3D opportunity in aerospace and defense

Additive manufacturing takes flight

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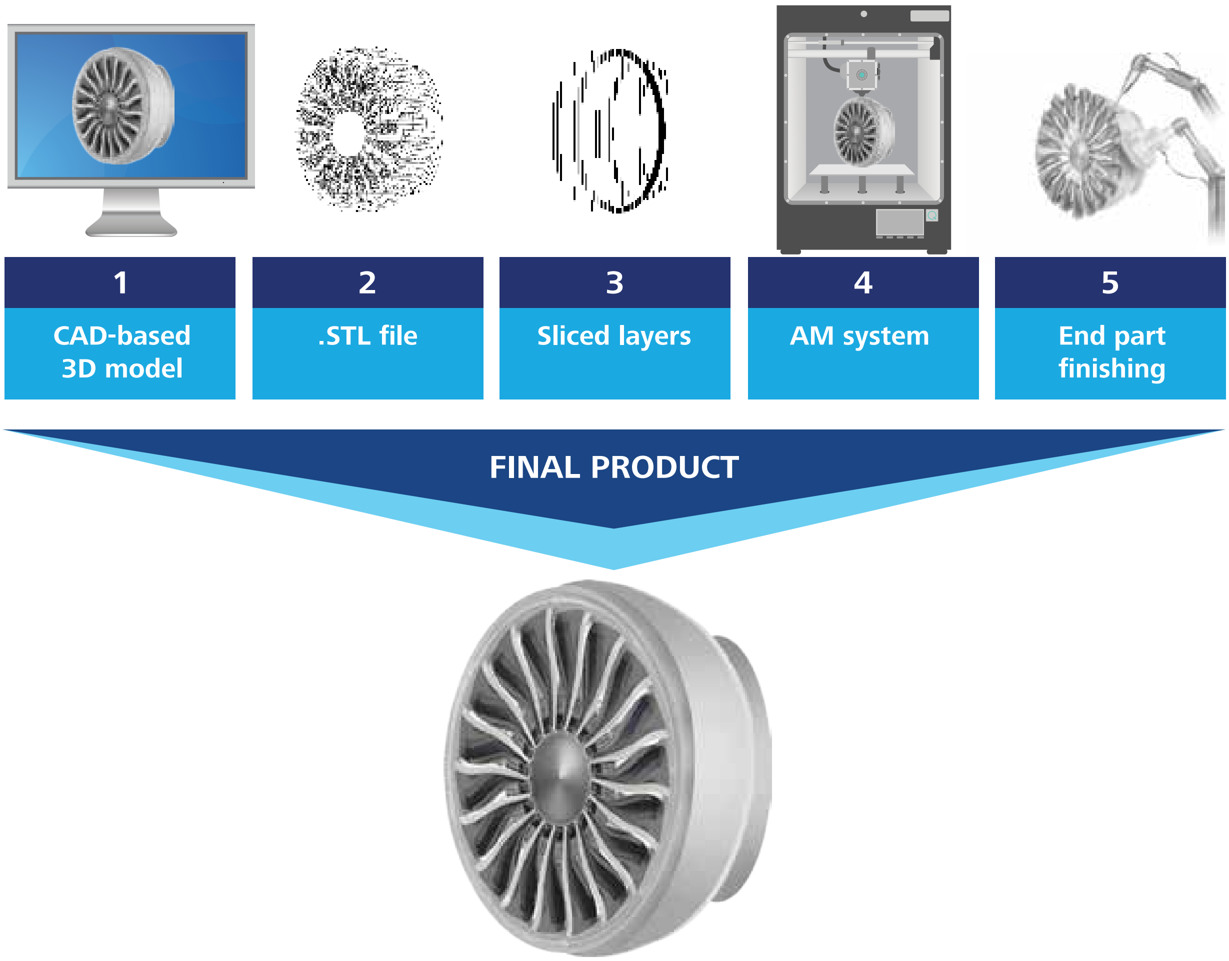
Introduction

ADDITIVE manufacturing (AM), popularly known as 3D printing, is a manufacturing technique that builds objects layer by layer using materials such as polymers, metals, and composites. Figure 1 depicts the overall AM process.[1] In the early stages of the 30 years of AM's deployment, the technology was largely geared toward prototyping and tooling applications; however, in recent years, AM has found success in end-part production, driven by improved manufacturability and reduced lead time compared to traditional manufacturing methods.

The aerospace and defense (A&D) industry was an early adopter of AM technology. The history of AM traces back to 1983 with some A&D companies beginning experimentation with the technology as early as 1988.[2] Over the years, AM's adoption has increased across industries, with the A&D industry contributing about 10.2 percent of AM's $2.2 billion global revenues in 2012.[3] Several reasons

Figure 1. Additive manufacturing (AM) process flow



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underlie AM's relatively widespread adoption in A&D. AM provides the flexibility to create complex part geometries that are difficult to build using traditional manufacturing. It can build parts with designs such as internal cavities and lattice structures that help reduce parts' weight without compromising their mechanical performance. Furthermore, AM machines produce less scrap than traditional machines, a critical attribute when using expensive aerospace materials such as titanium. Finally, AM's impact on economies of scale and scope make it a natural fit for A&D, which, in contrast to other mass production industries, is largely geared toward customized production. Figure 2 presents some of the performance enhancement benefits delivered by AM in various A&D applications.

AM's current applications in the A&D industry range from manufacturing simple objects such as armrests to complex parts such as engine components. Applications such as printing aircraft wings and parts in microgravity are foreseeable in the future.[4] Figure 3 shows the current and potential applications of AM in the A&D industry; this list is not exhaustive, as AM technologies and their applications are constantly evolving.

Currently, A&D companies are at different stages in adopting AM, and there is some debate about how real AM's impact on traditional processes will be. On the one hand, A&D executives who are skeptical of AM's potential may miss the opportunities the technology can offer. On the other hand, companies keen on benefiting from AM adoption may make hasty moves that do not align with their strategic imperatives.

The article *3D opportunity: Additive manufacturing paths to performance, innovation, and growth* provides Deloitte's perspective on the impact of AM, as illustrated in figure 4.[5] Using the framework as the basis, we reviewed relevant academic literature and case studies and interviewed AM experts to identify current and future trends that are expected to shape the application of AM in the A&D industry.

Figure 2. Examples of the benefits of producing different A&D parts

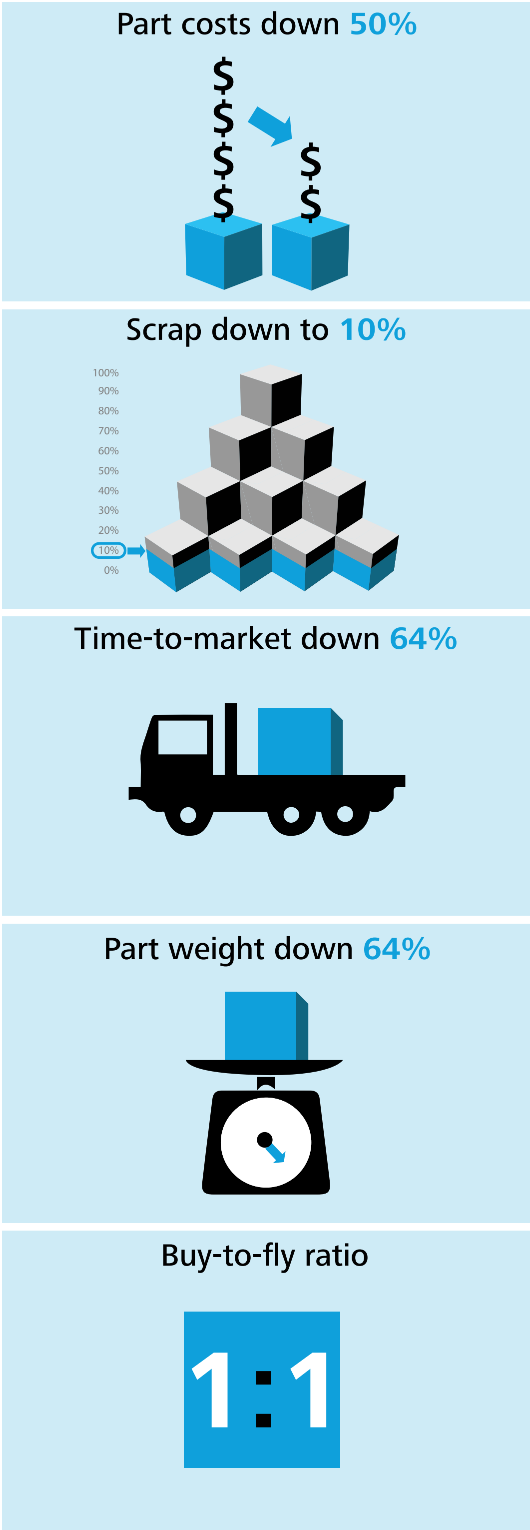

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Figure 3. AM applications in the A&D industry

	Current applications	Potential applications
Commercial aerospace and defense	• Concept modeling and prototyping • Printing low-volume complex aerospace parts • Printing replacements parts	• Embedding additively manufactured electronics directly on parts • Printing aircraft wings • Printing complex engine parts • Printing repair parts on the battlefield
Space	• Printing specialized parts for space exploration • Printing structures using lightweight, high-strength materials • Printing parts with minimal waste	• Printing on-demand parts/spares in space • Printing large structures directly in space, thus circumventing launch vehicles' size limitations

Sources: Deloitte analysis; CSC, *3D printing and the future of manufacturing*, 2012.
Graphic: Deloitte University Press | DUPress.com

As the AM technology evolves, its applications are bound to change; however, the larger dynamics that we have identified related to products and supply chains will not. This report will help readers appreciate how AM can aid their companies in achieving performance, growth, and innovation goals and help leaders choose the paths that best suit their organizations' value drivers.

AM paths to A&D companies' strategic imperatives and value drivers

AM is an important technology innovation whose roots go back nearly three decades. Its importance is derived from its ability to break existing performance trade-offs in two fundamental ways. First, AM reduces the capital required to achieve economies of scale. Second, it increases flexibility and reduces the capital required to achieve scope.

Capital versus scale: Considerations of minimum efficient scale shape the supply chain. AM has the potential to reduce the capital required to reach minimum efficient scale for production, thus lowering the barriers to entry into manufacturing for a given location.

Capital versus scope: Economies of scope influence how and what products can be made. The flexibility of AM facilitates an increase in the variety of products a unit of capital can produce, reducing the costs associated with production changeovers and customization and/or the overall amount of capital required.

Changing the capital versus scale relationship has the potential to impact how supply chains are configured, while changing the capital versus scope relationship has the potential to impact product designs. These impacts present companies with choices on how to deploy AM across their businesses.

The four tactical paths that companies can take are outlined in the framework below:

Path I: Companies do not seek radical alterations in either supply chains or products, but may explore AM technologies to improve value delivery for current products within existing supply chains.

Path II: Companies take advantage of scale economics offered by AM as a potential enabler of supply chain transformation for the products they offer.

Path III: Companies take advantage of the scope economics offered by AM technologies to achieve new levels of performance or innovation in the products they offer.

Path IV: Companies alter both supply chains and products in the pursuit of new business models.

AM is an important technology innovation whose roots go back nearly three decades.

Figure 4. Framework for understanding AM paths and value[6]

Source: Mark Cotteleer and Jim Joyce, "3D opportunity: Additive manufacturing paths to performance, innovation, and growth," *Deloitte Review* 14, January 2014.

Graphic: Deloitte University Press | DUPress.com

Traditionally, A&D companies have deployed AM to create value through path 1—leveraging AM primarily for concept modeling, prototyping, tooling, and production of select end parts. Companies on this path are at different stages of AM adoption. While a few are using AM only for prototyping, others are using AM for short-run production.

In the medium term, with advances in AM technology and materials, A&D companies are likely to move from path I to path III in order to develop complex products with improved functionality, even new products altogether, without any major changes in their existing supply chain structures. A few leading A&D companies are already pursuing path III, and we expect increased momentum in the medium term.

Companies might also benefit in the area of maintenance, repair, and overhaul through the possibilities for cost-effective distributed production enabled by AM. Demand-driven production of spares through AM could be relevant for low-volume, complex parts; spares for out-of-production legacy aircraft; or spares required at remote locations.

In the long term, A&D companies are likely to deploy path IV—that is, they could pursue product customization along with on-demand AM that will likely lead to supply chain disintermediation and the evolution of new business models.

Detailed analysis on each of the AM paths is presented later in the report. When analyzing each of these paths, it is worthwhile to evaluate how different AM attributes may lead to changes in A&D companies' products and supply chain structures. Figure 5 lists some common attributes of AM that distinguish it from traditional manufacturing and the effect of each of these attributes on companies' existing product offerings and supply chains. Although not obvious, some product-related attributes have a bearing on a company's supply chains, and vice versa. For example, "manufacturing of complex-design products" appears to be a closely product-aligned attribute, but it also has supply chain implications: Companies that are designing complex parts need to ensure the fit of that complex part with other components sourced from suppliers. In a similar fashion, companies need to consider the impact of each AM attribute on their products and supply chain structures.[7]

Path I: Stasis—The path currently pursued by most A&D companies

COMPANIES ON PATH I DO NOT SEEK RADICAL ALTERATIONS IN EITHER SUPPLY CHAINS OR PRODUCTS, BUT MAY EXPLORE AM TECHNOLOGIES TO IMPROVE VALUE DELIVERY FOR CURRENT PRODUCTS WITHIN EXISTING SUPPLY CHAINS.

Most A&D companies have been following a conservative strategy by adopting path I, "stasis," to leverage AM for modeling, prototyping, tooling, and short-run production without making any substantial changes to their supply chains and products.

Reduced time to market: AM helps companies quickly build prototypes with the required fit, form, and functionality, thereby accelerating design cycles, reducing time to market, and giving organizations a competitive advantage.[9] Research has shown that when A&D companies switch from traditional manufacturing to AM, they could benefit from time savings in prototyping ranging from 43 percent to 75 percent, depending on the conventional techniques used.[10] For example, when the Defense Advanced Research Projects Agency (DARPA) asked for proposals to improve the design of vertical takeoff and landing (VTOL) aircraft in 2013, Boeing additively manufactured a prototype, whose construction would have otherwise taken several months, in less than 30 days.[11]

Complex-design tools: AM's ability to create free-form designs helps in building tooling fixtures that are difficult or impossible to produce with traditional machining techniques. For example, traditional machining can create cooling channels only in straight lines, thus making it difficult to optimize fluid flow in corners. AM can create cooling channels that conform to the curvature of a part, a feature that is especially important for engine parts.[12]

Flexibility of design iterations: AM offers the flexibility to design and test products as many times as required, helping A&D companies reduce risks and uncertainties and improve product functionality at lower costs. With changes in software design files, companies can undertake multiple design iterations without expensive retooling. For example, NASA used 70 additively manufactured parts (such as flame-retardant vents, camera mounts, and housings) for the Mars Rover test vehicles.[13]

Tooling at lower costs: AM not only enables companies to quickly design and test products, but also helps bring down the cost of manufacturing tooling and fixtures.[14] A case in point is offered by the repair company

Figure 5. Impact of AM attributes on A&D companies' product offerings and supply chain structures[8]

AM attributes compared to traditional manufacturing	Impact on product offerings	Impact on supply chains
Manufacturing of complex-design products	Very high	High
New products that break existing design and manufacturing limitations	Very high	High
Customization to customer requirements	Very high	High
Ease and flexibility of design iteration	High	Medium
Parts simplification/sub-parts reduction	Medium	Medium
Reduced time to market	Medium	Medium
Waste minimization	Medium	Medium
Weight reduction	Medium	Low
Production near/at point of use	Medium	Very high
On-demand manufacturing	Low	Very high

Potential impact	Very high	High	Medium	Low

Source: Deloitte analysis.

Graphic: Deloitte University Press | DUPress.com

Advanced Composite Structures (ACS). ACS produces the majority of its tools using AM, leading to overall cost savings of 79 percent and lead time reduction of 96 percent compared with traditional tooling.[15] Tooling using AM is particularly relevant for short-volume applications in the A&D industry, as described below by Bruce Anning, a director at ACS:

> For the repairs and short-volume production work that we specialize in, tooling often constitutes a major portion of the overall cost. Moving from traditional methods to producing composite tooling with fused deposition modeling has helped us substantially improve our competitive position.[16]

Overall, path I, a starting point for AM adoption, leads to improved performance by reducing design and development costs and accelerating the speed at which cash flow can be realized without requiring significant changes in companies' products and supply chain structures.

Path II: Supply chain evolution—Limited AM impact expected in the medium term

ON PATH II, COMPANIES TAKE ADVANTAGE OF SCALE ECONOMICS OFFERED BY AM AS A POTENTIAL ENABLER OF SUPPLY CHAIN TRANSFORMATION FOR THE PRODUCTS THEY OFFER.

The A&D industry structure involves the manufacture and assembly of complex systems and sub-systems at select locations; the storage of parts in centralized warehouses; and maintenance, repair, and overhaul by skilled labor at relatively few locations. Boeing and Airbus aircraft typically consist of some 4 million parts sourced from across the globe. To avoid having an aircraft grounded, airlines commonly maintain an inventory of spares, some of which remain unused, and sometimes become obsolete with new aircraft designs. AM addresses the issue of warehousing and inventory obsolescence costs by enabling on-demand manufacturing where required. In line with Pareto's 20/80 rule, AM can co-exist with conventional manufacturing to make A&D companies' inventories leaner and save warehouse space.[17]

In the medium term, as AM machines become less expensive, aircraft maintenance, repair, and overhaul processes could benefit from cost-effective distributed production. Demand-driven production of spares through AM is relevant for low-volume, complex parts; spares for out-of-production legacy aircraft; or spares required at remote locations.

BAE Systems offers an example of AM's use in manufacturing spare parts. Earlier this year, the company received approval from the European Aviation Safety Agency (EASA) for its additively manufactured window breather pipes used in regional jetliners.[18] These additively manufactured pipes cost 40 percent less than pipes made through injection molding and are manufactured and shipped to customers on an as-required basis.[19]

In addition to manufacturing spare parts using AM, the technology is also helpful for manufacturing parts that are difficult to repair using traditional processes. Laser metal deposition (LMD) is an AM technology in which metal powder is melted using a laser beam to form a metallurgical bond to repair parts. LMD systems can be installed at locations where repairs of high-value aerospace parts are expected. Rolls Royce offers a case in point: The company has installed LMD machines for the repair of complex engine components at its facilities in Germany.[20] Starting this year, Lufthansa Technik also plans to repair high-pressure compressor blades in aircraft engines using AM. Dr. Stefan Czerner, consulting engineer at Lufthansa Technik, says, "Working with material which in some cases is just 0.2 millimeters thick is beyond even our best manual welders. We need high-precision positioning—accurate to a hundredth of a millimeter—and precisely metered energy input. The only way to do that is with a laser."[21]

Path III: Product evolution—AM raising the bar for product performance in the medium term

Currently, a few leading companies are looking for ways to integrate AM into their

ON PATH III, COMPANIES TAKE ADVANTAGE OF THE SCOPE ECONOMICS OFFERED BY AM TECHNOLOGIES TO ACHIEVE NEW LEVELS OF PERFORMANCE OR INNOVATION IN THE PRODUCTS THEY OFFER.

mainstream applications to produce end parts with the required fit, form, and functionality. AM applications in the A&D industry range from manufacturing engine components to food trays. According to one AM expert we interviewed, “Simple areas where I see growth in AM are seat belts, food trays, arm rests . . . All these things are getting additively manufactured. One of the interesting things you will notice is that companies are looking at bionic structures for parts such as arm rests. Additively manufactured bionic parts help improve the strength and aesthetic appeal of the parts while lowering their weight.”

In the medium term, with improvements in AM technologies and materials sciences, an increasing number of companies are likely to adopt path III and leverage AM to improve product performance without making significant changes to their supply chains.

Complex-design parts: AM enables product designs and dimensions that are hard to create through traditional manufacturing, thus transcending existing design and manufacturing limitations.[22] In traditional manufacturing, some designs that are optimized for topology are not feasible to manufacture due to their complex shape and design. However, with AM, parts can be designed not to accommodate manufacturing capabilities but to deliver maximum performance.[23] GE Aviation is using AM to create fan blade edges with complex shapes to optimize airflow; it is difficult and time-consuming to machine such blades through traditional manufacturing. By 2016, the company plans to manufacture these blade edges in large production runs using AM.[24]

Intricate geometries: Parts with designs such as internal cavities and lattice structures can be fabricated using AM. The AM process, while maintaining the parts’ strength by providing support only where required, can keep the parts’ weight low. For example, while producing Airbus A320 nacelle hinge brackets, EADS used direct metal laser sintering (DMLS) to build an optimized design that brought down the part’s weight by 64 percent while maintaining its strength and performance.[25] The cumulative weight reduction enabled by additively manufacturing such parts can have a significant impact on the industry. Literature suggests that removing one pound of weight from each aircraft of a 600+ fleet of commercial aircraft could save about 11,000 gallons of fuel annually, cutting down on fuel bills—which, as of 2013, typically absorbed 35 percent of an airline’s annual revenues.[26]

Waste reduction: Aerospace parts are built using expensive materials such as titanium, and it takes cost and effort to recycle scrap produced during machining.[27] Conventional machining can entail a scrap rate as high as 80–90 percent of the original billet; AM can bring the scrap rate down to 10–20 percent, given the basic distinction between subtractive and additive methods of manufacturing. Research shows that the buy-to-fly ratio of Lockheed Martin’s bleed air leak detector (BALD) brackets used in engines can be reduced from 33:1 to 1:1 by using electron beam melting (EBM).[28] In terms of cost comparison, even though the titanium alloy (Ti-6Al-4V) used in the AM process costs more than the wrought Ti-6Al-4V used in the traditional process, 50 percent of the cost of a bracket can still be eliminated without compromising its mechanical properties.[29]

Part simplification: AM’s ability to manufacture multiple A&D parts as a single component, thereby reducing assembly effort, is another product-enhancement attribute. Typically, it is easier to modify a single-component product than a system built out of multiple components; hence, uncertainty in demand becomes more manageable. A classic example is GE’s additively manufactured fuel nozzles, which are additively manufactured as a single part; they formerly involved the assembly of 20 different parts.[30] These nozzles, used in GE’s LEAP engines, are reported to be five times more durable than those produced using conventional methods.[31]

Improved functionality with embedded electronics: Ongoing advances in additively manufactured electronics embedded in parts offer product innovation opportunities. The field of embedded electronics, particularly for unmanned aerial vehicle (UAV) applications, is gaining momentum. Says David Kordonowy, aerostructures research group lead at Aurora Flight Sciences:

> "The ability to fabricate functional electronics into complex-shaped structures using additive manufacturing can allow UAVs to be built more quickly with more customization, potentially closer to the field where they're needed. All these benefits can lead to efficient, cost-effective fielded vehicles."[32]

The marriage of embedded electronics and AM is still nascent, and it currently appears relevant in the context of simple electronics. Its applicability to harsh defense environments is foreseeable only in the long term.

Ease of product customization: As discussed earlier, the scope economies enabled by AM can allow companies to customize products to customer requirements in much lower volumes than possible with traditional manufacturing. Companies that seek to develop customized versions of existing products, or develop new products altogether, need not change their production machinery. Savings in changeover time and effort enable companies to get products to their customers faster, improving their market responsiveness. One AM expert gave the following example:

> "A supplier of storage cabins moved completely from plastic molding to AM to print storage cabins and handles for the first-class cabins of a large commercial aircraft. First class is situated close to the nose of the aircraft, which is pointed, and each part has to be customized to fit in the "arch" design, thus making these parts a right fit for AM. Conversely, economy cabins are situated in a straight body, so parts are repeatable."

Overall, improved product functionality as well as the development of new products using AM will offer opportunities for product innovation as well as revenue growth in existing and new market segments. Progress down path III can improve companies' market responsiveness, thus enhancing their performance and prospects for growth.

Path IV: Combined supply chain and product evolution—AM's long-term role in business model changes

ON PATH IV, COMPANIES ALTER BOTH SUPPLY CHAINS AND PRODUCTS IN PURSUIT OF NEW BUSINESS MODELS.

In the last 30 years, AM applications have expanded from rapid prototyping to rapid tooling to end-part production as well as to the production of replacement parts. Path IV, "business model evolution," foreseeable in the long term, is the most significant path in terms of its impact on A&D companies' products and supply chain structures.

Collaboration with suppliers to create new products using AM: Currently, companies are using AM to improve the functionality of existing products or to build customized products. Going forward, this will continue. Additionally, in the long run, as AM technology improves, companies will likely take a step forward and leverage AM for designing new products altogether that are difficult to design and manufacture through conventional techniques. A&D companies are likely to collaborate with their suppliers and AM providers to build improved or new products using AM. The need to choose suppliers based on their AM expertise is likely to impact A&D companies' legacy supply chains. Some companies have already taken steps in this direction. Lockheed Martin is working with Sciaky to develop structural components for the F-35 aircraft.[33] An F-35 flaperon spar made through EBM can save about $100 million compared to the cost of a spar made through traditional manufacturing over the 30 years of an aircraft's lifetime.[34] Savings will naturally multiply as more parts are fabricated using AM.

Acquisition of niche AM providers to build in-house AM capabilities: On path IV, A&D companies may also choose to acquire select AM players to improve their in-house AM capabilities for critical applications, thus leading to some degree of supply chain disintermediation. For example, in early 2013, GE Aviation acquired Morris Technologies and Rapid Quality Manufacturing (RQM); both companies had earlier supplied additively manufactured parts to GE.[35] GE Aviation also plans to triple its AM staff over the next five years from a headcount of 70 in 2013.[36]

With an increasing emphasis on AM's adoption through organic and inorganic means, AM and traditional manufacturing can serve as complementary technologies to further companies' long-term strategic imperatives. Lockheed Martin's recent initiative to introduce a digitally integrated design and manufacturing process for its space applications is a good example. As highlighted by Dennis Little, vice president of production at Lockheed Martin, there are no hitches when the product advances from a 3D CAD model to the shop floor as traditional fabrication is replaced with an automated process:

> "Our digital tapestry of production brings digital design to every stage of the production process for a fluid product development cycle. From 3D virtual path-finding simulations to 3D printing, we are using innovative digital technology to streamline the manufacturing process for lower cycle times and reduced costs for our customers."[37]

Production at or near the point of use: As AM has the potential to reduce the capital required to reach the minimum efficient scale for production, companies can set up newer facilities at or near customer locations. Currently, we see only limited examples of on-site manufacturing, but on-site manufacturing is likely to expand to wider commercial and defense applications in the long term. The US Army's Rapid Equipping Force is deploying mobile AM labs in Afghanistan to manufacture quick replacements for products on the battlefield.[38] Similarly, NASA is working to install an AM device at the International Space Station.[39] Printing on-demand parts in a micro-gravity environment is well within the realm of the possible.[40]

Significant changes in products through the use of AM will create opportunities for innovation and revenue for A&D companies. As AM's adoption increases, fueled by economies of scope, companies may choose to manufacture critical components in-house. For other applications, they are likely to work with a limited number of suppliers that have experience and expertise in AM deployments. These changes are likely to lead to some degree of supply chain disintermediation, as well as changes to how suppliers are chosen. Overall, the changes that path IV will drive in companies' products and legacy supply chain structures will cause their business models to evolve in ways that bring the value embedded in paths II and III.

Significant changes in products through the use of AM will create opportunities for innovation and revenue for A&D companies.

What's holding back A&D executives?

IN December 2013, we interviewed several experts in the field of AM to get their views on the implications of the technology for the A&D industry. We took them through a structured interview process and cross-compared their responses. Although we cannot claim a comprehensive review of all opinions that might exist, we are confident that we obtained a representative sample of qualified reviews of the AM industry.

Our literature review and discussions with AM providers and experts highlighted that only a few leading A&D companies are proactively ramping up their existing manufacturing capabilities to be able to leverage AM for mainstream applications as AM systems improve in functionality and materials science matures.

Other executives are conservative and apprehensive about the stress that AM could bring to their operations. They are looking for successful case studies before committing capital to AM setups. It is here that the role of service bureaus becomes critical, as A&D companies can use them to access the AM technology without the need for huge capital investments and technical know-how. The following are some common reservations expressed by A&D executives.

Only a few leading A&D companies are proactively ramping up their existing manufacturing capabilities to be able to leverage AM.

How real is AM? Is it just another new technology or are there any long-term implications?

Currently, the benefits of AM for A&D applications have been demonstrated through research studies conducted by select A&D companies and AM providers under controlled conditions. However, the approach used to conduct these studies is not always available in the public domain, making it difficult for executives with limited practical exposure to AM to judge the studies' validity. One AM expert we spoke with said, "Of course, some of the leading aerospace companies have done extensive research, and they have all the data about the heating and cooling rates and how the structure is formed, etc.—but it is kept in-house and is not in the public domain." AM providers need to sensitize and convince A&D customers that AM performs, not just in research labs, but on the shop floor as well.

We own and understand existing manufacturing processes, but we are not so sure about AM.

As with any new technology, A&D executives have varying risk appetites when it comes to embracing AM. A&D experts have decades of experience and expertise in metals, plastics, and composites, as well as in their use in conventional machining. But their understanding of AM continues to be limited, because even though the technology has been around for 30 years, activity has accelerated only in recent years. One AM expert we interviewed said, "A lot of senior executives I speak to are not very comfortable with AM. With their collective experience in conventional machining that runs into the hundreds of years, they are comfortable with the knowledge they have about how metals behave, the properties of the materials, what can be done, what cannot be done. Suddenly a new technology comes along, and they are very apprehensive, as there is limited understanding of the grain structure and how the parts will be formed in AM."

We are a diversified manufacturer. Can AM help across the board?

A&D executives are keen to understand the extent to which AM systems can be deployed for varied applications in their organizations. We believe AM is especially relevant for diversified companies, as they can use AM systems for applications across business segments. AM can produce a "sword and a plowshare" sequentially without any change in the production machinery, thus demonstrating the technology's versatility to produce different products with reduced changeover time and effort.[41] GE, for instance, uses AM for applications across segments such as aviation and health care. Christine Furstoss, global technical director of manufacturing and materials technologies at GE, said:

> "We are committed to driving [AM] in as many areas as we can…We will always work with our strategic partners to do what's right for our collective companies."[42]

We make specialized equipment; we can't take chances with reliability.

Amid stringent regulations for commercial and defense manufacturing processes, consistency of quality is something on which A&D executives cannot compromise. As one AM expert described A&D executives' concerns about repeatability in AM applications, "A&D executives are particularly skeptical about replication accuracy, which is yet to be brought down to about the 2 micron level." An AM parts manufacturer that supplies parts to A&D customers described the gap between what the A&D industry requires and what AM systems typically deliver: "The accuracy that you can get through most metal AM machines is about 30–40 microns, while aerospace companies' tolerance limit is less than 10 microns; so currently we have the additional task of machining [the excess] away." AM providers need to improve existing systems to be able to consistently deliver high-quality parts; only then will AM likely reach its full potential in the A&D industry.

Increasing AM adoption: Challenges and potential solutions

AM'S ability to manage small volumes, create complex designs, and fabricate lightweight but strong structures makes it a natural fit for the A&D industry, which is not a mass-production industry in the typical sense of the term. In its current state, the technology faces some challenges associated with size and scalability, high material costs, narrow range of materials, limited multi-material printing capabilities, and consistency of quality. Continuing advances in AM technology and materials science are likely to address these limitations and are expected to drive wider adoption of AM in the A&D industry.

Size limitations: AM underperforms traditional manufacturing when it comes to the production of large A&D components.[43] AM providers are focusing their R&D efforts on addressing the size limitations of existing AM systems. Lockheed Martin is working with Oak Ridge National Laboratory (ORNL) on a big-area additive manufacturing (BAAM) system in which multiple deposition heads work in coordination to build large parts in an open environment, unconstrained by the typical envelope size.[44] BAE Systems developed a 1.2-meter titanium wingspar in collaboration with Cranfield University in December 2013.[45]

Scalability limitations: A&D companies that use traditional manufacturing and sourcing methods face the challenge of stocking large inventories, a majority of which may be unused. On the other hand, AM systems may not be able to scale up production when required. AM providers are working to improve the build speed of existing AM systems to support the industry's bulk-production needs.[46] As one AM expert suggested, AM systems where different parts can be produced concurrently or where production and unloading can happen simultaneously will help improve AM's scalability.

Narrow range of materials and high material cost: AM predominantly uses a narrow range of polymers and metal powder to manufacture A&D parts, and the costs of these materials are much higher than that of the materials used in traditional manufacturing methods. In 2013, AM thermoplastics cost about $200 per kilogram, while those used

Continuing advances in AM technology and materials science are likely to address these limitations and are expected to drive wider adoption of AM in the A&D industry.

in injection molding cost only $2.[47] Similarly, the stainless steel used in AM costs about $8 per square centimeter, which is more than 100 times the commercial-grade stainless steel used in traditional manufacturing methods.[48]

Over the next few years, advances in materials science are likely to expand the choice of AM materials and bring their cost down. One of the AM experts we interviewed said:

> "Traditionally, hardware capabilities have driven materials science developments. But we are going through a change now where material developments will start to lead hardware developments ... In the intermediate to long term, it should not be surprising to see AM companies getting into materials science in a pervasive symbiotic relationship—the marriage of technical science with materials science."

Limited multimaterial printing capability: AM systems that can print with multiple materials at a time offer huge design flexibility. Currently, only a few such systems are available.[49] Advances in multimaterial printing capabilities will help designers make a part using different materials with varying properties. For example, one section of an aerospace part can be built from a material with flame-retardant properties, while other sections can be made of an extremely lightweight material.[50]

Quality consistency: Quality consistency issues, especially in producing fully dense metal parts, result from excess heat that leads to stress and voids, particularly on layer boundaries. Repeatability can be improved by embedding controls within the machines so that in-situ dimensional accuracy is ensured, as well as by subsequently conducting automated inspections. According to one expert we interviewed: "Currently, the strength in the plane of layers is not uniform. Those are issues to be dealt with. In principle, you can deal with those quite well because you have access to each layer and the entire geometry. You can see every layer being laid down. I see these [issues] as temporary hiccups to getting good-quality parts, because you can, in principle, do a 100 percent computerized inspection in a completely automated process."

The way forward

AM'S capabilities speak to the core of the A&D industry's objectives and concerns. The technology enables design complexities that are hard to match with traditional manufacturing techniques. At the same time, AM helps reduce parts' weight, leading to improved fuel efficiency. The technology can also manufacture complex parts as single-component systems. And as discussed earlier, AM reduces the capital required to achieve economies of scale and scope, helping companies to enhance products and supply chains.

With these inherent attributes, AM is a natural fit for many A&D applications. It is not surprising that the technology has been increasingly adopted in the last three decades, starting from prototyping to end-part production in recent years. Figure 6 summarizes ways that AM can help A&D companies improve their production processes.

Figure 6. Where can AM help?

Manufacturing parts with complex designs
Manufacturing components that require extensive machining
Reducing parts' weight
Reducing complex assembly efforts
Speeding time to market

Figure 7. AM considerations/impact on companies' business functions

R&D/product development	• Choose components that favor AM over traditional manufacturing • Crowdsource ideas to break existing product design and manufacturing limitations
Supply chain	• Balance in-house manufacturing and outsourcing • Choose suppliers based on their AM capabilities • Explore co-production opportunities with suppliers and customers
Legal	• Be aware of IP issues • Understand regional and country regulations
Human resources	• Anticipate lower headcount needs • Look for talent with requisite skills in areas such as design and material sciences
Finance	• Make fixed and variable cost comparisons between AM and traditional manufacturing
IT	• Evaluate/reconfigure CAD/CAM systems • Integrate IT systems with R&D and manufacturing platforms

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There is little doubt that AM's penetration into the A&D value chain will grow. A&D companies should carefully assess how AM can help advance their performance, growth, and innovation goals. Companies' choice of AM paths will depend on their choice of strategic imperatives and value drivers.

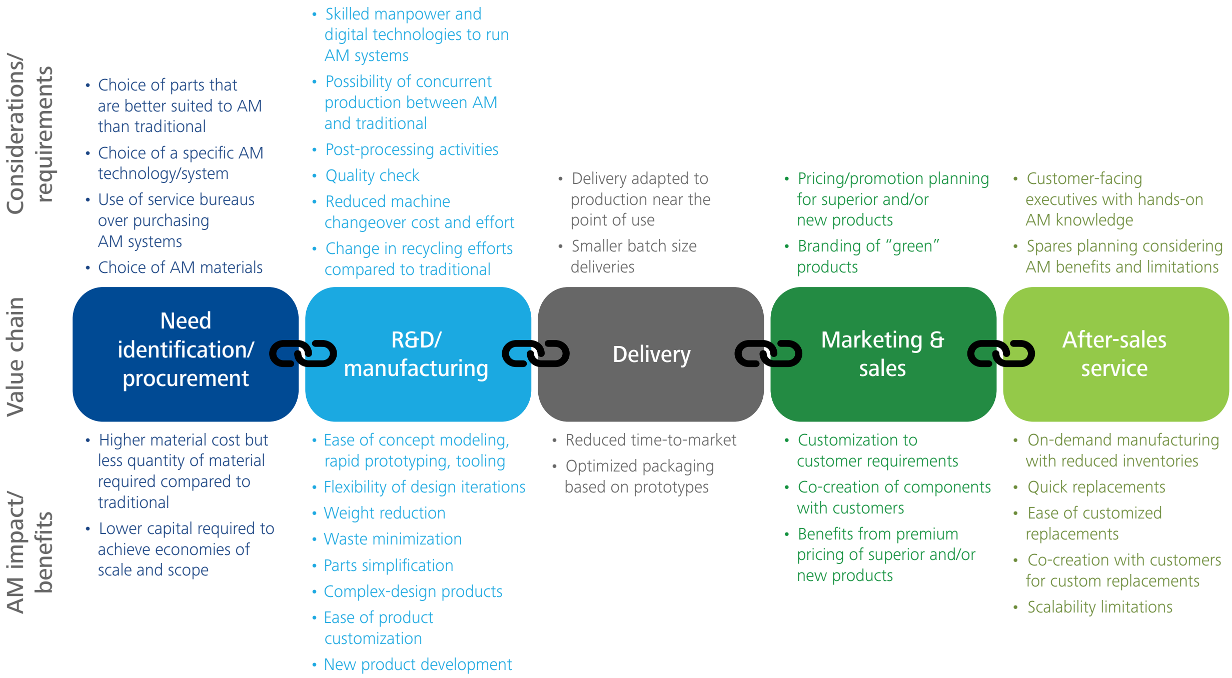
Historically, A&D companies have pursued path I, the least risky AM path. Even with no major changes in their product offerings and supply chains, companies can reap benefits by deploying AM in prototyping and tooling applications that help reduce product development time and costs. In the medium term, as AM technologies and materials science advance, companies are likely to pursue path III to build end parts with improved functionality. The prospect of additively manufacturing increasingly complex items at little additional cost will likely fuel the development of new products that can lead to growth opportunities within new customer segments. Also, AM's increasing use in the MRO industry may lead to a certain degree of distributed production. In the long term, A&D companies are likely to leverage AM for both product evolution and supply chain improvements. A combination of improved manufacturability and supply chain disintermediation could lead to changes in companies' business models.

As companies increasingly look to AM in pursuit of their strategic imperatives, they will need to factor various strategic considerations into their business functions (figure 7).

As shown in figure 8, depending on the extent of AM deployment, A&D companies will need to make changes that will allow them to reap benefits at each stage of the value chain. While AM opportunities, as well as the likely benefits from AM, are more significant in the earlier stages of the value chain, the technology's impact across the other stages should not be dismissed. Some benefits, such as parts simplification and weight reduction, can be obtained in current applications; others, such as production at/near the point of use, are foreseeable only in the longer term.

The comparison of what companies need to know and do and the benefits they could accrue highlights AM as an important element of the way forward for leading A&D companies.

Figure 8. Strategic considerations and benefits for AM adoption across value chain elements



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Deloitte Consulting LLP's supply chain and manufacturing operations practice helps companies understand and address opportunities to apply advanced manufacturing technologies to impact their businesses' performance, innovation, and growth. Our insights into additive manufacturing allow us to help organizations reassess their people, process, technology, and innovation strategies in light of this emerging set of technologies. Contact the author for more information or read more about our alliance with 3D Systems and our 3D Printing Discovery Center on www.deloitte.com.

Endnotes

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