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The Exhaust Emission Tests of a Zlin–142 M Aircraft

Abstract: Due to a rapid development of air transport there is a need for assessment of real environmental perils related to the aircraft operation. The main environmental risks are the products of incomplete combustion contained in the exhaust gases. The paper presents the results of the emission tests of a Zlin–142 M under the stationary test conditions.

Key words: *exhaust pollutants, exhaust emissions, research, piston aircraft engine*

1. Introduction

For many years transport as one of the basic fields of economy has been characterized by a continuous development. This is particularly conspicuous on the example of the emerging markets. As the society gets wealthier more branches of transport get developed. On the example of Poland we can see certain cause and effect relations. As of the moment of Poland's accession to the European Union several job markets were opened to Poles. This resulted in a sudden demand for a fast, long-distance means of transport. Initially coach connections between larger European cities were very popular, yet as the society grew richer with the money earned outside of Poland the time of travel became more important. Air transport became high in demand. In a short time in regional airports direct connections between several European cities were initiated and new carriers began their operations in Poland. Mutual competitiveness of the operators only added to the reduction of the prices of air tickets, which again resulted in a greater interest in such a form of transport. Aviation as a means of transport is tightly related to the economic situation in the country level and worldwide, which was well confirmed by the last economic crisis. A less

noticeable but, nonetheless, important general aviation is also characterized by a dynamic growth. The growing wealth in the population, the specificity of the economic activities and the revaluation of the economic factors as well as the ever-growing value of time and at the same time still obsolete and insufficient land transport infrastructure facilitates the development of this type of air transport. The demand for general aviation air transport almost directly translates into the growth of the number of aircraft. This however has impact on the natural environment. Still the emission of carbon dioxide and particulate matter is a serious threat, which is a barrier in the development of modern combustion engines. Current legislation on the influence of air transport on the environment as introduced by EPA (Environmental Protection Agency), ICAO (International Civil Aviation Organization) contained in JAR 34 (Joint Aviation Requirements), FAR 34 (Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes) are chiefly related to the emission of noise and other exhaust emissions particularly nitric oxides. These regulations pertain to flow machines and describe stationary tests depending on the engine operating conditions. The said standards do not pertain to piston aircraft engines.

Due to the differences in the combustion processes between piston and turbine engines we should expect the exhaust emissions from a piston engine to be greater than those of a turbine engine. A significant growth in the number of general aviation aircraft in use could constitute a serious threat to the natural environment.

Current level of measurement technology related to the testing of exhaust emissions allows a performance of the said test under real operating conditions of the tested objects [1–7]. Such tests allow determining of the level of exhaust emissions of individual exhaust components under real operating conditions. Besides, they allow an assessment of the specificity of operation of a given means of transport in terms of time density of engine loads. Such information allows determining of the operation states of the drivetrain along with their share in the total operation time. The possibilities of usage of portable testing devices become particularly important in the tests of small aircraft under real operating conditions. Unfortunately, it is not possible for all the small aircraft cases. The mass of the admissible load that the plane can lift and the cargo space are decisive here. That is why it is vital that a testing procedure be developed for small aircraft that will allow an evaluation of the exhaust emission of aircraft in a stationary test performed on the runway.

2. Testing methodology

2.1. Tested object

The exhaust emissions tests were carried out for a Zlin–142 M (fig. 1) aircraft fitted with Avia M

337 AK supercharged (fig. 2). The Zlin–142 M aircraft parameters have been listed in table 2.

Fig. 1. Zlin–142 M [8]

Fig. 2. The engine - Avia M 337 AK supercharged (M 337 C) [10]

Table 1

Technical specifications Zlin–142 M [9]

Version	Zlin–142 M
Wingspan	9.16 m
Length	7.33 m
Height	2.75 m
Wing area	13.30 m^2
Max. take-off weight	1 090 kg
Engine	Avia M 337 AK supercharged (M 337 C)
Engine power	156 kW / 3000 rpm
Maximum speed	230 km/h
Cruising speed	215 km/h
Minimum velocity	102 km/h
Propeller	Avia V-500A two bladed constant speed

A significant meaning for the exhaust emissions measurement from aircraft engines has the engine design, its technological level, quality of workmanship,

let alone the engine wear. The tested Zlin–142 M was fitted with a 5.970 dm3, air-cooled, flat 6-cylinder spark ignition piston engine - Avia M 337 AK supercharged (M 337 C).

For the needs of the exhaust emissions tests the exhaust system was extended by 4 meters. This enabled the measurement to be realized in a spot where the measuring probe could be easily fitted (fig. 3).

Fig. 3. The fitting location of the measuring probe

2.2. Measurement equipment

The aim of the tests was to evaluate the exhaust emissions from the aircraft as it was stationary on the runway under conditions closest to the real operating ones. For the measurement of the concentrations of the exhaust components a portable analyzer SEMTECH DS by SENSOR was used (fig. 4).

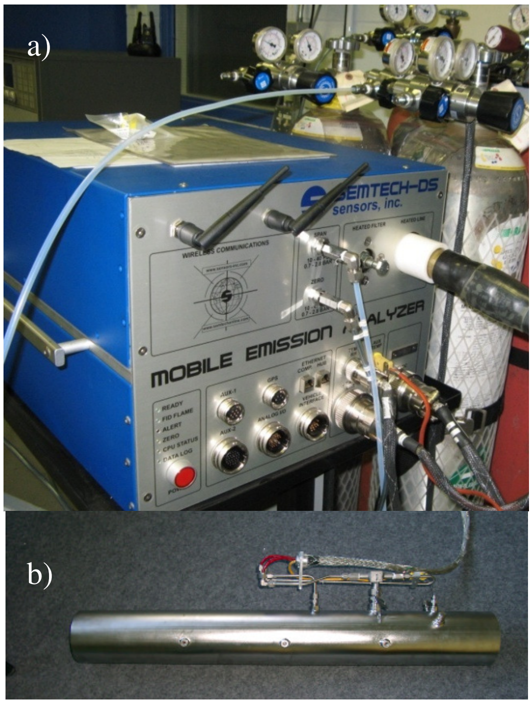

Fig. 4. The view of the exhaust emission analyzer (a) and the measuring probe for mass exhaust flow (b)

The analyzer measures the concentrations of exhaust components (table 2) at the same time measuring the mass exhaust flow. The exhaust gases are introduced into the analyzer through a probe that maintains the temperature of 191°C (fig. 4) and then they are filtered out of the particulate matter (diesel engines only) and the measurement of hydrocarbons takes place in the flame ionizing detector. The exhaust gases are then cooled down to the temperature of 4°C and the concentrations of nitric oxides (non-dispersive ultraviolet – measures nitric monoxide and nitric dioxide), carbon monoxide, carbon dioxide (non-dispersive infrared) and oxygen (electrochemical analyzer) are measured. To the central processing unit of the analyzer we can connect data links from the OBD and GPS systems, which, however, was not necessary in the tests presented in this paper.

Table 2

The characteristics of the portable analyzer SEMTECH DS

Parameter and Measurement method	Accuracy
1. Concentrations in the exhaust gases	
CO NDIR – non-dispersive (infra-red) range 0–10%	±3%
HC FID – flame ionization range 0–10 000 ppm	±2.5%
$NO_x = NO + NO_2$ NDUV – non-dispersive (ultraviolet) range 0–3000 ppm	±3%
CO_2 NDIR – non-dispersive (infra-red) range 0–20%	±3%
O_2 Electrochemical - range 0–20%	±1%
Sampling frequency 1–4 Hz	
2. Exhaust flow	
Mass exhaust flow	±2.5% of the range
T_{max} up to 700°C	±1% of the range

3. The results of the measurements

The measurements of the exhaust emissions from the Avia M 337 AK supercharged (M 337 C) engine fitted in Zlin–142 M were performed at an airport in a stationary test. In the standard course of the flight of the aircraft we can distinguish several phases. These are: taxi, takeoff, climb, steady flight phase, approach to landing, landing and taxi. Depending on the performed task the time share of individual flight phases in the flight differs. For the realization of the tests in the stationary conditions three test phases were selected: I – taxi, II – takeoff, III – cruise/steady flight (the settings of the engine and propellers were as under real flight operating conditions). Additionally, the exhaust emissions during engine startup were measured. The obtained results have been presented in table 3 and graphs (fig. 5–9).

Table 3

The measurement results of the exhaust emissions from the Avia M 337 AK supercharged (M 337 C) engine

Parameter	Flight phase			
	Startup	Taxi	Takeoff	Cruise
Speed [rpm]		1200	2600	2400
Duration [s]	94	229	67	61
Average concentration				
CO [%]	3	4	5.5	2.5
HC [ppm]	1500	1000	1200	700
NO_x [ppm]	50	60	330	500
CO_2 [%]	5	5.2	7	9.5
Emissions [g]				
CO	188	538	432	183
HC	16,8	7.4	5.8	2
NO_x	0.26	0.8	3.8	5.2
CO_2	394	1072	992	1276
Hourly emissions [g/h]				
CO	7208	8458	23 212	10 847
HC	643	116	312	118
NO_x	10	12,6	204	307
CO_2	15 089	16 852	53 301	75 305

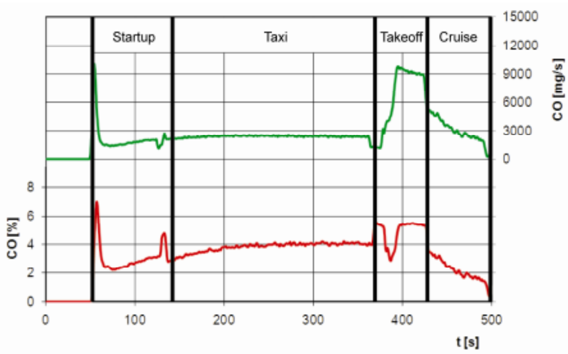

Fig. 5. The measurement of carbon monoxide during the tests

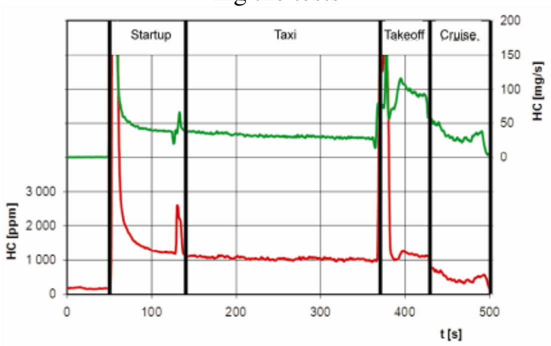

Fig. 6. The measurement of hydrocarbons during the tests

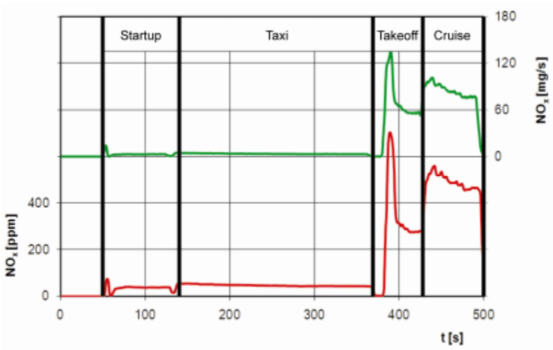

Fig. 7. The measurement of nitric oxides during the tests

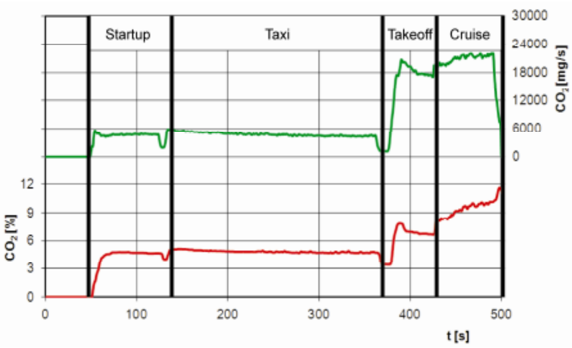

Fig. 8. The measurement of carbon dioxide during the tests

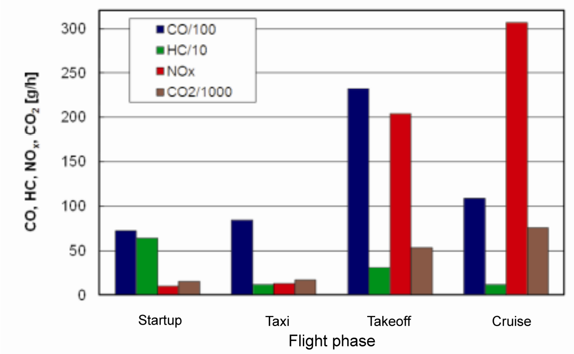

Fig. 9. The average hourly emissions of the exhaust components

4. Conclusions

The performed investigations and the analysis of the obtained results confirm the significant influence of many parameters related to the ideas of fueling of piston aircraft engines on the exhaust emissions. The paper indicates great dependence of the concentrations of the exhaust components on the operating conditions of the engine, which are tightly related to the operating conditions of the plane, realized plane trajectory, pilot's driving style, his skills and particularly the appropriate selection of the fuel air mixture. The composition of the air fuel mixture significantly affects the exhaust emissions as it directly influences the course of combustion in the cylinder, thus generating mutual relations between the emission of hydrocarbons and nitric oxides. These relations are particularly visible on the example of emissions of these components in the takeoff and cruise phases.

The performed investigations are to be treated as preliminary of an explorative nature. The analysis of the obtained results indicates a serious issue of an increased concentration of carbon monoxide and hydrocarbons in the whole range of the engine operation. These results should be correlated with the results obtained for the aircraft of the same type but fitted with an engine of a newer generation.

The obtained information could be used to develop and validate testing procedures for small aircraft that do not have sufficient cargo capacity to be fitted with specialized, full-sized measuring devices. Eventually, the realization of this type of tests could help develop universal testing procedures for the measurement of the emission level of small aircraft and their impact on the natural environment.

Nomenclature

CO	Carbon monoxide
CO_2	Carbon dioxide
EPA	Environmental Protection Agency
FAR	Fuel Venting and Exhaust Emission Requirements
HC	Hydrocarbons
ICAO	International Civil Aviation Organization
JAR	Joint Aviation Requirements
NO_x	Nitric oxides

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