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3D-PRINTING IMPACTS ON SYSTEMS ENGINEERING IN DEFENSE INDUSTRY

Jason Deters
General Dynamics Land Systems
Sterling Heights, MI

ABSTRACT

Today's combat vehicle designs are largely constrained by traditional manufacturing processes, such as machining, welding, casting, and forging. Recent advancements in 3D-Printing technology offer tremendous potential to provide economical, optimized components by eliminating fundamental process limitations. The ability to re-design suitable components for 3D-printing has potential to significantly reduce cost, weight, and lead-time in a variety of Defense & Aerospace applications. 3D-printing will not completely replace traditional processes, but instead represents a new tool in our toolbox - from both a design and a manufacturing standpoint.

3D-PRINTING DEVELOPMENT ACCELLERATES

While the fundamental science has existed for decades, 3D-printing has gained incredible momentum in recent years for applications like rapid prototyping - and is now being adopted for niche production applications. 3D-printing holds tremendous potential, but considerable challenges exist before this process can truly revolutionize the future of manufacturing. This paper highlights examples of how 3D-printing is being used in Aerospace & Defense industries today, how it may be applied in the future, and what obstacles must be overcome before widespread applications become mainstream.

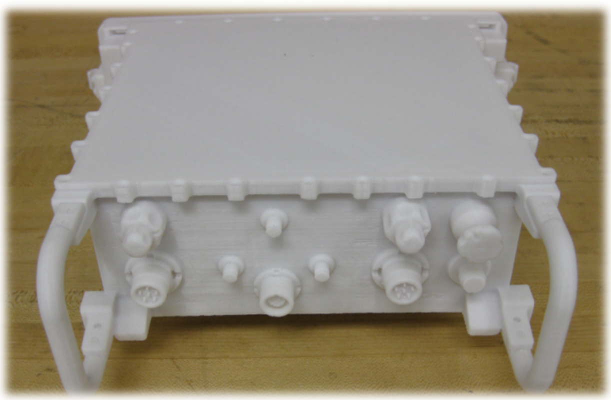
From a business standpoint, the primary over-arching benefits that 3D-printing offers are related to economies of scale and scope, essentially increasing the variety of products a unit of Capital can produce. For this reason, 3D-printing is particularly well-suited for the Defense and Aerospace industries thanks to its ability to produce multiple design iterations on a single machine setup. Like other organizations providing equipment to the US Armed Forces, GDLS constantly searches for innovative methods to improve performance, reduce lead time, and deliver meaningful value where it matters most. 3D-printing can undoubtedly contribute to these objectives, but fully realizing this potential will take strategic vision, technical innovation, and willingness to move beyond traditional process limitations.

NEAR-TERM APPLICATIONS ABOUND

While many people picture 3D-printing as a single technology, there are actually several unique processes that use distinctly different methods to build a component one layer at a time from a CAD model. A common process used today for the templates, prototypes, and tooling mentioned above is called Fused Deposition Modeling (FDM), which has gained popularity in recent years as 3D-printing of plastic parts evolves beyond traditional stereolithography. A wide variety of organizations currently use high-temp polymers for 3D-printing; dramatically reducing lead time and cost while enabling design freedoms not possible with traditional processes. From a Systems Engineering standpoint, the ability to quickly and easily 3D-print prototypes holds substantial promise in reducing design cycle time, comparing multiple design iterations, and optimizing overall packaging layout. This rapid prototyping capability enables design teams to identify issues early in the process and optimize component geometry for seamless integration. A variety of advanced polymers and similar materials for this type of 3D-printing have emerged in recent years, each with unique properties suited for particular applications.

General Dynamics Land Systems (GDLS) has utilized FDM technology in a number of applications that illustrate the capability of 3D-printing to provide measurable efficiency gains without actually being used for production components. One example is a fit-check model for a radio that requires weeks of lead time to obtain. Since the design team was only interested in how the radio integrated into the vehicle to identify any interference or access issues, the 3D-printed plastic model of the radio satisfied all the objectives.

Figure A: Radio hardware (above) and 3D-printed plastic fit-check model (below)



This part went from CAD model to 3D-printed model in two days and prevented costly delay to the program schedule. Another recent example is a wiring harness connector that was on backorder, posing a program delay of several weeks. Instead of accepting this negative schedule impact, GDLS was able to quickly print plastic versions of the component and use them in place of the backordered item in an engine test application at over 350-degrees F. Not only is this an illustration of the rapid turnaround time that 3D-printing can deliver, but also shows that the engineered polymers being used in 3D-printing are robust enough to handle demanding conditions, such as this high-temperature test.

Given the rapid manufacturing capability for FDM to create low-cost plastic components with optimized geometry, GDLS has investigated the possibility of incorporating a thin, high-strength structural metal cladding to be applied to a 3D-printed plastic component. This combination could offer performance similar to a metal component at a fraction of the weight, but would likely only apply to non-critical areas, such as brackets, etc. Extensive testing is necessary to better understand the long-term properties and failure modes of both the 3D-printed polymer core and the structural cladding. If this hybrid solution is proven to be a viable option, it opens up a number of possibilities for applying 3D-printed "semi-metallic" components for end item use in the near term.

To further leverage the Systems Engineering benefits that 3D-printing can provide throughout the design process, GDLS has also developed sophisticated reverse-engineering capabilities that employ a 3D-scanning unit that can quickly capture the geometry of a physical part or assembly, convert it to a CAD model, and 3D-print as needed. Current applications at GDLS are using the scan data to 3D-print plastic parts for instances where CAD data is not readily available, but in the future this same capability can be used for metallic components as well.

TREMENDOUS OPPORTUNITIES, SUBSTANTIAL CHALLENGES

Applying 3D-printing for solid metallic components, on the other hand, presents a host of technical obstacles that are the focus of ongoing development efforts in industry, academia, and Government organizations. The primary challenge to qualifying 3D-printed metallic components for end-item production use, especially in Defense & Aerospace, is difficulty in controlling process inputs to achieve consistent outputs. Industry standards are being developed to regulate the composition and quality of raw materials used for 3D-printing, and similar efforts are underway to create a centralized database for material-specific process parameters as well. This level of industry standardization is crucial to the advancement of 3D-printing in metal-based production applications, and is the focus of substantial research and development. These development initiatives are encouraging, but until they're approved for broad use on Defense & Aerospace components, it's impossible to qualify a component without conducting a detailed analysis of each individual part. 100% inspection would obviously be cost-prohibitive and limits to use of 3D-printing metal components to niche applications.

GDLS has committed substantial effort in recent years to better characterize how and when 3D-printing technology will impact the ground combat vehicle industry. Partnering with industry and academia, GDLS is pursuing 3D-printing production solutions in a variety of areas, with a prime example being part consolidation on complex welded components. Part consolidation, such as converting a multi-piece weldment to a one-piece 3D-printed part, reduces complexity, production cost, and component weight. In addition, 3D-printing enables optimization of the design by eliminating constraints imposed by traditional fabrication methods.

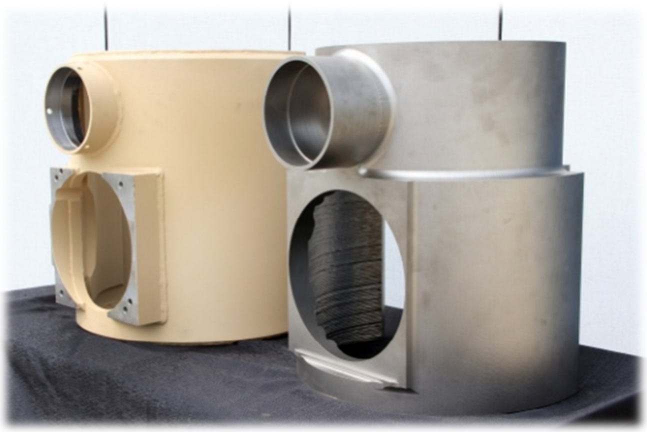


Figure B: 3D-printed titanium component (on right) with nine-piece welded steel version

In a recent demonstration, GDLS selected a nine-piece steel weldment and partnered with academic and industry partners to 3D-print it as a single piece, which GDLS then machined to final configuration. Consider all the process costs associated with fabricating a multi-piece weldment, such as the one shown in Figure B. A part like this requires several time-consuming steps, including material transfer, plate cutting, forming, machining, welding, and multiple inspection processes. The component can, in theory, be built as a one-piece 'preform' on a 3D-printer, then have the critical interfaces, such as tapped holes and key datum surfaces, cleaned-up on a machining center. For this specific demonstration, using 3D-printing reduced the part's complexity, but a prohibitive amount of machining was required to meet end-item requirements. Since the demonstration was only intended to illustrate the work envelope and material properties possible with Electron Beam Additive Manufacturing (EBAM), the component design was not optimized for 3D-printing.

The large amount of post-processing was required because the part is designed for traditional processes, such as bending, welding, and machining. As a result, the project did not fully leverage the advantages 3D-printing offers in geometry optimization and material efficiency. The next step in this effort aims to redesign and optimize this same component specifically for 3D-printing, reducing the amount of post-processing required while still satisfying performance and integration requirements. Leveraging advanced design software capabilities, this component can be redesigned for 3D-printing with a process called 'topology optimization'. This capability captures the performance and integration design requirements for the component and optimizes material layout for the specified loads within the given design space. This capability represents an advanced Design for Manufacturing (DFM) exercise, except in this case a number of the traditional process constraints have been removed.

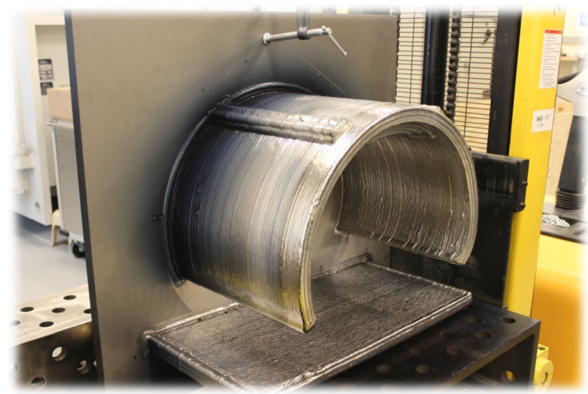
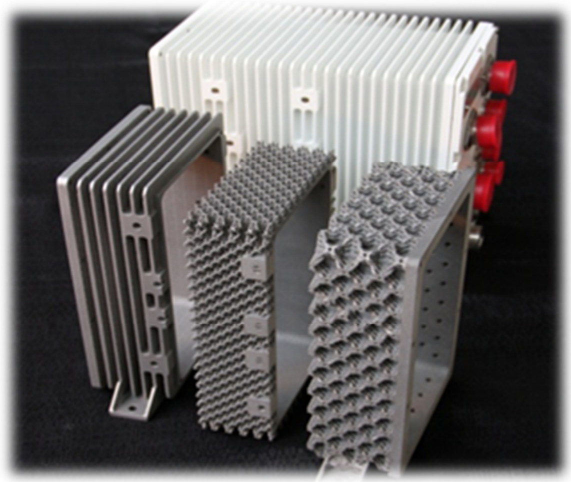


Figure C: 3D-printed titanium pre-form before final machining

Another example application where GDLS has explored the application of 3D-printing is for reduction of heat-induced failures in electronic housings. High-end electronics are used in virtually all defense and aerospace vehicle platforms and excessive heat is a common cause of failure for these expensive components. Many electronic enclosures used in these industries are produced from cast aluminum and feature simple "fins" to increase surface area on the exterior of the housing, which helps dissipate heat.

Figure D: 3D-printed concepts with 'cooling-fins' version



3D-Printing eliminates geometric constraints; enabling unique and optimized passive cooling features instead of standard cooling fins (see Figure D). These innovative geometries can significantly improve thermal characteristics of the housing, thereby protecting its sensitive contents. In addition, the geometric freedoms afforded by 3D-printing allow designers to incorporate small conformal cooling channels into the wall thickness of the electronic housing, which further improves heat dissipation.

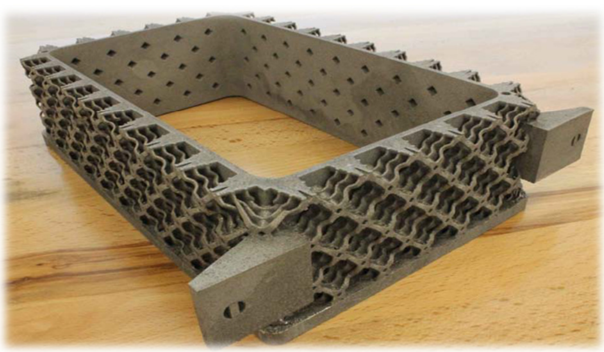


Figure E: 3D-printed titanium pre-form before final machining

While traditional machining can only create straight-line cooling channels, 3D-printing enables the channels to conform to the specific shape of the housing for maximum efficiency. An effective solution in this area will apply to many Defense & Aerospace platforms, where heat generated by high-density electronics is an important design consideration. Low production volumes often associated with these industries also enables 3D-printing to be cost-competitive with traditional castings.

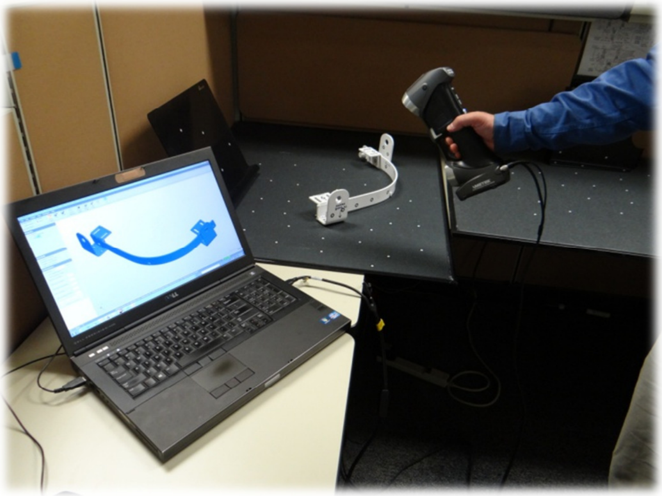
As 3D-printing continues to open up new opportunities for innovative applications, an interesting potential application is embedded electronics & sensors. This application consists of encapsulating a rugged sensor or electronic device within a printed component. Applicability in harsh environments is likely a long-term possibility, but the potential impacts of this capability would be tremendous. For example, the ability to embed sensors in a structure to measure and communicate damage from a ballistic or mine-blast event would provide valuable real-time data to improve mission effectiveness.

3D-PRINTING OFFERS FAR-REACHING POTENTIAL

As these examples illustrate, 3D-printing of metallic components has game-changing potential in Aerospace & Defense applications, but this technology is relatively immature and several technical obstacles exist. Commercially-available material options are limited, and the lack of industry-standard material and process parameter specifications makes part qualification very difficult. While there are a number of organizations partnering to develop a common set of specifications to effectively standardize 3D-printing, it's expected to take several years for 3D-printing of metallic components to become a widely-accepted production process.

An important business and security aspect of 3D-printing that cannot be overlooked is the ownership and sharing of intellectual property related to chemical composition, process parameters, and communication of design information. At this point, most large manufacturing companies developing 3D-printing processes to build their products are protecting this information as proprietary, which provides short-term competitive advantage, but at the same time slows the effort to develop industry-wide process standardization. This industry standardization is critical to successfully implement 3D-printing for end-use components in Combat Vehicles, and many other business sectors.

Figure F: 3D scanning capability for parts without models



To further leverage the Systems Engineering benefits that 3D-printing can provide throughout the design process, GDLS is has also acquired sophisticated reverse-engineering capabilities that employ a high-fidelity 3D-scanning unit that can quickly capture the geometry of a physical part or assembly, then convert it into a CAD model that can then be 3D-printed with an impressive degree of accuracy (See Figure F). Current applications at GDLS are using the scan data to 3D-print plastic parts for instances where CAD data is not readily available, but in the future this same capability can be used for metallic components as well. One example application envisioned for this technology is building replacements for obsolete components where models and drawings are not available. The scanning and printing aspects of this capability have been proven, but this technology will have limited application until 3D-printing of metallic end-use components becomes a viable option.

Figure G: On-demand spare parts will dramatically enhance the ability to quickly service combat vehicles

While not directly related to Systems Engineering, another promising application for 3D-printing in Defense applications is cost-effective, on-demand spare parts. Developments are underway to create an integrated system to 3D-print, finish-machine, paint, and assemble components on an as-needed basis, with minimal human interaction. When this process capability matures, it has the potential to revolutionize the infrastructure and logistics involved with supplying spare parts to the front line. This "beyond the supply chain" capability will dramatically cut inventory cost, reduce obsolescence waste, and can be used for repair/refurbishment of worn parts as well. Instead of filling and maintaining a warehouse for spare parts, a 3D-printer can conceivably print the desired part when and where it is needed.

This sounds too good to be true for good reason; as there are several technical limitations that must be overcome before this concept can revolutionize the way spare parts are supplied to the front line. For a simple metal bracket or enclosure, the solution may be relatively straightforward – but for more complex components that require multiple materials, surface treatments, precision machining, assembly processes, etc., the solution becomes much more complex. Adding to the complexity is the important consideration for how technical data, such as 3D models, are owned, transferred, and securely maintained at a remote base or similar setting. This is sure to be an area of further development, as 3D-printing technology and communications infrastructure continue to evolve and mature.

CONCLUSION

3D-printing will not completely replace traditional processes in our lifetime, but instead represents a new tool in our toolbox - from both a design and a manufacturing standpoint. While the examples described in this paper show significant potential for 3D-printing to transform Systems Engineering, true adoption of this technology must start in the earliest stages of product and process design. Adding 3D-printing to our existing capability set requires a paradigm shift in how we develop a concept, prove it out, and ultimately manufacture it. This change in mindset is gradually taking place in a variety of industries, and will gain broader acceptance as cost and technical barriers are overcome. Streamlining the design and manufacturing process to this extent can provide dramatic reduction in production cost and lead-time, both of which are critical in supplying the best capability and value to the brave men and women who defend the freedom of the United States and its allies.

REFERENCES

All photos courtesy of General Dynamics Land Systems