ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1213579

INFLUENCE OF THE SELECTED EXPLOITATION TASKS ON AIRLINE OPERATING COST AND FLIGHT SAFETY TAKING AS AN EXAMPLE TURBOFAN ENGINE

Pawel Glowacki

Institute of Aviation, Department of Space Technologies
Krakowska Avenue 110/114, 02-256 Warsaw, Poland
tel.: +48 22 8460011 ext. 618
e-mail: pawel.glowacki@ilot.edu.pl

Abstract

The total cost of the aircraft maintenance was in 2012 about $ 80 billion, including maintenance, repair and overhaul, ie. MRO market (Maintenance, Repairs and Overhaul), the operators of these aircraft have spent about $ 60.7 billion – of which 40% were direct maintenance costs of the engines.

It can be concluded that main influencer on airline direct maintenance costs are spending for power plants.

The article shows that the appropriate exploitation of the engine, leading not only to the total operating costs (mainly the cost of fuel and maintenance) reduction. Also through continuously engine health monitoring, resulting in a higher reliability, and thereby increases the safety of flying and – what is now especially important – by decreasing fuel consumption reduces greenhouse gas and exhaust toxic components emissions.

The modern aircraft engine and its basic performances were described.

Based on data, analysis from approximately twenty thousand flights of the specific operator and self-experience, the benefits from the use of specific maintenance and operational tasks are presented.

Results of the calculations were demonstrated which proved that engine life extension between overhaul (TBO) has impact on the operator's maintenance reserves reduction, positive cash flow and fuel cost savings.

The article confirms that it need not be contradiction between aircraft operator economic effect, and the improvement of safety of flying.

Keywords: *aircraft engine, maintenance, exploitation cost, flight safety*

1. Introduction

The operators of Commercial Aviation in 2011 have bought with the delivery of new transport and passenger aircraft 1,862 turbofan engines. Between 2006 and 2011 the cumulative Compound Annual Growth Rate (CAGR) for these engines amounted to 1%, which has resulted in an increase in the sales value of 16.7 billion US dollars in 2006 to 21.2 billion in 2011[6].

In 2013, the number of operated passenger and cargo including large-powered turboprop aircraft was 23 731 units. In the same year, the operating costs of airlines totalled $ 665 billion and increased by 14% compared to the previous year [6]. The distribution of such expenses was as follows:

32% fuel cost
12% maintenance cost } Direct engines operating cost;
27% cost of operations, includes: flight deck crew, stations, administration;
10% aircraft ownership: rentals and depreciation;
8% navigation and landing fees;
6% ticketing, sales and promotion;
4% passenger services, cabin crew;
1% IT and communications, insurance.

Total maintenance operating cost in 2012 was approximately $80 billion. Only on Maintenance, Repairs and Overhaul market (MRO) $49.5 billion have been spent by aircraft operators. Engine "share" in these expenses have reached $22.4 billion (45%).

It is expected that in 2022 spending on engines can reach $31.6 billion i.e. 46% total MRO expenses [6].

The above numbers clearly indicate a major share of expenditures for the exploitation of engines in aircraft operating costs. The exploitation is defined as – operation and maintenance [3].

The purpose of this article is to present facts supporting the thesis that a properly developed by the operator strategy of the engine exploitation not only leads to lowering overall operational costs for the fuel and maintenance, but also through consistent monitoring of the engine condition (Engine Health Monitoring), increases the probability of its reliable operation. It should be emphasized that a good technical condition of the airplane's powerplants also has a significant impact on the aircraft residual value. For example, the price of twenty years old aircraft is determined in more than 80% by the engines installed on it, when on new about 30%.

In other words, investing in exploitation activities related to aircraft engines lowers airline-operating costs, provides increased safety of flying and, which is not without significance, raise the level of technical culture and sense of responsibility of aviation ground services and pilots.

Reliability and safety in aviation are particularly important due to the fact that in contrast to the other means of transport there is no, for example side of the road.

2. Turbofan engine

Today commercial aircraft are powered mainly by turbofan high thrust engines (from 100 kN to 500 kN).The design of the aviation turbine jet engine is extremely complex in terms of structure, technology and material engineering. Especially turbofans are representing state of the art design, combining the latest achievements in many fields of science.

It can be already imaginable the structure in every respect “perfect” but unacceptable for economic reasons (the enormous costs of production and safe exploitation).

New engine designs in which the main components: fan, compressors and turbines can operate under the optimum ranges for each of these parts are being introduced into service.

The level of the development of turbine jet engines is characterized by values of such parameters as thrust and specific fuel consumption.

In the forties of the last century engines with a thrust of approximately 800 daN and the specific fuel consumption (SFC) of about 1 kg / daN * hr were operated. Today, the engines achieve thrust to 500 kN, and the specific fuel consumption of close to 0.28 kg / daN * hr.

Such improvements however, has led to an increase in the cost of manufacturing these engines from about $ 220 per 1 daN of thrust during the 90’s of the last century to about $700 now.

This is due to the high parts prices of the hot engine part. For example, one blade of the high-pressure turbine first stage (there are about 80 of them) installed on the engine with a thrust 100 kN costs about $10,000, while on engine with a thrust 500 kN more than $27,000.

As another example, in order to prevent compressor and turbine blade tip wear during light rubbing, Cubic Boron Nitride (CBN) coating is widely used on the blade’s tip. Without CBN coatings, the radial clearance at assembly would have to be increased to ensure a safe margin against rubs. Due to the extremely high temperature, resistance (approx. 1850 K) CBN variant called borazon is applied. It is about 30% more expensive than the diamond.

Figure 1 shows a drawing based on the CFM 56 features. Engine is mainly installed on passenger medium-range aircraft such as the Boeing B737 and the Airbus A320.

3. Engine parameters and their influence on maintenance cost

The most important – often called as the key parameters characterizing the engine during operation are low pressure rotor speed (fan) denoted as N1 and the temperature of the exhaust gases denoted by EGT.N1 speed is expressed in percent and indirectly indicate the value of the engine thrust. Some engine manufacturers as an indicator of the thrust amount are using so-called Engine Pressure Ratio (EPR), which is the ratio of the turbine discharge pressure divided by the compressor inlet pressure.

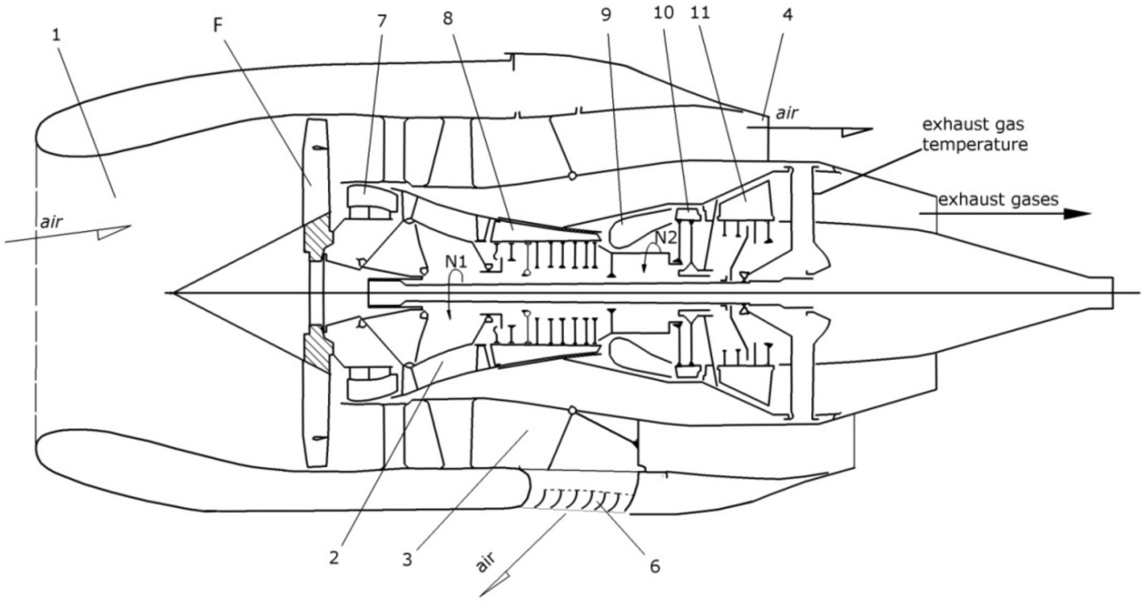

Fig. 1. Schematically presented basic features of modern turbofan engine: 1 – Engine inlet, F – Fan, 2 – internal duct, 3 – external duct, 4 – Air exhaust, 5 – Exhaust nozzle, 6 – Thrust reverser vanes, 7 – Low pressure compressor, 8 – High pressure compressor, 9 – Combustion chamber, 10 – High pressure turbine, 11 – Low pressure turbine, N1 – Low pressure rotor speed, N2 – High pressure rotor speed

Exhaust gas temperature is generally expressed in Celsius degrees. It indicates engine condition and is a measurer of the engine efficiency in thrust generation.

To sustain the maximum thrust level this temperature increases with decrease in the efficiency of the engine during operation, also fuel consumption is increasing. The parameter which the best expresses the current quality of the powerplant is exhaust gas temperature margin (EGTM).It is the difference between a specified by the engine manufacturer permissible value of the exhaust gas temperature (EGT red line), and the value of the EGT measured. The higher the exhaust gas temperature margin for the same type of engine, the higher the quality of its manufacture or repair process. The engine manufacturer provides information, that the decrease in the EGTM in the first period of operation is 10 °C to 15 °C for first 1000 cycles then about 5 °C for each additional 1,000 cycles to overhaul [4]. Operational experience has shown that, after installation of a new or overhauled engine it loses about 10 °C temperature margin compared with that given in the test-cell documentation. Direct engine maintenance cost can be calculated using formula below:

$$K_O = \frac{K_R}{T_P}, \tag{1}$$

where:
K_O – Direct Maintenance Cost (DMC),
K_R – Engine overhaul cost,
T_P – Time on Wing (TOW).

An engine has several shop visits during its life; however, frequency of the overhauls depends on various operational parameters as follows:

1. Thrust rating;
2. Operational severity;
3. Age status
4. Workscope management policies.

Operating severity comprises:

1. Flight length;
2. Take-off derate;
3. Ambient temperatures;
4. Environment.

All the above conditions, in which the aircraft is operated, (and therefore the engines installed on it) affect the level of the exhaust gas temperature or the frequency of its high value occurrences. They are of serious importance to the rate of lowering the EGTM and thus an increase an engine specific fuel consumption. For engine considered in this paper decreasing of EGTM by 10°C causes increase of the Specific Fuel Consumption (SFC) by 0.7% [4] which for take-off thrust rating fuel consumption is higher about 290 kg/hour.

4. Exploitation methods to improve the selected engine operating parameters and their impact on reducing the operating cost of an airline

In the practice, however, operators are obtaining from overhaul enterprises engines with medium values of EGTM.

Figure 2 shows the situation after installation on the airframe engines delivered to the operator from repair. The EGTM has been specified in the overhaul documentation. The main reason of engine removal for repairs is an EGT margin deterioration, so operator should take a number of operational measurements to reduce the rate of such phenomenon.

If operator does not undertake any activities that improve the EGTM, engines would be removed in a very short period of their life.

It is well known that a major factor in deterioration of engine efficiency is the gradual increase in the clearance between the turbine blade tips and surrounding static seals or shrouds. In addition, deposition of dust and oil mixture on the compressor blades and vanes and increasing air leaks through the seals are additional contributors to EGTM reduction.

Precise monitoring of the engines technical condition results in adopting measures that enable the restoration of temperature margin, as also reduction of SFC. The predominant procedure is engine gas path wash. Currently manufacturers advise to perform this procedure during scheduled maintenance tasks. Experience allows stating an opinion that this procedure should be performed also when the first signs of increased fuel consumption and the loss of temperature margin is observed, which the same as the manufacturers indications are not always.

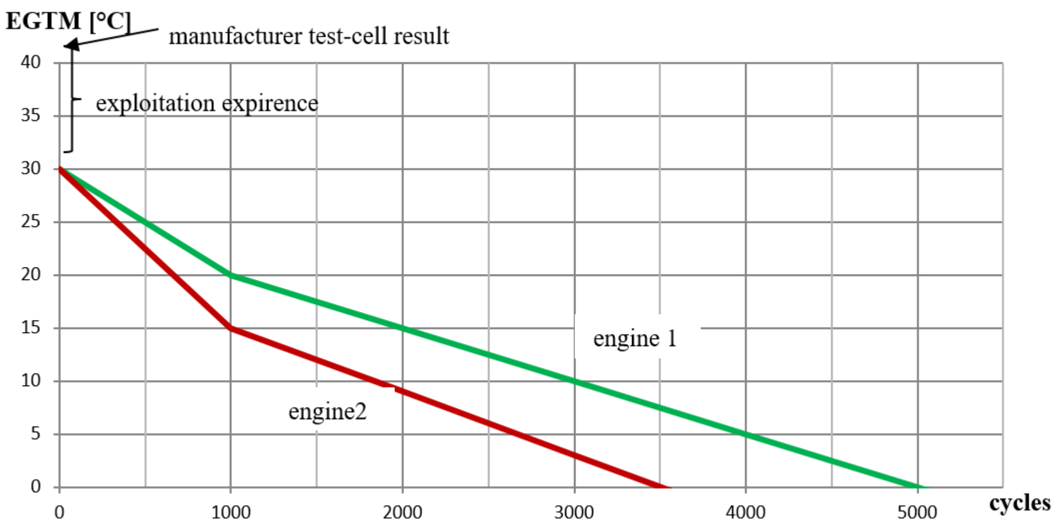

Fig. 2. Expected time on wing for two engines delivered to the operator from overhaul

Figure 3 shows changes of engines EGTM during one-year period of exploitation.

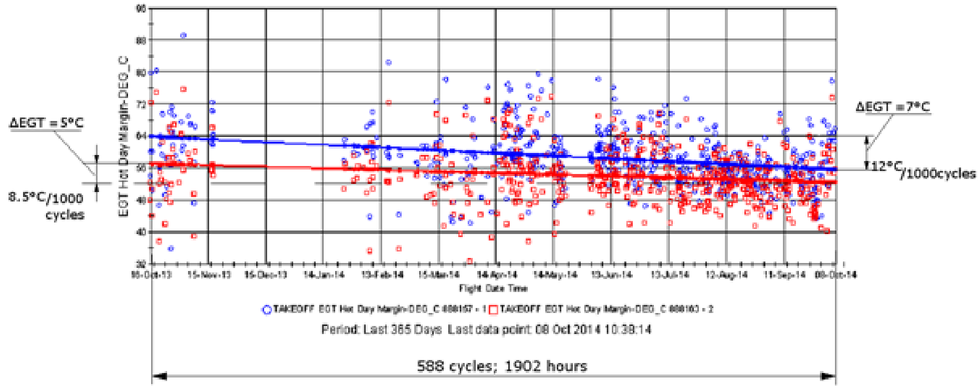

Fig. 3. EGTM decrease of the 100 kN thrust engines installed on medium range aircraft (Airline approval)

The airplane and its engines had 588 cycles/year amounting to 588 flights in 1,902 hours. The engine marked blue loses its temperature margin much faster than the one marked red. The blue engine wash could be performed more often than the red one but it is practically impossible due to maintenance planning.

Washing the engine gas path regularly can delay the repairs up to 2,000 cycles. This procedure does not require costly investments and the expenditures are of marginal value. The decreased cost for the engines mentioned above are ceteris paribus \$10 for the blue one and \$14 for the red one (see Fig. 3).

Additionally, by reducing SFC operator can save up to approx. 70 tonnes of fuel/per airplane in the first year of operation with installed new engines. In the following year sup to the eleventh cost reductions on fuel, reach approx. 20 tonnes per year/airplane. Taking into account the current fuel price of \$550 per ton (although his value is hard to predict and is likely to change) it can give the operator savings of \$210,000/per year. The calculations presented in the article concern an operator utilizing 15 twin-engine single-aisle airplanes. An assumption has been adopted that the engine's wash is performed every 500 cycles and the temperature margin restoration after the first two procedures carried out on new or overhauled engine equals approx. 3ºC and for the subsequent 1ºC. Each cycle is a 2 hours flight including 1.5 hour of cruising. Annually, the operator's airplanes carry out 1,500 cycles each.

Another method of increasing the temperature margin and decreasing fuel consumption is direct cleaning of high-pressure compressor blades and vanes, and also replacing variable stator vanes bushings and seals. This procedure requires advanced instruments and trained personnel. Taking into account how time-consuming this procedure is. It can be only performed during heavy maintenance, which requires engine removal and then separation of the upper compressor case. Such a procedure is called "top case". When it is done EGTM margin increases by 10ºC.

The numbers mentioned in the preceding sentences are based on exploitation experience and analysis of the results of hundreds gas path wash procedures and "top case" tasks performed on different types of engines and in various climate zones.

The decision to perform "top case" procedure should be taken after considerations and deepened analysis of the risks regarding the maintenance and technical conditions.

There are different limits regarding a removed engine and an installed one. However, the benefits of this procedure are substantial. The operator can prolong the period until the next maintenance up to 1,000 cycles in result decreasing the cost of engine operations to \$75per cycle (blue) and \$91(red). The cost effectiveness on fuel consumption reach up to 760 tonnes in two years/per airplane that accumulates to approx. \$210,000/year per aircraft. From this data, the cost of "top case" procedures has to be deduced. On the basis of years of experience in managing such procedures their cost can be estimated for approx. $70,000 thus, the actual savings amount up to $140,000 per airplane annually. If such a procedure is performed within a 10-year period for 5 airplanes, the operator can save on fuel costs approx. $1.5 million. At the same time, an airline can considerably improve the powerplants condition ensuring flight safety. Reducing (the amount of) fuel consumption will also result in lower fees for CO_2 emissions.

To sum up, on prolonging the duration of operating – the profit (for the described airline) is the reduction of the maintenance reserves for future expenditures from $4 million to $3.4 million. The positive cash flow in a year will reach $600,000 and the savings on fuel consumption $360,000. These cost effective measures, which result from these undertakings, are related to the maintenance.

Another factor, which has a significant impact on the airline financial results, is the way the crew operates the aircraft (especially the powerplant). In the pursuit of reducing fuel consumption and the engines life on wing extension, it is recommended to adjust the thrust to the conditions on the runway and the Take-off Mass. TOM depends on the number of passengers aboard, freight weight and the amount of fuel necessary for the flight. Adjusting to such conditions helps to avoid the needless use of maximum thrust while the TOM is minimal.

In practice, the reduced take-off thrust or derated take-off thrust is usually used. Decreasing the thrust by 5% from the maximum during take-off extends the engine life for 400-500 cycles, while reduction by 15% prolongs the period between overhaul for appx. 1,100 cycles [cfm].

Utilizing reduced take-off thrust or derated take-off thrust apart from environmental benefits (noise reduction, NO_x emissions, fuel consumption reduction during take-off and climb) has also an economic impact by reducing the cost of maintenance for approx. $10/per one flight hour by engine's operational life extension.

Maximizing the benefits from the use of the possibilities of take-offs in the lower ranges of the engine thrust can be achieved when the technical and operational staff work closely with flying crews, and the parameters of each take-off are analysed by the continuing airworthiness management personnel regarding engine performances.

Subsequent analysis should be climb and approach phases of flight. It is very difficult because the duration of these manoeuvres often depends on the specificity of the airport and air traffic control decisions.

However, in this case negotiations with the airport authorities and air traffic control should take place.

Table 1 a) and b) presents averaged results of the analysis for several operations of the single aisle aircraft in two airports. Similar calculations were performed for many airports using the data from 25,000 flights registered on Quick Access Recorder (QAR) of one operator for one type of aircraft. Numbers in tables show that the shorter climb of the aircraft of about 10 seconds, the lower fuel consumption of about 20 kg. The fleet of 15 aircraft performing 22,500 flights a year could save about $250,000. Major reductions can be expected in the case of shortening the time of approach by 1 minute. Consumption in this case is lower than approx. 35 kg of fuel per aircraft, which on balance, could result in savings in the amount of $435,000.

Tab. 1. Average landing and take-off cycle of aircraft fleet in one of the airports

a)

Manoeuvre	Duration [s]	Fuel consumption [kg]	CO emission [g]	NO_x emission [g]
Take-off	46	86	40	1911
Climb	89	165	69	3491
Approach	272	148	571	1475
Taxiing	700	149	2683	824
Total	**1107**	**548**	**3363**	**7701**

b)

Manoeuvre	Duration [s]	Fuel consumption [kg]	CO emission [g]	NO_x emission [g]
Take-off	49	99	39	2426
Climb	74	148	55	3424
Approach	302	168	629	1722
Taxiing	1100	228	4175	1261
Total	**1526**	**644**	**4898**	**8832**

For operators there is possibility of fuel burn reduction thereby emissions by such flight planning that back jet stream is the biggest. Jet streams occurring at cruise altitudes have a significant impact on fuel consumption and such high altitudes phenomenon has to be considered during flight planning. Routes where high speeds of the jet streams have occurred were analysed.

Figure 4 and 5 are showing the result of calculations for the flights of one type of aircraft with similar take-off mass, on certain route.

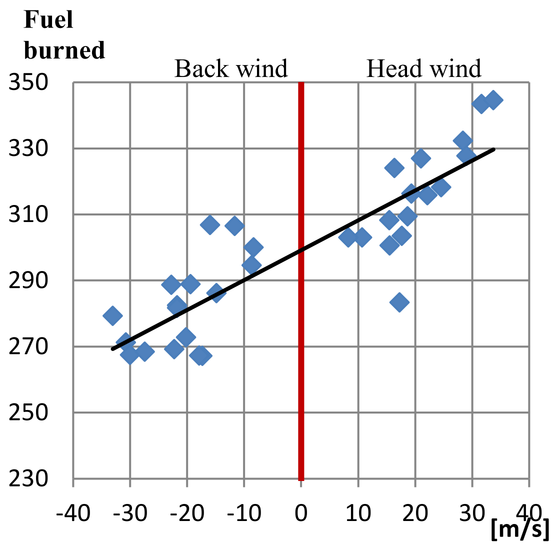

Fig. 4. Aircraft fuel consumption per 100 km on certain depending on axial component of the jet stream

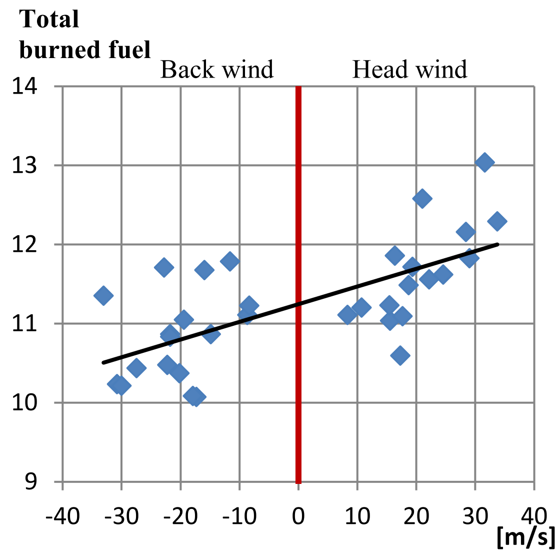

Fig. 5. Total aircraft fuel consumption on certain route depending on axial component of the jet stream

For the operator important information is that each 10 m/s speed, opposite axial component of the jet stream increases fuel consumption by about 300 kg, for approx. 4 hours flight. Increased axial component of the head jet stream by 10 m/s causes' fuel consumption increasing by 0.125 ton per one-hour flight.

5. Conclusions

Technical and operational measures described in this article have an effect by reducing the airlines operating costs, mainly by decreasing the fuel consumption and extending the engines life until the first overhaul and between it. Other measures for reducing costs also have been indicated. The afore-mentioned benefits result from meticulous observations of parameters that determine the performances of an airplane's engines.

Costs reduction and increasing the reliability of an airplanes powerplants thus the safety of flying is a consequence of evaluation the engines performances by engineers.

High-level of the engine exploitation require an experienced team of engineers that not only understand the technical aspects but also can anticipate the economic consequences of their decisions.

The scope of further detailed analysis should focus on the reduction of the engine thrust during take-off so that the benefits will not be diminished by the prolonged climb resulting in higher fuel consumption.

A new approach has to be applied to flight planning so that the jet streams will be used to an airplanes advantage on a such way that head jet stream has the lowest speed and back the highest.

Airline executives have to be reminded that the profits resulting from adequately supervised engine exploitation amounted up to $/ 0.5 million per year for the airline described in the article. The cost of hiring an additional specialist is approximately $40,000 /per year.

References

[1] CFM, *Flight Operations Support*, December 2005.

[2] Global, *Commercial Aero Turbofan Engine Market, Supply chain and Opportunities, 2011-2017*, Lucintel Brief, July 2012.

[3] Glowacki, P., Szczeciński, S., *Transport lotniczy. Zagrożenia ekologiczne oraz sposoby ich ograniczania*, Wydawnictwo – Biblioteka Naukowa Instytutu Lotnictwa, s. 121, Warszawa 2013.

[4] IATA, *Airline Maintenance Cost Executive Commentary FY 2012 data.*

[5] Koff, B. L., *Gas Turbine Technology Evolution: A Designer's Perspective,* Journal of Propulsion and Power, Vol. 20, No. 4, 2004.

[6] Lewitowicz, J., Żyluk, A., *Podstawy eksploatacji statków powietrznych, Tom V, Techniczna eksploatacja statków powietrznych*, ITWL, Warszawa 2009.