In last years increase number of aircrafts makes a lot of benefits, but they have also brought negative effects. This is mainly due to an increase of air traffic noise and increase of toxic gases emissions. Substances emitted from the main aircraft engines are carbon dioxide CO₂, unburned hydrocarbons HC, carbon monoxide CO, nitrogen oxides NOₓ, particulate matter PM (mainly soot and heavy hydrocarbons in the liquid state). The exhaust gases from engines of this type can be divided into three basic groups: natural products of fuel combustion (CO₂, H₂O), products of incomplete combustion (CO, HC, NOₓ (indirectly)) and products of imperfect combustion (PM, PN). The study attempts to test LTO emissions for turbine engine model GTM-120, which is research equipment in the Department of Internal Combustion Engines, Working Machines and Transportation Poznań University of Technology.

Keywords: emission testing, turbine engine, exhaust compounds

1. INTRODUCTION

Air transport is the youngest and most dynamically developing branch of transport. Increased demand for air transport for passengers and commodity is caused by the competitiveness of this industry primarily in terms of time and transport safety. Boeing, one of the world leaders in the manufacture of aircraft, in 2009 report predicts that by 2029 the number of aircraft almost doubles compared to 2009 [4]. The rapid increase in the number of aircraft is also spectacular in-
crease in the number air transport, this will generate growth of the negative impact of air transport on the environment. In order to reduce the negative impact of transport implementes standards and limitations for the assessment of the current level of emissions.

Increasing number of housing building development surrounding airports and the ongoing development of air transport is an important problem of air pollution around airports. Concerns about the local environment deal with the effect during landing and take-off operations when pollution from aviation are staying in the areas of society.

2. MEASUREMENTS OF EXHAUST EMISSION FROM TURBINE ENGINES

Aircraft engines are characterized by a variable emission of toxic and harmful substances in different cycles. The emission standards for jet engines is determined relative to the LTO cycle (called landing and take-off cycle), which is the standard cycle take-off and landing. This cycle can be classified into four steps [1, 2]:
- take-off,
- climb,
- landing,
- taxi/ground idle.

During standard LTO cycle engine test must be carried out for thrust setting necessary to determine the emissions of harmful exhaust gases and smoke from the engine so that size of mass emissions and smoke can be specified for characteristic percentages thrust nominal value, in accordance with the act of public authority certifying the aircraft. During the first stage of the motor is running using 100% of engine thrust. This stage is characterized by the lowest emission of unburned hydrocarbons (HC) and carbon monoxide (CO) as well as the largest emissions of nitrogen oxides NOx. Climbing step (No. 2, Fig. 1) is only slightly different from the start. Engine is running at a slightly weaker parameters, but it doesn’t change significantly the structure of emission. During landing step (No. 3, Fig. 1), engine works using about 30% of maximum thrust. There is much higher emissions of CO and HC than during take-off or climb. In the last-mentioned step – taxiing (No. 4, Fig. 1) – engine is operating under a value about 7% of maximum power.

The emission values in Fig. 1 are presented in form of EI emission (emission index). The emission factor is a value of emissions which is related to the unit quantity of the processed raw material. In this case, the unit [g/kg] means grams of compound per kilogram of fuel burned.
Fig. 1. Indicative course of changes in emission: EICO, EIHC, EINOx, with respect to the thrust. The following markings are applied four distinctive stages of engine work: 1 – start, 2 – climb, 3 – landing, 4 – taxi [1]

3. RESEARCH METHOD

Ability to perform the test was verified on model turbine engine GTM-120. The test engine is composed of a single-stage radial compressor, driven by means of a single-stage axial turbine. The GTM-120 engine uses annular combustion chamber and the fuel is supplied to the spray nozzles. The start-up of this engine is done by electric starter. To start the engine is used the electric starter. During startup, the engine is powered by LPG. After obtaining the appropriate thermodynamic parameters it switches to the proper fuel supply.

<table>
<thead>
<tr>
<th>Parameters of model turbine engine GTM 120 [3, 6]</th>
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<tbody>
<tr>
<td>Static thrust [N]</td>
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<tr>
<td>The minimum rotational speed of the turbine shaft [rpm]</td>
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<tr>
<td>The maximum rotational speed of the turbine shaft [rpm]</td>
</tr>
<tr>
<td>Weight of the engine [g]</td>
</tr>
<tr>
<td>Proper fuel</td>
</tr>
<tr>
<td>Fuel consumption [g/min]</td>
</tr>
<tr>
<td>Engine dimensions [mm]</td>
</tr>
<tr>
<td>Engine mass flow rate [kg/s]</td>
</tr>
</tbody>
</table>
On the test bench (Fig. 2) control electronics kit is installed, which task is the realization all the control functions including automatic engine start-up and cooling. Engine management is realized by controlling the fuel pump output. On the test bench are measured: rotational speed of the motor shaft, the exhaust gas temperature at the propelling nozzle and engine thrust. This engine reaches the maximum thrust at 120 N at the pressure ratio of about 2.1, and the air flow in the range of 0.3 kg/s at fuel consumption 340 g/min. Due to the small size the engine has a low efficiency, which is about 3.4%. The maximum rotational speed of the turbine shaft is 120 000 rpm, and the minimum 33 000 rpm. The values of the technical parameters of the engine are summarized in Table 1.

For the measurement of the concentrations of the exhaust components a portable analyzer TESTO 360 was used. The analyzer measures the concentrations of exhaust components such as: nitric oxides (NO\(_x\)), carbon monoxide (CO), carbon dioxide (CO\(_2\)) and hydrocarbons (HC). The integrated mobile computer enables saving data in memory and their processing. During performing the test a measurement probe was located at the engine outlet. This solution is necessary due to the high excessive heat which might damage the analyzer.

Appendix 16 to Convention on International Civil Aviation Organization ICAO precisely defines the procedures for the LTO test for measuring emissions from the gas turbine jet engines with a thrust above 26.7 kN [5].

In addition to setpoints the percentage of maximum engine power is also specified at the time of measuring each of the parameters. For the assessment the possibility of adapting the test for the model turbine engine, these times
were proportionally reduced. Table 2 shows the durations of the standard tests and durations of tests adopted for research.

Table 2

Summary of the durations of the individual phases of the LTO cycle contained in ICAO Annex 16, together with durations and engine setpoints adopted for research

<table>
<thead>
<tr>
<th>Phase</th>
<th>STANDARD (Appendix 16 ICAO)</th>
<th>RESEARCH (GTM-120 Engine)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thrust [%]</td>
<td>Operating time [min]</td>
</tr>
<tr>
<td>Start</td>
<td>100</td>
<td>0.7</td>
</tr>
<tr>
<td>Climb</td>
<td>85</td>
<td>2.2</td>
</tr>
<tr>
<td>Approach</td>
<td>30</td>
<td>4.0</td>
</tr>
<tr>
<td>Taxi/ground idle</td>
<td>7</td>
<td>26.0</td>
</tr>
</tbody>
</table>

4. ANALYSIS OF THE RESEARCH RESULTS

In order to evaluate exhaust emission from a model turbine engine a chart which shows the lines representing the concentrations of exhaust emission compounds has been prepared (Fig. 3). The figure includes the phase of the LTO cycle time ranges adopted for the purpose of testing.

Fig. 3. The concentration of exhaust emission compounds in test
The first phase of the LTO cycle requires 100% of the thrust, which in studies was 120 N. In this step, the engine operates with the parameters required for take-off and has the lowest emission of HC and CO, which results from a good mixing of fuel and air, the optimum air fuel ratio in the combustion zone and the high pressure and temperature at the inlet to the combustion chamber. The engine parameters for the take-off phase cause an increase in NO\textsubscript{x} emission to a maximum value which is result of high mixture temperature in the combustion zone. This stage is also characterized by the highest concentration of carbon dioxide caused by the largest fuel consumption [g/s] compared to other phases of the LTO cycle.

The second stage of the cycle, which is the phase of the aircraft climb shows the changes in the values of the concentrations of exhaust emission caused by reduced of thrust value to 85% of the maximum value (102 N). The second stage of the cycle, which is the climb phase shows changes in values concentrations of exhaust emissions. The reason of that was 15% reduction of thrust (to 85% of the maximum value equals 102 N). In the combustion chamber is still an optimal air excess factor and a good mixing of fuel and air. Concentration of carbon monoxide and hydrocarbons decreased slightly in compared to the value, which obtained for the take-off phase. When the engine was working with the parameters set for the climb phase observed decrease in the concentrations of nitrogen oxides, which was caused by a reduction in exhaust gas temperature. Temperature profile of the exhaust gas from model turbine engine is shown in Fig. 4.

The approach phase, which is the next stage of studies in accordance with the LTO cycle require a reduction in the thrust value to 36 N. In this phase the inlet pressure to the combustion chamber was reduced. There was also fuel depletion. Under these conditions, there might be areas of uneven fuel concentration. The result was deterioration of the conditions of combustion fuel mixture and an increase in CO and HC emissions. The lower temperature of the gases in the combustion zone in relation to the take-off and climb phase resulted in a decrease in the NO\textsubscript{x} emission.

![Fig. 4. Exhaust gas temperature in dependence on the engine thrust [3]](image-url)
In the last phase the engine worked at 7% of the maximum thrust. There is a large increase in the concentrations of CO and HC. Concentrations of NO\textsubscript{x}, which was obtained for this phase of the cycle were similar to values at maximum thrust. Changes in temperature measured in the propelling nozzle confirm the validity of the values obtained concentrations of nitrogen oxides. High temperature of exhaust gases and the related high level of NO\textsubscript{x} at the low engine thrust was caused by the low mass flow rate. The further values of the exhaust gas temperature results from the characteristics of the compressor and gas turbine.

The total concentration of exhaust emission compounds for each phases of the LTO cycle shown in Fig. 5. During the tests was obtained the highest total concentration of exhaust emission compounds for thrust settings specified for taxiing and idling phase. The values obtained for this phase is the result of the longest phase in the LTO cycle. In this phase the engine had the greatest of demand on fuel and worked at the low rotational speed of turbine shaft. The turbine engine which works at the settings specified for the taxiing and idling phase is characterized by low efficiency and high specific fuel consumption.

5. SUMMARY

Emissions from aircraft engines is released mainly at altitudes above 1000 m, but the impact of emissions at ground level is essential due to the location of airports, mostly bordering the large urban agglomerations. This confirms the appropriateness of introducing emissions regulations focusing on air quality around airports. In the conducted emission test LTO confirmed the adverse im-
impact of a jet engine parameters corresponding to obtain a small amount of force within.

In addition to improve the overall environmental air propulsions through the use of modern turbofan design, characterized by a less fuel and at the same lower emissions, it is necessary to search for alternative solutions to traditional aviation operations. If implemented to the operation of modern aircraft engines it is possible to reduce emissions mainly at altitudes higher than the maximum included in the LTO cycle (3000 ft), which is why this concept does not solve the problem of the negative impact of ground movement at airports. A much more effective solution may be a changes in procedures taxiing aircraft. Taxiing supported by innovative technologies based on electric wheel drive systems can significantly reduce exhaust emissions. The main idea of this kind of technology is to reduce emissions during taxi operations, which are the longest stage in the movement area of an airport, by shortening the work time of aircraft engines in the low overall efficiency.

REFERENCES


MOŻLIWOŚĆ ODWZOROWANIA TESTU EMISJI LTO NA MODELOWYM SILNIKU TURBINOWYM GTM-120

Streszczenie

W artykule przedstawiono próbę odwzorowania testu emisji LTO na modelowym silniku turbinowym GTM-120. Badania prowadzono w Zakładzie Silników Spalinowych na Wydziale Maszyn Roboczych i Transportu Politechniki Poznańskiej. W artykule opisano pomiary wykonane w poszczególnych fazach pracy silnika, tj. start, wznoszenie, lądowanie i kołowanie. Start charakteryzował się najmniejszą wartością emisji
Evaluation of possibility to use the LTO cycle for emission test on example of… 33
