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Original Research

JET ENGINE – CONSTRUCTION AND MODERN DEVELOPMENT EXAMPLES

TURBINOWY SILNIK ODRZUTOWY – BUDOWA I PRZYKŁADY OBECNEGO ROZWOJU

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Abstract

The article presents the construction and operating principle of a turbine jet engine. The basic types of engines of this type are presented, such as single-rotor single-flow jet engines, single-flow dual-rotor engines (which are another development version of single-rotor engines), as well as dual-flow engines which are currently most commonly used in passenger aviation, and contra-rotating propeller engines and turbine propeller engines. Also presented their applications, such as propulsion of various types of. In the further part of this paper, the development trends of turbine jet engines are described, based on patents that have been granted in recent years. One of the cited patents is the use of a fuel cell to power an electric motor used to start a turbine jet engine. Also presented the concept of an electric motor providing propulsion of aircraft. An engine of this type is devoid of a turbine and a combustion chamber, and the machine shaft rotates only using electricity. The purpose of this paper is to present the construction and operating principles of turbine jet engines and examples of the current development of this type of construction, as well as to determine future development trends for those devices.

Keywords: engine, power unit, drive, airplane, aircraft

Streszczenie

W artykule przedstawiono budowę oraz zasadę działania turbinowego silnika odrzutowego. Przedstawiono podstawowe rodzaje silników tego typu, jakimi są odrzutowe silniki jednowirnikowe jednoprzepływowe, jednoprzepływowe silniki dwuwirnikowe (które są kolejną wersją rozwojową silników jednowirnikowych), a także silniki dwuprzepływowe która są obecnie najczęściej stosowane w lotnictwie pasażerskim oraz silniki przeciwbieżne śmigłowentylatorowe i turbinowe silniki śmigłowe. Przedstawiono również ich zastosowania jakimi jest napęd różnych typów statków powietrznych. W dalszej części niniejszego artykułu, przedstawiono tendencje rozwojowe turbinowych silników odrzutowych, na podstawie patentów jakie zostały przyznane w ciągu ostatnich lat. Jednym z przywołanych patentów jest zastosowanie ogniwa paliwowego do zasilania silnika elektrycznego, użytego do rozruchu turbinowego silnika odrzutowego. Przedstawiono również koncepcję elektrycznego silnika zapewniającego napęd statków powietrznych. Silnik tego typu, jest pozbawiony turbiny i komory spalania, a wał maszyny obraca się jedynie za pomocą energii elektrycznej. Celem niniejszego artykułu jest przedstawienie budowy oraz zasady działania turbinowych silników odrzutowych i przykładów obecnego rozwoju tego typu konstrukcji oraz określenie przyszłych tendencji rozwojowych tych urządzeń.

Słowa kluczowe: silnik, zespół napędowy, napęd, samolot, statek powietrzny

1. Introduction

The jet engine is the basic element of every aircraft. It is responsible for providing the necessary thrust to generate lift, which allows the aircraft to fly.

The design of jet engines has clearly evolved along with the development of the entire aviation industry. This was a consequence of the continuous process of improving air transport, in the face of the growing demand for the provision of air services - in the form of transporting people and goods. It should also be clearly emphasized that there would be no development of civil aviation without the development of military aviation. For a very long time, modern solutions were first introduced in military applications, and when they proved themselves there, they were transferred to the civilian environment.

A jet engine consists of several sections, which are: inlet, compressor, combustion chamber, turbine and nozzle. An optional addition is an afterburner, which allows both achieving high forward flight speed and minimizing the time to reach this speed. A cross-sectional diagram of a jet engine is shown on Fig.1.

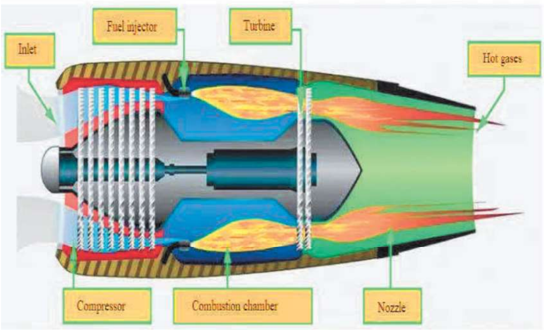

Fig. 1. Cross- sectional diagram of a jet engine, (Source Aeronautics-Guide)

The principle of operation of a turbine jet engine is based on the increase in pressure of the air flowing into the device, with the help of the related pressure it flows into the combustion chamber, where it is mixed with fuel using evaporators or swirlers. It is in the combustion chamber that the resulting fuel-air mixture ignites, which generates thrust. Next, the air with an increased temperature falls onto the turbine blades. The main task of the turbine is to drive the compressor. It is worth noting that this component is the most critical part of the entire engine. This is because the turbine operates at a very high temperature, in the range of several hundred to a thousand °C. Due to the enormous thermal loads and those caused by continuous rotation, it is considered that the turbine determines the parameters of the entire jet engine.

The engine is started in several different ways. For this purpose, it is possible to use the APU Auxiliary Power Unit. This device is placed at the rear of the aircraft, the purpose of which is to provide electrical energy to a miniature electric engine, coupled to the jet engine. The value of this speed is several thousand rpm. By giving the shaft rotational speed, the rotational speed of other engine components also increases. Through this action, it is possible to supply fuel to the chamber and ignite it, which causes a further increase in rotational speed.

As mentioned, the design of the jet engine has evolved as a result of the growing requirements placed on aircraft structures. Therefore, the purpose of this article is to present the various variants of turbine jet engines, the history of their development, and the effects of current research.

2. Types of turbine jet engines

Due to the specificity of their operation, turbine jet engines have several basic variants. This division results directly from the different conditions of use of such devices, and consequently different values of rotational speed achieved by aircraft power units. In addition, it is necessary to distinguish the application of a given type of engine. An engine used in civil aviation will look different than in military aviation. This results from the specificity of this use. For example, before a civil aircraft takes off, it is necessary to start the engine earlier in order for the power unit to gain temperature and for the materials to adapt to the working conditions. In military aircraft, we deal with different situations. Often, when we deal with the so-called duty pair (a pair of aircraft standing on the airport tarmac in combat readiness), the pilots of these machines must immediately start the aircraft to perform the flight task after receiving the order. As a result, they do not warm up the engine. Therefore, engines used in military machines are exposed to greater thermal loads and those resulting from the action of axial and radial forces of the operating engine.

2.1. Single-rotor single-flow jet engine

These are the simplest turbine engines. Currently, they are used as a drive for "target aircraft" or flying models and some types of cruise missiles or unmanned reconnaissance aircraft. They can also be used as a source of power for selected types of disposable, training, training-combat aircraft (Stefan Szczeciński and others).

The advantages of this type of construction are the simplicity of the design, which enables low-cost production and operation. The value of available thrust, generated by single-rotor, single-flow turbine jet engines, oscillates within the range of 1,000 daN to 2,000 daN for combat aircraft and within the range of several to a dozen or so daN for flying models. Fluctuations in the generated thrust value in such a wide range result from the very versatile use of this type of engine. The disadvantages of these single-flow machines are the limitation of operational parameters due to their simplicity of construction. These limited parameters are the short engine start-up time, or the acceleration and deceleration time.

These, the simplest jet engines are not economical. The value of the specific fuel consumption is slightly lower than 1 kg/daNh, during operation in the cruise range. As the described design developed technically, air vents, adjustable guide vanes (in the case of axial compressors), adjustable outlet nozzles or adjustable guide vanes were introduced. The improvement of the device allowed for a significant reduction of the acceleration and deceleration time without the risk of stalling and damage to turbine or compressor parts. As a result of these changes, the safety of flying and the efficiency of performing aviation tasks improved (Stefan Szczeciński and others). A cross-section diagram of this type of engine is shown in Fig. 2.

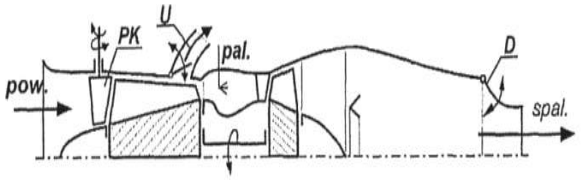

Fig. 2. "Diagram of a jet engine with a mechanized pre-flow channel: PK – adjustable compressor guide vanes, U – air release after the compressor, D – adjustable outlet nozzle, pal. – fuel, pow. – air, spal – exhaust gases (Stefan Szczeciński and others)"

An example of an aircraft equipped with a single-flow turbine jet engine is the MiG-19 aircraft, which were used in Poland at the turn of the 1950s and 1960s. They were equipped with a pair of RD-9B engines developed in the design office of Alexander Mikulin. In engines of this type, air bleed was used during start-up and operation in the lower range of rotational speeds with simultaneous, full opening of the exhaust nozzle flaps (as is the case during afterburner operation). During engine operation in the cruise range, the flaps were partially closed. In turn, full deflection was used at the maximum range of rotational speeds during flight without afterburner (Stefan Szczeciński and others).

One of the modifications of the single-flow engine was the introduction of a twin-rotor design.

2.2. Single-flow dual-rotor jet engine

The diagram of a single-flow, dual-rotor engine is shown in Fig. 3.

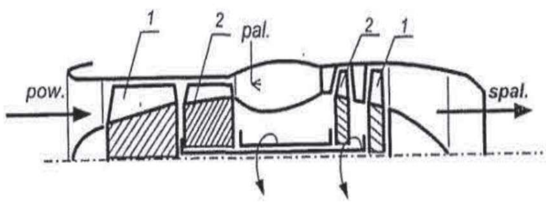

Fig. 3. Single-flow, twin-rotor jet engine: 1 – low-pressure rotor, 2 – high-pressure rotor, 3 – medium-pressure rotor, 4 – afterburner, pal – fuel, spal – exhaust gas, (Source: Stefan Szczeciński and others)

An example of a used twin-flow turbine jet engine is the British Olympus engine from Bristol Aero Engines. It was introduced into production in 1955, and its development versions (Rolls-Royce/SNECMA Olympus 593) were used to power the famous supersonic Concorde aircraft. Twin-rotor engines were used in Poland, and their production began in 1959. An example of an engine from this period is the R11F-300 engine, equipped with an afterburner. It was the powerplant of various versions of the Mig-21 aircraft. A characteristic feature of the R11F-300 engine is its compact design, and the eight-stage compressor (4+4) it is equipped with allows for obtaining a compression ratio of about 8.6…9.55. The value of the obtained compression ratio depends on the engine version (Stefan Szczeciński and others).

2.3. Dual-flow engine

Dual-flow engines are now commonly used in civil passenger aviation. An example design of this type of engine is shown in Fig. 4.

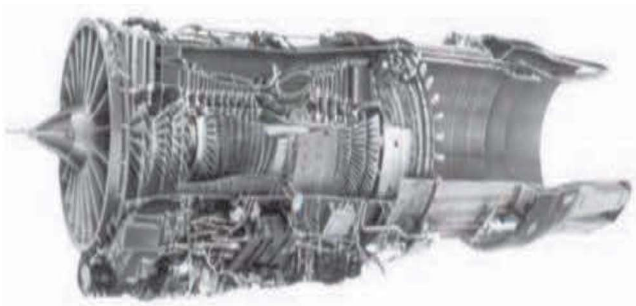

Fig. 4. A dual-flow turbine jet engine equipped with a mixer and afterburner F100- PW-229, (Source: Paweł Przybyłek, Andrzej Komorek)

As we can see in the above diagram and from the name of the presented device, it is equipped with a second air flow, bypassing the basic engine components. Thanks to this, the dual-flow engine allows to achieve cruising speeds in the range of 0.8…0.85 Ma with a simultaneous, moderate fuel consumption of 0.35…0.3 kg/daNh (Stefan Szczeciński and others).

2.4. Contra-rotating propeller engine

The next step in the development of turbine jet engines was the introduction of the contra-rotating propeller fan drive.

The term "counter-rotation" means the swirling of the air behind the propeller, which increases the amount of air flow energy moving parallel to the direction of flight, which is converted into thrust of the power unit. The diagram of the described counter-rotating propeller-fan engine is shown in Fig. 5.

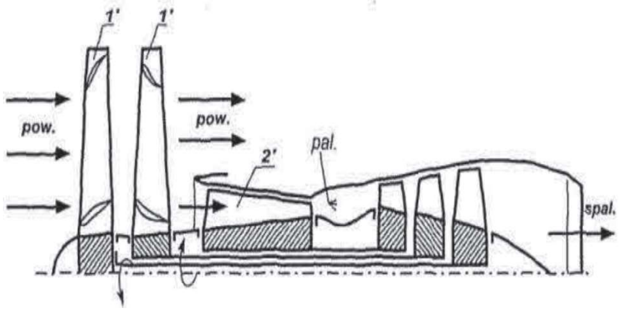

Fig.5. "Diagram of a propeller-fan engine: 1' – propeller-fan, 2' – exhaust gas generator compressor, pal. – fuel, pow. – air, spal. – exhaust gases", (Source Stefan Szczeciński and others)

One example of the use of aircraft powertrains equipped with a fan-type engine is the An-70 aircraft.

2.5. Turbine propeller engine

Turbine propeller engines are characterized by the addition of a propeller to a turbine jet engine in order to improve the operating properties of the power unit in a limited speed range. An example of the use of this type of engine is passenger and transport aircraft that do not require high-speed flight and are characterized by low acquisition and use costs. These include, for example, the ATR-72 civil aircraft or the CASA C-295 military transport aircraft. The diagram of the turbine propeller engine is shown in Fig. 6.

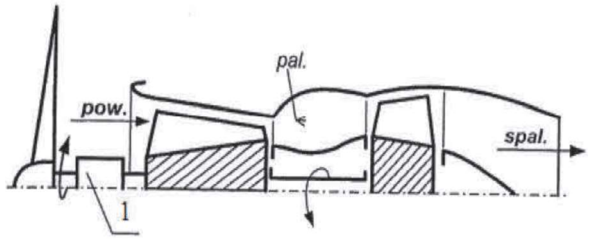

Fig. 6. Schematic diagram of a single-rotor propeller engine: 1 – rotor of the exhaust gas generator, pal – fuel, spal. – exhaust gas, pow – air, (Source Stefan Szczeciński and others)

Currently, turbine propeller engines are implemented as single- or, currently more often, twin-rotor, which can be considered as another development version of this type of drive.

3. Current development of turbine jet engines

Nowadays, more and more attention is paid to renewable energy sources. This has its resonance in the face of quite clear efforts to reduce greenhouse gas emissions. These voices of opposition to CO2 emissions do not bypass the aviation industry either. In 2016, in the United States, a patent was filed for an aircraft engine using a fuel cell.

3.1. Application of fuel cell in turbine jet engine

A fuel cell is used to obtain electrical energy from hydrogen fuel.

The need to develop an engine using a fuel cell arose from the imperfections of the compressor. If the compressor reaches the so-called threshold temperature, the air can interfere with the operation of the compressor, which causes difficulties with lubrication of this element. As a consequence, the amount of work necessary to compress the air to a given pressure increases. Consequently, this can adversely affect the efficiency of the compressor, i.e. not using its full potential. The solution to this shortcoming may be the elimination of air heat energy from the compressor section, which is provided by the engine using a fuel cell. In addition, the use of a fuel cell provides power to the electric motor used to start the turbine jet engine, and the final product of the chemical reaction in the fuel cell is water (General Electric Company, Mohammed El Hacin Sennoun). The diagram of this solution is shown in Fig. 7.

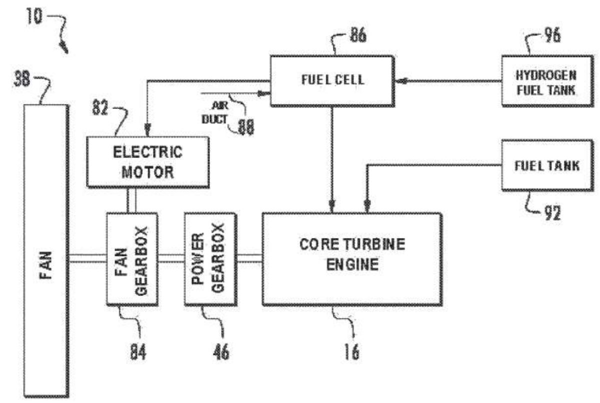

Fig. 7. Schematic representation of a turbine jet engine equipped with a fuel cell: 10 – axial direction, 16 – sample core of a turbine jet engine, ,38 – variable pitch fan, 46 – power transmission, 82 – electric motor, 84 – fan transmission, 86 – fuel cell, 96 – hydrogen tank as fuel for the fuel cell, (Source: General Electric Company, Mohammed El Hacin Sennoun)

3.2. The concept of a fully electric turbine jet engine

Another interesting concept is a motor that uses electric current to rotate the motor shaft. A diagram of such a concept is shown in Fig. 8.

As we can see in the diagram above, this engine lacks a combustion chamber and a turbine. This is due to the lack of need to burn fuel in this type of engine, because the entire engine is, in a way, one large electric coil.

Due to the lack of most moving parts in the engine and the absence of a combustion process, this type of engine is characterized by overall greater operational safety (Codrin-Gruie Cantemir), which is of great importance in the aviation industry.

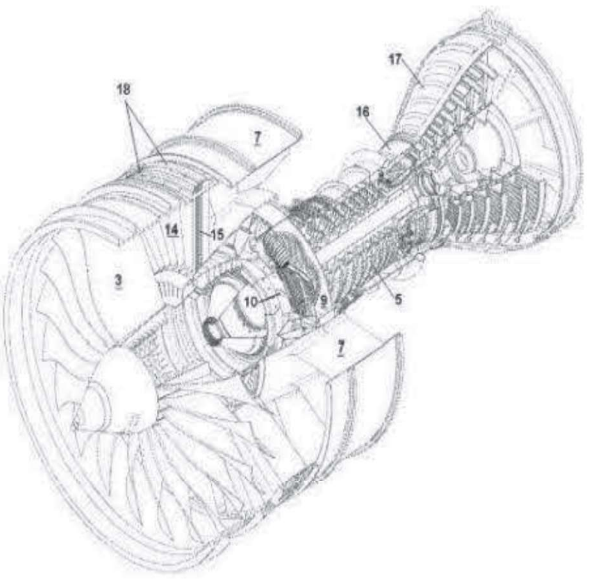

Fig. 8. Isometric diagram of a hybrid turbine jet engine: 3 – main rotor, 5 – high-pressure compressor, 7 – mid box, 9 – rotor, 10 – bent spokes, 14 – booster, 15 – cooling channels, 16 – combustion section, 17 – turbine assembly sockets, (Source: Codrin-Gruie Cantemir)

4. Development of fuel technology in aviation

Currently, there is an increasing talk about the need to reduce emissions of harmful greenhouse gases. This also applies to aviation. One of the alternative solutions is the use of biofuels in aviation. Currently, one of the most interesting works on a fuel competitive to the currently used E85 and AGE 85 is the work on synthetic fuel from biomass. They are conducted by Prof. Jan Rusek from Purdue University's School of Astronautics and Aeronautics Engineering, founder of Swift Enterprises Ltd. A characteristic feature of this type of fuel is the lack of oxygen compounds. Its composition is 82.5% m/m mesitylene and 16.9% m/m isopentane and trace amounts of other hydrocarbons. After completing the initial tests, Swift, in cooperation with the FAA, conducted engine tests. The test results confirmed low wear of engine parts, no contamination and good fuel quality. The only drawback was a slight deformation of the fuel pump diaphragm. It should be mentioned, however, that tests of the discussed fuel type were carried out on piston engine (Zbigniew Pągowski).

When considering substitutes for fuels currently used in turbine jet engines, it is worth mentioning the concept of Bio-Jet fuel. This is a fuel produced using oil processed from biomass. The first breakthrough event related to the use of this type of fuel was obtaining certification for Jet fuel produced from microalgae by the American company Solazyme. Using this type of fuel, the reduction of greenhouse gas emissions reaches 95%. Work on Bio-Jet fuels was also carried out by Boeing, which in 2008, in cooperation with UOP LLC Honeywell, presented the practical application of Bio-Jet fuel, developed by itself a year earlier under a government contract. This type of fuel also meets the requirements for fuels used in turbine jet engines, i.e. a freezing point value of less than -47°C and a flash point exceeding 38°C The fuel developed by UOP was called Bio-SPK. Moreover, in the case of this fuel, the basis for production was a process involving catalytic hydrorefining of oil from microalgae and vegetable oils.

In favor of the use of biofuels, there are a number of other important factors. By using a significant degree of raw material conversion, we can minimize the amount of waste products. In addition, through greater production of biofuels, it is possible to obtain the use for current agricultural wastelands or poor quality soils (Bohdan Naumienko, Grzegorz Rarata). This will be a huge advantage for supporting domestic agriculture. It should also be taken into account that in the production of more technologically advanced fuels, it is necessary to use algae or microalgae, which entails the need to build appropriate infrastructure and have the appropriate experience.

5. Conclusions and summary

The turbine jet engine is an extremely innovative device. Despite the various concepts presented in this study, this device is still being developed. This is due to the constantly increasing demand for innovative devices of this type, as aviation has more and more applications. This has been demonstrated by the current war in Ukraine, where various types of aircraft are very often used - including drones.

Given the ongoing international tensions, we can expect an increase in interest in the design of turbine jet engines, which will be designed to provide propulsion for aircraft in such a way that they can gain air superiority in confrontation with enemy machines. Based on history, we can say that technology used for military needs will pass into the civilian environment and gain its new applications there.

In civil aviation, more and more attention is being paid to the need to protect the environment. It is often said that the conventional aircraft propulsion, which is constituted by turbine jet engines, should be replaced by renewable energy sources. The solution to this problem may be the use of the engine presented in this study, in which a fuel cell is used to drive an electric starter engine, or the presented hybrid turbine jet engine, in which electricity plays the leading role. It is also worth emphasizing that this type of energy can be generated using renewable sources, but it can also be easily transferred and stored, for example using batteries. In the coming years, we can expect the development of just such a source of aircraft propulsion.

The development of fuel technology is inevitable if we are to talk about the development of the aviation industry. This is related to the current efforts to reduce greenhouse gases. The use and further development of biofuels in aviation will have a huge impact on the shape of the aviation industry in the coming years.

This study can be an introduction to a more in-depth analysis of the development of turbine jet engines, which is extremely innovative and has enormous research potential. It can also be a review of the individual types of turbine jet engines currently in use.

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