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ANALYSIS OF OPERATIONAL CHARACTERISTICS OF AVIATION DIESEL AND GAS TURBINE ENGINES FOR LIGHT PASSENGER AIRCRAFT

Vasiliy Loginov, Yevgeniy Ukraintes
Kharkiv Air Force University named after Ivan Kozhedub, 77/79 Sumskaya str., 61023, Kharkiv, Ukraine
Login_ov@ukr.net, EUkrainetz@ukr.net

Abstract

A comparative analysis of aviation diesel and gas turbine engines in the light passenger aircraft system was conducted. Aircraft operational characteristics were obtained with the help of developed modular software system „Integration-2.1". For the formation of 5-9 seater modifications of aircraft as a prototype was taken aircraft Diamond DA42 with the location of passengers without aisle, crew consisted of 1 person. For the formation of 10-20 seater aircrafts modifications as prototypes were taken aircrafts EV-55 and L-410UVP, the crew consisted of 2 persons, was adopted the full completion of aircraft equipment, power plant consists of two engines was adopted. It shows the economic advisability of the aircraft gas turbine engines use for airplanes of local airlines (5-6 people). It was found that the life-cycle cost of the aircraft with more passengers become lower in modifications with gas turbine engines, therefore, the use of this type of engine is advisable for aircraft with greater passenger capacity. It was found that the main factors influencing the life-cycle cost of the aircraft, are the resource characteristics of the engine, the cost of its maintenance and repair, as well as the price of fuel.
Keywords: parametric shape, light passenger aircraft, local airlines, aviation diesel engine, turboprop engine, gas turbine engine, the aviation powerplant, technical and economic characteristics, operational characteristics, life-cycle hour cost.

1. INTRODUCTION

Research of aircraft performance and economic characteristics of the local airlines aircraft with diesel and gas turbine engines for justification of the value of its life-cycle is important. Currently, there are intensively conducted researches of perspective local and regional air transport systems. Works [1-6] show that the light multipurpose aircraft must provide flights at a distance of 2500 kilometers. Wherein the composition of equipment and aircraft design should ensure trouble-free operation at ambient temperatures from -55°C to +40°C, the ability of takeoff and landing from ground, snow and ice fields has to be implemented.

Important issue is the valuation of aircraft and its maintenance. The economy of this air freight segment is complex, as a result, to put into practice profitable projects without substantial government support is difficult. Thus, the average cost of a new 9-seat aircraft is 2.5 million dollars [7, 8], the cost of four twin-engine Austrian aircraft DA 42 (Fig. 1) depending on the configuration is 660-840 thousand dollars, the cost of a turboprop An-3 is 1.5 million dollars, the minimum cost of 19-seat Canadian aircraft Twin Otter is 6 million Dollars, Czech 14 seat EV-55 Outback (Fig. 2) is nearly 3 million Dollars. The desire to reduce the cost of 19-seat aircraft to 3.7 million dollars necessitates the search of a rational combination of aircraft performance and economic characteristics, largely determined by the characteristics of the power plant engines.

Fig. 1. Aircraft DA 42 [20]

Fig. 2. Aircraft EV-55 Outback [21]

A lot of aviation companies offer aircraft with diesel engines for operation on local airlines, which is due to more fuel efficiency of diesel engines in comparison with gas turbine one [9, 10]. It should be noted that the production of aviation diesel engines is expensive (comparable to the cost of turboshaft engines manufacturing), many experts note shorter aviation diesel engines life [7, 8].

Interestingly, work on the study of different operators of small passenger aircraft were conducted at the Institute of Aviation. Examples of the use of various propulsion systems in small aircraft prototypes are presented in [23].

2. RESULTS

Researches of the characteristics of the passenger aircraft of local airlines were carried out with the help of developed modular software system „Integration-2.1" based on the methodology described in work [11], with two types of engines for two types of flight profiles:

a) flight with a total length of double-handle route $L_{fl} \approx 1000$ km with the restrictions on continued takeoff with concrete and ground runway with length of 800 meters;

b) flight with a total length of route $L_{fl} \approx 1500$ km with the restrictions on continued takeoff with concrete runway with length of 800 meters;

If passenger capacity is from 5 to 9 members, then the crew includes 1 pilot. If passenger capacity is from 10 to 20 people, then it has 2 pilots. The settlement researches used predictive characteristics of diesel engines produced by processing of statistical data [12-15].

For the formation of 5-9 local modifications of aircrafts as a prototype the aircraft Diamond DA42 [16] was taken, with the location of passengers without aisle, 1 person crew. The increase in takeoff weight was conducted in accordance with the increase of passengers number (Diamond driver also counts as passenger, and in our case the crew and passengers are counted separately). The power plant consists of two engines.

For formation of 10-20 local modifications aircraft as prototypes were taken the aircrafts EV-55 [17] and L-410UVP (Fig. 3) [18, 19].

Fig. 3. Aircraft L-410UVP [22]

The crew included 2 persons, between the passengers was left the aisle that increased the diameter of the fuselage, full complement of aircraft equipment was adopted. The power plant consists of two engines. In total, this resulted in a significant increase of takeoff weight and, consequently, an increase of aerodynamic resistance and the required power of engines.

Calculation of economic characteristics of aircraft modifications with different engines was conducted for the following initial data:

– specified life (resource) of airframe – 20,000 hours;
– time between overhaul (TBO) of aircraft – 4,000 hours;
– the loading factor of the aircraft – 1.0;
– average annual aircraft time – 1,600 hours;
– the initial price of the aircraft (5 passengers without engines) 0.34 million dollars.

Initial data for the gas turbine engines:

– specified life(resource) – 12,000 hours;

– TBO – 3000 hours;
– mean time to 1 failure for all the reasons that led to early removal of the engine – 3,000 hours;
– the cost of 1 kg of fuel – 1.3 dollars/kg;
– the cost of 1 kg of oil – 14.2 dollars/kg;
– the average price of 1 kW 661 dollars.

Initial data for diesel engines**:**
– specified life (resource) – 5000 hours;
– TBO – 1500 hours;
– mean time to 1 failure for all the reasons that led to early removal of the engine – 1,500 hours;
– the cost of 1 kg of fuel – 1.3 dollars/kg;
– the cost of 1 kg of oil – $ 20/kg;
– the average price of 1 kW is nearly 769 dollars.

It should be noted that in the conducted researches was adopted condition that for modification of aircraft with 5...9 and 10…20 seating capacity it is assumed to install engines with different range of power. Conditional engines differ in price, but have the same resource characteristics.

Modification of aircraft was carried out with the condition that the total length of the double-handle route $L_{fl} \approx 1000$ km with the restrictions on continued takeoff with ground runway with length of 800 meters and without it (for diesel engines, due to their lack of emergency mode). Required power of engines determined by the selection for a given distance restriction on continued takeoff. Since takeoff and landing distances are very sensitive to the takeoff engine power, discrete of power values in the selection leads to a slight spread in results.

Taking into account the necessity for forming engine parametric shape for the modified aircraft, it was decided to modify the installed engine by increasing (or decreasing) the power and weight in proportion to the existing turboprop engines AI-450C and AI-450C2. The increase (or decrease) of power and weight of the modified engine selected for takeoff mode of these two engines. It was later found that the power characteristics of the modified engines (denoted as Turboprop-1 and Turboprop-2) are close to the power characteristics of the existing engines.

Analysis of aircraft performance characteristics of aircrafts type Diamond DA42 has shown that for small capacity aircraft with diesel engines it is difficult to ensure the continued takeoff in case of failure of one engine, because there is no emergency operation. To fulfill requirements for ensuring the continued takeoff of aircraft the power of diesel engines forcedly increased by the method of selection at takeoff at nearly 14%. The subsequent calculations show two variants of modifications of diesel engines. The first version of the engine (designated as Diesel-1) has the cardinality data for normal takeoff without ensuring a predetermined distance of the continued takeoff in case of failure of one engine. The second version of the engine (designated as Diesel-2) has a higher power characteristics for ensuring a given distance of the continued takeoff.

Fig. 4 shows the obtained and approximated by polynomials dependence of average kilometer fuel consumption of power plant at cruising on the number of passengers in the aircraft modifications. Fig. 5 shows dependence of hourly fuel consumption of the power plant at cruising flight on the number of passengers in aircraft modification.

Presented dependence leads to the conclusion on the superiority of fuel flow characteristics of the power plant with diesel engines. However, it is clear that the hourly fuel consumption at cruising flight of the aircraft with diesel engines (N_{pass}>16) became bigger than the hourly fuel consumption of the aircraft with gas turbine engines (Fig. 5). Such redistribution of the expenditures caused by significant increases in weight and size of the diesel engine, which causes a significant increase in the drag coefficient and, therefore, fuel consumption.

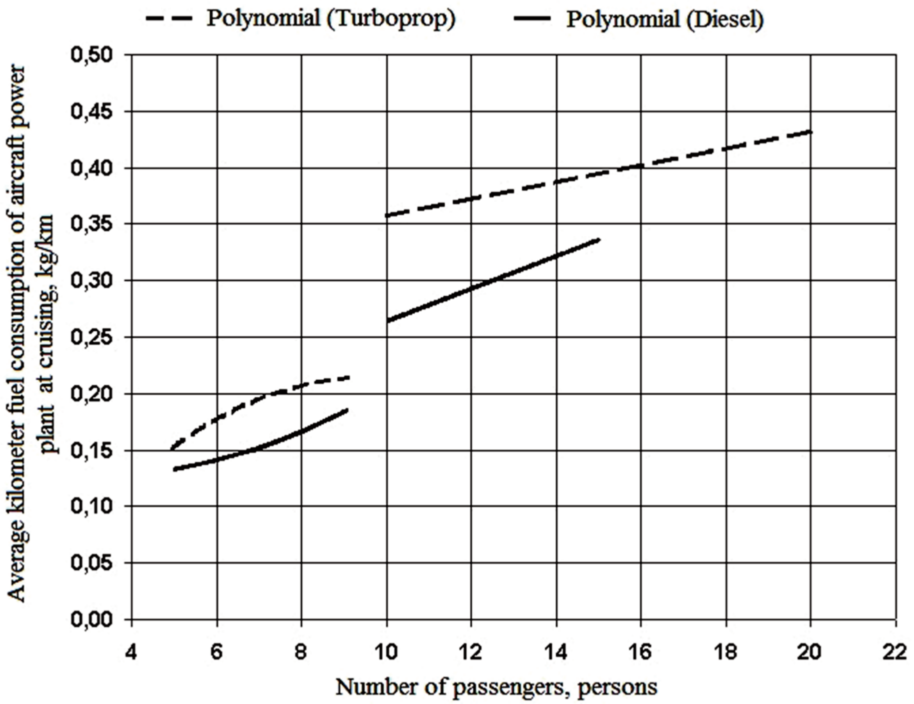

Fig. 4. Change in the average kilometer fuel consumption of aircraft power plant at cruising [3]

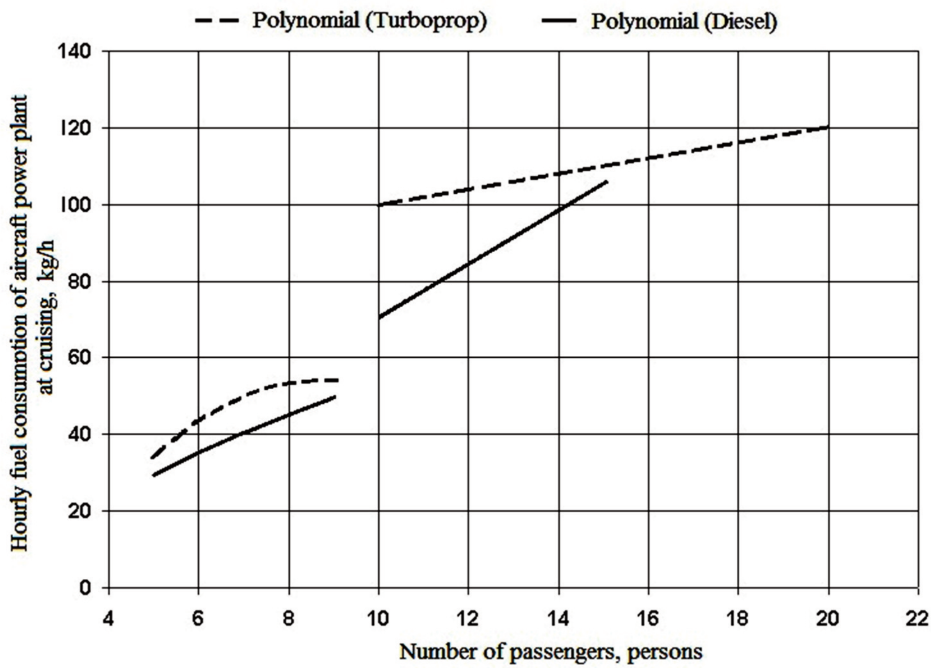

Fig. 5. Change in hourly fuel consumption of aircraft power plant at cruising [3]

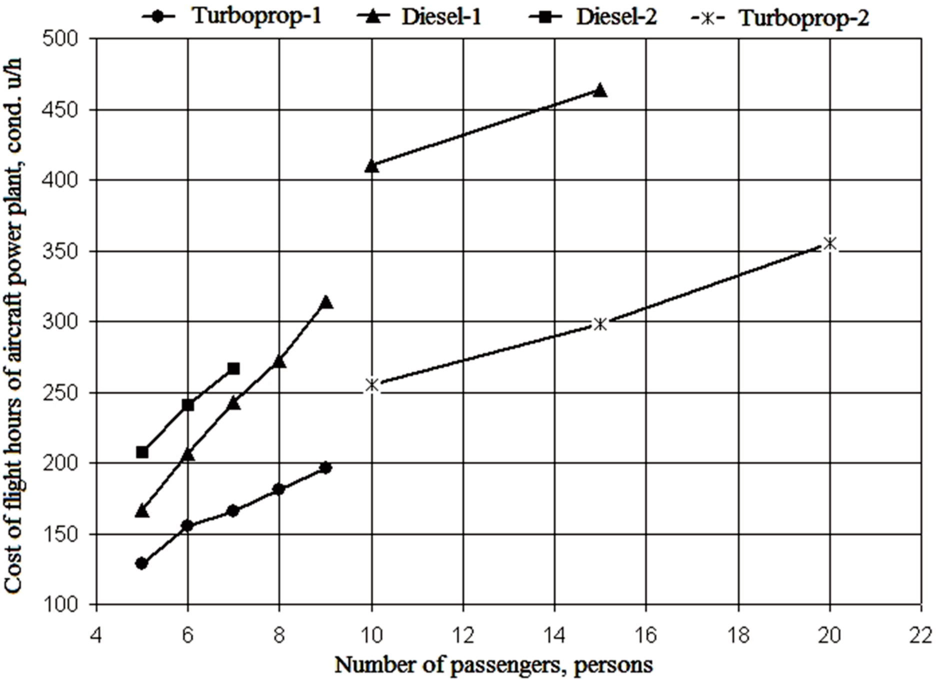

Fig. 6. Dependence of the cost of the flight hour of aircraft power plant on the number of passengers (L_{fl}1000 km) [3]

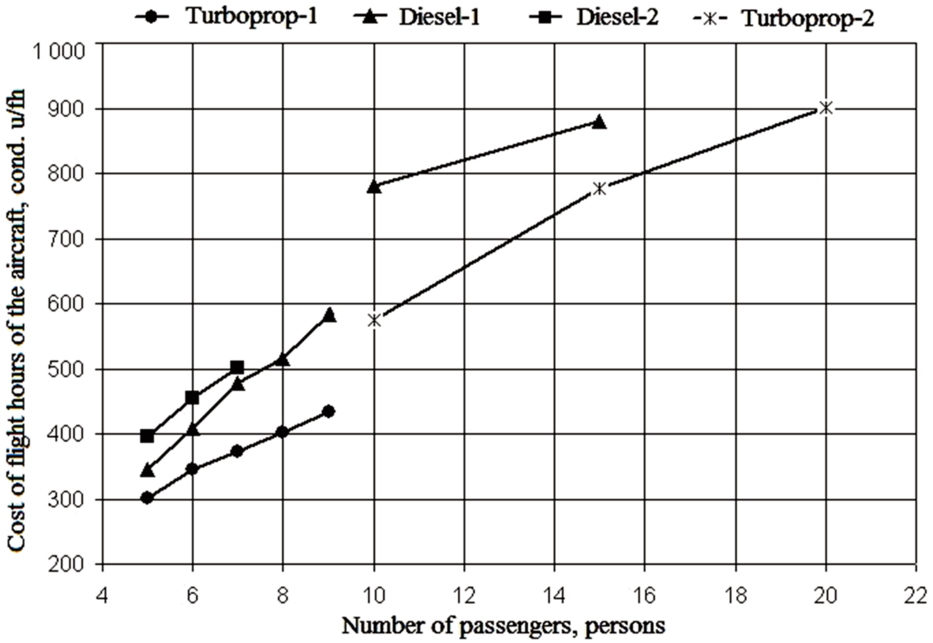

Fig. 7. Dependence of the cost of flight hours of the aircraft on the number of passengers (L_{fl}1000 km) [3]

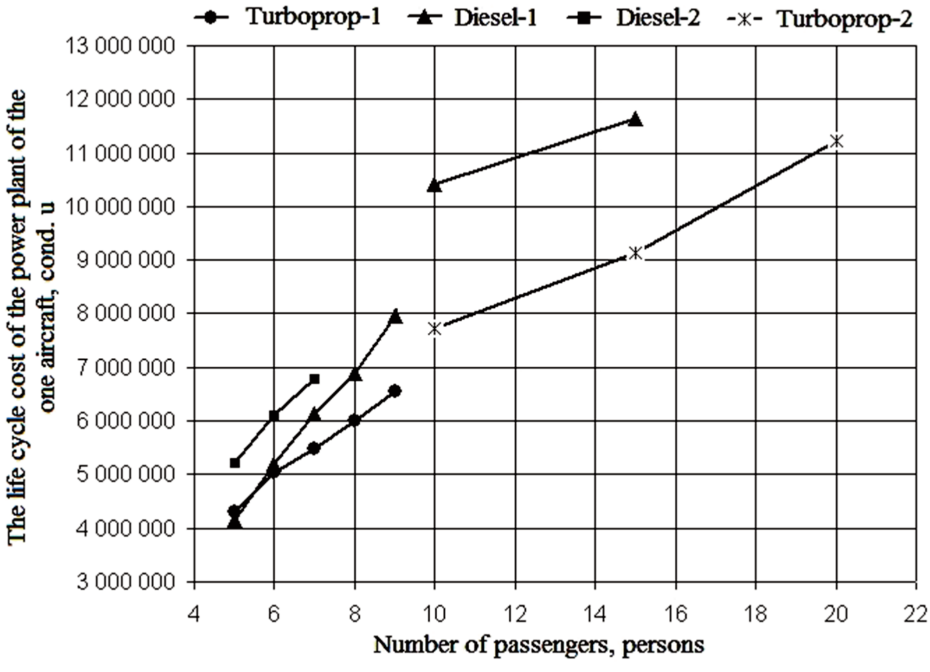

Fig. 8. Dependence of the life cycle cost of the power plant of the aircraft on the number of passengers (L_{fl}1000 km) [3]

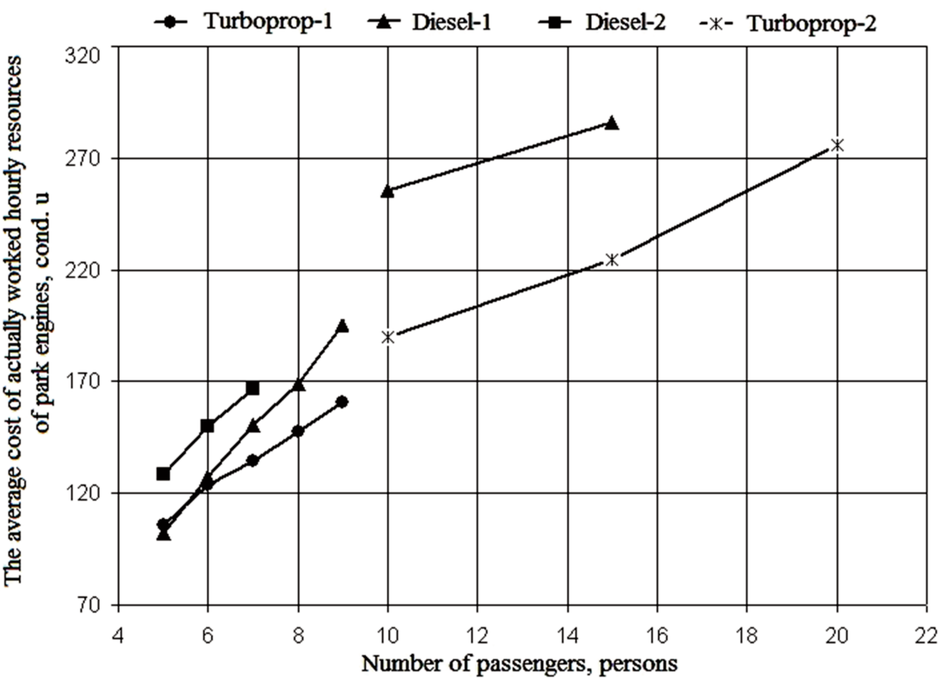

Fig. 9. Dependence of the average cost of actually worked hours of the resource engine park on the number of passengers (L_{fl}1000 km) [3]

Basic economic characteristics of the aircraft modifications with different types of engines are shown in Fig. 6-9. Analysis of the results leads to the conclusion that the life-cycle cost of the aircraft with diesel engines is less important for the modification of aircraft with 5-6 passengers. The life-cycle cost of the aircraft with a large number of passengers become lower in modifications with gas turbine engines (Fig. 8). Such redistribution is due to the cost of maintenance and repair of diesel engines for the entire life cycle. Since the time between overhauls of diesel engines significantly less time between overhauls of gas turbine engines, the costs for all types of maintenance and repair of diesel engines will be substantially higher. The average cost of actually worked hours of resource of the engine park is shown in Fig. 9.

Thus, the study of modifications with different types of aircraft engines suggests the following conclusions:

1. Economic characteristics of aircrafts with a capacity of 5-6 people with diesel and gas turbine aircraft engines are comparable. The economic feasibility of the use of small aviation gas turbine engines for small aircrafts from 5-6 people is visible. The research results show that the magnitude of the life-cycle cost hour of this class of gas turbine engines is smaller than modern aviation diesel engines. Thus, with increase in the number of passengers aboard the aircraft, this difference is increasing in favor of gas turbine engines.
2. For accepted flight conditions in five-seater aircrafts (excluding the restrictions on continued takeoff), the growth of power plant mass with diesel engines is fully offset by a decrease in the fuel needs of the masses because of the greater efficiency of diesel engines. In other words, takeoff weight for performing the double-handle distance flight of 1000□ km1000 km of these modifications are almost identical. In modifications with more passengers the takeoff weight of aircraft with diesel engines significantly increases in comparison with aircraft turbine engines.
3. In the aircraft with diesel engines it is more difficult to ensure continued takeoff in the case of failure of one engine (and sometimes impossible), since there is no emergency mode of operation. It is a serious disadvantage of aircraft with diesel engines.
4. Selection of flight mode (speed, altitude) very significantly affects the efficiency of the power plant. Therefore, multivariable study with the aim of engine „selection" faced with the need to integrate not only the rational aerodynamic configuration of the aircraft components and power plant, but also the need to optimize all modes of flight. Wherein the influence of flight mode may take precedence over other influences.
5. Diesel engines have a larger mass and shorter life compared with the gas-turbine engines. In view of the large area of rubbing couples, special oil is applied. Due to the low resource characteristics of diesel engines a gain in fuel economy for the entire life cycle does not always lead to sufficient efficiency in operation. Power plant with a diesel engine for the small capacity modifications is good only for its fuel efficiency and the ability to use heavy fuel oil.
6. Hourly fuel consumption at cruising flight of the aircraft with diesel engines (N_{pass}>16) is greater than the hourly fuel consumption of the aircraft with gas turbine engines. Such redistribution of costs caused by significant increases in weight and size of the diesel engine nacelle, which causes a significant increase in the coefficient of drag, and hence fuel consumption.
7. The minimum cost of operating the aircraft with diesel engines at N_{pass} = 6, and then its rapid rise should be noted.

Comprehensive research has allowed to develop the following recommendations:
– on modifications of the aircrafts with 6...10 passengers it is appropriate to use engine with power on takeoff up to 330 kW;
– on modifications of the aircrafts with 11...20 passengers it is appropraite to use engine with power on takeoff up to 520 kW;

– the use of diesel engine is advisable for aircraft modifications with passenger number at least 6 persons, otherwise, on the aircraft diesel engines with high resource and low cost are recommended.

The fulfillment of condition of the double-handle route total length $L_{fl} \approx 1000$ km, taking into account the restrictions on continued takeoff from ground and concrete runway with length of 800 meters does not change radically the scope of rational use of gas turbines and diesel engines but corrects some quantitive estimate of the main parameters of the modified aircraft and their power plants.

The research of aircraft performance and operating characteristics of various modifications of aircraft engines on the condition of the total length of the one-handle route $L_{fl} \approx 1500$ km was held. Modification of aircrafts was in slight increase in takeoff weight by „missing" fuel for the flight by a predetermined distance. For 5...9-seater modifications it was added 30...50 kg, for 10...20-seater modifications the weight of fuel was 90...100 kg. Such an insignificant change of takeoff weight causes a slight difference between the results from previous researches.

The greatest interest represents dependence on average kilometer consumption and hourly fuel consumption at cruising flight in different aircraft modifications (Fig. 4, 5). It can be seen that the hourly fuel consumption of the power plant with diesel engines becomes equal to the fuel consumption of power plant with gas turbine engines at $N_{pass} = 16$.

Study of economic and operational characteristics of aircrafts with different engines was held under the previous input data. Graphic dependences of the basic economic characteristics of the aircraft are shown in Fig. 10-13.

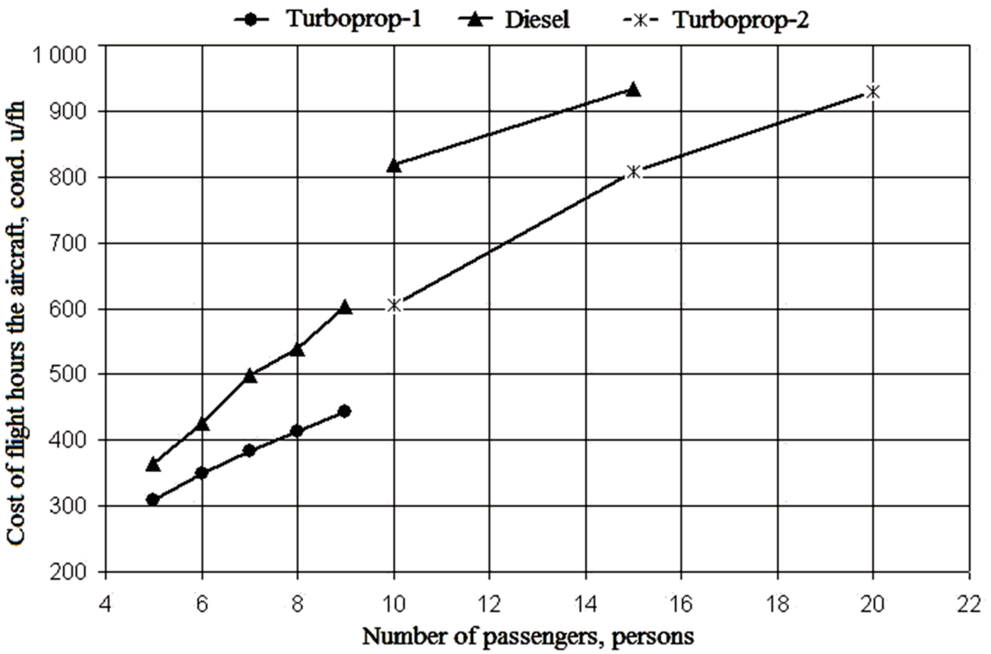

Fig. 10. Dependence of the cost of flight hours of the aircraft on the number of passengers (L_{fl}1500 km) [3]

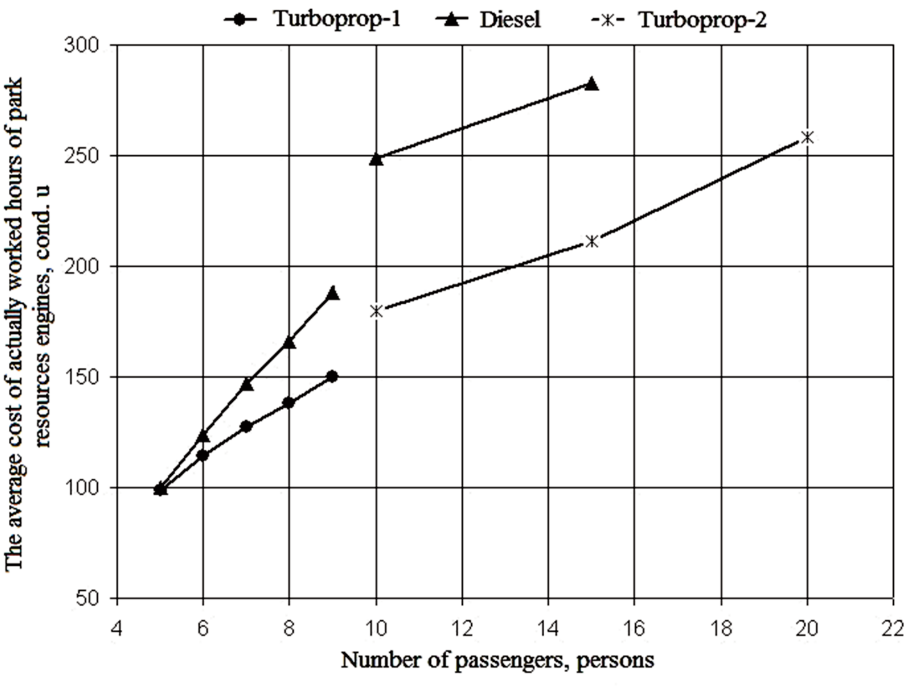

Fig. 11. The dependence of the average cost of actually worked hours of the resource engine park on the number of passengers (L_{fl}1500 km) [3]

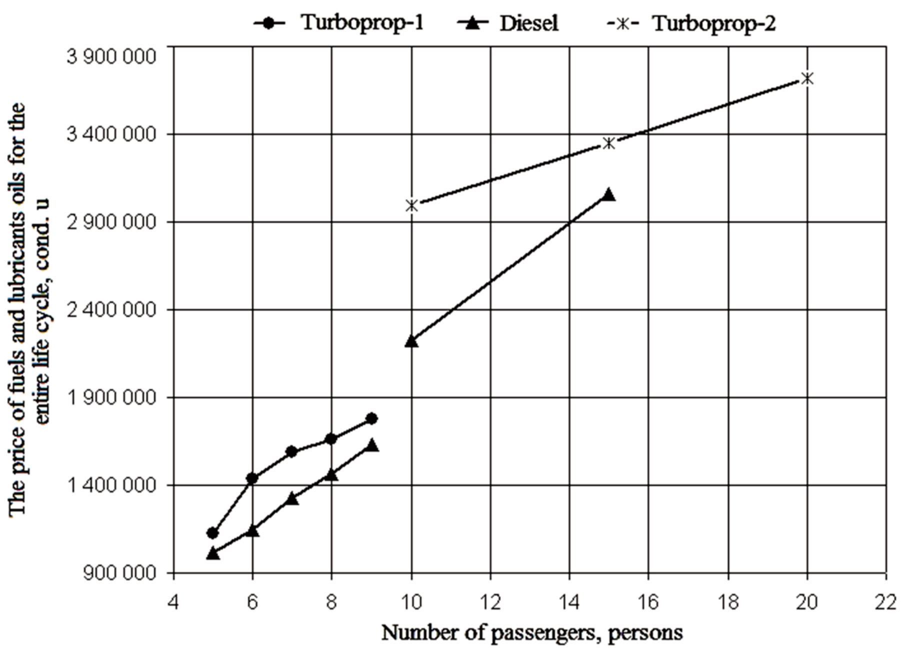

Fig. 12. The dependence of the price of fuels and lubricants oils for the entire life cycle of the aircraft on the number of passengers (L_{fl}1500 km) [3]

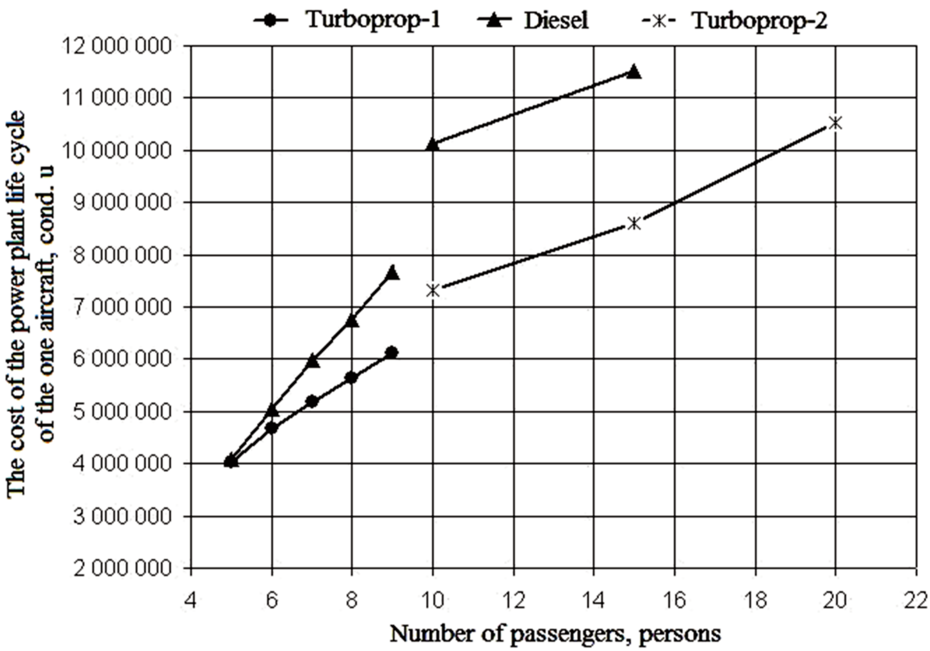

Fig. 13. Dependence of the life cycle cost of the power plant of the aircraft on the number of passengers (L_{fl}1500 km) [3]

3. SUMMARY

Analysis of the results leads to the conclusion that the use of diesel engines on the aircraft with a range of 1000 km and 1500 km is advisable for small capacity aircrafts (up to 5-6 persons). The cost of the life cycle of the aircraft with more passengers become lower in modifications with gas turbine engines, therefore, the use of this type of engine is advisable for aircraft with greater passenger capacity.

Based on the analysis results of the research, we identified the following advantages of gas turbines over diesel engines:

- small weight and overall dimensions;
- simplicity of design and greasing system;
- good mechanical balance;
- multi-fuel and low operating pressure;
- quick start in all climates;
- easier operation and maintenance;
- availability of emergency mode.

Disadvantages of gas turbine engines, compared with diesel engines: increased fuel consumption, the high cost of acquisition.

Advantages of diesel engines compared with turbine engines: fuel economy, low value, the ability to use fuel with a higher density (diesel fuel).

Disadvantages of diesel engines compared with turbine engines:
- the worst mass-dimensional characteristics, which leads to deterioration of aircraft performance characteristics;
- high maintenance costs compared with gas turbine engines;
- diffucult engine start at low ambient temperatures;
- mechanical balancing difficulty;
- absence of emergency mode;
- use of two types of oil (separately for the gearbox) and coolant.

In recent years, in a relationship with the search for cost-effective solutions on the market worldwide air drives appear in the work on fan drives air to small and medium-sized aircraft. Interesting research on the drives of „FAN" presented in [24]. In our opinion, in the next few decades will make an important impact on the development of a small civil aviation.

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ANALIZA OPERACYJNYCH CHARAKTERYSTYK LOTNICZYCH SILNIKÓW DIESLA I SILNIKÓW TURBIN GAZOWYCH DLA LŻEJSZEGO SAMOLOTU PASAŻERSKIEGO

Abstrakt

Przeprowadzono analizę porównawczą lotniczych silników diesla i silników turbinowych dla lekkich samolotów pasażerskich. Eksploatacyjne charakterystyki samolotu uzyskane przez rozwinięty modułowy system oprogramowania „Integracja-2.1”. Do opracowania modyfikacij 5-9 miejscowych samolotów jako punkt wyjściowy wybrano samolot Diamond DA42 z kabiną pasażerską bez korytarza i jednoosobową załogą. Do opracowania 10-20 miejscowych modyfikacji samolotów jako punkty wyjścia wybrano-samoloty EV-55 i L-410UVP, z dwuosobową załogą, przyjęty przez pełny skład sprzętu lotniczego, punkt mocy składa się z dwóch silników. Wykazano wykonalność ekonomiczną wykorzystania lotniczych turbin gazowych dla samolotów miejscowych linii lotniczych (do 5-6 osób). Stwierdzono, że koszt cyklu życiowego samolotu z wielką ilością pasażerów staje się mniejsza u modyfikacji z turbiną gazową, więc, wykorzystanie tego typu silników jest wskazane na samolotach o większej liczbie miejsc pasażerskich. Stwierdzono, że głównymi czynnikami wpływającymi na koszt cyklu życia samolotu, są cechy silnika, koszt jego utrzymania i naprawy, a także ceny paliwa.
Słowa kluczowe: kształt parametryczny, lekki samolot pasażerski, lokalne linie lotnicze, lotniczy silnik wysokoprężny, silnik turbośmigłowy, silnik turbinowy, zespół napędowy samolotu, charakterystyki techniczne i ekonomiczne, wydajności eksploatacyjne, koszty godziny cyklu życiowego.