CASE STUDY ON AIRCRAFT NOISE REDUCTION BY VARIATION OF DEPARTURE PROFILES DURING NIGHT FLIGHTS

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Abstract

Since the civil air transportation sector has been growing significantly, with an increase not only in number of flights, but also with regards to their environmental impact, emissions have been growing to the same degree. Residents in areas around airports are therefore exposed to an increasing strain of noise pollution. Past scientific research has identified large potential through the implementation of operational noise abatement procedures. The following paper will present a case study concerning noise abatement procedures during departure flight phase as a measure to reduce aircraft noise. The study was conducted on behalf of the aircraft noise commission council of Berlin-Tegel airport. The main objective of this research was to assess whether the reduction of aircraft noise pollution can be achieved by noise abatement procedures, which are specifically adapted for the purpose of night-flights. Therefore, regular domestic overnight airmail flights were conducted as test flights between Berlin-Tegel airport and Stuttgart-Echterdingen airport. Those flights, which were performed from August 2016 to May 2017, qualify perfectly for this study, due to their specific schedule and uniform testing environment combined with a higher general focus on night-time noise immissions.

In order to develop sustainable operational procedures for aircraft noise reduction, a holistic approach is necessary. Hence, three distinct departures were introduced and performed during the domestic overnight airmail test flights. Subsequently, data about the test flights gathered from the FANOMOS database, contributed by air traffic control, were compared to data which was plotted at specific noise measuring points located at the two airports. With respect to the effectiveness, applicability and manageability of those procedures for flight crews, both airports were analysed separately.

The study results show that customized noise abatement departure procedures for Berlin-Tegel offer a significant potential of noise reduction in airport surrounding areas, whereas at Stuttgart-Echterdingen their impact on noise reduction is negligible. The procedures are generally feasible for daily operation and can easily be managed by flight crews. Ultimately, the study has shown that the success of noise reduction procedures strongly depends on the airport layout, it's surrounding area and population. Each airport has to be assessed separately in this perspective.

1 Introduction

Global air traffic faces the challenge of developing measures to reduce the emissions despite its continuous growth. These emissions are various and have in general a negative impact on humans and the environment. The growing number of residents who are affected by aircraft noise in airport surroundings, increase the importance of reducing air traffic noise. Several studies have shown that adjusted Noise Abatement Procedures (NAP) can reduce the noise immissions for departure and arrival [1] [2] [3] [4]. They often examined a large number of flights over a longer period of time, but without considering environmental aspects like wind and temperature, affecting the flight path significantly. Goal of this study is to find a noise optimized flight profile, with a close inspection of every test flight by taking also other factors like fuel consumption, air traffic situation and cockpit crew workload into consideration. The study was performed on behalf of the Airport Noise Commission of Berlin-Tegel and initial results were presented on the 71^{st} meeting of the commission in January 2018.

The focus is on exploring procedures to reduce the noise immissions during climb out for nightly air-mail flights, which are conducted during working days between Berlin-Tegel (TXL) and Stuttgart-Airport (STR) and therefore outside of the normal operating hours. In total there are approx. 450 air mail flights annually which depart around 00:15 a.m. and arrive around

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01:15 a.m local time. These flights are the testbed for different noise abatement departure procedures (NADP). Due to the relatively uniform testing environment with Airbus A319-112 aircraft, comparable weights and them being the only operating aircraft during the night time, unique opportunities arise to test different NADP and departure runways within the given regulatory framework.

2 Methods for Aircraft Noise Reduction

The approach to aircraft noise reduction has to take various factors into account. These include but are not limited to the specifics of each airport, the traffic situation, the prevailing weather conditions, aircraft type, load factor, crew training and workload and environmental emissions. Everything taken into consideration will determine the NAP suitable for the specific airport, which is part of the ICAO Balanced Approach to reduce noise [5]. In flight operations there are different NAP depending on the flight phase - they are relevant in altitudes up to 3000 m above ground level (AGL). Although there is a potential in noise reduction, NAP to some extend can cause higher CO_2-, NO_X- and other emissions. For this study, the attention will be specifically on noise abatement departure procedures.

2.1 Noise Abatement Departure Procedures

During departure, if the lateral routing is fixed (e.g. by ATC or published flight procedures), the vertical flight profile is of most relevance. For the airline conducting the airmail flights there are currently two NADP in place. They are in accordance to ICAO Doc 8168 – Volume 1 and are shown in Figure 1 [6]. Basic principles are:

- NADP 1, reducing aircraft noise in close proximity to the airport
- NADP 2, reducing aircraft noise farther away
- Safety is priority over noise reduction

Main influences on the vertical trajectory are:

- Take-off mass of the aircraft
- Take-off thrust setting until thrust reduction altitude
- Outside meteorological conditions
- Initiation of rotation for lift-off
- Speed control of v_2 + 10 kt after lift-off
- Thrust reduction altitude
- Acceleration altitude

Based on these factors a short- to midterm noise reduction can be achieved through:

- Reduction of thrust setting
- A higher trajectory
- Reducing aircraft velocity

However, these measures often cancel each other out or contradict each other. Therefore, it is important to do a case-by-case review for the appropriate procedure at each airport.
To show the potential of a higher acceleration altitude, ICAO conducted a study calculating the noise, carbon-dioxide and hydrocarbon emissions for different aircraft and four variants of NADP [4]. In case of an Airbus A320-214, the results show that a significant reduction in L_{Amax} of more than 6 dB(A) is possible at 4 NM from brake release, if NADP 1 is used as departure procedure. Furthermore, there is an overall reduction in noise in the area from 2 – 7 NM, which is pa result of the approximately 1000 ft higher flight path. From around 7,5 NM on, the NADP 2 profile leads to a noise reduction, which in magnitude is less than the NADP 1 profile.
The results show a significant noise reduction potential with NADP 1 and will, in chapter 4, be compared to the noise measurements taken during the test flights.

2.2 Departure Procedures for Test Flights

Based on the existing two NADP displayed in Figure 1, the test flights were conducted with three variants, specifically adapted for potentially reducing aircraft noise. In general, these variants differ among themselves only in the acceleration altitude and, compared to the standard NADP, they include an intermediate climb speed of 210 kt, after flap retraction, until passing 5000 ft, as shown in Figure 2. This means that until reaching 1000 ft and the setting of climb thrust all test procedures remain the same.
To create a uniform testing environment, the following variables were set specifically for all test flights to ensure comparability, although the number of test flights is relatively low. Furthermore, the study incorporates a close examination of each flight, versus a large-scale observation.

- Aircraft type Airbus 319-112
- Take-off mass between 53,9 t and 59,6 t
- Take-off thrust fixed at FLEX 55 independent of take-off runway
- Take-off flap setting 1+F
- Activation of autopilot at 400 ft AGL to track v_2 + 10 kt closely and to achieve uniform acceleration rates

2.3 Noise Preferred Runways

In addition to the adoption of specific NADP, there is the opportunity to install noise preferred take-off and

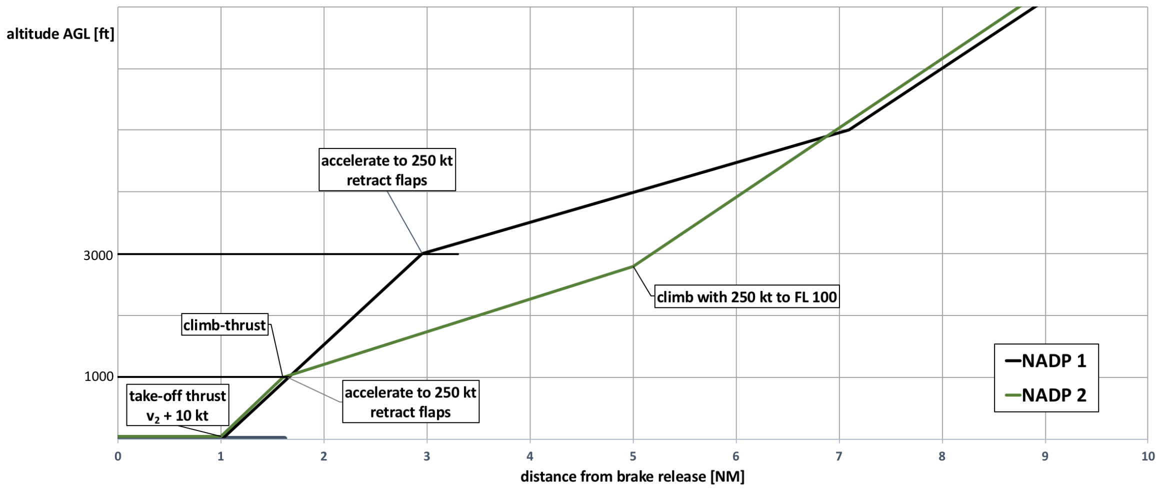

Figure 1: Departure procedures NADP 1 and NADP 2 [7]

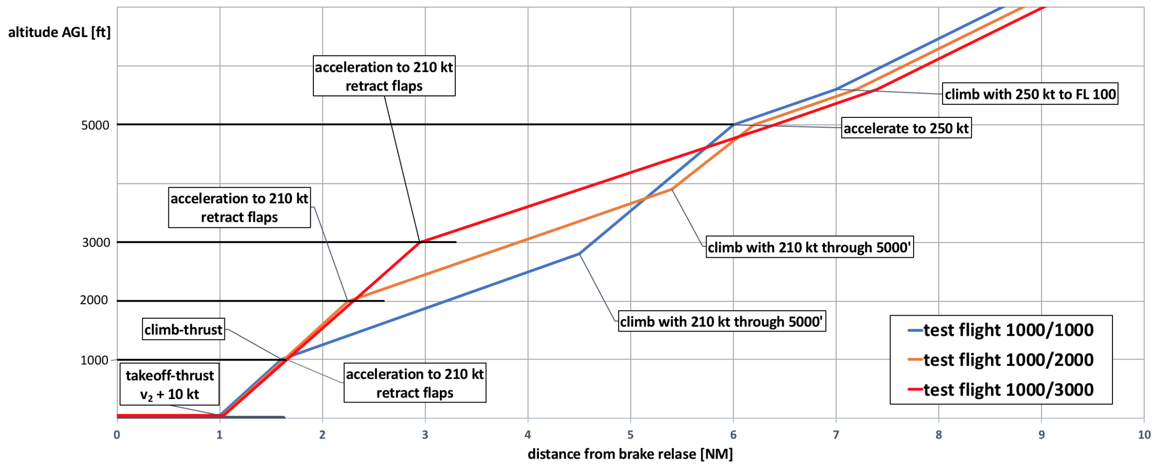

Figure 2: Departure procedures test flights

landing directions, if the meteorological conditions are within certain parameters [6]. This procedure can be used to create low-noise timeframes for specific areas or to avoid overflying densely populated areas. Over the period of one year, the operating direction of Berlin-Tegel is 2/3 westerly and 1/3 easterly [8]. The nightly postal flights show a different distribution, because of the possible shorter flight route if departing TXL to the west and approaching it to the east, on the routing TXL ⇔ STR. Table 1 shows that even more flights depart to the west during night time. The difference is even greater for approaching traffic and demonstrates, that a noise preferred operating direction has the potential of reducing noise for specific areas.

3 Test Flights

After introducing the procedures for conducting the test flights, the next step is to look at the data used for the flight analysis and also to go into detail in regards to the operated airports. On the one hand the "Flight Track and Aircraft Noise Monitoring System (FANOMOS) from the German DFS is used to display the flight tracks and vertical profiles. On the other hand, the results from the noise measuring points, provided by the airports, is analysed. Additionally, the information on the displays inside the flight deck was recorded for the test flights, to generate the necessary information on wind and temperature.

Night Postal Flights	Approach	Departure
08 L/R	63,9 %	21,5 %
26 L/R	36,1 %	78,5 %

Table 1: Distribution of operating runway for TXL night postal flights August 2016 - May 2017

3.1 FANOMOS

The German air traffic control is operating FANOMOS enabling the visualization and evaluation of approach and departure air traffic around most of the German airports using flight progress data. This data is processed from radar data (Tracker) and enhanced by flight plan data. In FANOMOS, the barometric altitude above mean sea level in reference to the local QNH is recorded. Depending on the temperature, the true altitude can differ significantly from the displayed altitude. Therefore, a temperature correction is performed for all flights within the period of assessment according to equation 1. The corrected altitude h_{korr} [ft] is a result of the altitude above ground level (AGL) and outside air temperature T [°C]. Every altitude shown in diagram 5 and diagram 6 is corrected for airport altitude and displayed in altitude AGL.

$$h_{korr} = h + h \cdot (15 - T) \cdot 0,004 \tag{1}$$

$$d_{korr} = d - v_{wind} \cdot 4s \tag{2}$$

Aside from the outside air temperature, the wind vector has a significant influence on the trajectory of an aircraft. To create comparability between the test flights, the wind vector was monitored from inside the flight deck enabling the calculation of a corrected flight path angle γ_{korr} with the four seconds interval of the FANOMOS data. The first step was to correct the travelled distance d [NM] for its wind component to calculate d_{korr} [NM]. In a second step, the altitude reached was corrected for temperature. The corrected flight path angle γ_{korr} is:

$$\gamma_{korr} = \arctan(\frac{h_{korr}}{d_{korr}}) \tag{3}$$

As described in chapter 3.3, the corrections applied reveal that reproducible flight paths can be generated and therefore demonstrate the potential of noise abatement procedures.

3.2 Aviation Noise Monitoring

German airports are obligated to conduct noise measurements in the vicinity and immediate surroundings, acc. the German Noise Act. The Airport Berlin-Brandenburg GmbH, who operates the Airport Berlin-Tegel put a total of seven noise measuring points (MP) in place for Berlin-Tegel airport, as shown in Figure 3. The stations are generally placed below the flight paths and the measurement results are made public each month [8]. MP 42 and 49 are closest to the airport and the first ones to be overflown for departure. They also mark the beginning of residential areas around the airport. For the district of Spandau, in the west, MP 43 and MP 41 are relevant. East of the airport, with MP 47 and 48, there are two stations for the districts of Wedding and Pankow.

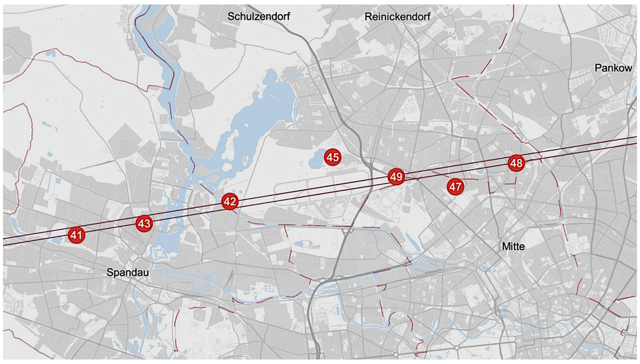

Figure 3: Noise measuring points Berlin-Tegel

3.2.1 Berlin-Tegel Airport

In this paper the focal point will be on TXL, as it did show the most promising results for potential noise reduction, due to the airports close proximity to surrounding housing areas, which increases the necessity for tailored NAP. For departure and approach, Berlin-Tegel offers two parallel runways in close proximity to each other. In principle both can be used for take-off or landing, for example if there is construction work during night-time. During daytime operation runway 26L/08R is used for take-off and the northern runway 26R/08L is used for landing traffic.

By using the FANOMOS data, it is possible to locate the areas affected by the night postal flights through overlaying the departure flight tracks with the land use plan for Berlin. Figure 4 shows all of these flights from August 2016 till May 2017. The departure tracks indicate clearly that the MP are always overflown directly. Since short term adjustments on the published flight procedure cannot be introduced and the horizontal paths variations are not relevant for noise abatement in this setup, the study focused on the operational adjustment of vertical profile.

3.3 Departure Profiles

In Chapter 2.1 the potential of noise abatement through higher flight profiles was shown theoretically. Now the actual test flights will be compared to the predicted potential of NAP and will thereby be validated. Figure 5 displays 15 test flight profiles and 175 reference flight profiles, obtained from FANOMOS, within the period under review. All four departure runways used during that time, are shown in one diagram, with distances being referenced to each brake release point. The share of 77 % of all departures towards the west from runways 26L/R is higher than the annual average for normal traffic operating into TXL. This results from the possibility to request the departure direction within operational limitations, as the night postal flight is the only traffic.

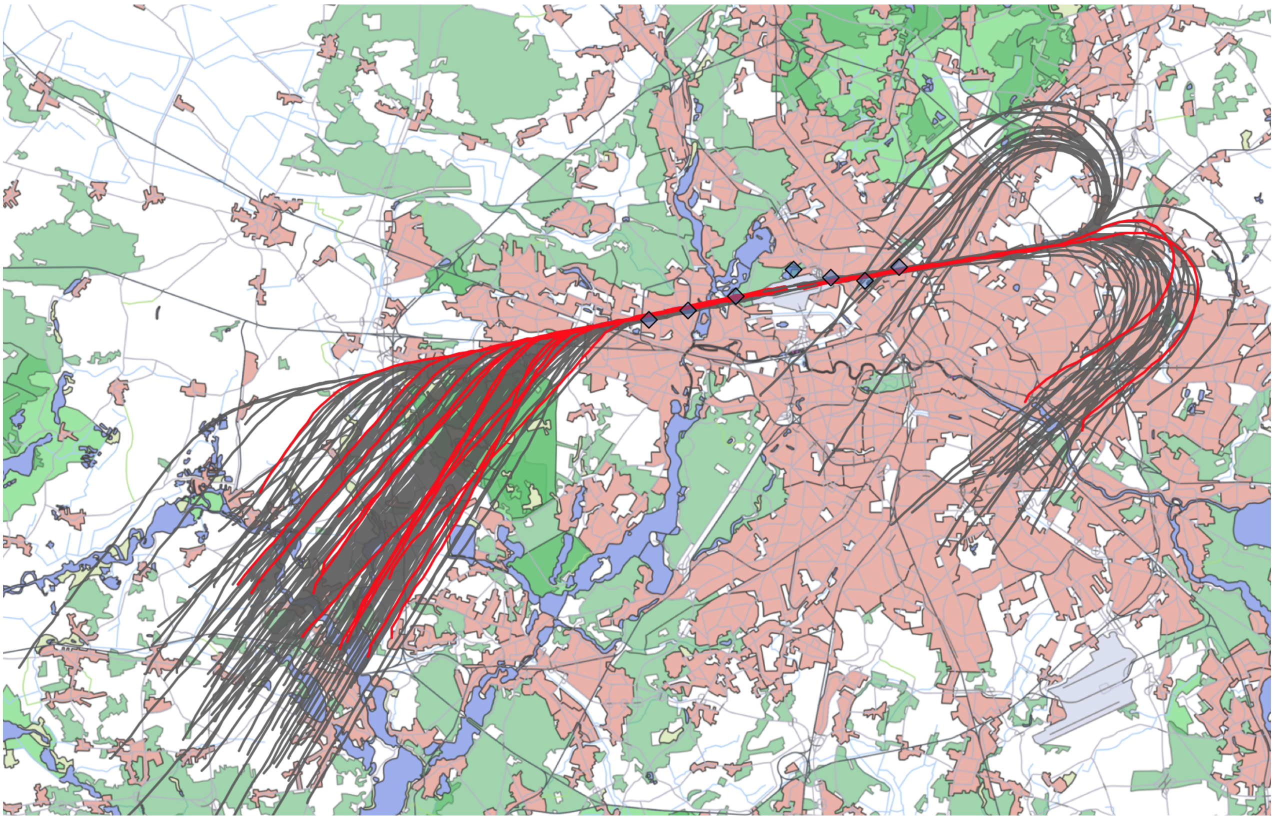

Figure 4: Flight tracks for westerly and easterly departures Berlin-Tegel - reference flights (gray) and test flights (red)

With 86 % the share of westerly departures is even higher for the test flights.

Demonstrative is the considerable vertical variation displayed in Figure 5, despite the relatively uniform testing environments for the postal flights. Most influential are the meteorological conditions and the adherence to the initial climb speed of the crews. Also, the variation is greater for westerly departures because easterly departures will most likely have a significant headwind component. The profiles for the test flights show in general a higher trajectory and less spreading since tracking of the initial climb speed v_2 + 10 kt and a uniform acceleration procedure was part of the testing program.

Examining the relevant altitudes at the measuring points, the magnitude of dispersion becomes obvious. For departures towards the west, first MP 42 is passed over. At this point the altitudes vary between 940 ft and 2500 ft, which after only 2,4 NM results in an altitude difference Δh of more than 1500 ft. For MP 43 the altitudes vary between 1800 ft and 3700 ft and MP 41 has the largest dispersion with Δh of 2600 ft between 2500 ft and 5140 ft.

Departures towards the east are more uniform since they normally require headwind and the crews are aware of shortcuts given at altitudes of 8000 ft. MP 48 is being passed over in a range of 2200 ft and 3470 ft, which has a smaller corridor of approx. Δh 1200 ft. As there were only two test flights departing towards the east, the focus will be put only on westerly departures.

The test flight profiles are corrected for temperature and wind influence, as described in chapter 3.1. These corrected flight profiles are shown in Figure 6. The only difference is the acceleration altitude of 1000 ft, 2000 ft or 3000 ft. After take-off the test flights climb through 1000 ft, still being above the runways and therefore thrust reduction takes place overhead the airport parameters. From this point forth, only the acceleration altitude has an influence on the vertical profile. When comparing the profiles of each variant, they display only slight deviations. It becomes clear that a precise control of vertical departure profiles is possible. Only one test flight of the 3000 ft variant has a lower profile, which is possibly the result of an increased take-off mass of approx. 4 t.

Overhead MP 42 the vertical differentiation begins to develop. The 2000 ft and 3000 ft variant still have the same climb gradient, the 1000 ft variant has a lower gradient. At MP 43 the maximum altitude difference of approx. 1200 ft is reached, where the 2000 ft variant, as expected, is in the middle between the two others. For MP 41 the procedures again close in at each other and a minimal higher altitude remains with the

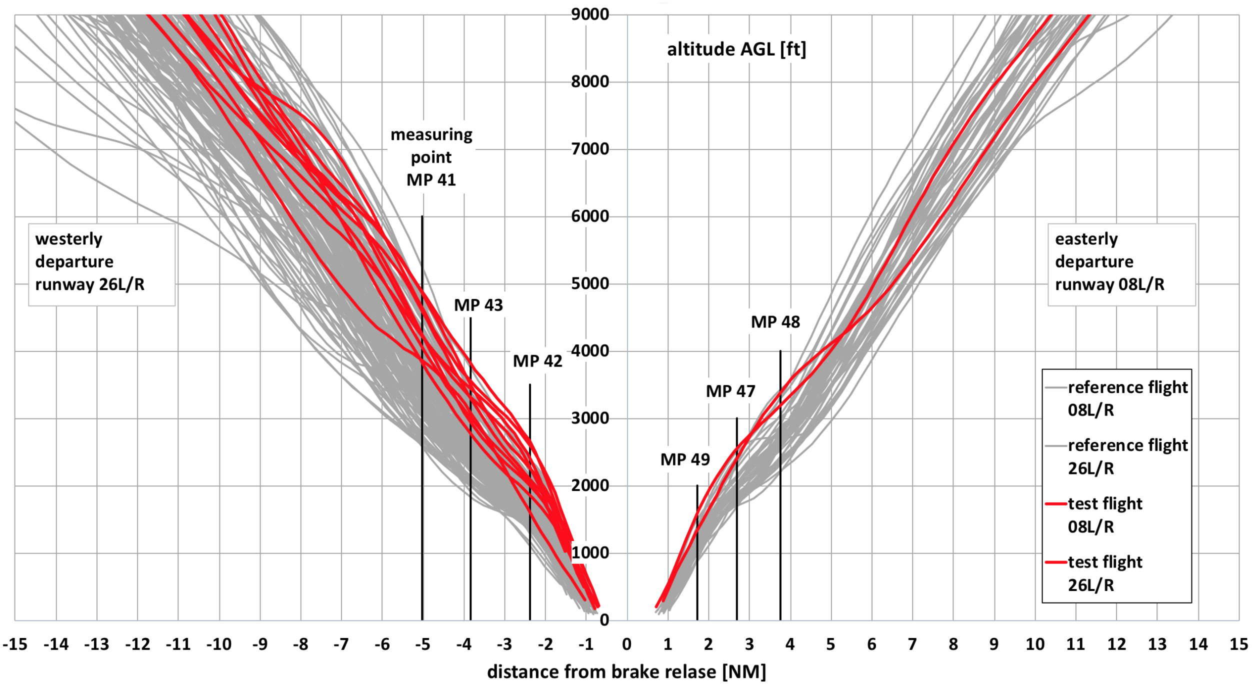

Figure 5: Departure profiles Berlin-Tegel in westerly- and easterly direction without correction method - reference flights (gray) and test flights (red)

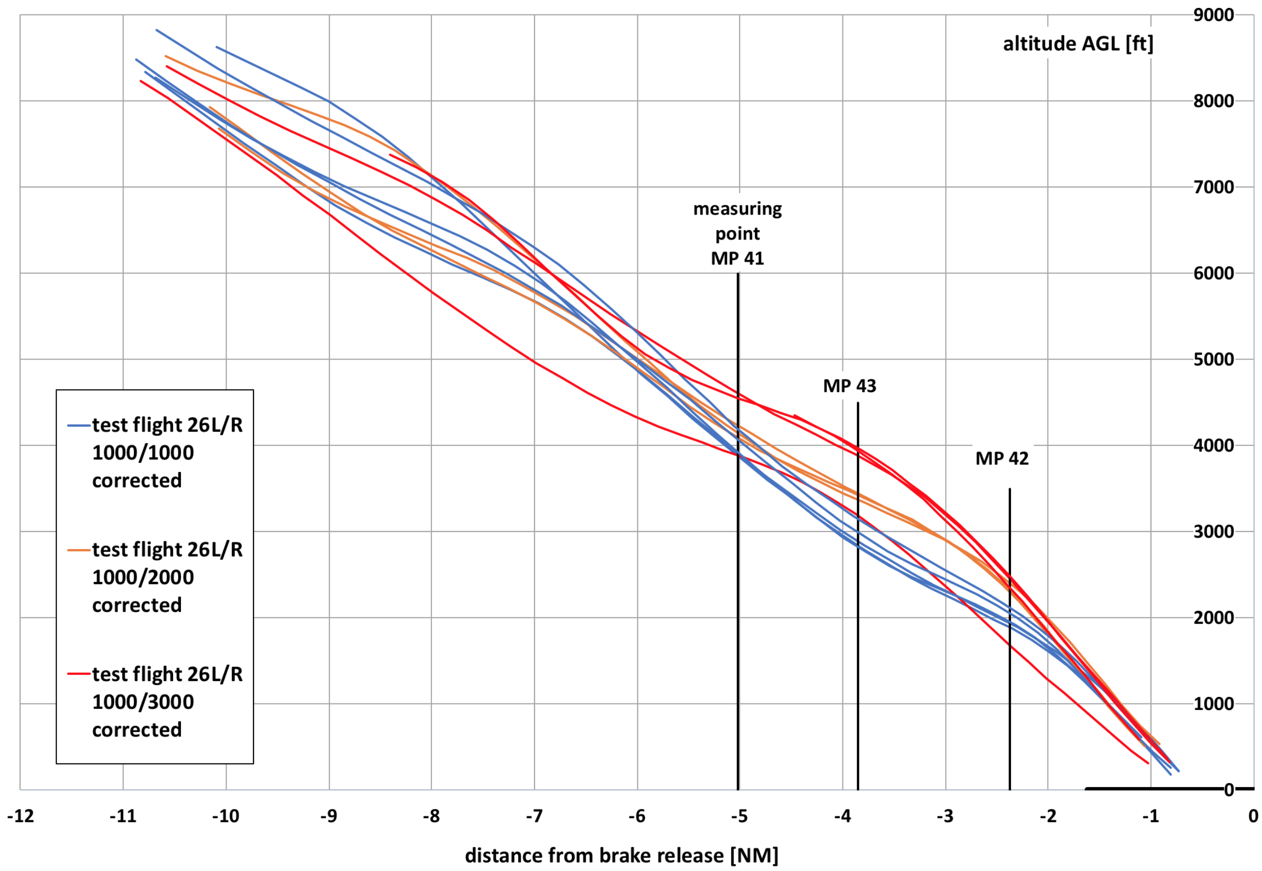

Figure 6: Departure profiles of test flights Berlin-Tegel in westerly direction with temperature and wind correction

3000 ft variant. By reaching 5000 ft the vertical differentiation is concluded and flight paths are similar from here on. With regard to the distance from brake release, the area where a higher acceleration altitude has an effect is between 2 NM and approx. 5,5 NM for this case study. This study also confirms the theoretical considerations introduced in chapter 2.1.
Thereby could be established, that adapted noise abatement departure procedures can be implemented and different vertical profiles can be operated precisely. Because of the altitude difference at MP 43 it is expected to result in a significant noise immission reduction.

4 Results of noise measuring

Through evaluation of the data retrieved from noise measuring points around TXL (recorded noise metric was L_{Amax}), the aim is to prove, that higher departure profiles and adapted NADP lead to a reduction in noise immissions. Hence, the maximum noise levels for MP 42, 43, and 41 are displayed in a boxplot format. The boxplots show 50 % of the values within the box itself, including the mean value. Additionally, each branch displays 25 % of the values including the minimum and maximum values. Important for interpretation is that there are no corrections for wind, temperature and humidity made in regard to the noise measurements and are therefore subject to variation. For each measuring point maximum noise levels for the 1000, 2000 and 3000 variants are displayed, as well as the maximum noise levels for the reference flights.
As expected, the noise levels decrease with increasing altitudes above MP 42 to MP 43 and MP 41. Also, a large difference in altitude at which the MP are overflown is displayed in the noise levels of the reference flights. Despite a share of 50 % from the reference flights having maximum noise levels within 2 dB(A), the values for minimum and maximum differ by 8 dB(A) for MP 42, 10 dB(A) for MP 43 and 11,2 dB(A) at MP 41. To this effect the noise levels correlate with the increasing spread in altitude further away from the airport.
Examining the maximum noise levels of the test flights, it becomes clear that the dispersion is less compared to the reference flights. This proves the results from the analysis of the vertical flight profiles of Figure 6. Greater vertical gradients lead to an overall noise reduction, in such a way that all test flights have lower noise levels than the quietest 25 % from the reference flights.
Starting with MP 42, there seems to be a noise reduction trend of the 3000 ft variant, but not significant enough due to its spread along the test flights noise records of 5 dB(A). The test flights at this measuring point are always quieter than the lower 25 % of the reference. Maximum noise levels of the three variants have a difference of up to 5 dB(A), which is a result of the different environmental conditions.
The greatest distinction between the three variants was predicted to be at MP 43. This theory could be confirmed by the measurements. Noise immissions of the three variants correlate with the vertical profiles of the 3000 ft acceleration altitude being the quietest procedure. During the entire test period the 3000 ft variant is always quieter than the 2000 ft variant, which on average is quieter than the 1000 ft variant. The mean noise reduction of the 3000 ft variant is 5 dB(A). The 2000 ft variant shows still an approx. 2 dB lower maximum noise level. The highest achieved noise reduction is 7,4 dB(A) for the test flights.
Overflying MP 41 the profiles become again more adjacent, which is also reflected in the noise levels. They are close to each other with a slight advantage for the 3000 ft procedure. The mean levels are again quieter than the lower 25 % of the reference flights.

Analysing the noise levels for Berlin-Tegel airport has shown, that a noise reduction, analog to the control of the vertical profiles, between 2 NM an 5,5 NM from brake release, can be achieved. The standardization of the flight trajectory can be accomplished through crew training and identically flown procedures (shown in Figure 6), after correcting the profiles for wind and temperature influences. Thereby a reduction in maximum noise level of up to 5 dB(A) is possible. This also confirms the investigation made by ICAO, introduced in chapter 2.1, in regard to the magnitude of reduction and area which benefits from tailored NADP. A maximum gained altitude difference of 1200 ft and the highest reduction taking place at 4 NM are also confirmed. Even under different meteorological conditions did the consistent implementation on NADP reduce noise levels compared to the reference flights.

5 Results from noise and engine emissions modeling

The Aviation Environmental Design Tool (AEDT) of the US Federal Aviation Administration (FAA), version 2d SP1, was used for noise modeling purposes within the framework of the demonstration of the evaluation procedure (e.g. noise contours, flight times and fuel consumption) [9].
Using AEDT and the integrated BADA flight performance module, the aircraft performance is modelled in 4D (space and time), allowing aircraft noise, flight time required, fuel consumption and engine emissions to be calculated. AEDT is used to model both single flight events (departure, approach, overflight, engine test runs, taxiing, APU/GPU usage, etc.) and complex air traffic scenarios at airports and within

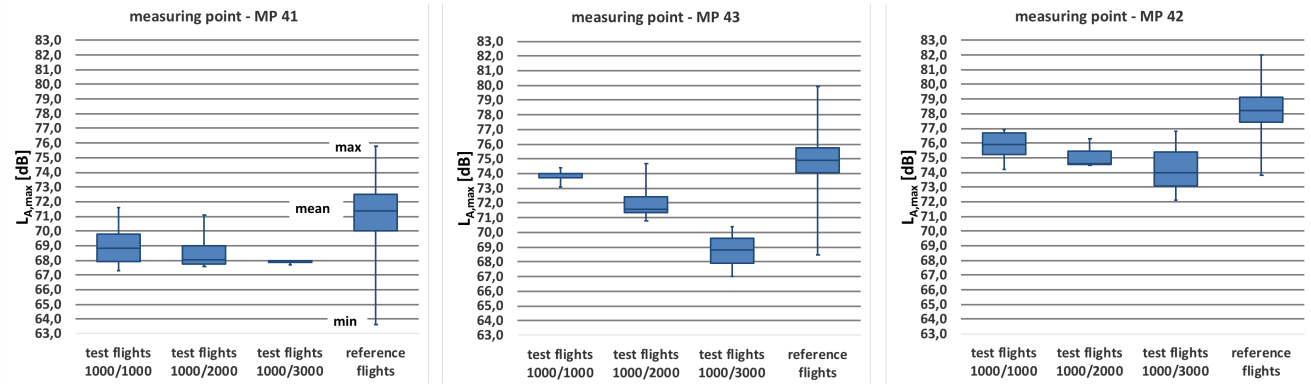

Figure 7: Boxplot L$_{Amax}$ MP 41 - MP 43 - MP 42 Berlin-Tegel

TMAs and to comprehensively investigate dependencies between fuel consumption, noise emissions and air quality.

The aircraft noise calculation methods implemented in the current AEDT Version 2d correspond to the European Civil Aviation Conference (ECAC) Doc 29 (4th Edition) "Report on Standard Method of Computing Noise Contours around Civil Airports" and the International Civil Aviation Organization (ICAO) Doc 9911 (1st Edition), "Recommended Method for Computing Noise Contours Around Airports" [10] [11]. The flight trajectories relevant to aircraft noise are determined in accordance with ECAC Doc. 29, Society of Automotive Engineers (SAE) Aerospace Information Report (AIR) No. 1845 (SAE-AIR-1845) and EUROCONTROL Base of Aircraft Data (BADA 3 Family) [12] [13].

As part of the noise study, the a-weighted, maximum sound level L$_{Amax}$ is calculated for a grid dimension of 50x26 km and 200 m grid spacing, with the airport reference point of Berlin-Tegel Airport representing the center of the grid. Emissions, fuel consumption and time consumption are calculated centrally for each individual operation in the flight plan. The contours were calculated based on the actual aircraft weight, reduced take-off thrust setting based on the flight operational data and 3D trajectory data retrieved and processed from the FANOMOS data set. The respective noise contours for westbound departures are illustrated in Figure 8.

The noise contours show that a reduction in noise immission levels start 2 NM after the brake release point at the earliest by adjusting the NADP profiles. Furthermore, the effect of the moment of thrust reduction is achieved already during overflying the runway end. Compared to the baseline NADP 2 scenario, the NADP 1 scenario (1000 ft cutback, 3000 ft acceleration altitude) could be shortened considerably by 2 NM for the 70 dB(A) contour. To underline the results from noise modeling, the noise contours were overlaid with population and census data for the airport vicinity. Applying a NADP1 procedure (1000 ft cutback, 3000 ft acceleration altitude) for westbound departures at Berlin-Tegel airport can reduce the amount of affected people within the 70 dB(A) contour by -95 % and within the 65 dB(A) contour by -31 %. However, the fuel and efficiency assessment show an increase in fuel burn by 50 kg and 34 s longer flight time until passing 5.000 ft AGL, if the noise-optimal NADP1 (1000/3000) would be introduced.

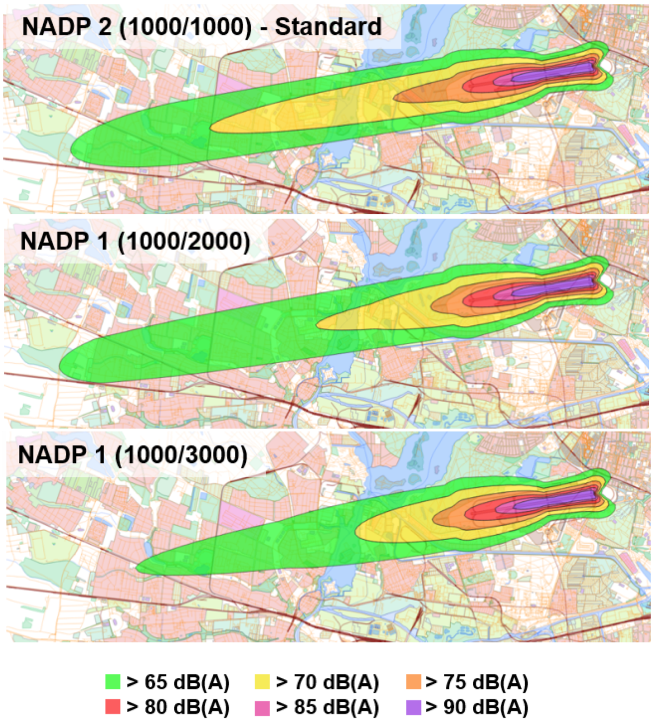

Figure 8: L$_{Amax}$ noise footprints for selected NADP variations

It should be noted that the results of the modelled noise contours and the overlap with population data refer exclusively to the use case in Berlin-Tegel, while the results of the fuel and efficiency evaluation are site-independent.

6 Discussion

In this case study, the noise reduction potential through adapted noise abatement procedures was analysed. Because of the operating times, the nightly postal flights, are critical concerning aviation noise. The goal was to identify and verify noise reduction potential for airport surrounding areas with tailored procedures.

The theoretical findings given in chapter 2.1 could be substantiated by the test flights. In particular the westerly departures from Berlin-Tegel could benefit from a noise reduction of up to 5 dB(A) in an area of 2 – 5 NM from brake release. From the standpoint of aviation noise, this is a significant improvement, especially during night time and for residential areas close to the airport. However, the other environmental aspects, like higher emission of toxic gases and CO_2 have to be considered in a holistic approach. In daily operations, the procedures are easy to be implemented and the workload for flight crews does not increase. A cutback in flight safety did not manifest.

The continuous growth of air traffic should be accompanied with scientific research to at least, maintain current emission levels. Therefore, every airport, where a large number of residents is affected by aviation noise immissions, has to develop specific procedures. For example, through actual immitted noise fees, as it is planned for the two Berlin airports. The implementation has to involve all stakeholders. Only then an aircraft noise reduction for the nightly postal flights can be achieved and approval within the concerned housing areas could be achieved.

Further testing is necessary whether implementation of the new procedures brings a long-term improvement of noise reduction in daily flight operations. The evaluation and validation procedure should be transferred to other airports, where a similar complex of noise issues exists.

To increase the fact-based arguments on advantages and disadvantages of different NAP, a methodology should be developed that takes into account interrelationships for noise immissions, environmental and (socio-)economic aspects, and ultimately a global optimum for all emission metrics (pollutant and noise), from which all parties involved would benefit.

Acknowledgements

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