NEW AND IMPROVED LAQ MODELS FOR ASSESSMENT OF AIRCRAFT ENGINE EMISSIONS AND AIR POLLUTION IN AND AROUND AIRPORTS

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Many studies emphasize high concentrations of toxic compounds due to airport-related emissions and their significant impact on the environment, and directly on the population living near airports. Today, special attention is being paid to nitrogen oxides (NOx) and particulate matter (PM) emissions from aircraft engines because of their contributions to photochemical smog and the associated hazards to human health[1].

The purpose of local air quality (LAQ) control is to limit or reduce the impact of aviation emissions on local air quality. In practice, this means to limit or reduce the masses of emitted toxic compounds into the environment[2]. Over the years, tremendous efforts have been made and results achieved in reducing aircraft engine emissions at source. Scientists, designers and manufacturers have worked tirelessly to produce cleaner burning aircraft engines and produce an ever cleaner fleet of aircraft. New aircraft engine designs show 50% to 80% less emissions during the landing-take-off cycle (LTO-cycle) of flight, as well as en-route[3].

In order to understand the big picture with respect to the impact of aviation operations, air quality maps are developed. ICAO Doc 9889[4] provides guidance on how to perform robust air quality assessments in and around airports. This requires the conduct of an inventory analysis of all emissions from all sources at the airport. The ICAO guidance also recommends the performance of dispersion calculations and pollution measurements based on the monitoring all air pollution at airports. Ultimately, this allows airport operators to define the mean concentrations of air pollutants and to compare them with the regulatory air quality standard values applicable for humans or/and eco-systems.

Complex Model PolEmiCa

The analysis of emission inventories at major airports, including at Ukrainian airports, shows that aircraft are the dominant source of air pollution[5]. This conclusion was reached by considering a number of elements linked to the dynamic nature of pollutants sources including: emission dispersion parameters, changes to aircraft engine power settings during the LTO cycle between the idle and maximum thrust modes, and the difference between engine emission changes in a wide range of different aircraft engine emission certification data[6]. In addition, a jet engine which travels in parallel to the ground surface may transport pollutants relatively long distances; sometimes more than 1 km[5].

A complex computer model known as PolEmiCa (**Pol**lution and **Emi**ssion **Ca**lculation) was designed to perform an emission inventory and dispersion analysis for the main sources of air pollution at and around airports. It is based on the requirements listed in ICAO Doc 98894 which specifies that the following be covered: aircraft during LTO-cycle, including engine start-up procedures; Auxiliary Power Units and Ground Support Equipment; the main stationary sources; and road vehicles inside the airport area for the pollutants - CO, HC, NOx, SOx, PM. With respect to stationary sources and road vehicles, specific rules exist in Ukraine to define the emission factors, depending on the type of fuel used and the type and technical characteristics of the fuel combustion units. These include corrections for the emission factors due to national and international standard requirements. Comparison of total results (including the contribution of all the character sources listed in ICAO Doc 9889) of inventory analysis for various calculation tools, verified by CAEP MDG for CAEPort[7], shows that PolEmiCa results are within ±10-15% difference from the averaged inventory data from other tools (**LASPORT, EDMS, ALAQS, ADMS, PEGAS**) for all the pollutants, except SOx, because the national standard for content of sulphur in aviation kerosene is equal to 0,5, much higher than other similar national and international norms.

PolEmiCa is built upon a methodology for the calculation of ambient concentrations of harmful substances[8] that is widely used in the former Soviet Union States.

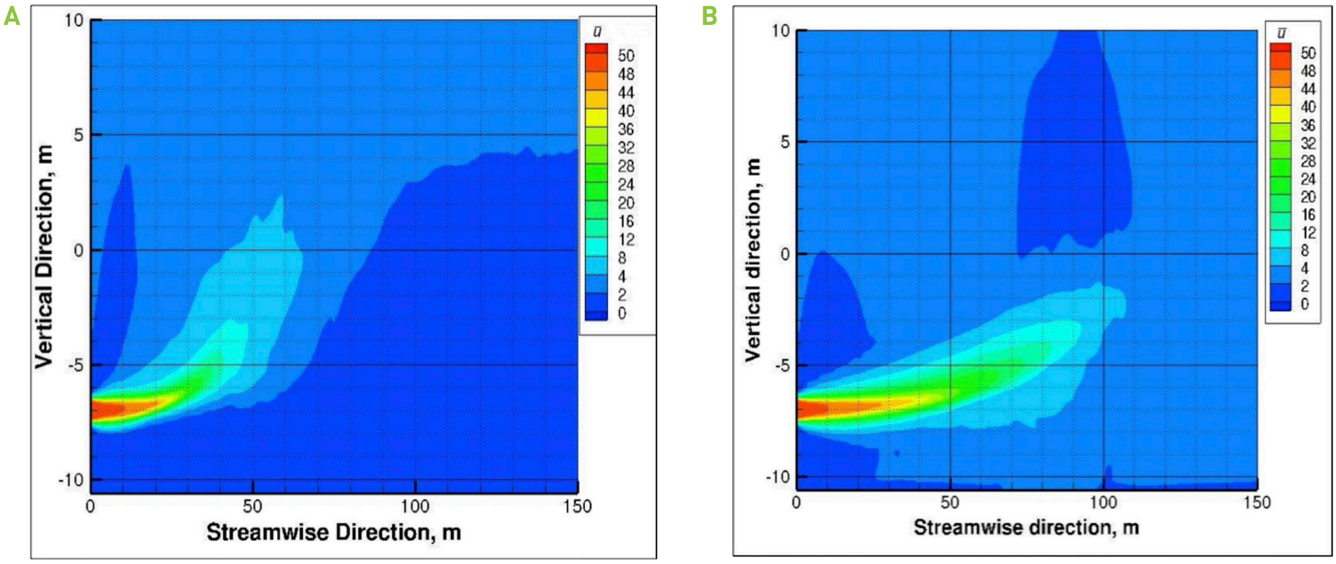

Figure 2. Mean Velocity Contours of the Jets in Streamwise Direction After 10 Seconds: free jet (a) and wall jet (b).

Under normal conditions, during aircraft taxiing (the longest part of the LTO-cycle), the distribution of contaminants by jet engine exhaust occurs within the atmospheric surface layer (i.e. up to 100 m above ground level). PolEmiCa evaluates the basic components of the contaminants emitted and provides basic parameters[9,10] to the dispersion model, including height and longitudinal coordinate of buoyancy effect of the engine exhaust jets. Current jet model (Computer Fluid Dynamics (CFD) modeling results for conditions of ground surface influence are used) in PolEmiCa (**Figure 2, b**) shows engine jet rise approximately[3] times lower and its longitudinal coordinate is approximately 30% longer on ~ in comparison with previous semi-empirical jet (for free jet conditions – without influence of the ground surfaces) transport model (**Figure 2, a**), reducing air contaminants dilution by jet and increasing their concentrations near to ground surface accordingly.

The verification of the PolEmiCa model with measurement data was done during trials conducted at Athens Airport (Greece, 2007) and Boryspol Airport (Ukraine, 2012). Comparison between calculated and measured NOx concentrations in aircraft engine plumes under real operating conditions (e.g. aircraft accelerating on the runway during take-off at Athens Airport) is shown in **Figure 3**. The improvements brought by the use of a CFD codes for assessing the dispersion of the jet are evident.

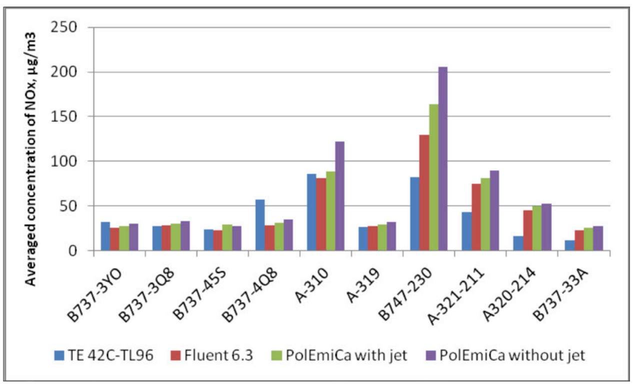

Figure 3. Comparison of Measured and Modeled NOx Concentrations (averaged for 1 min) Under Take-off Conditions (maximum thrust operation mode of aircraft engine).

Experimental studies at Boryspol Airport[11] focused on measurements of NOx concentrations in aircraft engine jets using the chemi-luminescence technique, and by estimating NOx emission indices under real operating conditions (i.e. aircraft taxiing and accelerating on the runway for take-off).

Figure 4 shows the emission indices from the study when compared with ICAO values for idle and maximum engine modes[6]. The variations between measured and ICAO certificated data were clearly evident in this trial.

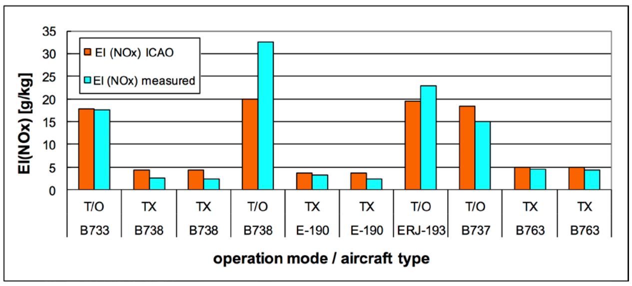

Figure 4. Comparison of Measured EI$_{NOX}$, Under Real World Operating Conditions (take-off (T/O) and Taxing (TX)) with the ICAO Database.

Those measured emission indices served as input for the validation and enhancement of the PolEmiCa model. NOx concentration calculations were improved by taking into account the interactions between the jet engine exhaust and the wing trailing vortices during aircraft take-off, **Figure 5**.

The analysis of the air pollution model developed from aircraft engine emissions allowed the definition of the main operational parameters that may influence air quality in the vicinity of an airport. A key finding shown in **Figure 6** is that, close to the aircraft the maximum concentrations may be derived at weak to moderate atmospheric turbulence intensity, but for very weak intensity – at greater distances. The higher the wind speed, the higher the concentration.

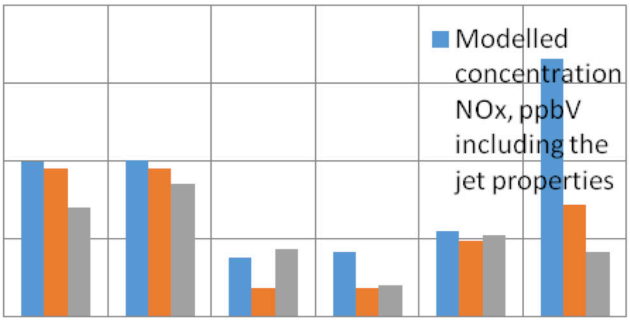

Figure 5. Comparison of the PolEmiCaResults (previous and improved by wing trailing vortices versions) with the Measured NOx Concentration from Aircraft Engines Exhausts under Maximum Operation Mode: blue columns – modeled concentrations for engine jet transportation model; orange columns – modeled concentrations for model of interactions between the jet engine exhaust and the wing trailing vortices; grey columns – measured concentrations.

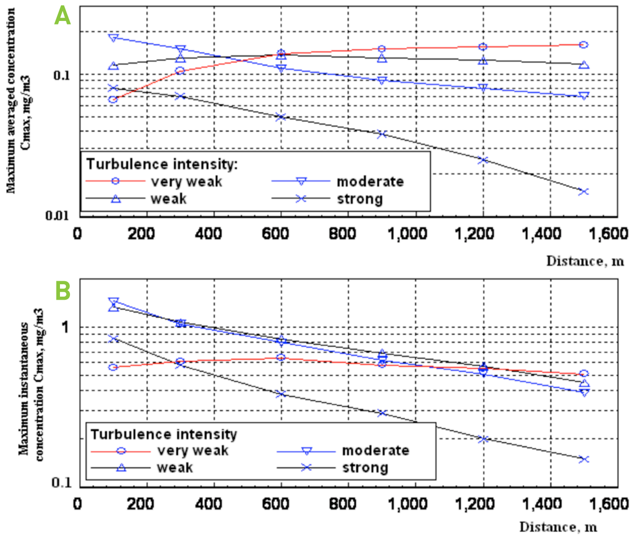

Figure 6. Influence of Atmospheric Turbulence Intensity on the Levels of Air Pollution Produced by Aircraft Engine Emissions:
a) maximum average concentration (per 20 minutes);
b) maximum instantaneous concentration (per 1s).

Conclusions

PolEmiCa is still under development, and future enhancements to this model will have two important objectives: to improve the jet/wake transportation modelling by CFD codes, and to verify the modelling results against measurement data collected at various airports.

Further improvements to dispersion calculations are expected, based on the use of more accurate engine emission data which is expected to come from the use of aircraft engines operating under real airport conditions, as power thrust and other operating conditions, such as weather have an impact on the emission parameters. For example, the NOx emissions factor shows variations of up to 25% when compared with the value for Standard Atmosphere (air temperature 15ºC) for temperatures as low as -20ºC, or as high as 30 ºC.

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