UDC 503.3.054:629.735.03 (045)

K.Ulianova, master, K.Synylo, associate professor
(National Aviation University, Ukraine)

Methods of aircraft engines emissions assessment within the airport

According to the analysis of airport emissions sources inventory, the contribution of aircraft engines emissions reaches 3% at the global level, while at the local level it exceeds 50% of the total emissions within the airport. Thus, an aircraft is a predominant source of air pollution within the airport and at adjacent territories. The problem of regional pollution is relevant for Ukraine in connection with the increasing approximation of residential areas to airports. In order to successfully solve this problem, it is necessary to organize control of the aircraft engines emissions.

Air pollution within the airport is caused by operation of stationary and non-stationary (mobile) sources. Emissions from these sources are products of fuel combustion and vaporing: nitrogen oxide (NO_x), carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (CH), benzene, soot and particulate matter with diameter 10 micrometers or less (PM_{10}, $PM_{2.5}$, $PM_{1.0}$). The paper represents the concerns of local air quality, which relates with the emissions of nitrogen oxides, carbon dioxide and particulate matter from the mobile sources, namely from aircrafts.

At the moment of aircraft operation within the airport, during the landing-takeoff cycle (LTO)-cycle 94.3 % of carbon monoxide released by the aircraft under taxiing conditions before take-off and after landing including starting andrun-up the aircraft engines. Nitrogen oxides emissions during the (LTO)-cycle are classified as stages: take-off, climbing, landing and idling. Correspondingly, they make up 26.7%, 53.6%, 10.5% and 9.2% of total NOx emissions during the (LTO)-cycle [1]. Aircraft`s emission rate depends on type and operational mode of the aircraft engines, their number, aircraft’s speed and motion direction and other operational factors.

To regulate the engines’ emission characteristics, ICAO has introduced the notion (LTO)-cycle that is limited by the altitude of atmospheric boundary layer (900 m), *table 1*[2].

Table 1.

ICAO emission standardization by the(LTO)-cycle for aircraft operation

Stage	Engine thrust,%	Duration, min
Take-off	100	0.7
Climbing	85	2.2
Landing	30	4
Taxiing	7	26

It should be noted that engine thrust in real conditions differs from certified conditions. In this case, for maximal and idling modes the real engine thrust is lower than in the ICAO database (100% and 7 % correspondingly). In addition, taxiing duration depends on airport infrastructure, so mentioned period 26 minutes is not enough reliable.

The basic methods to identify the pollutants from aircraft engines are ICAO, $BFFM_2$, P_3T_3 [3, 4]. The major methods of mass pollutants assessment (emission inventory) from aircraft engines are based on the formula (1):

$$QQ = FF\ x\ EI\ x\ T\ x\ n \quad (1)$$

where *FF* – fuel flow rate, kg/sec; *EI* – emission index, g/kg; *T* – engine operation time, sec; *n* –number of the aircraft engines .

Information on number of engines n and time *T* is available for everyone. While fuel flow rate *FF* and emission index *EI* are the most important parameters, which are not always reliable. Depending on chosen approach to assess data, there are three main methods to define the pollutant emissions from the aircraft engine (NOx, CO та HC) [3]:

- ICAO method is based on quite elementary calculation scheme and is marked by availability of initial data provided by the ICAO Bank [4].
- $BFFM_2$ method is average in terms of the complexity of calculations and availability of the necessary initial data. Calculated emission indexes are characterized by a high level of accuracy [4].
- P_3T_3 method contains quite complex calculation algorithm. It requires a series of initial data, the availability of which is very often confined to the secrecy and engine manufacturer's property (pressure (P_3) and temperature (T_3) at output the engine's combustor chamber [4].

Thus, taking into account the influence of operational (fuel consumption) and meteorological conditions (environmental temperature) on the values of the emission indexes from the aircraft engine is an important task. It provides reliable output data, in contrast to ICAO values, for further modeling of the processes of transfer and dilution of contaminants by exhaust gases jet from aircraft engines and by atmospheric turbulence.

The ICAO Doc 9889 "Airport Air Quality" [5] offers active and passive methods for instrumental monitoring. The experience of main European airports demonstrates the prevalence of spectroscopic methods.

At European airports the most popular systems of aircraft emissions measurement are FTIR spectroscopic systems (Fourier-transform infrared spectroscopy) and DOAS (Differential optical absorption spectroscopy) [6, 7, 8]. The principle of spectroscopic measurement systems is to determine the nature and characteristics of the substance, depending on the structure and properties (by number and position of the peaks) of the fixed spectrum range, and, accordingly, the concentration of the detected substances - from the intensity of absorption bands of radiation in the characteristic range of the spectrum. Thus, based on the revealed spectrums, a qualitative and quantitative analysis of an exhaust gases emission can be carried out [9].

FTIR and DOAS systems measure the pollutant concentrations in continuous mode, with a period of averaging of 3 minutes. In this case, the FTIR method captures CO and CO_2 simultaneously, and the DOAS method captures NO and NO_2

concentrations in sequential mode. The obtained results of measurement provide the identification and determination of the aircraft engines and the ground support equipment emissions contribution to airport air pollution.

The analysis of aircraft emissions at main European airports (Zurich, Frankfurt, Vienna, Budapest, Athens, and Heathrow) [6,7,9] indicates the application of the chemiluminescent method for detecting pollutant concentrations in jets from aircraft engines (gas analyzers of type AC32M or TE42CL-95/96) on the following indicators:

1. The high degree of concentration detection in time (3 s) provides the measurement of the maximum concentrations that are formed in the jet from each engine of the aircraft.
2. The high sensitivity of the system (± 2 ppbv) ensures its remoteness in accordance with the airport security rules, the detection of maximum concentrations from aircraft engines and their separation from other pollution sources within the airport.
3. Unlike DOAS and FTIR, the considered system allows collecting the exhaust gases mixture at different altitudes, which is an important advantage for the airport pollution monitoring, namely the ability to take into account the effect of the buoyancy of the jet/plume from aircraft engine.

The combination of AC32M and LICOR systems for detecting $NO/NO_2/NO_x$ and CO concentrations in a jet from aircraft engine allows determining the emission indexes under real operating conditions within the airport [9]:

$$\mathrm{EI(X)} = \mathrm{EI(CO2)} * \frac{\mathrm{M(X)}}{\mathrm{M(CO2)}} * \frac{\mathrm{Q(X)}}{\mathrm{Q(CO2)}}, \quad (2)$$

where M(X) – molecular mass of pollutant admixture (X); Q(X) – detected concentration of pollutant; $EI(CO_2)$ = 3200 g/kg.

The best option for the monitoring is the combination of the following measurement system: AC32M or TE42SL-95/96 and LICOR to measure respectively $NO/NO_2/NO_x$ and CO_2 concentrations in the jet from the aircraft engine. Characteristics of the chosen measurement systems correspond to the laws of air contaminants distribution in the plume from the aircraft engine, the diffusion by wind and atmospheric turbulence. The given practical recommendations for organization of the monitoring of aircraft engines emissions were realized at the International airport "Boryspil".

According to the complex model PolEmiCa, a monitoring station placement scheme was developed to measure the maximum instantaneous concentrations of pollutants, which are formed in jets from the aircraft engine for maximum (accelerating run along the runway, takeoff) and nominal (landing) modes.

Taking into account the characteristics of the jet formation during the taxiing, accelerating run along the runway, the take-off and landing stages of the aircraft in the flight zone # 1, the mobile station B was oriented towards the prevailing direction of the wind (220°) and is located at 150 m from the runway axis in the eastern direction (Fig. 1). The height of the mast for collecting the gas mixture was 3 m and 6 m.

Thus, the scheme of the monitoring stations placement (Figure 1) provides measurement of pollutant concentrations in the jet from the engine during the flight of the aircraft along the runway, takeoff and landing stages are oriented to 180° the magnetic course.

Figure 1. Location of stationary and mobile stations of instrumental monitoring of pollutant emissions from aircraft engines within the Runway -1 at the International airport "Boryspil", with a predominantly south-west (225°) wind direction.

Based on the results of continuous measurement of NO, NO_x concentrations (AC32M) and CO_2 concentrations (LICOR) in the jets from the aircraft engines, the emission indexes by the formula (2) were calculated for maximum mode (aircraft accelerating run along the runway and takeoff), Table 2.

Table 2.

Comparison of ICAO emission indexes and calculated indexes based on measurement campaign at Boryspil International Airport

#	Time of peak	Engine type	Mode	EI ICAO	EI_{calc} (calculated)	Air tempe ratu-re, ° C	Wind speed, m/sec	Wind direction
1	13:10:11	CFM56-3	T/F	17.7	9.2	22.6	2.9	225
2	13:10:50	CFM56-3	T/F	17.7	14.8	22.6	2.9	157.5
3	13:23:14	CFM56-3	T/F	17.7	16.7	22.5	4.2	202.5
4	13:44:30	CFM56-7B	T/F	25.3	21.0	22.8	5	247.5
5	13:58:33	JT8D217C	T/F	16.5	24.2	22.9	4.4	225
6	14:13:07	PW4000	T/F	32.8	32.2	23.5	2.3	225

Based on the comparative analysis, a difference was found between the values of the NO_x emission indexes and the values given by ICAO for the studied types of aircrafts, Table 2. This pattern is due to the fact that the real operating conditions for the maximum mode do not meet the certification conditions of the ICAO, particularly by thrust value.

References

1. Воротынцев В.М., Запорожец А.И., Карпин Б.Н. Постановка задачи описания воздушных судов как источника загрязнения атмосферы // Проблемы защиты окружающей среды от воздействия ГА: Сб. науч. тр. – М.: ГосНИИГА, 1981. – вып. 197. – С.14–21.
2. Annex 16 to the Convention on International Civil Aviation. Vol. II: Aircraft engine emissions. – ICAO, 1993. – 2nd ed. – 249 p. – [International standards and recommended practices].
3. Aviation and the Global Atmosphere. IPCC (Intergovernmental Panel on Climate Change) / J.E. Penner, D.H. Lister, D.J. Griggs, D.J. Dokken, M. McFarland (Eds.) // Cambridge University Press, 1999. – 12 p.
4. Procedure for the Calculation of Aircraft Emissions. SAE Committee A-21// Report SAE AIR 5715 – 2009. – 128 p. – [Report].
5. ICAO Doc 9889. Airport Ait Quality. – 1st ed. – 2011. – 200 p.
6. Schürmann G. The impact of NOx, CO and VOC emissions on the air quality of Zurich airport / G. Schürmann, K. Schäfer, C. Jahn, H. Hoffmann, M. Bauerfeind, E. Fleuti, B. Rappenglück // Atmospheric Environment. – 2007. – №41. – P.103–118.
7. Air quality monitoring campaign at Zurich airport from 30 June until 15 July 2004. Final report / Schäfer K., Schörmann G., Jahn C., Utzig S. – IMK-IFU, Garmisch-Partenkirchen, 2004. – 52 p.
8. Heland, J., Schäfer, K. Determination of major combustion products in aircraft exhausts by FTIR emission spectroscopy / J. Heland, K. Schäfer // Atmospheric Environment Journal. – 1998– №32, 18. – P.3067–3072.
9. Aircraft emission measurements by remote sensing methodologies at airports / K. Schäfer, C. Jahn, P. Sturm, B. Lechner, M. Bacher // Atmospheric Environment Journal. – 2003. – Vol.37. – P.5261–5271.