ENVIRONMENTAL PROTECTION

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Oleksander I. Zaporozhets, D.E., Prof.
Kateryna V. Synylo, asst.

MONITORING AND MODELLING OF AIR POLLUTION PRODUCED BY AIRCRAFT ENGINE EMISSION INSIDE THE ATHENS INTERNATIONAL AIRPORT

Experimental measuring of air pollution inside the airport, produced by aircraft engine emission during accelaration and take-off on the runway. Measurement data were used for verification of modelling results according to complex model «PolEmiCa». It consists of the following basic components: engine emission inventory calculation; transport of the contaminants by engine jets, dispersion of the contaminants in atmosphere due to wind and atmospheric turbulence.

Надано опис проведених експериментальних досліджень концентрацій забруднення повітря викидами від двигунів повітряних кораблів під час розгону на злітно-посадковій смузі. Наведено результати експерименту, що були використані для перевірки достовірності комплексної моделі оцінки забруднення PolEmiCa, яка складається з моделі емісії забруднюючих речовин авіаційних двигунів, моделі перенесення домішки забруднюючих речовин струменями відпрацьованих газів авіаційних двигунів, моделі розсіювання домішки забруднюючих речовин в атмосферному повітрі в результаті перенесення вітром і дії атмосферної турбулентності.

air pollution, aircraft engine emissions, averaging period of concentration, concentration disribution, concentration measurement, contaminants dispersion, LTO-cycle, meteorological conditions, nitrogen oxides NOx

Introduction

Transport play essential role in economic and social development as well as in the creation of wealth of our society. It is acknowledged that aviation industry is exercising the quickest growth compared with other transport modes.

Additionally it is forecasted by Eurocontrol, that the number of flight in Europe 2025 will be between 1.6 and 2.1 times the traffic of 2003, up to 17 millions flights in case of a fast growth scenario [1]. According to such tendency, air transport will cause global ecological problems, as green house effect, destruction of ozone layer and acid precipitation.

In recent years a lot of studies are focusing on the aeronautic impact to the upper troposphere and lower stratosphere on regional to global scale ozone chemistry and the climate impact of light scattering and absorption of contrails and associated high altitude clouds. Such impact of aircraft exhaust emission can lead to significant atmospheric warming over the first half of the 21st century.

Even though all the benefits that airport brings, they have significant impacts on those living nearby. Lately, this problem intensifies in connection with increasing air traffic and growing public awareness of local air quality around the airports. The environmental issues arising from airport have been generated by activity at an airport (aircraft, vehicle, fixed sources), which in turn generate emissions (combustion, evaporation, spraying), that reduce air quality and adversely affect human health.

Consequently, it is becoming more important to estimate airport local air quality, according to emission inventory and dispersion modeling, with aim to predict pollutants concentration inside and outside the airport.

Aircraft (during approach, landing, taxi, take-off and initial climb of the aircraft, engine run-ups, etc.) are the dominant sources of air pollution at airports in most cases under consideration.

During last decade a lot of studies are also focusing on the aircraft emissions impact on local and regional air quality in the vicinity of airport. The basic objects of attention are Nitrogen oxide (NOx) and fine particle emissions from aircraft engine emissions as initiators of photochemical smog and regional haze, which directly impact human health.

So, development and implement models and methods for assessment of air pollution produced by aircraft engine emission is actual research. Verification of developed models requires experimental investigation.

The monitoring of air pollution produced by aircraft engine emission is actual task, providing evidence on the actual pollution situation, validation the model and useful initial data for improving air quality simulation systems thus aiding an increased understanding and control of airport-related air pollution.

Concentrations measurement of air pollution from aircraft engine emissions in the vicinity of Athens International Airport

With aim to develop a database of airport air quality and meteorological data, a measurement campaign was performed at Athens International Airport (AIA) from 13 until 25 September 2007 within the frame of international project «ECATS».

The results of measurement campaign in AIA used as an input and validation data set for modelling work due to complex model «PolEmiCa» [2].

Description of measurement campaign at Athens International Airport

The scientific objectives for the experimental investigation [3] in AIA were aimed to monitoring of airport air quality, influence of airport emissions upon air quality in the surroundings and provide reliable data for modeling systems, development of meteorological database.

Nitrogen oxide (NOx) is subject to very intensive research as it may have a serious impact on the ozoneproduction in the lower and upper atmosphere. Essential concentrations of NOx are generated during maximum operation mode of aircraft engine, when aircraft is accelerating on runway before take-off. For detection and estimation of NOx concentrations in vicinity of IAA, a differential optical absorption spectrometer (DOAS) and TE 42C-TL 96 were used [4].

Local air pollution inside the airport is caused by aircraft engine emission during LTO-cycle. The DOAS and TE 42C-TL 96 measurement sites inside the AIA (site A) were chosen in such a way, that the influence of runways can be identified in the concentration measurements.

The careful choice DOAS location is defined by main wind directions, it was guaranteed, that most part of exhaust from aircraft, accelerating on runway, will be fixed by spectrometer [5].

The DOAS System and and TE 42C-TL 96 were located at the beginning of a runway “03L”, at distance 210 m from runway end, according to the aim of the measurement campaign, dominated wind direction (north - east) and magnetic head of take-off «21R»(fig. 1).

According to considered experimental investigation in the vicinity of IAI, one day was chosen – 20 September, which is characterized by 20 peaks of Nitrogen oxide concentrations and corresponding 20 aircraft departures at the runway during afternoon period (14.00–16.00). The clear correlations between peak concentrations and aircrafts movements exist.

Nitrogen oxide measurements by DOAS and TE 42C-TL 96 systems (20.09.2007) was used for verification modeling results according to complex model «NAU». Meteorological initial parameters (wind velocity and direction, temperature for each 30 s) were provided by meteorological station of airport (site B). The derived datasets will allow estimating of contaminants dispersion in horizontal and vertical directions with taking into account turbulence diffusion in mixing layer of atmosphere [6].

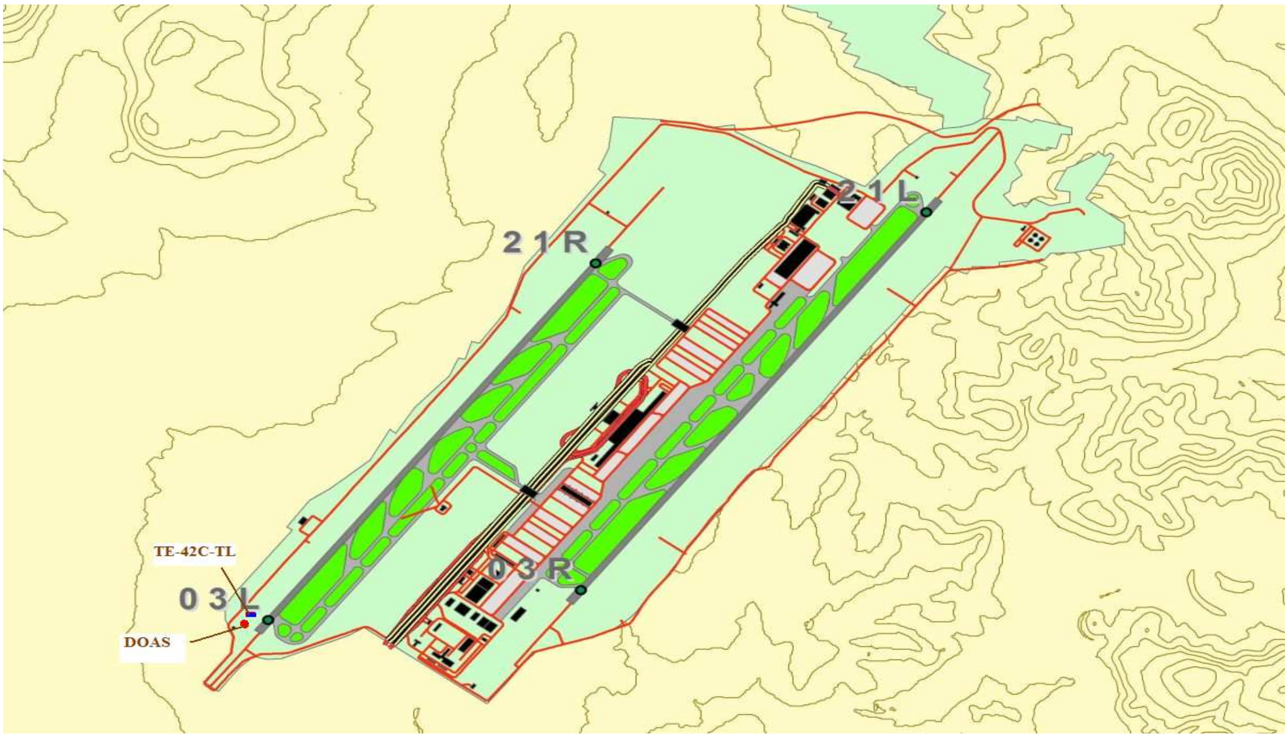

Fig. 1. Location of air pollution and meteorological measurements equipment at AIA

Complex model «PolEmiCa» for air pollution assessment from aircraft engine emission inside the airport

In the National Aviation University a complex model «PolEmiCa» for assessment of air pollution and emission produced by aircraft activities inside the airport has been developed. It consists of the following basic components:

− engine emission model – emission factor assessment for aircraft engines, including influence of operational factors;

− jet transport model – transportation of the contaminants by engine jets;

− dispersion model – dispersion of the contaminants in the atmosphere due to turbulent diffusion and wind transfer.

Contaminants are considered like not reactive.The frame of reference is set so that the wind velocity vector u_w and the *x*-axis are collinear. The *z*-axis is directed upwards and the *y*-axis completes the right-hand triple. Thus, with the assumption for the all turbulent diffusion coefficients k_x, k_y, k_z being constant, a dispersion equation (Eulerian approach) takes the form (no sources are expected):

$$\frac{dc}{dt}+u_w\frac{dc}{dx}=k_x\frac{d^2c}{dx^2}+k_y\frac{d^2c}{dy^2}+k_z\frac{d^2c}{dz^2}, \qquad (1)$$

where

c is contaminant concentration; u_w is wind velocity;

k_x, k_y, k_z are coefficients of atmospheric turbulent diffusion.

$$c(x,y,z,t)=\frac{M}{8(\pi t)^{3/2}\sqrt{k_xk_yk_z}}\exp\left(-\frac{(x-x_0-u_wt)^2}{4k_xt}-\frac{(y-y_0)^2}{4k_yt}\right)\times$$
$$\times\left[\exp\left(-\frac{(z-z_0-H)^2}{4k_zt}\right)+\exp\left(-\frac{(z+z_0+H)^2}{4k_zt}\right)\right];$$

where

x’, *y’*, *z’* are current values of co-ordinates of an emission source:

$$x'=x_0+u_{PL}t'+0{,}5at'^2+u_w(t+t');$$

$$y'=y_0+v_{PL}t'+0{,}5bt'^2;$$

$$z'=z_0+w_{PL}t'+0{,}5ct'^2,$$

x_0, y_0, z_0 are initial co-ordinates;

u_{PL}, v_{PL}, w_{PL} are vector components of source speed;

a, *b*, *c* are vector components of source acceleration;

u_W is wind velocity.

Coordinates of moving emission source – aircraft (x_0, y_0, z_0) are the variables, therefore for integration of equation (1) during concentration averaging, coordinates of moving emission source are defined by its velocity and acceleration for each instant *t*.

Abciss axis *X* of cartesian coordinate system directs in wind direction, *z*-axis directs up and perpendicular to ground level, ordinate axis *Y* adds frame to right vectors triple.

Contaminants are not reactive.

The maximum value of instantaneous concentration q_{max} in a point under consideration (*x*, *y*, *z*) will be derived at moment t_{max}, which is approximately determined by the formula:

$$t_{\max}=\frac{\Delta x}{U_W}+\left[\Delta x\times\frac{K_X}{u_W}\right]^{1/2}.$$

The complex model “PolEmiCa” allows treating the aircraft as a discrete moving point source with emission factors for each time step (1 s).

A puff model is used for computation of transient contaminants concentrations and dispersion parameters for each newly created puffs during interval Δt:

$$q(x,y,z,t)=\frac{Q\exp\left[-\frac{(x-x')^2}{2\sigma^2_{x0}+4K_xt}-\frac{(y-y')^2}{2\sigma^2_{yx0}+4K_yt}\right]}{\{8[\sigma^2_{x0}+2K_xt][\sigma^2_{x0}+2K_yt]\}^{1/2}}\times$$
$$\times\left\{\frac{\exp\left[-\frac{(z-z'-H)^2}{2\sigma^2_{z0}+4K_zt}\right]+\exp\left[-\frac{(z+z'+H)^2}{2\sigma^2_{z0}+4K_zt}\right]}{[\sigma^2_{zx0}+2K_zt]^{1/2}}\right\}\Delta t, \qquad (2)$$

where

K_X, K_Y, K_Z are turbulent diffusion factors.

Besides instantaneous puff model (2) the models of instantaneous moving source, fixed point source and instantaneous linear source are used in PolEmiCa also.

For comparison, Gaussian puff algorithm for modelling contaminants dispersion in atmosphere includes influence stability atmosphere (from Pasquill stability classes), thermal buoyancy and vehicle wake effects:

$$c(x,y,z,t)=\frac{Q\,exp\left[-\frac{(x-x')^2}{2\sigma^2_x}-\frac{(y-y')^2}{2\sigma^2_y}\right]}{(2\pi)^{3/2}\,\sigma_x\sigma_y\sigma_z}\times$$
$$\times\left\{exp\left[-\frac{(z-z'-H)^2}{2\sigma^2_z}\right]+exp\left[-\frac{(z+z'+H)^2}{2\sigma^2_z}\right]\right\}\Delta t,$$

where c is concentration, g/m^3;
Q is emission factor, g/s;
Δt is time interval between puff release, s;
x_p, y_p, z_p are center of puff, m;
x_r, y_r, z_r are receptor location, m;
H_m is height of mixing zone, m;
σ_x is standard deviation of puff in the x-direction, m;
σ_y is standard deviation of puff in the y-direction, m;
σ_z is standard deviation of puff in the vertical z direction, m.

Comparison measurement and modelling data according to experiment conditions in the vicinity of Athens International Airport

Complex model NAU was used for calculation of averaged concentration (1 min) of the contaminants, produced by aircraft engine emission during take-off in Athens airport. Appropriate model for this case was defined as a puff-model (2). Puffs were assessed for each engine of the aircraft separately, because of their separate influence on averaged concentration at point of monitor installation. It means that moment $t_{\max}$ for each engine is quite different, for example for take-off of Boeing 747 (shoulder between aside engines 42 m), $\Delta t_{\max}$ for aside engines was assessed as equal to 60 s due to small angle between the wind and rolling directions.

Because of that two averaged values of the concentration were calculated:

− maximum for this case total puff was considered inside interval of the averaging (*1*, *2* lines in a fig. 2 below);

− minimum for this case half of the puff was considered inside interval of the averaging (*3*, *4* lines in a fig. 2 below).

Besides, results were defined for the cases with and without jets from the engines to show that with jets they are more equal to measured data.

For every take-off different values of wind speed and direction were measured, so the different values for K_X , K_Y, K_Z – turbulent diffusion factors were calculated and used for following concentration assessment. Distances between each aircraft engine and DOAS for the moment of their maximum emission contribution are shown also.

For example, case 13 (take off of the A320-214) was defined with very small angle (6,9°) between the take-off and wind, so calculated distances 1486.0; 1569.8 are quite big, they show that DOAS measured the pollution from this take-off when an aircraft was in flight, not on the runway. Thus a height of the source can be defined not by an engine installation height for this aircraft type, but by the height of the flight – it may be an explanation for the difference between calculated concentrations (max = 49,99 and min = 26,47), and measured (DOAS = 23,32, TE 42C-TL 96 = 16,42± 1,64).

For huge difference between measured and calculated data for the Boeing 747 take-off a possible explanation is that used averaging interval (1 min) is equal to Δtmax for aside engines (was assessed as equal to 60 s due to small angle between the wind and rolling directions), so not all of the puffs were included in measurement results.

For example, in Delta – Atlanta Hartsfield (UNA-UNA) Study [7] it was shown in Sample Event 1 for Boeing 747 with CF6-80C2B1F Engines 9/27/2004 12:40:00 (fig. 3) that two separate plumes were detected, each of them possibly was defined by separate pare of engines installed on each half-wing of the aircraft.

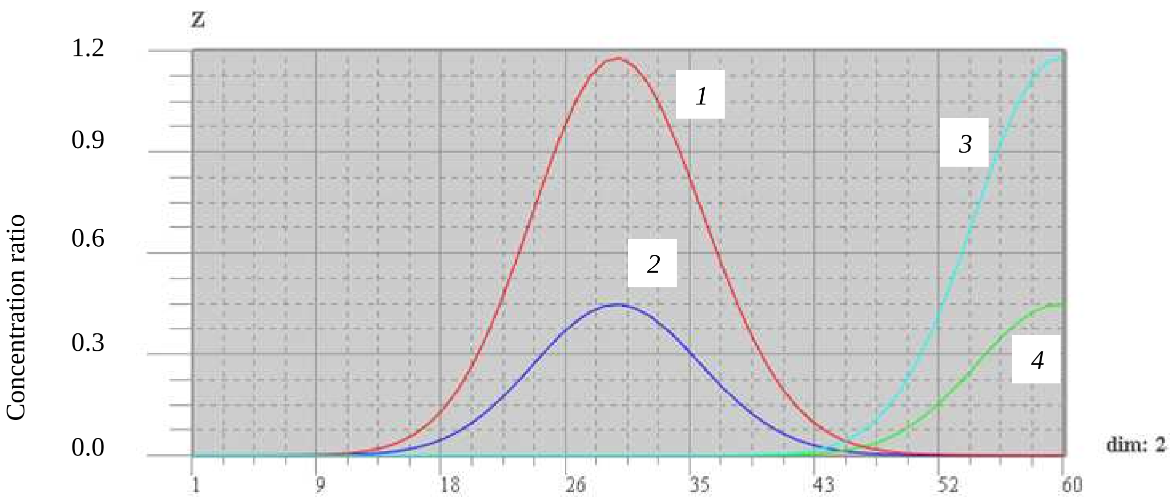

Fig. 2. Concentration distribution in exhaust from aircraft engine due to averaging period 1 min

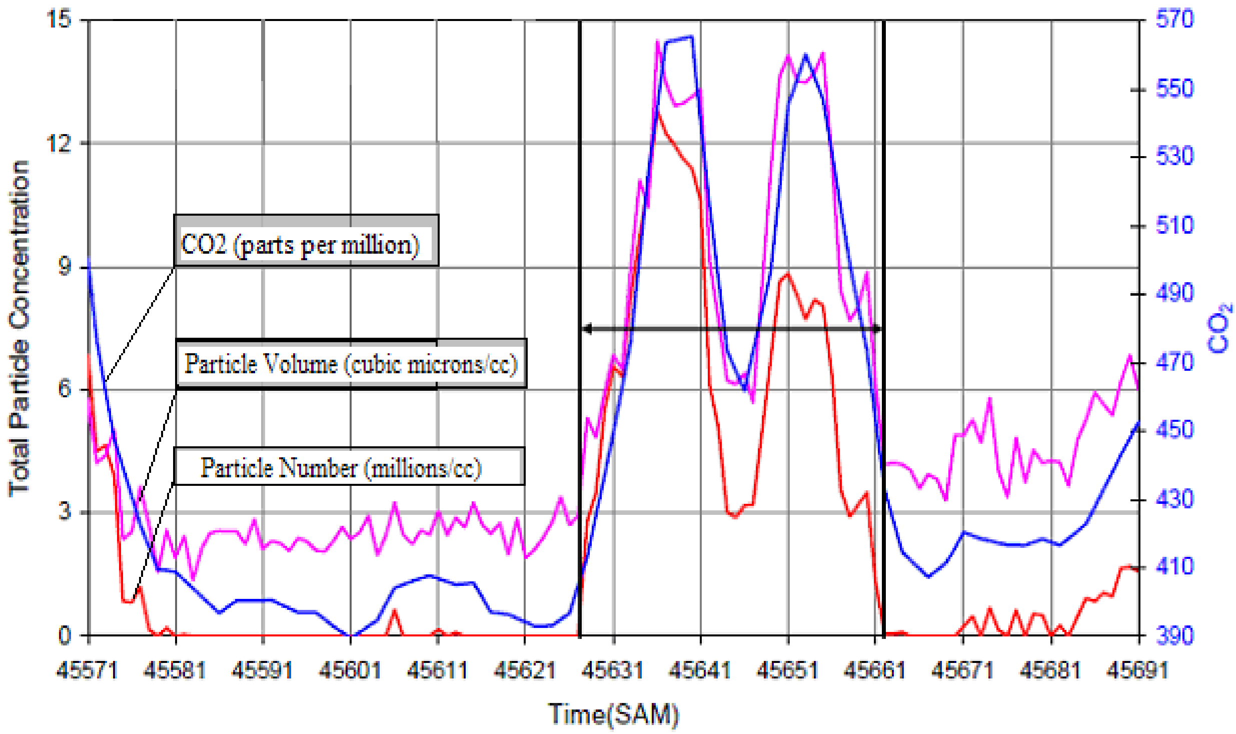

Fig. 3. Sample Event 1 − Total Particle Concentration (Number and Volume) and CO_2 Concentration as a Function of Time

So it was too difficult to include a contribution from each engine to measured result. Second possible explanation is the same as for a case 13 calculated distances - 1529.1; 1601.9; 1796.1; 1868.9 – are quite big, they show that DOAS could measure a pollution from this take-off when an aircraft was in flight, not on the runway.

Thus a height of the source can be defined not by an engine installation height for this aircraft type, but by the height of the flight.

Tables below are showing that most part of the measured data are inside an interval between maximum and minimum calculated data, which were explained before.

Measurement results by system TE 42C-TL 96 and calculation results due to complex model «PolEmiCa» of nitrogen oxides (NOx) concentrations produced aircraft engine emission during take-off aircraft in the vicinity of IAA

Aircraft	Engine	Calculated maximum µg/m^3	Measured concentration, delta NOx by TE 42C-TL 96, mg/m^3		Calculated minimum µg/m^3	DOAS
			value	error		
B737-3YO	CFM56-3C1	27,430	31,8	3,2	33,00	14,850
B737-3Q8	CFM56-3B2	30,700	28,0	2,8	32,9	16,570
B737-45S	CFM56-3B2	29,760	23,6	2,4	30,57	16,000
B737-4Q8	CFM56-3B2	31,280	56,9	5,7	62,64	16,940
A310	CF6-80C2A8	88,860	86,1	8,6	89,46	48,400
A319	CFM56-5B5/P	29,850	26,9	2,7	46,09	15,920
B747-230	CF6-50E2	163,630	82,5	8,2	90,41	86,910
A321-211	CFM56-5B-3/P	81,780	43,3	4,3	51,7	44,070
A320-214	CFM56-5B-4	49,990	16,4	1,6	23,32	26,470
B737-33A	CFM56-3B1	25,500	11,5	1,1	17,98	13,730

Conclusion

Basic sources of difference between calculated and measured of contaminant concentration from aircraft engine emisiion are following:

− emission factor – contaminant mass exhaust. I used for my modelling values of emission characteristics for aircraft engine from ICAO certification. These emission values were defined for ambient temperature15°C. But in case of measurement campaign in AIA, air temperature was 26.8°C. Such temperature difference effect on input and output of modelling data and composes 10 % of accuracy;

− meteorological data, particularly, wind direction fluctuation was not discounted.

− plume dispersion (σx, σy, σz,) and buoyancy effect are estimated by model , taking into calculation jet parameters. But developed complex model “PolEmiCa” is semi – empirical model which also effect on accuracy.

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