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Twd-10 b/pzl-10s engine emissions evaluation for PZL M28b Bryza airplane

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Abstract. The specificity of measurements of the concentration of harmful exhaust components of turbine engines used for propulsion of aircraft is connected with tests carried out in stationary conditions during engine tests. The conditions of engine load during the test and the concentration of harmful exhaust compounds determined during the measurements may be used to estimate the emissions of these compounds during the flight of the aircraft. A prerequisite is to obtain a correlation of the engine load conditions during a stationary test to the engine load conditions during the flight of the aircraft. This correlation was carried out on the basis of records of the operating parameter values recorded by the on-board aircraft flight recorder. The article presents the results of measurements of concentration of harmful compounds carried out during the pre-start test of the TWD-10B/PZL-10S engine being the source of propulsion of the PZL M28B "Bryza" airplane, implemented on the airport board. The article presents the results of tests and their analysis, allowing us to assess the emission of harmful exhaust gases from turbine propeller engines.

1. Introduction

Air transport as an economic field is characterized by dynamic development. Currently, it is estimated that air transport will be the most dynamically developing branch of transport [11]. The growing number of aircraft, including turboprop-driven aircraft, has a direct impact on the state of the environment [1, 2, 4, 8]. Turboprop drive units are mainly used as a source of propulsion for transport aircraft such as: PZL M28B "Bryza", Lockheed C-130 "Hercules", Airbus A400M, Alenia C-27J Spartan. The hazards associated with the operation of turboprop engines are associated with the emission of carbon dioxide, carbon monoxide and nitrogen oxides. The provisions in JAR 34 (Joint Aviation Requirements) and FAR34 (Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes) introduced by ICAO (International Civil Aviation Organization) and EPA (Environmental Protection Agency) regulate the stationary test procedures and emission standards [1, 3, 12]. The assessment of the actual emission of harmful exhaust gases of aircraft engines during the flight of the aircraft is crucial for the future development of the turboprop drive unit [5]. Limitations related to measurements of concentrations of harmful aircraft are due to the inability to perform flight tests. This is due to the necessity of mounting the measuring equipment on the airframe, which makes it impossible to perform the flight operation due to the loss of flight characteristics of the aircraft. The emission of harmful exhaust gases is closely related to the combustion process carried out in the engine. It depends on the type of engine and its operating conditions [1, 3, 4, 6, 7, 9]. In order to estimate the emission of harmful exhaust gases of aircraft engines during the flight, the data obtained during the stationary engine test were analysed, associating them with the recording of the flight data recorder. The requirement for correlation is the knowledge of engine load conditions during stationary test and engine load conditions during aircraft flight.

2. Methodology

The basis for determining the emission of harmful exhaust emissions during the flight of the PZL M28B "Bryza" aircraft were the results of a TWD-10B/PZL-10S engine stationary test carried out on the airfield (Fig. 1) [9]. The engine parameters are shown in Table 1.

Figure 1. TWD-10 B/PZL-10S engine on PZL M28 „Bryza" aircraft [9]

Table 1. Basic parameters of TWD-10 B/PZL-10S engine [10].

Power for start parameters	705 kW (960 KM)
Engine weight	$230^{+2\%}$ kg
Hartzell propeller	HC-B5MP-3D/M 10876 ANSK
Propeller type	Pulling with variable pitch with the possibility of switching to the reverse and setting into a flag Direction of rotation: right Number of blades: 5 Flag: 79°
max reverse	-14°
Maximum rotational speed of the propeller	1700 rpm
Rotational speed of the propeller	Flag: max 400 rpm Reverse: 1650 rpm

The results from the stationary engine test of the PZL M28B "Bryza" aircraft are presented in Table 2.

Table 2. Results of tests of emission intensity of harmful exhaust gases in the stationary TWD-10 B/PZL-10S engine test

	CO_2 [g/s]	CO [g/s]	NO_X [g/s]
Taxi	10,8	0,00133	0,000129
Start parameters	38,0	0,00173	0,000877
Revolutions 60%	22,9	0,00128	0,000426
Revolutions 90%	22,7	0,00167	0,000347
Reverse	18,0	0,00272	0,000202

To estimate the actual emission during the flight, an algorithm was implemented. In the first step of the algorithm, 6 flight phases were identified from the data obtained from the on-board flight recorder: taxi warm-up phase [I], start phase [II], climb phase [III], flight phase [IV], landing approach phase [V], braking and reverse phase [VI] (Fig. 2). The parameter binding results from a stationary engine test and the actual emission of harmful exhaust compounds is the setting of the engine power control lever.

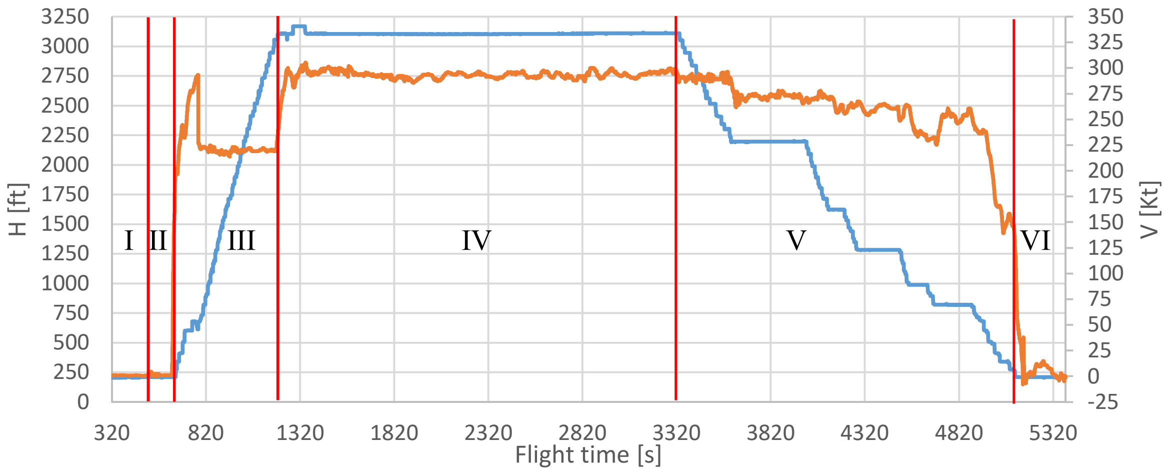
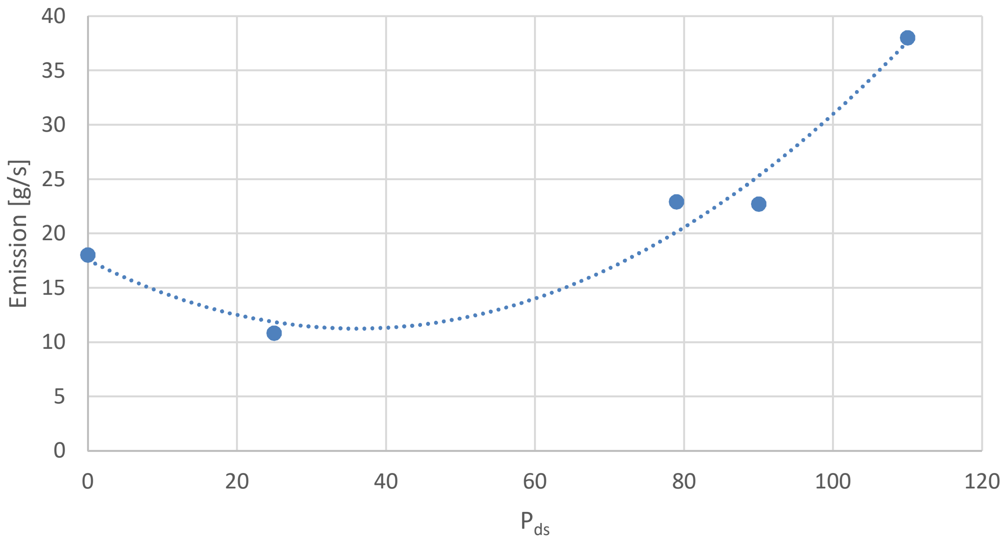


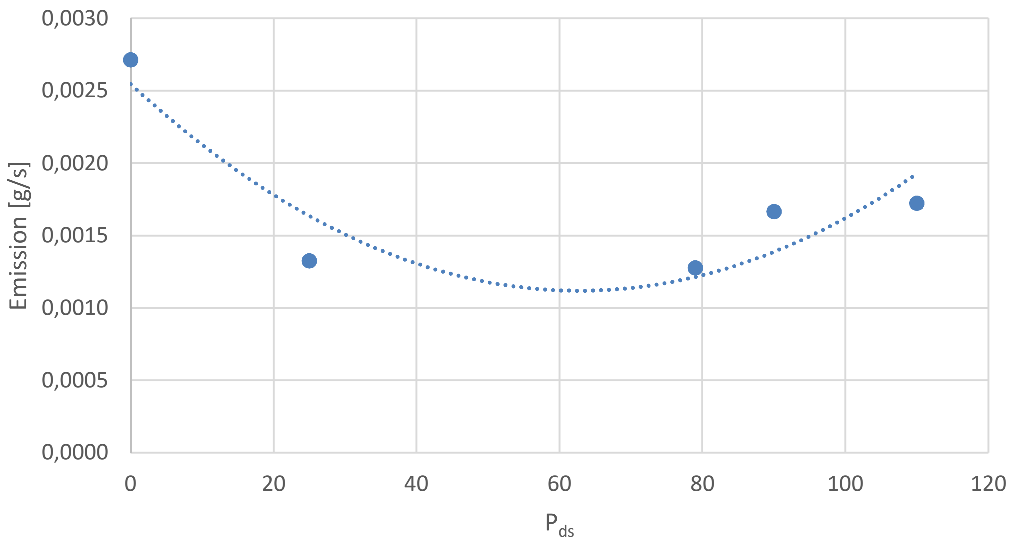
Figure 2. The division into flight phases according to the data from the on-board recorder: H - barometric altitude, V - instrument speed

The next step of the algorithm was to determine the average setting values of the engine power control levers for individual phases of the PZL M28B "Bryza" aircraft flight. The setting values were successively: I 36.63%, II 105.25%, III 87.30%, IV 86.5%, V 75%, and VI 31.2%. The key step in the proposed algorithm is to determine the function describing the emission value of the harmful compound obtained during a stationary test from the setting of the engine power control lever P_{ds} (Fig. 3-5).



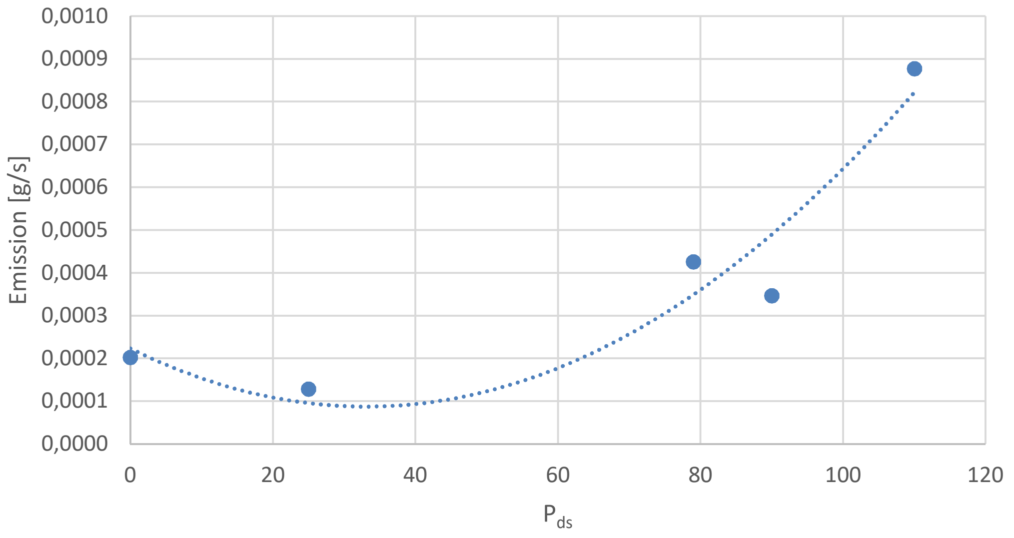
$$E_{CO2}=0{,}0048\cdot P_{ds}^{2}-0{,}3497\cdot P_{ds}+17{,}574$$
$$R^2 = 0{,}9603$$

Figure 3. The graph and the equation of the function describing the CO_2 emission values as a function of the engine power control lever setting P_{ds}



$$E_{CO}=4E\text{-}07\cdot P_{ds}^{2}-5E\text{-}05\cdot P_{ds}+0{,}0025$$
$$R^2 = 0{,}8158$$

Figure 4. The graph and the equation of the function describing the CO emission values as a function of the engine power control lever setting P_{ds}



$$E_{NOx}=1E\text{-}07 \cdot P_{ds}^2 - 8E\text{-}06 \cdot P_{ds} + 0{,}0002$$
$$R^2 = 0{,}9101$$

Figure 5. The graph and the equation of the function describing the NO_x emission values as a function of the engine power control lever setting P_{ds}

The emission of harmful exhaust gases in individual phases of flight was calculated using the equations of functions determined in the previous step of the algorithm. The algorithm described above allows linking the results of emissions of harmful exhaust gasses from a stationary engine test with data from the flight data recorder, which allows estimation of the actual emission during the flight of the aircraft.

3. Results

The algorithm used to determine the actual emission of harmful exhaust gases during the flight of the PZL M28B "Bryza" aircraft made it possible to determine the emission values for individual phases of flight (Fig. 6-8). To estimate the actual emissions of harmful compounds for particular phases of flight it is required to determine the duration of a given phase (Fig. 2).

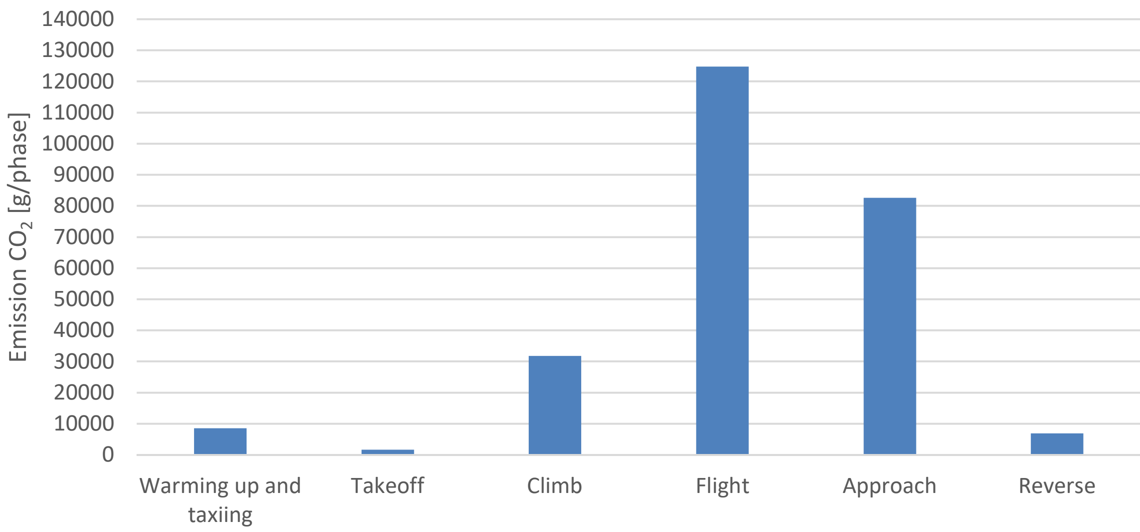


Figure 6. CO_2 emission values for individual phases of flight

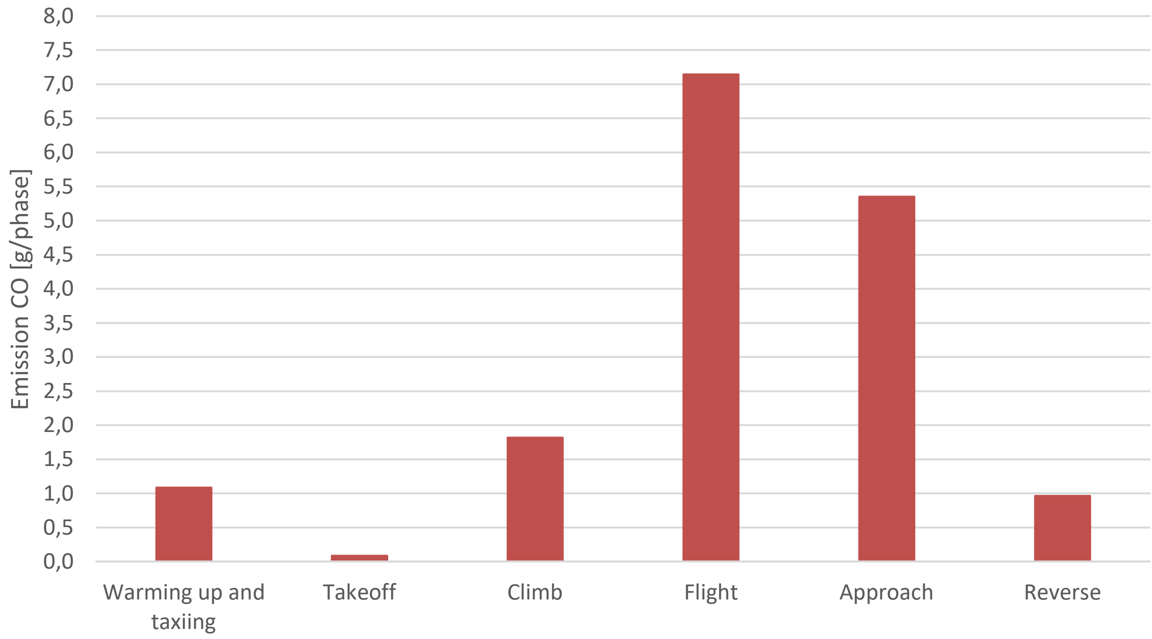


Figure 7. CO emission values for individual phases of flight

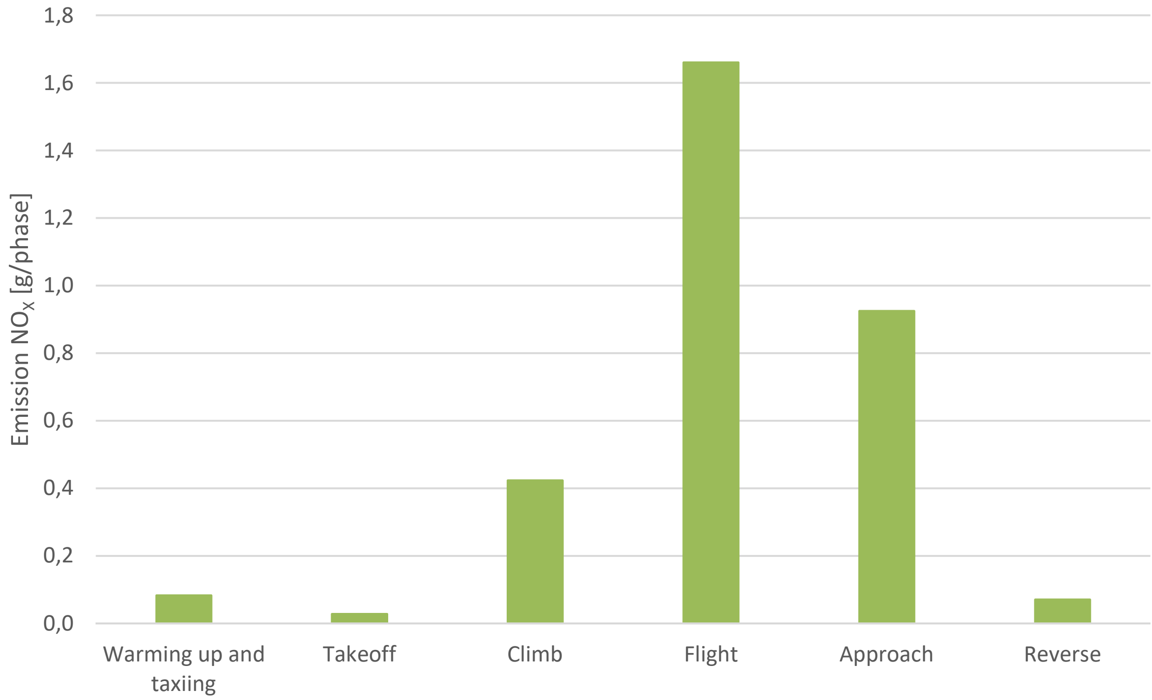


Figure 8. NO_x emission values for individual phases of flight

Data of the determined values of actual emissions of particular exhaust gas compounds made it possible to estimate the total emissions during the execution of the air operation of the PZL M28B "Bryza" aircraft (Fig. 9).

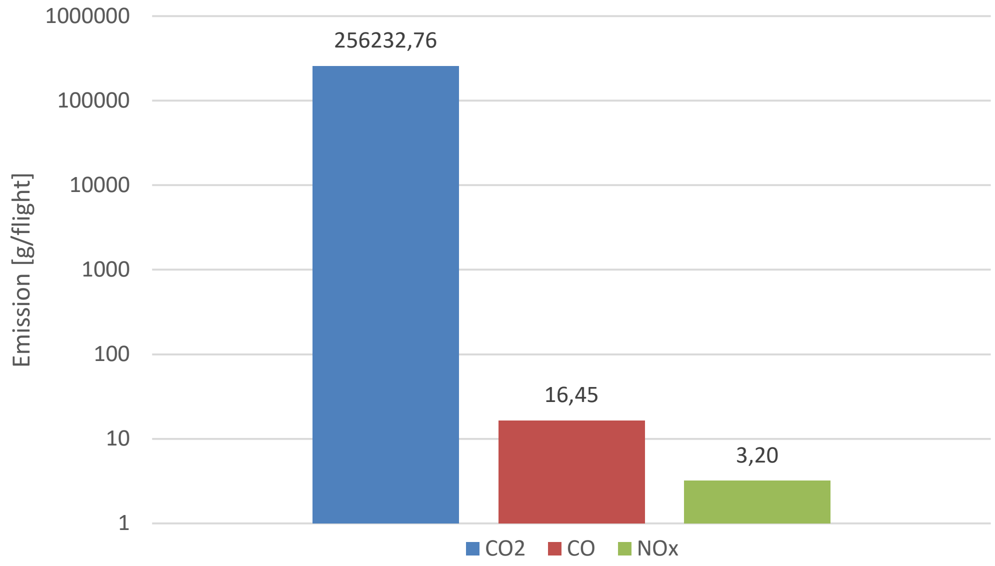


Figure 9. Emission values of harmful exhaust compounds of the PZL M28B "Bryza" aircraft

The values of harmful exhaust emission of an aircraft depend on the duration of individual phases. In order to compare and determine which of the phases is the greatest threat during the operation of the aircraft's propulsion, the values of the emission intensity of harmful exhaust compounds were determined as the emission value for one second of a given flight phase (Fig. 10).

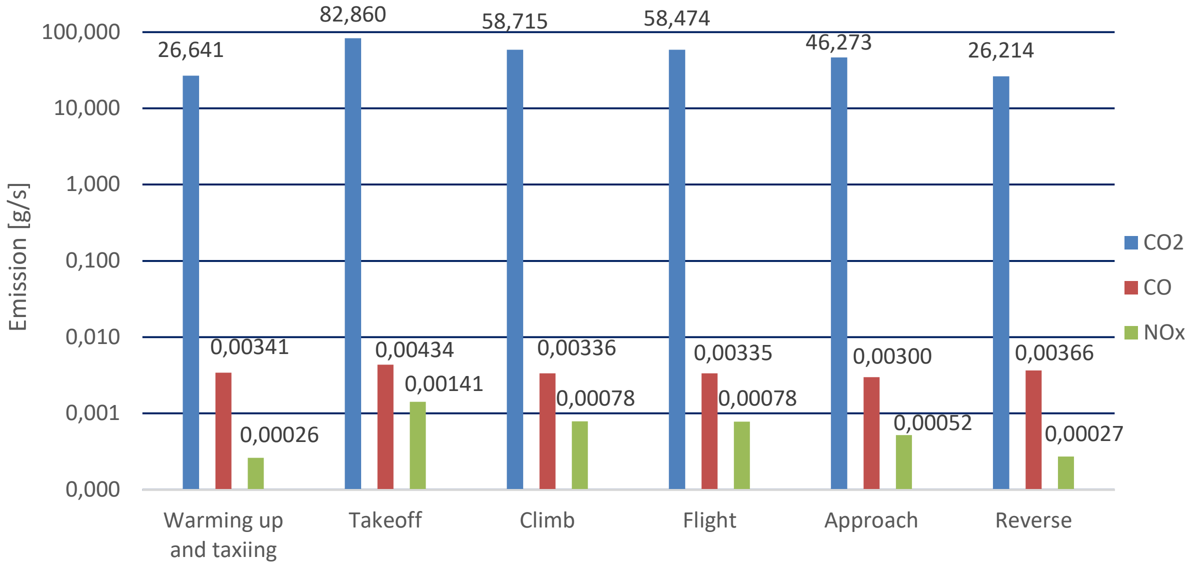


Figure 10. The intensity of harmful exhaust compounds emissions of PZL M28B "Bryza" aircraft for individual flight phases

4. Conclusions

The algorithm proposed in this article allows us to estimate the emission of harmful exhaust compounds of turboprop air propulsion for the actual flight conditions of the aircraft, by correlation of results of stationary tests of engines with data obtained from the aircraft flight recorder. The highest value of the emission intensity of harmful compounds of aircraft engines was determined for the aircraft's take-off phase. This is due to the engine load and the need to obtain maximum starting power. However, when considering the total emission, the emission values are smaller than the others, because this phase lasts relatively short compared to the remaining phases of the flight. The largest emission is characterized by the phase of the plane's flight at a given ceiling. This is due to the longest duration of this phase. Then, the highest emission stage of the flight is the approach to landing and ascent. The highest emission values among the tested harmful compounds were obtained for carbon dioxide. Values of carbon monoxides and nitrogen oxides emission are significantly lower than CO_2. In conclusion, the above article shows the most important components and the process of creating an algorithm used to assess the actual emission of harmful compounds of an aircraft engine during a flight. There is a real need to create tools for evaluating the emissions of individual harmful exhaust gas compounds, which the above algorithm allows.

5. References

[1] Jasinski R, Pielecha J and Markowski J 2016 Emission of particulate matter during aircraft landing operation. *E3S Web of Conferences* Volume: 10 Article Number: UNSP 00030

[2] Khadilkar H and Balakrishnan H 2012 Estimation of aircraft taxi fuel burn using flight data recorder archives. *Transportation Research Part D: Transport and Environment* Volume: 17 Issue: 7 p. 532-537 DOI: https://doi.org/10.1016/j.trd.2012.06.005

[3] Kotlarz W 2003 Turbinowe zespoły napędowe źródłem skażeń powietrza na lotniskach wojskowych. *Wyższa Szkoła Oficerska Sił Powietrznych*. Dęblin

[4] Koudis GS, Hu SJ, North RJ, Majumdar A and Stettler MEJ 2017 The impact of aircraft takeoff thrust setting on NOX emissions. *Journal of Air Transport Management* Volume: 65 p. 191-197 DOI: 10.1016/j.jairtraman.2017.06.009

[5] Markowski J, Pielecha J and Jasinski R 2017 Model to assess the exhaust emissions from the engine of a small aircraft during flight. *Procedia Engineering* Volume: 192 p. 557-562

[6] Merkisz J, Markowski J and Pielecha J 2013 Emission tests of the F100-PW-229 turbine jet engine during pre-flight verification of the F-16 aircraft. *WIT Transactions on Ecology and the Environment* Volume: 174 p. 219-230

[7] Merkisz J, Markowski J and Pielecha J 2012 Exhaust emissions from the PZL W-3 Sokol helicopter based on the measurements of the concentrations of exhaust components in the exhaust gases during a pre-flight test. *IEEE Vehicle Power and Propulsion Conference VPPC* p. 897-902

[8] Merkisz J and Pielecha J 2015 Nanoparticle Emissions from Combustion Engines. *Springer Tracts on Transportation and Traffic* 8

[9] Merkisz J, Markowski J, Pielecha J, Mikutel T and Kozłowski R 2010 Badania emisji silnika TWD-10 B/PZL-10S podczas próby silników samolotu PZL M28B Bryza. *Zeszyty Naukowe WSOWL* ISSN 1731-8157 Nr 4 (158)

[10] Instrukcja eksploatacyjna samolotu M28 „Bryza”

[11] Opinia Europejskiego Komitetu Ekonomiczno-Społecznego z dnia 28 lipca 2009 roku w sprawie *„Europejski sektor lotniczy: stan obecny i perspektywy”*

[12] ICAO 2011 Airport Air Quality Manual