Current Trends of Additive Manufacturing in the Aerospace Industry

L. Jyothish Kumar and C.G. Krishnadas Nair

Abstract Additive Manufacturing offers unmatched flexibility in terms of part geometry, material composition and lead-time. It is moving towards revolutionizing the aerospace manufacturing sector through production of highly complex, light-weight parts with reduced material waste. It can also be employed for repair of complex components such as engine blades/vanes, combustion chamber, etc. Complex geometry thin walled aircraft engine components and structures, difficulty in machining of materials are other main factors forcing aerospace sector to adopt the use of additive manufacturing technology. In this paper an attempt has been made to explore the additive manufacturing research and development activities in aerospace industry.

Keywords 3D printing · Additive manufacturing · Free form fabrication · Aerospace application

1 Introduction

Aerospace industry is one of the important adopters of Additive Manufacturing (AM) technology for prototyping, testing and production of end use parts. Laser Metal Deposition, Laser Cusing, Direct Metal Laser Sintering, Laser Melting and Selective Laser Melting are the major AM technologies used to produce aerospace parts.

As per the recent survey, only aerospace applications accounted for 12.3 % in the global Additive Manufacturing field. The survey also predicts that the AM sector is expected to grow from $1.5 billion industry to $100 billion within the next 20 years and much of this growth is accounted from the aerospace sector only [1].

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2 Background

2.1 Additive Manufacturing Application for the Aerospace Industry

The aerospace industry demands stronger, lighter and more durable components. Today Additive Manufacturing technology creates new possibilities to meet these challenges. Also the aerospace industry has incorporated AM process from concept design to end use parts and repairs. The areas of applications include rapid prototyping of components in the design phase using plastic and metal followed by making of dies/mould/tools for mass production and direct manufacture of complex shape metal parts, repairing of damaged parts instead of scrapping or replacement of damaged parts.

Laser Metal Deposition (LMD) Technology is the best process to repair aerospace components. In case of LMD for repair the metal powder will be directly fed onto the damaged portion of the part and laser cured, restoring the original strength of the part.

Currently machining, forging and other conventional processes are producing the aerospace parts. There is an extreme waste of highly expensive material in the conventional manufacturing processes and only less than 5 % of the original material is the content in the finished part. In case of Additive Manufacturing there is maximum utilization of material and also produces near net shape parts.

In case of aero engines, the increase in the operating temperature will have direct impact on fuel efficiency. AM has the potential to process higher temperature materials such as nickel alloys and inter metallic materials which are difficult to cast and machine. These materials are also used at higher temperatures. The process has flexibility to produce sophisticated component assemblies, with varying shape, composition, structures and properties, as required by the designer. Replacing the conventional method of forging/machining of several components and assembling them for, e.g. assembled turbine disc with blades, assembled compressor discs with blades, stator and rotor turbine vane assemblies, etc.

2.1.1 GE Aviation—Leap Engine Fuel Nozzle Production Using Additive Manufacturing

GE Aviation has been evaluating Additive Manufacturing for over a decade and now it has successfully produced ***Leap*** **Engine Fuel Nozzle** in **cobalt chrome** by laser AM melting process as shown in Fig. 1.

The Leap engine fuel nozzle has already cleared ground-based engine testing and has been certified for use on civil aircraft. The AM part has replaced *an assembly of 20 components* with reduced cost, weight, without joints and improved performance.

Fig. 1 Laser sintered leap engine fuel nozzle in cobalt chrome

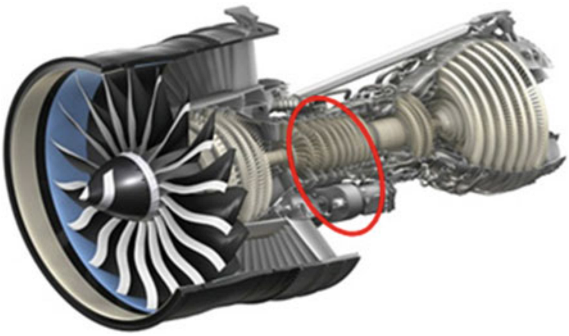


Fig. 2 Leap engine (nozzle indicated) *Courtesy* GE aviation

As shown in the Fig. 2 on each LEAP engine there are 19 fuel nozzles. By 2018, it is expected that the production volume increase from 25,000 to 40,000 parts, and by 2020 more than 100,000 parts will be manufactured [2, 3].

2.1.2 SAFRAN R&D Employs Additive Manufacturing for Developing Engine Components and Aircrafts

SAFRAN Group has identified additive manufacturing process as a breakthrough technology for a number of engine components for development of prototype and engine both Turbomeca and Snecma. Turbomeca, which makes helicopter engines and Snecma aircraft engines, extensively used this technology in the design phase. As shown in Fig. 3 Snecma has guide vanes for the silver-crest business jet engine and manifold for Vinci rocket engines, hydrogen turbo pump. Snecma has successfully used the technology for speedy implementation of design changes and also for repair of components. Extensive researches have been under taken to develop complex assemblies as integrated single component by this process. Examples are guide vane assemblies, integrated fuel manifold and combustion chamber and the like [4].

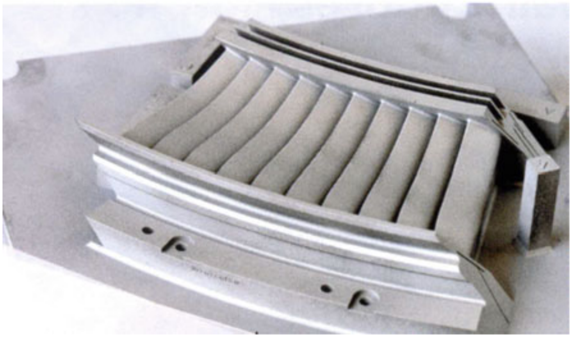


Fig. 3 Engine stator vane aircraft in high temperature alloys

Fig. 4 The first test piece produced on the M2 cusing machine (*Courtesy* NASA/MSFC/Andy Hardin)

2.1.3 NASA Creates Complex Rocket Injector Using Additive Manufacturing

NASA engineers used Additive Manufacturing technology to produce intricate metal rocket injector part (as shown in Fig. 4) for their next-generation Space Launch System (SLS) J-2X engine.

Rocket injector was manufactured from selective laser melting (SLM) additive manufacturing process using nickel–chromium alloy powder. The traditionally manufactured injector had 115 parts and 3D printed injector had only two parts.

Additive Manufacturing process considerably reduced the manufacturing time needed to produce injector part from months to weeks. The part was built into single piece without joints, which was structurally stronger and more reliable leading to the overall safety of the vehicle. It was a significant improvement in saving time and cost for NASA. This part will undergo structural and hot-fire tests and finally will be used in the J-2X engine by 2017 [5].

Fig. 5 Cabin bracket for the Airbus A350 XWB made of titanium, manufactured using the laser CUSING technology (*Courtesy* Airbus)

2.1.4 Additively Manufactured Titanium Component in Airbus A350 XWB

The leading commercial aircraft manufacturer Airbus has been increasingly *gaining the importance* of Laser Melting of Metal Powders in aircraft manufacturing.

The *'Cabin bracket connector'* (shown in the Fig. 5) used in the Airbus A350 XWB. The bracket was additively manufactured using Laser CUSING (Concept Laser GmbH) technology. Earlier this part was milled and machined out of aluminium alloy and now it is a 3D printed part, which is made out of titanium (Ti) powder material with a more than 30 % weight reduction. Milling of aircraft parts leads 95 % waste, which can be recycled where as with Laser Cusing the percentage of waste is only 5 %.

In AM process tools are not required to produce functional sample part thereby eliminating the tool cost. This also helps in identifying early stage design errors and design optimization. Earlier Airbus projected 6 months to develop component and now it has reduced to 1 month [6].

2.1.5 Fused Deposition Modelling Reduces Tooling Cost and Lead-Time to Produce Composite Aerospace Parts

Advanced Composite Structures (ACS), a US-based company produced a camera fairing (as shown in Fig. 7) which is used by the military aircraft in forward looking infrared camera. The Fused Deposition Modelling technology (FDM) machine from Stratasys used to build layup tool directly from a CAD data. FDM tooling can be produced in a single day compared to several weeks for *Computer Numerical Control* (*CNC*) *tooling*. The technology helped to reduce cost and time in developing layup tool (shown in Fig. 6). FDM tool cost was $400 compared with USD CNC tool of $2000. Also the lead-time to produce FDM tool was between 2 and 45 days in CNC, which shows a significant reduction in lead-time and cost [7].

Fig. 6 FDM-layup tool

Fig. 7 FDM-layup tool produced the aircraft camera fairings

2.1.6 Boeing Using 3D Printing Technology

3D Printing technology is being significantly used by Boeing. According to a news source (*Geek Wire*), around 300 aircraft production parts are made out of 3D printing technology, on 10 different aircraft production programs. At present it is projected that more than *20,000 non-metallic* additive manufactured parts are used on their vehicles. The company spokesman Nathan Hulings says "The *F/A-18 Super Hornet has approximately 150 parts in the forward fuselage area that have been produced through selective laser sintering*" [8].

At present the company only uses non-metallic 3D printed parts on production programs and evaluating other materials like metals and alloys.

2.1.7 Lockheed Martin Space Systems Company Demonstrates Digital Production Innovations

Additive Manufacturing of Titanium Parts

Lockheed Martin Space Systems Company is employing 3D printing technology to produce satellite parts out of *titanium material* to reduce cost, cycle time and

Fig. 8 3D printed titanium part

material waste. At present, the company is metal 3D printing technology to develop 3D printed satellite parts (as shown in Fig. 8) and plans to increase the process to manufacture complex parts in the future [9].

2.1.8 Rolls-Royce 3D Prints Largest Component for Trent XWB-97 Engine

Rolls-Royce plans to test the largest engine part '***front bearing housing***' as shown in Fig. 9 made by 3D printing technique. The intricate design and large titanium front bearing part which is having a 1.5 m diameter and 0.5 m thick, *holding 48 aero foils was manufactured using 'Electron Beam Melting' additive manufacturing process.* This process builds complex, solid metal parts by melting metal powder using focused electron beam. The front bearing housing holds the bearing for the low and intermediate pressure compressor inside Rolls-Royce Trent XWB-97 engine.

By using this AM process, Rolls-Royce saved 30 % manufacturing time compared to conventional manufacturing methods [10].

2.1.9 Pratt and Whitney Uses 3D Printing for Aero Engine Parts

Aero engine maker Pratt and Whitney use additive manufacturing technology to manufacture compressor stators as shown in Fig. 10 and sync ring brackets for its first ***Pure Power PW1500G*** engine. Pratt and Whitney delivered its first engine to the world's largest aircraft manufacturer **Bombardier,** for its **CSeries** passenger aircraft. Compressor stators and sync ring brackets components that are produced using AM process have undergone rigorous engine testing before using in the engine assembly.

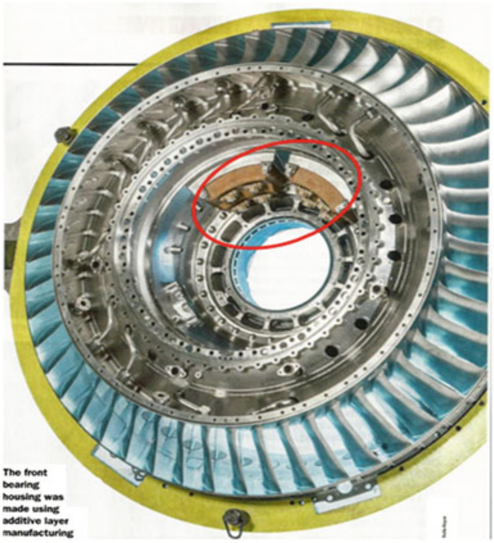


Fig. 9 The front bearing housing was made using additive layer manufacturing (bearing housing *indicated*)

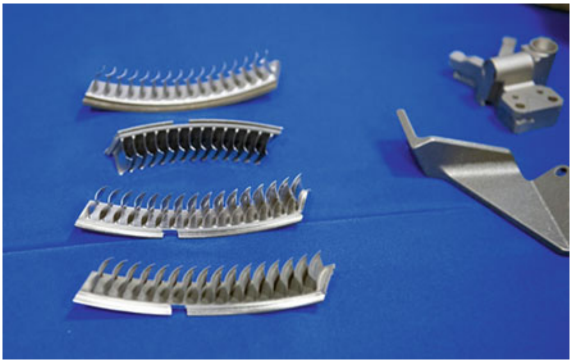


Fig. 10 3D-printed: Pratt Whitney's compressor stators

Lynn Gambil, Chief engineer, Manufacturing Engineering at Pratt and Whitney commented "AM offers a number of benefits: It dramatically reduces production time, from design, to prototype, to finished product and it decreases waste and consumption of raw materials. Furthermore it allows precision production of parts with complex geometry with reduced tooling, and permits multiple parts from an assembly to be made in one integrated piece" [11].

By using AM process Pratt and Whitney have saved 15 months lead-time compared conventional manufacturing processes and up to 50 % weight reduction in a single part.

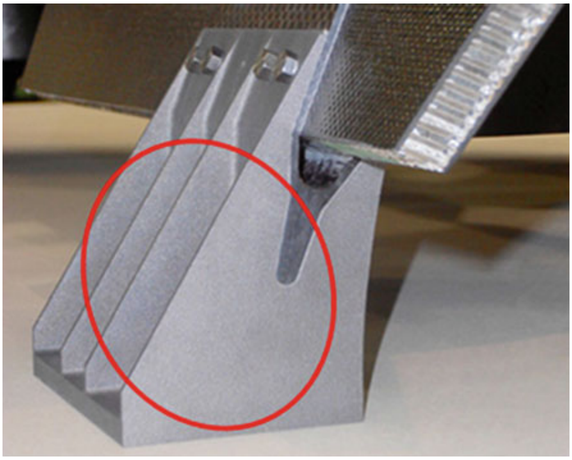


Fig. 11 The robust one-piece 3D-printed titanium brackets (*indicated*) have better thermal conductivity characteristics than conventionally manufactured parts. They are able to withstand the high temperature and external forces in space (*Courtesy* EOS)

2.1.10 Airbus Defence and Space Used Additive Manufacturing to Reduce Production Time of Satellite Parts

The latest generation of satellites from Airbus Defence and Space contains the special ***clamps*** as shown in Fig. 11 made by AM. These clamps join the body of the satellite to the feed and sub-reflector assembly at the top end.

Airbus Defence and Space engineers selected additive manufacturing method from EOS GmbH for production of Clamps using titanium metal powder. Laser fuses the metal powder selectively to produce solid part in case of EOS-Direct Metal Laser Sintering process.

These components withstand the range of 330 °C at a force effect of 20 kN without any problems. The Spanish aerospace experts could also reduce the production time of by 5 days, production cost saving over 20 % and significant weight reduction of the component [12].

2.1.11 Hindustan Aeronautics Ltd., Used 3D Printing Technology for Aircraft Engine Model

Hindustan Aeronautics, Ltd. (HAL), India's only military aircraft producer is taking great strides toward making "Made in India" a world-class label. HAL used 3D printing technology to create prototype model for a 25-kN aircraft engine as shown in Fig. 12. The first engine prototype was on display as an operational model at Aero India expo-2015. Following Fig. 12 shows the various engine prototype components produced from Nylon plastic material using Selective Laser Sintering AM process. Bangalore-based company RAPITECH SOLUTIONS INC produced these components in less than 20 days. In this project Additive manufacturing drastically reduced prototype development time and cost compared to conventional manufacturing [13].

Fig. 12 The 25-kN aircraft engine prototype made out of selective laser sintering AM technology during Aero India expo-2015

2.1.12 Research and Development on Laser Metal Deposition Technology at Hindustan Aeronautics Ltd. (HAL)

Hindustan Aeronautics Limited Engine division is evaluating Laser Metal Deposition (LMD) additive manufacturing (from RPM Innovations Inc., & Efesto LLC, USA) for multi alloy deposition and repairing of aero engine parts. The technology is capable of free form fabrication and repairing of intricate aerospace parts using blown powder additive manufacturing technology.

Figure 13 shows the multi alloy (Inconel 625-Haynes 230—Inconel 718) LMD specimen with functional gradient zones with excellent properties for large aerospace user [14].

HAL R&D is also adapting AM technology for development of high pressure HPT Rotor blades, Nozzle guide vanes, Combustion chamber, HPC stator Stage 5 assembly, Vane IGV blades, HPC Stage 5 blades along with gear box assembly and with intricate cooling passages. Another area of application, HAL Foundry and Forge division is considering, is the manufacture of sand mould and cores for

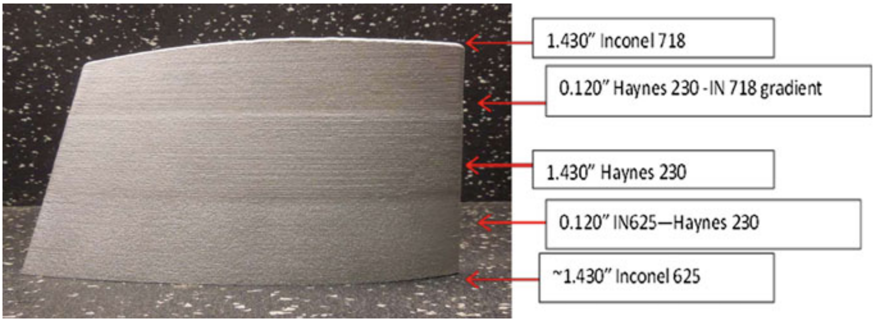


Fig. 13 Aerofoil with multi alloy deposition (Inconel-Haynes-Inconel using LMD technology from RPM Innovations, USA) for testing and evaluation of application of laser metal deposition (LMD)

manufacture of aluminium alloy and magnesium alloy castings as well as tools for investment castings.

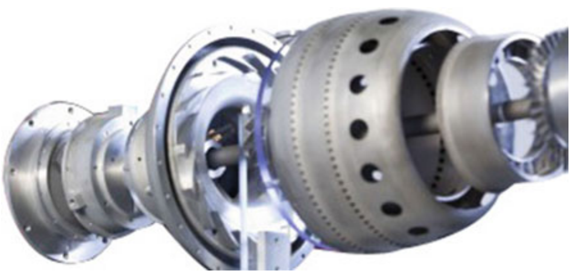
2.1.13 Research and Development of Jet Engine at Monash University, Australia

Australian Research Council (ARC) has been promoting Australia's manufacturing industry through high value additive manufacturing technology in collaboration with Monash University. Professor Xinhua Wu is leading this research team. ARC has funded $9 million (AUD) to focus and develop Australia's aerospace industry.

The research group is focusing on Selective Laser Sintering (SLS) additive manufacturing technology to build Titanium alloy components. Professor Wu has printed a prototype of small jet engine (as shown in Fig. 14) using SLS metal AM technology as apart of their research and development [15].

The research team found that using 3D printing technology, engine components could be produced in less time, cost, reduced weight and carbon emissions.

Fig. 14 3D printed small jet engine



2.1.14 Research on Additive Manufacturing of Ceramics for Direct Digital Investment Casting—Georgia Tech University, USA

The Innovative Large Area Maskless Photopolymerization (LAMP) is an additive manufacturing technology, which was invented and developed by Georgia Tech University with support from the Defense Advanced Research Projects Agency (DARPA)'s Disruptive Manufacturing Technologies program, and the project is titled "Direct Digital Manufacturing of Airfoils".

LAMP technology directly produces complex ceramic cores and integral-cored shell moulds for investment casting directly from CAD data. The high resolution UV light selectively cures ceramic filled photo curable resin layer by layer and solidifies to a physical object. 3D printed moulds are then thermally post-processed which are foundry-ready for casting.

These castings are used for production of single crystal nickel-super alloy airfoils for aero turbine engines. This helps in cost reduction of manufacturing of turbine airfoils [16].

2.1.15 The World's First 3D Printed Aircraft—Southampton University Laser Aircraft

Prof. Jim Scanlan and Andy Keane University of Southampton, Computational Engineering and Design Group University of Southampton, UK designed and 3D printed plastic aircraft model (as shown in Fig. 15) using Selective Laser Sintering

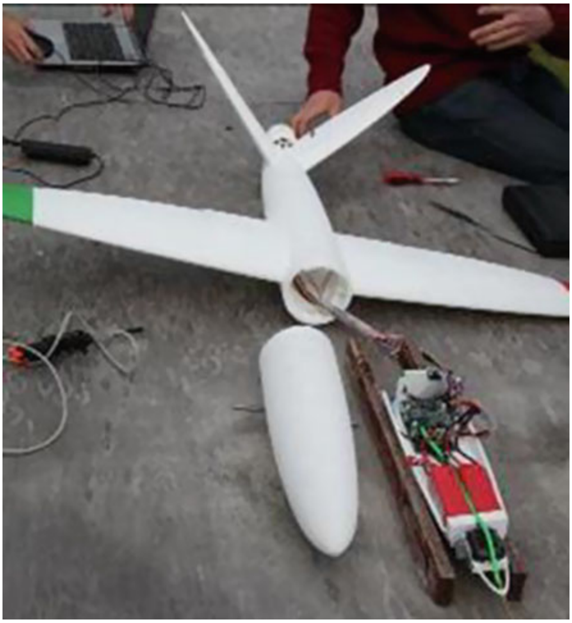


Fig. 15 World's first 3D printed aircraft model

(SLS) technology. The 3D printed aircraft model was assembled with five structural/aerodynamic components and without conventional fasteners.

The purpose of the research was to study the

a. Use of snap fit methods to locate avionics, payload and propulsion items.
b. Use of a complex geodetic internal structure, which is directly 3D, printed to the internal surfaces of the aircraft.
c. Use of a concept optimization process to provide an optimal shape and minimal structural weight

Specification of the 3D printed aircraft

- 0.5 kg payload
- Full Nylon 12 SLS printed structure
- 30 min endurance
- Electric propulsion
- Top speed of 90 mph
- On-board GPS systems
- SMS capable
- Fastener-free assembly [17].

2.1.16 Development of New Material for Additive Manufacturing Aerospace Components—GKN Aerospace, UK

GKN Aerospace supported by Aerospace Technology Institute (ATI, UK) and consortium partners-Phoenix Scientific Industries Ltd., UK, Metalysis and University of Leeds will be investigating titanium alloys and powders characteristics using Additive Manufacturing for the aerospace industry.

The research team says "Today additive manufacturing uses metal alloys and powders which have not been developed for these processes and are not optimized for this environment". The research partners will investigate developing titanium alloys and powders with the characteristics that are specifically suitable to additive manufacturing. Later, they will define the production methods that produce additive manufacturing designed materials to ensure the cost is minimized and at the same to retain the production quality, quantity and rigorous standards required by aerospace industry [18].

2.1.17 Additive Manufacturing Research in China—Aviation and Aerospace Applications

Additive Manufacturing Research in China has commenced recently. The Chinese Government has made major investment in AM technology to develop China's high value manufacturing sector and to focus on production of large aerospace parts using Chinese developed technologies.

Fig. 16 Laser cladding cell at NPU

Northwest Polytechnic University (NPU) has developed the production of large-scale laser cladding cell. The laser-cladding cell can build a part size of 5 × 2.5 × 0.6 m; accuracy of deposition speed is ±1 mm and an inert atmosphere of 50 ppm (shown in Fig. 16).

Fig. 17 C919 central wing spar

During 2013, Northwest Polytechnic University (NPU) Laser Cladding Cell has developed central wing spar for 'Comac C919' passenger-plane and it is predicted to enter the commercial service in 2016. The length of this central wing spar is 5 m and having mechanical properties equal to forging parts as claimed by the NPU University (shown in Fig. 17).

Airbus Industries has signed an agreement with NPU in 2014 to manufacture titanium test specimens. Later, these specimens will be measured and evaluated by Airbus. The replacement of parts, which are not in the production line, is the future application of this technology [2].

3 Summary

The introduction of latest additive manufacturing processes like Laser Metal Deposition, Laser Cladding, Electron Beam Melting, Direct Metal Laser Sintering, Selective Laser Melting and advanced high temperature super alloys have drastically enhanced the applications of additive manufacturing technology in the aerospace industry. The increased demand for complex and lightweight metal parts such as turbine disc with blades, stator and rotor turbine vane assemblies, combustion chamber, fuel nozzle, etc., from the aerospace industry has made the technology most suitable for aerospace applications. Continuous innovations and growth in additive manufacturing will thus have a significant place in the future of aircraft manufacturing.

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