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Issue 7

3D printing: A potential game changer for aerospace and defense

3D printing is crossing the chasm between interesting concept and legitimate production technology

An exciting new technology has come on the scene with the potential to revolutionize the way companies manufacture products, including those for aerospace and defense. This technology, known as additive manufacturing or 3D printing, involves building physical objects one layer at a time, using digital models and special material deposition devices. Although they are nowhere near having the capabilities of a science fiction replicator, today's 3D printing machines have come a long way in a short time and are capable of fabricating complex components out of a variety of materials, including steel, aluminum, titanium, and a variety of plastics. As evidence of its potential, 3D printing is crossing the chasm between interesting concept and legitimate production technology.

The promise of 3D printing

In a perfect world, 3D printing would be used to manufacture parts on demand, quickly and cheaply. There is little to no scrap and parts can be produced remotely. Such a device could open up many opportunities for an A&D company. Early prototypes and demonstration units could be fabricated quickly, with minimal investment in part-specific tooling. Production units could be produced on demand, avoiding expensive setups or large quantities of safety stock. Spares could also be produced on demand, even in battlefield theater, significantly reducing the amount of inventory throughout the entire service supply chain.

Although 3D printing is not able to do all those things yet, it has already demonstrated its usefulness as a rapid prototyping tool and is becoming a contender for specialized production applications as well. And the technology is evolving quickly, with major backing from the government and industry players alike. Industry leaders such as Boeing, GE, and others are already experimenting with 3D printing technologies to see where they can improve manufacturing productivity and costs. The US government also is stepping up its investment, having launched the National Additive Manufacturing Innovation Institute in August of 2012.

The mechanics of 3D printing

At the heart of 3D printing lies a common set of underlying principles. It uses precision material deposition devices to convert digital models into physical parts. The complexity of the part is limited only by the imagination of the designer and the computing power of the 3D modeling software. And though most applications involve single component parts, 3D printing is able to create simple sub-assemblies of inter-connected parts, too. This ability to print complex parts without regard to geometric complexity opens up new frontiers for design flexibility and optimization. 3D printing significantly relaxes the geometric design constraints imposed by traditional production technologies.

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> *"Part quality remains one of the biggest hurdles to mass adoption. The material properties are inherently different from machined parts and this will need to be addressed before critical parts are mass produced."*
>
> *– Leading academic*

But 3D printing has limitations, as well, with the most significant being materials, costs, and structural integrity.

- **Materials.** Today's 3D printers are currently limited to using only a handful of engineered materials, mostly plastics and a few metals. Innovation is occurring most quickly in plastics, because they are easier and cheaper to work with than metals. But the plastic materials are generally of low quality and not suitable for most production products due to their limited strength, toughness, surface quality, and UV degradation properties. Recently, a number of companies have introduced machines capable of 3D printing parts made out of metal. These machines are more complex and expensive than their counterparts because they involve using lasers to melt metal powder to build the parts up. Nevertheless, manufacturers have demonstrated their ability to build parts out of steel, aluminum, and titanium. Several aerospace leaders are experimenting with powder melting technologies to build engine blades and other specialty components.
- **Costs.** Today's 3D printing technology is also more expensive than traditional manufacturing alternatives. 3D printing machines, particularly metal producing machines, are expensive. Laser melting machines cost from $500K to millions of dollars each. They are complex pieces of capital equipment on par with sophisticated machine tools in regard to operating environment (vacuum or gas-filled chambers) and control software. 3D printing machines are also slower than the current manufacturing alternatives. It takes thousands of beads to build up a metal part one layer at a time, and most metal parts take hours or even days to build. And powder metal feedstock is up to 30 times more expensive, by weight, than its bulk counterpart. These costs will come down with time and volume of production, but there are some physical limits, such as the speed of laser melting, that will ultimately define the inherent cost structure of metal 3D printing.
- **Structural integrity.** Lastly, laser-melted parts are metallurgically different from machined parts. By its nature, laser melting introduces voids and a different metallurgical grain structure within the fabricated part. The structural integrity of these parts may be sufficient for some applications, but not for others. Much testing will be needed to demonstrate where a laser-melted part can be used and where it cannot. Alternatively, electron beam additive manufacturing is currently under development and capable of creating void-free and structurally sound parts comparable to today's machined parts. But this process usually creates near-net shapes, which often require post-process machining, a costly secondary step subject to all of the geometric limitations that traditional machining operations impose.

Current applications

Despite the current limitations, 3D printing is catching on in the A&D industry. A&D leaders recognize the unique capabilities of 3D printing and are seeking ways to exploit these capabilities. GE recently acquired Morris Technologies, a precision engineering services firm specializing in advanced fabrication techniques such as laser melting, electron beam melting (EBM), and other 3D printing applications.[1] Boeing is using 3D printing to fabricate plastic interior parts out of Ultem and nylon for prototypes and test evaluation units. Boeing is also using 3D printing technology to rapidly fabricate tools for making composite parts.[2] Pratt & Whitney is investing millions in an advanced additive manufacturing center in collaboration with the University of Connecticut.[3] NASA is using 3D printing to fabricate parts for its rocket engines.[4] As with any new technology, 3D

1 GE Aviation press release, "GE Aviation acquires Morris Technologies and Rapid Quality Manufacturing," November 20, 2012
2 Boeing Frontiers, Eric Fetters-Walp, "Laser technology has far-reaching applications at Boeing, from jetliner production to making wind-tunnel models," pg. 25, Apr. 2011
3 Hartford Courant, "Pratt to invest $8M in Additive Manufacturing Partnership at UConn," http://www.courant.com/business/hc-uconn-pratt-whitney-additive-manufacturing-cent-20130404,0,7414553.story, Apr. 5, 2013
4 Scientific American, "NASA Plans for 3-D Printing Rocket Engine Parts Could Boost Larger Manufacturing Trend," http://www.scientificamerican.com/article.cfm?id=nasa-3-d-printing-sls-rocket-engine, Nov. 9, 2012

> *"We were able to reduce the time and cost to manufacture our prototype components by a factor of ten. We just didn't have to deal with all of the costs and time lags associated with prototype tooling."*
>
> *– Defense contractor*

printing holds great promise, but it also requires significant experience to know where best to exploit it. Based on the industry's current set of capabilities, 3D printing has emerged as a viable fabrication process for a number of A&D applications:

- **Prototypes.** 3D printing, particularly in plastic, has matured into a mainstream, rapid prototype fabrication methodology. 3D printing enables designers to skip the fabrication of tools and go straight to finished parts. And although printing a prototype part might take several hours, it is still significantly faster than building tools that are then used to fabricate prototype parts. This ability to quickly fabricate prototypes enables engineers to validate design concepts faster, speeding up the overall development process.
- **Demonstration units.** 3D printing is emerging as a viable technology for supporting rapid development and fabrication of technology demonstration units. TD units, used by the government to evaluate functionality and cull design concepts, are a market extension for 3D printed parts. Quantities are small, delivery lead times are short, and budgets are tight, particularly in today's defense spending environment. 3D printing enables manufacturers to fabricate parts of complex shape, bypassing expensive and time-consuming prototype tooling.
- **Small-volume production.** Certain low-volume, weight-sensitive products are opening up additional opportunities for 3D printed parts. Satellites and launch vehicles, for example, require intricately designed parts to reduce weight and minimize packaging space. Many of these parts are produced in very small quantities and are very expensive to fabricate using traditional machining or injection molding technologies. In many cases, these kinds of parts can be fabricated more quickly and cost-effectively than via traditional processes.

Future potential

But if 3D printing remains confined to prototypes, demo units, and spacecraft, then it won't be much of a game changer for industry. Does 3D printing have the potential to significantly change the A&D value chain? Perhaps, but it ultimately will depend on how far 3D printing can improve its quality and its speed.

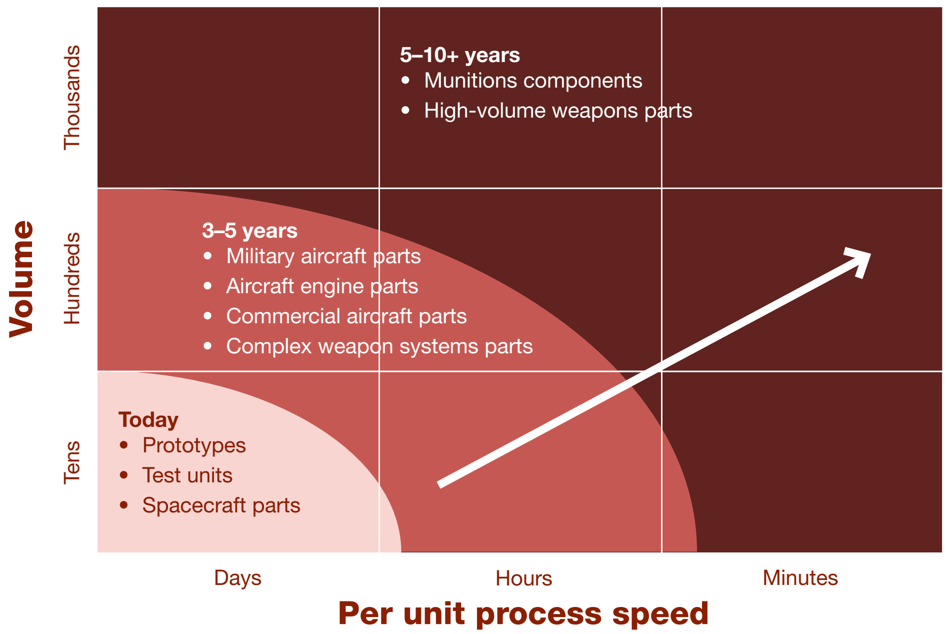
- **Product quality.** Product quality is the Achilles' heel of every production technology. Laser melting has improved significantly over the past several years, but it still produces parts with micro-voids and heat-induced stress. Equipment manufacturers are continuing to improve the deposition quality of this technology, but it will probably never be void-free, thus limiting its use to non-critical load-bearing parts. Electron beam melting has emerged as a higher quality alternative to laser melting. The very high-energy density of the electron beam technology enables it to produce fully dense, void-free parts. Electron beam technology is increasingly being used in the manufacture and repair of turbine blades.
- **Processing speed.** The biggest hurdle to mass adoption is processing speed. Because of its intricate, layer-by-layer nature, current 3D printing technology takes hours to days to complete jobs. This cycle time is sufficient for prototypes and very small production quantities, but it quickly becomes untenable at higher production volumes. However, advances in electron beam and powder feedstock technologies may enable higher speeds, making EBM a viable production technology suitable for many more applications, including those for most aerospace and defense programs.

"Additive manufacturing has the potential to change the world … the capability of the technology is very good."

– Paul Adams, COO, Pratt & Whitney

As quality and speed continue to improve, 3D printing will become a viable process for an ever-increasing number of applications, including traditional production parts. No one knows how rapidly the technology will take to mature, but most experts believe it will make significant strides within the next five years.

3D printing—adoption map



Source: PwC Analysis, 2013

In theory, intellectual property (IP) theft is also a concern. Counterfeiters can reverse-engineer parts using laser imaging technology, then 3D print replicas without payment to the design data owner. Although possible, the incentives for IP theft, particularly in the A&D industry, are minimized by 3D printing economics. Unlike music or movies, the marginal cost of 3D printing is not negligible. And the available market is small and fairly sophisticated. So although it is technically possible to 3D print counterfeit parts, it's not any more convenient than using currently available machining technologies.

Crossing the chasm

3D printing is making inroads into the manufacturing value chain, particularly within the A&D industry. Although the popular press sometimes tends toward hyperbole, 3D printing is an interesting technology and will find its way into increasing numbers of applications. But will it ever become a game changer for the A&D industry? And what should executives track to determine when 3D printing is poised to cross the chasm, if ever? PwC recommends that A&D companies take an "active technology tracking posture" on the topic of 3D printing: watch technical developments and set thresholds for the point at which it makes sense for your firm to start investing in 3D printing technology yourselves. Based on our experience, PwC recommends the following three technology maturity criteria:

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① *Process quality*

Carefully monitor advances in material density and consistency. Pay particular attention to advances in the electron beam melting field. Once electron beam technology demonstrates that it can affordably produce high-quality parts, 3D printing will become a viable production process for a wide variety of aerospace and defense parts, including critical load-bearing parts.

② *Process speed*

Also, monitor advances in unit production speeds. Right now, at eight or more hours, 3D printing is not competitive with most traditional production process technologies. But as machine speeds improve, 3D printing will become a viable option for an increasing number of fabricated parts.

③ *Feedstock costs*

At the present time, metal powders are up to 30 times more expensive than their bulk counterparts. Costs will come down with increasing volumes, but powder metals will always be more expensive than bulk materials because of the additional processing steps required to produce them. If powder metal prices decline to a level where they compare favorably with bulk materials (taking into consideration scrap produced in traditional machining operations), then the current powder-based 3D technologies will become viable alternatives to traditional machining processes. Also, monitor the development of wire-fed 3D printers, because wire is an inherently low-cost feedstock.

All aerospace manufacturers need to be tracking developments in the 3D printing field. Those companies that fabricate parts for their own operations or fabricate parts for other customers should be experimenting with 3D printing technologies. Once 3D printing reaches any one of the above three maturity criteria, start re-evaluating your manufacturing strategy and estimating the future capital requirements. Once 3D achieves two of these three criteria, start making the transition to 3D manufacturing—and it may be sooner than you think.

How PwC can help

To have a deeper discussion about 3D printing, please contact:

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