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Model to assess the exhaust emissions from the engine of a small aircraft during flight

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Abstract

Evaluation of the exhaust emissions from aircraft engines applies to turbine engines with high values of thrust and power. This assessment is conducting on the basis of the guidelines contained in the standards introduced by ICAO Annex 16. It concerns the procedure for stationary tests according to the Landing/Take-off cycle (LTO). This test includes operating parameters of the engine corresponding to approach, landing, airport operations and take-off. Such procedures do not apply to small aircraft with piston engines. Therefore, a number of research and testing of exhaust emissions from aircraft piston engines were made. On the basis of these works, model to determine the exhaust emissions from piston engines during the flight of the aircraft was developed. The model is presented in this article.

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1. Introduction

To improve environmental performance of general aviation propulsion systems based on piston engines it is necessary to develop more innovative technologies. The starting point in this respect is an analysis of gaseous emissions of hazardous compounds contained in exhaust gases in terms of the performance of piston engines. In the case of small aircraft propelled with piston engines, no efforts at investigating in-service exhaust emissions had been

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taken until 2007, mostly because the available measurement equipment was too large. By now the said issue has not been fully solved and analysis of hazardous emissions from aviation piston engines in actual operating conditions is possible only for airplanes providing enough space and capable of carrying the weight of the instrumentation. Therefore, emission models must be developed in order to identify emissions of hazardous compounds from small aircraft.

Currently there exist few solutions for modeling hazardous substances emitted in exhaust gases from aircraft propelled with piston engines, and their characteristics are closely related to the landing and take-off cycle (LTO) test provided for in ICAO standards for assessing emissions from large aircraft with turbine engines [4,11,12,13,14,15,16]. The LTO test models emissions in the airport area and excludes the flight phase.

Available literature presents existing models for hazardous emissions in exhaust gases from other means of transportation. The presented characteristics of total emissions models are approximations over a range of considered physical values of empirical tests. Therefore, the most difficult task consists in providing reliable data for analyzing the emission model, particularly because of the high degree of generality of official transportation statistics [1,2,3,6,7,8,9,10]. Therefore, emission models are too imprecise, and inaccuracies in the model's parameters are multiplied when determining the final values. Therefore, this publication aims at developing hazardous compounds' emission models dedicated to small general aviation aircraft with piston engines as well as at identifying their in-service emission of hazardous gaseous compounds contained in exhaust gases.

2. Pollutants emission models

Identification was made with regard to the inputs into models used for calculating the mass of pollutants emitted by aircraft. On that basis it was determined that of key importance are the values of specific emissions of each compound (e_j) obtained in the proposed test, as well as engine power (N_e) and flight duration (t_{fly}).

$$m_j = e_j \cdot N_e \cdot t_{fly} \tag{1}$$

where:

- m_j – mass of the exhaust gas compound j [g],
- e_j – specific emission of the exhaust gas compound j [g/kWh],
- N_e – effective power resulting from a given load [kW],
- t_{fly} – flight duration at a given load [h].

Therefore, the model needs to include such values as the duration of each flight phase, flight altitude, ascending velocity upon take-off and descending velocity upon landing. The duration of each operation phase is of key importance for mass modeling because together with engine operation parameters (engine speed and load) they directly affect the concentration of pollutants in exhaust gas and the mass of exhaust gas ejected from the engine. Therefore, the modeling exercise should begin with searching for a method of identifying the relative share of flight phases in the entire flight duration. When identifying flight phases one can assume that the flight duration t_{fly} is the sum of take-off and ascent times t_{asc}, steady flight time t_{steady}, and descent and landing time t_{land}, as shown by the following equation:

$$t_{fly} = t_{asc} + t_{steady} + t_{land} \ [s] \tag{2}$$

Take-off and landing times depend on the airplane's performance, as well as on the airport's procedures for ascent after take-off and approaching to land. In commercial airports and for operational flights, these times are typically shorter than one hundred seconds and do not represent a major share in the entire flight duration. In the case of training flights, usually being shorter and involving smaller altitudes, the absolute durations of those flights are similar, but their share in the overall flight duration is significantly greater. Therefore, it is necessary to develop pollution mass models featuring a division of the entire flight duration into individual phases.

The duration of take-off time depends on the airplane's design and performance, i.e. the design of the airframe determining the minimum take-off velocity and the design of propulsion system, determining the airplane's