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EXTENDED ABSTRACT

APPLICATION OF THE PolEmiCa MODEL TO EVALUATE AIRCRAFT EMISSIONS AT SCHIPHOL AIRPORT

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Abstract: Air quality around airports has become an increasingly important concern, with aircraft engine emissions playing a direct role in local air pollution. This study aims to evaluate the local air quality around Schiphol Airport by using the PolEmiCa dispersion model. The main purpose of the model is to provide the dispersion (air pollution - Pol) and inventory (emission - Emi) calculations for aircraft engine emissions during the landing/take-off cycle inside the airport area. The model consists of two basic components: the engine emission model provides emission factor assessment for aircraft engines, including influence of operational and meteorological factors by BFFM2 and P3T3 methods; the jet transport model evaluates basic mechanisms of pollutant transportation and dilution by the jet from the aircraft engine exhaust providing basic parameters of the jet; the dispersion model calculates the instantaneous/averaged concentration, taking into account the atmospheric turbulent dispersion. Since 2019, PolEmiCa has been involved in the feasibility study carried out by the CAEP LAQ Task Group, which aims to define a methodology to assess pollutant concentration around airports in the trends and stringency analysis. The maximum instantaneous concentration at a grid point is defined as the solution to the turbulent diffusion equation, using the Eulerian/Gaussian approach for a moving point source. This includes the initial transport and dispersion of pollutants by the exhaust gas jet and the effects of atmospheric turbulence. The PolEmiCa model uses a segmentation approach for the stage of the take-off run, in accordance with ICAO Doc 9911. The infrastructure of Schiphol Airport is captured into the GIS via the input of the coordinates of the runways, positions areas, taxiways, aircraft stands and roadways. The model then calculates the concentration field within the airport area, considering factors such as flight intensity, an aircraft movement parameter, a loading factor of different taxiways and runways, and other operational circumstances. This study makes a valuable contribution to the emerging field of local air quality modelling in aviation, specifically focusing on the surrounding areas of airports.

Key words: *dispersion model, airport, aircraft emission*

Introduction

Air quality in and around major airports has become an important topic in both environmental and aviation policy discussions. Aircraft engine emissions, particularly during ground-level operations such as taxiing, take-off, and landing, contribute significantly to local air pollution (Schürmann et al., 2007). As airport traffic increases and urban areas continue to expand around airports, there is a growing need for accurate models that can assess the impact of these emissions on the surrounding communities. Understanding how pollutants disperse from aircraft engines in real-world airport settings is essential for developing effective mitigation strategies and informing regulatory decisions (Synylo et al., 2017; 2024).

Standard air quality monitoring at airports includes measurements of pollutants like carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x) and particulate matter (PM) (Moradi et al., 2024). While global estimations are typically summarized in annual environmental reports by airport authorities, the latter do not fully address several gaps in the understanding of how emissions affect local air quality under operating conditions (Xie et al., 2017). Given the proximity of residential communities to the airport and the exposure of apron workers and other ground personnel to aircraft emissions, a more detailed evaluation can help support targeted mitigation measures and protect the health of both nearby residents and personnel.

Emission behavior varies with engine load; lower thrust settings typically result in incomplete combustion, leading to higher CO and lower NO_x, while higher thrust levels produce a more complete combustion and higher temperatures, resulting in increased NO_x and reduced CO emissions (ICAO, 2023). In its Engine Emissions Databank (EEDB), ICAO assumes a constant 7% thrust level for taxiing operations (ICAO, 2022). However, in real-world scenarios, taxi thrust can vary, and is often lower than the assumed value, which may lead to discrepancies between certified emissions data and actual emissions on the ground.

The study area is situated at Amsterdam Airport Schiphol (AAS). The airport infrastructure includes eight passenger piers used for aircraft turnaround operations prior to departure, as well as six runways designated for take-off and landing. The specific taxi route taken by an aircraft varies depending on its assigned pier and departure runway, which in turn depends on weather conditions.

Methodology

This study evaluates the local air quality at AAS using the PolEmiCa model, a dedicated dispersion and emission inventory tool designed for airport environments (Synylo & Zaporozhets, 2017). The main purpose of the PolEmiCa is to provide the dispersion (air pollution - Pol) and inventory (emission - Emi) calculations (Ca) for the aircraft engine emission during the LTO cycle of the aircraft movement inside the airport area, Fig.1. PolEmiCa combines several modelling components, including aircraft engine emission factors, jet exhaust transport mechanics and atmospheric dispersion calculations. It also takes into account operational and meteorological conditions.

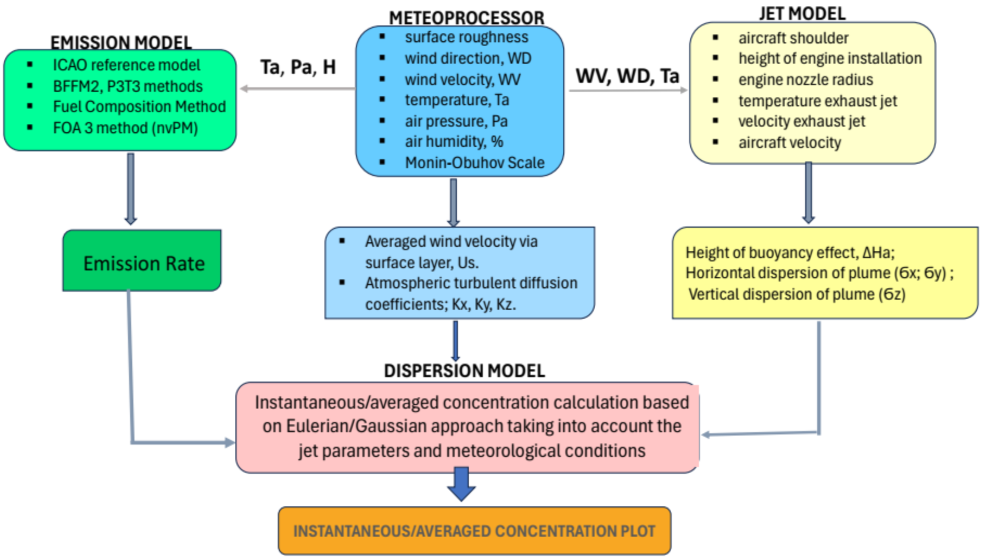


Fig. 1. PolEmiCa: Local Air Quality (Data Flows)

PolEmiCa is a customized GIS application. It is designed to capture airport pollution sources and to process the different types of the emission source estimates into a standard format in preparation of dispersion modelling. The infrastructure of AAS is captured into the GIS, together with the precise location of the various emission sources, as well as the runways, positions areas, taxiways, aircraft stands and roadways. Taxiway paths were determined for each aircraft type, in accordance with the aircraft movements journal for the departure and arrival cycles. Each aircraft's taxi time was estimated based on aircraft type, airport infrastructure, taxiway paths length and taxing velocity.

The maximum instantaneous value of the concentration in each grid point is a solution of the turbulent diffusion equation according to a Eulerian/Gaussian approach for moving point sources, with preliminary transport and dilution of contaminants by an exhaust gases jet and atmospheric turbulence, as in equation 1.

$$Q(x,y,z,t) = \int_0^{T_S} \frac{Q\exp\left[-\frac{(x-x^1)^2}{2\sigma_{x0}^2+4K_x(t+t^1)} - \frac{(y-y^1)^2}{2\sigma_{yx0}^2+4K_y(t+t^1)}\right]}{\{8\pi^3[\sigma_{x0}^2+2K_x(t+t^1)]\,[\sigma_{x0}^2+K_y(t+t^1)]\}^{1/2}} \times \left\{\frac{\exp\left[-\frac{(z-z^1-H)^2}{2\sigma_{z0}^2+4K_z(t+t^1)}\right]+\exp\left[-\frac{(z-z^1+H)^2}{2\sigma_{z0}^2+4K_z(t+t^1)}\right]}{[\sigma_{zx0}^2+2K_z(t+t^1)]^{1/2}}\right\} dt' \qquad (1)$$

where Q - the emission rate, µg/m^3; T_S - source operating time (realisation of emission), s; x', y', z' - current values of co-ordinates of an emission source: $X' = X_0 + U_{PL}t' + 0{,}5\ a\ t'^2 + U_W(t + t')$; $Y' = Y_0 + V_{PL}t' + 0{,}5\ b\ t'^2$; $Z' = Z_0 + W_{PL}t' + 0{,}5\ ct'^2$, x_0, y_0, z_0 - initial co-ordinates; u_{pl}, v_{pl}, w_{pl} - components of source speed vector; a, b, c –components of source acceleration vector, m/s^2; k_x, k_y, k_z - the turbulent diffusion coefficients, m^2/s and u_w - wind velocity, m/s; σ_i^2 - dispersions of contaminant dilution by jets, m.

Aircraft movements for July 2024 were analysed by aircraft group (large, medium, small, and regional), being July the month with the maximum number of operations (41659 movements). Fig. 2 shows the fleet at AAS, dominating the small or narrowbody aircraft category with a contribution of 58%. Aircraft emissions were estimated for individual aircraft/engine combinations. Fuel flow and emission indexes were applied for four standardized thrust settings during the LTO cycle: idle (7% of maximum thrust), approach (30%), climb-out (85%), and take-off (100%) (ICAO, 2022). The taxi modes and times were used in accordance with the observed configuration of the taxiways, whereas for take-off, climbing and approach the times-in-mode of the ICAO LTO cycle were applied.

Results and Discussion

Fig. 3 presents the estimated monthly emissions of CO, NOx, HC and nvPM, presented both categorized by aircraft type and as an aggregate total. Medium and small aircraft are major contributors to monthly NOx emissions, due to a high NOx emission rate and the fact that small aircraft make up a dominant portion of the airport fleet.

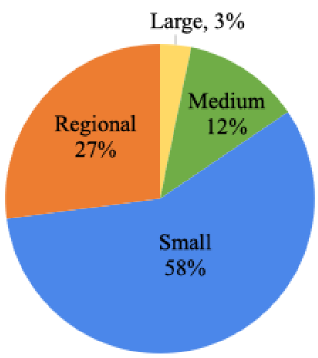


Fig. 2. Aircraft fleet structure

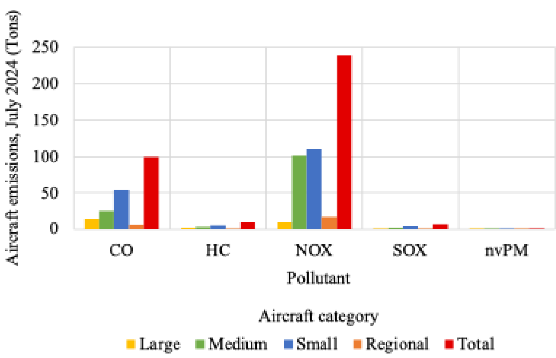


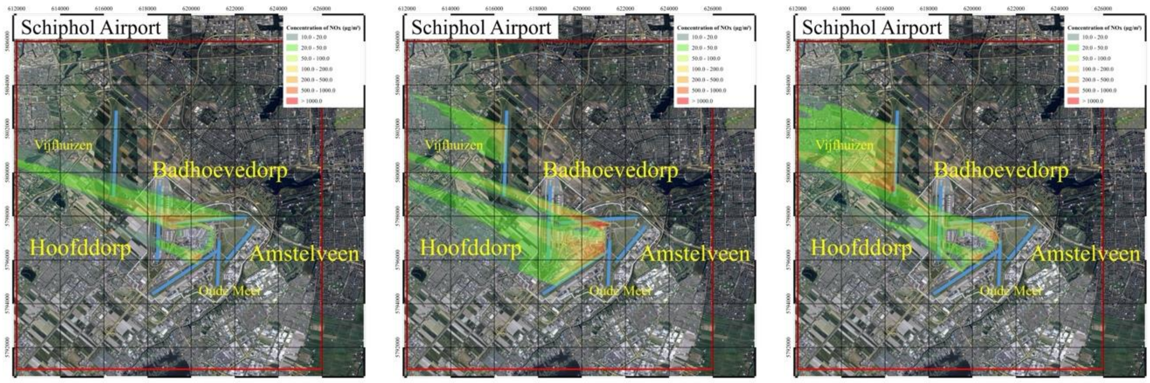
Fig. 3. Aircraft emissions in July, 2024

Hourly meteorological conditions for the study period were obtained from https://daggegevens.knmi.nl/klimatologie/uurgegevens, and the corresponding Paquill-Gifford classes were estimated in R based on the previous information. Dispersion modelling and analysis was performed for three peak hours with a different contribution of departure and arrival operations (Table 1, columns D and A). To assess whether the proportion of departure and arrival conditions affect the degree of air pollution, the scenarios were compared for the same meteorological conditions. NO_x, and particulate matter concentrations were estimated, presenting here only the results of NO_x estimation.

Table 1. Scenarios for LAQ studies at Schiphol Airport

Scenario	Time	D	A	Total	WD	WV	T	Class
Scenario 1	29/07/2024 08:00:00	35	65	100	110	4	20,6	C
Scenario 2	15/07/2024 12:00:00	55	36	91				
Scenario 3	31/07/2024 13:00:00	46	46	92				

The aircraft movements were modelled in the form of a moving source (line sources for aircraft on the taxiways and runway). The dispersion of the substance puffs emitted by the aircraft was modelled in a truly time-dependent manner with full vertical and horizontal resolution for engine jets including buoyancy and Coanda effects and further air stratification influence. Fig. 4. shows the results of the estimation of NO_x concentrations for each scenario.



Scenario 1: $C_{max} = 580 \mu g/m^3$ Scenario 2: $C_{max} = 1599 \mu g/m^3$ Scenario 3: $C_{max} = 754 \mu g/m^3$

Fig. 4. Hourly concentration of NO_x [µg/m3] for peak hour, scenarios 1, 2 and 3. The contour indicates Schiphol boundaries, including the buffer areas, while nearby localities are shown in yellow, and the blue lines correspond to the runways.

As shown in Fig. 4, higher NO_x levels are observed at the start of the runway, and on the taxiway prior to take-off. This can be explained by the higher fuel consumption in take-off conditions, including the phase where the aircraft is waiting in the queue to take-off with the engines running.

The simulation results for hourly NO_x concentrations depend on the contribution of departure operations during peak hours. The maximum NO_x concentration was observed in scenario 2, which had a higher number of departures (55 operations) — 1.6 times higher than scenario 1 (35 departures) and 1.2 times higher than Scenario 3 (46 departures), indicating that queueing and take-off generate more NO_x pollution than arrival operations. Note that as aircraft scenarios are based on observed aircraft movement data, the runway was different for different scenarios. In scenario 1, the upper left runway was only partially used and NO_x concentrations are not visible for the levels established in the legend. In scenario 2, the upper runway is used from north to south, but in scenario 3 in the opposite direction.

Simulation results also suggested that the NO_x produced by aircraft operation during LTO-cycles, although low concentrations are observed at the habitational area around Schiphol (localities shown in yellow in figure 4), are sufficiently diluted by exhaust gas jets and atmospheric diffusion and air quality standards (EU, 2008) are not exceeded for the simulated meteorological conditions. Hourly NO_x levels from aircraft emissions at Hoofddorp are 10 times lower than the hourly limit value for NO_x (200 $\mu g/m^3$). Other meteorological conditions might produce increased affectation to the population.

Conclusions and future work

The PolEmiCa model was used to estimate the effect of aircraft NO_x emissions at Amsterdam Schiphol Airport for the busiest day/hour in July 2024. High emission levels are found in a very localized area around the taxi-out queue and initial part of the runway. Although emissions do not arrive to the nearby locations, ground personnel working near the take-off area may be affected by pollutant emissions.

The results presented here do only consider aircraft emissions. The Schiphol area is crossed by very busy highways, where also important quantities of NO_x and other atmospheric pollutants are emitted (see, for example, https://www.atlasleefomgeving.nl/kaarten).

Future work includes the comparison of aircraft and highway pollution for both NO_x and particulate matter, the comparison of model results with air pollution monitoring information, and the determination of monthly and annual averages to assess both ambient exposition in nearby localities and occupational exposure limits for ground personnel.

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