A FRAMEWORK TO ASSESS FUTURE AIRPORT NOISE APPLIED TO A TWO-RUNWAY AIRPORT

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Abstract

Aircraft noise in the vicinity of airports presents a major challenge for the future development of civil aviation. A crucial prerequisite in the definition of effective noise-mitigation strategies is the capability to model future airport noise and consider underlying noise-relevant effects. In a recent study, we have presented a framework that is capable of modelling future flight plans, noise emissions at the aircraft level, and ultimately airport-level noise exposure. The novel contribution of this paper is an application of the framework by studying future airport noise of a typical two-runway airport. Future fleet mix, flight plans and airport noise are modelled up to 2040. Furthermore, the impact of airport capacity constraints on resulting day-evening-night levels is examined.

1 Introduction

During the last decades, air traffic demand has grown tremendously. Since the eighties, world annual traffic has approximately doubled every 15 years [1]. At the same time, as a result, noise emissions in the proximity of airports have increasingly become a challenge. This trend in air traffic demand is expected to continue in the future [1,2].

In terms of aircraft noise, during recent years the effect of increasing air traffic has been moderated by the significant reduction in single-event noise of new aircraft types entering service [3]. However, future noise reductions may be more difficult to achieve for two reasons: Firstly, a further increase in the bypass ratio of jet engines, which historically allowed significant aircraft-level noise reductions, may be limited [4]. Secondly, with today's reduced engine noise levels, airframe noise has generally become significant, too. Hence, a reduction in aircraft-level noise might require the simultaneous reduction of both engine and airframe noise [5].

Besides the purely physical development of aircraft noise, psychoacoustic research indicates that the same noise levels today may generally cause higher annoyance levels than they have caused in the past [6]. The combination of these effects shows that the challenge posed by aircraft noise is likely to intensify in the future. To cope with this, the aviation industry must develop effective fleet- and airport-level noise reduction strategies as well as aircraft-level noise-reduction technologies.

In order to define and evaluate possible noise-mitigation strategies, capabilities to model future airport noise and underlying noise-relevant effects are fundamental. For this purpose, in recent research a comprehensive framework has been developed for the assessment and quantification of impacts on future airport noise exposure [7]. An analysis of the tool applying the flight plan modelling capabilities to Munich Airport for validation purposes is found in a further publication [8].

Multiple advantages of the presented framework can be named. Firstly, the approach is able to iteratively model the aircraft fleet mix depending on scenario-specific air traffic growth, aircraft retirement, and aircraft introduction rather than postulating a priori assumptions on the future shares of different aircraft. Secondly, the framework's modelling of future flight plans is based on passenger traffic demand rather than aircraft operations, which leaves the average seat capacity of future aircraft a degree of freedom. Thirdly, the framework considers aircraft at an aircraft-type level rather than relying on a substitution of the fleet with a number of representative aircraft types, allowing for an improved model accuracy especially on the short- and medium term. Fourthly, the framework includes a simple consideration of the impact of airport capacity constraints on future flight plans. Lastly, the framework is capable to principally assess any given airport with respect to runway system and flight route geometries as well as baseline flight plans. In the literature, little comparable research is found. A current research project that principally pursues similar goals is presented by [9]. Therein, recent research has mainly focussed on novel and efficient airport noise modelling capabilities [10].

In the following, an application of the framework is presented with the objective of estimating the future noise exposure of an exemplary two-runway airport. Therein, Section 2 provides a brief overview of the developed framework and associated methods. Section 3 specifies the scenario-specific inputs of the subsequent simulations. Section 4 then presents the simulation results, followed by a conclusion in Section 5.

2 Approach

The following section briefly introduces the framework's top-level approach (Section 2.1), the flight plan modelling (Section 2.2), the aircraft-level noise modelling (Section 2.3), and the airport-level noise modelling (Section 2.4).

2.1 Top-Level Approach

The top-level approach of the "Future Airport Noise Assessment Method" (FANAM) is depicted in Figure 1 [7]. Firstly, in order to assess future airport noise exposure the modelling of an airport's future flight plan is required. Secondly, aircraft noise needs to be modelled at the aircraft level. Thirdly, based on the future flight plan and the aircraft models, airport noise exposure may be modelled. Each of the three areas will be briefly summarized in the following sections.

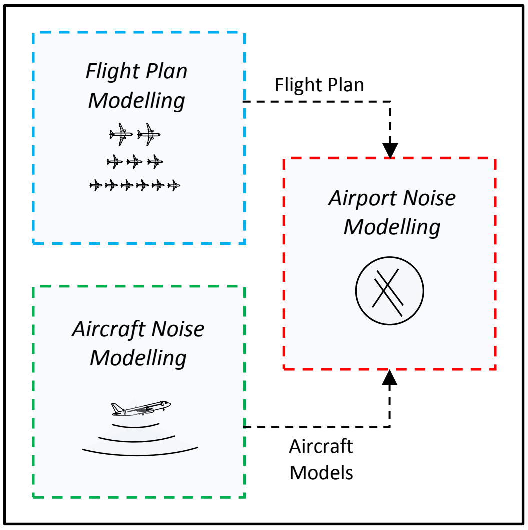

Fig. 1. Top-level approach of the framework [7]

As suggested by the European Union, day-evening-night (DEN) noise levels are used to quantify airport noise [11]. In the DEN level, noise events during the 'evening' (7 pm to 11 pm) are penalised by +5 dB, noise events during the 'night' (11 pm to 7 am) by +10 dB. Throughout this work, aircraft generations are differentiated into three groups: Current Technology (CT) aircraft types indicate aircraft types with entry-into-service year prior to 2007, New Technology 1 (NT-1) aircraft types include aircraft with entry-into-service year 2007 or later, NT-2 aircraft types denote the generation that will succeed NT-1 aircraft in future years.

2.2 Flight Plan Modelling

The flight plan modelling capabilities realized by the "Future Flight Plan Development Tool" (FFDT) are presented in Figure 2. The essential idea is, for a specific airport, to derive a future flight plan from a given flight plan of a baseline year through the consideration of relevant impacts on the evolution of individual flight plan entries. Altogether, as seen in Figure 2 the FFDT consists of six modules. The first four modules model future flight plans through iterations of all years to be considered. Therein, future flight plans are solely quantified by transport capacities (in Available Seats, AS), which allows the average seat capacity of a future aircraft fleet to remain a non-predetermined degree of freedom.

Only prior to the Airport Capacity Module are transport capacities of a flight plan transferred to actual aircraft movement numbers. Methodically, the FFDT considers all operating aircraft as part of one single airline, thus neglecting individual airlines' fleet strategies. Consequently, with respect to the retirement and introduction of aircraft the world fleet behaviour is applied. Furthermore, the FFDT as well as the top-level FANAM approach do not rely on the categorization of aircraft movements into a small number of representative aircraft, but rather considers aircraft at an aircraft type-individual level. In the following, an overview on the FFDT's individual modules is provided.

Air Traffic Growth Module. In this module, user-defined air growth growth rates are applied to the flight plan entries in order to iteratively determine the traffic demand of a subsequent year. Therein, the user may define air traffic growth rates on a yearly basis. Furthermore, differentiated growth rates may be specified according to air traffic to different world regions. In the definition of world regions, the regions of the Airbus Global Market Forecast are used [1].

Aircraft Retirement Module. In this module, the future retirement of aircraft is considered in order to determine the future transport capacities of the active aircraft fleet that remain after retirement. For this, a statistical retirement approach developed by Randt in former research is applied [12]. The approach describes aircraft retirement by logistic survival curves that quantify an aircraft's retirement probability as a function of aircraft age. On aircraft-cluster level, multiple survival curves are established based on the historical data of past aircraft retirements. Furthermore, information on the baseline year's aircraft type-specific age distributions are used by the module.

Flight Plan Gap Module. This module determines the capacity gaps resulting from, on the one hand, air traffic growth and, on the other hand, aircraft retirement. Since the FFDT assumes that traffic supply equals traffic demand, the calculated capacity gap quantifies the transport capacity of a subsequent year to be provided by new aircraft introduced to the fleet.

Aircraft Introduction Module. In this module, the capacity gaps are filled by new aircraft introduced to the fleet. For this, the user may define scenario-specific future aircraft introduction by so-called swap rules, such as: "A flight plan gap of 1 AS of aircraft type x is filled with 20% by aircraft type x, 50% by aircraft type y, and 30% by aircraft type z." Principally, the module allows swap rules to be defined for each aircraft type individually. Furthermore, as for air traffic growth input, the module allows a specification of swap rules on an annual basis. As further described in Section 3.2, an exemplary aircraft introduction scenario is defined based on the analysis of open aircraft orders.

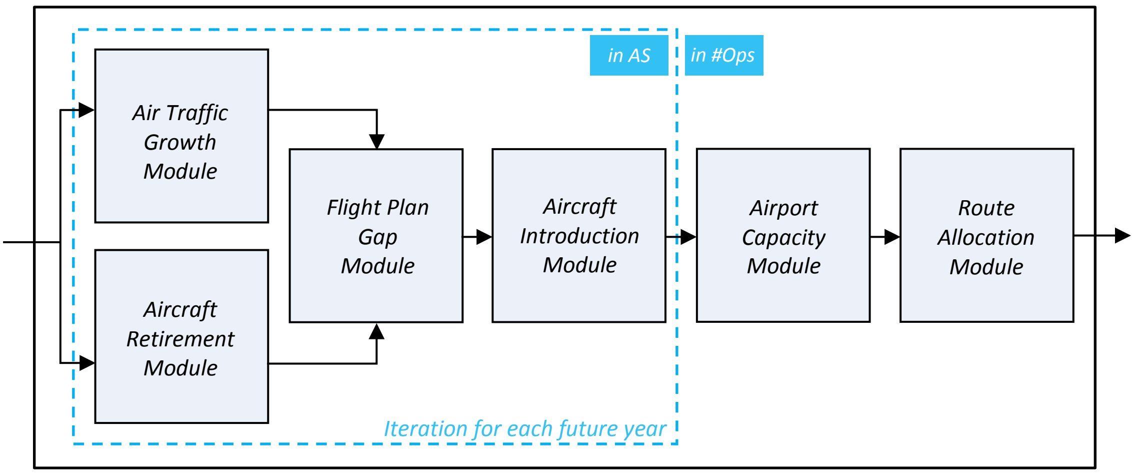

Fig. 2. The flight plan modelling approach (the FFDT) [7]

Airport Capacity Module. This module considers the effect of airport runway capacity constraints on flight plan evolution. Therein, if the aircraft movements of a given hour exceed a maximum user-defined aircraft throughput, aircraft movements are shifted to the closest neighbouring hours that still have free capacities. Thereby, it is neglected that, in reality, rather than a complete shift to other times of the day, a certain share of the additional traffic demand might not be met at all (demand spill). The Airport Capacity Module's consideration of capacity constraints can therefore be regarded as a worst-case estimation in terms of future airport noise. The module is noise-relevant if aircraft movements are shifted to hours in the evening or night of a given day (e.g. in the assessment of DEN noise levels).

Route Allocation Module. This module assigns the aircraft movements of the modelled future flight plan to an airport's specific arrival and departure routes according to user-defined input. In the module, firstly, the amount and designation of Standard Instrument Departures (SID) and Standard Arrival Routes (STAR) are specified. More importantly, the distribution of aircraft movements onto the specified routes is defined, which may be of high significance for resulting local noise levels. Through the definition of the route distribution, the shares of a runway system's operating directions (e.g. Western vs. Eastern) may be easily specified by the user, too.

From the resulting future flight plan, the FFDT then generates a simulation input file that entirely specifies a noise simulation to be calculated by the airport noise modelling capabilities (see Section 2.4).

2.3 Aircraft-Level Noise Modelling

The aircraft-level noise modelling approach follows the modelling procedures proposed by the ECAC Doc. 29 (3rd Edition) "Report on Standard Method of Computing Noise Contours around Civil Airports" [13]. This report, firstly, suggests a method to describe the flight path of an aircraft operation. Subsequently, based on the modelled flight path, single-event aircraft noise is determined through the consideration of aircraft-specific noise emission data. Therein, aircraft noise is primarily described by Noise-Power-Distance (NPD) data, which specify noise levels as a function of engine power and distance between aircraft and observer.

As aircraft database, the Aircraft Noise and Performance (ANP) database by Eurocontrol is used [14]. For today's relevant aircraft types, this database contains the required aircraft-specific information to model an aircraft's single-event noise based on the above-mentioned ECAC method.

For NT-1 aircraft types that have entered service only very recently, ANP datasets may not yet be published by Eurocontrol. In the same way, no ANP datasets are available for NT-2 aircraft that are to be considered in the modelling of future airport noise exposure. In these cases, an approach proposed by ECAC Doc. 29 is applied as described in the following [13]. The method essentially is a surrogate-aircraft approach that for specified criteria selects a surrogate aircraft type with maximum resemblance. The aircraft type to be modelled is then based on the ANP dataset of the selected surrogate aircraft type. In order to account for a possible difference in single-event noise, certification noise levels are used as published by EASA [15]. During aircraft noise certification, noise levels at three specified locations are measured, specifically one during arrival ("approach"), and two for departures ("flyover" and "lateral") [16]. In FANAM, for an aircraft type to be modelled, the relative noise reduction compared to its surrogate aircraft according to noise certification levels is applied. The according noise level delta in the approach point is applied to approach NPD data, the averaged noise level delta in flyover and lateral points to departure NPD data, respectively.

2.4 Airport-Level Noise Modelling

The airport-level noise modelling capabilities are provided by the Aviation Environmental Design Tool (AEDT) [17]. The AEDT is the Federal Aviation Agency's successor of the former Integrated Noise Model (INM). In the AEDT, amongst others, the geometry of the airport's runway system and flight routes are considered. Furthermore, relevant information on the airport's ambient conditions are defined, such as temperature, pressure or humidity. Besides, the receptor grid of a noise simulation is defined. Using the AEDT, airport noise exposure is ultimately calculated for a given scenario.

For FANAM, the AEDT's capability of defining an entire simulation through a single AEDT Standard Input File (ASIF) is relevant. As previously mentioned (see 2.2), the FFDT automatically generates such an ASIF that subsequently can be read into the AEDT.

3 Simulation Input

The following section presents information on relevant simulation input data. At first, the study airport is introduced (Section 3.1). Then, the specific input data of the simulated scenarios are detailed (Section 3.2).

3.1 Study Airport

As study airport, a parallel two-runway airport is chosen, which may be regarded as the most representative runway layout in terms of global air traffic [18]. A representative airport geometry is derived from the geometries of several international two-runway airports. The two runways are modelled in East-West direction (09L/27R and 09R/27L). The runway lengths are 3.4 km and the lateral distance between the runways is 1.8 km at a lengthwise offset of 1.0 km. In terms of flight routes, altogether four arrival routes, and eight departure routes are modelled. The STARs are modelled as straight segments in the extension of the runways. Two SIDs per runway end are modelled, of which one is a straight SID, and one including a turn. The turned SIDs consist of an initial straight segment of ca. 7 km followed by a 92° turn away from the airport's centreline and ultimately by another straight segment. As airport location Western Europe is used, which is relevant for the region-specific air traffic growth rates (see 2.2).

3.2 Scenario-Specific Input Data

3.2.1 Modelled Time Period

The baseline year of the simulations is set to 2016. The simulations are to model flight plans, and hence airport noise exposure, up to the year 2040.

3.2.2 Baseline Flight Plan

In order to consider a flight plan as realistic as possible, the actual flight plan of a real airport is used. Note that this flight plan determines the particular fleet mix operating at the airport in the baseline year. Since in this study a parallel two-runway airport is examined, it is decided to use the flight plan of Munich Airport as baseline flight plan. The applied flight plan is derived from the Official Airline Guide (OAG) 2016, which includes scheduled flights [19]. A flight plan of a representative day is derived by averaging the flight plan of the entire year 2016.

3.2.3 Air Traffic Growth Input

As input data for the Air Traffic Growth Module, the specific passenger growth rates of the Airbus Global Market Forecast (GMF) 2016 are applied [1]. This report specifies growth rates for the years 2017 to 2036. For years to be modelled after 2036, the 2036 growth rates are assumed.

3.2.4 Aircraft Retirement Input

The Aircraft Retirement Module applies the original aircraft survival curves as derived in previous research [12]. Furthermore, as described in Section 2.2, aircraft type-specific age distributions evaluated as of 2016 are used.

3.2.5 Aircraft Introduction Input

The modelled aircraft introduction is specified by the definition of a specific aircraft introduction scenario. Therein, it is assumed that narrow-body aircraft are always replaced by narrow-bodies, and respectively, wide-body aircraft by wide-bodies. As mentioned, open aircraft orders as published by the manufacturers serve as foundation for the introduction scenario. The underlying idea is that today's open orders indicate which aircraft types and to what shares will enter the fleet in future years once produced. For this purpose, order books of four major manufacturers (Airbus, Boeing, Bombardier, Embraer) are analysed as of 31st December 2016 and, for each aircraft type, the total ordered transport capacity ($TOTC$) is derived according to equation (1). Tables 1 and 2 list the most ordered aircraft types considered by the aircraft introduction scenario.

$$TOTC = Orders * Seats \qquad (1)$$

Tab. 1. Introduced narrow-body aircraft types

OEM	Aircraft type	Generation
Airbus	320 (ceo & neo)	CT/NT-1
Airbus	321 (ceo & neo)	CT/NT-1
Bombardier	CS3	NT-1
Boeing	738 (-800 & -MAX8)	CT/NT-1
Boeing	739 (-900 & -MAX9)	CT/NT-1

Furthermore, for each aircraft type, entry-into-service years and end-of-production years are considered through aircraft type-specific entry-into-service factors (EISF) as a function of simulation year as described by equation (2). If known, real entry-into-service and end-of-production years are applied. If public sources do not indicate an end-of-production year, a production period of 24 years is assumed based on the analysis of historic aircraft production intervals. During production time, an aircraft type's EISF is 1, prior to entry into service and after the end of production the EISF is 0. For ramp-up and ramp-down a three-year transition is assumed between the values 0 and 1.

$$AOTC_{year} = TOTC * EISF_{year} \qquad (2)$$

Tab. 2. Introduced wide-body aircraft types

OEM	Aircraft type	Generation
Airbus	332 (-200 & -800neo)	CT/NT-1
Airbus	333 (-300 & -900neo)	CT/NT-1
Airbus	359	NT-1
Airbus	351	NT-1
Airbus	380	NT-1
Boeing	777 (-300ER & X)	CT/NT-1
Boeing	788	NT-1
Boeing	789	NT-1
Boeing	781	NT-1

Ultimately, swap rules are formulated by the swap factors (SF) described through equation (3). In this way, swap rules are defined for all future years to be modelled. The same narrow-/wide-body swap rules are applied to all narrow-body aircraft and wide-body aircraft, respectively. As a result, for instance, in the case of narrow-body aircraft by the year 2020 mainly the three aircraft types (A320neo, A321neo, Boeing 737-MAX8) are introduced, which in combination make up for more than 90% in added transport capacities. In the case of wide-body aircraft, added transport capacities are more evenly distributed over several aircraft types, with the most significant NT-1 aircraft type to be added being the A350-900.

$$SF_{A/C,year} = \frac{AOTC_{A/C,year}}{\sum_{A/C=1}^{n} AOTC_{A/C,year}} \qquad (3)$$

3.2.6 Aircraft Capacity Input

With respect to airport capacity, two different scenarios are examined. As presented in Section 4, a "Reference Case" assumes the airport to be unconstrained. Additionally, a "Constrained

Case" is examined, which limits aircraft throughput to 90 movements per hour.

3.2.7 Route Allocation Input

The route allocation input defines the share in operating direction as 60% Easterly vs. 40% Westerly operations. Furthermore, aircraft movements to/from Northern directions are assigned to the Northern runway (09L, 27R), movements to/from Southern directions to the Southern runway (09R, 27L).

3.2.8 NT-2 Aircraft Assumptions

In the simulations, NT-2 aircraft types enter service as successor aircraft of NT-1 aircraft types. Since uncertainty concerning future NT-2 aircraft types is high, only one NT-2 narrow-body aircraft, and one NT-2 wide-body aircraft is postulated for the simulations. These NT-2 aircraft types serve as representation of the actual variety of real future NT-2 aircraft types. Both considered NT-2 aircraft types are defined following the long-term noise reduction goals published by the CAEP Noise Technology Independent Expert Panel [4]. The NT-2 aircraft's specified reference aircraft as well as the noise reduction at the three noise certification points relative to the reference aircraft are presented in Table 3.

Tab. 3. NT-2 aircraft assumptions for narrow-body (NB) and wide-body (WB) aircraft

	NT-2 NB	NT-2 WB
Reference Aircraft	*B737-800*	*A330-300*
Approach	*-5.0 dB*	*-5.0 dB*
Flyover	*-7.5 dB*	*-7.0 dB*
Lateral	*-12.0 dB*	*-10.0 dB*

The aircraft introduction scenario (Section 3.2.5) assumes that, as soon as a given NT-1 aircraft type reaches its end-of-production year, it is followed by the production and, hence, introduction of the corresponding NT-2 aircraft type.

4 Simulation Results

In the following section, the simulation results are presented. Section 4.1 describes the fleet mix and flight plan results, while Section 4.2 presents the calculated airport noise exposure.

4.1 Fleet Mix and Flight Plan Results

4.1.1 Reference Case

For the Reference Case as defined by Section 3, the modelled evolution of transport capacities (in AS) is shown in Figure 3. As seen, the FFDT models a continuous increase in transport capacity, which is reasonable according to the growth input defined by the Airbus GMF. From 2016 to 2040 the transport capacity approximately doubles. Thus, 24 years are needed to double air traffic, which represents a significantly lower rate than the 15 years forecasted by Airbus for the development of global air traffic [1]. This is plausible, too, since a Western European airport is expected to experience lower air traffic growth compared with global air traffic.

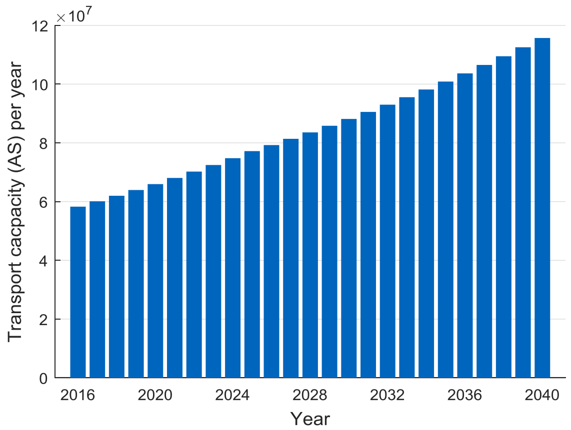

Fig. 3. Modelled annual transport capacity in available seats (AS)

The modelled evolution of aircraft movement numbers is presented in Figure 4. In addition to the absolute movement numbers, for each year the corresponding shares of aircraft generations are illustrated both for narrow-body and wide-body aircraft. Similarly to the development of transport capacities, aircraft movement numbers continuously increase over the modelled years.

However, contrary to transport capacities, aircraft movement numbers do not double within the 24 modelled years, but grow at a slower rate.

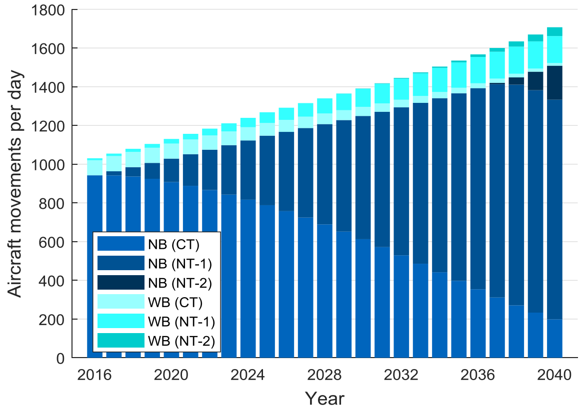

Fig. 4. Modelled daily aircraft movements and according aircraft generation shares for narrow- and wide-body (NB/WB) aircraft

As may be seen, wide-body aircraft movement numbers are about one order of magnitude lower than narrow-body aircraft movements. Yet, the share of wide-body aircraft movements increases over the course of modelled years from around 9% in 2016 to around 12% in 2040. The reason for the increasing wide-body aircraft share lies in the Airbus GMF's considerably higher air traffic growth rates for long-range flights for the case of a Western European airport that usually are served by wide-body aircraft.

In terms of aircraft generations, Figure 4 depicts a continuous decrease in the share of CT aircraft types for both narrow- and wide-body aircraft. Simultaneously, from the first modelled year, the share in NT-1 aircraft types increases. For the last modelled years, the introduction of NT-2 aircraft into the fleet can be observed.

The simulated average aircraft seat capacity as result of the modelled fleet mix evolution is presented in Figure 5. As seen, the total aircraft fleet shows a significant increase in average seat capacity over the modelled 24 years. Yet, the narrow-body and wide-body fleet do not grow in the same manner. Wide-body aircraft seat capacity approximately remains constant between 2016 and 2040. The slight increase in the first modelled years is mainly caused by the introduction of further aircraft of the type A380, whose end-of-production year, as assumed by the aircraft introduction scenario, is in 2031. On the contrary, driven by the A320neo, A321neo, and B737-MAX8, the average seat capacity of narrow-body aircraft increases significantly from 2016 to 2040. This increase in narrow-body seat capacity consequently drives the observed increase in the seat capacity of the total fleet.

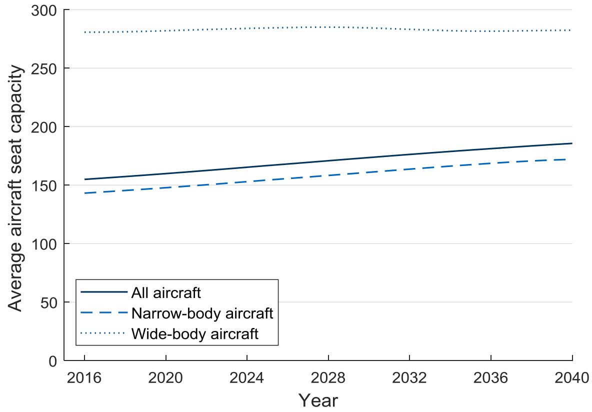

Fig. 5. Modelled average seat capacities of total aircraft fleet, narrow-body and wide-body aircraft

The increase in average seat capacity also explains the lower growth rate of aircraft movement numbers compared to the increase in transport capacity (see Figures 3 and 4). Through the operation of larger aircraft, less aircraft movements are necessary to provide a given air traffic demand. In this way, the growth in traffic demand is decoupled from the growth in movement numbers.

4.1.2 Constrained Case

For the Constrained Case, modelled fleet mix and flight plans prior to the Airport Capacity Module (see Figure 2) are identical to the previously discussed Reference Case. However, unlike in the Reference Case, where the Airport Capacity Module remains inactive, in the Constrained Case aircraft movements beyond the maximum throughput are shifted as seen in Figures 6 and 7. The figures show the hourly distribution of aircraft movements for an unconstrained airport and the Constrained Case (Figure 6 for 2030, Figure 7 for 2040).

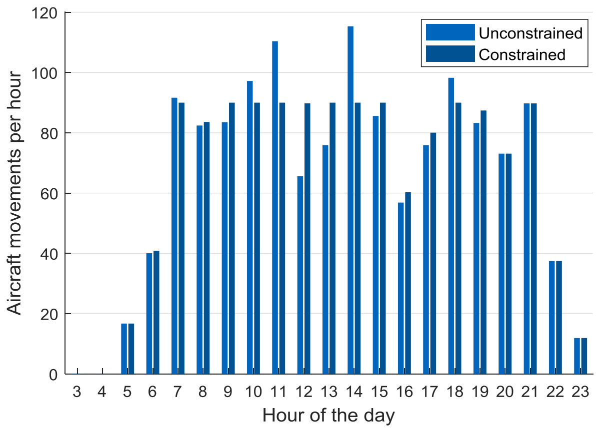

Fig. 6. Modelled effects from airport capacity constraints for 2030

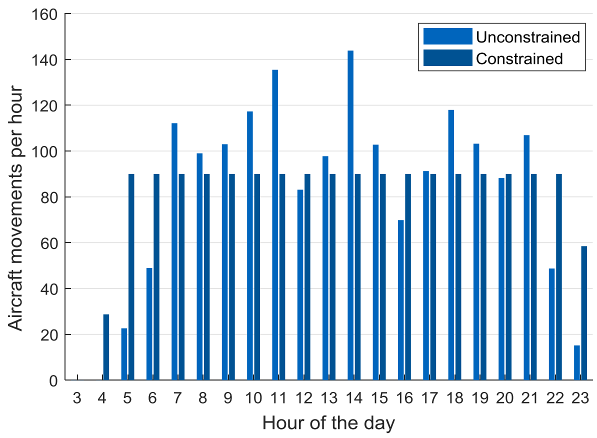

Fig. 7. Modelled effects from airport capacity constraints for 2040

In the year 2030, the maximum throughput of 90 movements per hour is exceeded during five hours of the day. As may be observed in Figure 6, excess movements are shifted to the neighbouring hours. However, only a small number of movements is shifted beyond the corresponding original period of the day (see 2.1). In the year 2040, a significantly higher amount of aircraft movements is shifted due to capacity constraints. Figure 7 shows that, in the Constrained Case, maximum throughput is reached during every single hour between 5 am and 23 pm. This is accompanied by a considerable amount of aircraft movements shifted from either ‘day’ to ‘evening’, from ‘day’ to ‘night’, or from ‘evening’ to ‘night’. Although not in the focus of this work, these results indicate that for the given airport by 2040 the two-runway system will be insufficient even considering a future growth in average aircraft seat capacity.

4.2 Airport-Level Noise Results

The modelled future flight plans are then used to model future airport noise exposure as described in Section 2. The most interesting question is: How will overall airport noise evolve over time? Will airport noise exposure further increase in the future or will the projected noise-reduction of the future aircraft fleet compensate for the assumed air traffic growth?

4.2.1 Reference Case

The airport noise simulation results of the Reference Case are presented in Table 4. The noise exposure is quantified by the area enclosed by the corresponding DEN noise contour. The table provides information on the noise contour areas of 55 dB, 65 dB and 75 dB noise levels. In the table, simulation results for the baseline year 2016 as well as for the years 2030 and 2040 are shown.

Tab. 4. DEN noise contour area in km^2 of Baseline Case (2016) and Reference Case

dB	Baseline	Reference Case 2030		Reference Case 2040	
55	*93.7*	*100.9*	*+8%*	*101.0*	*+8%*
65	*15.1*	*16.2*	*+7%*	*15.2*	*+1%*
75	*2.6*	*2.7*	*+4%*	*2.5*	*-5%*

As seen, from 2016 to 2030 noise contour areas show a single-digit growth. As major finding it can thus be stated that, according to the assumed scenario inputs, airport noise will slightly grow in the medium-term future. Apparently, the modelled fleet renewal introducing noise-reduced aircraft types to the fleet is unable to compensate for the assumed air traffic growth up to 2030. In the analysis of the 2040 simulation results it can be found that noise contour areas decrease compared to the former year 2030. In 2040, for instance, the 65dB noise contour is again about as small as in the baseline year (+1%).

The supposed main reason for the found effects can be explained from Figure 4. In general, an increasing share of noise-reduced NT-1 aircraft types moderates the effect of increased air traffic growth since NT-1 aircraft on average have lower noise emissions than CT aircraft. However, in the first modelled years, the share of NT-1 aircraft only increases at a lower rate than in subsequent years, as still a significant share of CT aircraft is introduced to the fleet in the first years. A second, yet weaker impact explaining the observed effects is found in the traffic growth input assumptions stated by the Airbus GMF 2016: Compared to the GMF growth rates specified for the years 2017 to 2026, the growth rates for the period 2027 to 2036 are slightly lower.

Besides the general development of noise contour size, Table 4 further reveals that noise contours of different noise levels do not evolve alike. Rather, it is found that with increasing years, contours of higher noise levels show a weaker increase (or a decrease) than lower noise levels. The assumed reason for this observation lies in the different expected noise reductions of future aircraft for take-off and landing. Due to maximum thrust during take-off, high-level noise contours are particularly influenced by departure procedures. Since noise certification levels are expected to reduce more strongly for take-off and departure than for approaches (see Table 3), high-level noise contours experience a stronger noise-reduction than low-level noise contours.

4.2.2 Constrained Case

The simulation results of the Constrained Case are presented in Table 5. In the year 2030, the DEN noise contours at the capacity-constrained airport are almost identical to the unconstrained Reference Case (compare Table 4). The few movements shifted by the Airport Capacity Module to other periods of the day are insignificant for the resulting DEN noise contours. However, in the year 2040, noise contour areas increase strongly by two-digit growth numbers. This effect is even more noticeable considering the fact that, as discussed in Section 4.2.1, the Reference Case's noise contour areas decrease from 2030 to 2040. These results follow from the effects found in Figure 7. As seen, in the Constrained Case of the year 2040, the airport is able to process air traffic demand only through a continual operation at the airport's maximum throughput from 5 am to 11 pm. The tremendous increase in aircraft movements during the periods 'evening' and 'night' consequently leads to a severe increase in DEN noise contours.

Tab. 5. DEN noise contour area in km² of Baseline Case (2016) and Constrained Case

dB	Baseline	Constr. Case 2030		Constr. Case 2040	
55	*93.7*	*101.2*	*+8%*	*128.3*	*+37%*
65	*15.1*	*16.2*	*+8%*	*22.1*	*+47%*
75	*2.6*	*2.7*	*+4%*	*3.4*	*+28%*

5 Conclusion

In summary, the simulation results show that according to the scenario-specific assumptions concerning air traffic growth, aircraft fleet evolution, and aircraft-level noise reduction the studied unconstrained airport's noise exposure will neither improve considerably nor worsen dramatically from 2016 to 2040. The results thus indicate that the increase in air traffic will be approximately counterbalanced by noise-reduced aircraft introduced through aircraft fleet renewal. However, the simulations including airport capacity constraints show that the according negative effects on DEN noise exposure are considerable.

Furthermore, from the study of the exemplary airport, some fundamental capabilities of the developed framework could be demonstrated. For further applications, the framework allows the assessment of future airport noise exposure in a variety of noise-relevant scenarios. For instance, possible questions to be analysed with the framework's help may be: What if air traffic demand developed according to a given scenario? What if aircraft retirements were accelerated significantly? What if the seat capacity of future aircraft increased further? What if a future NT-2 aircraft type with particularly strong noise reduction entered service by a given year? What if constraints in airport capacity were alleviated by an additional runway? In this way, the developed framework is able to provide useful practical modelling capabilities in the quest to define and evaluate effective future noise-mitigation strategies.

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