REAL-TIME AIRCRAFT NOISE PREDICTION FOR TRAJECTORY BASED ARRIVAL MANAGER

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Abstract

In this paper, we introduce a method for aircraft noise estimation adapted to the planning characteristics of the DLR arrival manager 4D-CARMA with significantly reduced computing times by connecting the planning algorithm with a trajectory-based aircraft noise database. Thus, it is possible to support the air traffic controller with noise abatement routes during real-time approach planning and guiding. The sound-source aircraft, the propagation medium atmosphere including actual meteorological conditions, a three dimensional model of the earth's surface, and the population distribution around an airport were taken into account for the noise propagation calculation.

1 Introduction

The growing number of aircraft and flights at major international airports leads to increasing noise complaints in the vicinity of civilian airports. During the last 30 years many technical innovations like noise reduction at the source, operational measures for arrivals and departures, or regulatory requirements by governments made a reduction of air traffic noise possible. Nearly all aircraft approach procedures used today were developed to reduce the size of the noise effected area on the ground. This area is called the noise footprint for a specific acoustic noise value and its size depends mainly on flight altitude, thrust, speed, slats, and landing gear. To reduce the size of footprints, noise abatement procedures were developed with computer simulations, noise measuring around airports, and arrival procedure flight tests as well as regional adopted variations of these procedures. In this context, the best noise abating effects during approach have been achieved by Low-Drag-Low-Power Approach (LDLP), Continuous Descent Approach (CDA), Steep Approach, and 2-Segment Approach.

2 Noise abatement procedures

The main idea of today common approach procedures is that aircraft produce less noise in high altitude with low engine power and reduced speed. Noise abatement procedures often have the drawback that they reduce the capacity of airports [1]. The very noise efficient approach procedure CDA for example was introduced at Schiphol/Amsterdam and reduced the runway capacity to the half. More complex noise abatement operations were developed during the last years, but not all aircraft types are suited for this kind of approach procedures [5]. Besides adapted flight procedures, reducing engine noise directly by the jet engine engineers was very effective during the last years. However, this will be fully realized only in the long term since new developments in aircraft design can only be achieved when older aircraft or at least engines are exchanged. Regulatory measures are suited to force airlines to exchange their old aircraft by newer and quieter ones [8].

3 Trajectory Optimization

Regarding noise criteria, not only flight procedure but also arrival and departure flight paths can be optimized with mathematical trajectory calculations. DFS (Deutsche Flugsicherung GmbH, German air navigation service provider) uses e.g. NIROS (Noise Impact Reduction and Optimization System) for the off-line calculation of noise reduced departure routes in the vicinity of civilian airports. The trajectory generation and optimization process takes aircraft type, 3d-position, thrust, population distribution and density, meteorology, and 3d-global surface topography into account. The use of this assistance tool for real-time aircraft guiding leads to some difficulties. Because of the amount of parameters, each trajectory optimization takes several minutes up to hours computation time on a standard computer, so that it is not yet suited for online approach service.

4 Aircraft Noise Calculation

For aircraft noise calculation we overlaid the earth surface with a regular mathematical grid with fixed spacing. The local altitude of the representing earth's surface was assigned to every grid point. The towns and cities were positioned on this grid and every grid point was associated with the number of residents living in the area represented by this point. The aircraft flight path was mathematically modeled as 4d-trajectory with 2d-position, flight altitude, time, speed, and heading. For every populated grid point we calculated the maximum A-weighted sound level L_{Amax} and converted it with the exposure time t_{10} to the Single-event Exposure Level *SEL* (sometimes also named Sound Exposure Level) [7]. The *SEL* is one of the most common measures of cumulative noise exposure for a single aircraft flyover regarding the exposure time. Mathematically, it is the sum of the sound energy over the duration of a noise event. The 10 dB-down-time t_{10} describes the noise duration, where the noise level doesn't fall below 10 dB under the maximum noise level of a single event:

$$SEL = L_{A\max} + 10 \cdot \log\left(\frac{t_e}{t_{ref}}\right) \qquad (1)$$

With the approximation of

$$t_e \approx 0.5 \cdot t_{10} \qquad (2)$$

and the reference time $t_{ref} = 1$ s, equation (1) is suited for a fast calculation of aircraft noise exposure.

5 Noise Rating of Trajectories

Depending on the local air space structure, the arrival manager generates trajectories for all aircraft noise classes and a selected number of starting points in the vicinity of the airport. For meteorological constraints the European standard atmosphere with an air temperature of 15°C and a relative air humidity of 70% are considered. If the typical local weather conditions differ obviously from these values, it is possible to calculate the trajectories taking these typical meteorological constraints into account and generate a second or even more databases. The air space structure defines standard arrival routes (STAR) with mandatory flight altitudes and speeds, so that the number of possible arrival trajectories for each kind of aircraft can be confined. For all generated trajectories an aircraft noise value is calculated and stored together with the flight time following this trajectory in the noise database.

The population dependent Flight-Route-Aircraft-Noise-Burden Index (*FRANBI*) is calculated for each arriving aircraft trajectory on the base of the Single-event Exposure Level *SEL*, the number of affected people *E*, and the number of people living around the airport E_{all}. For our exposure evaluation, affected people are only taken into account if *SEL* is greater than 30 dB (N_{30}):

$$FRANBI = \frac{1}{E_{all}} \sum_{i=1}^{N_{30}} \sqrt[3]{E_i} \cdot 7.079 \cdot 10^{-5} \left(SEL_i\right)^{3.496} \qquad (3)$$

This model takes into account that higher populated areas have usually a higher background noise level and the inhabitants are less sensitive for aircraft noise [1]. The connection between *FRANBI* and an individual noise exposure is build by the results of a meta-study of the Federal Interagency Committee on Noise (FICON). In this report the authors analyzed how many people awake by single aircraft noise

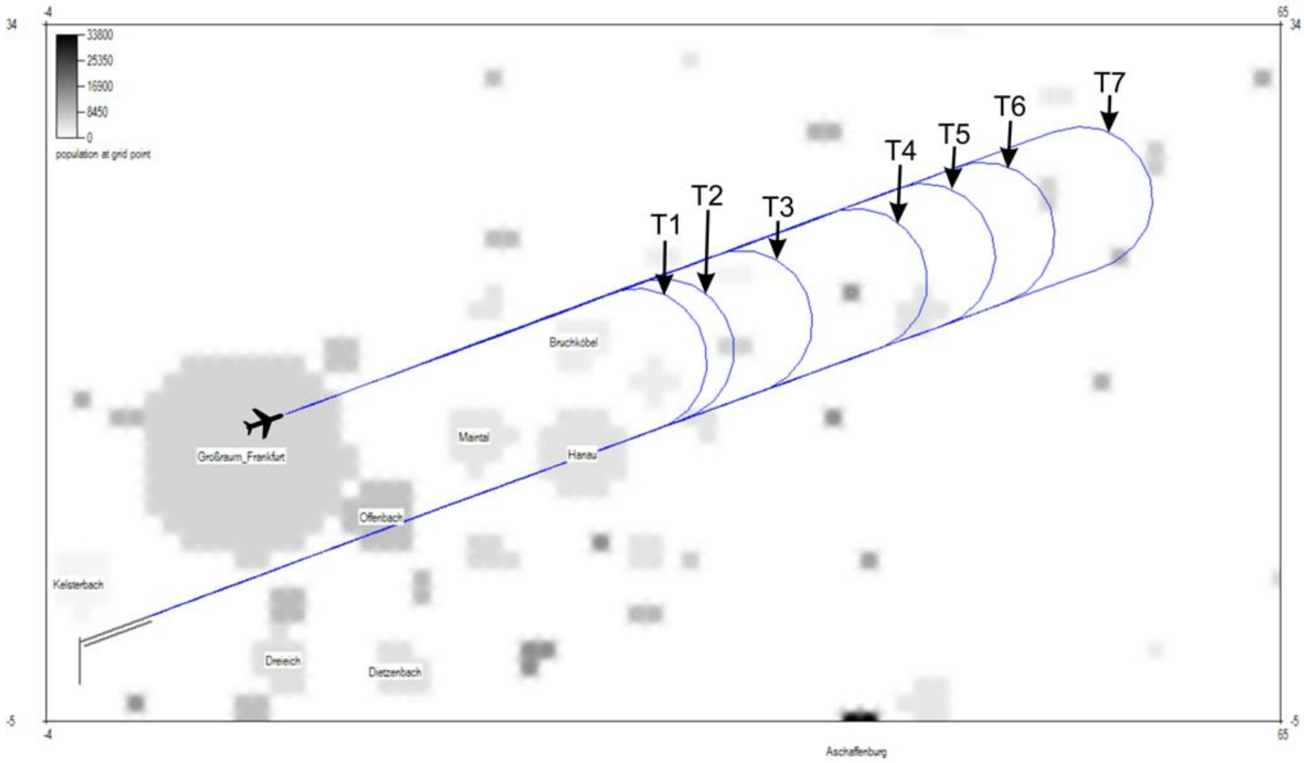

Fig. 2: Seven different arrival trajectories (T1-T7) planned for one aircarft landing on runway 25R at Frankfurt Airport

events of different sound levels [3]. They presented an equation to estimate the percentage of sleeping people who awake in average by the noise of one overflying aircraft. The correlation between *SEL*, residents per grid point and resulting *FRANBI* is displayed in Fig. 1.

For the earth surface we use a 3-dimensional grid with a lattice spacing of 1 km and an altitude accuracy of 1 m. Trials with different grid spacings have shown that 1 km is an acceptable compromise between estimation accuracy and calculation speed. Every grid point represents its surrounding area and the population living within: If a city with 10,000 residents is dispersed on a region represented by 20 grid points, each point represents an area with 500 people affected by the estimated *SEL*. In Fig. 2 seven different 3d-trajectories are shown for one approaching aircraft, at that time above the city of Frankfurt/Main.

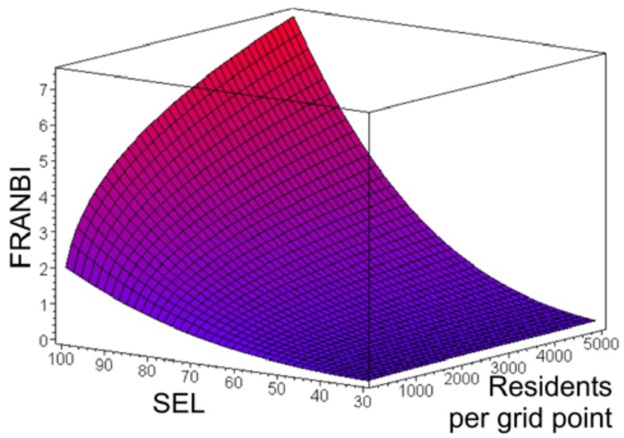

Fig. 1: Correlation between *SEL*, residents per grid point and resulting *FRANBI*. In difference to following diagrams and tables, here the loudest trajectories get the highest rating values.

Every route (T1-T7) represents another scheduled time of arrival (STA). In dependence on flight altitude, speed, distance to the populated areas, and weather conditions *FRANBIs* for the trajectories are calculated, normalized to one, and charted in Tab. 1.

For the noise estimation as part of the trajectory rating with an arrival manager, *FRANBI* is normalized – zero represents poor and one stands for best values (this normalization took more trajectories into account than displayed). The comparison between the described flight routes and the corresponding – population dependent – noise burden indices demonstrates noticeable differences: In this example the best-rated trajectory is No 3, because its route lies between all larger cities.

Tab. 1: The population dependent Flight-Route-Aircraft-Noise-Burden Index (FRANBI) for each arriving aircraft trajectories of Fig. 2

Trajectory No	*FRANBI* (Normalized to 1.0)
1	0.545
2	0.065
3	0.997
4	0.168
5	0.363
6	0.141
7	0.007

Trajectories 4 to 7 are directly above small towns with higher population so they are less suited for noise abatement guiding. The routes of trajectory 1 and 2 are nearly identical, but the rating is different: With Trajectory 2, two more cities are overflown than with route 1 leading to a reduced rating for alternative 2. For comparison: Estimating the noise exposure on the basis of the FICON study [3], an aircraft following the loudest flight paths causes about 15,000 awakenings in this area, whereas following the gentlest paths leads to 11,600 in average. Taking different aircraft types with individual noise characteristics into account, different arrival sequences produce adapted trajectories for each aircraft, whose medium noise exposure is below the standard medium arrival noise level.

6 Noise Rating Database for Trajectories

The database with aircraft noise trajectories is calculated off-line and afterwards connected to the arrival manager. The database contains several entry points, metering fixes and waypoints at the boundary and inside the TMA. For any of these significant points, a set of aircraft type dependent possible trajectories were calculated and rated regarding the noise criteria. Each

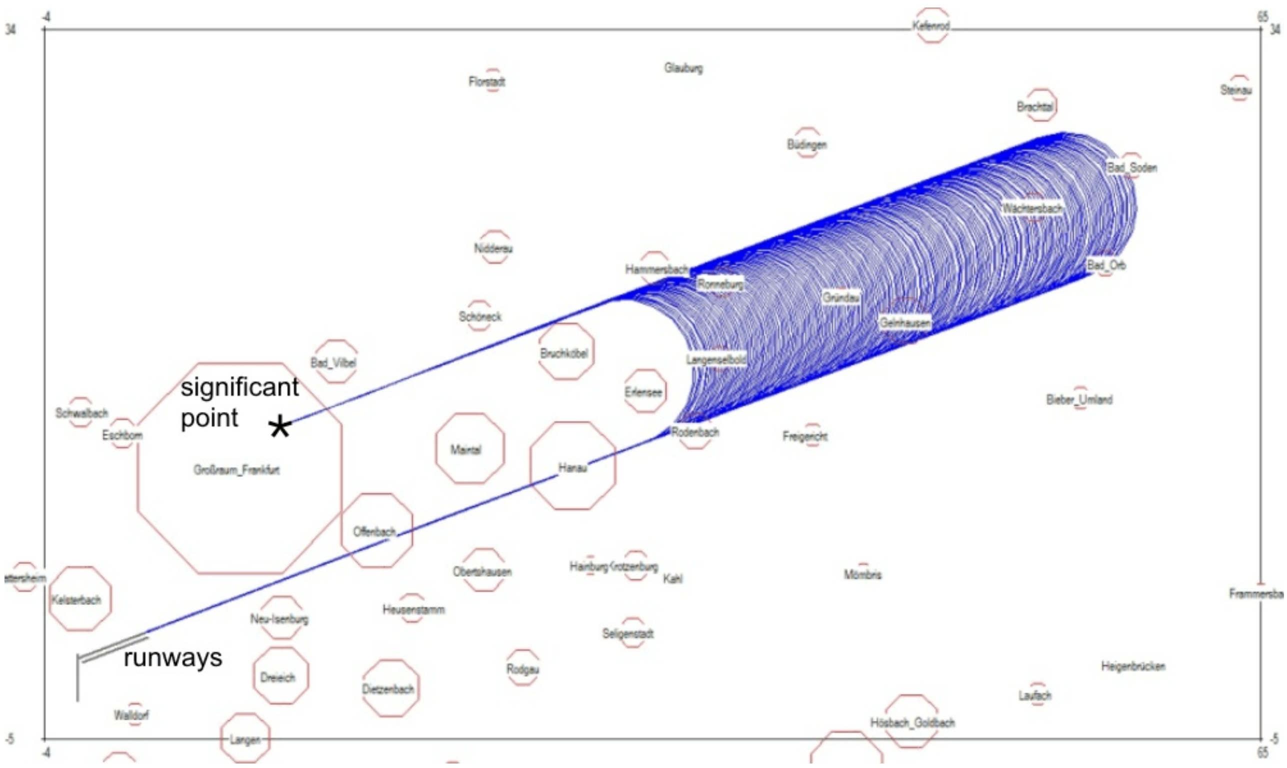

Fig. 3: Example of a set of 185 different trajectories for one kind of aircraft from one significant point inside to the TMA to the allocated runway. The temporally delay at the threshold between two trajectories is two seconds.

trajectory has a temporal delay at the threshold of two seconds in proportion to the other ones (Fig. 3).

The database contains the typical remaining flight times (as a result of the trajectories) for different kinds of aircraft (classified in aircraft noise categories) and from this flight times (respective routes) resulting *FRANBIs*. In Fig. 4 the normalized *FRANBIs* for the 185 trajectories of Fig. 3 are displayed in one diagram. The higher values represent trajectories with reduced aircraft noise exposure, the lower values on the other side indicate arrival flight paths leading directly over more populated areas.

The database access runs with the remaining flight time to the runway, which represents a typical approach trajectory and returns the corresponding *FRANBI* value.

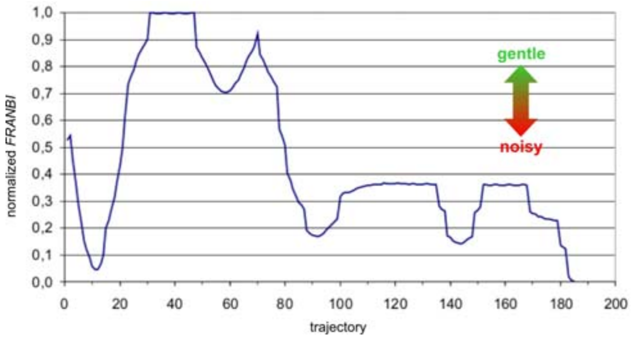

Fig. 4: Normalized *FRANBIs* for the 185 trajectories displayed in Fig. 3. Higher values represent trajectories with reduced aircraft noise exposure, the lower values indicate arrival flight paths guiding directly over more populated areas.

7 The Arrival Manager 4D-CARMA

During the last years the Institute of Flight Guidance at German Aerospace Center (DLR) developed the Arrival Manager (AMAN) named 4D-CARMA (4-dimensional Cooperative Arrival Manager) to assist controllers at civil airports in organizing the multitude of arrivals. 4D-CARMA is the latest development of DLR’s previous arrival managers COMPAS [9] and 4D-Planner [4], both research projects in cloth cooperation with DFS.

Taking various constraints into account, e.g. separation criteria, target times, and runway allocation, 4D-CARMA uses actual radar data and additional information of all arriving aircraft and calculates sequences with complete conflict free trajectories from the actual position to the runway threshold. Furthermore, this AMAN provides the opportunity to generate guiding commands for the controller to navigate the aircraft through the Terminal Maneuvering Area (TMA).

For controller assistance, 4D-CARMA calculates first the shortest and the longest possible flight route in the Terminal Maneuvering Area (TMA) from the actual aircraft position to the allocated runway. On the basis of these two legs the earliest and the latest arrival time (without holdings) are estimated and a sequence for all arriving aircraft is created. For this calculation, different kinds of dynamic constraints are incorporated into the sequence rating. Taking wake vortex safety distances into account, 4D-CARMA calculates the scheduled times of arrival (STA) and finally generates the trajectories. If there are conflicts between two or more trajectories, a trajectory equalize algorithm varies the calculated routes until all arriving aircraft hold the safety clearance to each other.

Sequencing, trajectory calculation and deconflicting of trajectories consume the most computation time for online controller support. Normally the aircraft trajectories are used for noise simulation, because they contain the relevant data set for sound propagation calculations. But the complete trajectory is not yet available at the end of the sequencing generation. To consider noise criteria in the optimization process, numerous repetitions of the complete sequencing and trajectory calculation algorithm would be necessary. Therefore today affordable computer power is not suited to optimize approach routes for online controller support.

With the aid of the trajectory-noise-database the expected noise propagation of an individual approach flight can already be estimated after STA calculation and so the expected noise exposure is available before the trajectory generation takes place. During the sequence generation we calculate different kinds of arrival sequences and rate these with a set of measures. One of these measures is the population dependent noise criterion *FRANBI*. With different

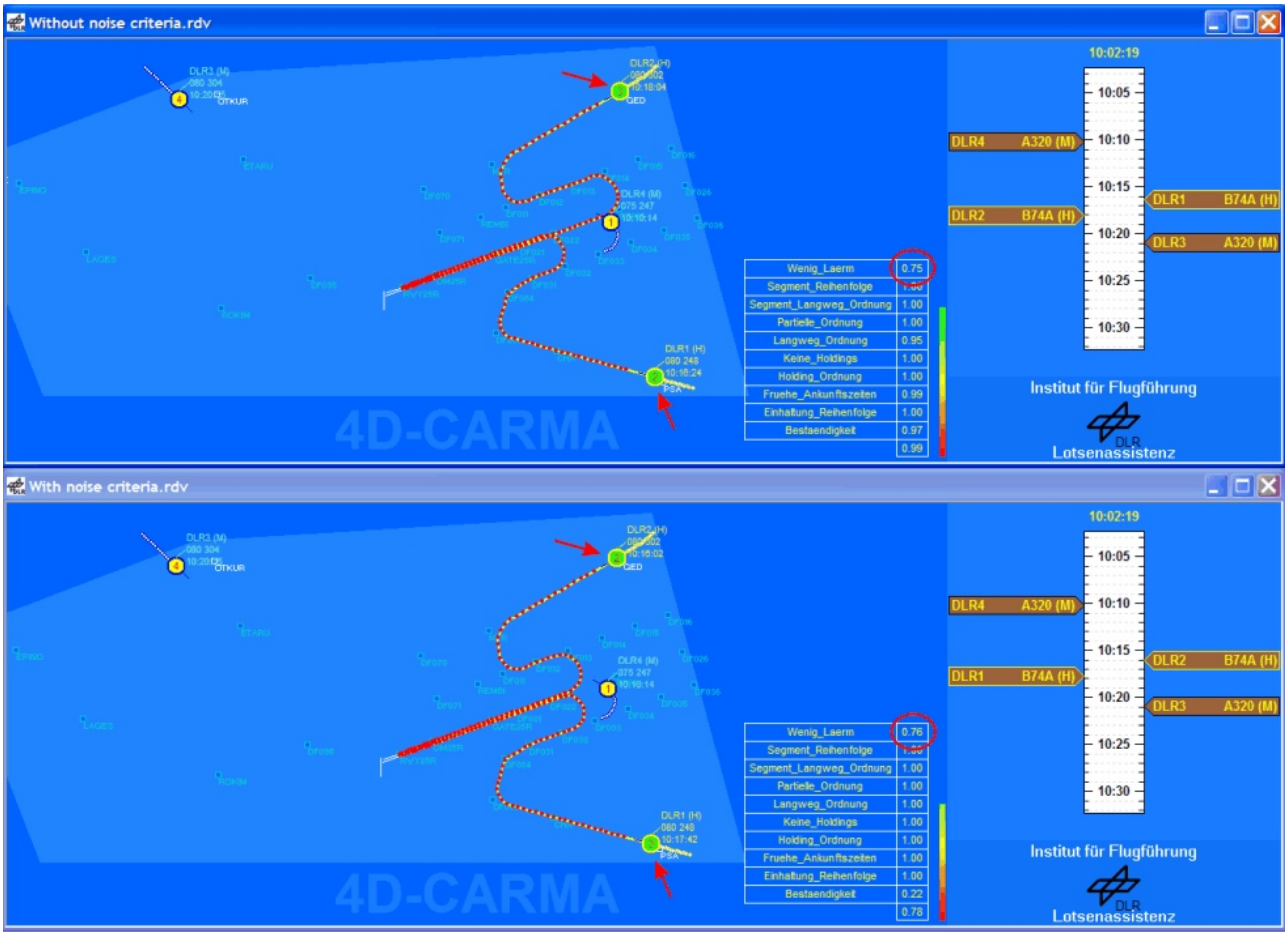

Fig. 5: Example for the influence of the population dependent noise criteria during arrival sequence planning.

weighting factors of the single measures, we can influence the importance of one or more constraints during sequence generation. This way, not the flight path of an individual aircraft is optimized, but the sequence of all actual arriving aircraft can be aligned with noise criteria. This procedure allows the reduction of the computation time significantly and at the same time delivers acceptable aircraft noise prediction values for a complete sequence.

8 Results

The influence of *FRANBI* on the recommended arrival sequence depends on the weight that is associated to noise criteria during the sequencing calculation. In Fig. 5 a radar display is shown with the positions of arriving aircraft (circles). The numbers in these circles represent the planned positions of the aircraft in the actual sequence. The red dotted lines show the planned trajectories of selected aircraft, the yellow dotted ones the positions of the last seconds. In this example, resulting sequences of arriving aircraft at the Frankfurt/Main airport are displayed. In both pictures the same situation at the same time is displayed, but on the upper illustration without and on the lower one with consideration of noise criteria (the noise criteria were calculated for both sequences, but the weighting factor for the upper picture was set to zero). The aircraft with the callsigns “DLR1” and “DLR2” changed their positions in the arriving sequence, because the aircraft noise criterion of the second sequence is with 0.76 better than the noise rating of the first sequence with 0.75 (red marked numbers in the table of Fig. 5). Depending on the individual position within the sequence, the STA differs for those two aircraft. As a result of the new landing times the generated trajectories changed, too.

In this example the price of considering noise criteria is the reduced constancy of arrival planning. In the upper sequence the appearance of “DLR2” has negligible influence on the existing sequence (criterion “Bestaendigkeit” with 0.97 means only little changes by integrating “DLR2” into the sequence). In the second displayed sequence the criterion “Bestaendigkeit” went down to 0.22, because the planning algorithm of 4D-CARMA found a quieter flight path for aircraft “DLR1” and shifted the STA of this aircraft accordingly to integrate “DLR2”. Other simulations show, that sometimes aircraft have to fly longer arrival routes inside the TMA to avoid the flyover of highly populated areas.

9 Summary

Regarding noise criteria, mathematical trajectory calculations of arrival and departure flight paths can be optimized. The use of optimization tools for real-time aircraft guiding leads to difficulties, because each trajectory optimization takes several minutes or hours computation time on a standard computer, so that it is not yet suited for online service. Unlike standard instrument departure routes (SID), which follow fixed flight paths, arriving aircraft are guided flexible by the aircraft controller with radar-vectoring. This procedure inhibits trajectory optimization with regard to noise criteria and the storage of results in a database for online service as controller assistance, because there are uncountable possibilities of aircraft type, route, speed, and altitude variations, which would have to be calculated and stored in a database. Reducing the amount of possible arrival trajectories by including the local airspace structure around the airport and taking the trajectory calculation rules of an arrival manager into account, it is possible to reduce the number of possible flight paths significantly and to archive them together with a noise value – depending on population values - in a database. This way, the arrival manger has the possibility to take aircraft noise besides security, punctuality, and capacity constraints during the arrival sequencing generation into account.

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