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Additive Manufacturing for Canine Training

AIR travelers nowadays are accustomed to the gauntlet of scanners and detectors used by airport security to detect contraband and potentially harmful materials. Yet, for all the sophisticated science and engineering that underpins these extensive security procedures, in one threat category, innate biology consistently outcompetes technology: canines remain unmatched in their ability to detect dangerous substances from the slightest chemical traces.

For law enforcement and security agencies, such as the Transportation Security Administration, detection dogs are no less a strategic investment than metal detectors and x-ray devices. The dogs undergo intensive training to identify specific threats and interact effectively with their handlers. Livermore technology may now help canines and their trainers adapt their preparation to the demands of an evolving threat landscape.

Accept No Substitutes

"I have incredible respect for the people who train detection dogs. You can't imagine how difficult their work is and how much commitment it takes," remarks John Reynolds, a researcher in Livermore's Energetic Materials Center (EMC). Reynolds recently led a project leveraging the Laboratory's expertise in additive manufacturing to equip canine handlers with long-awaited training resources that simulate improvised explosives.

The fundamentals of detection dog training center on learning distinctive "odor pictures" of hazardous materials and pairing these odors with objects that could harbor them. Dogs practice alerting their handlers to the presence of explosives such as black powder, trinitrotoluene (TNT), pentaerythritol tetranitrate (PETN), and cyclotrimethylenetrinitramine (RDX) which are embedded into training objects. Critically, trainers cannot rely on imitation ingredients; otherwise, the dogs might become attuned to substitutes rather than to the actual explosives, which may be almost molecularly identical.

The need for authentic ingredients reveals a fundamental challenge: how can training aids utilize real-life explosive materials while remaining safe to handle during exercises? Livermore has approached this issue before. In fact, the Laboratory boasts a decades-long relationship with canine training. Thirty years ago, Livermore pioneered and patented a collection of nonhazardous explosives security testing and training (NESTT) resources, which are now commercially available as silica beads or wax suspensions containing low-concentration explosives that simulate real threats. While NESTT resources significantly broadened the range of available training aids, the technology could not account for improvised explosives—binary mixtures of reagents that are innocuous when separate but devastating when combined. This breed of explosives proliferated in the second half of the 20th century and has since been employed in multiple terror attacks on U.S. soil.

Alex Gash, deputy director of EMC, explains that the two-part formulation is precisely what makes training for the binary substances characteristic of improvised explosives more difficult than training for monomolecular explosives (TNT, RDX, and PETN). In binary mixtures, the oxidizer and fuel remain separated until use, meaning the dog is seeking an uncombined pairing rather than simple individual ingredients. “Homemade, mixed explosives are a signature of asymmetric nonstate actors,” says Gash. “Their ingredients are everyday materials such as honey, flour, and plastics—things that can hardly be regulated,” says Gash. Both ingredients must be present to properly train a dog, but placing them close together during exercises runs the risk of chemical reaction.

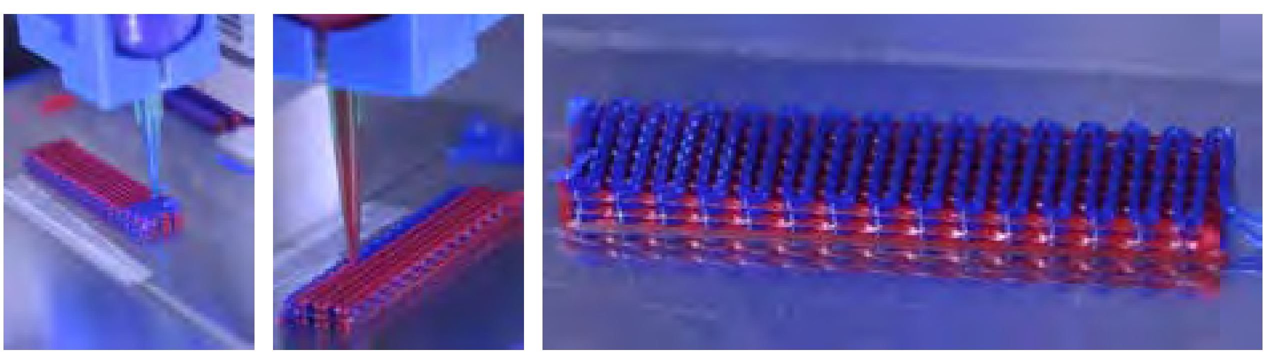
Lawrence Livermore’s relationship with explosives-detecting canines goes back decades. For example, in this on-site training in the 1980s, a trainee participates in a bomb-sniffing exercise with an officer from the University of California Police Department (the security force for the Laboratory at the time).

Taking the Lead

While explosives usage has changed since the introduction of NESTT aids, so too has Livermore technology, especially regarding additive-manufacturing capabilities. The Laboratory boasts one of the world’s only facilities that 3D prints explosives. The process precisely deposits layer upon layer of an explosives-laden substrate into nearly any shape. With 3D printing, the reactive ingredients of binary mixtures can be juxtaposed without risking ignition, making the printed products useful to dog trainers who are not certified to handle these explosives. The training aids can also be infused with chemical signatures and can take on diverse shapes to mimic cell phones and other objects known to be incorporated into improvised explosive devices.

The innovative approach safely alternates between layers of fuel and oxidizer. A serpentine extrusion path minimizes surface contact between the reagents, which, already below 10 percent concentration by mass, pose no danger of interaction. Altering the substrate material and the type of embedded explosive allows the process to provide a range of training resources. Gash explains, “When it comes to monomolecular explosives, we’re limited to the chemical formulation that nature gives us, meaning not all substances can be safely inserted into training aids. Additive manufacturing is a game changer because we

3D printing can deposit alternating layers of oxidizer and fuel to produce an inert training aid embedded with explosive substances.



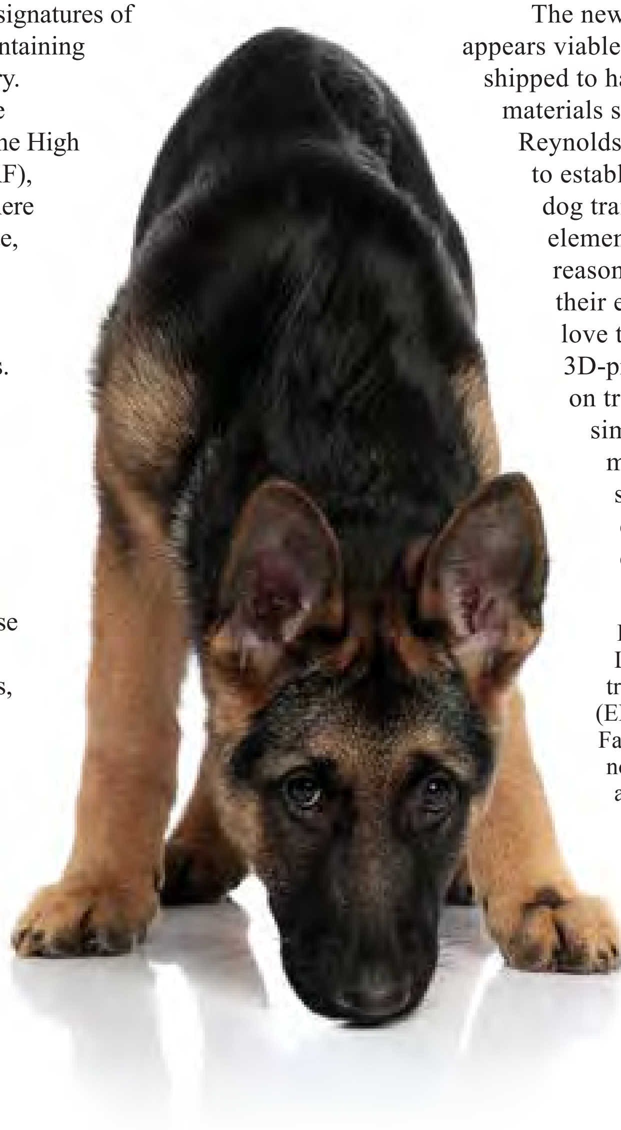
can now modify compositions and oxidizer-to-fuel ratios as we see fit to safely cover a broader spectrum of threats."

As proof of concept, researchers printed a prototype training aid using a silicone-based substrate embedded with the explosive octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX). After material extrusion, the curing process hardens the structure and removes contaminating odors given off by the substrate. "The aid produces very few volatiles as it is; eventually, we would like to use water-based ceramic ink because these materials have no vapor pressure," Gash says. Reynolds explains that eliminating volatiles is key. "If a dog smells both the TNT *and* the substrate material, which forms the bulk of the training aid, it must learn to isolate the material of interest." A dog may be able to detect the explosive perfectly well, but if confused by other distracting scents, it may not successfully recover the target. With minimal distracting aromas, dogs should avoid entangling the chemical signatures of explosives with traces of the object containing them, thus improving rates of discovery.

Training aid development was made possible by the unique capabilities of the High Explosives Applications Facility (HEAF), the research and fabrication facility where EMC scientists like Reynolds formulate, synthesize, and test explosives in a controlled environment. "Explosives are handled differently than any other substance in the world," says Reynolds. "Our work requires an extraordinary number of people from a range of disciplines to be safely carried out."

HEAF boasts fortified firing tanks, high-fidelity x-ray diagnostics, and powerful computers for running simulations, although printing the canine training aids required less intense procedures than the facility's usual, more potent experiments. "Nonetheless, even though the substances we use are at low concentration, we're still dealing with raw, reactive materials," Gash says. The printing process relied on expertise from the Additive Manufacturing Laboratory, which excels in 3D printing plastics, clays, and ceramics—each a medium that can imitate known threats. Ultimately, development of the training aids was relatively inexpensive because it paired an established institutional capability with a new use case.

3D-printed training aids can contain HMX explosives in a silicone-based material. The object will harden during curing, which also minimizes traces of volatiles. This sample has a dog-bone shape only as a proof of concept.



The new application of additive manufacturing appears viable. The training aids can be safely shipped to handlers, who also can transport the materials safely through airports. But first, notes Reynolds, potential manufacturers will need to establish rapport with trainers. "Detection dog trainers are hesitant to introduce new elements into their programs, and for good reason: they want to avoid interruptions to their established routine," he says. "What I'd love to see next is further study involving 3D-printed training aids and their impact on training outcomes." By providing safe simulants for binary explosives, Livermore manufacturing technology could provide security professionals and their canine colleagues the resources necessary to combat emerging security challenges.

—Elliot Jaffe

Key Words: Additive Manufacturing Laboratory, bomb detection, canine training, Energetic Materials Center (EMC), High Explosives Applications Facility (HEAF), improvised explosive, nonhazardous explosives for security training and testing (NESTT), Transportation Security Administration, 3D printing.

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