3D Printing In Aerospace

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Handbook of Innovations & Technologies (HIT)

A review on the research activities in additive manufacturing

A global perspective

2018

About this report:

This report is a Handbook of Innovations & Technologies (HIT), in the domain of 3D printing in the aerospace industry and provides insights into the technical challenges, existing solutions, innovation trends, market trends and key participants in the innovation ecosystem.

This report is essential reading for everyone associated with the domain of 3D printing, providing clear answers to problems and issues faced, enabling them to take key decisions. For example, this report can be beneficial to CEOs, heads and members of R&D departments, heads and members of IP/strategy departments, heads and members of HR departments, heads and members of marketing departments, academic researchers and scientists, patent agents and/or attorneys, as well as investors and consultants operating in the domain of both the 3D printing and aerospace industries.

This report provides valuable answers to the following critical questions:

Investment decision:

- ✓ When did patenting activity in the domain start and how has it evolved?
- ✓ Which countries are suitable market geographies for utilizing this technology?
- ✓ Who are the major players involved in this technology?
- ✓ What potential collaboration opportunities are available with smaller players?
- ✓ Who are the recent entrants?
- ✓ What are the different activities being taken up by the major players?
- ✓ Which are the best patents and who owns them?

R&D activities:

- ✓ What are their patenting strategies and areas of focus?
- ✓ How do the major players compare against each other in terms of IP potential, R&D capabilities and strategy?
- ✓ Which countries are the innovation hubs for this technology domain?
- ✓ Which research institutes / universities work in this area?
- ✓ Which technology areas are most focused on research and development?
- ✓ What are the latest technological advancements in the domain?
- ✓ What are the different 3D printing processes used?
- ✓ Which specific materials are used for 3D printing in the aerospace industry?
- ✓ What are the major technical challenges associated with various processes, materials and modelling techniques?
- ✓ Which companies are filing patents in different materials for respective 3D printing techniques?

Human resource:

- ✓ Who are the key inventors / experts in different technology areas?
- ✓ What is the area of expertise for the key inventors?

- ✓ Which law firms are available in different jurisdictions?
- ✓ What is the grant rate and average grant time for respective law firms?
- ✓ Who are the examiners in the domain and what is their grant rate?
- ✓ Which art units are available for the patent filing and what is their grant rate and grant time in the domain?

To prepare this report, multiple diverse searches were conducted to comprehensively identify all the patents pertinent to 3D printing in the aerospace industry. These patents were then analyzed manually to capture their focus and application areas and identify the technical challenges. Thereafter, informative and actionable insights were generated by combining this manual information with the bibliographic information of the patents. Expert industry analysis has also been included as part of the research.

This report includes three sections:

1. **Overall trends in the domain of 3D printing in the aerospace industry:**
   This section highlights technology evolution (patent filing trends), primary countries of research, major market geographies, existing collaborations and opportunities, new entrants, key patents, most active law firms, prominent inventors and important IPC classes as well as key player's IP position in the domain of 3D printing.

2. **Detailed technology analysis of patents and applications published in the technology domain:**
   This section highlights the focus of patents and applications relating to the production methods used in 3D printing, scanning and modelling techniques disclosed, materials used for 3D printing, applicable products being targeted and technical challenges faced.

3. **Major players trends in the domain of 3D printing in the aerospace industry:**
   This section provides an analysis of the major players in the domain focusing on their patent filing trends, their research centers, markets of interest, technology focus, partnerships, strategies and other important parameters.
   Based on patenting activity, the following companies were identified as the major players, and are analyzed in detail in this section:

   I. **United Technologies**
   II. **MTU Aero Engines**
   III. **Boeing**
   IV. **Airbus**
   V. **General Electric**
   VI. **Rolls-Royce**
   VII. **Siemens**
   VIII. **Safran**
   IX. **Honeywell**
   X. **Lockheed Martin**

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Appendices

Methods of 3D printing covered in the analysis:

- 3D inkjet printing
- Chemical vapour deposition (CVD)
- Cold spray
- Digital light processing (DLP)
- Direct metal deposition (DMD)
- Direct metal laser sintering (DMLS)
- Electron beam sintering (EBS)
- Fused deposition modelling (FDM)
- Laminated object manufacturing (LOM)
- Laser powder forming
- Micro induction sintering
- Microlithography
- Microstereolithography
- Physical vapour deposition
- Rapid plasma deposition
- Robocasting
- Scanning laser epitaxy / Selective laser-induced etching (SLE)
- Selective laser melting (SLM)
- Selective laser sintering (SLS)
- Solid freeform fabrication

- Stereolithography (SLA)
- Thermal spraying
- Transient liquid phase sintering
- Vacuum casting

Application areas covered in the analysis:

- Avionics
- Body
- Cockpit
- Defense weaponry
- Flight controls
- Fuselage
- Landing gears
- Passenger accessories
- Pilot accessories
- Spacecraft
- Structural components
- Tooling
- Wings and control surfaces
    - Empennage
    - Stabilizer
    - Rudder
    - Elevator
    - Trim tabs
    - Aileron
    - Flaps
    - Slats
    - Wing tip
    - Tail
    - Rotor assembly
    - Rotor blade
    - Tail rotor

Materials used for 3D printing covered in the analysis:

Composites

- Aramid fibre
- CFRP (carbon fibre reinforced polymer)
- CMC (ceramics matrix composites)
- Fibre reinforced polymers
- Fused Silica Glass
- GFRP (Glass fibre reinforced polymer)

Polymers

- PEEK (Polytetrafluoroethylene)
- PMMA (Poly Methyl Methacrylate)
- Polycarbonates
- Polypropylene
- Polyurethane
- PTFE (Polytetrafluoroethlyene)

Metal alloys

- Aluminium alloy
- Chromium alloys
- Cobalt alloys
- Copper alloys
- Nickel alloys
- Steels
- Titanium alloys
- Vanadium alloys

Metals

- Aluminium
- Antimony (Sb)
- Beryllium
- Bronze
- Cadmium
- Chromium
- Cobalt
- Copper
- Gallium
- Gold
- Indium
- Iron
- Lead
- Magnesium
- Manganese
- Mercury (Hg)
- Molybdenum
- Neodymium (Nd)
- Nickel
- Niobium
- Palladium
- Platinum
- Rhenium
- Rhodium
- Scandium
- Silver
- Tantalum
- Tin
- Titanium

Ceramics

- Alumina
- Barium oxide
- Barium strontium aluminosilicate
- Calcia
- Calcium fluoride
- Ceria
- Cordierite
- Cryolite
- Cubic boron nitride
- Dysprosium oxide (Dy203)
- Gadolinia
- Garnet
- Graphite
- Hafnium oxide
- Iron oxide
- Kaolin
- Lanthanum fluoride
- Lanthanum oxide
- Magnesia
- Mullite
- Neodymia
- Samaria
- Sapphire
- Scandia
- Scandium oxide
- Silicon carbide
- Silicon dioxide
- Silicon nitrate
- Silicon nitride
- Spinel
- Steatite
- Tantala
- Tantalum carbide (TaC)
- Thorium oxide
- Tin oxide
- Titanium oxide
- Ytterbium oxide
- Yttria
- Zirconium dioxide
- Zirconium silicate

1. Overall trend in the technology domain

1.1 Patent filing trend

The patent filing trend is indicative of the evolution of technology over time. Figure 3 below shows the number of patents filed over the past 16 years in the domain of 3D printing in the aerospace industry. The very first patent for 3D printing in aerospace was filed in 1979 by United Technologies Corporation, wherein the patent explicitly explains the manufacturing process for gas turbine engine components like thin fin knife-edge gas path seals and disc-shaped articles in a fashion of subsequent layer-by-layer deposition, with the help of energy beam to melt the substrate. The material used for manufacturing the components is a nickel-based alloy, composed of 18.6% chromium, 3.1% molybdenum, 5% columbium, 9% titanium, 0.4% aluminium and 18.5% iron, with the balance being nickel.

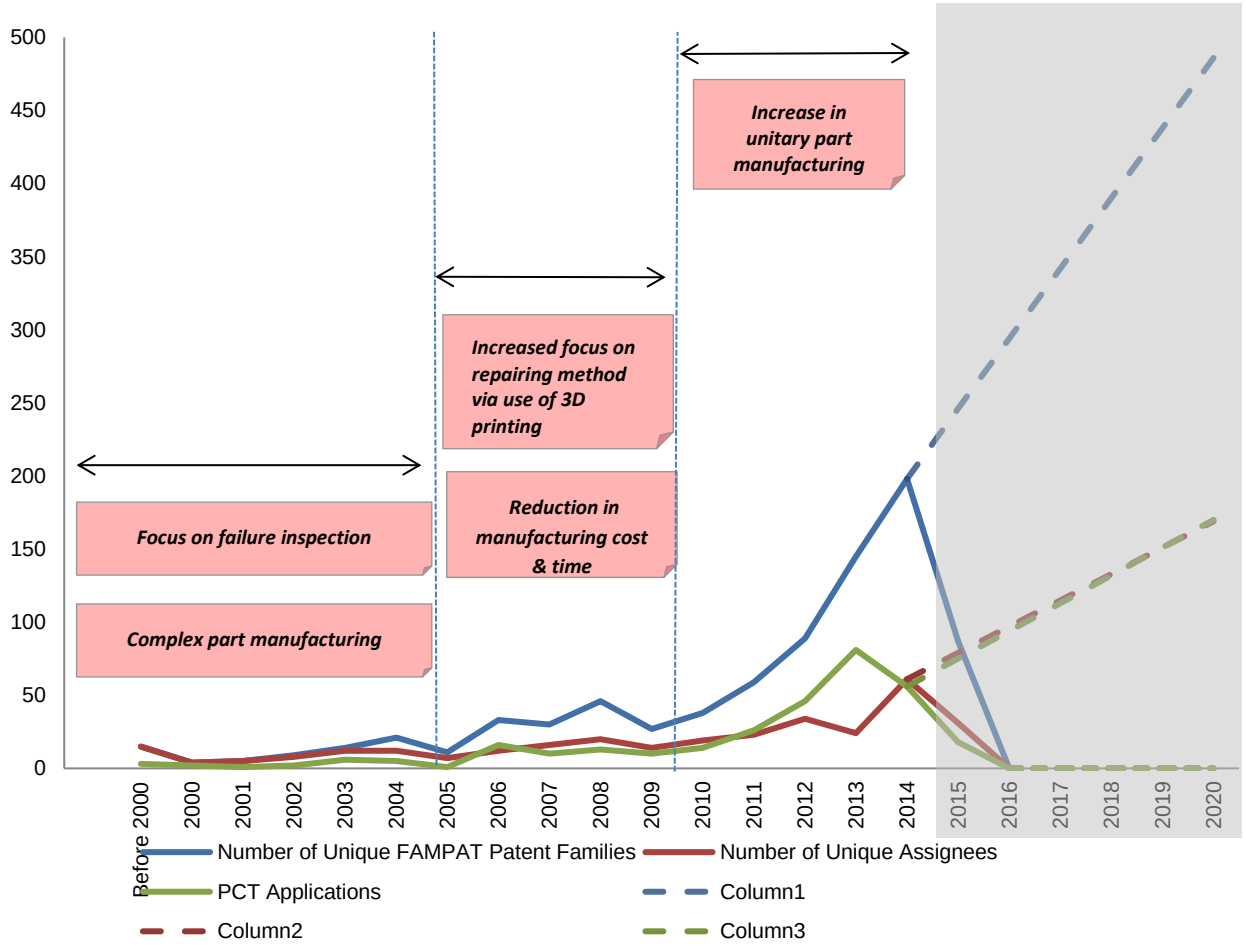


Figure 3: Patent filing trend

Note:
1. The number in the chart represents the number of unique FAMPAT families.
2. According to the available sources, the patent filing trend is shown (as per data available) as well as forecasted for the year 2015 and onwards (tentative).The dashed line represents forecast for filing trend based on cumulative average of patents filed from the year 2000 onwards.

1.6 Major players

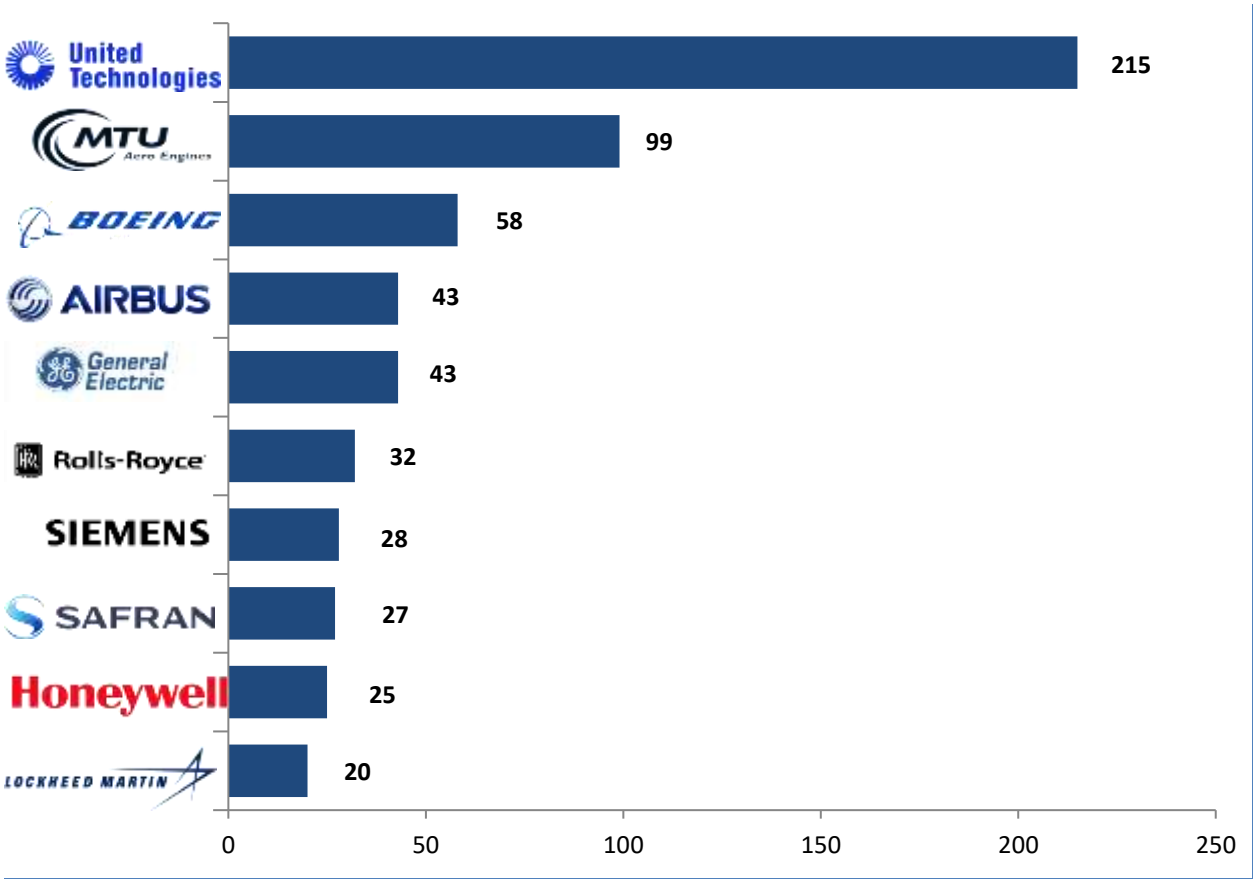


Figure 10: Major players (number of patents)

United Technologies is primarily focused on aircraft engine parts and their manufacturing, accounting for 38% of the total patents for this company, followed by their interest in manufacturing tools for use in the aerospace industry. In 1979 it was the first company to file a patent using the laser deposition method.

The various patented products include (but are not limited to) gas turbine engine blades, thermal barrier coatings (TBC), heat exchanger units and probes with an anti-icing feature that can be used in aircraft.

MTU Aero Engines also specialize in aircraft engine parts/components such as blades, vanes and sealing devices as well as additively manufactured tools such as cores for the manufacturing of aerospace components and measuring devices.

Note:
1. The numbers in the chart represent the unique number of relevant FAMPAT patent families owned by the company or its subsidiaries.
2. Detailed analysis of each of the major players is provided in section 3.
3. The companies filing maximum patents have been considered as the major (top ten) players.

2.3.2 Method of 3D printing vs major players (based on method of 3D printing)

Method of 3D printing	United Technologies (215)	MTU Aero Engines (99)	General Electric (43)	Boeing (58)	Honeywell (25)	Siemens (28)	Airbus (43)	Rolls-Royce (32)	Lockheed Martin (20)	Bae Systems (14)
Selective laser sintering (SLS)	60	54	17	20	12	14	8	7	3	1
Selective laser melting (SLM)	41	62	8	2	5	19	13	3	1	2
Electronic beam melting (EBM)	91	29	13	5	14	1	5	3	2	3
Direct metal laser sintering	96	7	11	3	17	2	2	2	1	2
Stereolithography (SLA)	24	6	15	14	3	1	6	6	6	2
Fused deposition modelling (FDM)	7	3	1	12	6	0	2	2	2	1
3D inkjet printing	6	1	12	7	0	0	2	0	2	0
Solid freeform fabrication	8	0	1	0	5	0	0	7	0	2
Laminated object manufacturing (LOM)	4	2	0	5	0	0	1	0	1	1
Chemical vapour deposition	5	2	1	2	0	1	0	0	0	1
Laser cladding	1	2	3	0	0	3	0	0	0	0
Direct metal laser melting (DMLM)	0	0	12	1	0	0	0	1	0	0
Rapid plasma deposition	4	1	0	1	1	0	1	0	0	1
Cold spraying	6	2	0	0	0	1	0	1	2	0
Physical vapour deposition (PVD)	4	3	1	0	0	0	0	0	0	0
Plasma spraying	2	0	3	0	0	1	0	2	0	0
Digital light processing (DLP)	1	0	0	0	0	0	1	0	0	2
Robocasting	0	0	0	0	0	0	0	0	0	0
Microlithography	1	0	0	0	1	0	0	0	0	0

Figure 31: Production methods vs major players

Note: The number in the table represents the number of unique FAMPAT families.

2.4.4 Materials used for 3D printing v/s products

Products		Materials				
Application area	Product category	Polymer	Metal	Metal alloy	Ceramics	Composites
Fixed-wing aircraft	Cockpit	1	1	1	0	2
	Fuselage	13	10	5	3	16
	Landing gears	0	0	1	2	2
	Engine/propulsion components	18	46	51	25	20
	Wings and control surfaces	5	11	9	2	14
	Empennage	0	1	1	0	1
Rotorcraft	Body	2	1	0	0	0
	Engine/powerplant components	2	2	2	1	2
	Rotor assembly	1	3	3	0	3
	Tail	1	0	0	0	0
	Rotorcraft - cockpit	0	1	0	0	0
Unmanned aerial vehicles	Avionics	0	0	0	0	0
	Power supply	0	0	1	0	0
	Body components	2	3	2	0	3
Defense weaponry	Body/surface components	1	3	4	1	4
	Electronics/control equipment	1	1	0	2	0
Spacecraft	Spacecraft	14	28	27	9	13
Tooling	Tooling	37	27	18	23	11

Figure 44: Materials used for 3D printing v/s products

Key highlights:

Polymers are used for diverse purposes, they can be used either in aerospace structural components like the fuselage or aircraft wings or gas turbine engine parts such as blades or airfoils. Most importantly vinyl polymers are used extensively in the fuselage, aircraft wing and aircraft interior components.

A relevant example would be a flame retardant polymer compound, used in the manufacture of aircraft interior components, comprising:

(a) Polybutylene succinate;

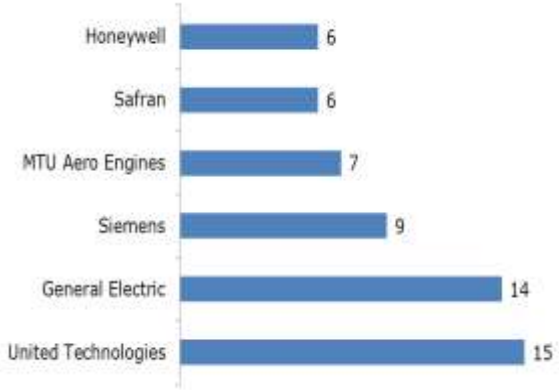
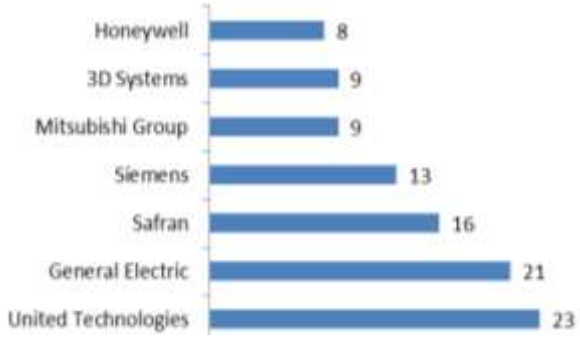
(b) Ammonium polyphosphate;

(c) Melamine cyanurate;

Note: The number in the table represents the number of unique FAMPAT families.

3.7.4 SWOT analysis

Figure 79: SWOT analysis of Rolls-Royce

Strength	Weakness
Greatest number of patent families: **Products** • Fixed-wing aircraft (11) **Methods of 3D printing –** • Solid freeform fabrication (7) • Selective laser sintering (SLS) (7) **Materials used for 3D printing –** • Metal alloy (15) • Metal (13)	**Least number of patent families:** **Products** • Tooling (5) • Spacecraft (3) **Methods of 3D printing –** • Fused deposition modelling (FDM) (2) • Direct metal laser sintering (2) **Materials used for 3D printing –** • Polymer (3) • Composites (3)
Opportunities	**Threats**
Most significant growth rate in last 5 years: ➢ **Methods of 3D printing –** • Electronic beam melting (EBM) • Selective laser melting (SLM) **Most cited patents by others** • US6355086 (107) • US8123489 (60) • US7343960 (45) **Citing Companies**  	**Most cited competitors:**  **Most cited patents by Rolls-Royce:** US833150 (4) | US5190674 (4) | US5295530 (4) | US3608621 (4) **Competitors' international markets without Rolls-Royce presence:**  China (165) | South Korea (32) | Brazil (32) | Russia (32) | Israel (4) | India (24) | Taiwan (6) | Vietnam (3) | Mexico (4)

3D printing in the aerospace industry

A global perspective & analysis on innovations in the aerospace industry

2018 edition

AEROSPACE

This exclusive report from ABOUT Publishing Group and Sagacious IP provides critical analysis of the technical challenges, existing solutions, market trends and key participants in the innovation ecosystem of the aerospace industry.

The research analyses the potential impact of 3D printing on the global aerospace industry through a patent landscape analysis. It provides insights into the fundamentals of technologies, materials and processes used, as well as an analysis of future applications.

The report provides answers to such vital questions as:

- What are the major technical challenges associated with various processes, materials and modelling techniques?
- How do the major players compare against each other in terms of IP potential, R&D capabilities and strategies?
- Which are the best patents, and who owns them?
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- List of important innovators and service providers
- Analysis of major players and competitive insights
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