Standards and Advances in Airport Air Quality Modelling

By Ulf Janicke (Janicke Consulting)[1]

Airport emission sources

Airports are a source of pollutant emissions and affect the local air quality (LAQ) at and around the airport. The dominant emission sources are the aircraft main engines during the landing-takeoff cycle (LTO) which is comprised by the flight segments approach, taxiing, take-off, and climb-out, traditionally up to 3000 ft (914 m) above ground level. Other emission sources are auxiliary power units (APU), ground support equipment (GSE), motor traffic (airside and landside), and other sources at the airport such as fuel-burning power devices.

The basis for aircraft emissions calculations is the ICAO Engines Emission Databank (ICAO EEDB) [1]. The databank is hosted by the European Union Aviation Safety Agency (EASA) on behalf of ICAO. It contains fuel flows and emission indices (EI, emission per kg fuel burned) of existing aircraft jet engines with a static thrust greater than 26.7 kN, measured at the four LTO thrust settings (7%, 30%, 85%, 100%) according to the procedures in Annex 16 "*Environmental Protection*", Volume II "*Aircraft Engine Emissions*" to the Convention on International Civil Aviation. Together with defined operation times at the four thrust settings, aircraft emissions over the LTO can be calculated.

Dispersion calculations

For aircraft, the release height of emissions has a major influence on the resulting near-ground pollutant concentration: 1 kg of a pollutant emitted during taxiing yields a much higher pollutant concentration as compared to 1 kg emitted during approach or climb at a height of some 100 m. This is in strong contrast to aircraft noise, which is transported through the ambient air at the speed of sound, while pollutants are vertically dispersed with the ambient air by turbulent diffusion.

Therefore, LTO emission is not a fully suitable concept for assessing local air quality. A dispersion calculation is required that models the atmospheric transport of the released emission and determines the pollutant concentration, usually at ground level, for suitable time periods of hours, days, or a year. Beside emissions and their localizations, a dispersion calculation requires information on meteorological key parameters (e.g. wind speed, wind direction, atmospheric stability), additional transport effects like deposition or chemical conversions, and the dynamic properties of the emitted exhaust. The latter is particularly relevant for aircraft, because the exhaust from main engines exhibits a high excess temperature and momentum significantly influencing near-field dispersion. Figure 1 shows an example result of an airport dispersion calculation.

The ICAO Document 9889 ("*Airport Air Quality Manual*") [2] provides useful information on emission and dispersion calculations for airport-related sources. In past cycles of the ICAO Committee on Aviation Environmental Protection (CAEP), several airport dispersion models have been evaluated in view of their use by CAEP. The main focus of CAEP work is nitrogen oxides (NO_x, sum of NO_2 and NO with the latter in molar mass unit of NO_2) and non-volatile particulate matter (nvPM). CO_2 emissions, which are proportional to the amount of fuel burned, are also calculated for assessing climate impacts. The following focuses on NO_x and particulate matter.

1 Ulf Janicke is lead of the Local Air Quality Task Group in the Modelling and Databases Group of the Committee on Aviation Environmental Protection.

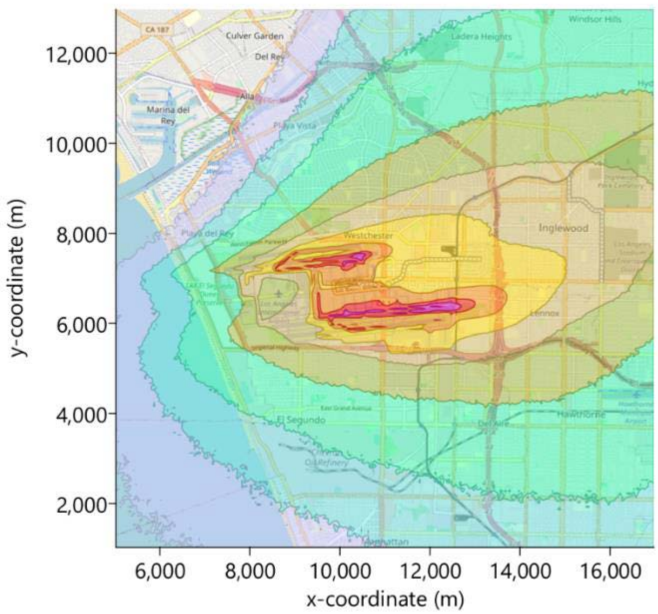

FIGURE 1: Example result of an airport dispersion calculation: NO_x monthly concentration distribution due to aircraft and GSE emissions at Los Angeles International Airport (background map: OpenStreetMap Contributors).

Nitrogen oxides

The calculation of NO_x emissions is straightforward as the ICAO EEDB contains traceably measured NO_x emission indices. Also, a dispersion calculation is straightforward as NO_x can be assumed as a chemically passive substance at time scales corresponding to typical transport times at and around airports (up to about one hour).

On the other hand, ambient air quality limit values refer to NO_2 and the calculation of NO_2 concentrations is considerably more demanding, because emitted NO can be converted into NO_2 (secondary NO_2), and vice versa. Conversion rates depend on meteorological conditions and ambient concentrations of other substances such as ozone (O_3). In addition, the NO_x emission from aircraft engines must be split into NO_2 (primary NO_2) and NO emissions, the ratio of which is dependent on type of the engine and thrust level. In the European Union, NO_2 concentrations at airports may become increasingly relevant over the next years because the ambient annual limit value will be reduced from 40 $\mu g/m^3$ to 20 $\mu g/m^3$ [3].

Non-volatile particulate matter

Particulate matter emitted in the core exhaust of aircraft main engines and APU consist of particles with mean diameters below 100 nm (ultrafine particles, UFP; 100 nm = 0.1 µm = 0.0001 mm) [4]. The particles have a mainly carbonaceous solid core which is regulated as nvPM. During atmospheric transport, secondary particles are created from emitted gaseous precursors (volatile particulate matter, vPM). Geometric mean diameters of non-volatile particles from aircraft engines are typically in the range of about 10 to 60 nm, whereas nucleated volatile particles start at diameters of a few nm and can grow to 10 nm or more during atmospheric transport, with volatile precursors also coating nvPM as they cool and condense.

Since 2023, new regulatory limits apply for nvPM mass and number. Accordingly, the ICAO EEDB contains with each update additional nvPM emission indices for in-production engines. For legacy engines in the ICAO EEDB, ICAO Document 9889 provides a method for estimating nvPM mass and number emission indices (First Order Approximation Version 4, FOA4). Figure 2 shows a comparison of estimated and measured emission indices and the resulting emissions over the reference LTO (fixed times-in-mode for the four thrust settings: 1560, 240, 132, and 42 s).

These tools make emissions calculations of nvPM mass and number straightforward. A dispersion calculation of nvPM number concentration can then be performed if agglomeration effects during atmospheric transport are neglected, which is a commonly applied assumption. The calculation of nvPM mass concentration is more complex because the particles can grow through condensed coatings of volatile substances. But, in general, it is the number concentration of particles that is of interest in the size regime of ultrafine particles.

Measurements of nvPM number concentrations require removal of the volatile particles, which is generally achieved by actively heating the measured aerosol (using a catalytic stripper or thermodenuder). In the sampling and measurement system, particle losses occur due to various physical processes (e.g. diffusion, thermophoresis, inertia etc.). In general, these losses are dominated by diffusional loss, hence the smaller the particles, the higher the particle

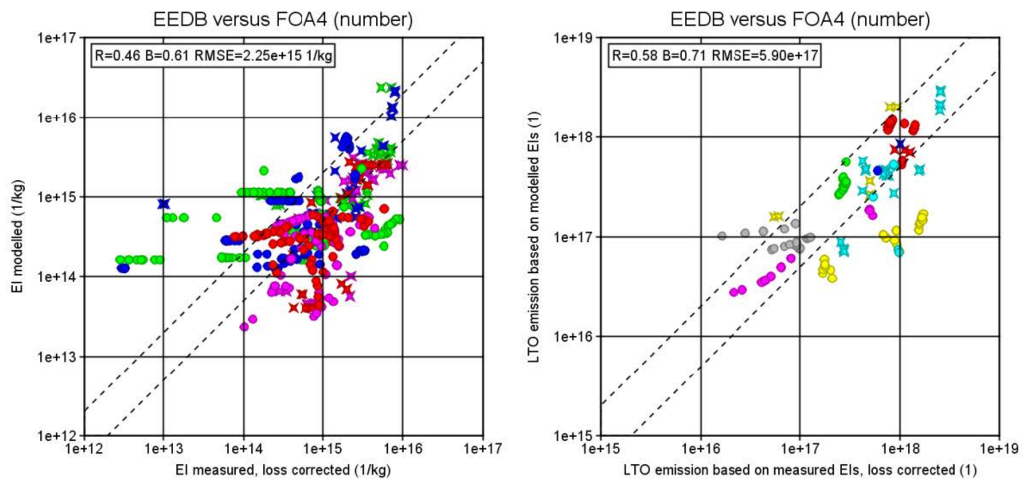

FIGURE 2: Left: Comparison of measured (ICAO EEDB 28c) and modelled (FOA4) nvPM number emission indices. Red: take-off, magenta: climb-out, blue: approach, green: taxiing, circles: turbofan, diamonds: mixed turbofan. Right: Comparison of the resulting emissions over the certification LTO (plain average over each combustor type). Red: PHASE, magenta: LEC, gray: TAPS, green: TECH, yellow: TALON, cyan: other. Dark blue symbols are the plain averages over all turbofan and mixed turbofan engines.

loss (exceeding 90% for the smallest aircraft nvPM). The ICAO EEDB provides uncorrected and loss-corrected emission indices, with more advanced loss-correction methods which use measured particle size being developed [5]. For dispersion calculations, loss-corrected emission indices should be applied.

Volatile particulate matter

Measurements have shown that a major constituent of UFP in the cooled and diluted downwind engine exhaust consists of volatile particulate matter (vPM). Modelling vPM number concentration from aircraft engines is subject to current research, with no current standard. Chemical transport models are able to cover some of the relevant processes, but often only at a low spatial resolution. Physio-chemical models have provided additional insight into relevant mechanisms [6]. In LAQ dispersion modelling, first attempts are being made to include vPM, see Figure 3 for an example. Corresponding methods will be provided in forthcoming updates of ICAO Document 9889.

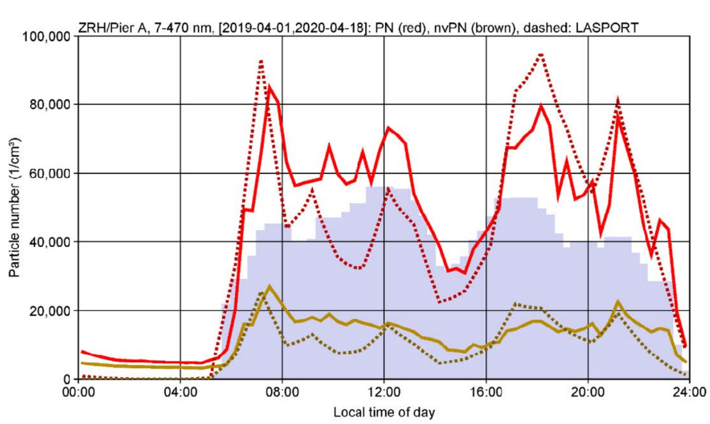

FIGURE 3: Comparison of measured (solid lines) and modelled (dashed lines) nvPM (brown) and total PM (red) number concentration at Pier A of Zurich Airport [7]. The background denotes the average aircraft movements.

Standards and harmonisation

The fact that the ICAO EEDB and ICAO Document 9889 (2nd edition) have been made freely available by ICAO significantly contributed to the global harmonisation and standardising of aircraft-related emission and dispersion calculations. This practice is expected to be maintained in the future.

Currently, the LAQ task group of the Modelling and Databases Group (MDG) in CAEP investigates the setup and application of a LAQ metric based on pollutant concentrations. Such a metric is a valuable supplement to the established LTO emissions metric and allows a better connection to impact assessments and ambient air limit values. This work may also lead to recommendations for ICAO Document 9889 and possibly to the identification and provision of so-called “gold standard” data sets, which can be used to verify and validate LAQ dispersion models in the context of aircraft and airports.

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Figures 1 and 3 show modelling results from the airport dispersion model LASPORT, the data shown in Figure 2 were created with the open-source tool SECTOR [8].

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