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FLIGHT PLAN MODELLING WITHIN AN APPROACH TO ASSESS IMPACTS ON FUTURE AIRPORT NOISE EXPOSURE: A TEST CASE

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Abstract

Aircraft noise is a major challenge for the future of civil aviation. However, assessing future airport noise situations is difficult due to a high number of impact factors and their corresponding uncertain future development. In recent research, an approach has been developed providing simulation capabilities that enable an enhanced understanding of impacts on future airport noise exposure. The approach includes the modelling, firstly, of future flight plans, secondly, of aircraft noise at the aircraft level, and thirdly, of noise exposure at the airport level. This paper applies the flight plan modelling capabilities of the developed approach to a Test Case. For this, from a flight plan of the year 2008 flight plans for the years up to 2016 are derived for Munich Airport. Although the method is designed for impact assessments rather than analyses of absolute noise levels, the Test Case results are then compared to actual, historic data published by the airport and to Official Airline Guide data. The results prove the capabilities of the developed approach to derive future noise-relevant flight plans from scenario-specific input for airport-level noise assessments.

1. INTRODUCTION

In recent years, the aviation industry has faced increasing environmental challenges. The European Union has agreed on ambitious goals in the Flightpath 2050 programme, including a 75% reduction in CO_2 emissions, a 90% reduction in NO_x emissions, and a 65% reduction in perceived noise based on a typical aircraft with technology of the year 2000 [1]. Whereas the implications of gaseous emissions are perceived on a more global scale, at a local level, aircraft noise can be regarded as the primary environmental challenge. At many airports, therefore, the main reason for opposition by residents are air traffic-induced noise emissions.

Aircraft noise research consequently is an important research field in order to meet aviation's challenges of today and tomorrow. Fig. 1 gives an overview of different levels of aircraft noise research from aircraft component level up to noise contours at the airport level [2]. Whereas for component analyses, physics-based models are able to reach a high level of accuracy, current models at the airport level rely on experimental databases that, as a matter of course, offer a lower level of accuracy.

The research presented in this work is situated at the level of aircraft noise research assessing airport noise contours. For residents of airports, compared to single-event assessments the evaluation at the multi-event level is of particular importance. The objective of this research is to develop modelling capabilities that enable a better understanding of impacts on future airport noise exposure. For this purpose, in recent research activities an approach was developed named the Future Airport Noise Assessment Method (FANAM) [3]. This method combines the modelling of three necessary areas: Firstly, capabilities to estimate future flight plans, secondly, capabilities to model aircraft noise at the aircraft level, and thirdly, capabilities to calculate aircraft noise at the airport level. This paper concentrates on the flight plan modelling within FANAM by applying the flight plan modelling capabilities to a Test Case at Munich Airport.

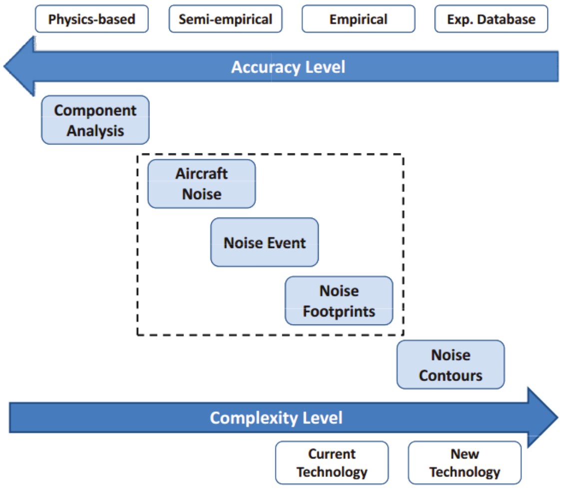


FIG. 1: Overview of different levels of aircraft noise research [2]

2. APPROACH

2.1. The Future Airport Noise Assessment Method (FANAM)

The objective of the FANAM approach is to enable impact assessments realized by relative comparisons

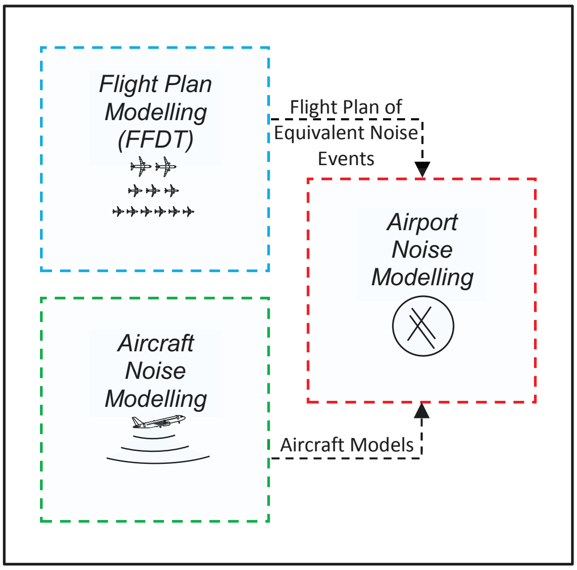


FIG. 2: Top-level approach of the Future Airport Noise Assessment Method (FANAM) [3]

between different scenarios of interest. Principally, the approach of FANAM is applicable to any given airport. Its top-level approach is outlined in Fig. 2. In order to assess future airport-level noise exposure, future flight plans of the assessed airport are required as well as aircraft models including noise emission at the aircraft level. The airport noise modelling relies on the capabilities of the Aviation Environmental Design Tool (AEDT) by the Federal Aviation Agency (FAA) which is incorporated into pre-processing and post-processing steps [4]. The aircraft noise modelling is based on Aircraft Noise and Performance (ANP) data published by Eurocontrol for current aircraft [5]. Future, noise-reduced aircraft are considered through a surrogate-aircraft approach using ANP datasets of current aircraft with modified Noise-Power-Distance (NPD) data. The flight plan modelling uses the MATLAB®-based Future Flight Plan Development Tool (FFDT) developed in recent research. The FFDT and its underlying methods are briefly introduced in Section 2.2. A more detailed presentation of the developed approach is given in [3].

2.2. The Future Flight Plan Development Tool (FFDT)

2.2.1. Idea and Concept of the FFDT

The FFDT uses a concept of so-called Flight Plans of Equivalent Noise Events [3]. This flight plan structure is specifically tailored to airport-level noise studies summarizing all flight events with noise-equivalent characteristics in a corresponding flight plan entry. The flight plan consists of primary flight plan parameters (hour of day, destination/origin airport, and aircraft type) and secondary flight plan parameters (period of day, region-route, stage length, and departure/arrival route). Flight plan entries are quantified and modelled by their aggregated annual transport capacity in available seats (AS) for all future years. The corresponding transport capacity of a flight plan entry is translated to daily frequencies just prior to the airport noise modelling (cf. Fig. 2). This allows for the consideration of the average aircraft size as a non-predetermined degree of freedom depending on the particular scenario under consideration.

The FFDT derives a future flight plan for a future year from a given flight plan of the base year, following the approach depicted in Fig. 3. For a particular airport, in reality, future flight plans are influenced by local, airport-specific effects resulting from individual airlines' fleet strategies, especially from such operators with high operation share, e.g. airlines using the specific airport as a hub. The FFDT does not aim at the modelling of individual airlines' fleet strategies, which undoubtedly are hard to predict. For the purpose of impact assessments with representative significance, the FFDT rather considers fleet behaviour at a higher level with respect to aircraft retirement and the introduction of new aircraft to the fleet. The FFDT therefore consists of five main modules, taking into account air traffic growth, aircraft retirement, resulting flight plan gaps, future aircraft introduction behaviour, and a simple airport capacity module, as specified in the following sections.

2.2.2. Air Traffic Growth Module

First of all, as seen in Fig. 3, the FFDT considers scenario-specific air traffic growth in the Air Traffic Growth Module. Therein, air traffic growth is considered based on air traffic growth rates specified for different world region-pairs as suggested by the Airbus Global Market Forecast (GMF) [6]. Region-specific growth rates enable the FFDT to reflect effects of unevenly distributed air traffic growth on future airport noise. The module allows for the definition of scenario-specific growth behaviour on a yearly basis. Growth rate data published by the Airbus GMF are used as reference scenario input while the module principally allows the user to define arbitrary growth rate input. Assuming constant average flight distances for a given region-pair, revenue passenger kilometres (RPK), as defined by the Airbus GMF, can be transferred to transport capacity in AS as used by the FFDT. The FFDT assigns each flight plan entry to a corresponding region-route.

2.2.3. Aircraft Retirement Module

The second module of the FFDT is the Aircraft Retirement Module considering the retirement of aircraft of a given fleet. It is based on a statistical approach of modelling aircraft cluster-specific retirement curves and on information describing

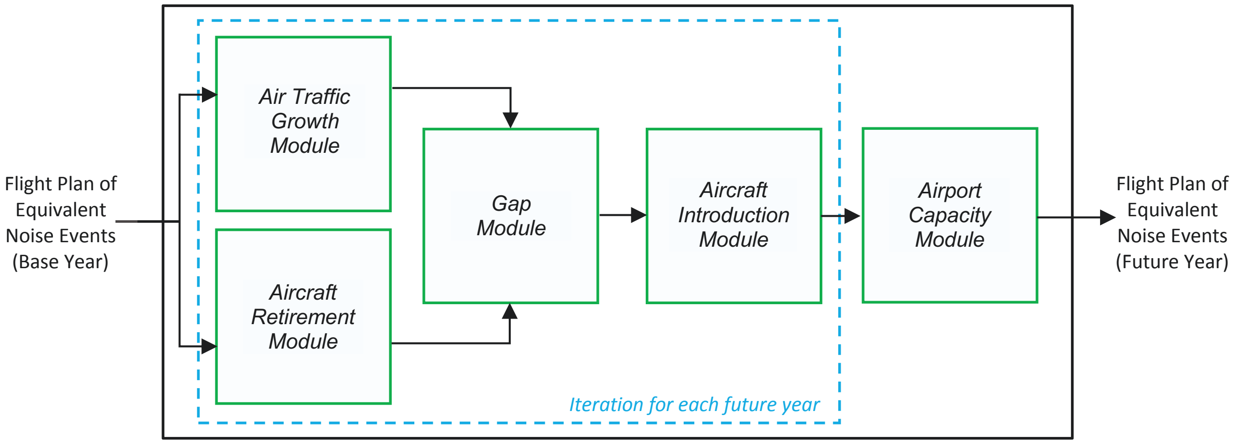


FIG. 3: Approach of the Future Flight Plan Development Tool [3]

aircraft type-specific age distribution. The aircraft retirement curves are based on a methodology by the Forecasting and Economic Analysis Support Group (FESG) of the International Civil Aviation Organization (ICAO) [7]. Retirement curves are used for nine different aircraft clusters developed at the Institute in former research [8]. The curves are independent from the year of iteration, thus it is assumed that average retirement age remains constant for future years. Necessary information on the age of aircraft was obtained from an open-source worldwide fleet database [9]. In addition to retirement curves, for aircraft present in the base fleet (base year), the actual age distribution of the base fleet is considered. Age distributions of aircraft in service are extracted through extensive analysis for the year 2014 from the same database [9]. In this way, through the combination of statistical retirement curves and the age distribution of the base fleet, future aircraft retirement can be modelled on a yearly basis.

2.2.4. Gap Module

Thirdly, the Gap Module calculates the flight plan gap resulting from the modelled air traffic growth and the considered aircraft retirement for each flight plan entry. The resulting flight plan gap demands the introduction of new aircraft to the fleet. Therein, regarding passenger transport, it is assumed that supply equals demand. The Gap Module does not yet specify which new aircraft types will meet future air traffic demand, but quantifies the transport capacity in AS to be provided by new aircraft for each future year.

2.2.5. Aircraft Introduction Module

Fourthly, the Aircraft Introduction Module allows to consider scenario-specific future aircraft introduction behaviour. The module uses the concept of so-called swap factors. A swap factor defines the share in flight plan gap of a flight plan entry that is filled by a particular aircraft type entering service. For example, a swap rule defined by the module is: In the year 2017, a flight plan gap of 1 AS of Airbus A320 is filled with 20% A319, 40% A320, and 40% Airbus A321. Supported by the analysis of airlines' press releases on fleet strategies the module further assumes that wide-body (WB) aircraft are always replaced by wide-body aircraft, and narrow-body (NB) aircraft by narrow-body aircraft.

In the definition of swap factors, a reference aircraft introduction scenario is defined based on the analysis of aircraft original equipment manufacturers' (OEM) order books and included open orders. The idea behind this approach is that aircraft corresponding to open orders will be introduced to the aircraft fleet in future years. It is refrained from defining different sets of swap factors for each individual aircraft type. Rather, the same set of swap factors is applied to groups of aircraft types, for instance for narrow-body aircraft types, and for wide-body aircraft types. From the corresponding numbers of ordered aircraft and an aircraft's specific seat capacity, total numbers of ordered transport capacity (in seats) are calculated per aircraft type. Following this, swap factors are determined as the aircraft-specific share in ordered transport capacity of the total ordered transport capacity. To assess a European airport, for further accuracy, in the definition of swap factors for narrow-body aircraft only those aircraft ordered by European airlines are considered. In this way, swap factors precisely define how an aircraft type is replaced by a mix of aircraft types for future years.

2.2.6. Airport Capacity Module

The four previously described modules are iterated for all future years to be modelled resulting in a flight plan for the target year based on the defined scenario-specific input. As final processing step of the FFDT, the derived flight plan is then applied to a simple Airport Capacity Module. This module considers a user-defined, maximum throughput of hourly aircraft movements. If the maximum throughput is reached for a given hour, excess movements are reallocated to the nearest possible hours, thus possibly shifting day-time operations to evening- or night-time operations.

The final result of the FFDT is a Flight Plan of Equivalent Noise Events for a future year of interest that subsequently can be applied to the Airport Noise Modelling as presented in Fig. 2.

3. APPLICATION OF THE FFDT TO A TEST CASE

3.1. Definition of the Test Case

As application case of the FFDT, a dedicated Test Case is established for Munich Airport. For this purpose, from a corresponding flight plan of the base year 2008, a future flight plan for the target year 2016 will be derived. In order to define the Test Case for subsequent modelling with the FFDT, input regarding the following areas is required:

1. A base flight plan of 2008
2. Air traffic growth rates from 2008 to 2016
3. Age distribution of aircraft types of 2008
4. OEM’s open aircraft orders of 2008
5. Maximum airport capacity (throughput)

Each area of required input data for the specific Test Case is detailed in the following sections.

3.1.1. Flight Plan of the Base Year (2008)

The base flight plan of the year 2008 is obtained from Official Airline Guide (OAG) data [10]. Due to data availability at the Institute, the OAG files of the months November 2007 to October 2008 are utilized. First of all, monthly OAG data are merged and relevant entries are sorted. All operations including Munich Airport either as origin or destination airport are extracted. Cargo flights and codeshare flights are excluded from the OAG data. Operation times are assigned to the next clock hour. The transport capacity in AS is provided by the OAG data. From the total number of annual operations, frequencies for one representative day are calculated. Through aggregation of all flights with identical primary flight plan parameters, a Flight Plan of Equivalent Noise Events (from now: Flight Plan) is derived.

3.1.2. Air Traffic Growth Input

In terms of air traffic growth, two different growth scenarios are examined within the Test Case: Firstly, air traffic growth rates of the Airbus GMF 2008 are applied. Furthermore, actual, historic growth rates for Munich Airport as published by the airport are used by the FFDT.

The Airbus GMF 2008 supplies growth rates for the years 2009 to 2028 for 180 region-pairs (e.g. Western Europe – Latin America) [11]. Since Munich Airport is assigned to the region Western Europe only region-pairs including Western Europe are relevant.

For the application of actual, historic growth rates, data published by Flughafen München GmbH (FMG) are applied. The annual transport capacity in AS is gained from official information on annual revenue passengers and annual seat load factors [12]. From this, historic growth rates with respect to AS are derived for the years 2008 to 2016. However, actual growth rate data derived from airport information are only supplied for total passenger numbers of the airport and not detailed for specific region-routes. Consequently, it is accepted that the input for annual air traffic growth rates is identical for each region-route. The applied, historic seat load factors at Munich Airport are shown in Tab. 1.

TAB. 1: Actual seat load factors (SLF) at Munich Airport as applied by the Test Case [12]

Year	2008	2009	2010	2011	2012
SLF [-]	72.8%	71.5%	73.8%	73.7%	74.5%
Year	2013	2014	2015	2016	-
SLF [-]	75.2%	75.9%	76.6%	75.1%	-

3.1.3. Aircraft Retirement Input

As the FFDT was developed for airport-level noise studies for future years, the Aircraft Retirement Module is based on the description of a current, not of a past fleet (see Section 2.2.3). However, for a 2008 base year as defined by the Test Case, the module requires an adaption to account for different aircraft ages of the base fleet as compared to a regular 2016 base year.

Whereas the retirement curves remain unchanged for the application of the FFDT in the Test Case, the age distributions corresponding to the base year require modification to the year 2008. Since, for a unique application case having the base year in the past, the derivation of new aircraft-specific age distributions represents a considerably high effort, all age distributions of the regular FFDT version are shifted by six years.

The emerging error in the retirement modelling of the Test Case, due to the retired aircraft between 2008 and 2014, is exemplary evaluated for the aircraft type Boeing 737-400. As the Boeing 737-400 is a relatively old aircraft type compared to the average fleet with still many aircraft in service, the error is expected to be large for this type. Considering the same retirement curve the share of aircraft in service for future years is evaluated for two cases: Firstly, based on a plain shifting of age distribution by six years, and secondly, based on a complete new analysis of the actual 737-400 age distribution in 2008 as derived from the above-mentioned database [9]. The resulting errors in the share of active aircraft between both age distributions are small, in numbers less than 1% for the first 13 years, and less than 2% for the first 31 years. The shifting of age distributions by six years is therefore accepted and applied to all aircraft types present in the base fleet of 2008.

3.1.4. Aircraft Introduction Input

The input of the Aircraft Introduction Module is defined according to the approach of the FFDT's reference aircraft introduction scenario (cf. Section 2.2.5). However, a new introduction scenario is required taking into account the perspective of the year 2008 instead of 2016. Following the approach to derive the reference introduction scenario, information by aircraft OEMs on open orders from the year 2008 are analysed and applied. Whereas for Boeing, Bombardier, and Embraer historic open order information are available through the Internet, historic order books of Airbus were provided through an enquiry at the manufacturer. Aircraft types considered for aircraft introduction in future years of the Test Case are listed in Tab. 2. Requirement for consideration of an aircraft introduction is that the corresponding number of open orders for the analysed point in time 2008 is larger than 20.

Aircraft types with no entry-into-service (EIS) year specified in Tab. 2 are already present in the base Flight Plan in 2008. EIS dates later than 2008 are shown in Tab. 2 as researched by OEMs' press releases. Consequently, these aircraft types are not introduced by the Aircraft Introduction Module up to the particular EIS year by setting corresponding swap factors to zero. For the formal logic of the FFDT, the EIS date is a year date. Hence, aircraft with an actual EIS date in the first half of a year are assigned to the ongoing year and EIS dates within the second half of a year to the following year.

As introduced in Section 2.2.5, based on the information on open orders by the OEMs of 2008, aircraft introduction behaviour is quantified through the definition of swap factors. Following the before-mentioned assumption, swap factors for narrow-body aircraft to be retired are set to zero for the introduction of wide-body aircraft and vice versa. From analyses of OEMs' information and under consideration of aircraft-specific EIS years, for each future year swap factors are determined as share of total ordered transport capacity (cf. Section 2.2.5). In this way, the mix of new aircraft introduced to the fleet for a given flight plan gap is defined for all years from 2009 to 2016.

TAB. 2: Aircraft types considered in the Test Case by the Aircraft Introduction Module

Manu-facturer	Aircraft Type	IATA Aircraft Code	Aircraft Group	EIS Year
Airbus	A319	319	NB	-
Airbus	A320	320	NB	-
Airbus	A321	321	NB	-
Boeing	737-800	738	NB	-
Bombardier	CRJ900	CR9	NB	-
Bombardier	CRJ1000	CRK	NB	-
Bombardier	Q400	DH4	NB	-
Embraer	E190	E90	NB	-
Airbus	A330-200	332	WB	-
Airbus	A330-300	333	WB	-
Airbus	A350-900	359	WB	2015
Airbus	A380	388	WB	-
Boeing	747-8	74H	WB	2012
Boeing	777-200LR	77L	WB	-
Boeing	777-300ER	77W	WB	-
Boeing	787-8	788	WB	2012
Boeing	787-9	789	WB	2015

3.1.5. Airport Capacity Input

The definition of the capacity module is aligned with the actual capacity limit at Munich Airport. Thus, the Airport Capacity Module limits the airport capacity to a maximum of 90 movements per hour.

3.2. Test Case Results

3.2.1. Evaluation Process of the Results

The results of the Test Case are presented according to the approach depicted in Fig. 4. As specified in Section 3.1.2, two different air traffic growth scenarios are applied to the FFDT: Firstly, actual, historic growth rates of Munich Airport, secondly, Airbus GMF growth rates published by 2008. Consequently, the application of the FFDT yields to two modelled Flight Plans for the year 2016.

Then, the FFDT results are compared to reference data representing actual operations at Munich Airport for the years until 2016. Firstly, as seen in Fig. 4, data published by FMG serve as reference data. Secondly, OAG data of 2016 serve as reference data allowing additional comparisons with the model results.

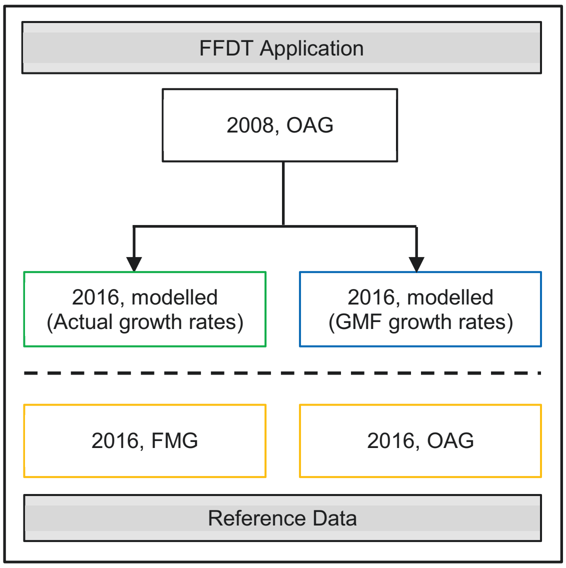


FIG. 4: Presentation and analysis of the Test Case results

In the following sections, the Test Case results are analysed according to four different characteristics:

1. Annual total transport capacity
2. Annual aircraft movements
3. Average aircraft transport capacity
4. Annual transport capacity shares per world region

For the analysis of annual transport capacity and of annual aircraft movements, FMG publications serve as reference data. As OAG data are not available at the Institute for all years from 2008 to 2016, FMG provides information on the above-named first two characteristics for all relevant years (Sections 3.2.2 and 3.2.3). For the evaluation of average transport capacity per aircraft and of annual transport capacity shares per world regions, the OAG data offers more comprehensive information compared to the published FMG data. Thus, for the above-named latter two characteristics, the OAG data serves as reference data (Sections 3.2.4 and 3.2.5).

3.2.2. Annual Total Transport Capacity

Fig. 5 shows the annual transport capacity results in AS modelled by the FFDT from 2009 to 2016 (in green and blue) in comparison to FMG data from 2008 to 2016 (in yellow). The striped bar additionally represents the Flight Plan of the base year 2008 as derived by OAG data. Transport capacity is given in million available seats.

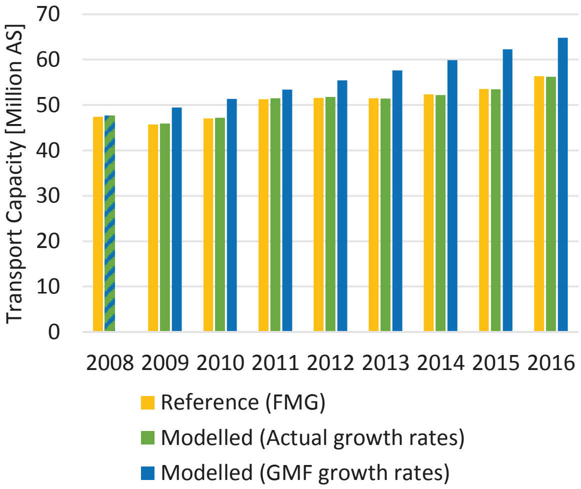


FIG. 5: Annual total transport capacity (in AS) of Test Case results and reference data

In general, transport capacities increase over the years for all three datasets. The FMG transport capacity numbers show a decrease from 2008 to 2009. The model results based on actual growth rates represent a corresponding drop in 2009 and generally follow the FMG data closely. In contrast, the model results based on the Airbus GMF growth rates show a steady and stronger rise in transport capacity.

The observed drop of the FMG data from 2008 to 2009 is caused by the global financial crisis and the subsequent negative impact on commercial aviation. The model results applying Airbus GMF growth rates rely on the forecast published by Airbus in 2008. As Airbus did not expect a financial crisis in their prediction, the published growth rates follow the assumption of a continued growth leading to an overestimated growth. This fact represents the basic motivation for a Test Case applying actual growth rates.

As expected, the model results applying actual growth rates closely follow the data published by FMG. This is reasonable since the model's input growth rates are received from historic FMG growth rates. Deviations in transport capacities between the model results and the FMG reference data rely on corresponding deviations already present in the base year (2008). This deviation of about 0.4% is caused by two main effects: The Flight Plan 2008 within this research is obtained from the OAG data from November 2007 to October 2008 (cf. Section 3.1.1).

Furthermore, the OAG traffic data contain scheduled flights, whereas the traffic data of FMG contain effectively flown flights. The Test Case brought forth a limitation of the FFDT connected to negative air traffic growth: The FFDT correctly processes negative growth rates only in the first modelled year. From 2012 to 2013, Munich Airport experienced a negative growth in transport capacity, thus, modelled transport capacities from 2013 on include small errors compared to the reference data. However, for the intend of representative impact assessments, negative air traffic growth only plays a minor role as aviation industry in unison expects future air traffic demand to grow.

In total, the Test Case results analysed by annual transport capacities demonstrate the FFDT's capabilities to take into account effects resulting from different air traffic growth scenarios on future flight plans, and ultimately, on future airport noise exposure.

3.2.3. Annual Aircraft Movements

Fig. 6. presents annual aircraft movement numbers modelled by the FFDT from 2009 to 2016 (in green and blue) compared to FMG data from 2008 to 2016 (in yellow). The striped bar, again, additionally represents the Flight Plan of 2008 as derived by OAG data.

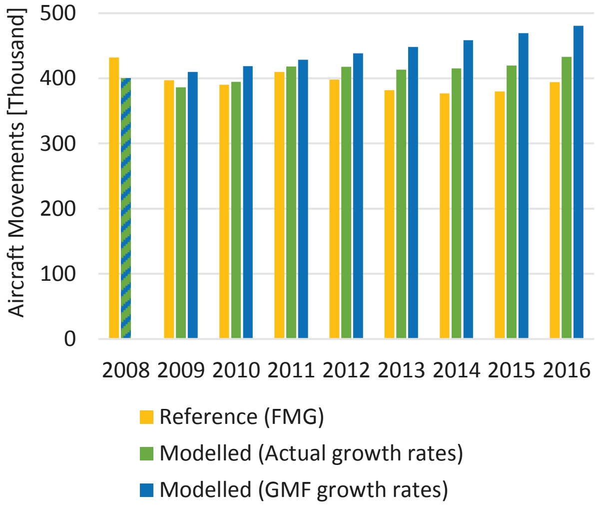


FIG. 6: Annual aircraft movements of Test Case results and reference data

In the analysis of the FFDT results it is to consider that the Flight Plan of 2008 already represents a significantly lower number of aircraft movements compared to the FMG data of 2008. For this, it is to note that the FFDT does not consider cargo flights and general aviation flights. Furthermore, the FMG aircraft movement numbers include all flight movements, whereas the Flight Plan 2008 is based on OAG data, which only indicate scheduled flights.

Considering the FMG data, the drop in 2009 as observed for transport capacity numbers can be found for aircraft movements, too (cf. Fig. 5). However, after 2009, a continued growth is not found for aircraft movements as observed for corresponding transport capacities. Regarding the model results based on actual growth rates, from 2010 on aircraft movement numbers lie above the FMG data. The model results based on Airbus GMF growth rates show a steady growth representing the largest movement numbers of the three datasets.

Concerning the development of annual aircraft movements for future years, deviations between the FFDT model results and the FMG numbers arise from at least two effects. Firstly, the model results rely on the corresponding transport capacity model results. Thus, deviations in modelled transport capacity directly cause deviations in aircraft movement numbers. A second reason lies in the aircraft fleet composition that provides the required supply in transport capacity. In this Test Case, although designed for representative impact assessments, the FANAM approach is compared to data of a specific airport whose flight plans are influenced by fleet strategy and detailed behaviour of individual airlines (cf. Section 2.2.1). For example, an abrupt aircraft swap or strategy changes by an airline with high operation share may lead to discrepancies between aircraft movement numbers modelled by the FFDT and actual movement numbers. Indeed, Lufthansa, the largest operator at Munich Airport, significantly modified its aircraft fleet strategy during the time-period of 2008 to 2016, for instance, by actively replacing smaller jet aircraft with larger jet aircraft and by retiring all turboprop aircraft in 2013 [13–15].

The observed deviations between the model results based on actual growth rates from the results based on GMF growth rates are caused by the deviation in transport capacity as the two cases only vary in the input of the air traffic growth module (cf. Section 3.1.2).

In Section 3.2.2 it has been presented that the FFDT results based on actual growth rates and the published FMG data show very similar quantities in terms of absolute transport capacity. However, corresponding aircraft movement numbers show higher deviations. Thus, given the fact that the model results based on actual growth rates rely on actual, historic air traffic growth rates, it is assumed that different aircraft sizes lead to the observed behaviour. Following this, the same transport capacity demand would then be provided by, on average, smaller aircraft in the modelled flight plan. The supposition of differing aircraft sizes as cause for the observed deviations is examined in the following section.

3.2.4. Average Aircraft Transport Capacity

Aircraft sizes are assessed as aircraft transport capacities (in seats) averaged across corresponding numbers of aircraft movements. Fig. 7 shows average aircraft sizes of the 2008 Flight Plan based on OAG data (striped bar), of the two modelled 2016 Flight Plans (in green and blue), and of a 2016 Flight Plan derived from OAG data (in yellow). The aircraft transport capacities are evaluated for the sub-groups of wide-body aircraft and narrow-body aircraft, as well as for the entire group of all aircraft types.

From 2008 to 2016 an increase in aircraft transport capacity can be observed for all cases, both model results, and reference data. However, the rise in transport capacity for the two model results is lower than for the OAG reference data. Comparing the OAG data of 2008 and 2016 shows an increase in aircraft transport capacity by as much as 28 seats.

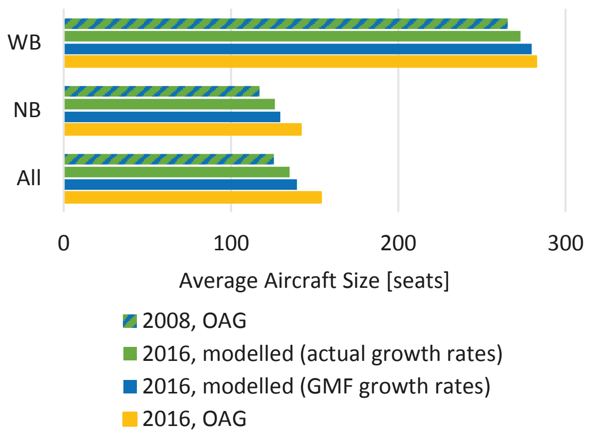


FIG. 7: Average aircraft transport capacity of Test Case results and reference data

The increase from 2008 to 2016 in the OAG data indicates the process assumed in Section 3.2.3: On average, smaller aircraft were replaced by larger aircraft. It follows that the risen demand in transport capacity is generally served by larger aircraft, thus decoupling the development of the increase in aircraft movements from the increase in transport capacity as observed in Fig. 5 and Fig. 6.

Fig. 7 confirms the above-mentioned supposition explaining the deviations in aircraft movements between FMG data and model results based on actual growth rates. During the assessed time period of 2008 to 2016, the actual increase in average aircraft size at Munich Airport was even stronger than the increase modelled by the FFDT based on world fleet behaviour during. Consequently, actual aircraft movement numbers at Munich Airport remain below the numbers of the model results.

This analysis points out the limitations of the accuracy of the method in estimating absolute future flight plans of a real airport, which, in reality, are due to airport-specific effects driven by the main operators of the particular airport. However, only in this Test Case, absolute FFDT results are compared to actual, airport-specific flight plans. As mentioned before, the FANAM approach rather is developed for relative assessments between scenarios, hence, for impact assessments. For this purpose, the evaluation of average aircraft transport capacities successfully illustrates the FFDT's capabilities to consider aircraft size as a non-predetermined degree of freedom. This is of advantage as it offers additional flexibility for studies with respect to the impact of different, future fleet mixes on future airport noise exposure.

3.2.5. Transport Capacity Shares per World Region

At last, the model results are analysed with respect to transport capacity shares for individual world regions. The evaluation of world regions is relevant for the application of the FANAM approach for two reasons: Firstly, destination and origin airports determine departure and arrival routes, which are important for airport-level noise assessments. Secondly, the assigned region-routes are crucial in the definition of region-specific air traffic growth rates for future years.

Fig. 8 shows transport capacity shares of Munich Airport aircraft movements assigned to world regions in four pie charts in the following order: The 2008 Flight Plan based on OAG data, the two modelled 2016 Flight Plans, and the 2016 Flight Plan derived from OAG data. The definition of world regions follows the region-routes defined by the Airbus GMF (cf. Section 2.2.2). World regions with less than one percent share are included in the category Others, shares larger than 5% are additionally detailed by numbers in the charts. The region Intra Western Europe of the Airbus GMF contains flights between two countries of the region Western Europe. Domestic Western Europe incorporates domestic flights within one country of the Western Europe region and is labelled Domestic (Germany) for a better distinction. PRC represents the People's Republic of China and CIS the Commonwealth of Independent States, which contains members of the former Soviet Union.

The general observation is that there are no particular strong deviations between the four presented transport capacity shares. For instance, the order of the largest regions is identical for all four flight plans, with Intra Western Europe standing in the first place, followed by Domestic (Germany), Central Europe, Middle East, and the USA.

The most noticeable deviation is found between the two flight plans not modelled by the FFDT: The deviation of the 2008 Flight Plan based on OAG data and the 2016 Flight Plan derived from OAG data for domestic flights whose share decreases significantly. Individual airlines' strategies and the particularly strong effect of the global financial crisis in Europe may cause the observed decrease in domestic air travel.

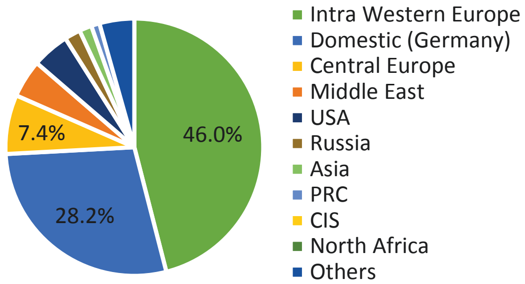
More importantly, analysing the FFDT results, the 2016 model results based on actual growth rates show no actual change compared to the 2008 Flight Plan. This behaviour is expected as the growth rates derived from FMG data are not detailed for individual regions and thus were assumed to be identical for all regions (cf. Section 3.1.2). Consequently, since flight plan entries of all regions grow alike, the shares in transport capacity remain constant. Comparing the 2016 model results based on the Airbus GMF growth rates to the 2016 OAG Flight Plan, significant deviations occur that have their origin in discrepancies between the Airbus GMF 2008 and actual growth rates. For instance, the GMF overestimated the growth of domestic flights and underestimated flights assigned to Intra Western Europe.

In general, the transport capacity shares of the FFDT results, as a matter of fact, strongly depend on the particular air traffic growth input. Altogether, compared to the reference data, Fig. 8 presents reasonable model results and visualises the FFDT's capabilities to reflect effects of region-specific air traffic growth on future flight plans.

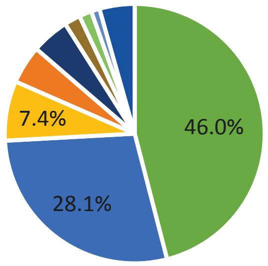
4. CONCLUSION

In previous research, we have developed the Future Airport Noise Assessment Method (FANAM) to provide modelling capabilities for studies on future airport-level noise exposure. Through the general FANAM approach of modelling future flight plans, aircraft noise at the vehicle level, and noise exposure at the airport level, the goal of impact assessments can be realised. A fundamental content of the method is represented by the comprehensive flight plan capabilities, which are necessary to account for relevant effects, for instance, resulting from future aircraft fleet changes. The flight plan capabilities have been realised through the development of the Future Flight Plan Development Tool (FFDT).

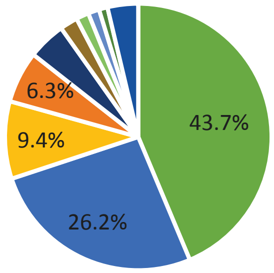
In the presented work, the FFDT is applied to a Test Case in order to verify and validate the developed method and its implementation. For this purpose, the FFDT is applied to Munich Airport. From a base flight plan of the base year 2008 the FFDT is used to derive flight plans up to the year 2016. In the application of the FFDT, two different growth scenarios are applied, using growth rates of the Airbus Global Market Forecast 2008, on the one hand, and applying actual, historic growth rates of Munich Airport, on the other hand. Although FANAM, designed for impact assessments, principally is not intended for the assessment of absolute levels, the Test Case does



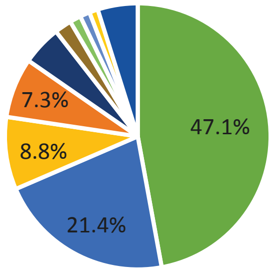
2008, OAG



2016, modelled
(actual growth rates)



2016, modelled
(GMF growth rates)



2016, OAG

FIG. 8: Annual transport capacity shares per world region of Test Case results and reference data

compare the FFDT results with actual, historic data of Munich Airport. Necessary reference data is provided by Flughafen München GmbH and by the Official Airline Guide.

The Test Case results are analysed with respect to different parameters. The modelled transport capacity results (in AS) show expected behaviour. Importantly, results of the application of actual, historic growth rates, as expected, match well with the reference transport capacities. Furthermore, under the specific aircraft retirement and introduction scenario, the modelled numbers of aircraft movements present comprehensible behaviour. Yet, the number of actual aircraft movements at Munich Airport in reality were lower than estimated by the model for the years up to 2016. The reason for the overestimation of aircraft movement numbers lies in the disproportionally high increase in average aircraft size for operations at Munich Airport compared to the development of the world fleet during the assessed time period. At last, analyses of transport capacity shares specified for different world regions presented the FFDT's abilities to account for region-specific growth rates in the derivation of future flight plans.

After the comprehensive application of the FFDT and subsequent thorough evaluations of the model results with respect to multiple parameters, the FFDT is thus shown to be a reliable tool for the flight plan modelling within the over-arching FANAM approach. From a given flight plan of a base year, depending on scenario-specific input, the FFDT is capable to derive Flight Plans of Equivalent Noise Events for a future year of interest. In upcoming work, the three different high-level areas to be modelled by the approach require consolidation and integration towards the top-level FANAM framework. Ultimately, for a given future year defined by the user, the method will provide capabilities to assess scenario-specific airport-level noise exposure.

References

[1] European Commission, *Flightpath 2050: Europe's vision for aviation*: *Report of the High Level Group on Aviation Research*, Publ. Off. of the Europ. Union, Luxembourg, 2011.

[2] A. Filippone, "Aircraft noise prediction," *Progress in Aerospace Sciences*, vol. 68, pp. 27–63, 2014.

[3] F. Will, C. Engelke, T.-O. Wunderlich et al., "Foundations of a Framework to Evaluate Impacts on Future Noise Situations at Airports," in *17th AIAA Aviation Technology, Integration, and Operations Conference*, 2017.

[4] J. Koopmann, A. Zubrow, A. Hansen et al., "Aviation Environmental Design Tool (AEDT) 2b User Guide," 2016.

[5] Eurocontrol, "The Aircraft Noise and Performance (ANP) Database," https://www.aircraftnoisemodel.org/.

[6] Airbus, *Global Market Forecast 2016-2035*, Blagnac, France, 2016.

[7] International Civil Aviation Organization, "CAEP-SG/20082-IP/02: Forecasting and Economic Analysis Support Group (FESG)," 2008.

[8] N. P. Randt, "Aircraft Technology Assessment Using Fleet-Level Metrics," *Dissertation, Technical University of Munich*, 2016.

[9] Airlinerlist.com, "Airlinerlist," http://www.airlinerlist.com/.

[10] OAG Worldwide Limited, "Official Airline Guide Schedules Data 2008,".

[11] Airbus, *Global Market Forecast 2009-2028*, Blagnac, France, 2009.

[12] Flughafen München GmbH, *Statistische Jahresberichte 2009-2016*, Munich, 2017.

[13] Lufthansa Group, *Letzter Propellerflug bei Lufthansa*: *Lufthansa-Kunden fliegen künftig noch komfortabler in reiner Jetflotte*, https://www.lufthansagroup.com/de/presse/meldungen/view/archive/2013/october/25/article/2648.html.

[14] Lufthansa Group, *30. Embraer seit heute im Liniendienst*: *Flugzeug zugleich 500. Embraer des Herstellers / Einsatz ab München*, https://www.lufthansagroup.com/de/presse/meldungen/view/archive/2012/january/16/article/2068.html.

[15] Flughafen München GmbH, *Statistischer Jahresbericht 2009*, Munich, 2010.