Meeting Challenges Across Defense and Beyond

Energetics R&D in Systems Engineering

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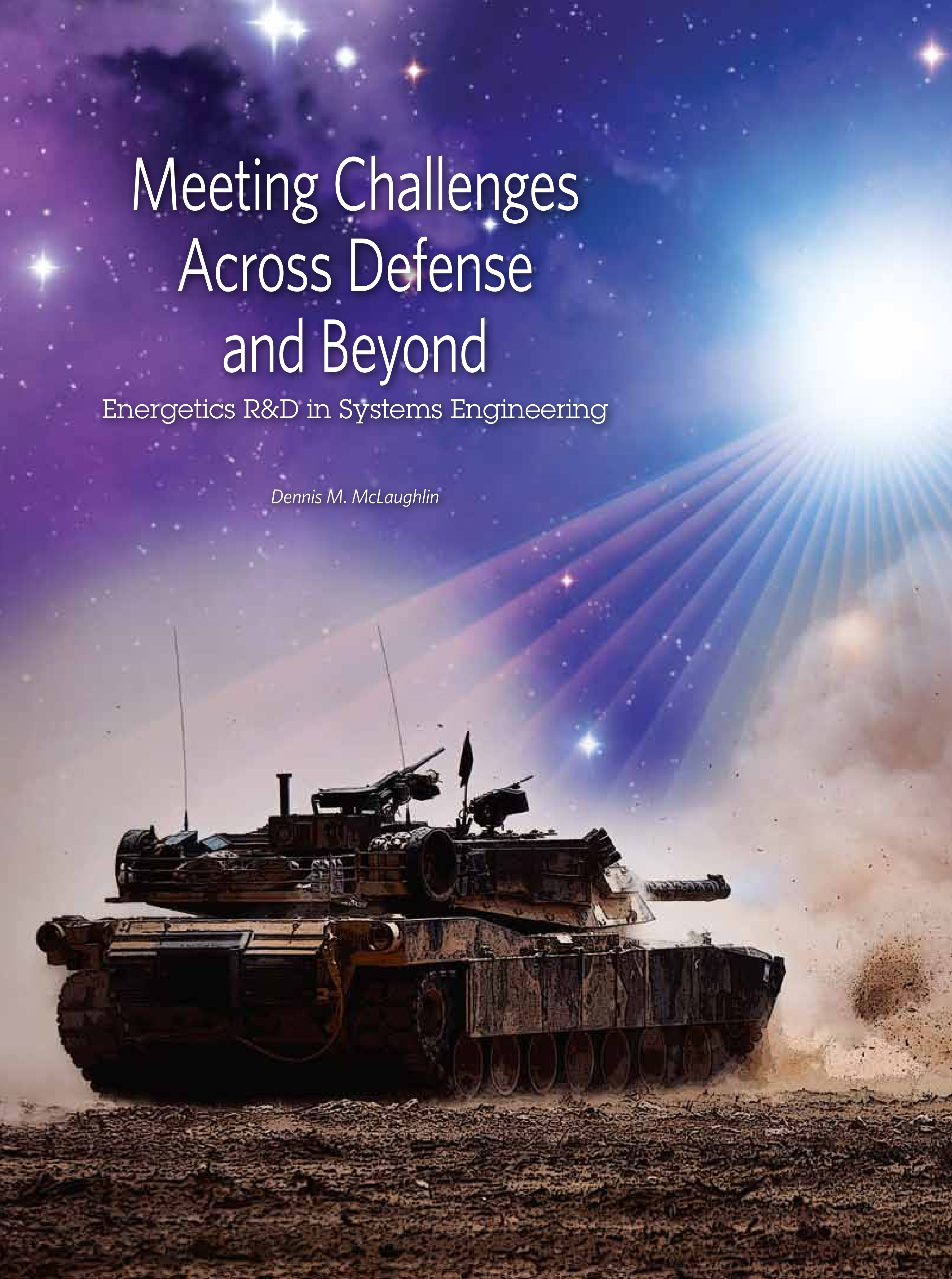

When U.S. Marine M1A1 tanks advanced on Basrah International Airport on March 21, 2003, the defending Iraqi T-55 tanks didn't have a chance. The U.S. tank was built to outrange opposing armor. It is enabled by a high-density, chemical propellant. Each grain is uniform, with measured holes, allowing more surface combustion, and energy release. A 120mm cannon, built for high pressures, focuses this energy, propelling a round down range.

At the center of the M1A1 tank's design was energetics R&D—the study and use of materials for explosives, propellants, and pyrotechnics. It was part of a systems engineering process that made U.S. weapons unequalled in war. In the Cold War's aftermath, this process became less focused and this R&D became an afterthought. Today, energetics R&D, integral to a systems engineering process, is needed more than before—and not just for developing munitions. Tomorrow, it will be vital to helping America meet a multitude of challenges.

It bears reminding that one of the core functions of the U.S. military is to fire on targets. For more than a century, energetics R&D helped do just that. From R&D, begun before World War II, came deck-piercing bombs that destroyed enemy ships at Midway; Naval gunfire that devastated beach defenses enabling amphibious assaults; and antiaircraft rounds with proximity fuses so lethal that the Japanese adopted kamikaze tactics.

Energetics scientists and engineers were part of a process. In developing such munitions, they worked with developers of guns, ships, and aircraft delivering them. And in the late 1940s, systems engineering emerged. It brought all key players together to design more complex systems, like missiles, with energetics R&D taking center stage. It developed a grain propellant—a hardened aluminum and gum slurry mix—for Polaris missiles, transforming submarines into strategic-launch platforms. Across defense, this R&D developed warheads, propellants, and fuses around which other missiles and launch platforms were built, ushering in the "missile age."

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But in the 1990s, "the practice of systems engineering became increasingly fragmented within DoD," according to Defense Acquisition University's Mary Redshaw. It was not guided by military standards, but by "proliferating industry standards, process improvement frameworks, and organization specific guides and handbooks." And energetics R&D in weapons development occurred on a fragmented, rather than systematic, basis. Too often, it was an afterthought, providing the explosive "goo" in a weapon after development, as one defense official put it.

Energetics R&D, in a sound systems engineering process, is needed more than ever before. This approach is critical to meeting many combatant commanders' urgent operational needs. It will be vital to achieving future capabilities, such as those prescribed in joint operating and integrating concepts, guiding force development over 8–20 years. In just three—Major Combat Operations, Global Strike, and Joint Urban Operations—this R&D is directly relevant to 100 future capabilities and indirectly to more.

Increasingly Wanted: Specialized Munitions—Fast

In 2006, U.S. Central Command had an urgent need. It sought a low-collateral damage munition for use against insurgents, engaging coalition forces, from positions near schools, hospitals, and religious buildings in Iraq and Afghanistan. The need demanded that Air Force energetics experts help reengineer the small diameter bomb system. They developed a multiphase blast explosive. A composite carbon fiber case was also developed. The result was the focused lethality munition, with a more intense and lethal near-field blast but less fragmentation.

That's just one of the many specialized munitions warfighters have sought in recent years. Increasingly, warfighters want weapons that do more, go more places, and go further. That's especially the case with target effects. Traditionally, munitions were designed mostly for the destruction of personnel, vehicles, and structures. Today, warfighters need such tailored target effects as:

- Increasingly less collateral damage
- Greater and more visible target destruction
- Destruction of increasingly hardened targets
- Shoulder-launched weapons that can take down a building
- Controlled kinetic energy for non-lethal projectile delivery
- Direct fire, multipurpose munitions with programmable target effects
- Reduced environmental impacts
- Destruction of in-flight missiles and rockets
- Destruction of chemical and biological agent storage facilities without dispersing agents

And warfighters need these specialized munitions fast, requiring all systems engineering aspects present at creation. The focused lethality munition went from concept to delivery in 18 months. For the thermobaric munition, designed to attack insurgents in deep, winding caves, it was 67 days.

Achieving such specialized target effects requires energetics experts, informing systems engineering. They must analyze the target and develop energetic materials for intended effects. For example, naval energetics experts determined that high explosives cannot destroy stored biological agents. High explosives lack the heat to burn off biological agents, and shock pressures can disperse any remaining agents. Thus, they developed an effective agent-defeat munition that produces flame temperatures above 6,000 degrees F for minutes. The munition was then engineered for air delivery.

Munitions for extreme environments also demand specialized energetics R&D. "The option to deploy weapons in space," proposed by the 2001 U.S. Space Commission and others, would need unique conventional explosives and propellants. The Navy's Anti-Submarine Warfare Concept of Operations for the 21st Century calls for "greater numbers of enemy submarines destroyed per unit of time," requiring undersea weapons that produce specific shock effects, which others try to counter in submarine design. Increasingly deeper and hardened targets require munitions that can survive high-speed delivery temperatures, impact, and sense when to detonate inside structures.

And all want more range—largely a propellant and systems engineering issue. To increase U.S. 81mm mortar ranges for Afghanistan, energetics experts couldn't just add more old propellant. The increased pressure and erosion in the mortar tube would reduce service life. Instead, they formulated a nitramine propellant, producing initially lower, but longer combustion. Therein is the lesson: greater ranges require new propellants and systems that can accommodate them. Now consider the 2010 Quadrennial Defense Review seeks to "Expand future long-range strike."

History, too, must repeat itself. The first bomb dropped by manned aircraft was a grenade. It happened Nov. 1, 1911, in a war between Italy and the Ottoman Empire, when an Italian pilot attacked a Turkish camp in Libya. It marked the start of a developmental quest for aerial bombs and their delivery aircraft.

That must now extend to unmanned systems. To date, existing weapons have been used to arm unmanned systems, such as Hellfire missiles on unmanned aerial systems, and M249 machine guns for unmanned ground systems. However, DoD's FY2009–2034 Unmanned Systems Integrated Roadmap envisions "a proliferation of unmanned systems conducting force application tasks," to include:

- Air-to-air combat and suppression and defeat of enemy air defense
- Dismounted offensive operations, and armed reconnaissance and assault operations

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- Mine laying and mine neutralization missions in the maritime domain.

Being smaller than manned systems, unmanned systems must have smaller, lighter weapons that can punch above their weight. Such weapons will be needed especially for Unmanned Combat Aircraft Systems, planned for suppression/destruction of enemy air defenses and penetrating strikes. Designed as a low-observable, it must carry and launch weapons from inside the aircraft, as carrying them externally will make them more observable. Such weapons will require a concerted energetics R&D and systems engineering effort.

Faster Logistics

Previously, munitions were shipped in a "box in a box," varying in sizes and shapes. Naval energetics engineers designed a "joint modular intermodal container," holding what seven pallets once did, with a uniformity allowing more efficient storage and transfer. The Defense Distribution Depot-Kuwait's first use of the containers reduced container handling by 23 percent in line-haul to Iraq. U.S. Transportation Command's evaluation found the containers reduced air pallet requirements by 32 percent and sorties by 25–50 for C-130s and by 7–14 for C-17s.

Energetics R&D impacts logistics. Working with logistics managers, energetics experts can develop ways to expedite the load. Such was the case with Joint Modular Intermodal Container which was part of a U.S. Transportation Command initiative to speed intermodal transfer. Working with systems engineers, energetics experts can lighten loads, which can help get material to the fight faster. It can also make a difference in how our forces fight.

Navy plans for the future CVN-78 carrier call for an increased sortie rate of 160 aircraft per day, compared to the USS Nimitz's 120. Thus, aircraft must be armed faster. Yet bombs have to move via elevators from below-deck magazines to flight deck "bomb farms," limiting their numbers. The bigger the bombs, the fewer moved in a given period. Smaller yet effective bombs would allow greater numbers to be moved, and thus arming more aircraft in a given period.

Major logistics and warfighting enhancements can come from energetics R&D for the grassroots level of war. In Afghanistan, the Taliban engage from higher terrain, knowing heavier U.S. forces have difficulty moving against them. A U.S. squad assault weapon gunner, for example, carries a 17.5-pound weapon and likely 1,000 rounds, weighing 33.8 pounds. Total load may be 130 pounds. "Added weight and thermal loading make Marines less effective in combat," according to Brig. Gen. Francis Kelley, commander of the Marine Corps Systems Command.

The Army's Lightweight Small Arms Technologies program portends the future. It is testing not only a 9.2-pound squad assault weapon, but also 40 percent lighter and 12 percent smaller polymer cased ammo. For a warfighter, 1,000 polymer-cased rounds weigh 21.7 pounds, a savings of 12.1 pounds. For a brigade combat team, it's estimated that polymer-cased ammo provides a 2-ton weight savings. Similar energetics R&D initiatives could reduce other infantry munitions' sizes and weights, providing significant weight reduction across ground units.

More Than Munitions

In Iraq, Marines used a system that x-rayed large containers, such as 55-gallon drums, to detect improvised explosive devices (IEDs). Wherever found, explosive ordnance teams often dispatched camera-carrying robots that more closely assessed, handled and even neutralized IEDs. On-scene EOD teams could also reach back to a help desk in Indian Head, Md., getting technical assistance on an IED and its possible neutralization. All these were enabled by energetics experts.

Countering explosive threats requires energetics R&D. It can develop detection means, working with intelligence agencies to target threat materials requiring detection. For example, 80 percent of IEDs use certain homemade explosives; this informed energetics experts' development of lightweight kits, which detect these homemade explosives in seconds.

Energetics R&D can also inform intelligence, as well as, systems engineering. To some intelligence analysts, another nation's development of a low-signature propellant may seem

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insignificant, but to energetics experts it means launching missiles will be harder to detect, thus leading to improved detection systems.

And informed by intelligence, energetics R&D can aid in engineering countermeasures, which is part of a deadly and never-ending contest. Modeling of known undersea threat explosions is used in U.S. ship and submarine construction. Knowledge of threat energetics also informed the engineering of ballistic protection for mine resistant ambush protected (MRAP) vehicles, including V-shaped hulls for deflecting blasts.

Today and more so in the future, energetics R&D is needed to develop other countermeasures. That's especially the case with traumatic brain injuries (TBIs); more than 150,000 U.S. military personnel have suffered TBIs since 2000, most caused by blasts. Energetics expertise is informing medical research on blast-induced brain injuries. It also can inform the engineering of vehicle and helmet countermeasures. Energetics experts have already developed tiny, unpowered sensors which could detect blast pressures causing brain injuries. Such detection could allow medical personnel to arrest brain cell death with serums and other means.

Additionally, energetics R&D is needed to develop and engineer detection and countermeasures in homeland security, as well as, defense. Just one example is the "Standoff Technology Integration and Demonstration Program," being conducted by the Department of Homeland Security. It seeks the prevention of explosive attacks at large public gatherings such as conventions and sporting events.

Ready or Not …

Energetics R&D is not static. In its 2004 report, *Advanced Energetic Materials*, the National Academy of Sciences (NAS) stated, "Many emerging technologies show promise for revolutionary changes. Realizing this revolution will not be achieved by energetics R&D working alone or even as afterthought. This revolution will depend on energetics R&D driving systems engineering."

As mentioned, increased ranges may be enabled by advances in propellants such as "high nitrogen compounds" and "azido-energetic thermoplastic elastomer polymers." However, referring to the needs for greater range, lethality and more, the NAS also reported, "Advances in propellants alone cannot meet all of these needs. There must be synergistic design of the barrels, breaches, recoil systems, munitions, and propellants."

The greatest change may come from nanotechnologies, notably "nano-energetics." Still in its early stages, this technology is already among us in devices like the iPod and portends change in almost every industry. It is likely to change warfare as well. Nano-energetic materials, 500 times smaller than a human hair width, will be more powerful than micron-size material, having quicker ignition and larger energy releases. In *The Impact of Nanotechnology Energetics on the Department of Defense by 2035*, Col. Ancel Yarborough, USAF, wrote:

> By 2035 nano-energetics will have advanced to replace current explosive materials and systems designed to deliver them. They will provide the explosive power of current conventional weapons at up to two orders of magnitude less overall mass. Weapons designers will capitalize on the molecular interactions that can be carefully constructed from the bottom up in combustible nano-materials, and a new class of very small, extremely lethal weapon system will emerge.

The race is on for energetic advances. Nations such as France, Germany, and the United Kingdom have ongoing energetics R&D programs and since the 1990's, Russia's program has been especially vibrant. "The number of people doing energetics science and technology in China is at least two orders of magnitude larger than what we have here in the United States," estimated James M. Short at University of Maryland's Center for Energetics Concept Development.

The Greatest Challenge

In the Cold War, energetics R&D, in a systems engineering process, provided U.S. forces with technological advantages. This approach was very focused and when the Soviet threat went away, it became less so. That must change. Today, "this is the Blizzard War," stated Secretary of Defense Leon Panetta, "a blizzard of challenges that draws on speed and intensity from rapidly developing technologies." Energetics R&D in agile systems engineering efforts across DoD and beyond will be key to meeting this blizzard—and America's greatest challenge: uncertainty.

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