Paradigm Shift

Additive Manufacturing and the New Way of War

Brett P. Conner

The attributes of additive manufacturing (AM) enable tremendous value for the Department of Defense (DoD). In order to take advantage of those attributes, the DoD must actively pivot away from the acquisition, logistics, sustainment and contracting practices developed from more than 100 years of experiences in utilizing conventional manufacturing processes from the Industrial Revolution. To understand why, we first need to examine what the Industrial Revolution gave us.

The Industrial Revolution resulted in a manufacturing framework predicated on the centralization of manufacturing in a facility called the factory. The factory is located ideally where desired labor skill can be found at reasonable cost, where energy and material costs are low and where transportation is available nearby. Inside the factory, the manufacturer will invest tens of millions of dollars to obtain specialized equipment. This equipment will use tooling to shape or assemble input material into a product. This tooling can cost tens of thousands or hundreds of thousands of dollars (or more) and take weeks or months to produce resulting in significant lead times. At times, the lengthy contracting process can be overlooked as the long lead times associated with tooling dominate production schedules.

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In the civilian commercial sector, mass manufacturing permits the cost of tooling and specialized manufacturing equipment to be amortized over the unit costs of hundreds of thousands or millions of an individual part or product. In the defense sector, most parts, assemblies and systems are produced in low enough quantities such that the cost of capital and tooling are a significant component of the unit cost. Design functionality is sacrificed to keep costs low: Simple parts are easier to make. Once a product design has been selected and tooling has been obtained, a change in design becomes too expensive to consider. As a result, customization is rare, and standardization is, well, standard.

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Once production starts, a typical approach is to fabricate sufficient quantities of parts for the production run of the weapon system as well as an additional quantity to satisfy a requirement for spare parts. This leads to a warehousing cost associated with storage of those spare parts. Both the factory and the warehouse for spare parts usually are distant from the war. Therefore, the "Iron Mountain" of spare parts must be moved into theater at the start of an operation, replenished during the duration of the operation, and returned to the warehouse at the end of operation.

Pivoting to AM's New Paradigm

Contrast conventional manufacturing with AM. To start production, AM does not require the tooling, fixtures or jigs typically associated with conventional manufacturing. All that is needed is a three-dimensional (3D) digital solid model that can be converted into a 3D printable file format such as .STL or .3MF. Computer-aided drawing (CAD) is used to create the file. However, 3D scanning can be used to reverse engineer an existing part. Regardless of how it is obtained, the part file then is provided to a 3D printer's processing software where the user orients the part and chooses the location to print the file within the 3D printer's build envelope. That processing software slices the file into layers and then creates machine code that tells the printer where to deposit or fuse material. It also identifies locations to add support material if required. The machine code creation typically takes minutes. Machine code is then provided to the 3D printer. Depending on the size of the part and the 3D printing system being used, the printing process can take minutes to tens of hours. While metal AM post-processing (i.e., support removal and surface enhancement machining) can take a long time, post-processing for plastic printed parts is generally quick and simple. With AM, there is no waiting weeks or months for tooling to get into place before production starts.

The limitations of existing tooling or subtractive machining on part shape or functionality can be lifted. As a result, part weights can be reduced, assemblies can be consolidated into single parts, functionality can be increased. The GE Aviation fuel nozzles produced for the LEAP commercial aircraft engine are examples where all of these benefits of design freedom are realized. The original fuel nozzle design contained 18 parts joined together by brazing. The new design enabled by AM metal printing is a single piece. The new nozzle is 25 percent lighter and has a novel, complex design containing intricate cooling channels that improve efficiency and performance. The AM fuel nozzle is also 5 times more durable than the conventionally manufactured nozzle. Consider the total life-cycle costs and benefits of having a lightweight, single-piece, more durable and more fuel-efficient part.

If the best approach to make a part involves conventional manufacturing such as sheet metal forming, plastic injection molding, metal casting, composite layup or other processes, then AM can make the tooling itself. Humtown Products of Columbiana, Ohio, recently demonstrated the use of 3D sand printing to make a very complex cast aluminum manifold. The 3D sand printing was used to make the molds and cores used to make the cavity to form the molten metal into the manifold. Using conventional processes to make metal casting tooling would have taken at least 10 weeks to design the tooling, fabricate the tooling, create the molds and cores and then cast the part. Using 3D sand printing, the entire job took 12 days and saved $14,000 in nonrecurring engineering costs.

Whether it is tooling-less production or rapid low-cost tooling, AM takes away the cost and time barriers to custom production. At Youngstown State University, a group of mechanical engineering students recently created a 3D printed cast for a dog with a deformed leg. Working with a local veterinarian, the students 3D scanned a mold of the dog's leg, designed a lightweight and flexible 3D printed cast, and worked in Cleveland, Ohio, with the firm of rp+m, which used a specialized printer to fabricate the new cast. Military members can benefit (and are likely benefiting today) from custom production of medical casts, splints, prosthesis and implants. For the warfighter, custom wearable items such as blast-resistant helmets are certainly within the realm of the possible. And instead of completely standardized parts on platforms, mission tailorable 3D printed solutions can now be considered.

Instead of being half a globe away from the fight, the factory can now be moved to the point of need. Several AM polymer technologies such as material extrusion 3D printers are quite mobile. Such 3D printers were deployed as part of Rapid Equipping Force Expeditionary Labs (Ex Labs) supporting soldiers with rapid fabrication solutions. Other material extrusion 3D printers have been sent to sea including a recent deployment on the aircraft carrier USS *Harry Truman* (CVN-75). Even NASA has used polymer material extrusion 3D printers on orbit aboard the International Space Station. Metal AM technologies are not yet as mobile, but we should expect such systems in the near future. Instead of moving the Iron Mountain of spare parts, the focus shifts to moving raw materials and data into theater.

Enabling the Paradigm Shift

What could the DoD do to take advantage of AM? We can start the discussion with the need for a DoD strategy and vision for the implementation of AM. Stakeholders within the Office of the Secretary of Defense, the Joint Staff and the Services can examine models, regulations and practices relevant to the use of AM in support of acquisition, maintenance and sustainment, and logistics. From a technology standpoint, America Makes and its technology roadmap partnership with DoD can help identify many of the critical gaps common across all Services.

There is also need to encourage joint collaboration where applicable. The Services should continue to develop and implement their own strategies and visions that are relevant to their roles and missions. But there are areas that should be approached from a joint perspective. For example, joint certification processes could speed implementation of AM parts for aerospace applications. Perhaps inter-Service exchanges of engineers responsible for certification could help Services understand each other's processes and facilitate a common certification. The formation of joint AM communities of practice and sponsorship of user group meetings would allow crossflow of ideas.

As noted earlier, AM within the supply chain can happen faster than the speed of contracting. The DoD needs to develop agile contracting methods to ensure spare parts and 3D printing services can be rapidly obtained. For spare parts obtained through the supply chain, these contracting approaches can also incentivize the use of AM for tooling as well as for direct part production. General Services Administration Schedule 36 can be a starting place. For new weapon systems, the use of AM can be encouraged in the contracting process. There should be great thought as to how digital technical data packages (TDPs) can be included in the contracts for lifetime weapon system sustainment. If the DoD chooses to produce AM spare parts organically at depots or at forward locations, new business models need to be developed that would provide a win-win for both industry and government. A starting point could be the findings and recommendations from a recent working group event sponsored by America Makes and Deloitte that examined the effect of AM on business models for maintenance and sustainment.

The DoD also should foster cultural changes to adopt AM and other digital manufacturing technologies. The workforce development for the AM cultural evolution will involve hands-on experience with AM equipment. At the grassroots level, the proliferation of makerspaces or fablabs should be encouraged at DoD installations globally. DoD makerspaces should target all communities that can take advantage of the technology: maintainers, logisticians, technicians, engineers, contract specialists, program managers and even operators. No amount of computer based training, PowerPoint presentations, and white papers will convey the digital thread, design freedom, customization and creativity needed to maximize the potential of this technology.

3D printing lifts people out of their cultural and organizational enclaves. Because of the "democratization" of making enabled by 3D printing, here at YSU we started a program called Launch Lab that brings together faculty and students from business, arts and the "STEM" fields of science, technology, engineering and mathematics. Collaborative problem-solving yields creative solutions for community services, theater productions, art displays, SAE Baja racing cars, local industry challenges, and business startups. What does this mean for the DoD? AM will not stay in the domain of the engineers and technicians. In fact, the DoD should also examine the operational impacts of having rapid manufacturing colocated with the warfighter. There is a rich history of soldiers, sailors, Marines and airmen making creative solutions on the battlefield. Digital manufacturing will move this beyond duct tape, bailing wire and bubble gum. There is likely a need for joint experimentation exercises and battlelab-type activities to bring together the technologists and the operators.

Moving forward, the DoD can consider these and other approaches to the implementation of AM. The payoff is that AM offers an opportunity for the DoD to move from the speed of conventional manufacturing to the speed of war. Air Force Col. John Boyd created the Observe-Orient-Decide-Act (OODA) loop model stressing the importance of rapid, accurate decision making and action. AM can enhance the DoD's ability to get inside of an adversary's OODA loop through rapid design and manufacturing. We need to do this; enable this capability now before our adversaries do, as they might not be constrained by bureaucratic processes created since the days of the original Industrial Revolution.

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