ADDITIVE MANUFACTURING - APPLICATION OPPORTUNITIES FOR THE AVIATION INDUSTRY

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ABSTRACT

Additive Manufacturing also known as 3D Printing is a process whereby a real object of virtually any shape can be created layer by layer from a Computer Aided Design (CAD) model. As opposed to the conventional Subtractive Manufacturing that uses cutting, drilling, milling, welding etc., 3D printing is a free-form fabrication process and does not require any of these processes. The 3D printed parts are lighter, require short lead times, less material and reduce environmental footprint of the manufacturing process; and is thus beneficial to the aerospace industry that pursues improvement in aircraft efficiency, fuel saving and reduction in air pollution. Additionally, 3D printing technology allows for creating geometries that would be impossible to make using moulds and the Subtractive Manufacturing of drilling/milling. 3D printing technology also has the potential to re-localize manufacturing as it allows for the production of products at the particular location, as and when required; and eliminates the need for shipping and warehousing of final products.

Keywords: *3D Printing Technology, Additive Manufacturing, Application in Aviation Industry, Aerospace Applications, Unmanned Aerial Vehicles (UAV), Defense Applications*

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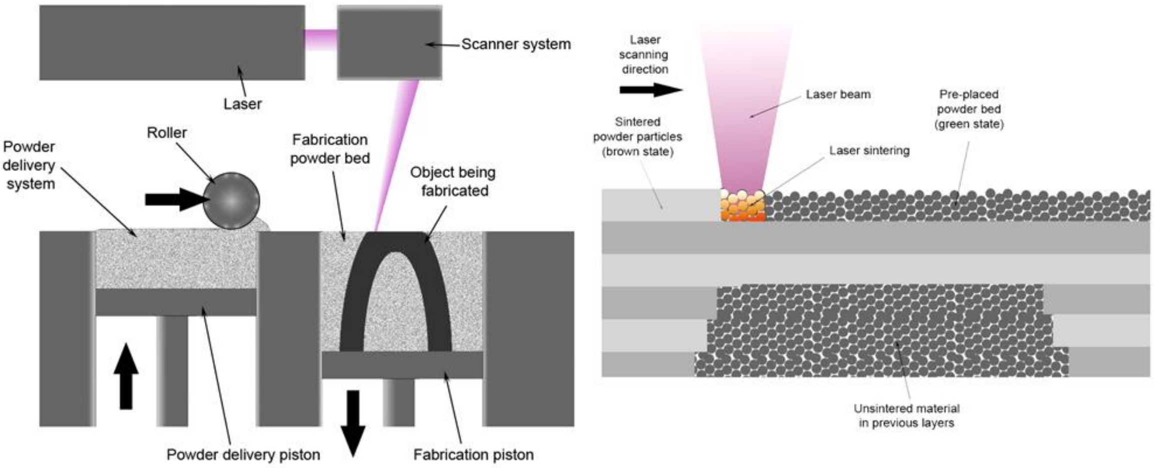
1. ADDITIVE MANUFACTURING

1.1 Definition

Additive Manufacturing (AM) also referred as "3D printing" is a process by which digital 3D design data is used to build up a component in layers by depositing material and fused together to create a single object as opposed to 'subtractive manufacturing technologies' (i.e., milling, cutting a work piece from solid block) (Anderson, 2013a). AM is opposite to the conventional manufacturing methods (e.g., extrusion and injection molding) in which the parts are molded into specific forms, or cut and formed from a block of material. AM is thus an alternative to these conventional manufacturing methods, while also providing cost efficiency and flexibility in production. With AM techniques such as laser sintering, it is possible to produce high quality industrial grade complex products (AT Kearney, 2015).

Fig.1 Selective laser melting system schematic



Source: Materialgeeza, 2008

1.2 Advantages

Karunakaran stated in Ipmd (2013) some of the advantages of additive manufacturing:

- "Assemblies without joints (elimination of welded joints),
- Produce complex shapes which are difficult/impossible by other means,
- Objects with gradient materials,
- Components of non-equilibrium materials (D'Aveni, 2015).

There are many other advantages of AM technology in comparison to the conventional 'subtractive' manufacturing techniques, which are described as follows:

1.2.1 Accelerated Time to Market

Along with the rise in competition in the market, the companies have to conceptualize and market their products quickly, which needs faster and accurate decisions during the conceptual phase. AM enables to produce prototypes easily and also materialize the concepts with necessary iterations as required. This enables faster and better decision making at early stages of product development and also helps to optimize profit (Huang et al., 2012). With AM, parts could be made directly from the CAD design. Some of the parts, considered impossible from conventional methods, could also be created easily using fewer machines (AT Kearney, 2015). Also, AM could be used in many industries for wide applications, and allows flexibility in design and customization. It also results in less scrap parts and has shorter production cycles (Anderson, 2013a). AM could be utilized along with Rapid Prototyping (RP) – which is the construction of functional prototypes.

1.2.2 Fewer Manufacturing Errors

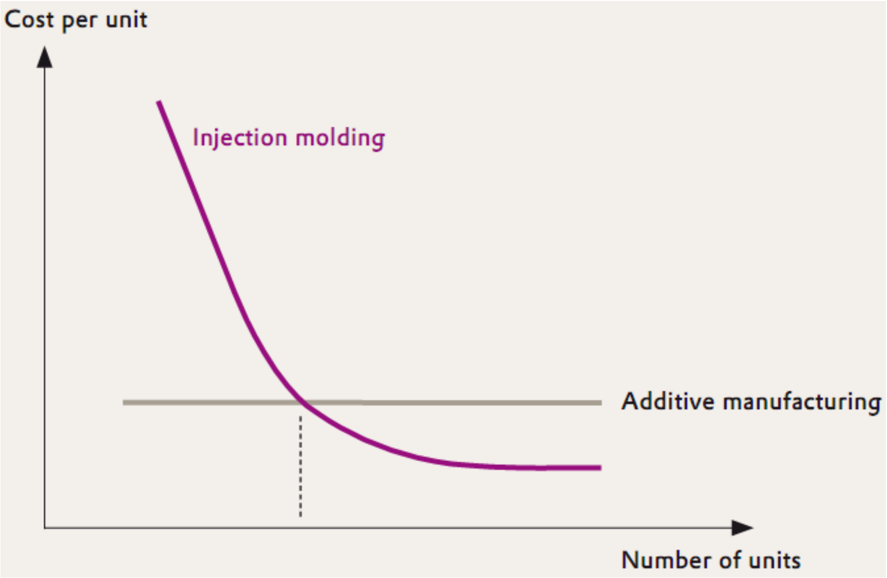
3D printers create a fully functional prototype, it enables designers to make inexpensive multiple iterations on the design. Possibility for such design optimization at the early stages reduces the chances of error in the final product output, and also minimizes the need for multiple product iteration at later stages which might be expensive and also lead to project delays (Huang et al., 2012).

1.2.3 Cost Savings

AM techniques over the traditional outsourced prototyping had helped businesses secure significant cost savings during the economic recession (Atzeni / Salmi, 2012). Now, AM is also used for series production. This provides Original Equipment Manufacturers (OEM) the opportunity to create a distinctive profile for themselves, provide flexible products and services to their customers, all supported within the cost saving benefits of AM techniques. AM also enables to manufacture small batches of products at low unit costs in comparison to the conventional method, as it does not need expensive mold creation or different machinery setup. In several cases AM would reduce a part's cost, compared to traditional manufacturing techniques by 90% (Bonezone, 2013).

AM also allows not only rapid cost-effective prototyping but also cost-effective batch production. Many product requests are for relatively high but limited piece counts. For these products, the conventional mass production technique is too expensive, as it needs costly molds and large plants. Thus, AM is furthermore beneficial for smaller batch productions. It has been found that AM technologies are significantly more economical for low-volume production than injection molding, as shown in Fig. 2. Injection molding is cost-effective only for mass production, because of the high cost of the mold required for this process (Monsheimer, 2010).

Fig. 1 Comparison of cost-effectiveness of additive manufacturing in comparison to the injection molding based on production volume



Source: Monsheimer, 2010

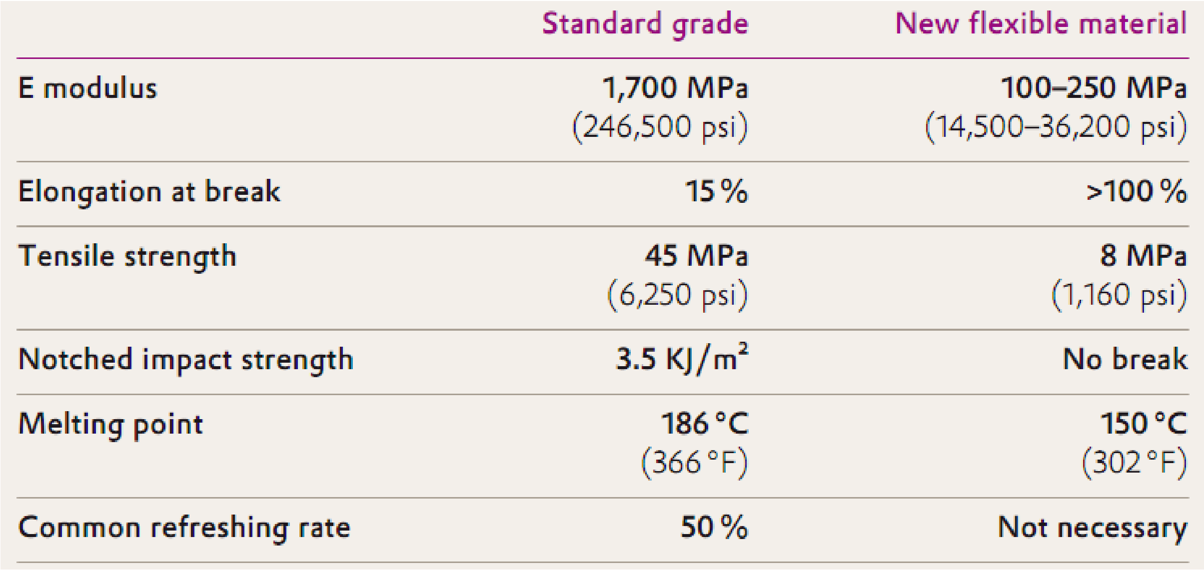
1.2.4 Greater Confidentiality

Using AM, a company can produce the product prototype in-house and prevent the leakage of designs and concepts. In today's competitive market, it is very important to maintain and protect the product development information and designs, as leakage might lead to lost opportunity (Huang et al., 2012).

1.2.5 New Functionalities Through Custom Tailored Materials

Thermoplastics are one of the materials that are ideal for AM. Thermoplastics are easy to pulverize, and can be selectively melted. Their chemical and physical properties can also be customized, which makes it suitable for AM uses. Also, custom tailored materials are being introduced for AM uses which enable new functionalities. For example, the German company Evonik developed an ultra-flexible polyamide (PA) that has 8 times the flexibility and 5 times the tensile strength of the standard material as shown in Fig. 3. Different industries have different requirement for materials. For example, the aircraft construction requires polymers that can withstand extremely high temperatures, and are flame resistant. Such optimized polymers enable new functionalities as per the need and demand, and could also clear ways to replace other conventional manufacturing materials, such as metals, with plastics (Monsheimer, 2010).

Fig. 3 Comparison of the material properties of a standard polyamide and an ultra-flexible polyamide specially developed for additive manufacturing



	Standard grade	New flexible material
E modulus	1,700 MPa (246,500 psi)	100–250 MPa (14,500–36,200 psi)
Elongation at break	15 %	>100 %
Tensile strength	45 MPa (6,250 psi)	8 MPa (1,160 psi)
Notched impact strength	3.5 KJ/m^2	No break
Melting point	186 °C (366 °F)	150 °C (302 °F)
Common refreshing rate	50 %	Not necessary

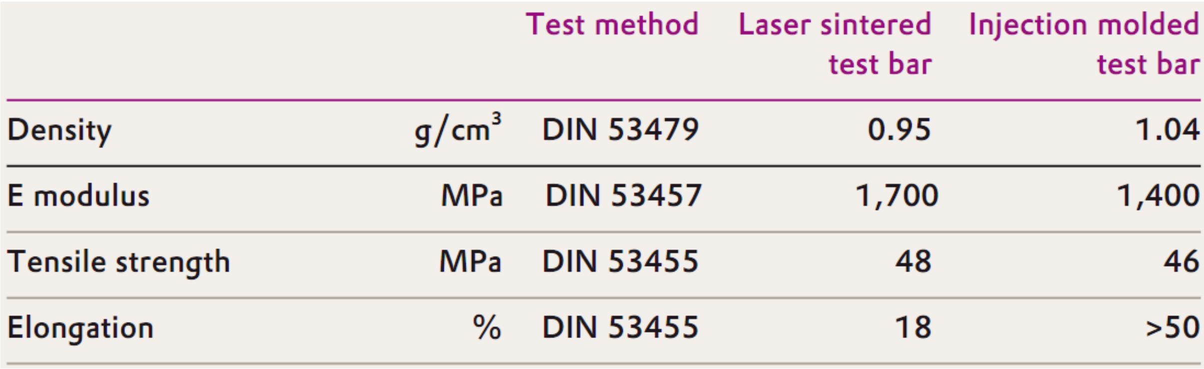
Source: Monsheimer, 2010

Similarly, AM techniques such as Electron Beam Melting (EBM), have high quality output such that it has been able to certify titanium alloys to the same ASTM and ISO standards as are in current use, which is a major plus point (Bonezone, 2013). But AM's true value proposition lies in the fact that it can produce parts that no other manufacturing technique can produce. These include novel porous structures and constructs that open up new markets and new opportunities for the products/components that truly did not exist before AM (Conner, B. et al., 2014).

1.2.6 Laser Sintering Enables Layers Only Millimeters Thick

In parts production using polymers, AM already competes with conventional extrusion and injection molding techniques, in terms of quality. Selective Laser Sintering (SLS), one of the AM techniques, is very well suited to plastics and can produce layers as thin as 0.15 mm. Much thinner layers (up to 0.08 mm) are also possible, although at this level of thickness the powder polymers used as raw material become very difficult to handle, because internal forces of attraction prevent the tiny particles from trickling (Frazier, 2014). Comparative measurements as shown in Fig. 4 indicate the performance of laser sintered AM technique in comparison to the injection-molded process.

Fig. 4 Comparison of the technical properties of a part produced by laser sintering and one produced by injection molding



		Test method	Laser sintered test bar	Injection molded test bar
Density	g/cm^3	DIN 53479	0.95	1.04
E modulus	MPa	DIN 53457	1,700	1,400
Tensile strength	MPa	DIN 53455	48	46
Elongation	%	DIN 53455	18	>50

Source: Monsheimer, 2010

1.2.7 Economies of Scale

AM with its capability to produce even low number of products at a very low cost margin could create an environment free of economies of scale. Additive manufacturing should be considered as a compliment to the manufacturing process, which provides cost savings and margin that could help job creation and growth. AM technology provides a competitive advantage in both time to market the product and return on investment. It thus, provides manufacturing capability to even the smaller manufacturing facilities serving the smaller markets. It thus gives manufacturing power back to the individual or small production levels (Conner et al., 2014).

1.2.8 Design And Redesign

Design and redesign is one of the important advantages of AM. With AM it is possible to produce a complex product through a simple design. AM enables to consolidate several individual parts of an assembly into a single, complex product output. This eliminates part numbers for assembly at later stages, inventory of separate parts, labor and inspection. It is also possible to redesign the parts relatively easily without the need for changing the mold or manufacturing machine. A redesign could be made in the parts to consist of thin skins and mesh structures, instead of solid material. This would save in manufacturing material, time and cost and result in a lightweight product. All this could be done easily with the redesign in the CAD design and get the final product 3D printed without the need for any other hassle or processes.

Also, parts could be redesigned using topology optimization, which is a method whereby the process decides mathematically to put materials in the parts to optimize the strength to weight ratio. The material used and the product weight have been found to be reduced by more than 50 percent in some cases, using these techniques (Anderson, 2013).

Also, a completely different product in comparison to the current product, or the stronger and lightweight product could be easily produced using the AM technique, by simply redesigning the part as desired (Anderson, 2013). It enables a design-driven manufacturing process - where design plays an important role and determines the production and not the other way around as it happens in conventional manufacturing method, where due the product facility and availability of molds for product designs, determine the production.

1.2.9 Elimination of Logistics Costs

Manufacturing will see a re-localization. Through affordable printers the production of certain products can take place anywhere and anytime and drastically reduce the costs of shipping and warehousing (Hagerty and Linebaugh, 2012).

"The technology opens up new design possibilities. Traditional manufacturing typically involves taking a big chunk of metal and cutting and shaping it into a useful object. The design is often kept simple to reduce the number and difficulty of steps and hold down production costs. With 3-D printing, everything is controlled by a computer code; an intricate design is no harder for the printer to spit out than a simple one."- David Burns (President of ExOne) (Hagerty and Linebaugh,2012).

Instead of ending the traditional manufacturing facilities, AM is being adopted by them, and utilized in the existing process to facilitate its advantages. 3D-printed tools, jigs, moulds etc allow set up of production lines more quickly. For example, in the field of aviation, cockpit and cooling-duct parts for aircraft are 3D-printed and then combined with other parts. 3D printing is as much a complement as a competitor to mass production (The Economist, 2013a).

Also, lightweight construction for airplanes is a key sector for additive manufacturing. Lightweight construction is an undisputed construction principle in the transportation industry, for example, where it is used to reduce fuel consumption and emissions (Liu et al., 2014).

1.3 Limitations

There could be certain limitations that OEMs might face regarding the AM technology in the beginning. The lack of an experienced AM partner might make it difficult for an OEM in the beginning, as it requires a bit of time and help. Also, the lack of budget and vision could be the obstacle to the wide scale adoption of AM techniques at this point, as it requires some capital costs at the beginning for the systems, while considering for a manufacturing facility.

Also, the lack of standard industry recognized standards for the materials, processes and testing methods could be another obstacle for the wide-scale implementation of AM techniques at present. For now, 3-D printing best suits products that are highly complex and need customization, for manufacturing in small volumes. The current limitation in build speed and maximum part size are also the challenges (Anderson, 2013). However, the process will get cheaper and faster along with the improvement in technology and wide-scale adoption (Hagerty and Linebaugh, 2012).

"*You need an economic and technical justification to manufacture a part in a certain way,"* Processes in certain industries, such as the aerospace industry, lend themselves better to 3D printing. For other industries, that follow different processes, the uptake is slow. *"It's a learning obstacle and it will take time for companies to change this (their processes for manufacturing)."* – Wohlers(Sharma,2013)

2. ADDITIVE MANUFACTURING PROCESSES

A number of additive processes are now available. Various classifications are found in different researches. Classifications based on 'layer deposition method' and 'state of materials' are presented in this report as follows:

2.1 Classification Based On Layer Deposition Method

They differ in the way layers are deposited to create parts and in the materials that can be used (Wong and Hernandez, 2012).

Table 1: Classification of based on layer deposition method

Type	**Technologies**	**Materials**
Extrusion	Fused Deposition Modeling (FDM)	Thermoplastics, eutectic metals, edible mate
	Fused Filament Fabrication (FFF)	PLA and ABS plastics
	Melted Extrusion Modeling (MEM)	Metal wire or plastic filament
Granular	DirectMetal Laser Sintering (DMLS)	Almostanymetalalloy
	Electron Beam Melting (EBM)	Titaniumalloys
	SelectiveHeatSintering (SHS)	Thermoplasticpowders
	Selective Laser Sintering (SLS) or Melting (SLM)	Thermoplastics, metal powders, ceramic powders
	Powder bed and inkjet head 3D Printing (PP)	Plaster
Laminated	Laminated Object Manufacturing (LOM)	Paper, metal foil, plastic film
Light Polymerised	Stereolithography (SLA) or SL	Photopolymer
	Digital Light Processing (DLP)	Liquid resins

2.2 Classification Based On State Of Material

Classification based on the criteria of material's state: liquid based, solid based, and powder based, are as follows: (Wong and Hernandez, 2012).

Table 2: Classification of Additive manufacturing technologies based on state of material.

Type	Process	Technologies
Liquid Based	Melting	Fused Deposition Modeling (FDM)
	Polymerization	Stereolithography (SLA) or SL
		Polyjet
Solid Based	LaminatedObject Manufacturing (LOM)	LaminatedObject Manufacturing (LOM)
PowderBased	Melting	Selective Laser Sintering (SLS) or Melting
		Electron Beam Melting (EBM)
		Laser Engineered Net Shaping (LENS)
	Binding	3D printing (3DP)
		Prometal

3. ADDICTIVE MANUFACTURING MARKET ANALYSIS

3.1 Global

According to the research from *'Markets and Markets'*, AM is growing in almost every manufacturing sector with a global additive manufacturing market of $1,843.2 million in 2012 and expected to grow at a CAGR of 13.5% to reach $3,471.9 million by 2017 (MarketsandMarkets, 2013). Another forecast from *'Forbes'* estimated the size of the emerging 3D printing industry to be $3.1 billion by 2016 and $5.2 billion by 2020 (Forbes, 2012). Additive manufacturing so far has tapped just 8% of its global market potential, according to industry experts surveyed by Wohlers. By that measure, the market opportunity could be $21.4 billion (DiChristopher, 2013). *'McKinsey Global Initiative'* expects the yearly economic impact of 3D printing technology to reach at least $550 billion by 2025 (Hasse, 2013).

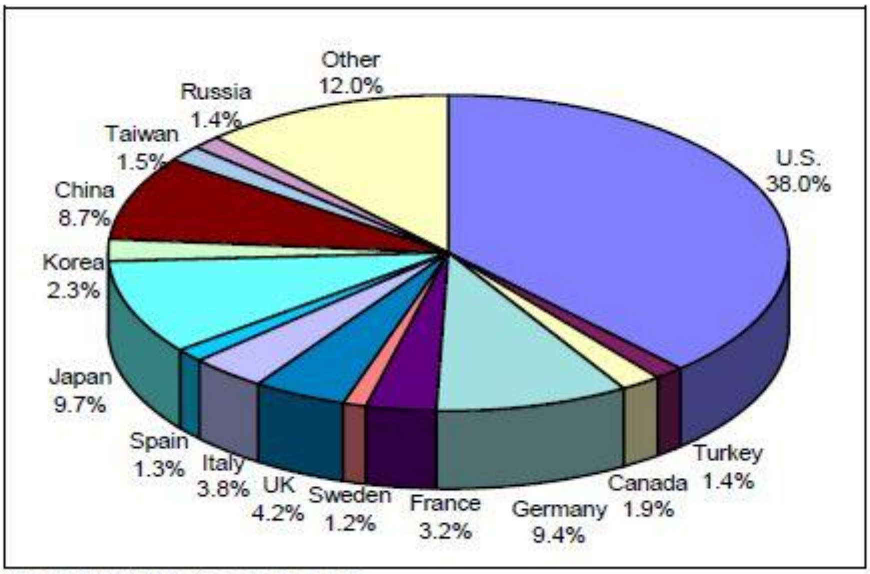
The Wohlers Report, 2011, showed a 37.4% increase in AM industrial system shipments, the highest growth in over 6 years. For the same year, the annual industry revenue for products and services was US$1.325 billion, a 24.1% increase over 2009. In the AM industry's 23-year history, its CAGR has been 26.2%. The report predicted the industry will ship 15,000 industrial systems per year by 2015, driven in large part by systems selling between US$5,000 and US$25,000, with annual revenues of US$5.2 billion by 2020 (Wohlers, 2012).

Market share by Country (Industrial AM Systems)

"Manufacturers from the United States, Europe and Australia are already investing heavily in AM as they sincerely believe that it will bring manufacturing advantage back to developed countries" – Guruprasad K.Rao (CEO, Imaginarium India Pvt. Ltd.)

Fig. 6. shows the percentage of cumulative industrial additive manufacturing systems installed by country from 1988 through the end of 2012. The U.S. continues to lead by a large margin. Japan, Germany, and China have the second, third, and fourth largest installed bases, respectively. The "Other" segment includes countries into which a relatively small number of AM systems have been sold. As of May 2013, 16 companies in Europe, 7 in China, 5 in the U.S., and 2 in Japan were manufacturing and selling AM systems. It has dramatically changed from a decade ago when it was 10 in the U.S., 7 in Europe, 7 in Japan, and 3 in China. Also, all of the metal powder bed fusion systems are manufactured outside the U.S. 7 manufacturers of these systems are in Europe and 2 are in China (Tctmagazine, 2013).

Fig.2 Percentage of cumulative industrial additive manufacturing systems installed by country from 1988 through the end of 2012



Source: Wohlers Associates, Inc.

Source: Tctmagazine, 2013

"China will ultimately become one of the largest and possibly the strongest [country] in applying and developing AM technologies" –Graham Tromans (Additive Manufacturing Consultant)

China currently lags behind US and few other countries. However, it is estimated to provide one of the biggest AM market growths in coming years. China has some of the world's largest 3D printers, including a 12-meter long machine that is used to print titanium wing and fuselage parts for short-haul aircrafts. China has also found a found a way to 3D print moulds in foundry sand, which could be a faster and more accurate way to cast metal. China has also utilized AM for its space program to make the seats for the astronauts. China eyes to upgrade its manufacturing potential into the future by the use of AM techniques; as the rising labor costs already takes away some of its advantages from the current manufacturing potential (The Economist, 2013a). Considering both the AM market and installed AM systems, China had only about 3.6% of the 3D printing market, compared to the nearly two-thirds of the market held by the US, and Europe. However, the AM market in China has been growing rapidly. In 2008, China's installed systems grew 39.7 percent, from 1,986 to 2,472 (Anderson, 2013a).

3.2 Aviation / Aerospace Market Segment for 3D Printing

Aerospace industry continuously pursues the improvement in efficiency of aircraft and reduction of air pollution. For these objectives to be met, the aircrafts should achieve weight reduction, and have lightweight parts. Also, the aerospace industry is highly characterized by the use of highly complex parts that are manufactured in small quantities and have high unit costs. Thus, this makes aerospace industry very suitable for the utilization of AM techniques.

Aerospace industry is already one of the three largest market segment for the AM technologies. Since, the manufacturing of complex parts in series production are very expensive, also due to the small lot sizes, aerospace industry has highly utilized AM techniques for various purposes. In 2011, 9.6% (US$115 million) out of the total US$1.2 million AM market was accounted for the aerospace market segment. (Gausemeier et al., 2011). AM is already being used for a various applications within the aerospace industry as mentioned below:

- Customized interior of business jets and helicopters,
- Structural parts of unmanned aerial vehicle (UAV),
- Turbine blades,
- Windshield defrosters,
- Swirler - fuel injection nozzle for gas turbine applications,
- Engine components by GE,
- Nozzles for rocket engines by NASA.

4. ADDITIVE MANUFACTURING (3D PRINTING) IN AVIATION/AEROSPACE

The involvement of military and defense sector has also played a huge role in the development and implementation of AM to the aviation/aerospace sector. For example, in China the AM-created parts are being used in the J-15, J-16, J-20, and J-31 jet fighters, the Y-20 transport aircraft, and the C919 commercial airliner (Anderson, 2013b).

4.1 Advantages for Aviation Sector

According to Airbus, an aircraft produced entirely through additive manufacturing would be 30% lighter and 60% more cost-effective than current machines. The Boeing 787 aircraft has more than 30 SLS-sintered components installed (Lyons, 2012). It is expected that such applications would further increase in the future. High cost of manufacturing aerospace parts has remained a challenge across the supply chain. However, AM techniques allow the use of different materials, optimized design, flexibility in design and manufacturing, and more energy efficient processes, which are highly beneficial to the aerospace industry. Use of AM has resulted in part optimization (improved part design requiring less raw material). It is more sustainable (lower energy consumption over the product lifecycle, resulting in a reduced CO2 site footprint).

A joint study by EADS and EOS, on the DMLS technology (one of the AM techniques), utilized for the re-design and production of the Airbus A320 nacelle hinge brackets, highlighted the potential cost and sustainability benefits of the DMLS technique during the process. By using the optimized design, energy consumption over the whole lifecycle (including manufacturing and operational phase) of the brackets was lowered by almost 40%. One of the advantages of such AM techniques is that the process itself uses only the material that is really needed to build the application. Thus the consumption of raw material can be reduced by up to 75%. The optimized design for the engine cowling hinge itself could reduce the weight of the aircraft by 10 Kg. Weight reduction is a very important factor in aviation and this could result in benefits regarding the savings in fuel consumption. For the door hinge parts, it was found that the CO2 emissions over the whole lifecycle could be reduced by almost 40% over by optimizing the design. The consumption of raw materials was reduced by 25% compared to the conventional rapid investment casting.

Laser additive manufacturing (LAM), has two main benefits in aircraft production, cost and efficiency. In January 2013, China produced the world's largest 3D printed titanium component - a 4 meter long primary load-bearing structure that is supposed to be used in China's C919 commercial airliner, using laser metal deposition. LAM was also used to produce a three-meter long central wing spar that will be used in COMAC's C919 passenger jet. The technology was also used to manufacture C919's front windshield frame in 2009 and a central wing rib in 2010. The windshield frames were to be purchased from a European company at a price of USD 500,000 per frame, with a two-year manufacturing cycle. In 2009, however, the frame was produced in China in only fifty days at one-tenth the cost as estimated for the conventional manufacturing technique. Similarly, the roughcast weight of the 3D-printed aircraft wing-rib was only 136 Kg, which is 91.5% less than the expected 1,607 Kg weight as obtained from the traditional forging method (Anderson, 2013b).

Also, compared to traditional methods of subtractive manufacturing, little scrap or waste is produced by additive manufacturing. LAM has been identified to save almost 90% of the raw material at 5% of the cost of the same part produced through subtractive manufacturing in some cases. LAM can also be used to repair damaged parts. Instead of scrapping and replacing damaged components, metal powder can be fused directly onto damaged areas, restoring the original strength of the component. Moreover, LAM could produce complex structural parts that would be extremely high-cost or even impossible to create using traditional manufacturing processes. In aircraft design, such benefits as provided by the AM techniques allow engineers to optimize the weight of the aircraft (Anderson, 2013b). The final output in terms of production could also be improved if small but multiple parts are made in the same production run (Conner et al., 2014).

4.2 Present Utilization In Aviation/Aerospace

In the US, LAM has been used in the production of nonstructural flight hardware components for Air Force fighter jets (F-35). It is also used in the Honeywell's T-Hawk Micro Air Vehicle, where the used polymer parts are created using laser sintering. Boeing has also sought the supply of titanium alloy parts for structural components on its commercial aircraft. These parts would be used as the substitutes for the currently used standard machine grades of alloy. Boeing has also made more than 20,000 parts using 3D printers that have been used in military aircraft, and there have been no incidents of a single part failure until now (Lyons, 2012).

NASA has also been utilizing the AM technology for various applications. A Mars rover being designed for future missions is supposed to use about 70 AM (using FDM technique) created parts including the pod doors, camera mounts and housings (Anderson, 2013b). NASA is also committed to send a 3D printer onto the space station by 2014, and aims to gradually increase the self-sustaining ability of such missions, and reducing their dependency for resupply of parts and components from earth. AM could be the solution, as it could produce the parts, tools and components in the space from only the raw material already available, for the replacement and maintenance purposes. Also, as per the use of the AM technique, the parts could be recycled and used to make new parts. This reduces the cost and time needed to manufacture and transport the space parts (Lyons, 2012).

An AM start-up company in the US has already tested the use of 3D-printing (in zero gravity) for outer space use. It has been demonstrated that the process would work successfully while also providing the advantages of 3D reduced material wastage, and reduced need for human involvement. AM is being seriously considered as an ideal manufacturing technology for outer space applications (Lyons, 2012). In smaller components, the European Aeronautic Defense and Space Company (EADS) Innovation Works printed metal hinges for engine covers that met performance requirements in tests for conventional parts in 2011. More recently, EADS used LAM to print an Airbus A380 wing bracket with a more complex shape than the original bracket design (Anderson, 2013b). In China, the J-15 variant fighter uses many titanium main bearing components printed using additive manufacturing, including the complete nose landing gear. Also, China's Y-20 transport aircraft, the J-16, J-20, and J-31 aircrafts, are also being designed to use 3D printed titanium and M100 steel (Anderson, 2013b). GE Aviation is also utilizing the AM technology for creation of parts for the hot side of turbine engines. Aerospace industry has highly utilized the metals-based additive manufacturing, in addition to the other polymer based AM techniques such as the FDM (Frazier, 2014)

4.2.1 Unmanned Aerial Vehicle (UAV)

The flexibility of AM technology for design and redesign has allowed for the use of trial-and-error approach for the design and construction of an Unmanned Aerial System (UAS). The first UAS made using the AM technology highly utilized the benefits of AM technique for trial-and-error approach. The builders of this UAV opted for design, print, test and repeat process, which was only possible because of the benefits as possible from AM technology. It also saved a lot of time and money. This UAV project was backed by the company 'SelectTech Geospatial' and only had two person team, with a shoestring budget (Grimm, 2012b). FDM based 3D printer was used for the construction of UAS parts (all parts excluding only the engine and landing gear) (Grimm, 2012a). With an airframe made entirely of FDM's ABS, it became the first 3D-printed UAS to do so (Stratasys, N.A.).

Complete designs and production of UAV parts and components using the AM technology is already on the verge of becoming a viable industry. 3D-printing can construct an UAV functional prototype ready to be used. The parts built with the SLS technology and Windform materials are light-weight, durable and performing. Another company, Aurora Flight Sciences Corp. in Cambridge, also uses FDM to manufacture UAVs as shown in Fig. 7. The UAV was 3D printed using a commercial, off-theshelf material called Ultem 9085. The UAV which weighs only 3.3 lb, and was constructed in 58 hours, and cost less than US$1,750 to build (Eitel, 2013).

Fig.3 Aurora's entire structure printed using FDM technology

Source: Eitel, 2013

"Printing the UAV helps minimize logistics because it reduces the number of parts going into the plane and slashes material usage. The technique also helps keep inventories low because it is location agnostic."

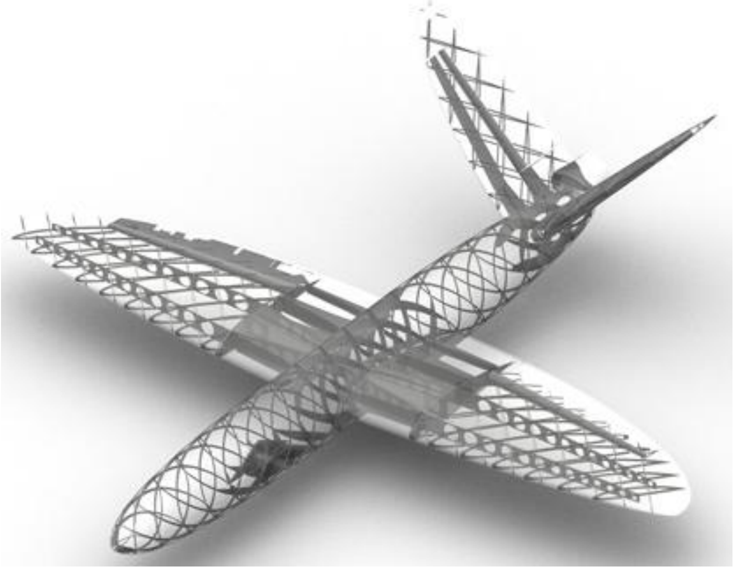
FDM isn't as strong as composite and lags a bit on the modulus-to-weight ratio. However, for small UAVs, its provides an immense benefit of design freedom, low cost and less build time. From various such small 3D printed UAV projects, it has been determined that the performance of such small UAV are almost close to that of the conventional composite UAVs (Coykendall, 2014).

Advanced AM technologies such as SLS, FDM and Composite Lay-up allow for the creation of rigid and lightweight UAV parts and structures not otherwise achievable with conventional manufacturing methods. Due to such advancements of technologies, UAVs are experiencing performance improvements as well as endurance enhancements due to the lightweight structure.

Another additive manufactured UAV, the SULSA (Southampton University Laser Sintered Aircraft) flew in 2011. The UAV was built in only four structural parts using the nylon based SLS technology. The four components consisted of the fuselage and rudder fins, the nose cone and two outer wings – which all simply clipped together to form an UAV with a 2m wingspan (Richardson, 2011). AM allows for the construction of a highly-tailored UAV to be developed from concept to first flight in days. Construction of a similar UAV using conventional method and materials, such as composites would normally take months, before the first flight. Also, since no tooling is required during the manufacturing process, complete changes to the shape and scale of the UAV can be made during the design stages at no extra cost. (Green Car Congress, 2012).

Even the complex aerodynamic structures can be manufactured cost-effectively and quickly from CAD design data using AM technology. Movable parts like flaps or hinges for example can easily be integrated into the wings or body within a single manufacturing operation (EOS, N.A.).

Fig.4 ***SULSA structural design*****.**



Source: EOS, N.A.

4.2.2 Aerospace

Aerospace designs are often made of titanium and are complex structures. AM technology in this segment is mainly used for preproduction and R&D, and not volume production yet. The 3D-printed parts include brackets and components for the fuselage and engine. The components are generally made in moderate volumes of thousands. However, low batch volumes, special materials and complex designs make it suitable for AM technology to be involved in the aerospace market segment.

Nine of the NASA centers use AM technology based manufacturing (Eitel, 2013). NASA also recently used AM technology (SLS based technique) to make the 3D-printed rocket injector, which is the largest 3D-printed rocket engine component NASA ever has tested, and generates 20,000 lb of thrust. The 3D-printed rocket injector was successfully tested, and further brings AM based technology to much wide-scale adoption and acceptance, in the field of aerospace. The injector part was made using the nickel-chromium alloy powder for SLS based process. One of the key elements to reduce the cost of the rocket engine parts is to minimize the number of components. By using the AM method, the rocket injector could be built in only two parts. However, a similar rocket injector manufactured from a conventional manufacturing method consists of 115 or more parts assembled. Fewer parts need fewer assembly. This along with the reduction in material usage highly accounts for huge cost savings.

Also, the rocket injectors manufactured traditionally using conventional methods take months to make because a lot of measuring has to be done and it has to be exact. AM allowed design and redesign in the CAD design data which was then 3D-printed into only two separate builds, attached together into a full-scale rocket injector (Eitel, 2013). A US based company, 'Made in Space', is also working with NASA to soon send a 3D printer that would be used in space to print tools for the crew of the International Space Station. Innovations like additive manufacturing, or 3D printing, foster new and more cost-effective capabilities in the U.S. space industry - NASA

4.2.3 Aircrafts

Boeing already makes about 300 different smaller aircraft parts using 3-D printing, including ducts that carry cool air to electronic equipment. Some of these ducts have complicated shapes and had to be assembled from several different pieces while using the conventional manufacturing method, resulting in high labor costs (Hagerty and Linebaugh, 2012). However, the same parts are reported to be successfully made using AM method at a cost savings of 25% to 50% per part (Wee, 2013).

Honeywell also utilizes AM method to build heat exchangers and metal brackets (Hagerty and Linebaugh, 2012). Also, it is very difficult to find spare parts and components for the old aircraft models during the MRO or repair requirements. Such rare spare parts are also being 3D-printed, and is one of the potential markets for the AM industry. For example, 3D-printing was used to build spare parts for leaking toilets on the ageing McDonnell Douglas MD-80 jets. The production of these aircrafts had ceased long ago and it is very difficult to find the specific spare parts. The spare part for MD-80 jet was 3D-printed using the aerospace-grade plastic (which does not ignite or produce toxic fumes if burned) (The Economist, 2013b).

A typical F-18 fighter jet also uses several of the 3D-printed components. A typical F-18 fighter jet contains some 90 3D-printed parts (for example, parts of the cockpit and cooling ducts) (The Economist, 2013b).

4.2.4 Engines

GE Aviation is one of the companies that is actively engaged in the field of AM technology for applications in aircrafts and engines. In 2012 it acquired *'Morris Technologies'* and *'Rapid Quality Manufacturing (RQM)'*. GE Aviation has used additive metals in the production of its next generation jet engine, the 'LEAP 56'. The AM technology has been currently used for the production of parts such as the fuel nozzles, which has a very demanding application in a harsh environment. This needs for the special material to sustain such working conditions, and AM built additive metals have been found very suitable for such purposes (Huang et al., 2015).

GE Aviation aims to produce more than 32,000 complex metal parts annually using the AM methods (19 nozzles per engine and 1,700 engines per year) (Anderson, 2013). By 2020, GE expects to 3D-print tens of thousands of such parts for its jet engines alone (The Economist, 2013b). *'Pratt & Whitney'*, another aircraft engine manufacturer, is also using the process to make blades and vanes in compressors inside jet engines (Hagerty and Linebaugh, 2012). Many other companies are also expected to introduce additive metal parts into the future aircraft engines, airframes and other aerospace applications.

"We're saving probably on the order of 50 to 75% in total cost," "That can be total material cost. It can be labor. It can be the design time," –Gareth Richards, (LEAP program manager at GE Aviation)

4.3 Future Potential for Aerospace/Aviation

According to one of the research reports (Gausemeier et al., 2011), the aerospace industry was identified to be one of the most promising business opportunities for the application of AM in the future as well.

Many manufacturers jumped on board and have been increasing their investments into AM-technologies. Thereby, they succeeded to improve the ratio of functionality and costs of AM technologies. Functional-driven design is the key to success, and AM is mainly used for manufacturing critical parts or for low scale production.

"Someday, Boeing should be able to make an airplane wing without cutting or bending any metal" – Michael Hayes (Design engineer, Boeing) (Hagerty and Linebaugh, 2012)

Production of aircraft wings using AM method could be one of the potential applications in the future. The wings could be made, layer by layer by fusing powdered metal or other materials using AM machines. Although AM technology has been around for 25 years, it had been mainly used for making models, prototypes and smaller items. Now big manufacturers including Boeing, GE and Honeywell are exploring ways to use it to make large scale parts pieces in much higher volumes.

The application of AM in the defense industry is also expected to grow as new techniques are developed and as additional materials are introduced. Military and aviation fields are especially suitable for the adoption of AM technology. AM is still expensive and not much suitable for mass manufacturing, but parts component manufacturing in the defense industry that require fewer part orders can already benefit from the technology.

Currently, there are few options for AM using carbon fiber parts. One of the challenges is the cost of material and the scale of production required to make it competitive. However, there are some technologies that produce nanofiber-impregnated materials. Such materials boost mechanical rigidity and resistance to chemicals and vibration. This could soon find its way into the aviation/aerospace application. For example, wing deflection in UAV's additive design could soon be addressed with carbon fiber to allow wider wingspans (Eitel, 2013). According to one of the research reports, within the aerospace industry, the production of aircraft has been selected as the most promising field for AM technologies in the future. The scenario for customized parts requirement in the aircraft production could highly fosters the application of AM technologies (Gausemeier et al., 2011)

5. CONCLUSION

3D printing 'Additive Manufacturing' has received a lot of attention and buzz in the industry these days because of the economic and technological advantages it provides. It's mainly relevant to aviation industry in terms of advantages like weight reduction, reduction in use of material, reduction in manufacturing cycle, ease in manufacture of complex components etc. Such technology should be further encouraged and implemented readily and widely as it has the potential to solve various issues ranging from fuel cost saving (weight reduction) to air and noise pollution reduction, and also provide an economic boost to the aviation / aerospace industry as a whole.

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