Advanced Aircraft Emission Modeling

Development of LASPORT to model performance based aircraft emissions in the scenario mode

Contents

1. Introduction

1.1. LASPORT

The program system LASPORT (LASAT for Airports) allows for calculating the emission and atmospheric dispersion of trace substances originating from airport-related sources. The dispersion calculation is carried out with the Lagrangian dispersion model LASAT.

Based on preceding experiences with LASAT applications at airports in Germany and Switzerland, LASPORT was developed in 2002 on behalf of the Federal German Airports Association (ADV) as a standard tool for emission and dispersion calculations. Since 2003 it is available as commercial software package. It has been continuously adapted to the requirements of practical demands, including projects with EUROCONTROL and ICAO/CAEP studies.

LASPORT has been approved for use by ICAO/CAEP (ICAO Environmental Report 2010). The current program version is 2.0. [1]

Air traffic is defined either based on general traffic information (scenario calculation) or by means of a movement journal with individual aircraft movements (monitor calculations). Monitor calculations allow a detailed study of actual aircraft traffic. Individual emission strengths per movement and LTO phase and individual profiles can be applied, including performance based values and profiles derived by the integrated performance model ADAECAM [2].

1.2. Improvement of forecasting local air quality emissions and concentrations

Scenario calculations are well suited for present or for prognosis calculations for which no detailed traffic information is available and default values are being applied. This can specifically be the case for smaller aircraft where traffic information is only available per aircraft group or for forecast calculation where air traffic is available for an annual reference (or peak) day. However, the use of more generic information (in terms of emission values and profiles) results in a lower accuracy. It further disables a like-for-like comparison between studies using the monitor calculation approach and studies using the scenario calculation approach (e.g. for future scenarios).

The project thus addresses this issue with the goal of providing a performance based scenario calculation approach comparable to monitor calculations.

The federal government uses revenues from aviation fuel tax to fund measures relating to environmental protection, security and safety in the civil aviation sector (an amendment to Article 86 of the Swiss Federal Constitution). The FOCA is responsible for the distribution of funds for this form of special financing. This project here has been funded through this special financing of civil aviation by grant SFLV 2013-017.

2. Calculation descriptions

2.1. Current LASPORT calculation options

LASPORT offers a range of methodologies to calculate the aircraft emissions and concentrations. Figure 1 displays the options starting from a very simple approach (left side: ICAO Doc 9889) to the very advanced method (right side: performance model per movement).

The standard application is the performance model for each movement (monitor calculation). However, this requires the information on individual movements as provided by a flight journal. The information on the movement not only includes number and identification of the engine with its respective emission factors, but furthermore information on the ambient conditions (pressure, temperature, humidity) and the flight profile, which is inter alia derived with help from the stage length of the actual flight (great circle distance from Zurich airport to the flight destination).

An alternative option is the use of the scenario calculation where movements are given by one of seven groups of aircraft and default fuel flow and emission indices are available. While user defined times in mode (TIM) or profiles can be specified, there is no performance based calculation possible.

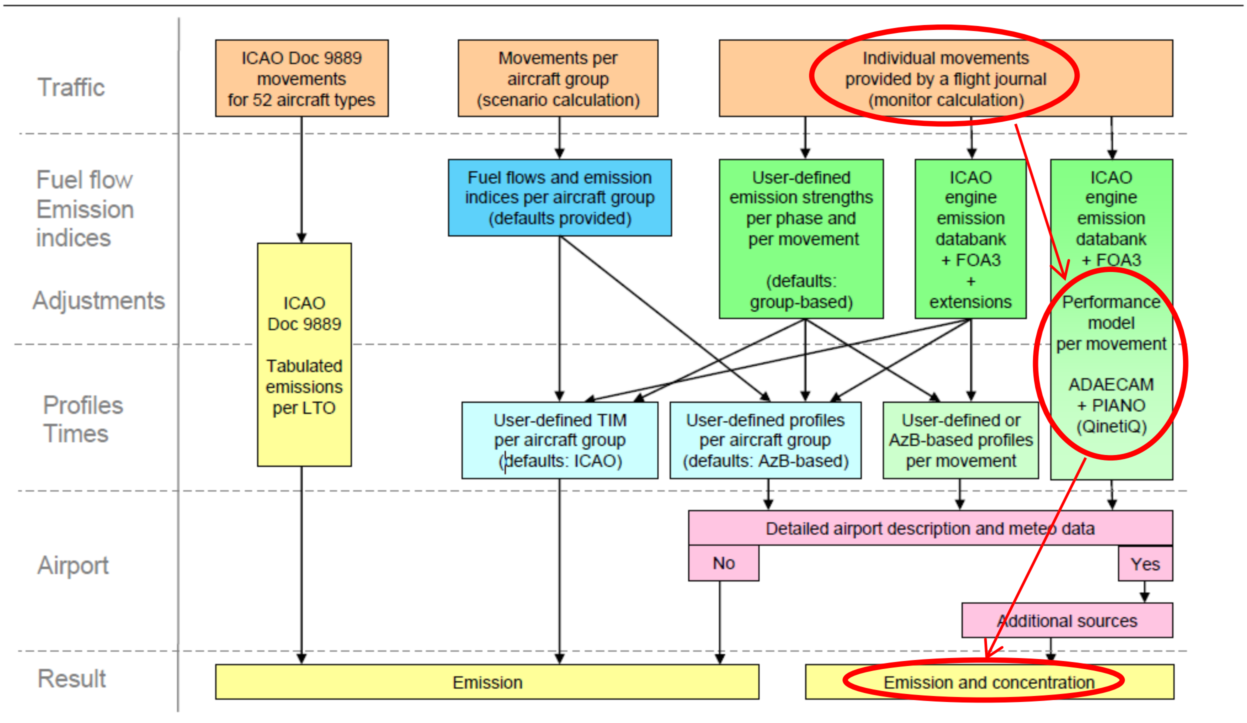


Figure 1 LASPORT calculation methodologies and best practise (red flow) [1]

2.2. Performance based scenario calculations

Aircraft emissions and profiles in the scenario mode are defined in the form of mean values or representative values. These values are the basis for the scenario calculation. They are also used for monitor calculations for aircraft movements, where no individual profile or emission value has been found. So far, the standard values offered by LASPORT were certification based (mean values on the basis of ICAO emission data base and AzB profiles).

The new version now provides the possibility to choose between certification based and performance based group values by introducing three new tables and a new parameter:

- Table: performance based emission values for aircraft groups
- Table: performance based arrival profiles
- Table: performance based departure profiles
- Parameter: Defaults base (can either be “Certification “ or “Performance”)

When evaluating the flight tables with individual emissions and profiles the mean emission information for each of the 6 LTO segments is determined (fuel burn and emission indices). The novelty now is that the average emission mass (product from emission rate and time in the segment) is calculated and additionally the most commonly used flight profile determined. This information, in the end provides the average emission values and profile for each aircraft group. These values can be imported into a study project. The simultaneous import of emission values and corresponding profiles enables the use of performance based values.

In case there is no flight table available for analysis, the system provides a set of default values (emission values and profiles) for each aircraft group. They are derived from a real airport annual average flight table. The user has the opportunity to edit these default tables, e.g. in order to simulate a technology improvement in one or several aircraft groups or of its home carrier (fuel efficiency, emission reduction).

The dispersion calculation has been adapted to account for the various turbulence parameters. They vary depending on whether a certification or a performance based set of data is used for the calculations. As they were determined by comparing DOAS measurements with certification-based concentration values, they had to be adjusted for performance-based concentration values. This “SigFac”-factor has been set at “SigFacCert” = 1.0 and “SigFacPef” = 0.6667.

3. Results for Zurich 2013

3.1. Study setup

The study uses the data from Zurich airport in 2013. Basis for the study are all aircraft movements between January 1st and December 31st. As the model development only addresses aircraft engine emissions, all other emission sources (other aircraft emissions, aircraft handling, airport infrastructure and landside access traffic) are not included in the study.

Figure 2 displays the various calculation methods applied:

- Monitor: certification emissions, performance emissions and performance based dispersion
- Certification scenario: certification emissions with defaults and its dispersions
- Performance scenario: performance based emissions with defaults and performance based dispersion

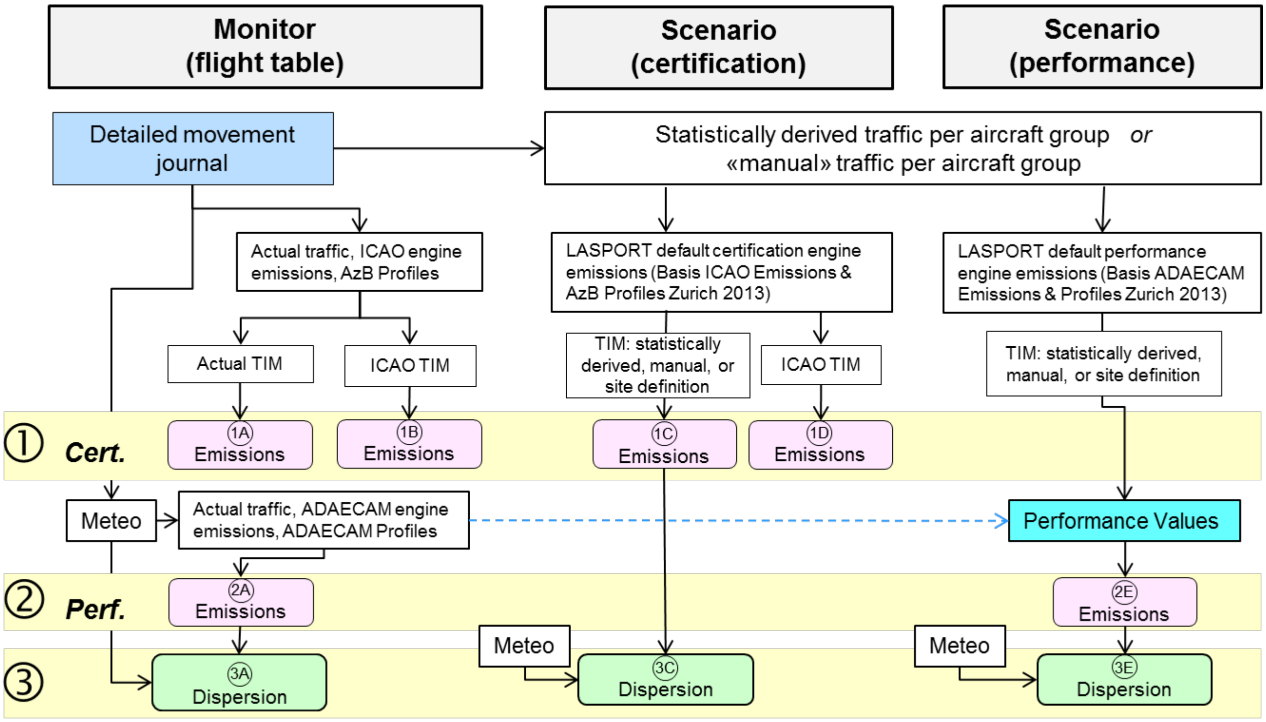


Figure 2 LASPORT study analysis: certification emissions, performance emissions, dispersions

The aircraft traffic in the two scenario modes are derived from a statistical analysis of the actual traffic table. The results – number of movements per aircraft group – could also be considered “manual” traffic, as this would be the case e.g. for a traffic forecast.

Actual engine emissions can also be statistically evaluated and used for defaults. However, LASPORT already provides default engine emissions that are more readily available for use in any forecast analysis. As such, emissions based on statistical evaluation of traffic and engines are not calculated, but instead, the default values used.

3.2. Certification based emissions

The certification based emissions (as ① in figure 2) only applies certification data: ICAO engine emission database with certification values, AzB profiles for aircraft. The emission results are shown in table 1 for the fuel burn and the various air pollutants.

Scenario #	**1A**	**1B**	**1C**	**1D**
Mode	Monitor	Monitor	Scenario	Scenario
Traffic	Actual	Actual	By aircraft groups	By aircraft groups
Emission factors	ICAO individual	ICAO individual	Group average	Group average
Flight profiles	AzB	AzB	AzB groups aver.	AzB groups aver.
TIM LTO	AzB	ICAO	AzB	ICAO
TIM taxiing	Real	ICAO	Calculated (length x speed + waiting)	ICAO
Defaults basis	Certification	Certification	Certification	Certification
Total Fuel (t)	92,825	107,781	84,806	107,921
Total NOx (t)	1,173.8	1,271.5	1,139.6	1,261.4
Total HC (t)	152.1	204.6	113.9	204.5

Table 1 Certification based emissions with LASPORT 2.1, Zurich airport 2013

The results demonstrate the differences in using real vs average vs standard data, but all without consideration of aircraft performance. Main findings:

- Scenario 1A presents the most accurate results for the given model choice and data.
- The differences between 1A/1B originate from times in modes (TIM) only and are very significant.
- The influence of using group averages vs actual information is shown in e.g. 1D vs 1B. These differences are small, as the group averages were derived from the actual Zurich 2013 flight data. Other years might show larger differences.
- Scenario 1A and 1C are expected to be likely similar, but are not. Further analysis showed the difference in the taxi phase, indicating the calculated time in mode (using trip length, average speed and adding a waiting time at the runway threshold) is too low. This is indeed the case and will be further discussed in the next section.

3.3. Performance based emissions

The performance based emissions (as ② in figure 2) introduces the performance based calculation: the model ADAECAM in the monitor mode and the new performance application in the scenario mode by way of the new tables and parameters. In this case, the "scenario (certification)" is not applicable anymore. Table 2 shows the various results and also compares the scenario certification and scenario performance mode.

Scenario #	**2A**	**2E**	**2E improved**	**Diff 2E impr. vs 2A**
Mode	Monitor	Scenario	Scenario	
Traffic	Actual	By aircraft groups	By aircraft groups	
Emission factors	ADAECAM individual	Performance based group average	Performance based group average	
Flight profiles	ADAECAM	Performance based	Performance based	
TIM LTO	ADAECAM	ICAO	ICAO	
TIM taxiing	Real	Calculated (length x speed + waiting)	Improved calculation (incl. de-icing)	
Defaults basis	Performance	Performance	Performance	
Total Fuel (t)	83,220	74,948	82,421	-1%
Total NOx (t)	954.7	919.2	948.8	-1%
Total HC (t)	181.3	135.7	170.9	-6%

Table 2 Performance based emissions and comparisons, Zurich airport 2013

The results of first 2A and 2E show the influence of a performance based approach vs a simpler certification based approach. Further they show the differences in using actual vs average performance data. Main findings:

- Scenario 2A presents the most accurate results for the given model choice and data.
- The differences between 2A/2E originate from times in modes (TIM) only and are very cant: -27% Fuel burn and -28% NOx in the taxi phase.

3.4. Taxi phase differences

As demonstrated in tables 1 and 2, differences are significant in the taxi phases between using actual data and calculated for the time in mode. LASPORT 2.1 provides the default values of 8.3 m/s taxi speed and 4 minutes waiting time before take-off. These data can be modified in the user interface.

Some detailed analysis has been performed for the arrival taxi-times and the departure taxi-times. Differences between actual and calculated taxi-times have been observed for landings (modeled times generally too short), but with the opposite for landings runway 34 (modeled times too long) and for departures (significant differences), as the de-icing times at the de-icing pads have not been considered.

In consequence several parameters have been re-calculated with the average taxi speed being lowered to 6.9 m/s and the waiting time increased to an average of 6 minutes per departure (to account for de-icing). Additionally the taxi-route for landings runway 34 has been modified.

The results of the modified calculations are listed in table2, scenario “2E improved” for the performance based approach. They now show differences of only 1% for fuel burn and NOx and 6% for HC.

3.5. Dispersion modeling

The resulting concentration of NO_2 (annual mean value) is displayed in figures 3 through 6. The dispersion modeling takes the performance based aircraft emissions from the movement journal as well as the meteorological time series of 2013 as the base case.

- Figure 3: Emission scenario 2A: performance based, detailed/actual monitor calculation (best case)
- Figure 4: Emission scenario 1C: certification based scenario approach
- Figure 5: Emission scenario 2E: performance based scenario approach

As the visible differences are rather small, a difference calculation has been performed of both those scenarios against the base case (figure 6).

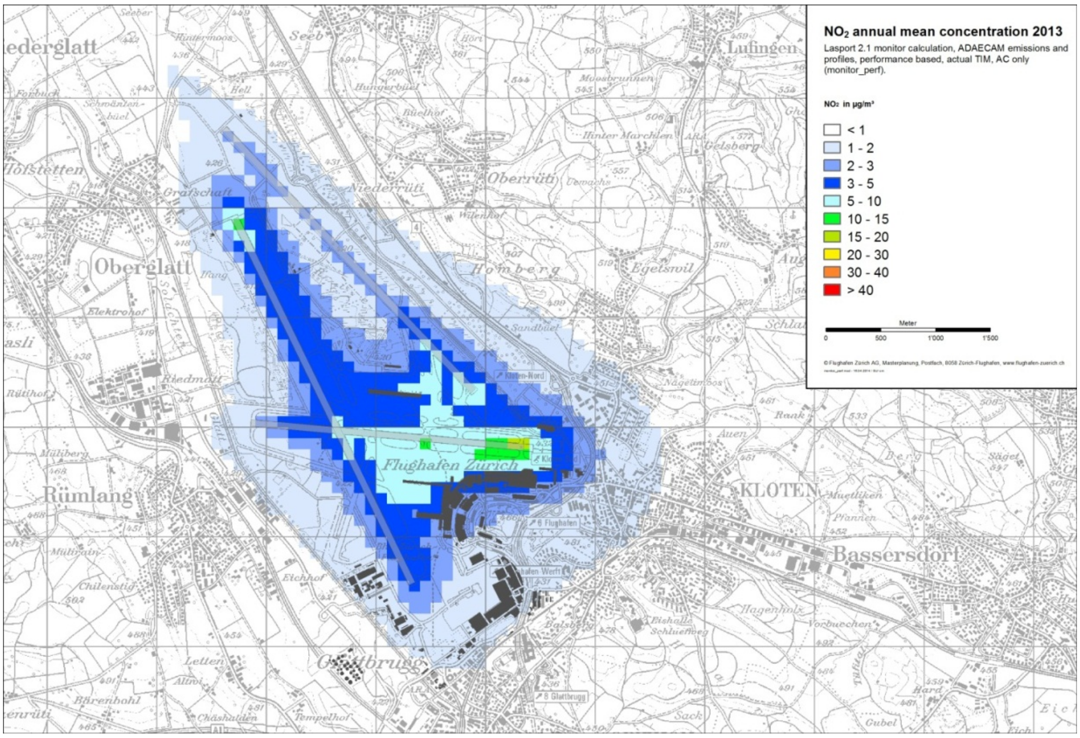


Figure 3 NO_2 annual mean concentrations Zurich airport 2013 from emission scenario 2A

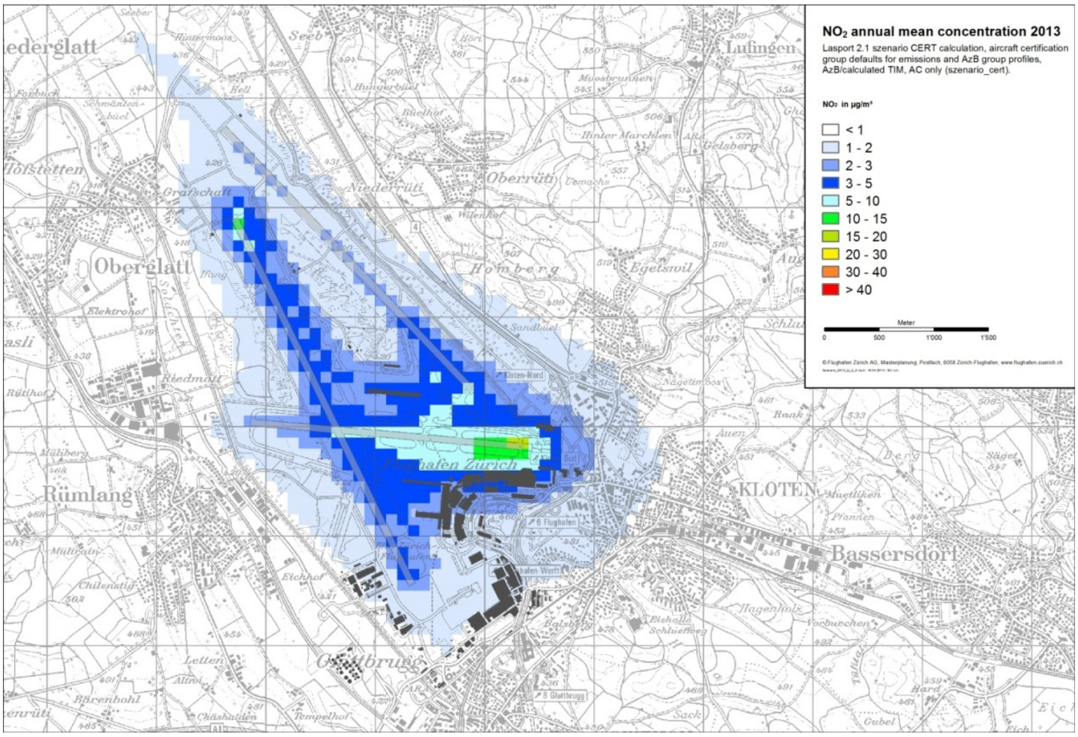


Figure 4 NO$_2$ annual mean concentrations Zurich airport 2013 from emission scenario 1C

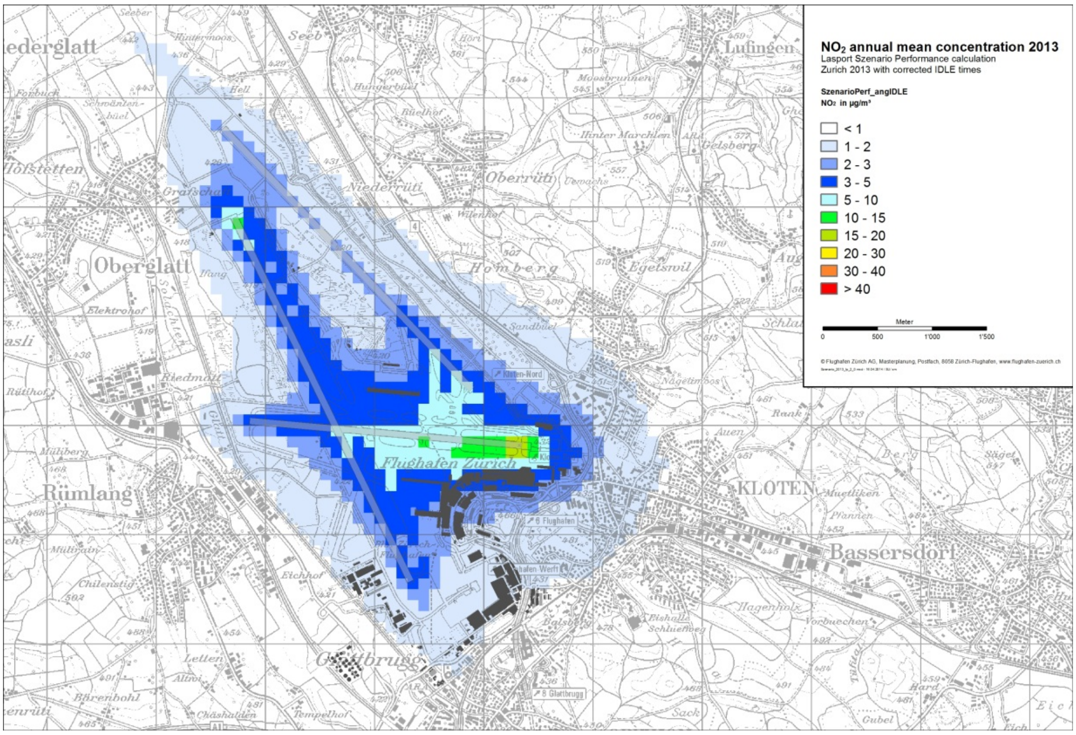


Figure 5 NO$_2$ annual mean concentrations Zurich airport 2013 from emission scenario 2E improved

The difference between the best case (performance based monitor calculation) and the performance based scenario approach (improved version) show differences ranging from -1μg/m^3 to +3μg/m^3, with the majority of the differences being between +/- 1μg/m^3. The use of a performance based scenario approach for a concentration modeling thus does not differ significantly from a performance based monitor approach.

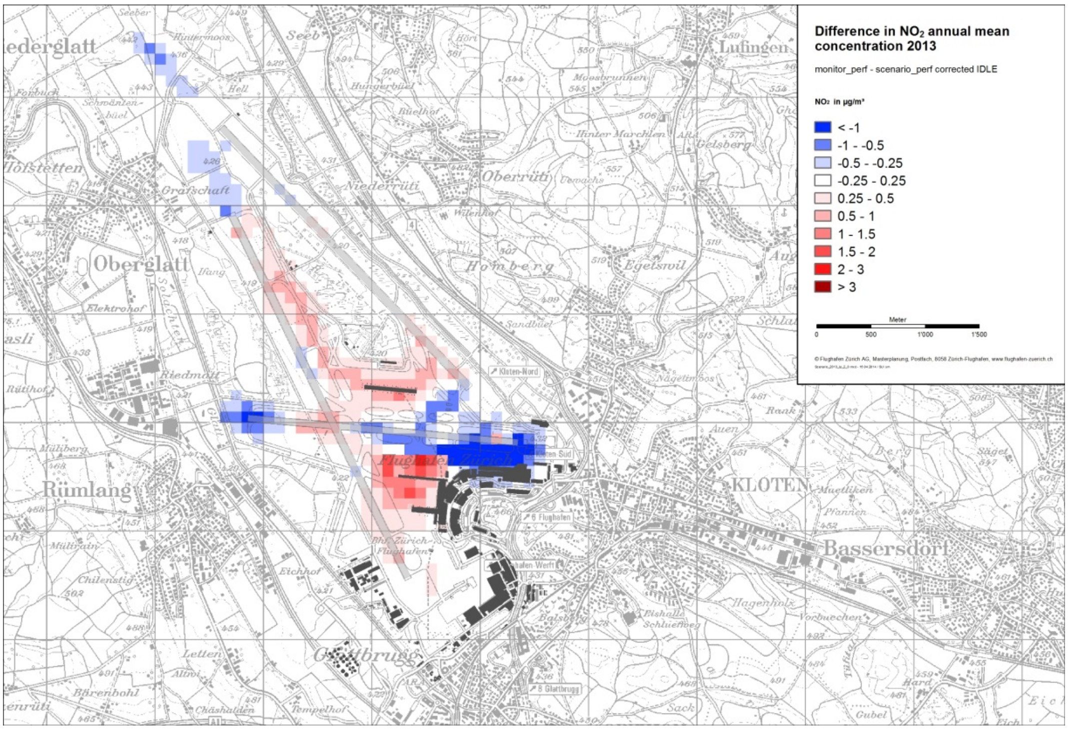


Figure 6 NO_2 annual mean differences concentrations Zurich airport 2013 (figure 3 minus 5)

4. Application with a different airport

The project development includes information specifically derived from Zurich airport operations in 2013. It is thus anticipated that the model development best suits Zurich airport. As such, detailed analysis has been performed for a different airport where data was available.

Specifically, performance emission calculations were performed both in the monitor mode (using ADAECAM) and in the scenario mode (using group averages). The results are listed in table 3.

First results show rather large differences (e.g. 24% for fuel burn). Further analysis revealed that the use of the Zurich airport based default values may have an undue large impact on the results. In consequence, the table with the default performance based emission values per aircraft group had to be replaced with defaults that better reflect the airport's actual fleet mix. For this purpose, a simplified movement journal has been created, using proportionally the main aircraft types operating at that airport and including all model required minimum data. The simplified movement table has then been used together with the proper meteo data to recalculate the aircraft group default performance based emission values.

The new results are also displayed on table 3, showing a much better correlation to the best case.

Scenario #	**Monitor**	**Scenario (ZRH)**	**Scenario (own)**
Mode	Monitor	Scenario	Scenario
Traffic	Actual	By aircraft groups	By aircraft groups
Emission factors	ADAECAM individual	Performance based group average Zurich airport	Performance based group average own airport
Flight profiles	ADAECAM	Performance based	Performance based
TIM LTO	ADAECAM	ICAO	ICAO
TIM taxiing	Real	Calculated (length x speed + waiting)	Calculated (length x speed + waiting)
Defaults basis	Performance	Performance	Performance
Total Fuel (t)	100%	124%	117%
Total NOx (t)	100%	114%	107%
Total HC (t)	100%	226%	117%

Table 3 Emission analysis for different airport

The remaining differences are again mainly caused by the differences in the taxi phase (54% for fuel burn, 44% for NOx, 23% for HC). Given the previously discussed improvement process for Zurich airport, it is reasonably assumed that a similar improvement process for this specific airport would as well improve the overall results. This improvement process would have to include the revision of the taxi speed, the waiting time before take-off and any additional de-icing times (added to the departure taxi time).

5. Application with a different year

The derivation of the default parameter tables is based on actual Zurich airport operations in 2013. This has proven very good correlation to the best case. As the fleet mix usually changes gradually over the years, the default data used may be showing increasing deviations.

This effect has been studied using the Zurich airport 2009 traffic data, evaluated by aircraft groups. Such an application would also be very typical for a scenario into the future.

Scenario #	**Monitor 2013**	**Scenario (2013)**	**Scenario (2009)**
Mode	Monitor	Scenario	Scenario
Traffic	Actual 2013	By aircraft groups 2013	By aircraft groups 2009
Emission factors	ADAECAM individ-ual	Performance based group average Zurich 2013	Performance based group average Zurich airport 2013
Flight profiles	ADAECAM	Performance based	Performance based
TIM LTO	ADAECAM	ICAO	ICAO
TIM taxiing	Real	Calculated (im-proved)	Calculated (im-proved)
Defaults basis	Performance	Performance	Performance
Total Fuel (t)	100%	99%	104%
Total NOx (t)	100%	99%	103%
Total HC (t)	100%	94%	104%

Table 4 Emission analysis for different traffic year (Zurich airport)

The results show a good correlation with the monitor calculation. A certain difference has to be expected, as the fleet mix in general and specifically for each group changes over time. The main differences have been caused by the aircraft groups “Turboprop”, “Business” and “Regional”.

6. Conclusions

The development to include the option for modeling performance based scenarios is a significant improvement of the overall modeling capabilities of LASPORT. It enables users to obtain not only best case results for present or past situations by using the performance based monitor approach, but also obtain same level information for scenarios in the future. This is important for comparing emission inventory development on the same level (performance based) and subsequent dispersion calculations as well.

In addition, several more observations have been made in the application of the LASPORT model that help to improve both the overall understanding of the model tool and the accuracy of the results.

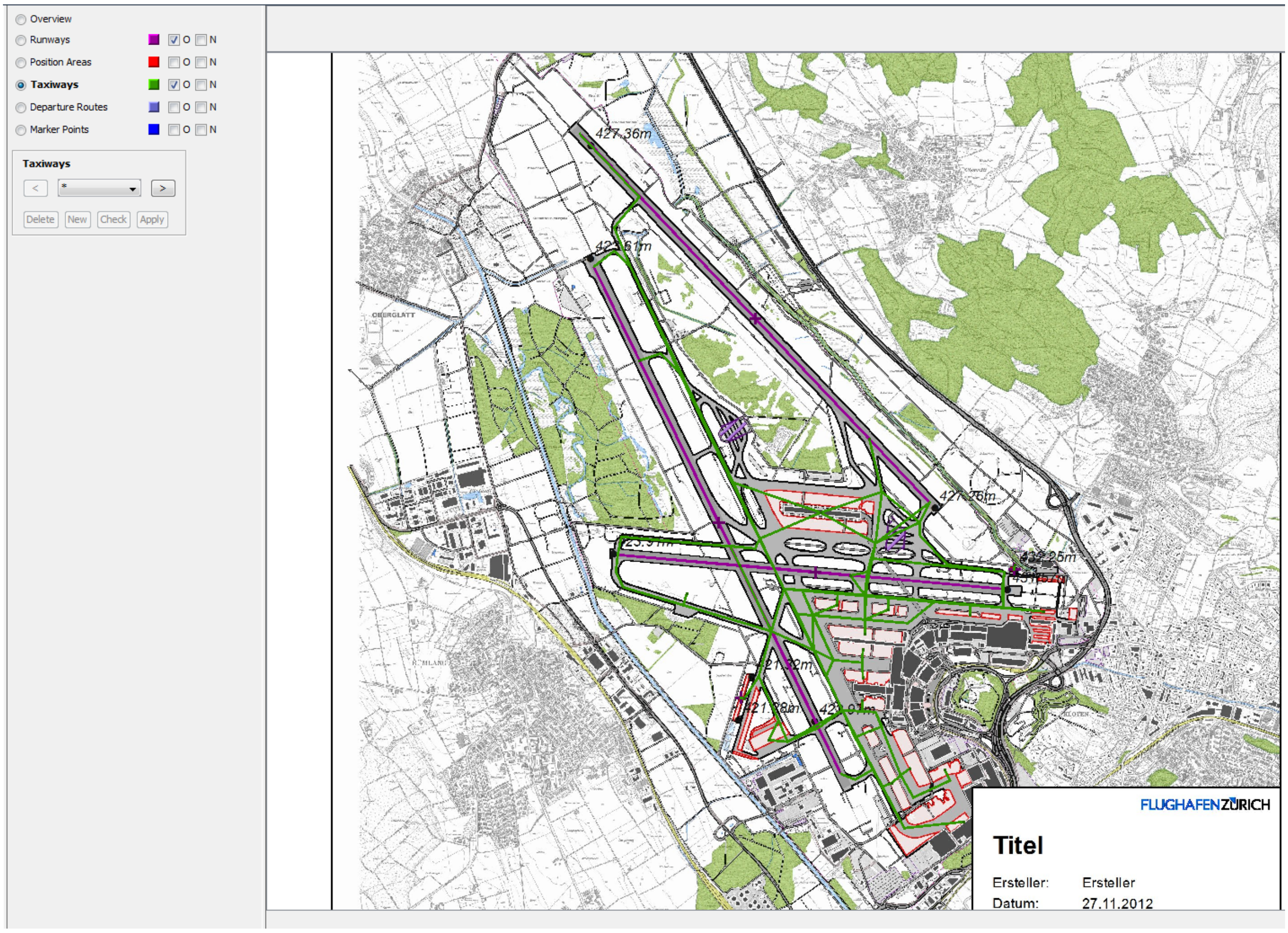
- LASPORT now offers a range of different calculation and modeling approaches: simple aircraft list, monitor or scenario calculation which are certification or performance based. The choice of approach depends on the specific problem, the required accuracy and the availability of data and information. Caution has to be exercised when modeling situations that will be compared and the user has to make sure that like-to-like study setups are then compared (e.g. performance with performance or actual TIM with modeled dynamic TIM).
- While LASPORT offers several operational default values, the user has to crosscheck the applicability of such default values. This holds true in particular for the time of the LTO-phase “taxi” as this is highly site specific. The available parameters are default taxi speed in m/s and the default queuing time in minutes. These parameters should reflect actual operations at that airport. So far, the option of de-icing operations has not been specifically included: at some airports, de-icing is performed at central de-icing pads with the aircraft’s engine operating. This idle time is automatically included in the taxi time when using the monitor data with off-block and take-off time, but has to be added when using the site defined information with taxi distance and speed plus queuing time.
- The newly introduced performance based default emission values have been based on Zurich airport actual aircraft traffic. This traffic differs at other airports and the resulting emission differences can be significant. As such, it is recommended to first develop site applicable performance based default values that better reflect the fleet mix at that airport and replace the existing parameters delivered by the system. This can be done with an actual movement journal and menu items provided by LASPORT and it increases the accuracy of the results considerably.

Annexes

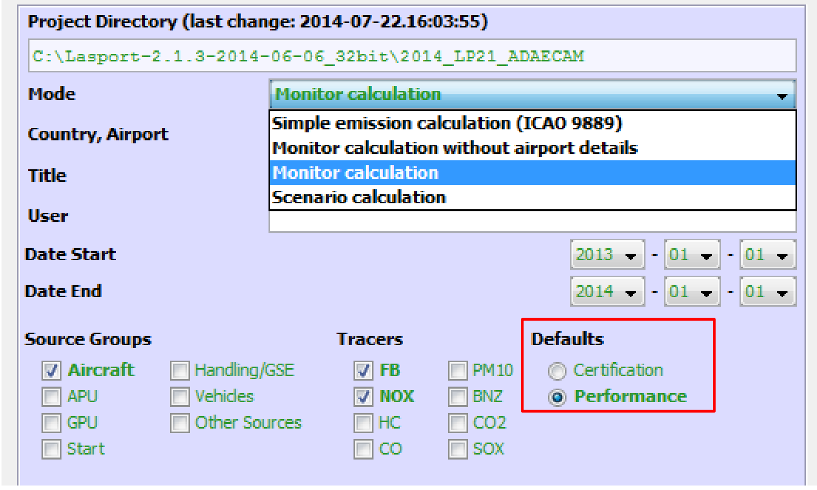
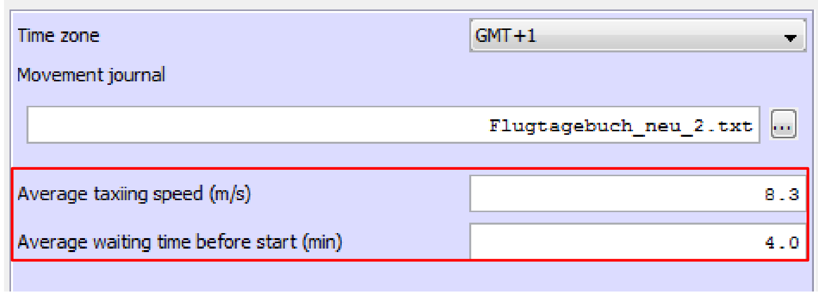
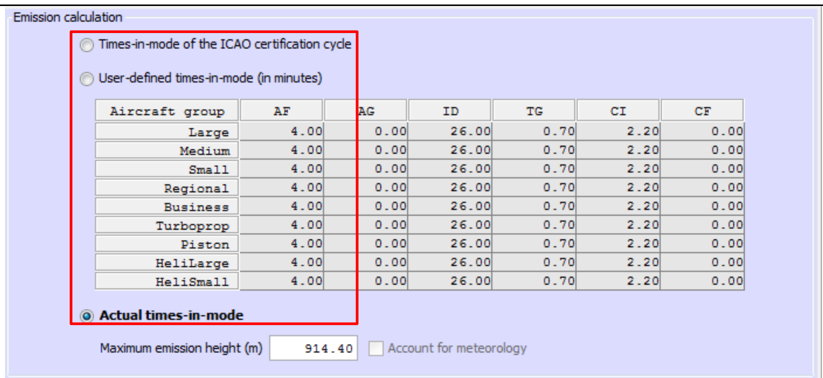
A.1. Abbreviations

ADAECAM	Advanced Aircraft Emission Calculation Model
AzB	Anleitung zur Berechnung von Lärmschutzbereichen (Germany)
FOCA	Federal Office for Civil Aviation (Switzerland)
h	Humidity
HC	Hydrocarbon
ICAO	International Civil Aviation Organization (Canada)
LASAT	Lagrangian Simulation of Aerosol Transport
LASPORT	LASAT for Airports
LTO	Landing and Take-Off (aircraft movement below 3,000 ft)
NO_2	Nitrogen Dioxide
p	Pressure
t	Temperature
TIM	Times in Mode
ZRH	Zurich Airport, Switzerland

A.2. Zurich airport layout in LASPORT



A.3. LASPORT screen pictures

"Project" Choice of mode and defaults basis	
"Parameters" Taxi speed and waiting time	
"Analysis" Times in Mode	

Figures

Tables

Sources

No.	Document Name
[1]	www.janicke.de (Products / LASPORT), 14.04.2014
[2]	G C Horton, C J Eyers (QinetiQ): An advanced method for calculating the emissions from aircraft engines in the vicinity of airports. QinetiQ/07/02460. October 2007
[3]	Janicke, Ulf: Erweiterung von LASPORT auf leistungsbasierte Szenario-Rechnungen. Juni 2014
[4]	Flughafen Zürich AG / Maraini, Silvio: Luftschadstoffmodellierungen mit Lasport 2.1. August 2014

Version	Date	Name	Modifications
1	27.8.2014	Fleuti	

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