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Adopted LTO cycle to operational conditions at polish airports

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The aim of this article is to take into account specifications of the airport area in the LTO test when the impact of the air transport at the airport-proximate area is analysed. The LTO test doesn't consider the specifications of e.g. airport manoeuvring area and length of taxiways. The LTO test calculation methodology requires knowledge of aircraft engine parameters, such as thrust, specific fuel consumption and emission values indexes. Based on the data contained in the Engine Emissions Database (ICAO), the parameters of the LTO test can be determined. The main analysis element was to conduct a taxiing simulation using the CKAS MotionSim5 Flight Simulator to indicate the operational taxiing time at individual polish airports. Statistically significant differences were found between the emissions of selected exhaust gas components in the regulation LTO test and the operational LTO test. Analyzes were carried out concerning three different propulsions that are most often used by carriers serving the largest number of passengers in Poland. The analysis covers current research topics, which are reflected in the presented discussion of the obtained results and their relation to conducted analysis by the scientific community in the area of aviation impact on the environment.

Key words: *LTO cycle, operational conditions, sustainability air transport, air transport impact*

1. Introduction

The dynamic development of transport systems is an important factor influencing the improvement of the economic world. For many years, one of the most important aspects of transport has been the assessment of its impact on the natural environment [13]. A significant issue in terms of the dynamics of air transport development is counteracting its harmful effects, achieving climate neutrality and reducing dependence on fossil fuels. The European Environment Agency puts the responsibility of air transport at around 4% of total greenhouse gas emissions in the European Union. On the other hand, they indicate an increase in the responsibility of air transport for greenhouse gas emissions by 146% over the years 1990-2019 [3]. According to European Union Aviation Safety Agency (EASA) reports, CO_2 emissions from all EU airports amount to 147 million tons (2019), of which emissions from long-haul flights (over 4000 km) are approximately 6% [5]. They account for half of the CO_2 and NO_x emissions in European air transport [1].

Carbon dioxide emissions, which directly contribute to the greenhouse effect, are relate to the combustion process in aircraft engines. The dominant units are the drives of passenger and transport aircraft, medium and long-range, which obtain mechanical energy from the combustion of aviation kerosene [19]. As indicated in one of the articles regarding Athens airport more than 6500 kt of CO_2, almost 28 kt of NO_x, about 18 kt of CO, almost 1.5 kt of HC and 0.3 kt of PM total have been released into the atmosphere during the total operating time of the airport [2]. Systems and projects gradually introduced into civil aviation, such as Single European Sky Air Traffic Management Research (SESAR) and Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), are aim at reducing CO_2 emissions in air transport. The above-mentioned projects, through activities such as more effective management of airspace, its capacity and the introduction of flexible route planning (an example is the Free Route Airspace project conducted by SEASAR), contribute to reducing emissions of harmful exhaust components from air transport. CORSIA is a global offsetting mechanism that aims to compensate for the increase in carbon dioxide emissions above 2020 levels, from international aviation. CO_2 offsetting involves calculating the emissions created during a flight and converting them into the purchase of project credits that aim to remove an equivalent amount of CO_2 from the atmosphere elsewhere. One of the articles showed, using the example of Antalya International Airport, that aircraft of the B737 family are found to have the highest global warming potential and environmental cost, with values of 630,633.3 GWP and 39,723.4 Euros, respectively [4]. The guidelines set by CORSIA and SESAR projects contribute to stabilizing carbon emissions from the aviation sector by implementing new technologies, improving operational efficiency and infrastructure, and gradually replacing fossil fuels with fuels from renewable sources. In the above-mentioned processes, it is also important to estimate the quantitative emissions of individual exhaust gas components, especially in areas surrounding the airport. Quantitative estimation of aviation emissions of combustion products is determined based on the landing and take-off cycle (LTO test). The test methodology is base on individual phases of the flight operation performed by the aircraft. The entire LTO test cycle lasts almost 33 minutes, of which the taxiing time is 26 minutes, which constitutes 78% of the entire cycle duration [18]. The LTO test does not take into account the specifications of the airport maneuvering area, the length of taxiways, and does not take into account the nature of a given airport.

The article focuses on a comparative analysis of the three propulsions most often used in the fleet of carriers that serve the highest number of passengers in domestic and international regular traffic at Polish airports. The analysis concerns the standard taxiing phase (following legal regulations) of the LTO test and operational taxiing, where the time of the mentioned phase is adapted to the actual infrastructure of a given airport.

2. Materials and methods

In the LTO test, the parameters depend on the phase of the flight operation and are specified by the legislator [19]. The emission values of toxins in gases emitted by jet engines are determined depending on the maximum thrust for take-off, in the range of 85% for climb, in the range of 30% for approach and 7% of maximum thrust for taxiing (Table 1) [8, 9, 18].

Table 1. Characteristic of time and thrust for LTO cycle [9, 18]

LTO phase	Thrust [%]	Phase time [min]
Take-off	100	0.7
Climb	85	2.2
Approach	30	4.0
TAXI/Idle	7	26

The LTO test calculation methodology requires knowledge of aircraft engine parameters, such as thrust, specific fuel consumption and emission values and indexes. Based on the data contained in the Engine Emissions Database created by ICAO [10, 17], the parameters of the LTO test can be determined. The largest and most recognizable aircraft manufacturers in the world are Boeing and Airbus. These aircraft models constitute the largest percentage of the aircraft fleet used by airlines [16]. Low-cost carriers (LCC) offer air transportation services at lower prices than traditional airlines. One way to reduce costs is to standardize the aircraft fleet, which reduces the operating costs of a given fleet. An example of a traditional carrier is LOT Polish Airlines, which offers aircraft in its fleet of various models from Boeing and Embraer [16]. The most passengers served at Polish airports in 2022 were: Ryanair 37% market share, LOT Polish Airlines 23.5% market share, Wizzair 21.2% market share [16]. For each carrier, the type and model of the aircraft that most often operates on the Polish market and the corresponding drive were selected (Table 2).

Table 2. Type and model of aircraft for each airline

Airline	Type of aircraft	Propulsion
Ryanair	B737 8200	LEAP-1B CFM International (LEAP)
LOT Polish Airlines	Embraer 195	GE CF34-10E turbofans (GE)
Wizzair	Airbus A321neo	PW1133G-JM (PW)

For each of the indicated propulsion, using data from the ICAO Database [11], emission indicators and fuel consumption for the taxiing phase are present (Table 3).

Table 3. Emission indicators in taxi/idle phase for chosen propulsions

Compound	GE	LEAP	PW
HC [g/kg]	6.39	0.71	0.05
CO [g/kg]	49.98	16.19	17.89
NO_x [g/kg]	3.51	4.74	6.98
PM [mg/kg]	13.42	0.23	7.04
FF [kg/s]	0.084	0.089	0.099

The next step was to conduct a taxiing simulation using the CKAS MotionSim5 Flight Simulator at all airports in Poland in order to indicate the operational taxiing time at individual airports. This is an advanced flight simulation device that can simulate the work of light aircraft class: with one piston engine, two piston engine, turboprop engine and jet engines. The LTO regulation taxiing operation covers the route from landing to arrival at the passenger terminal (taxi/idle in phase) and the route from the passenger terminal to the runway (taxi/idle out phase). For each airport in Poland simulated taxi/idle in and out phase. Taxi/idle phase was mapped using infrastructure schemes (in according to Aeronautical Information Publication AIP Poland) of each airport and according to taxi ways leads to passenger terminal. A jet propulsion module was used to conduct the simulation, and the speed of taxiing operations was assumed to be 28 km/h (15 kt). This is the standard speed for taxiing operations at the airport. During the simulation of taxi/idle in phase time of operation was measured and multiplied by 2 for an estimated time of the whole LTO operational taxiing phase. Table 4 shows the times determined on the basis of simulations for each airport in Poland.

Table 4. Time in minutes for taxi operation for each airport. Airport were marked by ICAO code

Airport	Time [min]	Airport	Time [min]	Airport	Time [min]
EPWA A	17.4	EPWA K	15.8	EPGD	8.68
EPWA B	19.4	EPWA L	19.4	EPKT	9.32
EPWA C	13.2	EPWA M	17.4	EPKK	10.92
EPWA D	16.8	EPWA N	19.4	EPZG	4.5
EPWA E	10.4	EPWA O	13.2	EPSC	4.5
EPWA F	12.4	EPWA P	16.8	EPLB	8.4
EPWA G	6.2	EPMO	8.68	EPLL	11.88
EPWA H	9.8	EPSY	8.04	EPRA	5.78
EPWA I	20	EPPO	10.92	EPRZ	9
EPWA J	22	EPBY	9.66	EPWR	4.5

Since Warsaw Chopin Airport is the largest airport in Poland, is responsible for 35% of all traffic and is the only airport in Poland with two runways, several different taxiing scenarios have been prepared for it. For the analyses, the 16 scenarios were adopted – the longest taxiway takes 6.8 km, the shortest 1.9 km and the average occurs 4.8 km. It’s caused that taxi time is from 3 to 11 minutes [9]. The analysis and preparation of scenarios for the EPWA airport were presented in detail in one of the authors' publications [15]. The last step was to calculate emissions in the operational LTO test (O_LTO) and the standard the LTO test (R_LTO). Emission in LTO cycle is calculated using the formula:

$$\mathrm{EPC} = \mathrm{TIM}/60 \times \mathrm{FFR} \times \mathrm{EF} \times \mathrm{NE} \qquad (1)$$

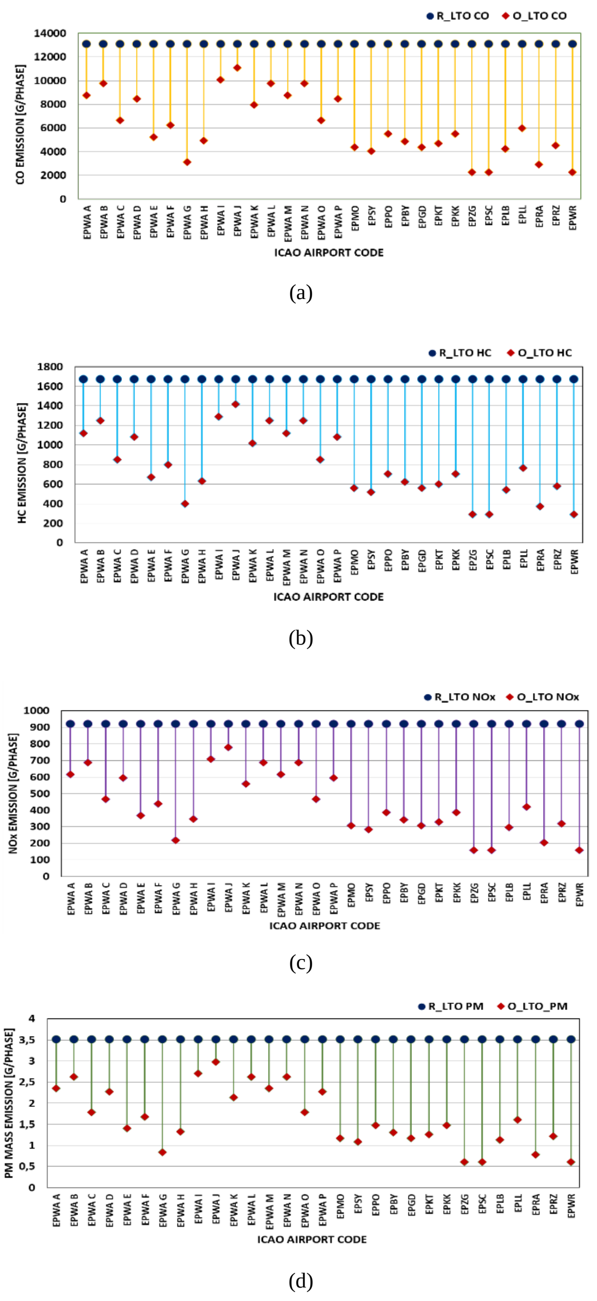
where: EPCpol,mode – emissions per cycle for a particular, mode [g/phase], TIM – time in mode [h/phase], FFR – fuel, flow rate [kg/h], EF – emission factor [g/kg], NE – number, of engines on aircraft [–].

3. Results

Based on calculated results, the authors prepared Fig. 1–3, which present the mass of gaseous harmful compounds in exhaust gases obtained in the taxi cycle and estimated for each airport and each propulsion. Additionally, for each of the analyzed exhaust gas compounds, tests for normality of distributions (Shapiro-Wilk test) and tests for the significance of differences (Wilcoxon test) were performed, using a sample prepared for all airports and scenarios. None of the compounds had a normal distribution. However, it was important from the point of selecting significance tests. Significance tests between the results for taxi operation in R_LTO cycle and O_LTO cycle showed statistically significant differences at the p-value < 0.05 level for each of the analyzed compounds.

Figure 1 shows the emission of selected exhaust gases for the GE engine, which is used on aircraft most often operated by LOT Polish Airlines. As you can see, the differences in emission levels for R_LTO and O_LTO are large.

In the case of Chopin Airport, the best scenario is scenario G. In the case of CO emissions, the reduction ranges from 3000 to 12,000 g/phase for each airport. Hydrocarbon emissions using operational conditions will be reduced by 200–1400 g/phase. The reduction in nitrogen oxide emissions is from 100 to 750 g/phase. However, the mass amount of particulate matter emitted by the GE engine during the operational LTO test conditions is less than 0.5–3 g/phase. Figure 2 shows the emissions of selected exhaust gases for the LEAP engine, which is used on aircraft operated most often by the low-cost airline Ryanair.



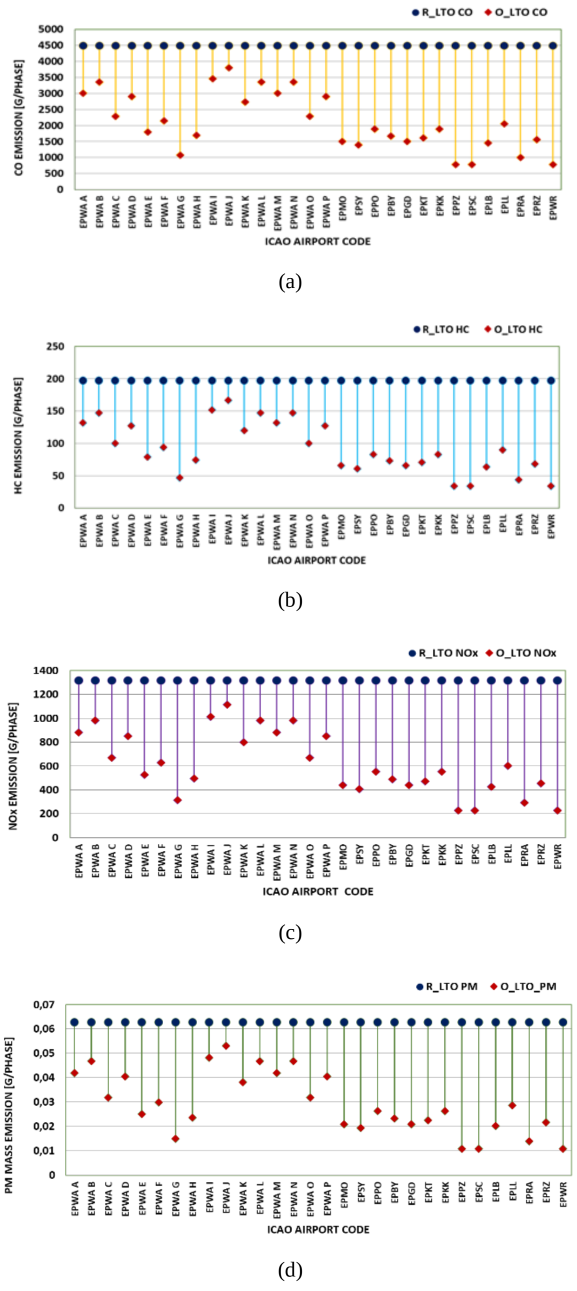
(a)

(b)

(c)

(d)

Fig. 1. Emission [g/phase] of harmful compounds from GE CF34-10E turbofans for each airport and scenario, (a) CO, (b) HC, (c) NO$_x$, (d) PM



(a)

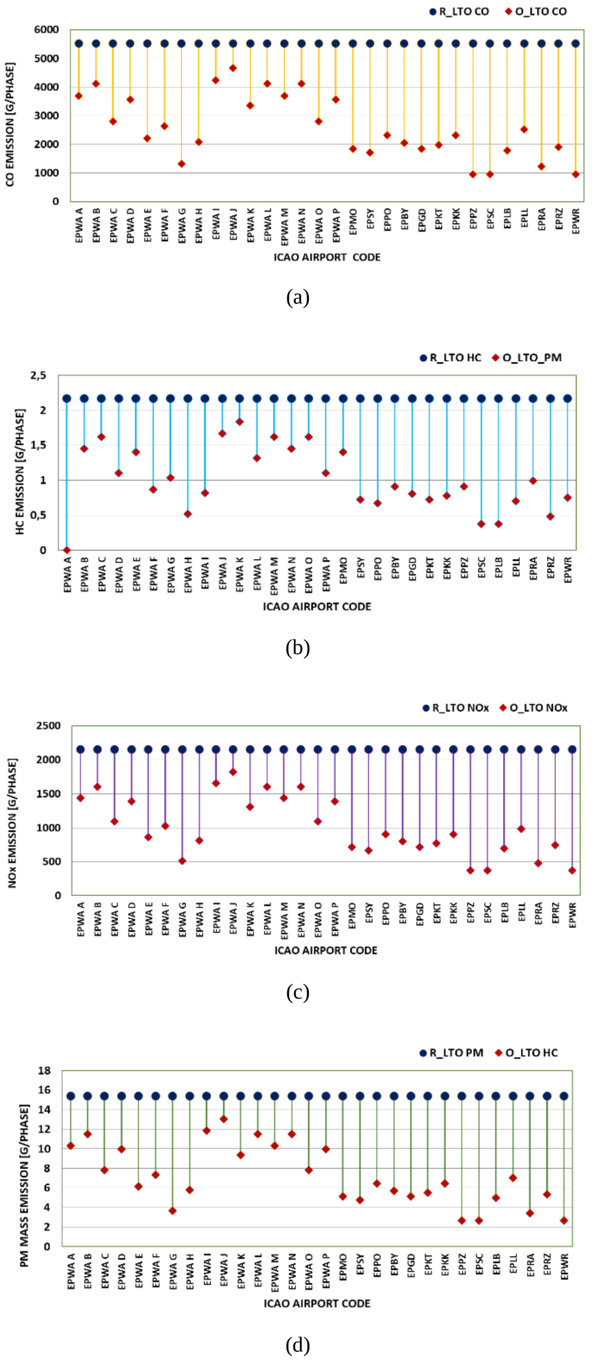
(b)

(c)

(d)

Fig. 2. Emission [g/phase] of harmful compounds from LEAP-1B from CFM International for each airport and scenario, (a) CO, (b) HC, (c) NO$_x$, (d) PM

As can be seen, the difference in emission levels for R_LTO and O_LTO is very large. In the case of CO emissions, the reduction ranges from 1000 to 3500 g/phase for each airport. Hydrocarbon emissions using operational conditions will be reduced by 50–160 g/phase. The reduction in nitrogen oxide emissions is from 300 to 1200 g/phase. However, the mass amount of particulate matter emitted by the LEAP engine during operational LTO test conditions is less than 0.03–0.05 g/phase. Figure 3 shows the emission of selected exhaust gases for the PW engine, which is installed on Wizzair's aircraft.



(a)

(b)

(c)

(d)

Fig. 3. Emission [g/phase] of harmful compounds from Pratt&Whitney PW1133G-JM for each airport and scenario, (a) CO, (b) HC, (c) NO_x, (d) PM

The difference in emission levels for R_LTO and O_LTO is very large. CO emissions are reduced by 1000–4500 g/phase, depending on the airport. Hydrocarbon emissions using LTO operating conditions will be reduced by 0.5–1.75 g/phase. The reduction in nitrogen oxide emissions is from 500 to 1750 g/phase. However, the mass amount of particulate matter emitted by the PW engine during the operational conditions of the LTO test is lower than 3 to 14 g/phase. Figure 4 shows the percentage reduction in emissions for each of the analyzed components. Due to the time variable used in formula (1), the reduction for each component will be the same percentage.

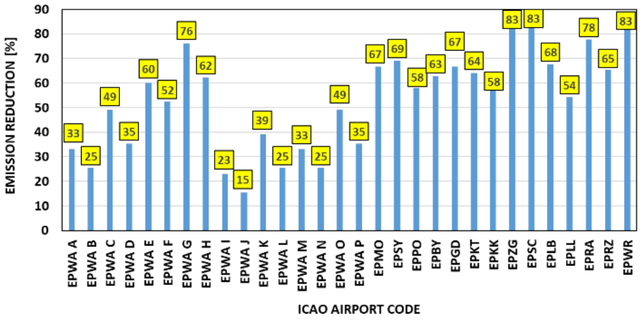
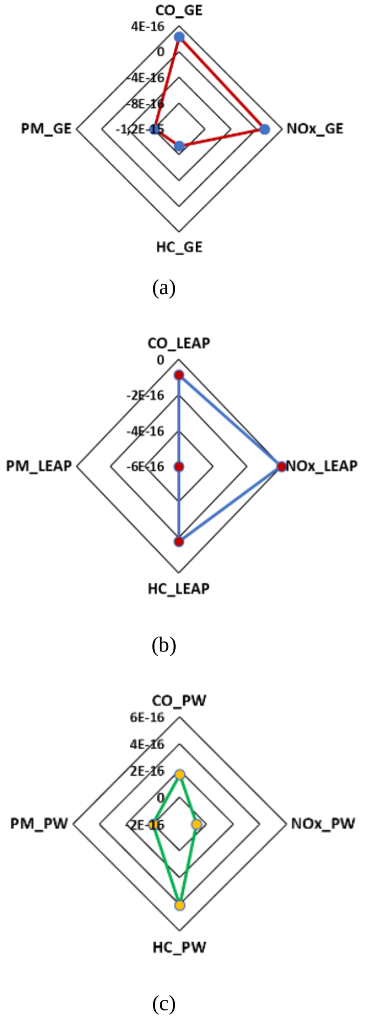


Fig. 4. Reduction of each analysed compound emission for each airport

As can be seen, the highest emission reduction occurs for the EPWR (Wroclaw), EPZG (Zielona-Gora) and EPSC (Szczecin) airports. For EPZG and EPSC airports, this is an expected result, due to the fact, that these are airports with one of the smallest numbers of passengers transported in Poland, so the infrastructure of these airports isn't highly developed. On the other hand, EPWR airport belongs to the group of airports that served at least 1 million passengers in 2022. A similar situation applies to the airport in Katowice (EPKT), Gdansk (EPGD) and scenario G at the Warsaw Chopin Airport (EPWA). The next step in the analysis was to compare and contrast the results obtained for each chosen propulsion. For this purpose, the analyzed variables were standardized (emissions for individual exhaust gas compounds).

Standardization enabled a numerical comparison of the analyzed propulsion units despite significant differences in the obtained emission values. Based on the calculated averages, charts were prepared showing the emission of each analyzed compound for each of the three compared drives (Fig. 5). Figure 5 shows the emission levels of selected exhaust gas components for each analyzed drive unit. As you can see, the GE unit, used mainly in the LOT Polish Airlines fleet, emits the largest amount of CO and HC and the lowest amount of NO_x. The LEAP engine used in the Ryanair fleet emits the lowest amount of PM, while the CO is emitted in larger amounts by GE and PW units. On the other hand LEAP unit emitted the highest values of PM. The PW engine, used mainly in the Wizzair fleet, is characterized by the highest emissions of NO_x. CO emissions reach a higher value for the PW unit than for the LEAP unit.



(a)

(b)

(c)

Fig. 5. Characteristic of compounds emission for each propulsion using standardization

The PW1133G-JM engine is the newest engine in terms of other units. It has the highest value of the double-flow rate and is designed with a fan reduction gear. This engine is most often found in the configuration of the Airbus A321neo aircraft. The value of the double-flow ratio is 12:1, i.e. for every 13 units of air sucked into the engine, 12 units bypass the core and do not participate in the combustion process [20, 21, 23]. The Pratt & Whitney engine produces the lowest emissions relative to the thrust produced, which means high engine operating efficiency. Continuous improvement of aircraft structures, construction and modification of combustion chambers and other elements used in aircraft engines has a significant impact on reducing emissions and improving the efficiency of engine units [15, 20, 23].

4. Discussion

To make accurate exhaust emission calculations from all modes of transport, the actual conditions should be considered. For example in road transport the emission measurements are performed in real driving conditions to receive the data in similar conditions in which the vehicle is operated by the user [18]. In aviation the regulation LTO cycle conditions present engine operation parameters during four phases, so this test procedure is proper in case of aircraft engines comparison. However, the same procedure is taken into account for calculations of the environmental impact of air transport to airport-proximate areas. For the taxiing phase, operational times at individual airports will be significantly different from those contained in the procedural regulations. The operational taxiing time of 26 minutes may apply to some of the largest airports in Europe, such as Istanbul, Amsterdam or Paris [17]. For Polish conditions and all smaller and medium-sized European airports, the time of 26 minutes used in assessing the impact of emissions from air transport on airport-proximate areas will be completely inadequate. In article indicated statistically significant differences between the emissions of selected exhaust gas components, which confirm legitimacy of operational conditions in the LTO aspect. EPWA airport served 14.5 million passengers in 2022, which is a larger number than airports in e.g. Barcelona or Copenhagen, and half of the passengers served at the largest airport in Europe – Istanbul [17].

Based on the research results, it was shown that LTO operating time is a very important aspect in analyzing the impact of air transport on airport-proximate areas. For EPWA airport, the best scenario is scenario G [9]. The location of the passenger terminal and arrival or departure procedures from the airport, as well as the location of taxiways, are key importance in this case. The above-mentioned factors mean that even an airport with relatively high passenger traffic (taking into account Polish conditions) can reduce the amount of exhaust gas components emitted through appropriate infrastructure and procedures. The issue of the impact of air transport on airport-proximate areas is actively discussed by the scientific community due to the dynamic development of aviation and emerging regulations aimed at limiting exhaust emissions [6, 7, 14, 22, 24, 25]. One of the articles discussed emissions at the Bejingdax International Airport. The article showed that among all aircraft types, the B738 emitted the most CO_2, as it accounted for almost half of all the flights. The air quality simulations showed that the air pollutant diffusion range was concentrated within 15 km of the airport and the surrounding areas. The contribution of airport emissions to NO_x concentrations was most apparent under the most unfavorable meteorological conditions [22]. One of the articles showed, using the example of Antalya International Airport, that aircraft of the B737 family are found to have the highest global warming potential and environmental cost, with values of 630,633.3 GWP and 39,723.4 Euros, respectively [4]. This is consistent with the research presented in the article. It was pointed out that the B737 emitted a larger amount of selected exhaust gas components compared to the Airbus A321neo. On the other hand, apart from the direct impact of air transport on airport-proximate areas, scientists also consider other sources of pollution occurring at the airport. One of the articles showed that motor vehicles including taxis and parking vehicles are a major source of air pollutants in the hub [7]. Another authors marked, that the impact of airport operations on a particular number concentration in the adjacent neighborhood is comparable to the combined impact of busy roads in the area [24].

The presented considerations are intended to highlight the importance of operational conditions in analyzes related to the impact of air transport on emissions in airport-proximate areas and to demonstrate that the types and models of aircraft used by airlines are of great importance in local emissions of exhaust gas components. This is indicated by the emission of propulsions units made in this article.

5. Conclusions

The article presents considerations regarding the operational conditions of airports, that should be taken into account when assessing the impact of air transport on airport-proximate areas using the LTO test. Statistically significant differences were found between the emissions of selected exhaust gas components in the regulation LTO test and the operational LTO test. Analyzes were carried out concerning three different propulsions that are most often used by carriers serving the largest number of passengers in Poland.

Presented analyzes are important in the context of the dynamic development of aviation and developing projects aimed at neutralizing exhaust emissions into the atmosphere. The analysis covers current research topics, which are reflected in the presented discussion of the obtained results and their relation to conducted analysis by the scientific community in the area of aviation impact on the environment.

Nomenclature

AIP	compression ignition
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
EASA	European Union Aviation Safety Agency
ICAO	International Civil Aviation Organisation
LCC	low-cost carriers
LTO	landing and take off
SESAR	Single European Sky ATM Research

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