Modern Ecological Approach to Air Transportation Management

Viktoriia Ivannikova(✉), Maryna Boldyrieva, and Valentyna Konovalyuk

National Aviation University, Kyiv 03058, Ukraine

Abstract. The paper analyzes the specifics of the impact of air transport services on the environment and provides methodology to solve emerging problems. This article is dedicated to the research of a relevance to upgrade the fleet for running cost-effective business. The main negative ecological influences of the aviation industry operation are noise, electromagnetic radiation, dangerous chemical substances emissions including carbonic acid, harm to animals, plant organisms and adjacent territories, waste production leading to climatic fluctuations, nature destruction and health problems, economic collapses. In addition, aviation sector itself will be affected by its disastrous actions – the main appearing problem can be loss of optimality in carrying out air transport service providers' activity. The performed researches allowed to find out new ways of air transport disastrous impact shortage. According to the research results, there were determined positive direction for the environment modifications in the airline industry activity – updated assessment method in the form of mathematical model of aircraft fleet usage, which will help to decrease the emissions of old aircraft. Mathematical model of aircraft replacement in the most optimal period of time allowing achieve ecologically safer and cost-effective carriage has been developed.

Keywords: Environment · Air transport ecological effects · Aviation sector · Fleet renewal · Noise · Air pollution · Aviation impact

1 Current Ecological State in Aviation Industry Worldwide

1.1 Global Impact

Nowadays the world is fighting against the great climatic catastrophe, which has resulted in each part of the Earth in multiple ways. Transportation no less than other human industries facilitates such damaging effects. Share of air carriages in the nature contamination has become a significant issue requiring attention and immediate actions as demand on it is still in steady growth.

According to the results of studies on the adverse impact of aviation on the environment [1], the following categories of factors exist in the vicinity of airports:

O. Prentkovskis et al. (Eds.): TRANSBALTICA 2021, LNITI, pp. 658–670, 2022.
https://doi.org/10.1007/978-3-030-94774-3_64

Chemical impact determinants:

- emission of harmful substances by aircraft engines and their effect on the ozone layer of the atmosphere;
- thermal pollution.

Physical impact indicators:

- noise during the operation of aircraft;
- sound shock;
- electromagnetic radiation;
- polluted runoff from the airport territory;
- waste from premises, warehouses and other facilities.

Table 1 presents the sources of the physical impact of civil aviation on the environment and the population [2].

Table 1. Sources of physical impact of civil aviation on the environment and the population.

Aircraft noise	Electromagnetic radiation	Thermal effects	Ionizing radiation	Vibration
Aircraft engines, auxiliary power units and wing mechanization elements	Radio equipment, magnetron ovens, radiotelephones, power transmission lines, transformer stations, power plants, computers, video monitors	Aircraft and special vehicle engines, boiler rooms	Tank level sensors on aircraft, devices with luminous dials, installations for radiation control at customs, electronic computers	Aircraft

To clarify and measure entire influence of emissions produced by air transportation sector on climate, the Intergovernmental Panel on Climate Change (IPCC) has determined that the total environmental effects of aerial operations performance is 2–4 times higher in comparison with its straight carbon dioxide emitting amount. This is evaluated as radiation exposure.

According to the IPCC research, among the climatic changes caused by human activity the aviation share takes approximately 3.5%, consisting of both CO_2 and non-CO_2 impacts. By its scientists were also developed forecasts of this indicator quantity in 2050. The potential value shows growth of aviation input up to 5% if any actions are not provided to manage these emissions, but there is also version of 15% portion. Besides, in case of substantial greenhouse gas emissions decrease in another sectors, the share of air transport industry considering residual emitting sources will grow as well [3].

Quantity of technogenic carbon (i.e. appeared after human activity) is shown in permanent increase since 2015. That is caused by the growth of emitting this product in coal, oil and gas combustions. According to the research of WMO, 2019 appeared to be one of the hottest years in the history, as well as for the last ten-year period. In the Fig. 1 it is shown increased amount of CO_2, CH_4 and N_2O density [4]. The lines colored in blue show quantity of these substances per month across the globe and in red ones – average value of emissions per month globally for the five year periods.

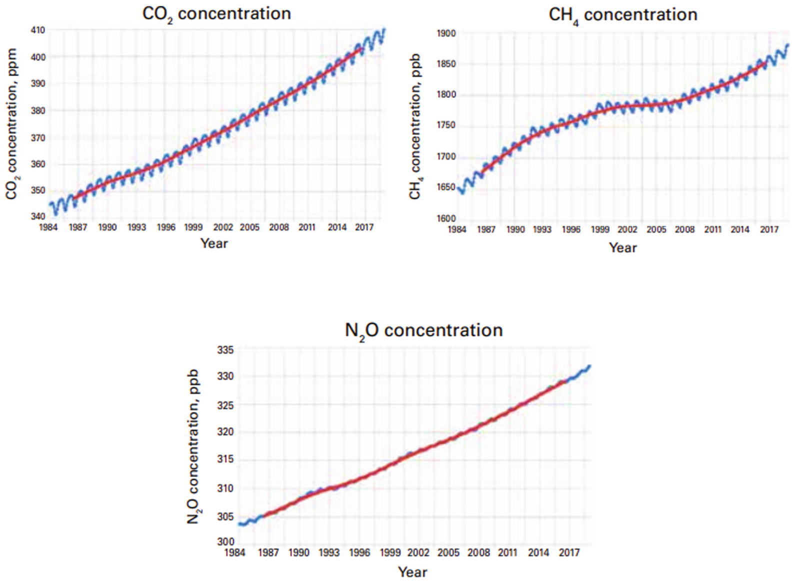

Fig. 1. Worldwide mean amount of concentrations of CO_2 in ppm (parts per million), CH_4 in ppb (parts per billion) and N_2O in ppb.

There were also detected the world areas, where this kind of pollution is concentrated the most (Fig. 2). Yellow points in the model show the emissions from the aircraft usage. The network for the methane is analogous [5].

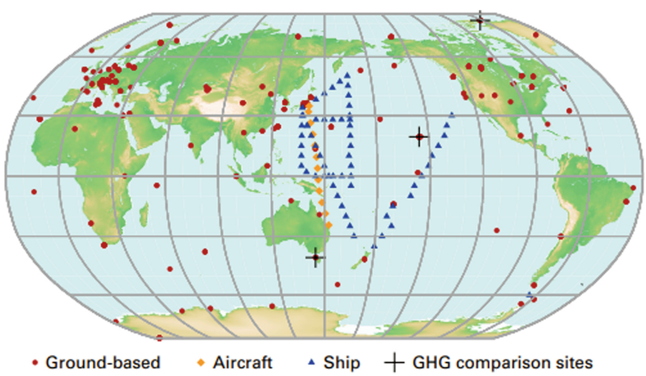

Fig. 2. The GAW (Global Atmosphere Watch) global network for carbon dioxide in the last decade (2010–2020).

Reviewing the received data about the speed of permanent CO_2 values expending in the 2015–2018 period in WMO's Global Climate 2015–2019 report, the revealed amount equals 18% higher than that over 2011–2015 (see Table 2).

Table 2. Concentration and growth rates of CO_2 (ppm), CH_4 and N_2O (ppb) in 2011–2015 and 2015–2018, their percentage in relation to period before 1750.

	Concentration			Growth rate		
	2015–2018	*2011–2015*	*2015–2018 % to pre-industrial*	*2015–2018*	*2011–2015*	*% change*
CO_2	404.2	395.5	145	2.5	2.2	+18%
CH_4	1856.0	1826.4	257	9.0	7.2	+21%
N_2O	329.6	326.2	122	0.95	1.0	–5%

After researchers' estimation there were received figures demonstrating the emission of specific substances by three hundreds of air vessels designed for transcontinental flights on the daily basis: 3.7 tons of carbon monoxide, 2 tons of hydrocarbon compounds and 1.7 tons of nitrogen oxides. Emissions of harmful substances in the airport area depend on the take-off and landing cycle for various types of aircraft [1, 6].

Despite the fact the scientist forecasted decrease of greenhouse gas emissions at least by 6% in 2021, which was forced by the COVID-19 pandemic restrictions and prohibitions in performing of air transportation services and economic downturn as well, there is no evidence of keeping such enhancement steady and constant. It may be called only environmental respite, so the climatic conditions continue the transformation process as the economic crisis has been resumed so the issues connected with greater emissions will be seen again not so far [7].

The graph below (Fig. 3) shows the share of all transport modes in the emitting of carbon dioxide and other harmful contents. According to the data of UK government, air carriages have the second position after road transport in amount of substances polluting air by one passenger per one kilometer traveled [6].

The data plotted in the next graph (Fig. 4) comprise the calculations of aviation impact on air pollution with carbon. The emissions included in this figure comprise those produced during passenger, cargo transportation, as well as military missions. The figures are taken from the Global Carbon Project, an organization aiming to measure the greenhouse gases and the reason generating them [8].

The red line shows aviation sector, which is an originator of 1.04 billion tons of carbonic acid.

As one of the main drawbacks must be also mentioned aviation noise. Noise caused by air transportation processes is an important factor in the negative attitude of the population to aviation in the territories adjacent to the airport. It affects a relatively large number of people living in the surrounding area, as well as airport employees and passengers. Aircraft noise has a negative impact on people's health (most often it is hearing impairment, stress conditions, problems associated with concentration) [5, 9].

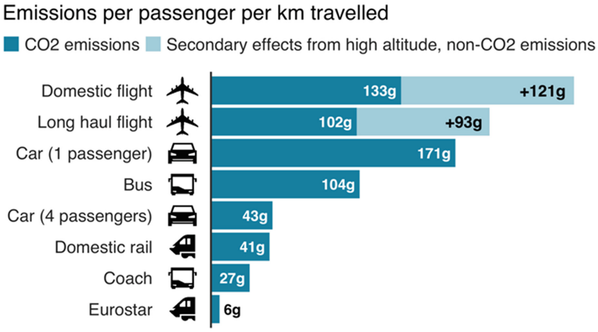

Fig. 3. The amount of emissions exuded by different modes of transport.

The main causes of aircraft noise are disturbances of air and gas flows created by the operation of aircraft engines, among which jet engines have the worst noise indicators. At the airport, the noises of take-off and landing moving along taxiways are joined by intense noises during the preparation of aircraft for departure as well as noises that occur at special sites during engine tests.

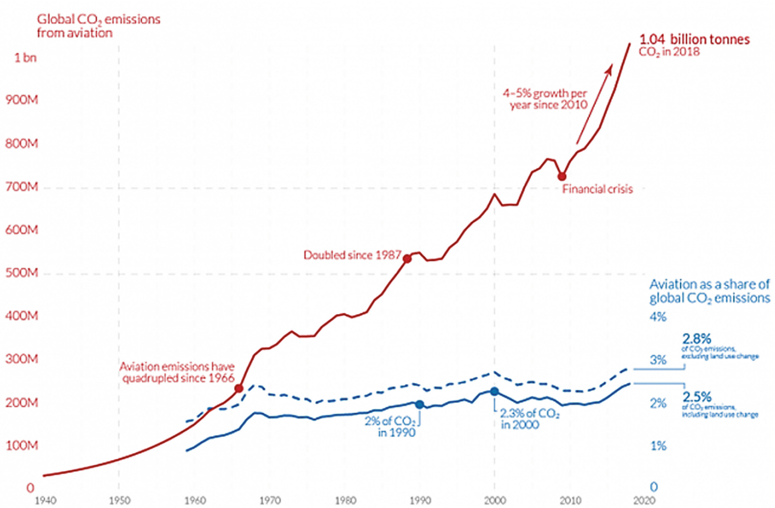

Fig. 4. Global carbon dioxide emissions from aviation.

All ecosystems are affected by the harmful effects of aircraft noise: humans, animals and plant organisms. The expected growth of air traffic means that potentially more people risk being exposed to aircraft noise in future. In fact, air traffic is forecasted to increase in the next years, as a result of an increasing demand for air travel, as shown in Fig. 5 from the European Aviation Environmental report (EAER) 2019.

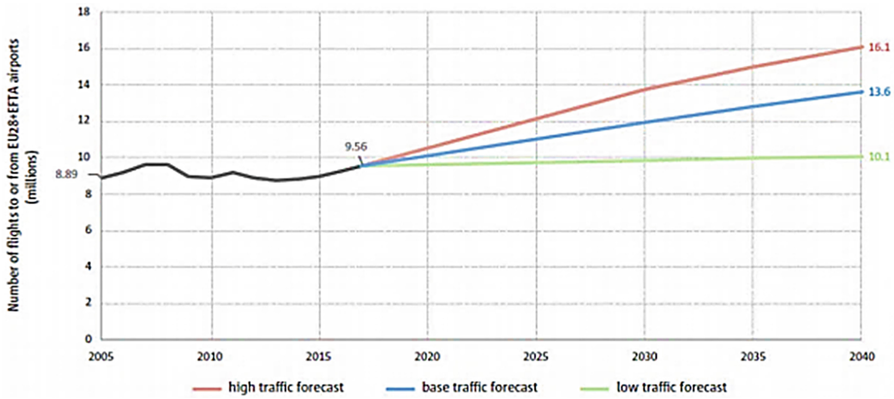

Fig. 5. Expected increase of air traffic for 3 different scenarios.

According to the EAE report, in 2017 3.2 million people were exposed to L_{den} (day-evening-night sound pressure level) 25 levels higher than 45 dB and 1.4 million people to L_{night} (night-time sound pressure level) 26 levels above 40 dB around the 47 major European airports. According to WHO (World Health Organization), these levels cause symptoms of high annoyance and sleep disturbance. For the same airports, it was also estimated that 1 million people were exposed every day to more than 50 aircraft noise events above 70 dB, when harmless noise does not exceed 30 dB.

Noise pollution around airports and air routes covers millions of square kilometers of territory, including residential areas. When the airport is close to the city the social problem of aviation noise, which interferes with the sleep and rest of the population and negatively affects health is acute [10].

2 Updated Technology in Provision of Ecologically-Friendlier Air Transportation

2.1 Mathematical Modeling in the Protection of Environment

Considering appearing trends and their popularity growth in the form of new vessels design, form and composition that are environmentally-friendly, the airlines should be aware of necessity to replace their fleet in not so far perspective. Another way to start being ecologically responsible is by reusage of aircraft parts and replacement of components that produce noise, emissions and other negative environmental influences [11].

Protection of the environment has become one of the parameters indicating the development, modernity and profitability of the airlines and airports as well. Ecological negative influences of the air transportation are controlled not only in the sphere of legislation in the form of regulations and requirements, climate sciences and ethics but also addressing to the taxation measures.

A number of foreign countries have introduced a tax on noise pollution caused by aviation. In France, the aircraft noise tax consists of two payments: the first of them is determined by multiplying the landing fee at the airport by five different coefficients, ranging from 0.9 (for "quiet" aircraft) and up to 1.2 (for "noisy" aircraft), which then goes to the airport budget; the second payment is from 0 to 20% of the amount of the landing fee and goes to a special fund, the money from which are used to finance measures for sound insulation of residential areas adjacent to the airfield area. In Denmark and Japan, such a tax depends on the mass of the aircraft and on the strength of the sound during take-off and landing [12]. One of the examples what charges are set in the European countries is shown in the Table 3 [13, 14].

Table 3. Estimated average aviation fuel tax necessary to cover main externality costs (noise and air pollution) (GBP per liter of aviation fuel).

Airplane Type	Noise Tax	Air Pollution Tax	Total Tax
A310	0.01	0.05	0.06
A340	0.01	0.06	0.07
BAe146	0.00	0.05	0.05
B737-100	0.06	0.04	0.10
B737-400	0.00	0.05	0.05
B747-400	0.01	0.06	0.07
B757	0.01	0.05	0.06
B767-300	0.01	0.05	0.06
B777	0.00	0.06	0.06
F100	0.00	0.05	0.05
MD82	0.01	0.05	0.06
Average	0.01	0.05	0.06

Whether it is an airline or airport, the company may be obliged to pay for contamination of harmful to nature substance, such as carbon dioxide and other chemicals produced while flight performance or other different operations. According to aviation experts, the absolute size of the damage caused by pollution is much greater than the costs required to solve them. As a result, the reason for replacement the aircraft with new, environmentally-neutral or even –friendly vessel turns to be pertinent and demanded in every case: it is necessary action for the present ecological situation globally and the future of the planet in one respect, and will save the costs of the company as the taxation on emissions is high enough to make the activity unprofitable.

The difficulties and challenges of aircraft updates are investments and risks of air carriers to fail with new approaches. To maintain these concerns and investigate how to become environmentally beneficial in a cost-effective manner, there is proposed a mathematical model described below. It will help the airline decide whether to spend money to replace an old aircraft component (for example, emitting carbon engine), or whether the best option is to attract a new or even different type over a certain period of time [15]. The task is based on a well-known equipment replacement model with a certain modification.

To determine the optimal service life of the aircraft by dynamic programming there were indicated the main elements of the model:

– *stage i* – serial number of the year of decision making (*i* = 1, 2,…n);
– possible decisions at the beginning of *i–stage* are alternatives – whether to continue operating an old aircraft or replace it with a new model;
– state at *i-stage* is life cycle *t* (age) of aircraft before *i-th year*.

In calculation will be considered the next data:

– *r(t)* – revenue per operation of *t-aged* aircraft per one period;
– *e(t)* – taxes an airline is obliged to pay for the emissions with the operation of *t-aged* aircraft per one period;
– *c(t)* – operational expenses of *t-year* aircraft during one period (replacement of spare parts, maintenance, airport fees, fuel, staff and crew fees, etc.);
– *s(t)* – salvage of *t-year* vessel;
– *l(i)* – costs of new aircraft [16].

For the analysis conduction there was considered a model of the feasibility of replacing a 3-year-old Airbus 320 aircraft with an upgraded vessel within 21 year (n = 21). At the beginning of each stage (every 3 years) there is made a decision on its replacement or further maintenance considering the earned profit and losses. There is assumed the average inflation rate for three-year period is equal to 2.1%. The initial data are shown in the Table 4.

Table 4. Initial data for the Airbus 320.

Aircraft age, t	Revenue, r(t)	Operating expenses, c(t)	Emissions charge, e(t)	Salvage value, s(t)	Aircraft cost, l(i)
0	96	12	0.42	–	80
3	95.9	13	0.4242	60	81.7
6	94	14	0.4284	57	83.4
9	92	15	0.4326	52	85
12	88	17	0.4368	48	86.7
15	84	18	0.441	43	88.4
18	79	20	0.4452	38	90.1

The conducted calculations show that it is more profitable to replace the aircraft on the 12th year of its operation (see Table 5 and Fig. 6).

Table 5. Results of calculations.

Stage 6	Time	Keep r(t)-c(t)-e(t)+s(t+3)	Replace s(3)-l(i) +r(0)-c(0)-e(0)+s(t)	$F_6(t)$	Decision
	3	95.9-13-0.4242+60=142.5	60-81.7+96-12-0.42+60=121.8	142.5	Keep
	6	94-14-0.4284+57=136.6	57-83.4+96-12-0.42+60=117.18	136.6	Keep
	9	92-15-0.4326+52=128.6	52-85+96-12-0.42+60=110.58	128.6	Keep
	12	88-17-0.4368+48=118.6	48-86.7+96-12-0.42+60=104.8	118.6	Keep
	15	84-18-0.441+43=108.5	43-88.4+96-12-0.42+60=98.2	108.5	Keep
	18	79-20-0.4452+38=96.5	38-90.1+96-12-0.42+60=91.5	96.5	**Keep**

Stage 5	Time	Keep r(t)-c(t)-e(t)+ F_6(t+3)	Replace s(t)-l(i)+r(0)-c(0)-e(0)+ F_6(3)	$F_5(t)$	Decision
	3	95,9-13-0.4242+136.6=219.07	60-81.7+96-12-0.42+142,5=204.4	219.07	**Keep**
	6	94-14-0.4284+128.6=208.2	57-83.4+96-12-0.42+142,5=199.7	208.2	Keep
	9	92-15-0.4326+118.6=195.2	52-85+96-12-0.42+142,5=193.08	195.2	Keep
	12	88-17-0.4368+108.5=179.06	48-86.7+96-12-0.42+142,5=187.4	187.4	Replace
	15	84-18-0.441+96.5=162.05	43-88.4+96-12-0.42+142,5=180.7	180.7	Replace

Stage 4	Time	Keep r(t)-c(t)-e(t)+ F_5(t +3)	Replace s(t)-l(i)+r(0)-c(0)-e(0)+ F_5(3)	$F_4(t)$	Decision
	3	95,9-13-0.4242+208.2=282.5	60-81.7+96-12-0.42+219,07=280.9	282.5	Keep
	6	94-14-0.4284+195.2=274.8	57-83.4+96-12-0.42+219,07=276.3	276.3	Replace
	9	92-15-0.4326+187.4=263.9	52-85+96-12-0.42+219,07=269.7	269.7	Replace
	12	88-17-0.4368+180.7=251.3	48-86.7+96-12-0.42+219,07=263.9	263.9	**Replace**

Stage 3	Time	Keep r(t)-c(t)-e(t)+ F_4(t +3)	Replace s(t)-l(i)+r(0)-c(0)-e(t)+ F_4(3)	$F_3(t)$	Decision
	3	95,9-13-0.4242+276.3=358.7	60-81.7+96-12-0.42+282.5=344.4	358.7	Keep
	6	94-14-0.4284+269.7=349.3	57-83.4+96-12-0.42+282.5=339.7	349.3	Keep
	9	92-15-0.4326+263.9=340.5	52-85+96-12-0.42+282.5=333.08	340.5	**Keep**

Stage 2	Time	Keep r(t)-c(t)-e(t)+ F_3(t +3)	Replace s(t)-l(i)+r(0)-c(0)-e(0)+ F_3(1)	$F_2(t)$	Decision
	3	95,9-13-0.4242+349.3=431.7	60-81.7+96-12-0.42+358.7=420.6	431.7	Keep
	6	94-14-0.4284+340.5=420.07	57-83.4+96-12-0.42+358.7=415.8	420.07	**Keep**

Stage 1	Time	Keep r(t)-c(t)-e(t)+ F_2(t +3)	Replace s(t)-l(i)+r(0)-c(0)-e(0)+ F_2(1)	$F_1(t)$	Decision
	3	95,9-13-0.4242+420.07=502.5	60-81.7+96-12-0.42+431.7=493.6	502.5	**Keep**

Thus, in terms of ecology it is also more relevant to address to the new vessel consuming less fuel and emitting less carbonic acid and other harmful particles in the air.

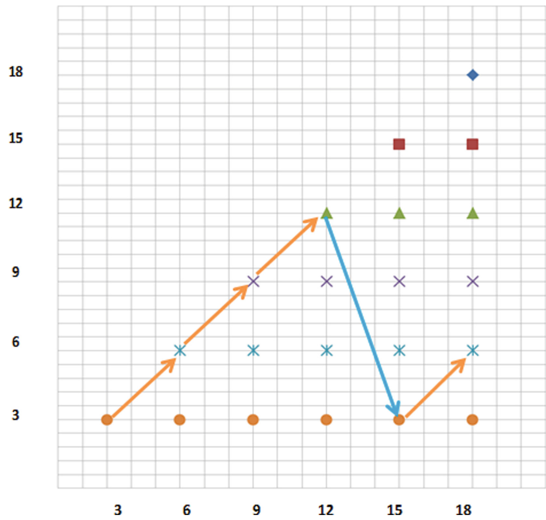

Fig. 6. Scheme of decision-making for the replacement of Airbus 320 (orange lines represent the decision “to keep current aircraft” and blue – “replace with new vessel”).

Nowadays, strong market players such as NASA, Lockheed Martin, Airbus and Boeing design new aircraft concepts: they create a hybrid of an airplane and a helicopter, install solar panels on the roof and wings to generate energy, make a glass floor or ceiling to lighten the weight. These innovative transport modes are an example of possible aircraft configuration that will replace an old aircraft and become a solution in optimization of air transportation management sphere [17, 18].

It is possible to increase the fuel efficiency of the aircraft by optimizing the flight dynamics and the distribution of the maximum take-off weight. Developments in the field of variable wing geometry are aimed at solving these problems that will be demonstrated in the form of aircraft with variable wing geometry, named in other materials as sweepback.

Adapting the wing design to the flight conditions (at high speed, a large wing sweep is effective, at low speeds is less) allows to increase the ratio of lift to drag of the wings by 15–20%, which helps to reduce fuel consumption, improve aerodynamics and in such a way decrease the noise.

One of the most promising developments in this area is led by FlexSys Inc., commissioned by NASA. Its technology of transformable flaps has already passed flight tests on the basis of the Gulfstream III aircraft, showing high efficiency (Fig. 7–8). Currently, the turnover of the civil segment of the market for aircraft with variable wing geometry is estimated at $135 billion [19, 20].

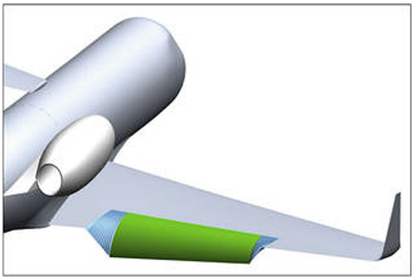

Fig. 7. FlexSys ACTE flap technology bridges gaps in wing for a seamless surface.

Fig. 8. Modified Gulfstream III aircraft tests for the ACTE flexible-flap research project.

3 Conclusions

There was carried out analysis of the specifics of environmental management and research of aviation sector air pollution, as well as were considered possible means to reduce emissions and mechanisms for achieving rational environmental management in the field of ecology protection from the air transport influence. According to data received after the analysis, it was found that the air transportation pollution taxation is one of the most effective and applicable measures that can appear in every country to force the aviation industry parties to pay attention to the environmental issues and modern technology that would be useful for management and decrease of airport and airline emissions and nature contamination. There was proposed for the first time the mathematical model that can be a tool to assist the aviation service providers in implementing of new technologies aimed to replace ecologically ineffective fleet with environmentally neutral aircraft and perform it at the appropriate time and in a cost-effective manner. The future research work will be focused on the deeper investigation of updated aircraft that will appear in not so far perspective.

References

1. Влияние авиации на окружающую среду и меры по ослаблению негативного воздействия / Иванова А. Р. // Труды Гидрометцентра России. Вып. **365**(С), 5–14 (2017)
2. Коробова, О.С., Филиппова, Д.В.: Воздействие объектов гражданской авиации на окружающую среду на примере международного аэропорта “Шереметьево”. Горный информационно-аналитический бюллетень. №. **5** С, 299–305 (2017)
3. Wuebbles, D.J., Gupta, M.L., Malcolm, K.W.: Evaluating the Impacts of Aviation on Climate Change. Eos **88**(3), 157–168 (2007)
4. Global Climate in 2015–2019: Climate change accelerates. World Meteorological Organization (WMO), p. 21 (2019)
5. Aviation Noise Impacts. White Paper. State of the Science: Aviation Noise Impacts, pp. 44–66 (2019)
6. Юрчук, А. П.: Влияние авиации на окружающую среду и меры по ослаблению негативного воздействия / А. П. Юрчук. — Текст : непосредственный // Молодой ученый. № 8 (350). — С. 198–201 (2021)
7. Comi, A., Savchenko, L.: Last-mile delivering: analysis of environment-friendly transport. Sustain. Cities Soc. **74**, 103213 (2021)
8. Greenhouse gas reporting: conversion factors 2019. Department for Business, Energy & Industrial Strategy (DEFRA), June 2019. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019
9. European Aviation Environmental Report 2019. European Aviation Safety Agency. https://www.easa.europa.eu/eaer/topics/sustainable-aviation-fuels
10. Декалин, А. А., Нечаева, О. А.: Воздействие авиационного шума на экологию. Журнал: E-Scio (2019). https://cyberleninka.ru/article/n/vozdeystvie-aviatsionnogo-shuma-na-ekologiyu
11. IATA. Best Industry Practices for Aircraft Decommissioning (BIPAD). https://www.iata.org/contentassets/ffbed17ac843465aad778867cb23c45c/bipad.pdf
12. Sameh, M.M., Scavuzzi, J.: Environmental Sustainability Measures for Airports. Occasional paper series VII, Centre for Research in Air and Space Law, McGill University (2016)
13. Mantecchini, L.: Airport noise charges and local communities: application to regional airports. J. Eng. Sci. Technol. **11**(11), 1518–1527 (2016)
14. Keen, M., Strand, J.: Indirect Taxes on International Aviation. WP/06/124, International Monetary Fund (2006)
15. Болдирєва, М. О., Тішин, І. А.: Проблематика заміни літаків авіакомпанією. Матеріали Міжнародної науково-практичної конференції «Проблеми організації авіаційних, мультимодальних перевезень та застосування авіації в галузях економіки» 21 листопада (2019)
16. Таха, Х. А.: Введение в исследование операций. М.: Вильямс, 912 с. (2005). http://bookre.org/reader?file=445915&pg=1
17. Yudin, O., Ziubina, R., Buchyk, S., Matviichuk-Yudina, O., Suprun, O., Ivannikova, V.: Development of methods for identification of information-controlling signals of unmanned aircraft complex operator. Eastern-Eur. J. Enterp. Technol. **2/9**(104), 56–72 (2020)
18. Savchenko, V., Laptiev, O., Kolos, O., Lisnevskyi, R., Ivannikova, V., Ablazov, I.: Hidden transmitter localization accuracy model based on multi-position range measurement. In: 2020 IEEE 2nd International Conference on Advanced Trends in Information Theory, IEEE ATIT 2020, Proceedings, pp. 246–249 (2020)

19. NASA. Green Aviation Project Tests Shape Changing Wing Flaps (2019). https://www.nasa.gov/image-feature/green-aviation-project-tests-shape-changing-wing-flaps
20. NASA. Past Project: Adaptive Compliant Trailing Edge Flight Experiment (2017). https://www.nasa.gov/centers/armstrong/research/ACTE/index.html