSMAS is being enhanced to do a better job of modeling soils and the loading that a buried blast transmits to a vehicle and its occupants—a difficult and complex problem given the wide range of soils and emplacement conditions that must be considered. DYSMAS also has been used to assess mine-rollers for Marine Corps vehicles and, recently, to study blast-induced traumatic brain injury. The goal is to understand the biomechanical response of the brain, enabling the development of protective technologies.

Predicting Weapons Effects to Protect the Homeland

Dams are designated as critical infrastructure in the United States. They are important national assets that provide water, power and flood-control to many Americans; but dams also hold back tremendous amounts of potential energy that, if released, can have devastating consequences. It is reported that terrorists and criminal organizations have targeted dams for attack.

To assist in addressing these threats, Indian Head researchers are collaborating with other government agencies to assess the vulnerability of dams to terrorist attack and to develop mitigation technologies. DYSMAS is the tool of choice for these studies, which include cratering of earthen dams and blast effects against arch dams and spillway gates.

DYSMAS has been useful in assessing other critical infrastructure, including that found in and around harbors and other waterways. Many pipelines, carrying energy supplies such as oil and gas, transit harbors and waterways on the sea floor. A major problem for explosive ordnance disposal (EOD) operations lies in assessing the risk to such assets when threats are found. DYSMAS has supported the EOD mission by analyzing the hazards to pipelines and enabling the development of safe standoff guidance for EOD operations. In related studies, DYSMAS has been used to assess the vulnerability of bridges and dry docks to explosions.

IED blasts continue to be a major source of casualties today. Better solutions are needed, and modeling and simulation continues to play an important role in the development and assessment process.

The Need, the Future

DYSMAS is a powerful tool for computing the effects of weapons—from torpedoes to IEDs—on a variety of structures—from ships to dams. The DYSMAS predictive capability is a unique asset within the Department of Defense. It provides the United States a strategic advantage on the battlefield and allows for the protection of citizens and infrastructure at home, preserving lives and the American way of life.

To retain this advantage the Navy should maintain a robust investment in the development, enhancement and support of DYSMAS. "By 2025, precision-guided weapons will be the norm among our adversaries," stated Chief of Naval Operations Admiral Jonathan W. Greenert in a 2011 U.S. Naval Institute publication. Naval weapons will likely include smart mines, super-cavitating torpedoes, armed unmanned systems and more. If these assertions are correct, weapons will become smarter, faster and more autonomous. The need to assess the effectiveness of future weapons will only increase. This need is equally important for homeland security. Domestic terror threats are real, and the need to understand infrastructure vulnerability remains a critical requirement.

In this age of dwindling budgets and environmental concerns, modeling and simulation will only grow as a critical part of this process. Testing is necessary, but is often expensive and can be harmful to the environment. Echoing the original goal from the 1980s, the objective will be to computationally assess systems in order to greatly reduce the physical testing needed—saving time, money, personnel and the environment.

This means investing in methods development while supporting users and pushing forward software validation. As this article is written, the United States and Germany are finalizing a fourth international project agreement to continue software development and validation. Strong collaborations have been established with U.S. Army and homeland security programs. DYSMAS currently supports 170 users throughout the United States, and that cadre is growing as new applications are added.

Today, DYSMAS stands as the most extensively validated modeling and simulation tool for predicting the effects of undersea weapons on naval platforms. Pushing beyond the undersea boundary, it has found successful application in air-blast, buried-blast and even traumatic brain-injury applications. It affects the defense research, development and acquisition communities, as well as the homeland security community. In the future, it can also inform the intelligence and targeting communities, by helping analysts understand threats, and even contribute to manuals on joint munitions effectiveness, by informing targeteers and weapons operators.

The DYSMAS team is supporting the programs of today and pushing forward the technology development and validation that will make the programs of tomorrow successful. In DYSMAS, the United States has a government-owned modeling and simulation tool that is unique and critical to the nation's defense. It is itself a piece of critical technology that provides a strategic advantage today and, with sustained investment, will continue to give the United States a strategic advantage for years to come.

The authors can be contacted at **john.hendershot@navy.mil** *and* **robert.kaczmarek@navy.mil**.