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STUDY OF ADDITIVE MANUFACTURING USED IN AEROSPACE AND DEFENSE INDUSTRY

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ABSTRACT

Additive Manufacturing (AM), is also known as 3D printing, it is a manufacturing process that builds objects layer by layer using different materials such as metals, polymers and composites. It is important to understand that AM was developed with other technologies. A.M. exist with innovations areas like 3D graphics and Computer-Aided Design software. This paper highlights some of the key research in development of Additive Manufacturing technology. The Paper Also highlights on general steps involved in Additive manufacturing processes.The Additive Manufacturing techniques are also used for manufacturing of complex shapes used in Biomechanics such as human implants, Dental Implants. The focus of this paper is application of Additive Manufacturing in Aerospace as well as defense Industry.

I. INTRODUCTION

Additive Manufacturing (AM) techniqueis a result of developments in a variety of different technology. Like with many manufacturing techniques, enhancements in computing power and decrease in mass storage costs covered the way for processing the large amounts of data typical of modern 3D Computer-Aided Design (CAD) models within practical time frames. We have habitual to use powerful computers and other complex automated machines, sometimes it may be difficult for us to imagine how the pioneers struggled to develop the first AM machines. This paper highlights some of the key steps of development of Additive Manufacturing technology. Furthermore, we will discuss how the application of Additive Manufacturing has evolved to include greater improvement in function and embrace a wider range of applications beyond the initial intention of just prototyping.

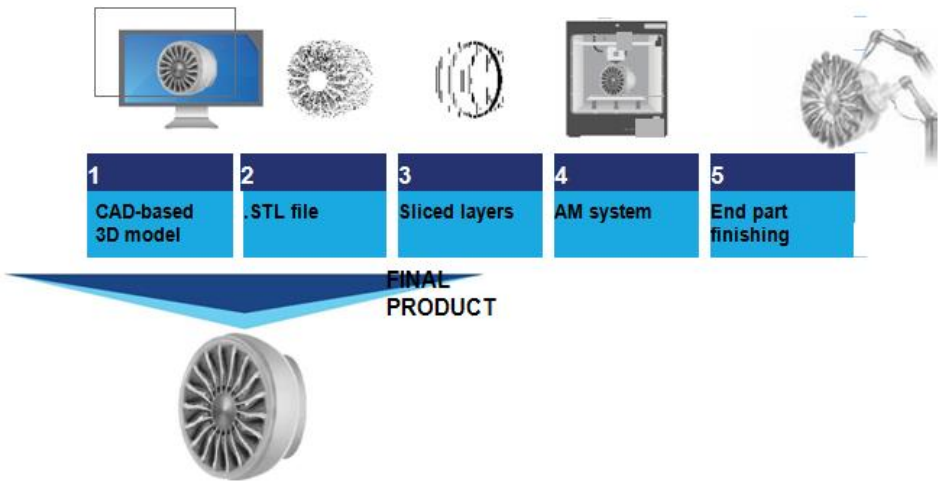


Figure 1. Additive manufacturing (AM) process flow

II. THE BENEFITS OF PRODUCING DIFFERENT A&D PARTS:

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.

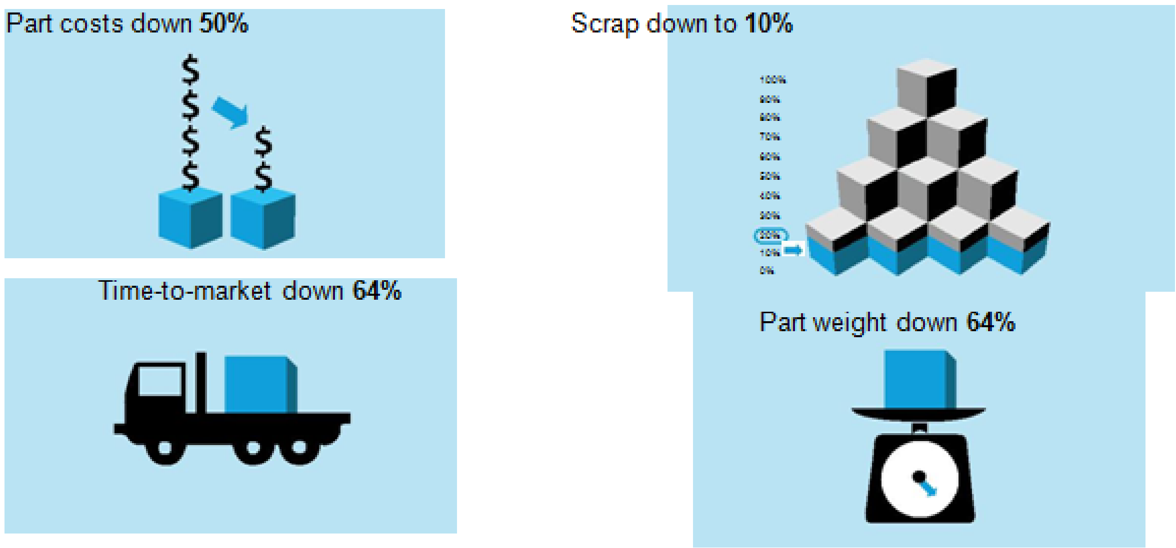


Figure 2. Examples of the benefits of producing different A&D parts

III. AM PATHS TO A&D COMPANIES' STRATEGIC PLANS INITIATIVES AND VALUE DRIVERS:

Its importance is derived from its ability to break current performance trade-offs in 2 fundamental ways. 1) AM reduces the cost required to achieve economies of scale. 2) It increases suppleness and reduces the capital required to achieve scope.

3.1 Cost 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 fences to entry into manufacturing for a given location.

3.2 Cost versus scope: The flexibility of AM facilitates a rise in the variety of products a unit of capital can produce, reducing the costs associated with production changes and customization and/or the overall amount of capital required.

Changing the inventory versus scale relation-ship has the potential to impact how supply Chains are configured, while managing the capital versus scope relationship has the potential to impact product designs. These impacts present companies with choices on how to implement AM across their businesses.

IV. THE 4 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 takes advantage of scale economics offered by A.M. 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'S CURRENT APPLICATIONS IN THE A&D INDUSTRY:

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 micro-gravity are foreseeable in the future. Figure3 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.

	Current applications	Potential applications
	• 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
As the AM technology evolves, its	• 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

Figure 3. AM applications in the A&D industry

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.

4.1 Path I: Stasis—The Path Currently Pursued By Most A&D Companies

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.

4.1.1 Reduced time to market: AM helpscompanies quickly build prototypes with the required fit, form, and functionality, thereby accelerating design cycles, reducing time to market, and giving organizations a competitive advantage. Research has shown that when A&D companies switch from traditional manufacturing to AM, they could benefit from time savings in prototyping ranging from43 percent to 75 percent, depending on the conventional techniques used 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.

4.1.2 Complex-design tools: AM's ability to create free-form designs helps in building tooling fixtures that are difficult or impossible to pro-duce 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.

4.1.3 Flexibility of design iterations: AM offersthe 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 for the Mars Rover test vehicles.[13]

4.1.4 Tooling at lower costs: AM not onlyenables companies to quickly design and test products, but also helps bring down the cost of manufacturing tooling and fixtures. A case in point is offered by the repair company Advanced Composite Structures (ACS).

4.2 Path Ii: Supply Chain Evolution— Limited Am Impact Expected In The Medium Term

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.

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 breatherpipes used in regional jetliners. 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.

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 beamto 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. 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."

4.3 Path Iii: Product Evolution-Am Raising The Bar For Product Performance In The Medium Term

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.

4.3.1 Complex-design parts: AM enables prod-uct designs and dimensions that are hard to create through traditional manufacturing, thus transcending existing design and manufacturing limitations. 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 maxi-mum performance. 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.

4.3.2 Intricate geometries: Parts with designssuch 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 hingeBrackets, 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. 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.

4.3.3 Waste reduction: Aerospace parts are builtusing expensive materials such as titanium, and it takes cost and effort to recycle scrap produced during machining. 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). 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 com-promising its mechanical properties.

4.3.4 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. These nozzles, used in GE's LEAP engines, are reported to be five times more durable than those produced using conventional methods.

4.4 Path Iv: Combined Supply Chain And Product Evolution— Am's Long-Term Role In Business Model Changes

4.4.1 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. 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. Savings will naturally multiply as more parts are fabricated using AM.

4.4.2 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. GE Aviation also plans to triple its AM staff over the next five years from a headcount of 70 in 2013.

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."

V. THE WAY FORWARD

AMs capabilities speak to the core of theA&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 threeDecades, starting from prototyping to end-partproduction 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

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.

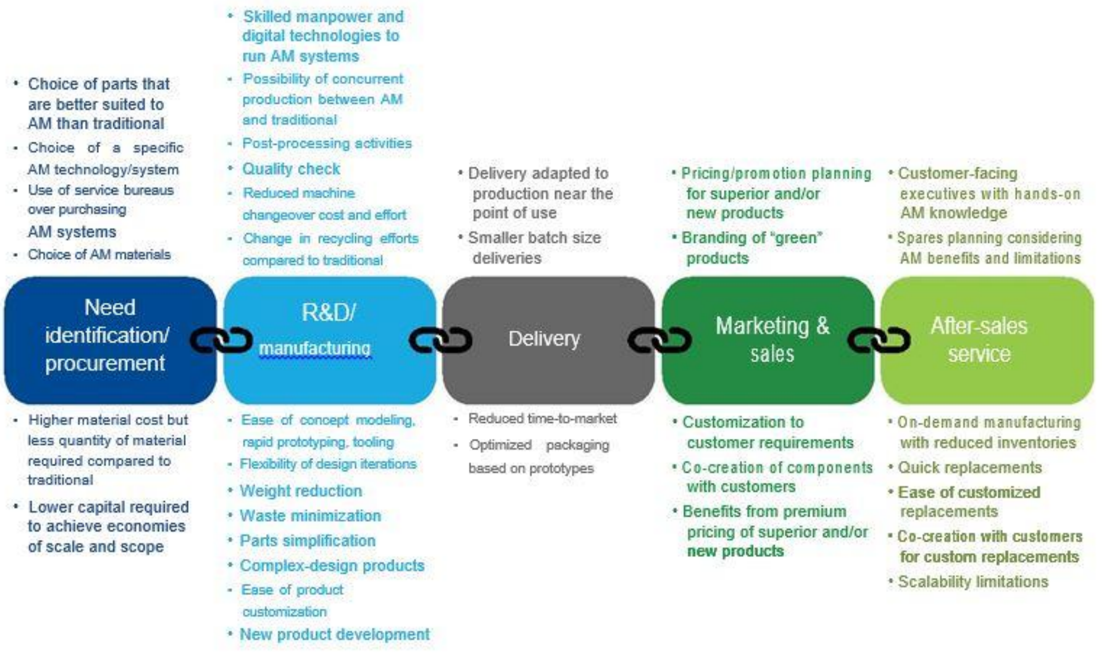
Historically, A&D companies have pursued path I, the least risky AM path. Even with no major changes in their product offerings and supply chains, companies can reap benefits by deploying AM in prototyping and tooling applications that help reduce product development time and costs. In the medium term, 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 andsupply 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.

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



VI. CONCLUSION

In this paper we had studied the various applications, limitation and implementations of Additive Manufacturing Processes used in the Aerospace and Defense. We studied that the use of additive manufacturing technics improves the production quality. Additive manufacturing technics in which component are produced by adding layer by layer. There is no subtraction of material hence no scrap generation process which reduces the production cost.

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