THE CENTER FOR CLIMATE AND SECURITY

BRIEFER

No. 22 | January 27, 2014

The U.S. Military, 3D Printing, and a Climate Secure Future

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"We can't solve problems by using the same kind of thinking we used when we created them." - Albert Einstein

The United States military has a long history of developing innovative technologies for improving war-fighting that are eventually repurposed for civilian life. This includes society-altering technologies like the computer and the Global Positioning System (GPS). As an institution with the capacity to assess long-term risks, and develop technologies to address those risks, the U.S. military is uniquely placed to lead in this arena. Today, we are faced with a new set of critical non-traditional security threats. And true to form, provided that fiscal constraints do not get in the way, the U.S. military is once again leading the way in developing critical new technologies to meet them.

One of those new technologies is additive manufacturing (or 3D printing), and one of those non-traditional risks is climate change. 3D printing, a manufacturing process that prints three-dimensional solid objects directly from a digital plan, offers the potential for rapid, cost-effective, high quality, complex and *on-site* manufacturing. As we have stated before, scaled-up and improved upon, 3D printing has the potential to "combine the solidity, durability and strength of the industrial age, with the nimbleness, flexibility and adaptability of the virtual age." This mix will be critical for addressing the complex challenges of a rapidly changing and uncertain world – not the least of which are the security risks of climate change.

While the U.S. military is developing and expanding 3D printing to enhance the security and operational effectiveness of the armed forces in the mountains of Afghanistan, these technologies could ultimately help places ranging from cities across America, to the beaches of the Philippines and the deserts of Mali, prepare for and respond to the significant increase in climate-induced natural disasters that we are already seeing, and will continue to see, throughout this century.

Why the U.S. Military Is Interested in 3D Printing

For the U.S. military, 3D printing helps overcome traditional time and space limitations to war fighting, and can dramatically improve operational effectiveness. It allows designers and engineers to rapidly print out exactly the part a military unit needs, and on the spot. In a world of evolving transnational security risks, from international terrorism to climate and water insecurity, such flexibility will be critical for the armed forces. At this stage, 3D printing essentially helps elevate the self-sufficiency and resiliency of the U.S. military by introducing three key benefits**:** resolving equipment problems quickly and efficiently, reduc-

ing resupply demands, and building better, stronger more complex and efficient designs.

First, if a piece of equipment breaks, 3D printers can give service members the ability to simply print the replacement part *in situ*, in a matter of minutes or hours. Without 3D printers, such a replacement could take weeks or months. In remote Forward Operating Bases (FOBs) in the mountains of eastern Afghanistan, this could mean the difference between life and death for either the troops in need of new supplies, or troops carrying those supplies through hostile territory. If, on the other hand, equipment is functioning but lacking in its ability to address specific needs on the ground, 3D printers can make it easy for field engineers to rapidly prototype customized equipment that might otherwise take years to develop in a lab. In battle, or in response to a disaster, quickly fixing a piece of equipment, or improving equipment on the spot, has the potential to dramatically improve the U.S. military's capabilities.

Second, 3D printing has the potential to reduce resupply demands. Storing supplies and equipment takes up space – a valuable commodity, especially out in the ocean on a naval vessel, or in a small FOB in a remote area. 3D printing reduces that storage burden. Instead of filling a ship up with thousands of what the U.S. Navy calls "medium-failure rate items," bringing along 3D printers gives military units the ability to print parts on demand - when they need them, where they need them, and how they need them. Given this ability to "resupply on demand," 3D printers could also dramatically reduce the amount of time and energy spent on resupply missions. For a military that needs to be ready to deploy globally, and with speed and efficiency, this is a key benefit.

Third, 3D printing opens up the opportunity to build more resilient and efficient designs for military equipment, including electronics, training models, weapon components, and even entire vehicles. For an institution with such a large fleet, and a wide range of terrain to operate in, these innovations will improve operational effectiveness, save lives and reduce costs.

How U.S. Military Demand for 3D Printing is Being Met

While the U.S. military is still in the early stages of exploiting this new technology, significant advances are already being made, with important implications for war-fighting, disaster risk reduction, and addressing transnational security risks like climate change.

A powerful example is the U.S. Army's Rapid Equipping Force (REF), which currently deploys an "Expeditionary Lab - Mobile" in Afghanistan. The Lab is a 20ft shipping container that was converted into a space equipped with 3D printers and other tools along with access to engineers, scientists and a wireless support network of experts to give troops the equipment and support they need to develop quick, on-the-ground solutions to equipment problems.

The Lab has performed in theater to help military units adapt to their environment quickly and efficiently. For example, troops in Afghanistan have utilized 3D printers in the Lab to adapt to extreme heat. According to Colonel Peter Newell, former Director of the REF: "the 54 °C heat in Afghanistan was playing havoc with the batteries in a ground-penetrating radar system used to search for mines, so soldiers used the 3D printer to make a shielding case to protect them. It worked so well that everyone wanted one..." Importantly, these mobile units can be utilized not just for combat missions, but also for critical disaster relief operations. To add to this capability, the Army recently launched Army CoCreate, a crowdsourcing website where "anyone can identify problems facing the Army, design a prototype solution and upload it."

Freed from the constraints of traditional manufacturing, 3D printing has also given innovators in the armed services the flexibility they need to solve problems, the benefits of which extend well beyond the armed forces. As reported in Stars and Stripes Magazine, the Walter Reed National Military Medical Center employs 3D printers to "scan a service member's wound and produce everything from custom titanium cranial plates to custom prosthetics that used to be fabricated by hand and almost always had to be whittled down because the fit wasn't quite right." According to Navy Captain Gerald Grant,"…Now we sit around and ask, 'What do we want these pieces to do?' instead of 'What kinds of pieces can companies build?'"

What the Future Holds for the U.S. Military and 3D Printing

For the foreseeable future, 3D printing will not replace the economies of scale associated with mass production. At this point in time, it is estimated that 3-D printing is only operating at about 1-2% of its potential. But non-traditional security risks are not going away, and there are encouraging signs of progress – with the U.S. military at the forefront of technological innovation.

Last May, President Obama announced three "new manufacturing innovation institutes," which will include a heavy emphasis on 3D printing. According to the U.S. Department of Energy, "the Department of Defense will lead two of the new Institutes, focused on "Digital Manufacturing and Design Innovation" and "Lightweight and Modern Metals Manufacturing", and the Department of Energy will be leading one new institute on "Next Generation Power Electronics Manufacturing."

The U.S. Army is also working on new "segmented structures" - easily repairable with 3D printed solutions – which should be available in the near-term. According to GCN, "The segmented structures the lab is working on would be highly resistant to damage. Vehicles and airplanes made of them would be more resistant to heat, cracks caused by constant vibration and combat damage…Once any of that damage does occur, a soldier could then diagnose the problem and use 3D printing to create replacement parts." On the battlefield, innovative uses of local materials may also soon be possible with 3D printing. For example, researchers have developed a system for printing entire structures on a "beachhead or forward operating base," with the capacity to even "print glass objects from desert sand." It almost goes without saying that this would be a useful tool in either a desert environment, or in a disaster relief mission on a typhoon-wracked beach.

The U.S. Navy is also foreseeing the benefits of 3D printing on the near-term horizon. For example, it may soon be in a position to build types of ships that were simply impossible before, and with fewer parts. As reported in the U.S. Naval Institute's *Proceedings Magazine*, "Senior mechanical engineer Peter Schmehl of MakerBot, a leading producer of desktop 3D printers, says he believes this process [3D printing] has the potential to "radically change ship construction, making designs that might not be possible using conventional techniques."

The national security benefits of 3D printing are not just future projections – they are already being recognized and acted upon, even if on a limited scale. And as the climate continues to change, it is likely that the U.S. military will be called upon more and more often to rapidly respond to natural disasters. In such a world, 3D printing may be an essential capability for the military, as well as society at large.

How the U.S. Military's 3D Printing Experience Can Help Address Climate Risks

The use of 3D technologies by the U.S. military for improving war-fighting has significant transferable potential for use in disaster preparedness and response, including for disaster relief and other operations related to climate-related events and natural disasters. This is especially the case as the U.S. military is often at the forefront of such missions.

As with technological innovation, the military is already leading the way in recognizing and preparing for the security risks associated with climate change. Among other actions, the threat of climate change was explicitly addressed in the 2010 Quadrennial Defense Review, the U.S. Navy hosts a Task Force Climate Change, and current Secretary of Defense Chuck Hagel cited the increased risks of climate change in a recent speech at the Halifax International Security Conference. The main preoccupation is that climate change may act as an "accelerant of instability," exacerbating others drivers of unrest such as water, food and energy insecurity.

But while the security risks that emanate from climate change will not always require military responses, the technological innovations that 3D printing makes possible can significantly improve the tools available for militaries and civilian institutions when responding to, and preparing for, those risks associated with a changing climate. These benefits come in five main forms.

Rapid Response & Rapid Prototyping. The nimbleness of the U.S. military's disaster response operations, in coordination with civilian institutions, can be inhibited by the availability and suit-

ability of supplies. For example, aid agencies keep storerooms full of supplies that then have to be shipped to disaster zones, sometimes thousands of miles away. That takes time, and supplies are not always perfectly-suited to precise conditions on the ground. Just as the U.S. military has utilized 3D printing to resolve battery failures in extreme heat – a problem with potentially fatal consequences - the quick production of supplies and prototypes to address the challenges of a specific disaster-response scenario could save lives and money. In the future, printers could even potentially use a variety of disaster debris to print temporary shelters for peoples displaced by a hurricane or typhoon. The possibilities are nearly endless.

Democratization of Preparedness & Response. The U.S. military uses its own support network of engineers and experts to help with 3D printing design and development. People across the world who are vulnerable to the risks associated with climate change do not currently have that capability. In this context, encouraging the development of 3D printing in vulnerable nations, and opening up networks of engineer experts to at-risk communities, could help advance resilience in fragile places and open up new markets. Indeed, social media has set a precedent for encouraging the popularization of technologies in the service of promoting both justice and security (see the role of independent blogger Brown Moses in confirming the use of chemical weapons by the al-Assad regime in Syria). Moving along this path of "open innovation" could also alleviate local capacity deficiencies.

By encouraging open source 3D printing, solutions could essentially be sourced globally, and printed locally. This would open up the possibility of citizens quickly uploading solutions developed for similar situations thousands of miles away, and tweaking the designs to suit local conditions. A community anticipating or experiencing climate threats could present their concerns to an online global platform, where experts could quickly offer a solution or even transfer "ready-to-print" technological solutions. Mobile labs, like the U.S. Army's aforementioned Expeditionary Lab-Mobile, could also be more broadly deployed to "print" location-specific parts, to fix a broken water pump handle, print a climate-resilient shelter or meet other infrastructure needs when parts or specialized engineers are not locally available.

De-globalizing Hazards. 3D printing can also help mitigate the "globalization of hazards," wherein a climate or environmental hazard in one place can have a significant impact on security thousands of miles away. For example, a tsunami in 2011 flooded factories in Japan that were the only ones in the world manufacturing specific car parts. This meant that Honda factories in the United States screeched to a halt. With 3D printing, the ability to cheaply and easily download and print the missing parts could buffer downline manufacturers from unexpected breaks in the supply chain. Just as the U.S. military is currently utilizing 3D printing to enhance the resilience of its own supply chain, the private sector would benefit as well.

But the effects of such natural disasters extend far beyond individual companies. In 2012, a severe drought leading to low water levels temporarily halted the transport of goods down the Mississippi, affecting the entire region. This is the type of problem we may see more of in a climate-changing world. The ability to print goods where they are needed would clearly decrease our vulnerability to droughts, and other disruptive weather events. Essentially, 3D printing could help de-globalize climate-related hazards, and enhance the resiliency of global and local markets to climate shocks.

Increasing Accessibility. There remain places in the world that are very difficult to get to. These places may be characterized by remoteness, conflict, disaster or government hostility. This imperviousness will not, however, stop the impacts of climate change. In this context, 3D printing can act as the 21st century version of the Berlin airlift. But instead of dropping supplies from airplanes, 3D technology can be deployed for printing those supplies (and perhaps even printing the delivery mechanisms for those supplies, when there are no printers on the ground – including printing more printers)! This could be particularly effective for disaster risk reduction or post-disaster assistance in inaccessible areas, such as some of the world's most fragile and conflict-ridden states.

The U.S. military, for example, already has the capability to print unmanned aerial vehicles (i.e. drones), which have proven to be very helpful in search and rescue missions, as well as environmental monitoring and disaster relief. And as mentioned above, the technology might even allow

places isolated from the international community to print shelters built to withstand location-specific environmental stresses. In places that are particularly vulnerable, this capability could provide an important lifeline.

*Enhancing Energy Efficiency***.** 3D printing could also help increase the energy efficiency of the U.S. military (with important implications for operational effectiveness and resupply mission casualties), reduce its carbon footprint, and set an example for the broader economy. 3D printing is inherently energy efficient. According to the U.S. Department of Energy, additive manufacturing on average uses 50% less energy and saves up to 90% on materials costs compared to traditional manufacturing. Because 3D printing is additive rather than subtractive, the printer prints out only the desired product and minimal support structures, greatly reducing the amount of materials used, and significantly reducing the energy required to manufacture the product. And since additive manufacturing involves sending data around the world via the internet, rather than sending physical materials around the world on trucks, ships and planes, shipping, packaging and storage is reduced significantly, dramatically reducing energy use.

The ability to cheaply print complex designs also leads to more efficient designs and products, which reduces the "footprint" throughout its production and lifespan, often strengthening the object in the process (see for example this formula one race car). Should 3D printing spread beyond its current limited niche, the ability to print replacement parts (with recycled materials) rather than buy new products could contribute to a dramatic reduction in waste and greenhouse gas emissions.

3D Printing is a Fiscally Responsible Pathway

Finally, an important aspect of 3D printing is that it has the potential to increase cost effectiveness. Along with other government entities, the U.S. Department of Defense is facing steep budget cuts, and disaster response efforts are almost always under-resourced. Having a network of experts that can help guide innovative and rapid solutions to problems thousands of miles away will be an added value under such constraints, and maintaining the capacity to print supplies and equipment to meet specific needs tailored to specific situations, rather than relying on costly mass production, might help alleviate the pain of such cuts. According to Chris Anderson, 3D printing is revolutionary because it "takes the expensive parts of traditional manufacturing, and makes them cheap." And since the costs of preparing for and mitigating climate change risks are estimated to be prohibitively high, cost-effective solutions like 3D printing could be of immense utility in a world of increased fiscal constraints.

U.S. Military Investments in 3D Printing Can Help Improve National Security, Reduce Climate Risks, and Enhance U.S. Leadership

As with all disruptive technological advancements throughout history, 3D printing is not without its risks. For example, the U.S. Congress has already banned the printing of guns. But the opportunities are much greater. 3D printing could entirely upend the traditional manufacturing paradigm, leading to increased manufacturing in the United States, and communities that are more resilient to future risks – climate-related and otherwise. The steps the United States has already taken to advance these technologies are promising, but will need to be defended.

The U.S. military's investment in, promotion and use of 3D technologies, if maintained, supported and advanced, could lay the groundwork for society-wide adoption, and U.S. leadership in the field. In the face of unprecedented transnational security risks - climate change included – U.S. leadership is exactly what the nation and the world could use. Though most of us don't know it yet, 3D printing has the potential to be one of the most transformative technologies since the advent of the personal computer. This technology could revolutionize the way we live in the present, and adapt to the future. It could help us address the unique and existential risks of the 21st century, such as climate change, and usher in a new era of resilience.

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