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TURBINE ENGINES TREND DEVELOPMENT

Trend rozwoju silników turbinowych

Abstract: *The aim of the following article is to define the directions of development of aviation turbine engines. It was assumed that these directions would determine the increase in pressure ratio and fuel combustion temperature as parameters determining the efficiency of the Brayton cycle.*
Keywords: *turbine aircraft engines, jet engine designs, development of turbine engines*

Streszczenie: *Celem artykułu jest określenie kierunków rozwoju lotniczych silników turbinowych. Założono, że kierunki te będą determinowały wzrost stosunku ciśnień i temperatury spalania paliwa jako parametry określające sprawność cyklu Braytona.*
Słowa kluczowe: *turbinowe silniki lotnicze, projekty silników odrzutowych, rozwój silników turbinowych*

1. Introduction

It was assumed that the directions of development are determined by such changes in the operating parameters of turbine engines by which the comparative Brayton cycle achieves the maximum values of energy efficiency.

Of course, many other factors (economic, environmental, performance limitations and application constraints) are taken into account when developing new airplane turbojet engines. It is even important whether the engine is developed for medium-haul and long-haul aircraft.

On the other hand, the usage of new construction materials and modern technologies as well as electronic engine control systems are activities aimed at ensuring, first of all, maximum fuel combustion temperatures and maximum engine pressure ratio values. The main goal of this procedure is to achieve the lowest possible fuel consumption and that will be possible for the conditions where the Brayton cycle shows the greatest efficiency.

The aim of the study was to determine how those engine operating parameters have changed in recent years and also which have the greatest impact on the efficiency of thermodynamic processes.

To calculate the development trends, the Moving Average and Least Squares Method were used, in that way it was possible to forecast the development directions of selected engine parameters such as: pressure ratio, bypass ratio, turbine inlet temperature, specific fuel consumption and the Thrust to Weight Ratio parameter.

2. Choice of engines for analysis

The analysis covered engines that were produced between 1981 and 2018 and are still operated in commercial airliners. One of the analysed development trends was the change of the bypass ratio, that is why all selected engines are turbo-fan engines. This type of engine is characterized by more complex design, but its main advantage regards low fuel consumption. The relationship is directly proportional - the higher the bypass ratio, the lower the specific fuel consumption. The selected engines are shown in tab. 1. The data was implemented from the documents that the manufacturers submitted to obtain the certificate for the engine.

Table 1

Engines selected for analysis [4–14]

Engine Manufacturer Plane	Year of EASA Certification	Engine pressure ratio	Bypass ratio	Turbine Inlet Temperature [K]	Thrust to Weigh Ratio
RB211-535C Rolls-Royce B757	1981	25	4.4	1643	5.20
PW4156 Pratt &Whitney B767	1987	27.5	4.8	1574	5.25
Trent 768-60 Rolls-Royce A330	1991	33	5	1450	4.96
V2527-A5 International Aero Engines A320	1993	32.8	4.8	1470	4.34
GE90-90B General Electric B777	1995	40	9	1380	5.40
Trent 560A2-61 Rolls-Royce A340	2002	35	7.6	1500	5.62
Trent 970-84 Rolls-Royce A380	2004	39	8.7	1800	5.45
Trent 772C-60 Rolls-Royce A330/Beluga	2005	35	5	1400	5.23
PW1133G-JM Pratt& Whitney A320neo	2013	40	12.5	1356	5.24
Trent 7000 Rolls-Royce A330neo	2017	50	10	1835	5.12
Trent XWB97 Rolls-Royce A350XWB	2017	50	9.6	1745	5.82
Trent1000 Rolls-Royce B787-900	2018	50	10	1810	6.00

3. Trend determination for engine pressure ratio

In both trend research methods, there is a noticeable increase of engine pressure ratio over recent years. In the moving average method (fig. 1), a large increase in the parameters is observed between 2013 and 2017. In the linear method, the function is derivated as Y = 0.6178x-1198.7. The parameter "b" in the given function has the value of 0.6178, that means that the engine pressure ratio increases by 0.6178 every year (fig. 2). According to that assumptions in 2030 the engine pressure ratio will exceed the value of Π = 55 [2, 15].

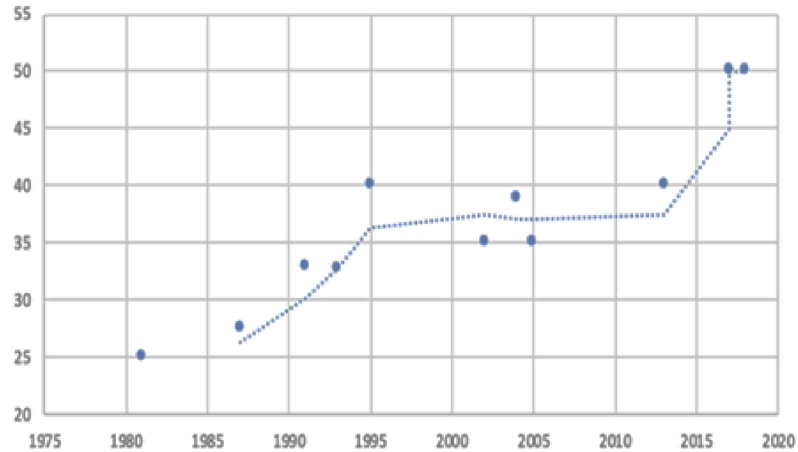

Fig. 1. Development trend of pressure ratio determined by the moving average method (smoothing coefficient k = 2)

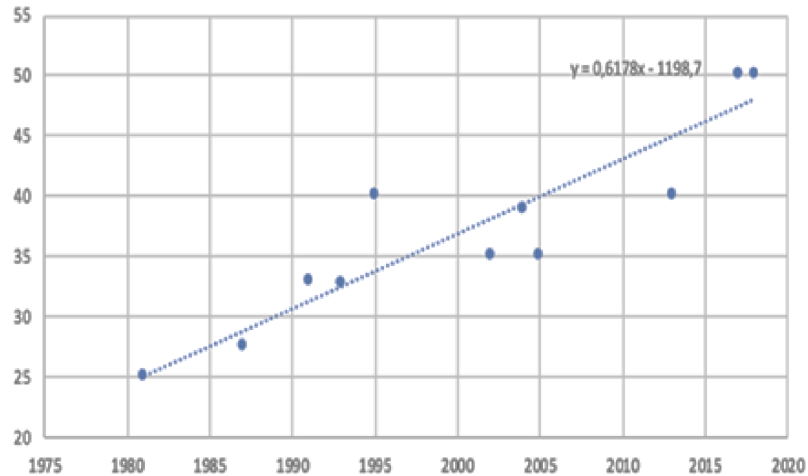

Fig. 2. The development trend of pressure ratio determined by the least squares method

4. Trend determination for bypass ratio

In both trend research methods, there has been a noticeable increase in the bypass ratio in recent years. In the moving average method, a significant increase in the parameters is observed in the years from 1990 to 2000 and from 2005 to 2015 (fig. 3). In the linear method, the function is described by the form Y = 0.1741x-340.96. The value of the "b" parameter means that the bypass ratio increases by 0.1741 year by year (fig. 4). In 2030, the bypass ratio will take a statistical value of 12.5, which is the same as in the currently operated PW1133G-JM engine.

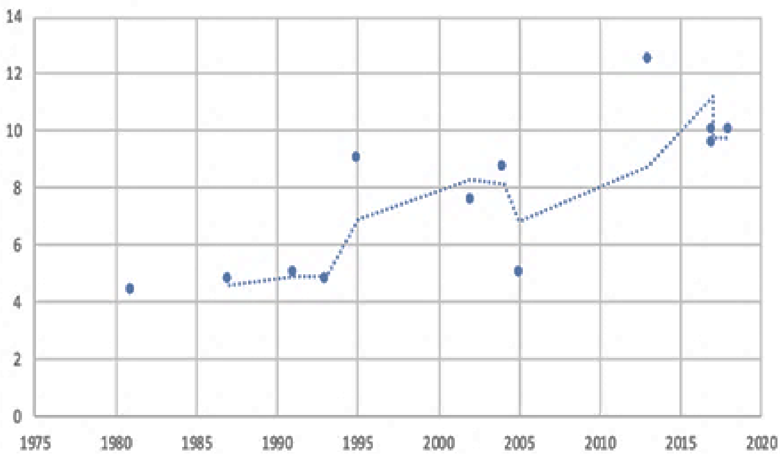

Fig. 3. Development trend of bypass ratio determined by the moving average method (smoothing coefficient k = 2)

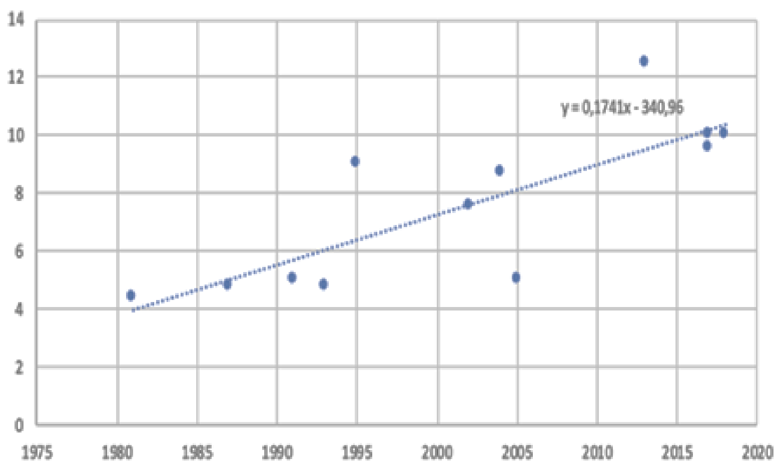

Fig. 4. The development trend of bypass ratio determined by the least squares method

5. Trend determination for turbine inlet temperature

In both methods, there is a noticeable increase in turbine inlet temperature over the years. In the moving averages method, a large increase in the parameter is observed from 2013 to 2018 (fig. 5). We can also see an "apparent" decrease between the years 2005 to 2013, which is caused by the very high turbine inlet gas temperature in the Trent 970-84 engine. It is significantly greater than in other engines according to this time period. In the linear method, the linear function will be described as Y = 5.693x-9817.9 (fig. 6). The value of parameters "b" means that the turbine inlet temperature increases by 5.7 K each year. This means that in 2030 the statistical average turbine inlet temperature will reach the value of 1740 K. In the currently operated Trent 1000 and Trent 7000 engines, those temperatures had already exceeded 1800 K.

In addition, it should be noted that the increase of turbine inlet temperature must be correlated with the increase of engine pressure ratio. Therefore, the increase in both those parameters was noted and it is necessary for the engine to achieve high energy efficiency [3].

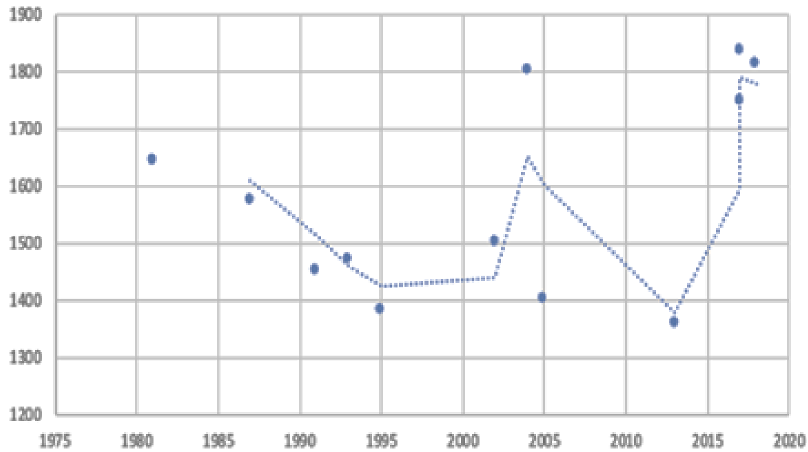

Fig. 5. Development trend of turbine inlet temperature determined by the moving average method (smoothing coefficient k = 2)

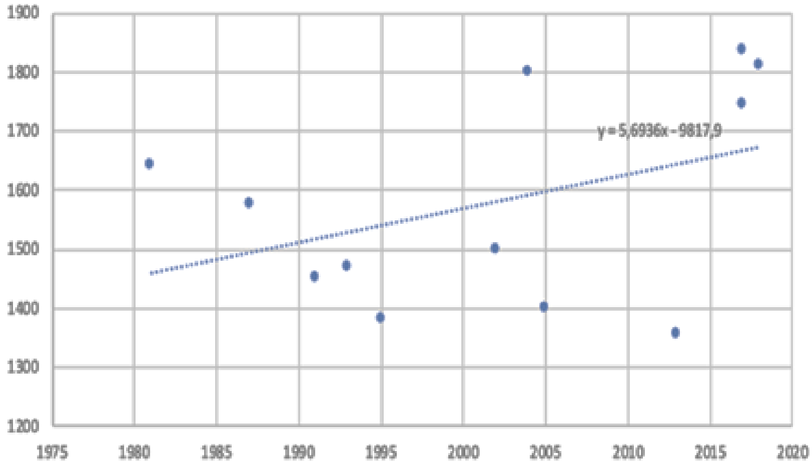

Fig. 6. The development trend of turbine inlet temperature determined by the least squares method

6. Trend determination for thrust to weight ratio

In both methods, visible can be a slow increase of the examined parameters through the years.

In the moving average method, a slight increase is observed over the entire examination period. A significant increase in this parameter occurs for the Trent XWB97 and Trent1000 engines that had been put into service in recent years (fig. 7). In the linear method, the function refers to Y = 0.0172x-29.214, i.e. the thrust to weight ratio increases by 0.0172 per year. This means that in 2030 this parameter will reach a statistical value of 5.70, what is less than in the currently used Trent 1000 and Trent XWB97 engines (fig. 8).

The analysis of the development trends according to the thrust to weight ratio parameter for selected turbofan engines shows its very slow increase. Many factors affect the weight of the engine, its thrust and the efficiency of its processes. Increase of such parameter requires the usage of new materials, new production technologies of structural elements, development of new material coatings, usage of counter-rotation and electronic motor control systems.

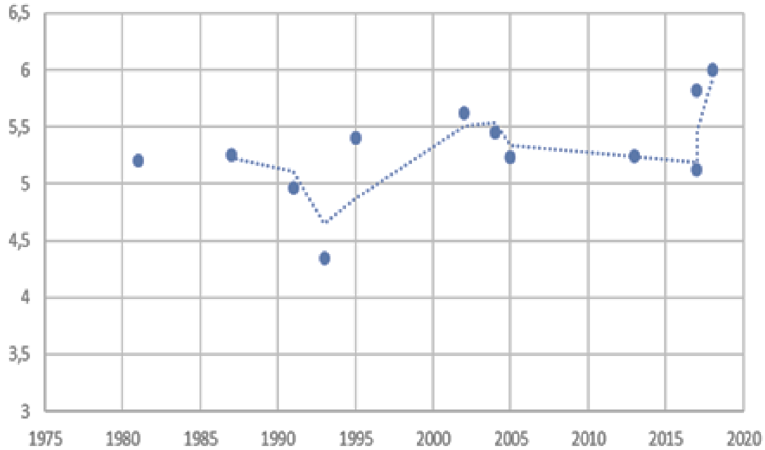

Fig. 7. Development trend of thrust to weight ratio determined by the moving average method (smoothing coefficient k = 2)

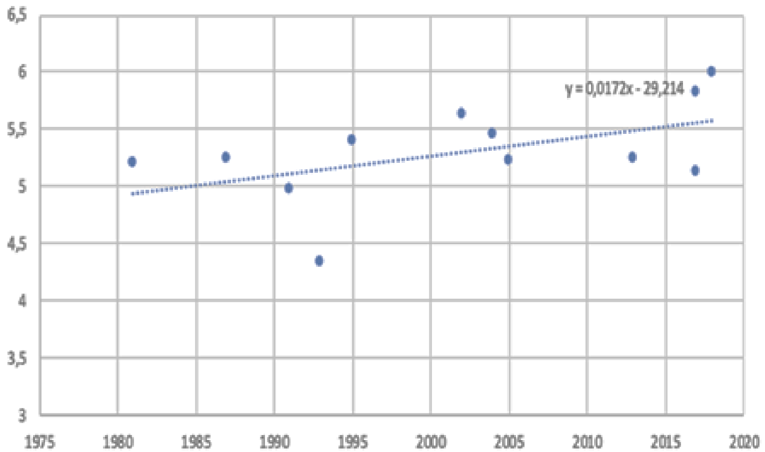

Fig. 8. The development trend of thrust to weight ratio determined by the least squares method

7. Trend determination for specific fuel consumption

Specific fuel consumption (SFC) is a widely used measurement of atmospheric engine performance. For the gas turbine family of atmospheric aircraft engines and for ramjets, performance is usually given in terms of thrust specific fuel consumption (TSFC) expressed as fuel mass flow per unit thrust output with customary units of pound-mass per hour per pound-force [(lbm/h)/lbf] or SI units of kilograms per hour per newton [(kg/h)/N]. The selected engines for specific fuel consumption are shown in tab. 2.

Table 2

Engines selected for SFC analysis [1]

Engine	Manufacturer	Type of Aircraft	Year of EASA Certification	Specific Fuel Consuption [g/(kN*s)]
RB-211- 524H	Rolls-Royce	B757-200	1975	16,90
CF6-80A2	General Electric	B767	1981	17,60
PW2037	Pratt & Whitney	B757	1983	16,45
JT8D-219	Pratt & Whitney	MD 80	1986	20,82
CFM 56	CFMI	A320	1987	16,84
CF6-80C2-A5	General Electric	A300	1987	16,33
V2522	International Aero Engines	A320	1993	16,22
GE 90-8513	General Electric	B777	1995	15,40
TRENT 772	Rolls-Royce	A330	1995	15,96
TRENT 892	Rolls-Royce	B777	1996	15,74
Trent 970-84	Rolls-Royce	A380	2004	14,75
Trent 772C-60	Rolls-Royce	A330/Beluga	2005	15,88
Trent 1000	Rolls-Royce	B789	2018	14,30

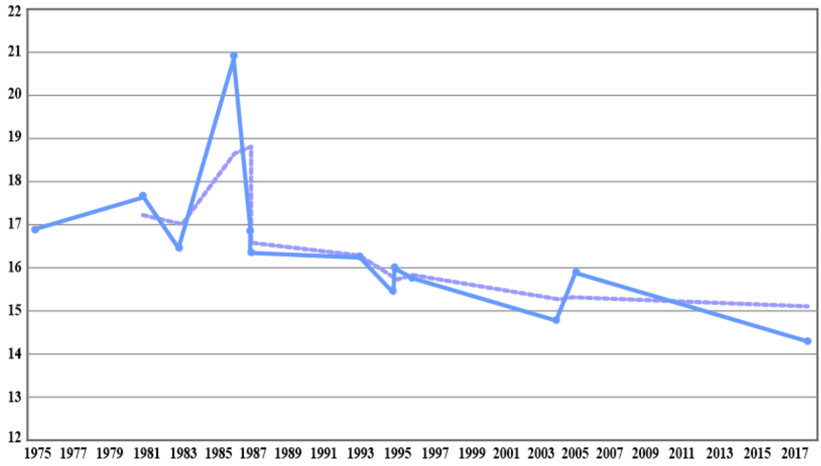

Fig. 9. Development trend of specific fuel consumption determined by the moving average method (smoothing coefficient k = 2)

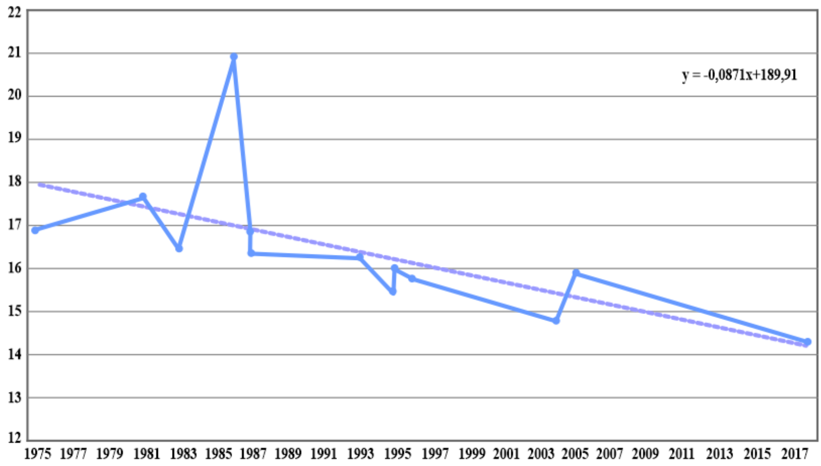

Fig. 10. The development trend of specific fuel consumption determined by the least squares method

In both methods, there has been a noticeable decrease in specific fuel consumption over many years. The mild decrease in the SFC value can be clearly visible (figs. 9 and 10). The parameter b is 0.0871, what means that the decrease in fuel consumption from year to year is lower by 0.0871. That also point out that in 2030 the specific fuel consumption will be 13.252 [g / (kN * s)]. Such small differences are the result of the fact that all considered engines are the same type. They are turbofan engines with large bypass ratio.

8. Conclusions

The analysis of the researched development trends leads to the following conclusions:

- all of the considered parameters of the turbine engines increased over the studied period;
- the highest increase was achieved by the bypass ratio, which increased by 2.5 times in the analyzed period;
- the highest "b" coefficient in the least squares method was recorded at the temperature at the inlet to the turbine and it was equal 5.69;
- the lowest "b" coefficient in the least squares method was recorded for the thrust to weight ratio parameter, which was 0.017;
- according to the least squares method forecast, in 2030 the pressure ratio will reach 55.5;
- according to the least squares method forecast, in 2030 the bypass ratio will reach 12.4;
- according to the least squares method forecast, in 2030 the temperature at the turbine inlet will reach 1740 K;

- according to the least squares method forecast, in 2030 the thrust to weight ratio (TWR) parameter will reach 5.702.

The PW1133G-JM engine is an exception of engine that has been certified after 2010 and has a turbine inlet temperature below 1400 K. It is over 400 K lower value than in the case of the Trent 1000 and Trent 7000 engines. The main advantage of this engine is its bypass ratio, which is 12.5. That means it is 25% higher than in the case of engines such as Trent 1000 and Trent 7000.

All parameters calculated using the least squares method with a forecast for 2030 are achievable. For the bypass ratio, turbine inlet temperature and the thrust to weight ratio parameter, the projected values for 2030 are already achieved by many modern engines currently being manufactured and used.

The bypass ratio forecast for 2030 has already been achieved for the PW1133G-JM engine, where it is 12.5.

What is more, the forecast turbine inlet temperature for 2030, i.e. 1740 K, is already exceeded today by the Trent 970-84 (1800 K), Trent 1000 (1810 K) and Trent 7000 (1835 K) engines.

In case of the predicted thrust to weight ratio parameter for 2030 (5.7) it is also achievable today by the Trent XWB97 (5.8) and Trent 1000 (6.0) engines.

Among all the analysed parameters, only the static pressure, which should be 55.5 in 2030, has not yet been achieved in any of the selected engines.

Regarding specific fuel consumption, the decrease in value is undoubtedly caused by an increase of the pressure ratio, turbine inlet temperature and bypass ratio, which for sure proves further technological progress in the construction of turbofan engines. In order to show more dynamic changes, the analysis should be extended to include older engines and even single-flow engines.

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