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**Dmytro Makarenko,
Pavlo Penziev,
Artem Oskorbin**

EVALUATION OF THE EFFECT OF AIRPLANES ON THE ENVIRONMENT ON THE EXAMPLE OF BOEING 747 AND BOEING 757

The object of research is the impact of airplanes on the environment. Aviation is an area of our life that has been developing faster and faster every year for more than a century. Accordingly, aircraft have a negative impact on the surrounding natural environment, and therefore the assessment of their impact on nature and people is an important and integral component of research in the field of ecology and sustainable development. In particular, the airplanes produced by Boeing are among those that are most widely used in both passenger and cargo air transportation, so a study was conducted on their example.

In the study, calculation methods were used to estimate the load on the surrounding natural environment from the operation of Boeing 747 and Boeing 757 aircraft, based on the declared characteristics of emissions from the engines of these aircraft.

The study shows that every aircraft has a certain negative impact on the environment due to the emission of pollutants during all phases of flight. However, there are opportunities to minimize this impact by implementing more complete fuel combustion, replacing standard fuels such as aviation kerosene with more modern fuels, reducing the weight of the aircraft, which will lead to lower fuel consumption and, accordingly, lower emissions into the atmosphere. Also effective is the introduction of technologies to reduce the noise load from the operation of aircraft, such as the introduction of noise-protective coverings of runways, new materials for the production of aircraft engines, as well as changing the design of engines and the use of double-circuit scheme.

The work assessed the impact of aircraft on the environment and the effectiveness of environmental protection measures using the example of the operation of Boeing 747 and Boeing 757 aircraft, and developed proposals for the implementation of environmental protection and technical measures to reduce this impact.

Keywords: *emissions, Boeing aircraft, environment, noise pollution, environmental pollution.*

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1. Introduction

Aviation is an area of our life that has been developing faster and faster every year for more than a century. Thus, according to statistical data, 1.25 billion people were transported in 1994, while in 2012 this figure was more than 3 billion people [1]. Such an explosive flow of passengers will continue in the future, which is of course very beneficial for the consumer, but is bad for the environment.

For the first time, environmental problems caused by aviation were discussed in Chicago, where a document called the «Convention on International Civil Aviation» (or «Chicago Convention») was signed on December 7, 1944 [2]. This document introduced some environmental standards into international aviation as a whole. The convention has successfully passed the test of time and today remains a reliable basis for the development and coordinated functioning of international civil aviation.

Also, in 2004, the International Civil Aviation Organization (ICAO) established three main environmental goals [3]:

1) limiting or reducing the impact of aviation emissions on local air quality;

2) limiting or reducing the number of people exposed to a significant impact of aircraft noise;

3) limiting or reducing the impact of greenhouse gas emissions on the global climate as a result of aviation activities.

ICAO is also considering market-based solutions to environmental issues based on aviation participation in emissions trading. After establishing a limit on the emission of certain substances in a certain territory and for a specific period of time, the distribution of the corresponding number of quotas begins. Emissions made without a certain quota are subject to a fine. The new system of trading quotas for emissions into the atmosphere of carbon dioxide began to operate in Europe on January 1, 2012.

The ICAO Aviation Environmental Protection Committee is constantly concerned about the quality of the environment.

In a special report on the impact of aviation on the global atmosphere, published by the Interstate Commission on Climate Change, it is stated that aviation activity has a detrimental effect on the ozone layer, that is, it destroys it [4].

It is possible to single out 2 main disadvantages of modern aircraft:

1) noise pollution;
2) atmospheric pollution.

Regarding the first drawback, airplane engines emit gases that create a greenhouse effect. Modern airplanes fly on aviation kerosene, a fuel produced from oil. The fuel mainly consists of carbon (C) and hydrogen (H). During combustion in the engine, carbon and hydrogen atoms separate from each other to combine with oxygen molecules from the air. Two new substances are released – carbon dioxide and water. It is the water vapor escaping from the nozzle that turns into fog, forming long white trails. Carbon dioxide and water vapor retain the heat emitted by the Earth, which in itself «helps» the development of the greenhouse effect.

Theoretically, nothing but carbon dioxide and water should be formed when kerosene burns. But in fact, during the operation of aircraft engines, there is an emission of exhaust gases, direct and by-products of fuel combustion, which can cause undesirable effects on the environment. This phenomenon is called «emission».

The emission of carbon oxides, unburned hydrocarbons and carbon particles is the result of incomplete combustion of fuel in the engine. The emission of nitrogen oxides is a consequence of the high temperature in the fuel combustion zone, at which oxidation of the nitrogen contained in the air becomes possible. It is nitrogen oxides that lead to depletion of the Earth's ozone layer.

Table 1 shows the coefficients for the emission rate of carbon and nitrogen oxides, unburned hydrocarbons [5].

Table 1

Emission rate coefficients of carbon and nitrogen oxides

Air temperature, °C	$K_q(N_xH_y)$	$K_q(C_xH_y, C_mH_n)$
–20	0.74	1.3
–10	0.81	1.2
0	0.88	1.1
10	0.96	1.04
20	1.0	1.0
30	1.11	1.0

From the data in Table 1, it can be concluded that the indices of carbon oxides and unburned fuel particles are greater, the lower the temperature and pressure in the combustion chamber. They are maximum when the aircraft is taxiing at the airport, reach a minimum during take-off and remain close to the minimum during all flight phases. For nitrogen oxides, the pattern is the opposite – as the temperature increases, the coefficient increases, this can happen during take-off and subsequent flight.

The second disadvantage is strong noise.

Jet engines are sound-making machines, and when landing, planes pressurize the air with their huge mass, which provides another source of loud noise.

It has been experimentally proven [6–8] that anthropogenic noise has an adverse effect on the human body and shortens life expectancy. It was established that a long stay in places with noise pollution leads to physiological and mental stress – insomnia, hypertension. People become irritable and nervous. In these studies, the relationship between the effect of noise from airplanes and the level of hospitalization due to cardiovascular diseases was revealed. It turned out that a sound exceeding 10 dB increases the risk of cardiovascular diseases by 3.5 %. Moreover, a high level of hospitalization is observed in areas where the constant noise level does not fall below 55 dB. And in places where the noise level fluctuates around 65 dB, hospitalizations due to strokes are 25 % higher, compared to those who experience a noise load of 50 dB.

The population living near the airports should be considered as an object of the natural environment during the environmental assessment. The placement of airports must meet special requirements not only for the conditions of ensuring the normative level of noise and air pollution, but also for guaranteeing the safety of the population in the adjacent territory.

Every year in the EU, more than 45,000 people die and more than 1.6 million are injured in traffic accidents. The largest part of the victims is attributed to the automotive sector. Damages from car and plane accidents in the EU are estimated at 45 billion euros per year: 15 billion – insurance and repair of means of transportation (cars and planes), 30 billion – fatal economic losses from the elimination of various kinds of consequences (including environmental ones). Avoiding at least one accident can save an average of more than 1 million euros. External costs of the transport sector, which are mainly determined by environmental damage (noise, air pollution) and transport events, make up mainly 4 % of the total gross national product [9].

A comparison of external transport costs in % of the cost of transport services defined in Europe and Canada is given in Table 2 [9].

Table 2

The cost of air pollution and transport events in % of the cost of transport services

Transportation	Aviation	Railway	Automotive
Canada	16	4	14
Europe	7	21	10–57

Thus, *the object of research* is the impact of airplanes on the environment. *The purpose of the study* is to assess the impact of aircraft on the environment and to propose environmental protection measures on the example of the operation of Boeing 747 and Boeing 757 aircraft.

2. Materials and Methods

The first and easiest way to reduce the impact on the surrounding natural environment is to make more capacious liners.

The heavier the plane, the more fuel it burns, that is, the more it pollutes the environment. Table 3 shows the comparative characteristics of Boeing 747-100 and Boeing 747-8 aircraft [10]. Analyzing the data in Table 3, it can be seen that the more capacious Boeing 747-8 consumes 15.4 liters per kilometer, with a capacity of 467 people and a weight of 215 tons, while the Boeing 747-100, carrying 366 passengers and weighing 162 tons, consumes 20.3 liters per kilometer.

The second most practical method is to lighten the hull and use less paint on the fuselage and wings.

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Table 3

Characteristics of Boeing 747-100 and Boeing 747-8

Characteristics	Mass, t	Capacity, passengers	Wing area, m^3	Fuel consumption, l/km
Boeing 747-100	162.4	366	511	20.3
Boeing 747-8	214.5	467	567	15.4

To reduce the initial mass of the aircraft, plastics with carbon and glass fiber reinforcement can be used.

These materials are lighter and stronger than the same steel.

The positive aspects of using composite materials are:
- high specific strength;
- high wear resistance;
- lightness.

But there is also such a negative point as the cost.

The next way is to change the type of fuel.

Many different fuel companies are interested in creating biofuel for aircraft. So, for example, as part of the tests of the British company Virgin Atlantic Airways, a Boeing-747 flew from the London Heathrow airport to the Amsterdam Schiphol using biofuel from coconut oil and babassu oil. The flight was successful, but the chief engineer noted that the production of such a large amount of fuel requires: a large area for planting plants and a large number of trees, cutting down which will lead to a sharp jump in the greenhouse effect [11].

The essence of eco-fuel is that part of the carbon dioxide produced during combustion will be absorbed by plants. Hydrogen is also in the plans, there are even aircraft with hydrogen engines, but the fact is there are no cheap methods to make hydrogen without using oil.

Of course, there are many methods of producing hydrogen without the use of oil and coal, but this requires either a large amount of electricity or expensive and rare metals. An example is the method of extracting hydrogen from water using solar energy, organized by the University of New South Wales, Australia [12, 13]. The hydrogen production reaction is carried out in the presence of solar energy, which will then turn into electricity, water and titanium dioxide.

There is also a method of obtaining hydrogen by electrolysis [14–16]. But it is unpromising, because in order to get the same electricity, again, oil or gas is needed. And using the energy of the wind or «peaceful atom» is also not promising, because in order to obtain hydrogen, which could drive all the cars in Britain, it would be necessary to force the entire coast of the island with windmills or to build 100 nuclear power plants, which in itself is dangerous.

Another way is to teach pilots new techniques of piloting during take-off and landing; rational organization of air traffic (so-called «minimum noise» routes, organization of flights at night, optimal ratio between the intensity of night and day flights).

The German Air Transport Authority (DFS) also used this method. It decided to test a new aircraft arrival system at Frankfurt Airport to reduce the noise that disturbs citizens living near the airports. According to the new rules, planes must approach the runway on a single route, not on parallel routes, as now. The advantage of this system is that the point at which the planes begin to line up in a column is located much higher than the current approach routes. Thus, the noise level from them will be lower. Such a system is already functioning at the Oslo airport [17].

In addition to ways to reduce sound vibrations around airports, it is possible to add construction and planning measures (new runways, for example). It is also necessary to strictly organize residential construction in areas with increased sound levels near airports. In some industrial centers of Europe, there are special noise control commissions, which include bodies of sanitary inspection and transport services.

And the last, probably the most radical way is to equip aircraft with large, but light-weight engines.

In order to reduce jet noise, two-circuit turbofan engines are used – a type of two-circuit turbojet engines with a high degree of two-circuit. In them, part of the intake air, flowing inside the engine, bypasses the combustion chamber, as a result, thrust increases, but noise decreases. The thing is that at the exit from the engine, cold air, which is under lower pressure, mixes with strongly compressed hot air from the combustion chamber. In order to achieve a serious reduction in the noise level, the engines themselves must be made as large as possible. But due to the weight limit, this is not possible now. However, materials of a new generation, so-called «composite», come to the rescue. Engines made of such materials will combine light weight, considerable size and low noise.

At the moment, it is almost impossible to say that there are no problems in aviation – there are many issues related to the economy, safety and ecology. The world does not stand still: everything that existed before is modernized or rendered unusable, and something completely new comes to replace the old. The same thing happens in aviation. Aviation kerosene will soon be replaced by a new biofuel, aircraft engines will become large, but light in weight; composite materials will soon become better building materials than metal and aluminum. More and more aircraft companies are trying to give airliners new shapes by integrating wings and fuselage.

3. Results and Discussion

3.1. Basic calculation ratios. For the purposes of a unified approach to the regulation of pollutant emissions, ICAO introduced the concept of a standard landing and take-off cycle (LTO). LTO includes all operations of the aircraft from the moment of starting the engines until the altitude gain of 900 meters, as well as from the moment of landing from a height of 900 meters until the engine stops after landing the aircraft [18, 19]. ICAO landing and take-off cycle parameters are given in Table 4 [19].

Table 4

ICAO landing and take-off cycle parameters

LTO stage	Relative engine thrust, %	Duration of the LTO stage, min
Rise	100	0.7
Height gain 900 m	85	2.2
Descent and landing from a height of 900 m	30	4.0
Taxiing (terrestrial low gas mode)	7	26.0

The analysis of Table 4 allows to conclude that the relative thrust of the engines are statistical averages for the world fleet of civil aviation, and the values of the duration of the LTO stages are given as corresponding to the landing take-off cycles in large international hubs.

An important stage in the assessment of emissions from an aircraft engine is the testing of engines in stationary ground conditions, which must be carried out after the completion of repair work or work according to regular forms of maintenance and is carried out according to the schedule (according to the test program). In some cases, according to regulatory documents, a shortened engine test procedure is allowed, and in this case, the actual operating time in the modes is used to calculate pollutant emissions.

The emission control parameter M_j/R_r, specified by ICAO for LTO, can be used for other stages of flight.

Knowing the emission index and the operating time of one engine, it is possible to calculate the mass of pollutant emissions of this type. In particular, for LTO:

$$M_j = \sum_i EI_{ji} G_{fi} \tau_i, \tag{1}$$

where G_{fi} – the fuel consumption, kg/s, and τ_i – the working time at the i-th stage of the standard cycle, s. The G_{fi} value is determined using the throttle characteristics of the engine:

$$G_{fi} = \frac{C_{\text{speci}} R_i}{3600}. \tag{2}$$

Dividing both parts of the expression for M_j by R_r, let's obtain the ratio for the emission control parameter:

$$\frac{M_j}{R_r} = \frac{1}{3600} \sum_i EI_{ji} C_{\text{speci}} \overline{R}_i \tau_i, \tag{3}$$

where C_{speci} – the specific fuel consumption at the i-th stage of the engine control system; $R_i = R_i/R_r$ is the relative thrust at the i-th stage.

Expression (3) allows to take into account the change in emission parameters during engine operation, since the efficiency of its units deteriorates with the increase in engine operating time, which, as a result, leads to an increase in specific fuel consumption.

Emission characteristics of the engine depend on external conditions. ICAO standards provide for the calculation of deviations of the actual temperature and pressure of the external air at the engine inlet from the standard atmospheric conditions (SAC) at sea level. When calculating pollutant emission indices in all engine operating modes during the LTO, appropriate corrections are made with the help of the K_j coefficient:

$$EI_{jr} = K_j \cdot EI_j, \tag{4}$$

where EI_{jr} – the reduced emission index of the j-th pollutant; K_j – the coefficient of bringing the j-th pollutant to the SAC.

The general expression for K_j:

$$K_j = \left(\frac{p_{k\,SAC}}{p_k}\right)^a \cdot \left(\frac{g_{t\,SAC}}{g_t}\right)^b \cdot EXP\left(\frac{|T_{k\,SAC} - T_k|}{C}\right) \times \times EXP\left(d \cdot |h - 0.00634|\right), \tag{5}$$

where p_{kSAC}, T_{kSAC}, g_{tSAC} – respectively, pressure, temperature and relative fuel consumption in the combustion chamber at the SAC; p_k, T_k, g_t – similar parameters corresponding to specific atmospheric conditions; h – ambient air humidity; a, b, c, d, e – calculated constants, which may be different for each pollutant and each type of engine.

The density ρ_{v0} of solid particles in the jet of exhaust gases of aircraft engines, reduced to the weight characteristic (kg) for the standard LTO cycle, denoted by M_{sp}, can be determined from the graph of the dependence of the mass concentration of soot on the smoke number SN (Fig. 1).

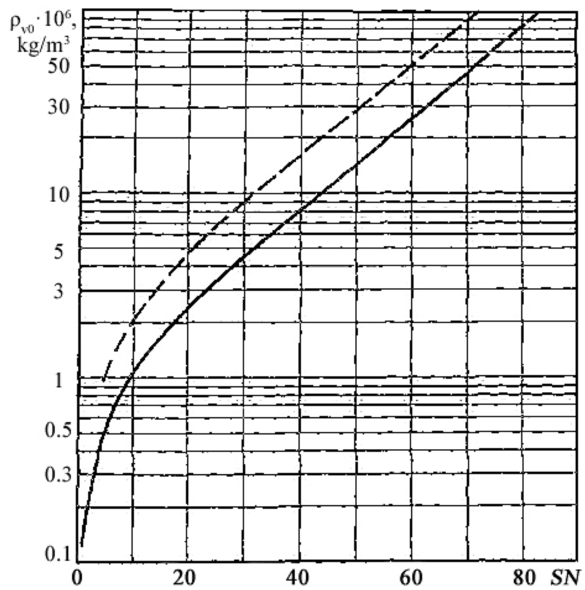

Fig. 1. Influence of smoke number SN on the mass concentration of soot [18]

The normative smoke number is determined from the ratio:

$$SN = 83.6 \cdot (R_r) - 0.274, \tag{6}$$

whether $SN = 50$ is chosen, whichever is smaller.

The use of a logarithmic scale for P_{v0} leads to the fact that this dependence becomes practically linear and is satisfactorily approximated by the formula:

$$\rho_{v0} = 10^{-6} \exp(0.07 SN). \tag{7}$$

Then the mass of soot emissions during the time τ of engine operation is determined by the formula:

$$M_e = \rho_{v0} \frac{G_a}{\rho_a} \tau = \rho_{v0} Q_a \tau, \tag{8}$$

where G_a – the air flow through the combustion chamber of the engine; ρ_a – the air density; $Q_a = G_a/\rho_a$ – the volume air flow through the combustion chamber. The use of the value of Q_a in the last formula is more acceptable, since it changes slightly for a specific engine. For example, for the P&W PW2040 engine, over the entire range of operating modes, Q_a changes by about 30 %, while the mass flow G_a changes by almost 4 times (400 %).

Based on the typical ICAO technical requirements for aviation fuel, after converting the known equations of chemical reactions, it is possible to determine the number of specific products of complete combustion depending on the mass of spent fuel:

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CO_2 (kg) $= 3.12 \cdot M_f$ (kg);

H_2O (kg) $= 1.35 \cdot M_f$ (kg);

SO_2 (kg) $= 0.005 \cdot M_f$ (kg).

The given estimates of the mass of fuel emissions are maximum, as they correspond to complete fuel combustion. Their error at the existing values of fuel combustion completeness does not exceed 2 %. Let's note that according to the report CAER/5 – IP/22, 2001 [20], the specific index is 3.15 for the assessment of CO_2 carbon dioxide; for sulfur oxides SO_X – 0.0009 (with a sulfur content of 0.05 %) and water vapor H_2O – 1.23, that is, the values are close to those obtained in the specified ratios.

Since methane is only one of the components of unburned hydrocarbons, for its evaluation by the type of assessment of CO_2, H_2O, SO_2, it is necessary to determine the share of unburned hydrocarbons in the mass of those harmful emissions that are products of incomplete fuel combustion.

The products of incomplete fuel combustion are carbon monoxide, unburned hydrocarbons (CH) and solid particles (soot). The processing of these emissions of pollutants from 43 engines from different countries of the world and different traction classes showed that, on average, the amount of unburned hydrocarbons is 2.58 times less than the amount of carbon monoxide. Based on this, and taking into account the fact that methane (CH_4) according to the work makes up no more than 10 % of the total mass of CH hydrocarbon emissions during the ICAO cycle, the following ratios were obtained:

CH (kg) $\approx 0.28 \cdot (1-\eta_c) \cdot M_f$ (kg);

CH_4 (kg) $\approx 0.028 \cdot (1-\eta_c) \cdot M_f$ (kg);

CO (kg) $\approx 0.72 \cdot (1-\eta_c) \cdot M_f$ (kg).

In the last three expressions, η_c – the coefficient of fuel combustion completeness, the values of which are taken from the engine characteristics. The last three expressions are approximate and should be used in cases where the emission characteristics of a particular engine are not known for any reason.

When using in the calculations of operational characteristics of engines, if necessary, the formulas of reduction to standard atmospheric conditions should be used. This allows to take into account the influence of atmospheric pressure and temperature at the entrance to the engine on the parameters of the air flow in the inlet section of the combustion chamber, fuel consumption and, therefore, on the amount of emissions of pollutants:

– rotate:

$$n_{red} = n\sqrt{\frac{288}{T}}, \text{ rev/min};$$

– traction:

$$R_{red} = R\frac{101325}{p}, \text{ N};$$

– specific fuel consumption:

$$C_{spec\ red} = C_{spec}\sqrt{\frac{288}{T}}, \text{ kg/(N·h)};$$

– fuel consumption:

$$G_{f\ spec} = G_B\frac{101325}{p}\sqrt{\frac{288}{T}}, \text{ kg/s};$$

– air consumption:

$$G_{a\ spec} = G_a\frac{101325}{p}\sqrt{\frac{T}{288}}, \text{ kg/s};$$

– relative fuel consumption:

$$g_{f\ spec} = \frac{G_{f\ spec}}{G_{a\ spec}} = g_f\frac{288}{T};$$

– air temperature behind the compressor (at the entrance to the combustion chamber):

$$T_{c\ spec} = T_c\frac{288}{T}, \text{ K};$$

– air pressure behind the compressor (at the entrance to the combustion chamber):

$$p_{c\ spec} = p_c\frac{101325}{p}, \text{ Pa}.$$

In the given formulas, T and p are, respectively, the temperature (K) and pressure (Pa) of atmospheric air under specific operating conditions [19].

3.2. Calculated data. The initial data for ecological load calculations are given in Table 5.

Table 5

Input data for environmental load calculations

Engine type	P&W PW2040
Type of aircraft	Boeing 757
Average smoke number	$SN = 13$
Average volume flow of air through the combustion chamber	7.1 m^3/s
Number of flights	4
LTO number	4

The parameters of the standard LTO and the emission indices of the P&W PW2040 engine are shown in Table 6.

Table 6

Parameters of the standard LTO and emission indices of the P&W PW2040 engine

Regime	Traction mode, %	Time, s	Fuel consumption, kg/s	Emission indices, g/kg		
				HC	CO	NO_x
Rise	100	42	1.739	0.12	0.35	37.0
Set height	85	132	1.431	0.12	0.40	31.5
Landing procedure	30	240	0.489	0.20	0.90	11.8
Low gas	7	1560	0.178	0.30	6.90	5.8

3.3. Calculation of pollutant emissions per flight. The calculation is based on the use of the data of the standard

ICAO LTO for the engine. Next, taking into account the number of engines *n* per Boeing 757 aircraft, the mass of each pollutant is determined.

The calculation procedure is as follows.

For one P&W PW2040 engine, the mass of emissions of the *j*-th pollutant according to the LTO:

$$M_j = \Sigma EI_{ji} \cdot G_i \cdot \tau_i.$$

Taking into account the fact that the mass of fuel consumed by one engine at the LTO is $M_{f\,\mathrm{LTO}} = 657$ kg, let's obtain:

$$M_{\mathrm{CH}} = 0.138 \text{ kg}; \; M_{\mathrm{CO}} = 2.123 \text{ kg};$$

$$M_{\mathrm{NO}_x} = 11.648 \text{ kg}; \; M_s = 0.035 \text{ kg};$$

$$M_{\mathrm{SO}_2} = 3.285 \text{ kg}; \; M_{\mathrm{CH}_4} = 0.014 \text{ kg};$$

$$M_{\mathrm{H_2O}} = 887 \text{ kg}; \; M_{\mathrm{CO}_2} = 2050 \text{ kg}.$$

Here, the calculation of the mass of CH_4 emissions is performed from the ratio $M(\mathrm{CH_4}) = 0.1 \cdot M(\mathrm{CH})$, and SO_2 from the condition $M(\mathrm{SO_x}) = 0.005 \cdot M_f$. The mass of emissions of M_s solid particles is calculated using formulas (6) and (7).

Using formula (6), let's determine the density of solid particles $\rho_{v0} = 2.484 \cdot 10^{-6}$ kg/m^3, and using formula (7) let's find $M_s = 35$ g.

The mass of H_2O, CO_2 emissions is calculated according to the formulas:

$$\mathrm{CO_2} \text{ (kg)} = 3.12 \cdot M_f \text{ (kg)};$$

$$\mathrm{H_2O} \text{ (kg)} = 1.35 \cdot M_f \text{ (kg)}.$$

For two engines according to the LTO, it turns out, respectively:

$$M_{\mathrm{CH}} = 0.276 \text{ kg}; \; M_{\mathrm{CO}} = 4.246 \text{ kg};$$

$$M_{\mathrm{NO}_x} = 23.296 \text{ kg}; \; M_s = 0.07 \text{ kg};$$

$$M_{\mathrm{SO}_2} = 6.57 \text{ kg}; \; M_{\mathrm{CH}_4} = 0.028 \text{ kg};$$

$$M_{\mathrm{H_2O}} = 1774 \text{ kg}; \; M_{\mathrm{CO}_2} = 4100 \text{ kg}.$$

The average estimated fuel consumption per flight on this route for the P&W PW2040 engine is ~7500 kg. Therefore, on the flight section without LTO, fuel production will be according to $M_{fcr} = 6843$ kg. The average time of a cruise flight is 2 hours (7200 s).

Then, the mass of CH, NO_X pollutant emissions in the flight section of the aircraft without LTO is determined from the ratio:

$$M_{jcr} = EI_{jcr} M_{fcr}, \text{ kg},$$

where EI_{jcr} is taken for the nominal operating mode of the engine.

As a result, for one engine in flight conditions along the route without taking into account the LTO, let's obtain:

$$M_{\mathrm{CH}} = 0.401 \text{ kg}; \; M_{\mathrm{CO}} = 1.337 \text{ kg};$$

$$M_{\mathrm{NO}_x} = 105.305 \text{ kg}; \; M_s = 0.127 \text{ kg};$$

$$M_{\mathrm{SO}_2} = 16.7 \text{ kg}; \; M_{\mathrm{CH}_4} = 0.04 \text{ kg};$$

$$M_{\mathrm{H_2O}} = 4513 \text{ kg}; \; M_{\mathrm{CO}_2} = 10430 \text{ kg}.$$

For two engines according to the LTO, it turns out, respectively:

$$M_{\mathrm{CH}} = 0.802 \text{ kg}; \; M_{\mathrm{CO}} = 2.674 \text{ kg};$$

$$M_{\mathrm{NO}_x} = 210.61 \text{ kg}; \; M_s = 0.254 \text{ kg};$$

$$M_{\mathrm{SO}_2} = 33.4 \text{ kg}; \; M_{\mathrm{CH}_4} = 0.08 \text{ kg};$$

$$M_{\mathrm{H_2O}} = 9026 \text{ kg}; \; M_{\mathrm{CO}_2} = 20860 \text{ kg}.$$

The mass of emissions for each type of pollutant from this type of aircraft is determined by summing the values of the mass of pollutants by flight stages for all engines installed on this type of aircraft.

Multiplying the total mass of pollutant emissions by 4, let's obtain the value of the mass of pollutant emissions for four flights.

The results of pollutant emission calculations for this type of aircraft are summarized in Table 7.

Limitations of the study: the practical implementation of the research results may require more recent results of pollutant emission measurements, which is currently impossible in Ukraine.

The state of war directly affects the availability and quality of data, because at this moment it is impossible to conduct research and update empirical data on emissions of pollutants from aviation equipment on the territory of Ukraine.

Prospects for further research include measurements of emissions of pollutants and other characteristics of the load on the surrounding natural environment from other types of aircraft used in passenger and transport transportation.

Table 7

Results of pollutant emissions calculation

Aircraft type	Engine type	Number of engines	Number of LTOs	Pollutant emissions, kg							
				CH	CO	NO_x	Smoke	SO_x	H_2O	CO_2	CH_4
1 Boeing 757	P&W PW2040	2	1	2.16	13.84	467.8	0.648	79.9	21600	49920	0.22
4 Boeing 757	P&W PW2040	2	2	8.64	55.36	1871.2	2.592	319.6	86400	199680	0.88

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4. Conclusions

Analyzing the emissions of harmful substances from a specific Boeing 747 and Boeing 757 type aircraft, the following conclusion can be drawn: the concentrations of ingredients emitted by this type of aircraft do not exceed the corresponding maximum permissible values. But if to take into account the total load on the natural environment, the results of the study show that the daily concentration may be exceeded. As for the noise load, it can be concluded that the aircraft engine is a source of increased noise level, which negatively affects a person. However, such an impact can be prevented by locating airports as far as possible from populated areas. Therefore, emissions into the environment ensure a satisfactory state of the environment in the area of the location of the object and outside the sanitary protection zone during the operation of modern types of aircraft, such as Boeing.

Each aircraft has a certain negative impact on the environment due to the emission of pollutants during all phases of flight. However, there are opportunities to minimize this impact by implementing more complete fuel combustion, replacing standard fuels such as aviation kerosene with more modern fuels, reducing the weight of the aircraft, which will lead to lower fuel consumption and, accordingly, lower emissions into the atmosphere. Also effective is the introduction of technologies to reduce the noise load from the operation of aircraft, such as the introduction of noise-protective coverings of runways, new materials for the production of aircraft engines, as well as changing the design of engines and the use of double-circuit scheme.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

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Data availability

The paper has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating this work.

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✉***Dmytro Makarenko,*** *Senior Lecturer, Department of Ecology and Technogenic Safety, National Aerospace University «Kharkiv Aviation Institute», Kharkiv, Ukraine, e-mail: d.makarenko@khai.edu, ORCID: https://orcid.org/0000-0002-4672-2880*

Pavlo Penziev, *Assistant, Department of Foundry, National Technical University «Kharkiv Polytechnic Institute», Kharkiv, Ukraine, ORCID: https://orcid.org/0000-0003-0402-9575*

Artem Oskorbin, *Postgraduate Student, Department of Information Technologies and Design, National Aerospace University «Kharkiv Aviation Institute», Kharkiv, Ukraine, ORCID: https://orcid.org/0009-0003-8728-2206*

✉*Corresponding author*