

Current Status of Jet Engines and Their future

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Abstract. Jet engines have important application value and status in the aerospace field, which directly affects the development of aircraft and spacecraft. This year, jet engines have gradually become the focus and hotspot of scholars at home and abroad. Through the method of literature comparison and analysis, this paper focuses on analysing two common jet engines, namely turbofan engine and pulse jet engine, and makes a detailed analysis and comparison of their working principles and applications; for the future development of parts, three-dimensional (3D) printing technology as an example, the use of different kinds of 3D printing, electron beam melting and selective laser melting to print jet engine parts and how to reduce errors is studied, and various techniques for improving high temperature parts are analysed., and looked forward to the future development trend of jet engines and put forward their own views. The research work in this paper will promote the development of jet engine and provide reference for engineers and technicians.

Keywords: Turbofan engine, jet engine, 3D printing, electron beam melting, selective laser melting.

1. Introduction

The aviation industry has a big role for humans to improve the development of economics and social life [1]. However, with the improvement of the aviation industry, more and more gas pollution are released by planes. Also, because of Covid-19 and the war between Ukraine and Russia, the cost of using fossil fuels as the energy supply for vehicles increase a lot in the past two years. So, it is necessary for people in the aviation industry to find new ways to support the plane to fly in the sky more environmentally and steadily [2].

So how do people reduce gas pollution and improve airplanes more stable and effective? Firstly, people can focus on the structure of jet engines. Jet engines are the power source of airplanes. Different jet engines have different components with their own advantages and disadvantages. Improving the properties of different jet engines is one possibility of a jet engine future [3]. Also, fuels are important to reduce pollution. Burning different fuels will occur in different chemical reactions. Some chemical reactions generate some common chemical substances, such as burning hydrogen only creates water and releases some heat [4]. Luckily, human has already found some new energy source to reduce gas pollution. In the fuel aspect, people use new mixed fuels and fuels like hydrogen. In the power aspect, people use hydrogen batteries, electric batteries, motor dynamo, and so on [5].

Also, because of Covid-19 and the war between Ukraine and Russia, the aviation industry is facing an unprecedented disaster. It is necessary for people in aerospace areas to improve the stability of manufacturing technology and reduce the cost of manufacturing aviation components.

2. Research Status of Jet Engine

2.1. Turbofan engine

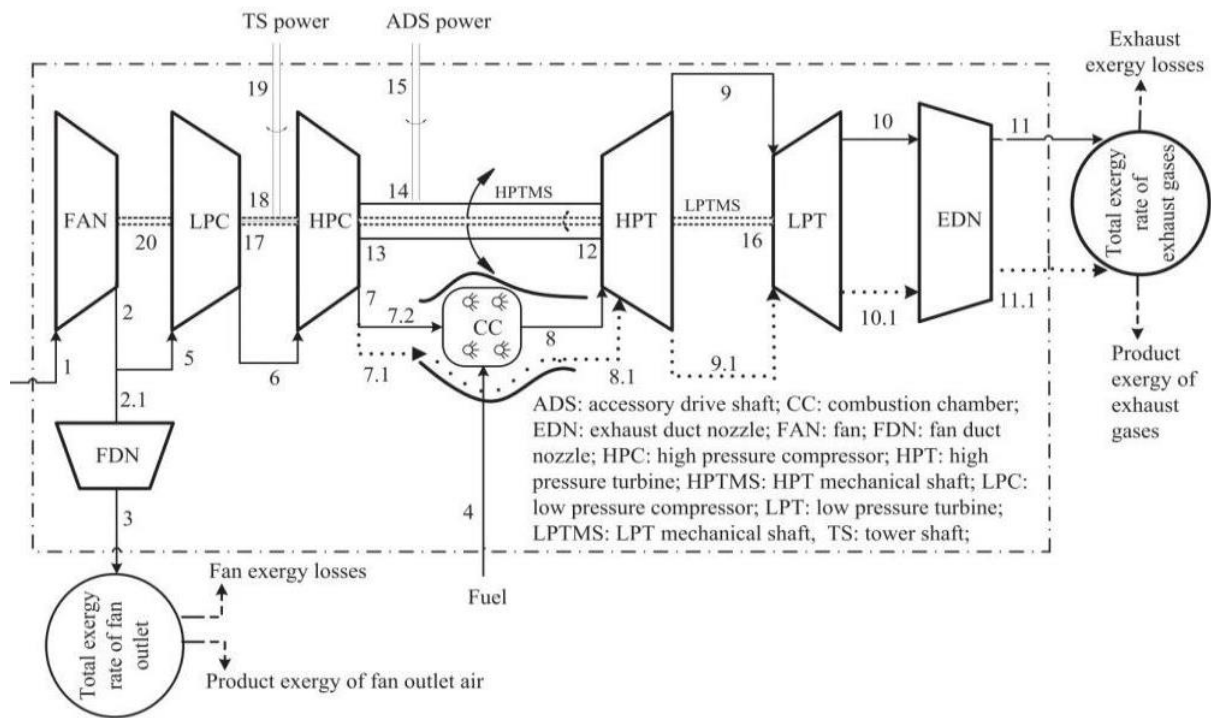


Figure 1. Simplified drawing of the turbofan engine.

Figure 1 is a simplified diagram of a turbofan engine. Turbofan is a jet engine with a bypass stream [6]. First of all, I want to introduce the structure of the turbofan engine. From left to right, it is a fan and compressor with different pressure. In order to change the pressure, compressors are used in turbofan jet engines. Also, using compressors can help more and more air enter the combustion chamber. After more and more air enters the chamber, burning fuels can create very huge energy. When these energies are exhausted from the nozzle, it creates a big thrust. In the middle, there is a combustion chamber. Then there are turbines with different pressures. In addition, there are two nozzles, a fan duct nozzle, and an exhaust duct nozzle. In this picture, the pressure is higher in the middle. The reason why the pressure is higher in the middle is that there is a chemical reaction in the combustion chamber. Also, bearings across all the parts of the turbofan. It is worth noting that the turbine and compressor with high-pressure match the high-pressure bearing. It means that in different parts, the bearings are also different [7].

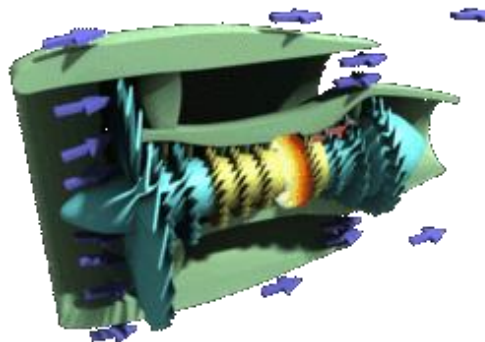


Figure 2. Turbofan engine.

There are many advantages of the turbofan engine. Figure 2 is a schematic diagram of a turbofan engine. Firstly, of all, turbofan has a large thrust. This image can be seen below, which shows that the thrust of the two parts is created. The most thrust created by the big fan. In the picture, it is shown in a blue direction. Also, the core engine creates thrust. The thrust in red can be seen in the picture. As I mentioned before, the compressors also support the turbofan to create bigger thrust. Secondly, It has high propulsion efficiency, low noise, low fuel consumption rate, and aircraft long-range. According to the advantages of the turbofan engine, it is known why it is the most popular jet engine in the world. It is cost-effective and comfortable [8].

The disadvantage of a turbofan is its large fan diameter, large resistance because of its large windward area, and complex engine structure, so it is hard to design.

2.2. Pulsejet engine

pulsejet engine is the engine whose combustion takes in the form of pulses. It has different types of pulsejet engines, such as single fuel inlet, three fuel inlet, and 5 fuel inlet designs. using the picture below to explain how the pulsejet engines work. Firstly, Let the combustion chamber under high pressure and increase the temperature. Then the spark burns the gas and fuels in the combustion chamber [9]. Figure 3 shows the combustion phase process in a valveless pulse jet engine.

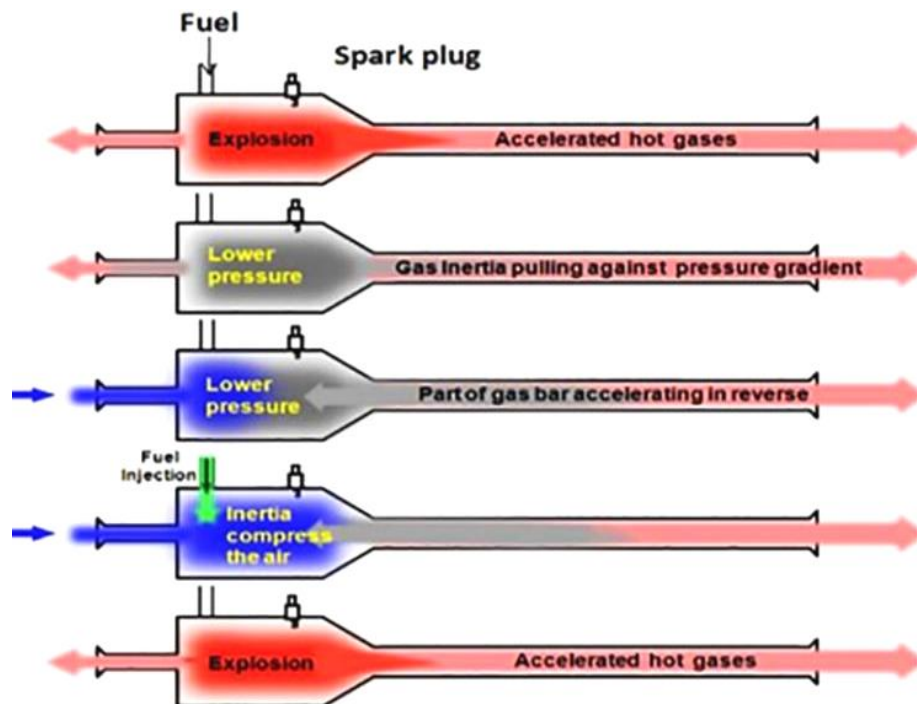


Figure 3. Combustion stages inside valveless pulsejet engine.

The gas was suddenly expended. Then it releases from the long and thin diffuser. At the same time, the pressure back to low pressure. New gas enters the combustion chamber and is mixed with fuels to form a work cycle [10].

It is true that the pulsejet engine creates a very big thrust. However, why people do not use pulsejet engines instead of other kinds of jet engines. Here are the reasons why people prefer to use other kinds of jet engines, such as turbofan which is the most popular jet engine in the world. Firstly, using a pulsejet engine creates a very loud noise. Civil aviation needs to support its passengers in staying in a comfortable environment [8]. So, it is necessary to reduce the noise in the airplane. Secondly, the fuel consumption rate is very high, however, the efficiency is very low. So, the cost of using the pulsejet engine is very expensive. For civil aviation, it is important to make a profit.

3. Prospect of Jet Engine

3.1. 3D print a Jet engine

3D printing (3DP) was hailed by journalists as a new industrial revolution at least 9 years ago. People also call 3D print additive manufacturing [5]. In simple terms, 3D printing is when people scan the things which they want to print as CAD or other kinds of files and save the files on the computer. Then use the machine and technology to print it according to the files. Also, there are different types to shape it, for example, Melting deposition.

Experiment by students of university of sheffield. There is an example that using 3D printing to print a jet engine by an undergraduate student at the University of Sheffield. So, it is more likes to help the undergraduate student to study more and get more experiences.

Then this experiment will be introduced. It was decided to base the first iteration of the 3D printed engine on an existing hobbyist engine (EHE) available for purchase. In order to collect the data easily, they will ignore some hard calculation in the aero or thermo-dynamic design aspect [9]. Also, all components are custom-made. So, the cost of printing these components is very expensive. As can be seen from Figure 4, the pictures in this slideshow were designed by these students.

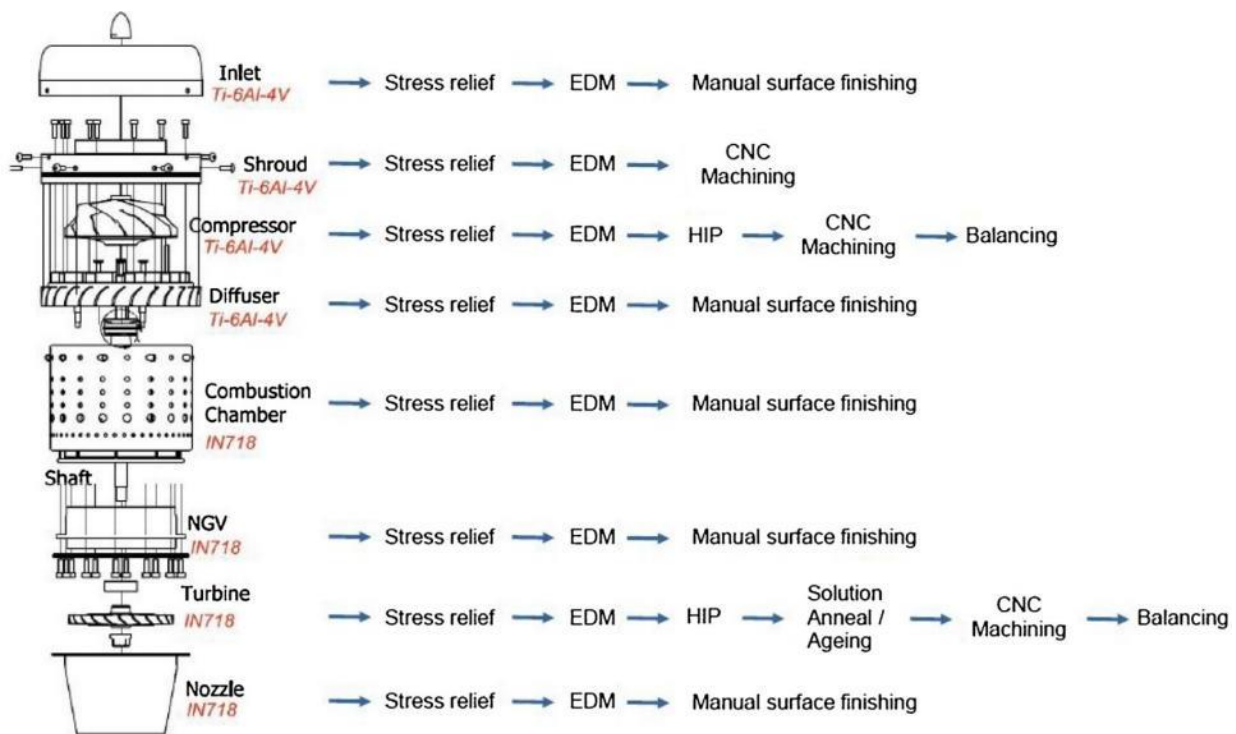


Figure 4. Designs by student of these students.

The materials of this experiment are two kinds of alloys. One is Ti-6Al-4V, which is one kind of titanium alloy with stable elements of aluminum and vanadium. Another is IN718, which is Precipitation strengthening nickel-based superalloys. Ti-6Al-4V is also called CT4. It is a very common alloy in the aviation industry because it has high hardness and great stability. However, why do these students use another kind of alloy, IN718? Because the temperature is very high in the combustion chamber. The combustion chamber to the nozzle needs to be stable at a very high temperature. So, these students use IN718 which is very stable at very high temperatures [1].

And the picture below on the left is what they really print. The picture below on the right is the results of this experiment. The result is that they failed. When the test starts, a serious failure of the engine occurred at ~83 rpm, whereby all the turbine blades detached from the hub and were ejected at high speed from the rear of the engine. Figure 5 shows the results of student design processing and analysis.

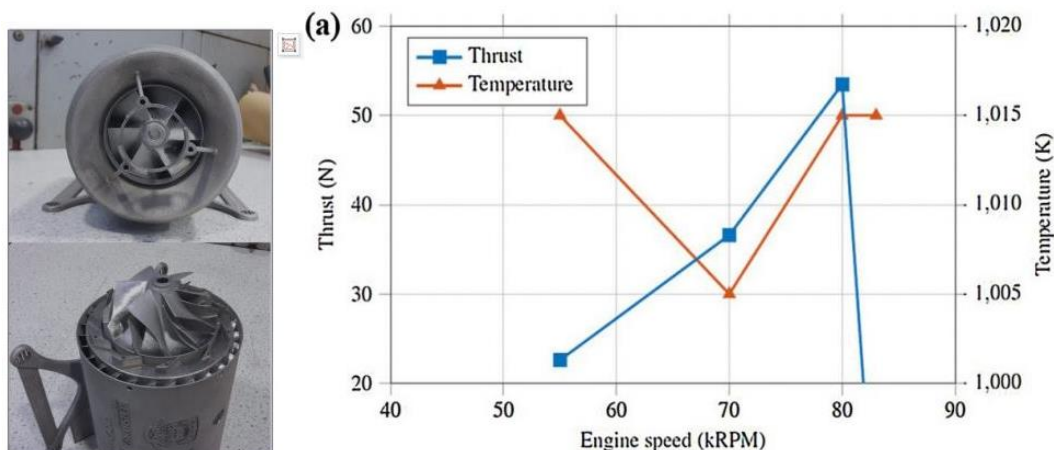


Figure 5. Results of these students.

3.2. Latest Examples for print blades of turbine

This experiment was made by 7 people from the Kalinga Institute of Industrial Technology and the National Institute of Technology in India. This journal is published by the Journal of Manufacturing Material Process in January of this year.

And They introduce using TiAl alloys to print the turbine blades. In the design stage, they take care of many aspects of turbine blades, because it is a big role which influencing the efficiency of the jet engine [4]. It works in a high-temperature environment. So, they take care of many aspects of the material, such as the structure of the materials, the composition of the material, the properties of the materials, and so on. It is worth noting that the latest blades can work at 1370 degrees. Also, because it works at high speed, it is necessary to choose materials which are High corrosion resistance and high hardness. Nowadays, the blades of modern jet engine turbines use Ni-based super-alloys that contain chromium and cobalt.

Then, people need to take care of how to print it. Firstly, using Electron Beam Melting (EBM) to print the blades. These Arcam EBM machines by General Electric Aviation company use a powerful 3-kilowatt electron beam to melt the final grains of TiAl powders to build 40 cm long blades. These blades are used for Boeing's 777X Jet engine. Boeing is one of the largest civil and military aircraft manufacturers in the world [7]. So, it is necessary for them to use the most stable components for their aircraft. It proves the stability of components printed by 3D. The picture below is what General Electric Aviation company really prints using EBM. However, sometimes, using 3D print may print imperfect products. Figure 6 shows a 3D printed TiAl blade for the GE90X engine LPT.



Figure 6. The 3D-printed TiAl blades for LPT of the GE90X engine.

Take another kind of 3D print which is Selective Laser Melting to support that 3D print has already been used in the aviation industry.

First of all, I want to introduce this kind of 3D print. It uses a high-intensity laser to melt the powder into a layer. The structure of their design has already been covered in a CAD file. For this kind of 3D print, it will work at high temperatures. So, it is necessary to control the thickness of the layers, the efficiency of the laser, the speed of scanning, and other kinds of parameters [8]. It is remarkable that the distance between the laser and the layer will influence the product. If the distance is too long, there will be some little hole in the blades of the turbine which is the imperfect product. Figure 7 is the SLM process sequence.

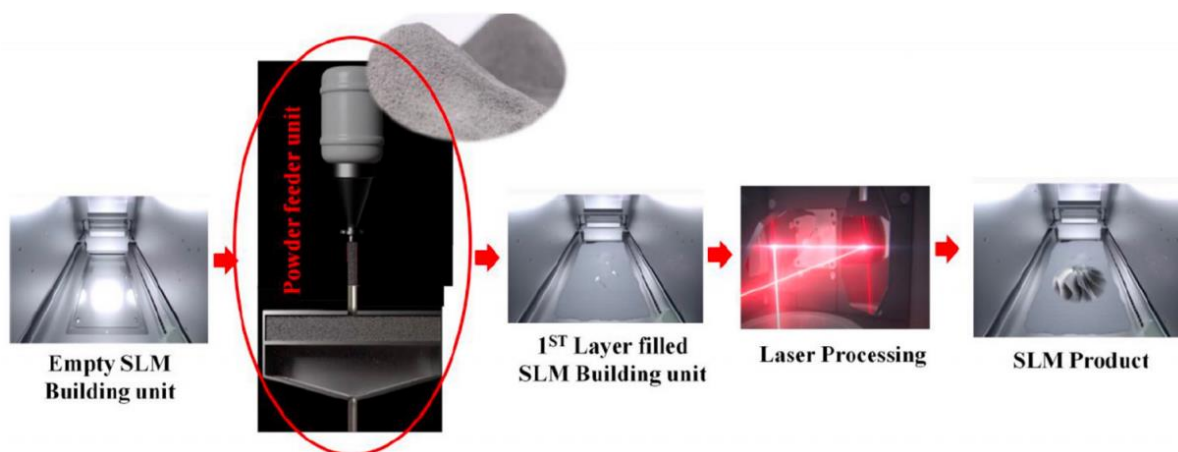


Figure 7. SLM process sequence.

Then I want to use the example of Siemens which is one of the most famously Manufacturing companies in the world [6]. The picture below is what Siemens really printed using a Ni-based super alloy. It is used for GT-400-type industrial gas turbines. Also, they take the experiment to check the stability of this kind of blade. The result is that it can work at about 1250 degrees and 13,000 rpm. Figure 8 is a Siemens 3D printed nickel alloy turbine blade.



Figure 8. 3D printed Ni alloy-based turbine blade by Siemens.

3.3. Thermal insulation material for jet engines

With the development of using high-temperature components, the demand for Ni-base superalloy components increases in past few years. People in the aviation industry try to improve the use of high-temperature, by reducing their costs and finding new kinds of materials. 3D print Manufacturing single crystals of pure nickel.

This is the latest technology from this year's additive manufacturing letters. People from Kyushu University, Osaka University, and the research center for structural materials use Selective Laser Melting which has been introduced in 3D print part to print single crystals of pure nickel.

Firstly, of all, the reason why people in the aviation industry cannot print the crystals of pure nickel successfully. In the past, the traditional beam profile is Gaussian-based. If people use a Gaussian-based beam profile, the energy flux decrease away from the center of the beam radius whose energy

distribution is like a cone. When the laser is shone on a metal powder material, the material will melt and forms a solid-liquid interface. It causes it hard to grow grains in the same direction near this kind of solid-liquid interface [4].

So how could people in the aviation industry help the crystals grow grains in the same direction? This latest experiment changes the shape of laser beam profiles. they use a flat-top laser beam. using this kind of laser beam, it can form a flat molten pool surface on the nickel powder. As a result, it is easy for crystals to grow grains in the same direction.

4. Conclusion

In conclusion, with the two examples in the previous section, some areas that can be improved by those in the aviation industry can be summarized. First of all, with the improvement of material study, people may find a new material which is cheaper than nowadays' materials in the future. Secondly, until now, the 3D print still may print some imperfect products. It is necessary for people in the aviation industry to improve the efficiency of printing perfect products.

Thirdly, by using 3D printing, people reduce the cost and weight of blades. It can also be used in other components of jet engines. At the same time, new structures or other new designs can be realized. It might become a new study area for the aviation industry to improve.

In general, using a flat-top beam profile for nickel to print will be used to print other types of material in the future. If people in the aviation industry can realize this technology to print with different kinds of materials, the cost of manufacturing different types of components of jet engines.

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