

# Chapter 10

## THE NOVEL MANUFACTURING TECHNIQUES OF THE AIRBORNE PARTS



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## 1. Introduction

Aviation is a well-regulated industry. The rules and regulations are well defined and the borders are bolt between the functions. The International Civil Aviation Organization (ICAO) is a top airworthiness organization that works as a conductor for the harmonization of air traffic. In accordance with the ICAO regulations, regional regulatory airworthiness bodies in Europe (European Aviation Safety Agency-EASA), the USA (Federal Aviation Administration-FAA) and Asia are responsible for the implementation of new technologies based on the manufacturer's dossier and ICAO Certification Specifications (CS).

The aviation industry can be considered as an indicator of a country's industrial level (Saraçyakupoğlu, 2021). It is a high value-added technology. Per the National Academies Press (NAP) report, the finished value of the land-vehicle per pound is only about 5 US Dollars, while the finished value of the commercial transport aircraft per pound is 300 US Dollars (NAP, 1993). In other words, the price of an airworthy part is 60 times higher than those in the automotive industry. It is noteworthy that, depending on its type, the modern commercial passenger aircraft consist of many million parts and complex components. For example, a Boeing 747-400 includes more than 6 million parts in the fuselage, landing gear, propulsion, avionics, aerodynamics, etc. parts and assemblies (Eugui & Bifani, 2014). It is worth emphasizing that the freighter conversions would have significantly fewer parts than the full passenger versions

Each part, assembly, and the component requires specific tests for being validated as an airworthy part. In the open literature, there are different names for the definition of "airworthy part" such as;

- Aviation-grade part,
- Airborne-part,
- Ready-to-take-off part,
- Ready-to-flight part,
- Flight-ready part,
- Flight-grade part (Saraçyakupoğlu, 2020).

For manufacturing an airworthy part, it is essential to follow the rules of airworthiness authorities that are dictated for design and manufacturing companies in the aviation industry. Airplanes can only operate with airworthy parts and waive off the airworthiness requirements of the parts is unacceptable by certification authorities (Saraçyakupoğlu, 2019). In the aviation industry, if a company concentrates on the design or manufacturing the airworthy parts/components should have Part 21 J/Design Organization

Approval (DOA) and Part 21 G/Product Organization Approval (POA) from the relevant airworthiness authorities.

On the other hand, the systems installed on an aircraft should provide, at least the given below items besides high performance;

- High flight reliability,
- Minimum maintenance requirement,
- Easy maintenance capability,
- Low maintenance-operating cost,
- Low engine fuel consumption,
- Being sustainable and eco-friendly (Ballı, 2020).

Each aircraft type-approved by a single airworthiness regulatory organization, based on the mutual recognition between the regulatory bodies. In other words "reciprocity is essential". For each and every individual aircraft a single certificate of airworthiness, recognized worldwide is granted by one Country Aviation Authority (CAA). The aircraft manufacturer companies are periodically and sometimes on-conditional audited by the authorities. This system provides the opportunity to operate worldwide without additional efforts (Gastineau, 2020). In accordance with ICAO Global Air Navigation Plan 2016-2030, the global air traffic has doubled size once every 15 years since 1977 (ICAO, 2016). Also, the International Air Transport Association (IATA) declares that almost 8 Billion people will fly in 2037, which means that there's an increasing demand from customers to fly more frequently on a global level (Bagamanova & Mota, 2020). It is also should be emphasized that the main forcer of the enlarging of the aviation industry is the increase in airfreight.

## **2. Challenges of the Manufacturing Technologies in the Aviation Industry**

For figuring out the environment of a regular commercial passenger aircraft, the working conditions should be understood properly. It is not hard to explain that, these state-of-art machines (airplanes) working conditions are extremely difficult.

### **2.1. A Commercial Passenger Aircraft's Operation Conditions**

A commercial passenger aircraft operates in a harmful condition. At the cruise altitude of a regular commercial flight, the outside temperature is about  $-55^{\circ}\text{C}$ . This temperature is 3 times colder than regular kitchen deep freezers. In the Table 1, the altitude and temperature change is provided.

**Table 1.** *The Altitude and Temperature Values Change*

Altitude (Meters)	Temperature (°C)
0	15
1000	8,5
2000	2
3000	-4,5
4000	-11
5000	-17,5
6000	-24
7000	-30,5
8000	-37
9000	-43,5
10000	-50
11000	-55

At the same flight level, the outside pressure is about 200 mbar. This pressure is approximately 5 times smaller than the Mean Sea Level (MSL) pressure. In Table 2, the altitude and pressure change is provided.

**Table 2.** *The Altitude and Pressure Values Change*

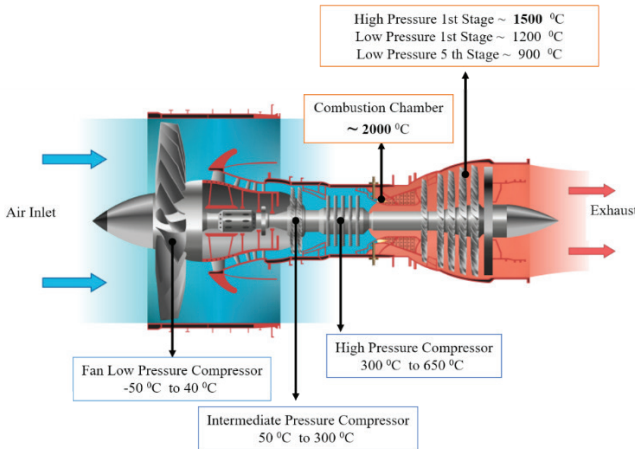
Altitude (Meters)	Pressure (mbar)
0	1013,3
500	955
1000	900
1460	850
2000	795
3010	700
4000	616
5000	540
5570	500
7000	410
9160	300
10000	264
11790	200
16210	100

While an aircraft is floating through the clouds in these mean conditions the crew and the passengers breath approximately 8000 feet of cabin altitude air (ASEM, 2008).

## **2.2. The Temperature Inside The Gas Turbine Engine is Hotter Than “Lava”**

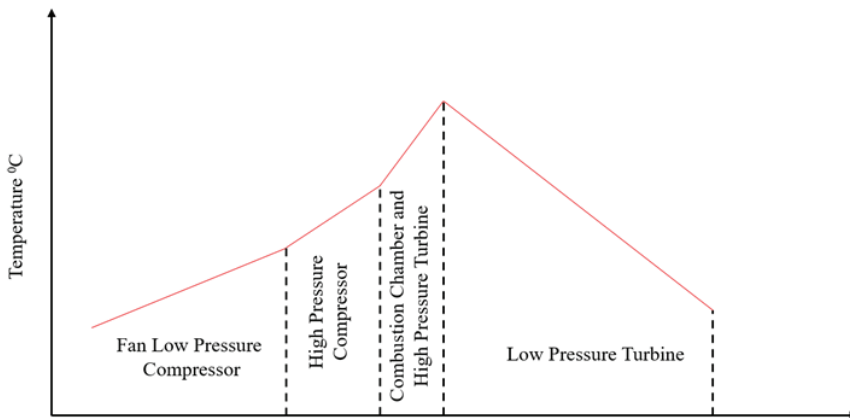
Gas turbine engines (GTE) are used as the propulsion system in the most commercial passenger aircraft operating at present. A regular GTE is composed of more than 30, 000 components, operating above their melting point. The technology used in the GTE’s as complex as they have to

operate reliably in exceedingly harmful environments where temperature and pressure vary dramatically in different parts and components. In the new type of GTE's maximum temperature can be as high as ~ 2.000 °C as it is demonstrated in Figure 1.



**Figure 1.** *The Sections and Temperatures Inside a GTE (Adapted from (Spittle, 2003))*

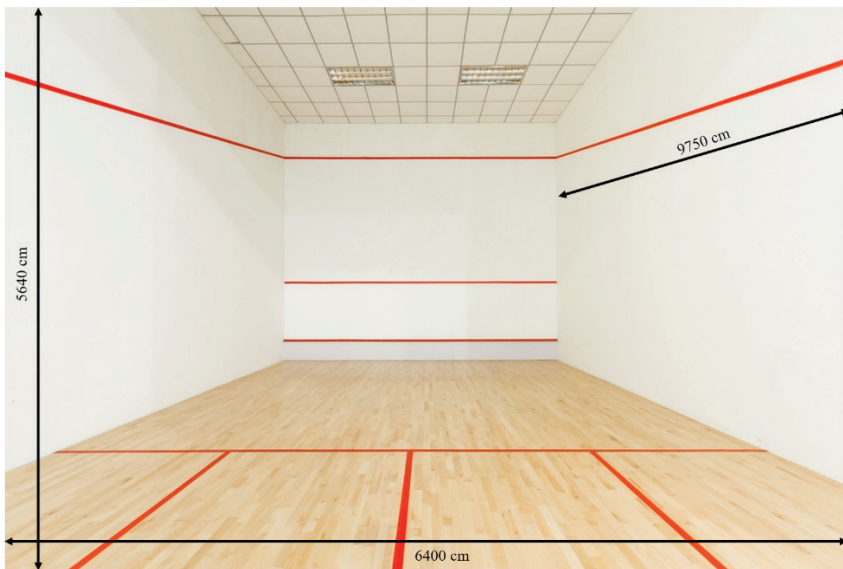
The GTE's are exposed to environments that vary from severe to mild conditions, therefore each one needs to have different characteristics to operate reliably (Ackert , 2009). For gases, it is known that pressure and temperature are in the right proportion while volume and pressure are in inverse proportion. The modules positioned near to the combustion chamber (High-Pressure Turbine and High-Pressure Compressor) are the ones that are exposed to the extremely harmful environment where pressure can go up to 40 Atm, while the temperature can go up to ~ 2.000 °C. Figure 2 shows the temperature change through the engine gas flow path.



**Figure 2.** *Temperature Distribution in a GTE (Centrich, et al., 2014)*

It is worth underlining that, the temperature inside the GTE is hotter than lava that comes from the volcano. For example, the field temperature measurements at Erta’Ale Lava Lake, Ethiopia shows that inside the magma the maximum temperature is 1.187 °C (Burgi, Caillet, & Haefeli, 2002). In another study, that was done for Kilauea active volcano in Hawaii shows that the temperature of the lava was measured as 1230 °C (Carling, et al., 2015). Conclusively, in the hot sections of a GTE the ambient temperature is more than “lava”. Even in the mean conditions mentioned in 2.1. and 2.2. the GTE should run reliably.

A typical commercial passenger aircraft gas turbine engine takes approximately 1.2 tons/second of air during the take-off phase of the flight. This amount of air equals the air of a squash court with the dimensions demonstrated in Figure 3. The mechanism by which a jet engine sucks in the air is mainly a part of the compression stage (Gavrieli, 2004).



**Figure 3.** A Typical Gas Turbine Engine Takes Air of a Squash Court per Second (WSF, 2020)

### 2.3. The Challenges of Manufacturing Activities in the Aviation Industry

Undoubtedly, manufacturing a flight-ready gas turbine engine, in a multi-layered facility has many limitations. Mainly, extreme complexity for modern aircraft jet engines manufacturers is caused by many reasons such as;

- The complexity of products and technology regarding working conditions,

- Novel innovations and fast changes in products, technologies, equipment, toolsets, etc.,
- Large number and size of manufacturing plants,
- Many unpredictable events like demand and resource fluctuations,
- Real-time resource allocation, scheduling, and lean manufacturing line optimization for new orders,
- Interdependent schedules of many workshops such as mechanic, avionics and assembling workshops,
- Intensive use of sensors and robotic multi-functional units which make enterprises more flexible,
- Numerous constraints on products, operations, workers skills, equipment, materials, compatibility, etc.,
- Individual agreements with major clients, suppliers, workers, etc. (Shpilevoy, et al., 2013).

It is obvious that the emerging trend of production is keenly concentrated on increasing productivity. Plant-Layout studies and lean-manufacturing line arrangements are effective for better productivity as was mentioned before.

In the aviation industry, competition is fierce. While implementing the newest technologies into the industry companies are looking for opportunities to increase their capacities. For example, thanks to the implementation of the novel technologies, the Boeing company which is a main role player in the aircraft manufacturing sector has increased their manufacturing capacity from 52 to 57 per month in their Renton / Washington facility (Sutedja, Smith, Muilenburg, & Musser, 2018).

#### **2.4. The Components and Manufacturing Structure For a Top Assembly (Aircraft)**

Aircraft is the top assembly which is the end product of the manufacturing line. As it was mentioned earlier, there are almost 6 million parts in a Boeing 747-400 (Eugui & Bifani, 2014) and there are almost 30.000 parts in a GTE (Spittle, 2003). It is noteworthy that the aircraft is the top assembly as it is illustrated in Figure 4. Aircraft is composed of the manufactured parts with the compliance of Part 21 J-G requirements, consumables, standard parts, COTS' and loose-items.





**Figure 4. An Aircrafts Components and Parts**

Meanwhile, it should be underlined that an airworthy part should be tagged with the forms for authorization. In general, these forms are called as "Authorised Release Certificate" by both FAA and EASA. But in detail, EASA titles its form as "Form 1" and FAA titles its form as "Form 8130-3". The mentioned forms are provided in Figure 5.

1. Approving State/Authority FAA (United States)		3. Authorized Release Certificate EASA Form 1 (EUROPEAN APPROVAL / ETC)		2. Form Tracking Number	
4. Organization Name and Address		5. Work Order/Contract/Invoice		6. Remarks	
7. Description	8. Part No.	9. Qty.	10. Serial No.	11. Status/Work	
13a. Certify that the items identified above were manufactured in conformity to: <input type="checkbox"/> Approved design data and in accordance with Part 121 <input type="checkbox"/> Non-approved design data specified in block 12					
13b. Authorized Signature		13c. Approval/Authorization Number		13d. Certificate/Approver Ref. No.	
13e. Name		13f. Date (dd/mm/yyyy)		13g. Name	
13h. Date (dd/mm/yyyy)		13i. Name		13j. Date (dd/mm/yyyy)	

a. FAA Form 8130-3

b. EASA Form 1

**Figure 5. FAA and EASA Authorized Release Certificate Forms**

Both Form 8130-3 and Form 1 can be released by a POA holder for stating that a product, a part, or a component was manufactured in accordance with the airworthiness' authorities' regulations (Bhopatkar, 2013).

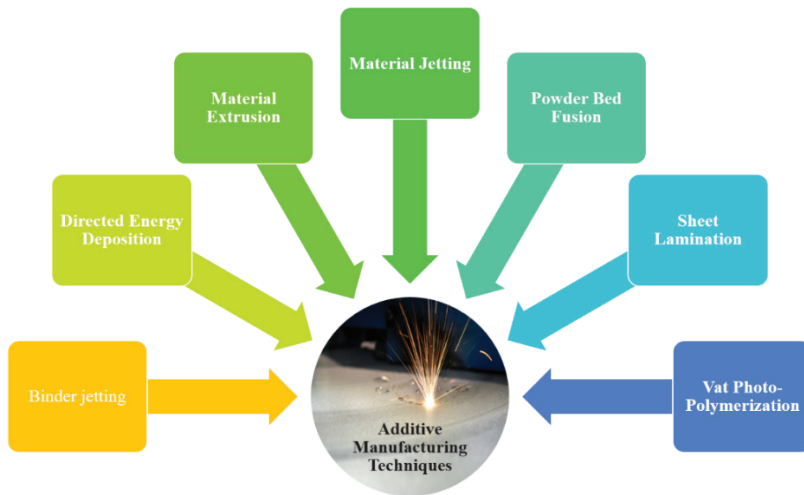
From bottom to top, the parts and components are manufactured in a flow line. It is noteworthy that, aircraft manufacturers and airliner companies are propelling each other in a harmony (Saraçyakupoğlu,

2020). It is clear that a strong air cargo fleet contributes to the country's development. In that case, the Logistics Performance Index (LPI) is a robust indicator for giving clues about the countries industrial position. The studies show that there's a positive correlation between LPI and air cargo transportation (Düzgün, 2020).

### 2.5. The Novel Technologies Such as Additive Manufacturing Implementation in the Aviation Industry

The aviation industry is a pioneer in implementing novel technologies. The airworthiness bodies are leading the aviation industry for having eco-friendly aircraft and engines. Naturally, it requires exploring using the newest techniques and advanced materials (GE, 2013). As it was mentioned before the aviation industry is highly regulated. The manufactured parts and the components need to be authorized by airworthiness authorities prior to marketing.

Additive manufacturing is an emerging methodology used for meeting the requirements of airworthiness organizations. Basically, it is a process of manufacturing parts layer-by-layer which is contrary to that chip-away conventional techniques. The materials differ from one AM technique to the other one. In Figure 6, material types are provided.



**Figure 6.** *Types of Additive Manufacturing Process (ASTM, 2013).*

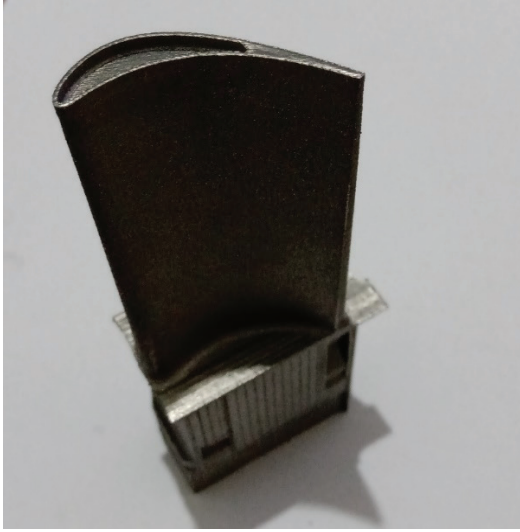
For example, wax-like materials can be processed with material jetting and binder jetting. Metals such as nickel-based alloys and aluminum can be processed with directed energy deposition. Thermoplastic filaments can be processed with Material Extrusion. With powder bed fusion, polymers, maraging steel, stainless steel 316 L, 15-5PH, 17-4PH, nickel-

based superalloys, Inconel 718, Inconel 625, Hastelloy X, Titanium TA6V, chrome-cobalt, aluminum ALSi10Mg can be used as raw materials. Adhesive coated papers, metal tapes, and foils, the plastic sheet material can be processed with sheet lamination, and light-curable resin and photopolymers can be processed with Vat Photo-Polymerization.

During the standing jump, power output mean values of 5.23 HP for men and 3.15 HP for women were recorded (Davies, 2007). Considering, on a Boeing 777, a single-engine produces 52,000 HP the manufacturing ability of "human being" will be understood clearly. In that perspective, additive manufacturing technology provides many opportunities from aviation-grade production to generating human organs (Murr, 2016). It is noteworthy that both medical and aviation industry has precise manufacturing limitations. In other words, if a technology is implemented to either of them it is a reliable reference for implementation to others.

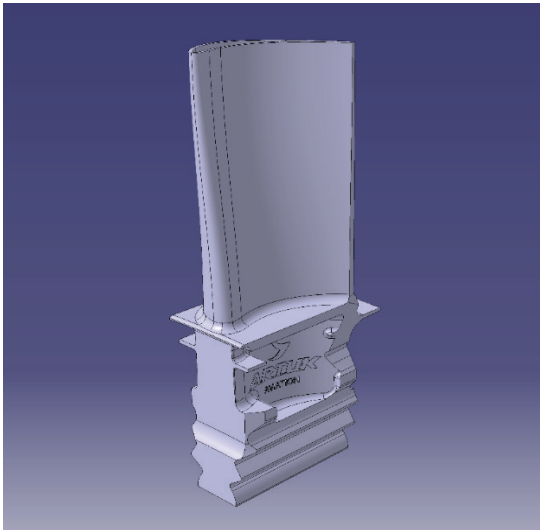
Because of the design freedom upon complex parts available with AM techniques of the airworthy parts which are used on the airplanes are perfect applications (Tomlin & Meyer, 2011). Additive manufacturing also provides opportunities to reduce operational man and machine hours and simplifying the manufacturing process (Despeisse & Ford, 2015). Since assessment of appropriate part candidates could be time-consuming, the part selection step is conducted in three phases as information, assessment, and decision (Poyraz & Kuşhan, 2019).

In Figure 7, an additively manufactured GTE hot section blade is provided. The material is selected as Ti6Al4V which is very common in the aviation industry. EOS M 290 Direct Metal Laser Sintering (DMLS) machine is used for manufacturing the blade.



**Figure 7.** *Additively Manufactured GTE Hot Section Blade (Courtesy of Artuk Aviation)*

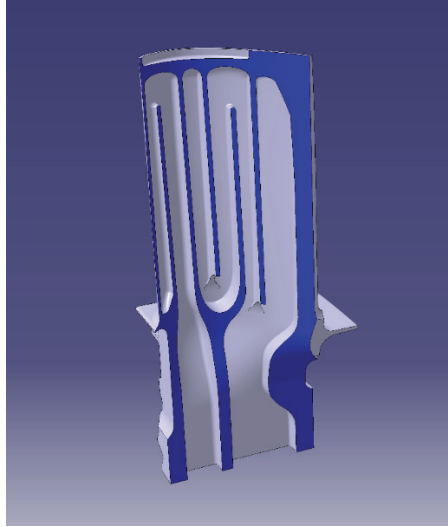
For manufacturing the upper mentioned blade a CAD model has been prepared with Catia V5 R21. As it is seen in Figure 8, this model is prepared only for training purposes. Albeit, the dimensions are very close to the genuine one, it still needs further numerical studies. This part can be considered as a sample for figuring out the behave of the process.



**Figure 8.** *CAD Model of the Hot Section Blade (Courtesy of Artuk Aviation)*

As demonstrated in Figure 9, for the GTE hot section blades, the cooling channels are the vital areas because of the extremely hot working

environment. As it was mentioned before both the combustion chamber and high-pressure combustion section have a temperature as high as lava from a volcano.



**Figure 9.** *Illustrated Cooling Channels Inside the Hot Section Blade (Courtesy of Artuk Aviation)*

### **Acknowledgment**

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### **Conclusion**

It is obvious that additive manufacturing has changed the face of the manufacturing industry. The ease of digitizing the technical data package and manipulation of the data is the main positivity of the process. The developments in additive manufacturing technology on behalf of the airworthy parts create a vast area of research criteria for producing the complex parts that are almost impossible with conventional manufacturing techniques. While reducing the labor and machine hours during the manufacturing phase it still needs process improvements because of its drawback of batch production of large-size components.

In the future, more additively manufactured airworthy parts will be encountered in the aviation industry.

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