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Aircraft noise assessment of next-generation narrow-body aircraft

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ABSTRACT
A new generation of aircraft types equipped with modern high-bypass-ratio turbofans (such as A320neo) is currently introduced to the global air traffic, promising significant reductions in fuel consumption and engine noise. In only three years, over 1,000 new aircraft were delivered and more than 11,000 are already ordered. Furthermore, new technologies and concepts are under development to simultaneously reduce the airframe noise. In this paper, a typical single-runway medium-sized airport, dominated by movements of narrow-body aircraft, is assessed for the noise impact of new technology aircraft. Four future scenarios are compared to the reference year 2015. The scenario 2025 assumes a share of 40% next generation aircraft, for those aircraft types where a successor is foreseeable, i.e., featuring high-bypass-ratio turbofans. For scenario 2035, a share of 70% of these next generation aircraft is assumed. It was found that such a modification of the future aircraft fleet reduces the sound exposure despite the growth in the air traffic. Finally, two new low-noise aircraft concepts with additional low-noise airframe technology and engine noise shielding were introduced to predict the noise reduction potential for the far future. These novel aircraft showed a strong effect on the noise contours with further reductions in the affected areas of up to 37%. The presented results are an application of the recently developed simulation process between DLR and Empa to include existing and new aircraft types in large scenario noise studies.

1. INTRODUCTION

Currently, the global aircraft fleet composition is subject to major changes. Many new narrow-body as well as wide-body aircraft are introduced, providing significant reductions of fuel consumption, pollutants, and noise. In particular, the most frequent aircraft types, such as the A320 family and the B737 new generation have been redesigned with modern high-bypass-ratio turbofans. With over 11,000

orders to date, Airbus and Boeing both plan to increase the production rate to 57 to 60 aircraft per month in 2019 [1, 2], which will quickly impact the global aircraft fleet composition, with consequences on the noise around airports.

The prediction of future aircraft noise scenarios requires a detailed flight plan modelling as well as high-quality aircraft noise emission models. Previous studies, such as [3, 4], focused on the flight plan modelling and on airports with two or more runways. However, the modelling of the noise emissions of novel aircraft is based on simple assumptions such as absolute or relative reductions of the total aircraft noise level.

In this paper, we focus on a high level of detail modelling of the aircraft noise emissions. Therefore, we combine the Parametric Aircraft Noise Analysis Module (PANAM), which is used for the single-event noise assessment of novel aircraft types, and sonAIR, which is used for the assessment of future scenarios based on a mix of current and novel aircraft types. In addition, the study examines a medium-sized airport with traffic limited to one runway, as applicable for about half of the civil airports in Europe. Compared to the existing studies on large airports, we thus focus on the influence of a new generation of narrow-body aircraft. Two scenarios, with a 10 and 20 year time horizon respectively, answer the question if the developments in the aircraft fleet compensate the air traffic growth. Furthermore, the study examines the potential of innovative low-noise aircraft designs.

2. METHODS

The calculation of future aircraft noise scenarios in this study is based on the simulation tool chain recently established and described within Ref. [5]. The approach depicted in Figure 1 allows assessing (1) novel technology and vehicles for their individual flight procedures (PANAM) and (2) the effect if these vehicles operate in a larger fleet consisting of novel and existing vehicles (sonAIR). Input data for the single flight assessment with the PANAM [6] are comprised of aircraft design and flight performance, engine design and performance, applied technologies, and flight procedures. Based on the noise prediction results, input variables can be selected for further adaption and optimization. If a promising and optimal solution, i.e., vehicle and individual flight procedure, is identified, the results can be included in the scenario for the overall scenario noise assessment.
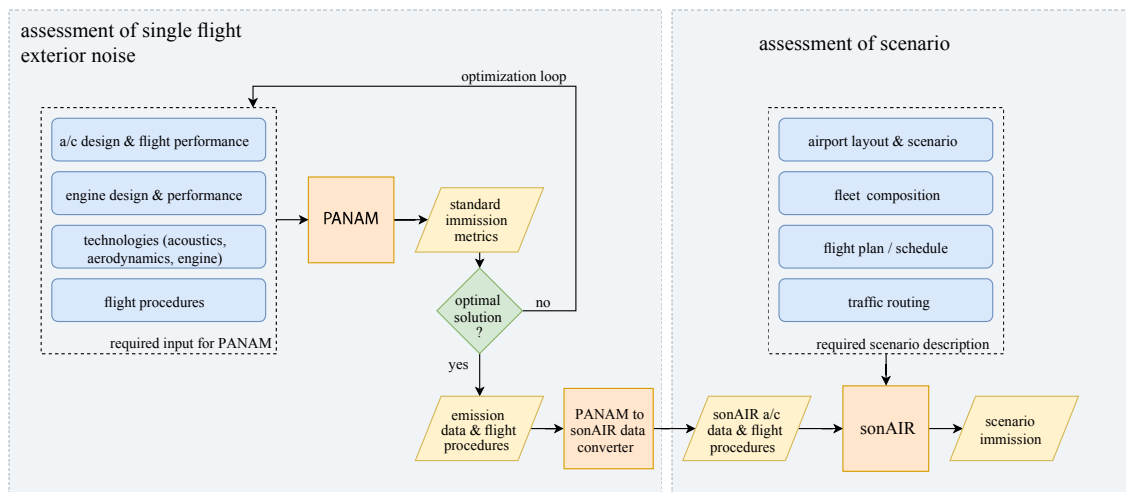

Figure 1: Combined aircraft noise assessment approach for new aircraft designs via PANAM (left box) and scenario calculations with current and next-generation aircraft types via sonAIR (right box).

The tool sonAIR [7] introduces the new vehicles into its existing emission data base, in the form of an aircraft-specific emission data set (containing all relevant operating conditions), to ultimately predict noise contours for future scenarios. Thereby, the scenario is defined by the airport layout, the fleet composition, the flight plan, and the traffic routing. For this study, the fleet mix and flight plan are varied whereas the airport layout and the traffic routing are kept constant.

2.1 Aircraft noise emission models

As mentioned, two different high-fidelity aircraft noise emission data sets are combined to cover current technology aircraft types (CT) as well as next generation aircraft types (NT-1 and NT-2). The abbreviations for the different levels of technology were adapted from Ref. [3], with CT indicating entry-into-service prior to the year 2007 and NT-1 after 2007. The latter are thus currently still being introduced into the market. NT-2 indicates a future aircraft generation succeeding NT-1.

For this paper, a reference aircraft and five novel low-noise aircraft concepts have been selected from a previous study [8] in order to assess the overall impact of these vehicles integrated into an airport scenario.

- ceo: reference aircraft similar to an A321 with turbofan (tf) engines similar to CFM56-5A (called "zero" in [8])
- neo: variant of ceo with geared turbofan (gft) engines similar to PW1133G
- neo (af): variant of neo with low-noise airframe technology (af)
- neodapt: variant of neo, aircraft design adapted to gtf engines
- neodapt (af): variant of neodapt with low-noise airframe technology
- fanex: noise shielding architecture, gtf engines and low-noise airframe technology

PANAM [6] models airframe and engine noise sources individually with a high level of detail. Most importantly, novel aircraft concepts and modifications to individual noise sources, e.g., a low-noise treatment of the landing gear, can be described. As an example, the neodapt (af) and the fanex with applied low-noise technologies are depicted in Figure 2.
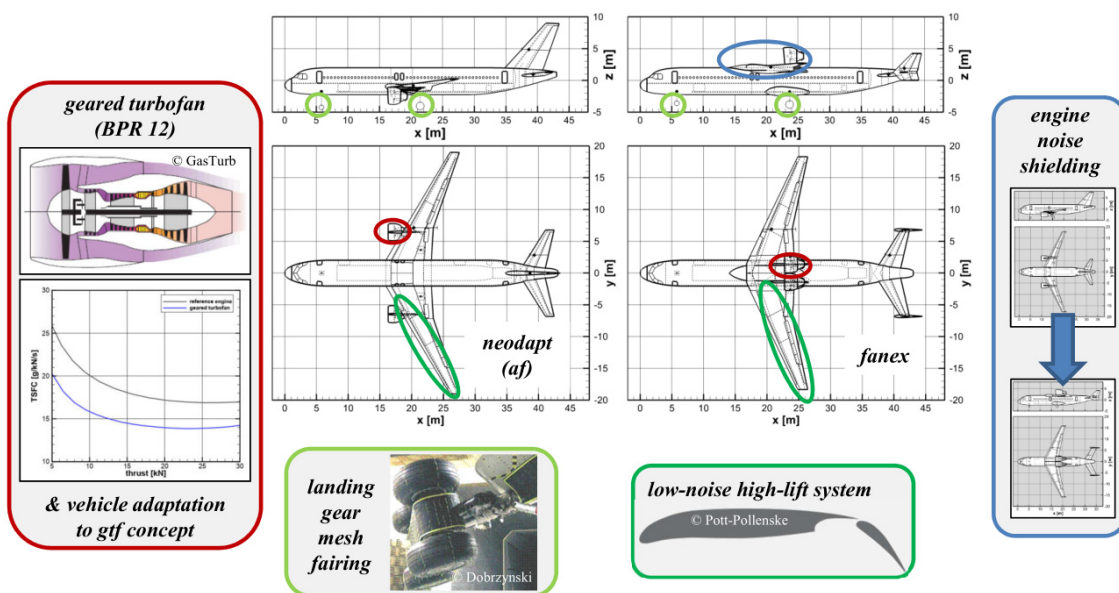

Figure 2: NT-2 aircraft designs and technologies

Modifications to the engine (geared turbofan vs. turbofan), the airframe (high-lift and landing gear), and the overall vehicle architecture (shielding and adaptation) are included for these vehicles in Figure 2. Detailed information about aircraft design, engine design, the low-noise technologies, and the resulting flight performance can be found in Ref. [8].

Eight additional aircraft types that are in current operation were adopted from sonAIR [9, 10]. The sonAIR model is based on measurements of real air traffic and uses a statistic approach that separates airframe and engine noise in dependency of the main flight parameters. In addition, emission data for business jets and large turboprop aircraft were included from the Swiss Aircraft Noise Calculation Database (SANC-DB, [11]). The complete list of the aircraft noise emission models, their technology level, and their origin are summarized in Table 1. All aircraft noise emission data sets describe the source by sound emission spheres based on one-third octave bands and are dependent on various flight parameters. Consequently, PANAM, sonAIR, and SANC-DB noise emission datasets could be combined in the emission lookup table for sonAIR.

Table 1: Aircraft and engine types applied in this study (existing aircraft are referred to as CT, aircraft that are currently introduced as NT-1 and novel aircraft as NT-2)

Aircraft type	Engine series	Origin	Technology
A333	TRENT7	sonAIR	CT
B737 NG	CFM56-7B	sonAIR	CT
B788	Genx-1B	sonAIR	NT-1
BCS1	PW1500G	sonAIR	NT-1
BCS3	PW1500G	sonAIR	NT-1
Business jets	PW500	SANC-DB	CT
ceo	tf similar to CFM56-5A	PANAM	CT
E190	CF34-10E	sonAIR	CT
F100	TAY650-15	sonAIR	CT
fanex	gtf similar to PW1133G	PANAM	NT-2
neo	gtf similar to PW1133G	PANAM	NT-1
neo (af)	gtf similar to PW1133G	PANAM	NT-2
neodapt	gtf similar to PW1133G	PANAM	NT-2
neodapt (af)	gtf similar to PW1133G	PANAM	NT-2
RJ1H	LF507	sonAIR	CT
Turboprops	AE2100J	SANC-DB	CT

2.2 Flight profiles

Individual mean flight profiles for approach and departure were used for all aircraft. For the emission models originating from sonAIR, mean flight parameters were derived from real flight trajectories, i.e., CT and NT-1 vehicles. The profiles of future aircraft from PANAM, i.e., NT-1 and NT-2 vehicles, were adapted to account for modified flight performance due to the different engines, low-noise technology, or vehicle layout (more information can be found in Ref. [5]). For the two remaining CT aircraft models from the SANC-DB, predefined profiles from the same database were used.

The individual profiles for approach and departure include the parameters altitude, airspeed, N1, density and aircraft configuration (flap and landing gear setting) in dependency of the ground distance covered along the ground. For all combinations of these parameters, noise emission data sets are available or will be interpolated for the noise prediction.

2.3 Aircraft noise calculation

The calculation of the noise footprints per aircraft and route as well as the calculation of the scenarios was performed with the ArcGIS-implemented calculation tool of sonAIR[3]. First, the input data (airport, terrain, ground cover) were prepared and flight trajectories were constructed by merging flight profiles and flight tracks. Then, the sound propagation was calculated using the propagation model sonX and each single flight was simulated (see Ref. [7, 12]). Finally, the scenarios were calculated by the superposition of the footprints using their individual statistics of movements, which are described in Section 3.

For the calculation of the noise exposure, no empirical equation for the lateral attenuation was used. Thus, the typical narrowing of the contours parallel to the runway cannot be found in the results of Section 4. The reason for this approach is the fact, that some effects that are usually covered within the lateral attenuation are already included in the calculations with sonAIR: First, the installation effect is included within the three-dimensional directivities of the emission models. Second, a physical calculation of the ground reflections is applied based on a Fresnel zone approach by the sound propagation model [7].

In addition, the sound propagation model allows to account for meteorological effects due to the gradients of temperature and wind. In this paper, the authors simplified the calculations assuming a homogenous atmosphere. Thus, the effects, which are usually combined in the lateral attenuation correction are not completely covered and are subject to ongoing work.

3. SCENARIOS

Five scenarios were calculated, studying the influence of future air traffic growth and of a quieter aircraft fleet. The reference scenario is based on the year 2015 and considers CT aircraft types only. Furthermore, two future forecast scenarios were calculated, one for a ten and another for a twenty year time horizon (scenarios 2025 and 2035). Assumptions were made for the air traffic growth as well for the pace of introduction of NT-1 aircraft types. *With these scenarios, we predict if the development of the fleet in the near future is able to compensate the growth of the air traffic in terms of ground noise exposure.*

The two remaining scenarios are explicitly undated (20XX-1 and 20XX-2) and focus on the development of the fleet in the far future after the year 2035. The number of flights is kept constant after 2035, while a rising share of NT-2 aircraft types is assumed. *The scope of these scenarios is to analyse the potential of innovative low-noise aircraft designs in terms of ground noise exposure.*

3.1 Airport

The study focusses on a typical medium-sized airport with a single runway. A virtual airport environment is used as the framework for the aircraft noise calculations. For this purpose, the airport area and parts of the input data of the Swiss Aircraft Noise Calculation Test Environment (SANC-TE) [13] were used. The latter included an artificial terrain, land cover data and idealized flight tracks including subtracks as depicted in Figure 3.

3.2 Air traffic growth

For the year 2015, a baseline of 160,000 movements was defined for the daily movements on the virtual SANC-TE airport. For comparison, that number corresponds to the number of movements for Geneva airport. The growth rate was

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[3] Implementation and distribution by n-Sphere, www.n-sphere.ch

assumed to be moderate, as a typical medium-sized European airport generally has a slower growth rate than the international mean [14].

For the first decade from 2015 to 2025, a yearly growth rate of 1.5% was used. Following the Airbus market forecast [14], which predicts a slight slowdown of the worldwide growth, the rate was decreased to 1% p.a. for the following decade until 2030. The total number of flights for 2025 adds up to 185,687 and to 205,113 for the year 2035, respectively. Based on a limit of 36 flights per hour during daytime from 6 a.m. to 10 p.m. [15], a single-runway airport can handle a maximum number of around 210,000 flights per year. Thus, the growth rate of the airport is also restricted by the capacity limit of the airport during daytime. At night, i.e., between 10 p.m. and 6 a.m., a ban on night flights was enforced. This applies to the NT-2 vehicles also, to focus on the 16h-L_{eq} at daytime.

The scenarios 20XX-1 and 20XX-2 are based on the same number of movements as scenario 2035, assuming limited airport development options, e.g. by building a second runway (due to political decisions or site restrictions).
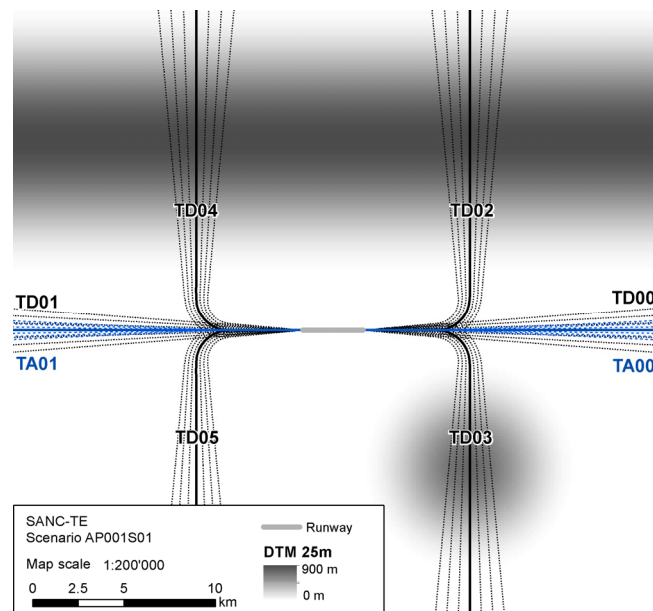

Figure 3: Input data for the scenarios from SANC-TE: topography, runway, five departure tracks (solid black lines, TD0X), two approach tracks (solid blue lines, TA0X), and their sub-tracks (dotted / dashed) are depicted (from [5]).

3.3 Aircraft retirement and introduction

The key modification to scenarios 2025 and 2035 with respect to the reference scenario is the introduction of the neo and the subsequent retirement of ceo[4]. The Airbus Market Forecast predicts a fleet size evolution in Europe of +190% until 2037 [14]. Due to the replacement of retired aircraft only 22% of the aircraft fleet from 2018 will still be in service in 2037. To date (January 2019), 8,135 ceo have been delivered globally (from Ref. [16]), with only 157 ceo still due for delivery. We assume that no new ceo orders will be placed, as 6,526 neo were ordered already (from [17]).

For the prediction of the retirement of the ceo, a cumulative distribution function (CDF) of a normal distribution was used as aircraft survivor curve.

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[4] In this study, the terms ceo/neo refer to the entire A320 family, with current and new engine option respectively.

Narrow-body aircraft have a mean retirement age of approx. 27 years [18], which is set as the mean value of the CDF. A standard deviation of 5 years accounts for a smooth phase out. Combining the aircraft survivor curve with the actual age structure of the ceo, the future fleet size of the worldwide ceo family is predicted. For the end of 2018, the method predicts 320 retired aircraft, which is close to the currently 356 retired ceo. For the future, around 970 ceo will be retired by the end of 2024 and 3,400 ceo by the end of 2034.

The introduction of the neo on the other hand is expected to be fast, as Airbus received a high number of orders and already delivered 635 aircraft in the first three years of production. Furthermore, Airbus plans to increase the production capacity to 60 aircraft per month in the year 2019 [2]. In 2018, the production capacity of ceo and neo has already been at 52 aircraft per month and can be solely used for the production of neo from 2020. Similar results are obtained, regardless if a production rate of 52 or of 60 aircraft per month is assumed: At the end of 2024 the global fleet is predicted to consist of approximately 60% ceo and 40% neo. By the end of 2034, the neo is predicted to have outpaced the ceo with a market share of approximately 70%.

Both predictions are subject to high uncertainties, as the oil price or a financial crisis could strongly influence the mean age of retirement, the demand on aircraft and the production capacity. In addition, if Airbus continues with a production rate of over 52 aircraft per month until 2034, a demand for more than 10,500 neo aircraft would be required by then.

3.4   Aircraft fleet

The reference scenario 2015 considers a fleet mix of 100% CT aircraft types, which were common in the year 2015 in Europe. As common in Europe, the ceo family dominates the aircraft fleet (see Table 2, 58% of all flights). Next to several other narrow-body aircraft accounting for a total of 22%, 10% of the flights are attributed to business jets, 7% to large turboprop aircraft and only 3% to wide-body aircraft.

Table 2: Assumed aircraft fleet for the different scenarios

Aircraft types	2015	2025	2035	20XX-1	20XX-2
Business jets	10%	10%	10%	10%	10%
ceo	58%	36%	18%		
B737 NG	6%	4%	2%		
Turboprops	7%	4%	3%		
E190	11%	5%			
F100	2%	1%			
A333	3%	2%			
RJ1H	3%				
neo		24%	42%	10%	10%
B37M*		2%	4%	4%	4%
B788		2%	4%	4%	4%
BCS1		7%	10%	5%	5%
BCS3		3%	4%	2%	2%
neo (af)			3%	20%	20%
neodapt				10%	10%
neodapt (af)				35%	
fanex					35%
Technology:	CT	➔	NT-1	➔	NT-2

*Substituted by aircraft noise emission model neo

Scenario 2025 considers 38% of NT-1 aircraft types and 62% of CT aircraft types. In addition, other NT-1 aircraft types are introduced via sonAIR as the BCS1/BCS3 and B788 for wide-bodies. Such changes are currently ongoing in the global aircraft fleet composition. In 2035 64% NT-1 aircraft types, 3% NT-2 and 33% CT aircraft types are included.

Both 20XX scenarios include 25% NT-1, 65% of NT-2, and 10% CT aircraft, where the latter are part of the business jet category. Scenario 20XX-1 is a conservative scenario including NT-2 aircraft that are only slight modifications (in the form of improved airframe noise) of modern gtf aircraft with classical low wing configuration. Scenario 20XX-2 accounts for new aircraft designs such as a high wing configuration with shielded engines, i.e., the fanex vehicle design.

4. RESULTS

As an overview, Table 3 summarizes the results of all scenarios by means of the noise contour areas of the 16h-L_{eq} (daytime) from 50 dB to 70 dB. The noise contours are depicted and compared with each other in Figure 4 to Figure 7 of the following sections.

Table 3: Noise contour area (km^2) of the 16h-L_{eq} (daytime) for each scenario and relative differences to scenario 2015 (Δ_{2015}) or 2035 (Δ_{2035}).

L_{eq} dB	2015	2025	Δ_{2015}	2035	Δ_{2015}	20XX-1	Δ_{2035}	20XX-2	Δ_{2035}
50	192.4	189.2	−2%	176.6	−8%	149.8	−15%	114.8	−35%
55	64.0	59.5	−7%	53.7	−16%	45.2	−16%	39.7	−26%
60	27.1	25.8	−5%	23.4	−13%	19.7	−16%	16.4	−30%
65	11.3	10.3	−9%	8.6	−24%	6.4	−26%	5.4	−37%
70	4.0	3.7	−9%	3.1	−22%	2.6	−18%	2.5	−21%

4.1 Scenario 2025 vs. 2015

The introduction in the fleet of 38% of NT-1 aircraft types until 2025 compensates the growth of aircraft movements (see Figure 4).
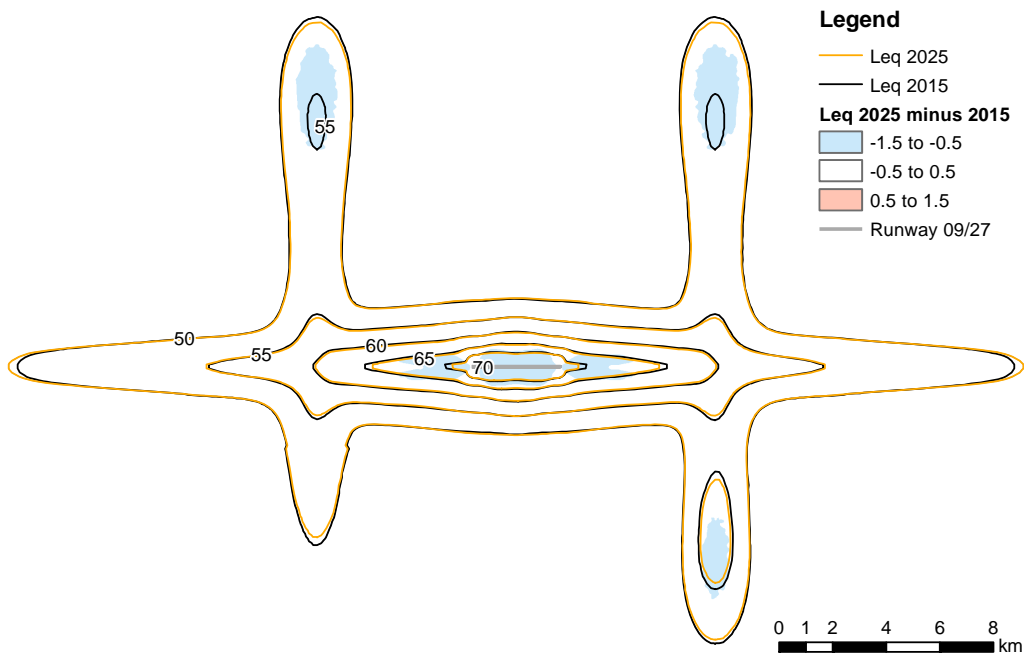

Figure 4: 16h-L_{eq} noise contours from 50 dB to 70 dB of scenario 2025 compared to 2015. Level differences (2025 minus 2015) are depicted in categories of 1 dB.

The increase in movements by 116% compared to 2015 on its own would have caused a rise the sound exposure level by 0.6 dB (assuming constant fleet and air traffic). However, due to the changes in the aircraft fleet, all noise contour areas between 50 dB and 70 dB are slightly smaller than in scenario 2015 (Table 3). Locally, the 50 dB contours are slightly larger below the approach tracks (east and west), with differences below 0.5 dB.

4.2   Scenario 2035 vs. 2015

For 2035, it was estimated that 67% of the aircraft fleet could be exchanged by NT-1 or NT-2 aircraft types. Such changes would lead to reductions of up to 1.6 dB below the flightpath for departures while the sound exposure level for approaches is constant. In particular close to the runway, the 65 and 70 dB contours cover much smaller areas (−22% and −24%), while the total number of flights increased by 128% compared to scenario 2015. Without any changes in the aircraft fleet and air traffic, levels would rise by 1.1 dB.
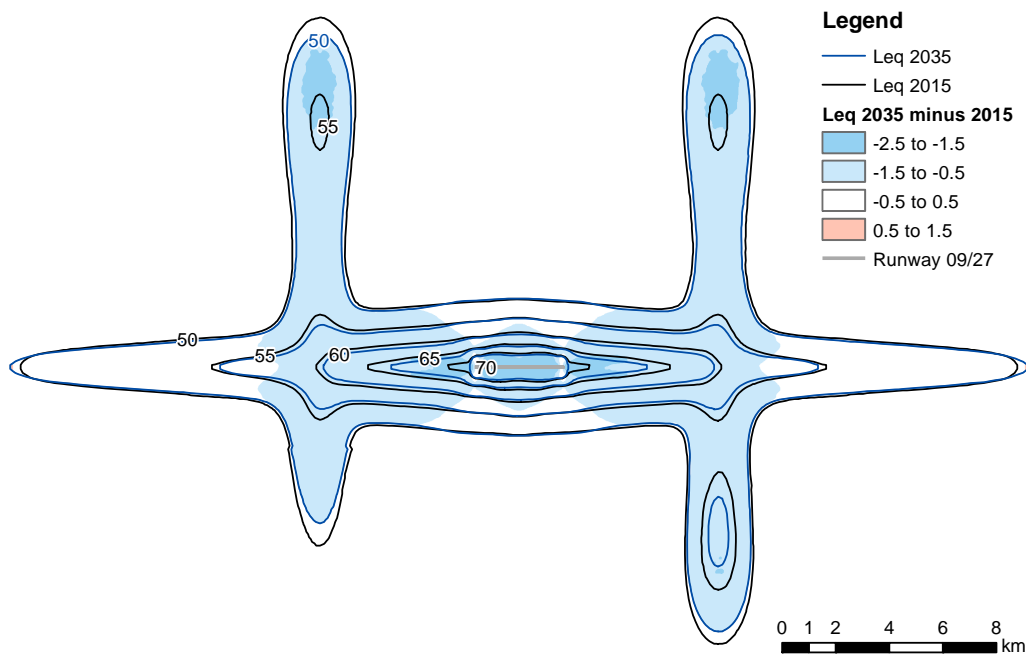

Figure 5: 16h-L$_{eq}$ noise contours from 50 dB to 70 dB of scenario 2035 compared to 2015. Level differences (2035 minus 2015) are depicted in categories of 1 dB.

4.3   Scenario 20XX-1 vs. 2035

For the following comparisons, the scenario 2035 is used as base scenario. As the capacity of one runway is reached and the forecast after 2035 is highly uncertain, we keep the number of flights constant and modify the aircraft fleet only.

The NT-2 aircraft types of scenario 20XX-1 primarily improved the sound exposure level for approaches with decreases in the level of −1.6 dB, as the main difference of these aircraft compared to the neo is the improved low airframe noise technology. In addition, the sound exposure below departures flightpaths is reduced by around 1 dB. Although the differences between the neo (af), neodapt (af) and neo are small for departures, the decrease can be attributed to a reduction of CT aircraft types by 23%. The total noise contour areas decrease by around 15%, and by 26% for the 65 dB contour.
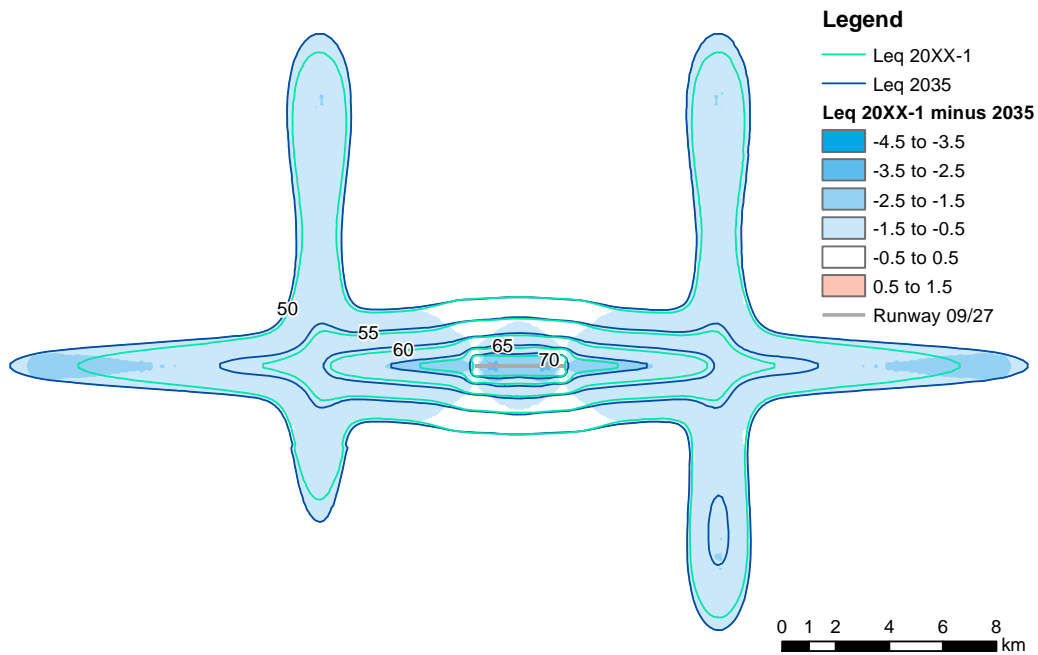
Figure 6: 16h-L_{eq} noise contours from 50 dB to 70 dB of scenario 20XX-1 compared to 2035. Level differences (20XX-1 minus 2035) are depicted in categories of 1 dB.

4.4 Scenario 20XX-2 vs. 2035

Scenario 20XX-2 is equivalent to 20XX-1 but assumes a major change in the aircraft industry. A new high-wing aircraft design called fanex is introduced, which is optimized for low-noise performance during the development process, starting as early as the conceptual design phase. While the total number of flights remains unchanged compared to scenario 2035, the sound exposure is found to be reduced by 2 to 3 dB. Particularly, these reductions were found both for areas affected by approaches as well as departures. The total noise contour areas decrease between 21% to 37% (Table 3).
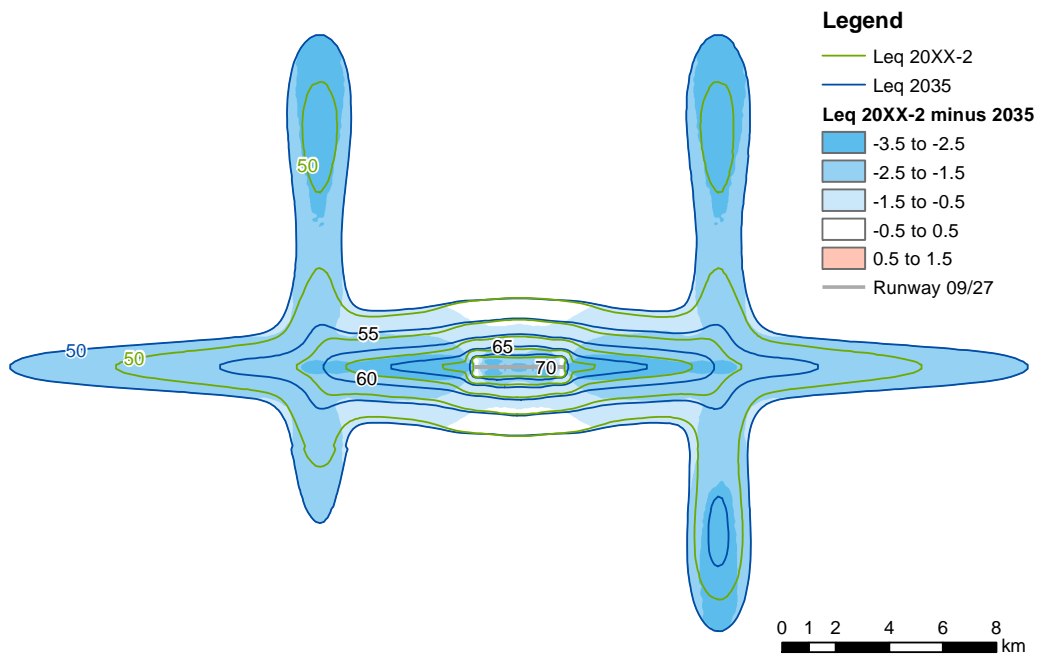

Figure 7: 16h-L_{eq} noise contours from 50 dB to 70 dB of scenario 20XX-2 compared to 2035. Level differences (20XX-2 minus 2035) are depicted in categories of 1 dB.

5. DISCUSSION

The first investigation of the study deals with the question if the future aircraft fleet is able to compensate the predicted air traffic growth. Both scenario 2025 and 2035 confirm that the fast introduction of NT-1 aircraft types can compensate and even reduce the future sound exposure of a medium-sized airport during daytime.

The second part investigated the potential of two novel low-noise aircraft designs. The scenario 20XX-1 was designed as the more probable scenario, considering similar aircraft architectures as today but equipped with improved airframe retrofit technology. A reduction of the noise contour areas was found, however, mainly caused by the further replacement of ceo by NT-2 aircraft with modern geared turbofan engines. The influence of improved airframe technology only added small noise improvements for approaches. With scenario 20XX-2, an unconventional aircraft architecture was introduced, which shields the engine noise with its airframe and uses low-noise airframe technology, i.e., the fanex vehicle [8]. A considerable reduction of the noise contour areas was found, which showed the high potential of new aircraft architectures.

A similar study on a larger airport with two runways (similar to the airport of Munich) was conducted in Ref. [3]. The unconstrained cases, with respect to the hourly airport capacity, resulted in comparable or slightly larger noise contour areas of the day-evening-night level for the years 2030 and 2040 compared to their baseline scenario in 2016. These results for a two runway airport are contradictory to the results shown in this paper for a single-runway airport.

One major difference of this study when compared to our work is the much larger assumed growth of the considered airport in Ref. [3] by approximately 2.4% p.a. over a longer period. Such a growth rate compensates a large part of the improvements in the (differing) aircraft fleet. A second major difference is the modelling of NT-2 aircraft types, which in the cited study were expressed by total sound level reductions during approach and departure. In our study, the assessment of single aircraft noise emissions as well as the calculation of aircraft noise scenarios is based on scientific calculation models (PANAM, sonAIR), which leads to a more realistic consideration of these aircraft types compared to other studies.

Finally, future predictions with a horizon of ten years or more are subject to a high degree of uncertainty. The current study makes assumptions about the growth of the air traffic, the retirement of CT aircraft types and the stage of maturation of technology as introduced with NT-1 and NT-2 aircraft types. In addition, the aircraft noise calculations involve uncertainties of the flight procedures that are used and of the noise prediction of current and future aircraft (see Ref. [19, 20]).

6. CONCLUSIONS

For medium-sized airports with a single runway, which are limited in their air traffic growth by the airport capacity and development restrictions, a reduction potential of up to 1.6 dB or 8% to 24% of the noise contour area was found for the year 2035. Such reductions will mainly affect large areas which are affected by the noise of departures, as the geared turbofans of the NT-1 aircraft cause less noise emissions. Thus, the fast introduction of NT-1 aircraft types due to high production capacities of the manufacturers and a large number of orders by airlines will compensate or even reduce the aircraft noise exposure in the next 15 years despite the growth in flight movements.

For the conservative scenario 20XX-1, the future reduction potential after 2035 of NT-2 aircraft was found to be small and mainly driven by the further

replacement of CT aircraft types. The noise contour areas decreased by 15% to 26%. A larger potential was identified for the case that manufacturers do start to take unconventional aircraft designs into account. Scenario 20XX-2 reduced the noise contour areas by 21% to 37%. The results indicate the importance of considering aircraft noise optimization in the conceptual phase of aircraft design for whole-airport scenarios.

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