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Flight testing of noise abating required navigation performance procedures and steep approaches

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Abstract

To test different types of noise abatement approach procedures the Institute of Flight Guidance and the Institute of Aerodynamics and Flow Technology performed flight tests on 6 September 2010 with a Boeing 737-700. In total, 13 approaches to the research airport in Brunswick, Germany (EDVE) were flown while the approach area of the airport was equipped with six noise measurement microphones. Brunswick airport is equipped with an experimental ground based augmentation system which allows the implementation of 49 instrument landing system (ILS) look-alike precision approach procedures with different approach angles simultaneously.

Keywords

Steep approach, curved approach, noise abatement procedures

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Introduction

One of the major concerns regarding the expected growth in air traffic is the increase of air pollution and the related climate change as well as the increase of noise especially in the vicinity of airports.

Currently, there are two large research programs in Europe which address this development. On the one hand, it is the Joint Technology Initiative 'Clean Sky JTI'[1] which will develop breakthrough technologies related to the aircraft itself to reduce environmental impact. On the other hand, it is the Single European Sky ATM Research (SESAR)[2] program which is the technological and operational dimension of the Single European Sky (SES). SESAR is trying to make flying more environmental friendly from the air traffic management point of view. Both programs look for extensive changes in air transport not only with major improvements but also with a relatively large time horizon.

Small improvements can be achieved already today by implementing new approach procedures that can be flown by many of today's aircraft.

This article describes the design of new approach procedures for Frankfurt (EDDF) airport which were implemented at the research airport Brunswick and flight tested with a Boeing 737-700. The approach procedures consisted of steep approaches[3] with approach angles from 4.5° over 5°–5.5° as well as of marginal steeper approaches with 3.2° approach angle instead of the widely used 3.0°[4] as well as area navigation (RNAV) procedures and required navigation performance (RNP) procedures.[5]

In order to fly the different approach angles under precision approach conditions, the experimental ground based augmentation system (GBAS), which is in operation at the research airport Brunswick since 2009, delivered the necessary navigation performance.

To guarantee the highest precision, all the approaches were flown in 0.1 NM RNP mode.

Procedure design

The RNAV procedures that have been validated in the flight trials have originally been developed by the 'forum flughafen und region' in cooperation with the German air navigation service provider Deutsche Flugsicherung GmbH (DFS) for the use at Frankfurt airport.[5] The procedures can be seen in Figure 1 (green lines); they are designed to avoid the densely populated area of Offenbach, which lies under

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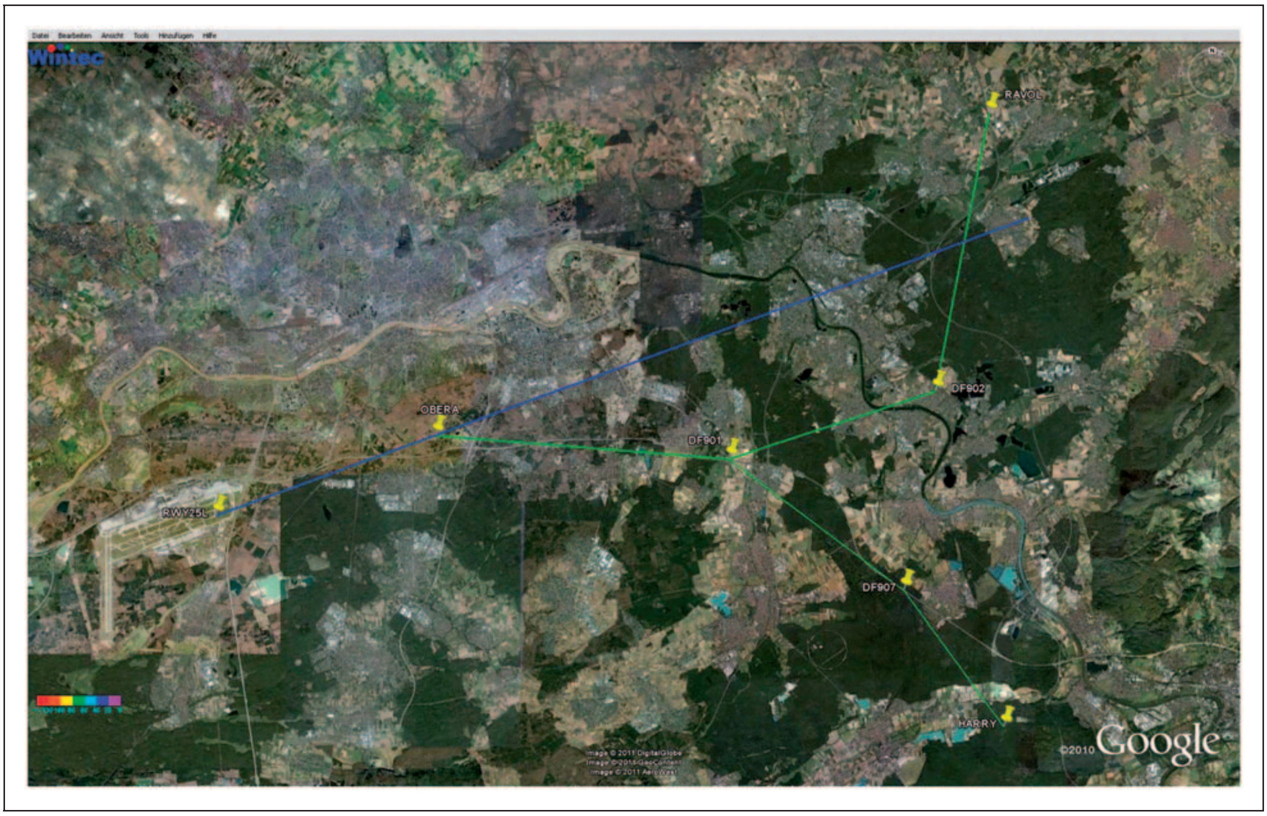

Figure 1. Straight in (blue line) and RNAV (green lines) procedure for runway 25 in Frankfurt (EDDF).

the extended centrelines (blue line) of the two main runways of Frankfurt (25L and 25R) at a distance of about 14 km or 8 NM from the threshold. The newly designed procedures will lead the aircraft around Offenbach in the south and onto the extended centreline at the waypoint OBERA. Here, the aircraft intercept the ILS approach at an altitude of 2000 ft, about 1650 ft above the thresholds. As these procedures should be evaluated at Brunswick airport, they were transferred to Brunswick as can be seen in Figure 2.[6–10] The distance and bearing from the threshold of Brunswick runway 26 to the different waypoints are exactly the same as to the waypoints from Frankfurt's runway 25 L. Hence the transferred procedure looks exactly the same as the original one and only rotated to fit the different runway orientation at Brunswick airport.

Figure 2 also shows a third procedure in the south leading from waypoint VE907 via VE906 and ENTSD to the runway. This procedure was added by DLR to investigate the feasibility of RNP approaches, where the aircraft is led onto the extended centreline in a fixed-radius turn. When an approaching aircraft intercepts the extended centreline, it has a height of just 1000 ft above the threshold, while already descending on a constant flight path angle of 3°.

The three procedures can also be seen in detail in Figures 3 and 4. The above-mentioned third procedure leads from VE906 to the waypoint ENTSD, which is the final approach fix (FAF), but does not lie on the extended centreline. At ENTSD the aircraft will intercept at an altitude of 2000 ft a glide slope of 3° leading constantly to the threshold of runway 26. Behind ENTSD, the aircraft – now in a constant descent of 3° – enters at VE905 a turn with a fixed radius of 2.0 NM which ends at VE904 exactly on the extended centreline. At VE904 the height above threshold on the 3° glide slope is precisely 1000 ft. From there, the aircraft continues on the centreline and on the constant glide path to the runway, as on any ordinary ILS approach.

The expected noise reduction through the avoidance of the densely populated areas of Offenbach can be seen in Figure 5.

Based on the Corine Land Cover (CLC) data[11] for the Frankfurt area, a simplified scenario has been designed, called Prankfurt. The land usage data allows a rough estimate of the population density similar to the Frankfurt area (Figure 5(a)). For this scenario, the aircraft noise-induced awakenings[12] have been evaluated with DLR's noise prediction tool PANAM.[13] The prediction results for the Prankfurt scenario confirm the expected noise dislocation effects. Figure 5(b) shows the prediction for the straight in three degree approach to runway 25 L. Compared to this approach, the RNAV procedure results in a 16% reduction in simulated awakenings for the Prankfurt scenario (Figure 5(c)). The RNP procedure will even decrease this number by 40%, as depicted in Figure 5(d).

As can be seen from Figure 5(b) and (c), comparing the awakening reactions between the

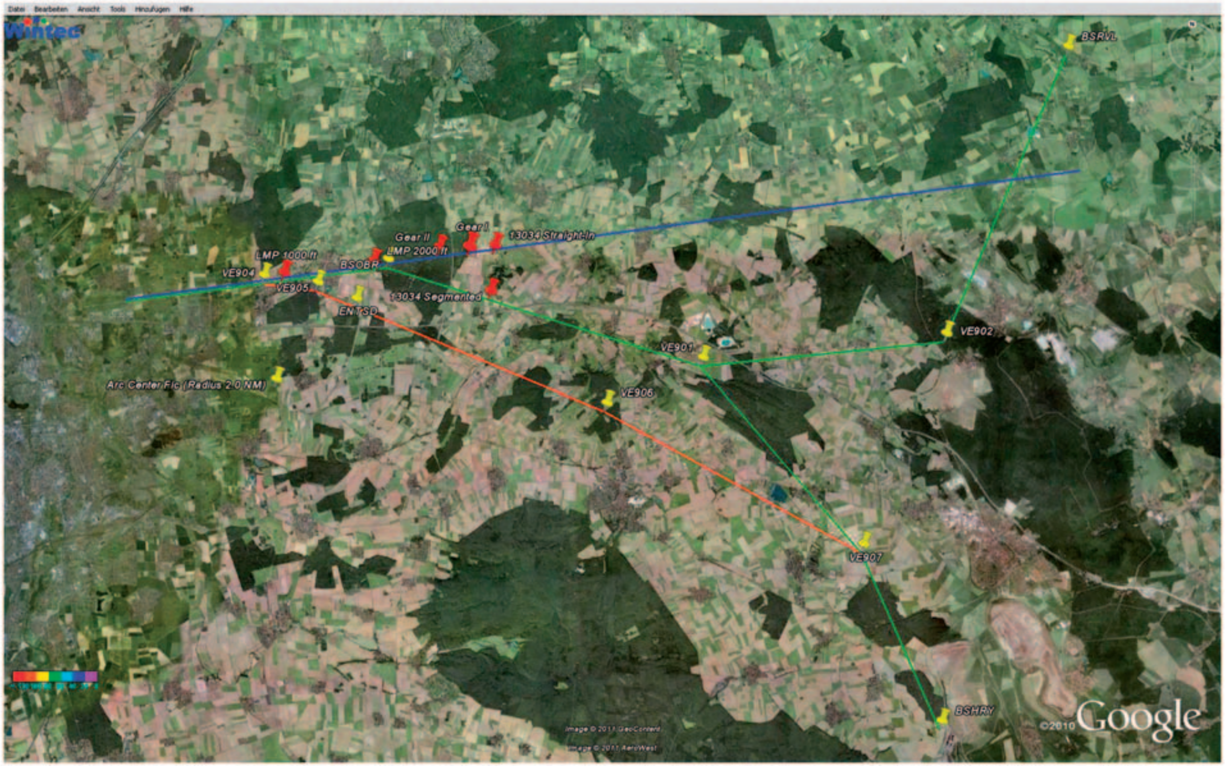

Figure 2. Straight in (blue line), RNAV (green lines) and RNP (red line) procedure for runway 26 in Brunswick (EDVE).

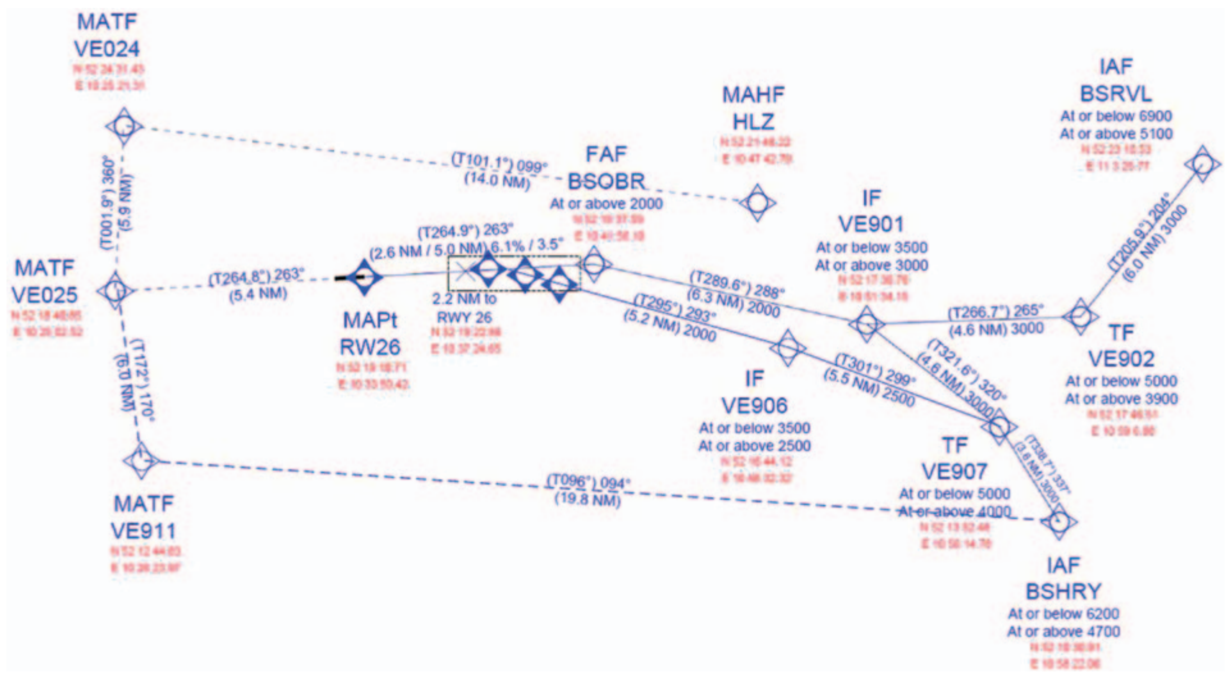

Figure 3. RNAV and RNP procedures for Brunswick (EDVE) in detail.

current straight-in approach and the procedure developed by DFS, the RNAV approach has been designed to avoid the densely populated area of Offenbach, thus reducing the total number of awakenings in the Frankfurt area. Still, this procedure was designed with two constraints also applied. One was to intercept the extended runway centreline at an altitude not below 2000 ft MSL. The second was to have an intercept

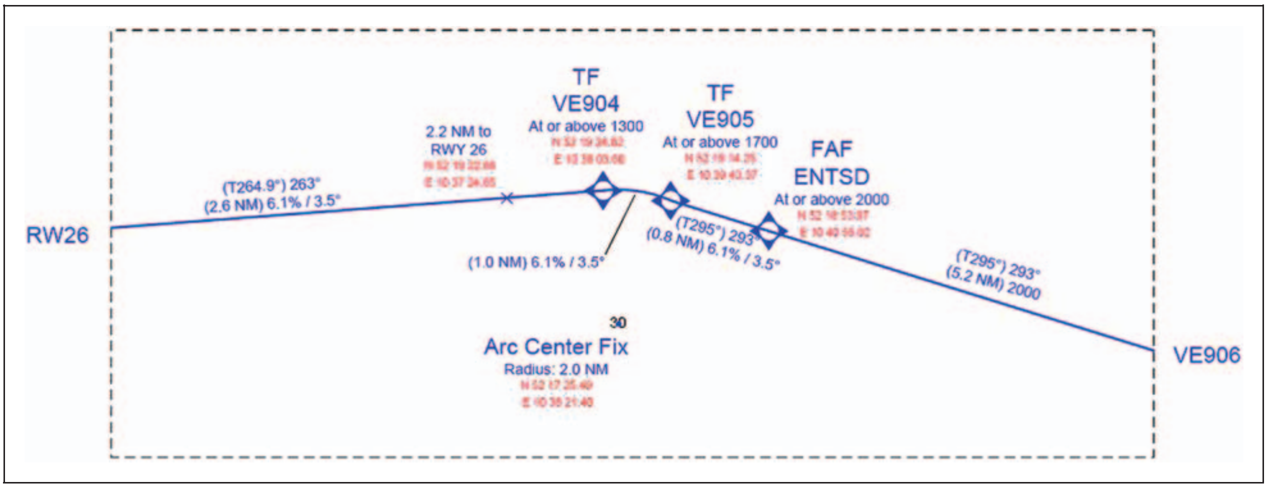

Figure 4. Fixed radius turn of RNP procedure for Brunswick (EDVE) in detail.

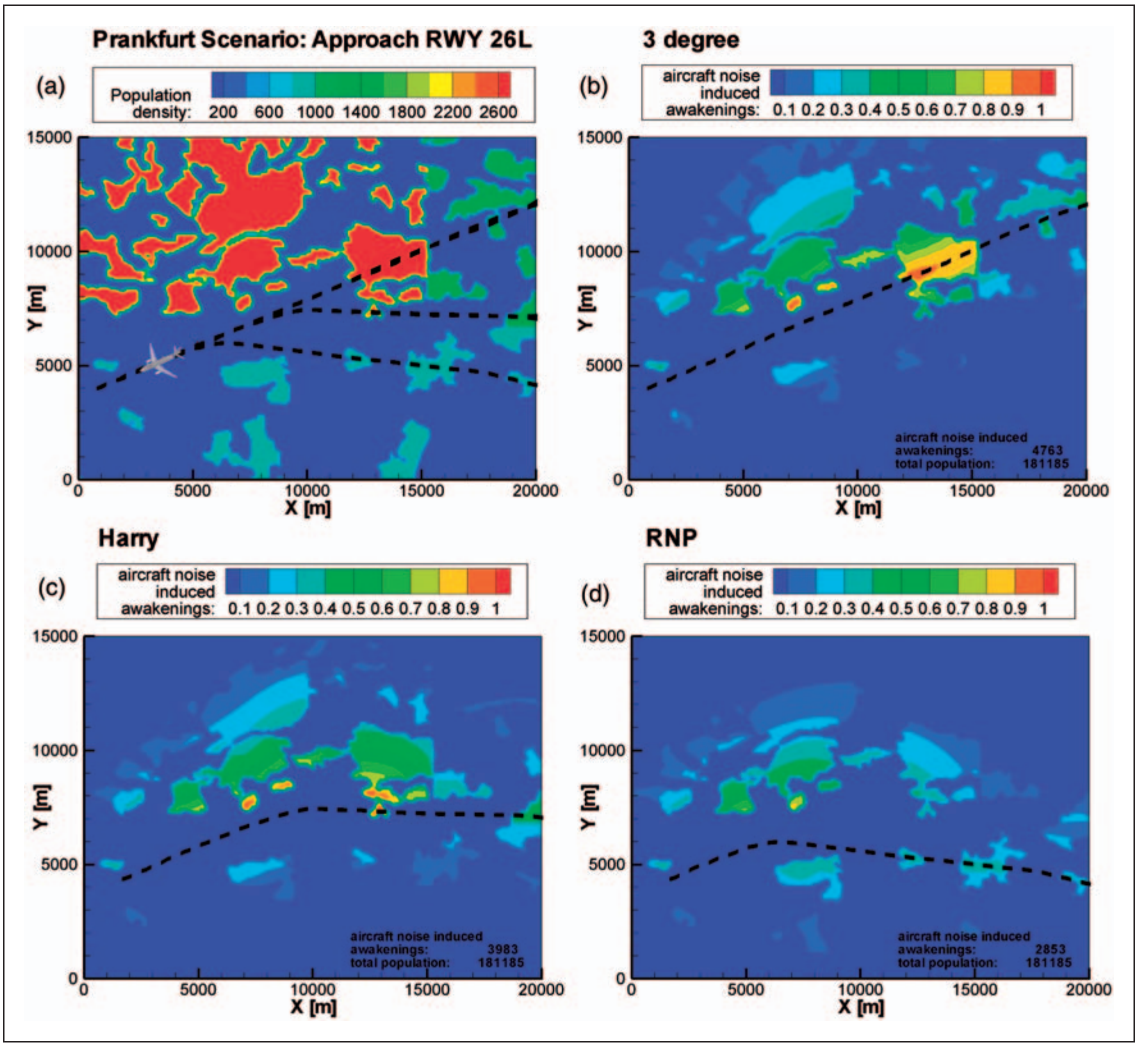

Figure 5. Comparison of awakenings per flight for the different scenarios based on a rough estimation of population density: (a) estimation of the population density, (b) affected people for a straight in, (c) affected people for RNAV and (d) affected people for RNP.

angle of not more than 30°. This way, the RNAV procedure does not overfly Offenbach, but is still quite near to that population area thus still causing several awakening reactions. The RNP procedure has been designed to further reduce the number of awakenings, as can be seen in Figure 5(d). The procedure was designed according to the guidelines of ICAO Doc 9905,[10] allowing to intercept the extended centreline at 1000 ft above threshold, while already in a 3° descent. This RNP procedure causes even less awakenings than the RNAV procedure. However, the workload on the operator to be allowed to fly an RNP is higher than for an RNAV. Hence, both procedures were investigated in this flight test.

Steeper approaches are a promising approach for reducing noise as well.[14] Therefore, also slightly steeper approaches with 3.2° glide slope on a 15 nm long straight final were tested that were also developed by the forum flughafen und region in cooperation with the German air navigation vice provider DFS for the use at Frankfurt airport.[4] In addition, DLR tested steep approaches with 4.5°, 5.0° and 5.5° glide slope on a straight 15 NM final. As there is an existing ILS installation at the airport Brunswick, these approaches were designed to be very similar to the existing ILS Procedure for an easy comparison between the ILS and the GLS approach. The airport has one concrete runway and an ILS installation for one runway end. The ILS installation has a 3.5° glide path angle for the runway 26. The localizer antennas are located at the opposite side of the runway. The procedure has its FAF 5.8 NM away from the threshold. It starts at 2500 ft above mean sea level (MSL). The glide path antenna mast is located approximately 310 m away (projected on the runway) from the runway threshold. With these values, the threshold crossing height (TCH) calculates to 62 ft. In contrast, on the official ILS approach chart, published with the AIP[16] Germany 0 a reference datum height (RDH) of 50 ft is given. With the descriptions given in Ref. 17 it was assumed that as a RDH of 50 ft is observed with the ILS installation it would be consequent that the TCH of the designed GBAS approach was also set to 50 ft instead of the calculated 62 ft. With this design the final approach point (FAP) for the GBAS approach was at the same coordinates and on the same altitude as the FAF for the standard ILS approach at the airport. For the transition from the initial approach to the final approach, the existing area navigation (RNAV) approach was adapted and a precision segment was integrated. The steep approaches have glide path angles of 4.5°, 5° and 5.5°. They have the same FAP according to the design described earlier but the decent starts at 3100, 3400 and 3700 ft MSL, respectively.

Testing

For the flight test and the noise measurements a Boeing 737-700 from airberlin was chartered, performing 13 different approaches to the research airport in Brunswick (Table 1 and Table 2). The aircraft was flown by Captain Marc Altenscheidt (chief pilot of the 737 fleet) and Captain Tim Techt (training captain of the 737 fleet). The flight trials were conducted in a series of two legs.

The approach area was equipped with a set of six noise measurement microphones. The position of the microphones can be seen in Figure 2. The two positions called '13034 straight in' and '13034 segmented' are located in a distance of 13,034 m to the runway threshold and correspond to a noise measurement point which also exists at Frankfurt airport and is located in the city center of Offenbach. The two points called 'Fahrwerk I' and 'Fahrwerk II' are located in an area where the gear should be down. The measurement point 'BSOBR' is located at a point where the flaps setting should be finalized. At the measurement point '1000 ft' the aircraft should be established on final approach especially after following the RNP route.

The test conditions were adverse for the required runway direction. The wind prevailed with easterly direction at an approximate speed of 2–5 m/s (METAR: 100°/7 kts 040V140 CAVOK). These wind conditions affected the approach speed and the power setting slightly. Regarding the precision on the flight path the effect was neglectable.

Results

Precision

The precision with which the aircraft follows the predefined flight track is a crucial item in the RNP concept. As the name implies, RNP requires the aircraft to show navigational performance, i.e. precision, within a certain value, e.g. 0.3 NM, which is then called RNP 0.3. Accordant to the RNP concept, an RNP of, for instance, 0.05 NM means it is assured the aircraft is within a radius of 0.05 NM around the indicated position 95% of flight time. The on-board navigation systems of the aircraft constantly monitor the Actual Navigation Performance (ANP). Whenever the ANP is above the RNP, in this example worse than 0.3 NM, the procedure for which the certain RNP is required has to be aborted. The ANP itself is continually calculated on-board by the navigational systems depending on data availability and general assumptions about drift rates as well as data integrity under different circumstances. The mentioned assumptions are based on experience obtained during the certification process of a certain system used for navigation in the aircraft or general rules and formulae outlined in the certification guidelines.

Figures 6 to 8 show the altitude and the ANP during the flight evaluations in Brunswick. Figure 6 shows ANP during the first leg, containing several approach procedures. Figure 7 shows the ANP during the second leg, also containing several approach procedures. The simple result derived from these figures is that the ANP always remained at the value of 0.02 NM. GPS and an Inertial Navigation System (INS) were used in combination to achieve

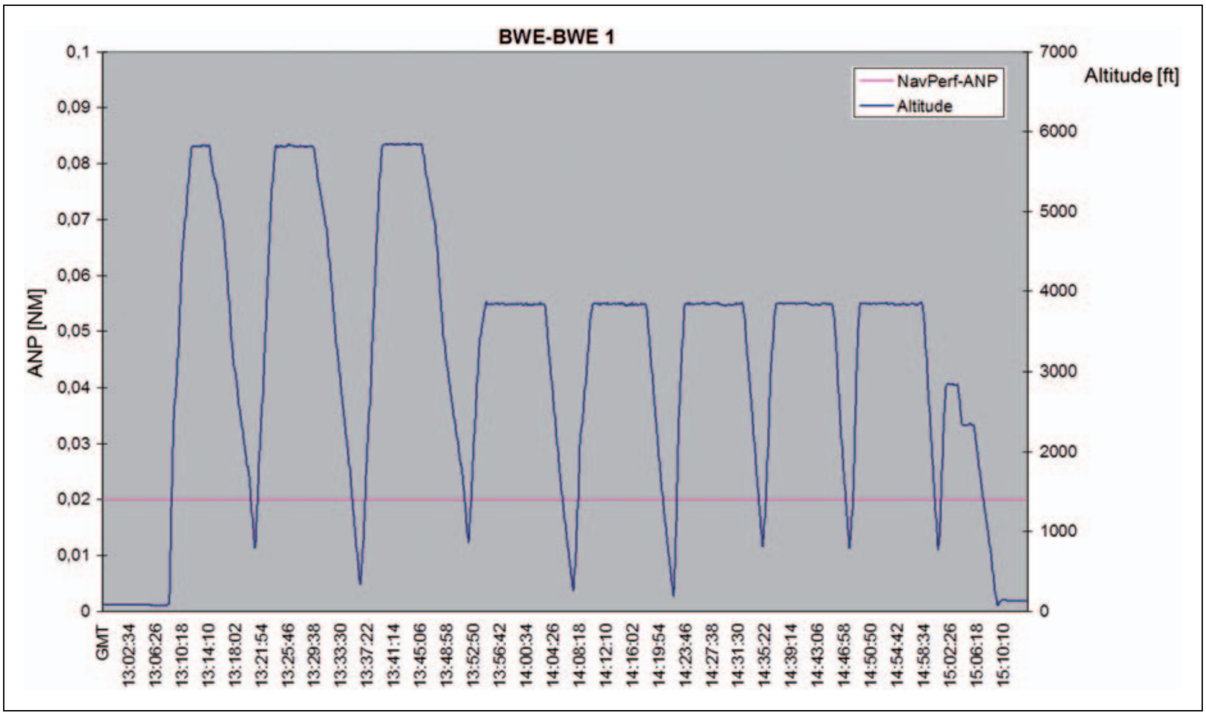

Figure 6. Actual Navigation Performance (ANP) and altitude during 1st leg.

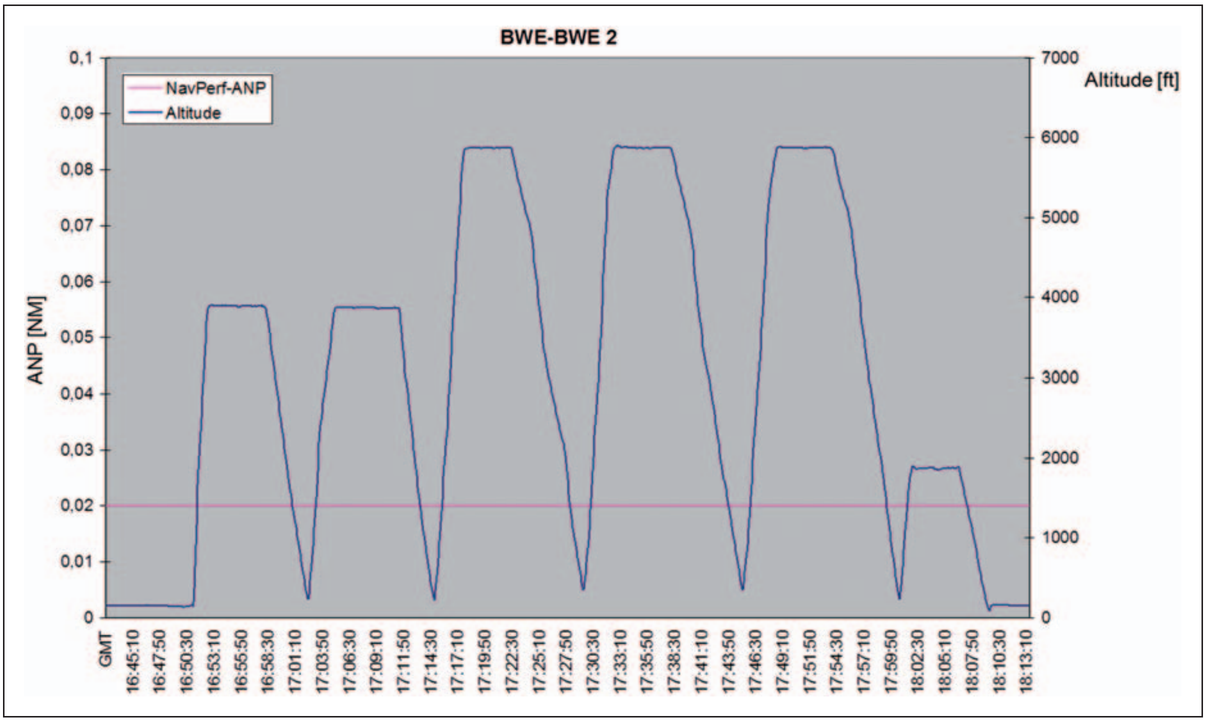

Figure 7. ANP and altitude during 2nd leg.

this value. It has been stated by the flight crew involved in the flight evaluations that from their experience, the ANP is almost always 0.02 NM near the ground and increases only during cruise flight at higher altitudes. As evidence for this, Figure 8 shows altitude and ANP during a flight that first contained several short approaches, i.e. stayed near the ground, thereafter one cruise flight at a typical cruise altitude of 27,000 ft. When the aircraft is above 10,000 ft and during taxiing after completion of the flight, the ANP is higher than 0.02 NM. Nevertheless, ANP never exceeded 0.031 NM during this flight campaign and thus always remained below the RNP of 0.1 NM required for approaches by a fair margin.

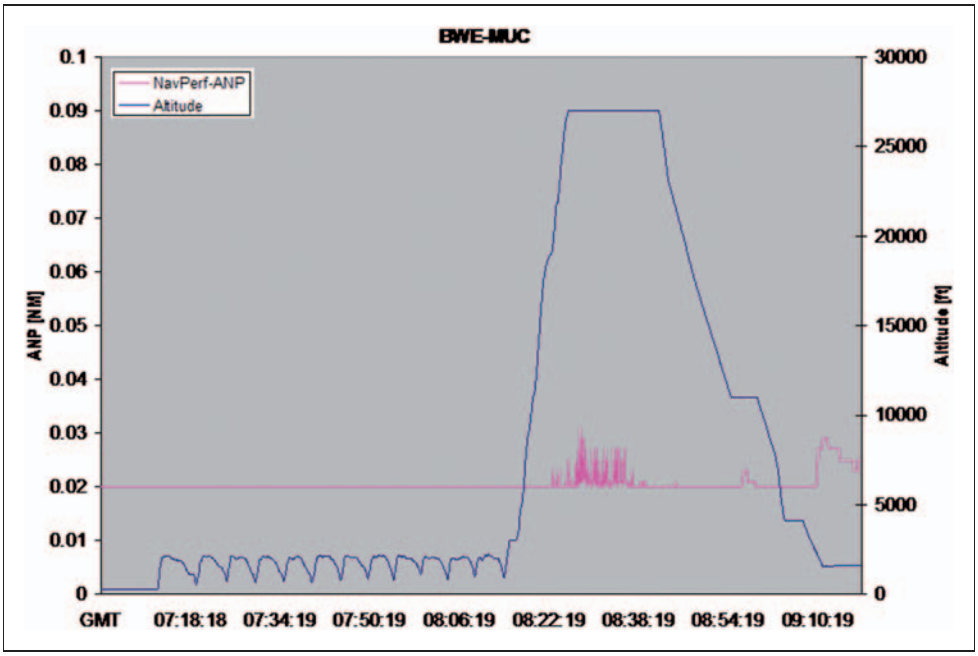

Figure 8. ANP and altitude during approach phase and cruise flight.

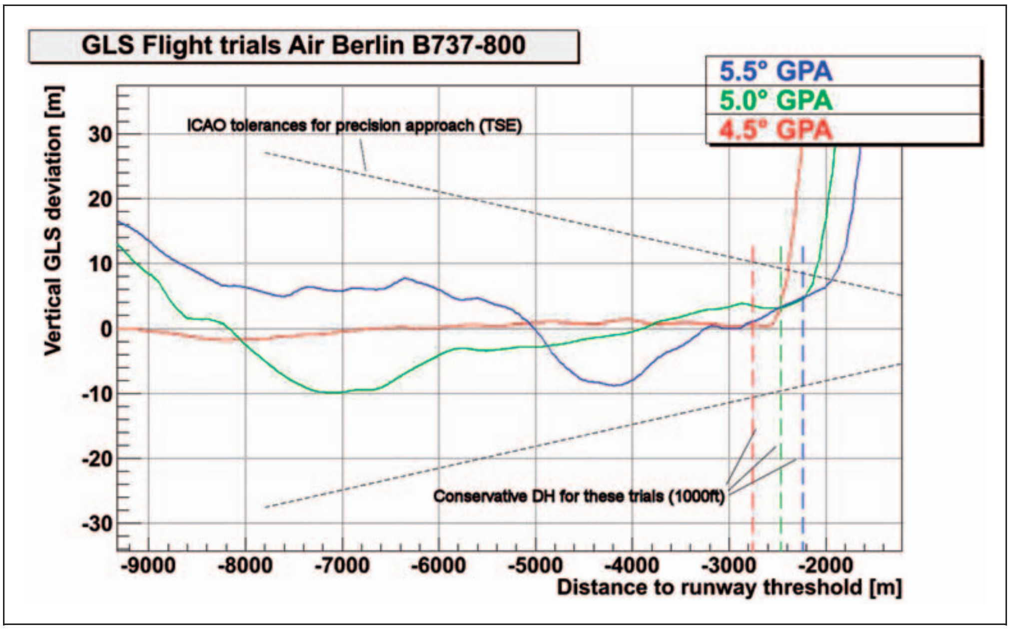

Figure 9. Vertical GLS deviations during steep approaches.

The observed vertical flight test error of the steep approaches is shown in Figure 9. As the vertical error is the critical case for approach procedures, only this axis is shown here. Laterally the results were comparable with standard precision approaches. It can be seen in Figure 9 that the error for the shown approaches is smaller than the allowed ICAO tolerances for precision approaches. Therefore, it can be stated that the procedures are flyable and safe. The pilots stated that the subjective workload increases with greater glide path angles. In their opinion the vertical velocity was getting challenging during steeper approaches and the geometry of the outside view was unfamiliar. There was a training effect noticeable, however (see also Refs. 17, 18).

Noise

Figure 10 shows the position of the microphones and the flight track. The outcome of the noise measurements has to be viewed with respect to the fact that the measurements were single events. As the

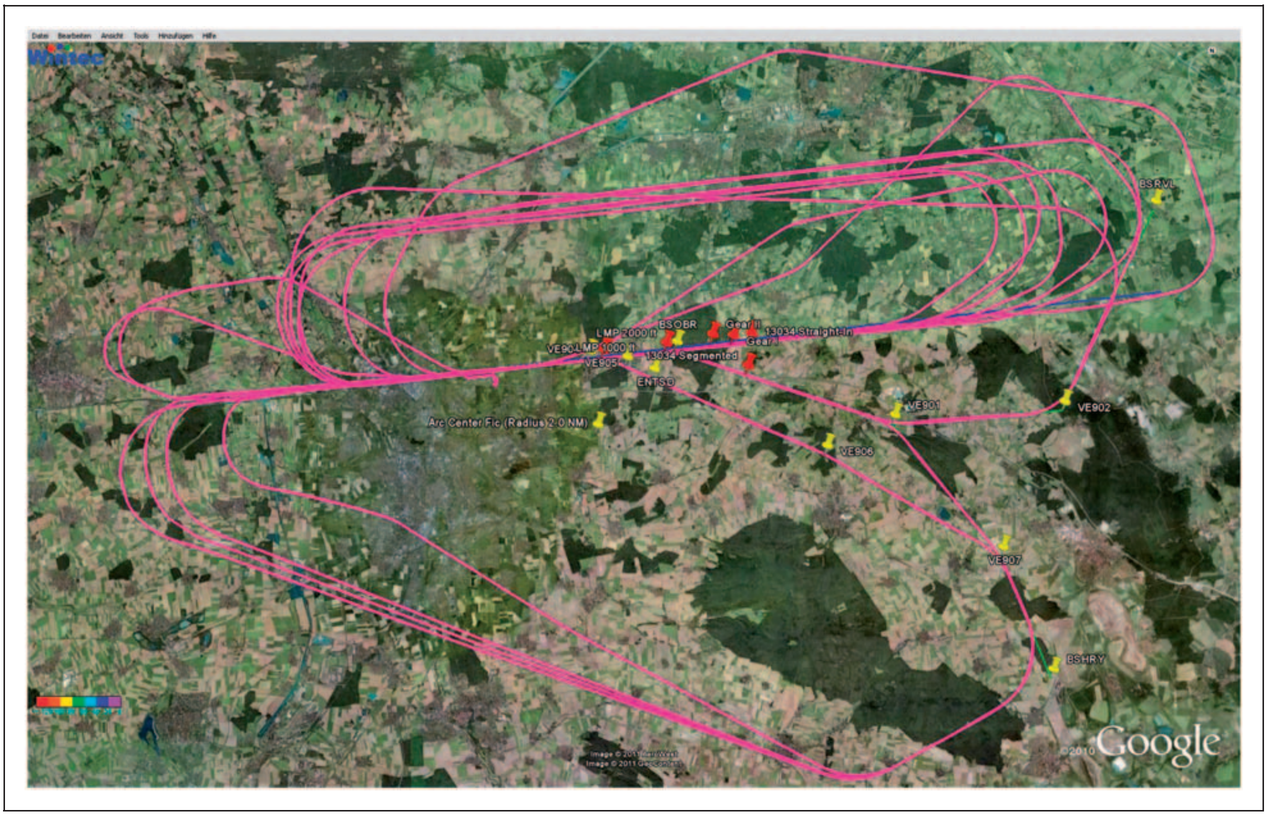

Figure 10. Position of the microphones (red pinboard needles) and GPS Track of the test flights.

Table 1. Test matrix 1st leg.

	Approach transition	Final approach	Remarks
BWE – BWE	RNAV Approach BSRVL	GLS 4.0° GPA	Low approach
BWE – BWE	RNP Approach BSHRY	ILS 3.5° GPA	Low approach
BWE – BWE	RNAV Approach BSHRY	GLS 4.0° GPA	Low approach
BWE – BWE	Traffic Pattern 26, 15NM Final	GLS 3.0° GPA	Low approach
BWE – BWE	Traffic Pattern 26, 15NM Final	GLS 3.2° GPA	Low approach
BWE – BWE	Traffic Pattern 26, 15NM Final	GLS 4.5° GPA	Low approach
BWE – BWE	Traffic Pattern 26, 15NM Final	GLS 5.0° GPA	Low approach
BWE – BWE	Traffic Pattern 26, 15NM Final	GLS 5.5° GPA	Low approach

Table 2. Test matrix 2nd leg.

	Approach transition	Final approach	Remarks
BWE – BWE	Traffic Pattern 26, 15NM Final	GLS 3.0° GPA	Low approach
BWE – BWE	Traffic Pattern 26, 15NM Final	GLS 3.2° GPA	Low approach
BWE – BWE	RNAV Approach BSRVL	GLS 3.0° GPA	Low approach
BWE – BWE	RNAV Approach BSHRY	GLS 3.0° GPA	Low approach
BWE – BWE	RNP Approach BSHRY	ILS 3.5° GPA	Low approach

conditions always vary slightly during such trials (especially the wind) one would need a much greater number of flights, a greater number of microphones and a correlation with recorded weather data to get statistically sound data. Nevertheless, based on these actual measurements earlier simulation results and expected noise dislocation effects might be confirmed. Tables 3 and 4 provide selected results of the

Table 3. Noise measurements 1st leg.

	LASmax (dB(A))	Altitude (m) SL	Speed (km/h)	Flaps (°)	Gear
RNAV RVL GBAS 4°					
13034 "segmented"	65.8	798	333	5	Up
Fahrwerk I	No data				
Fahrwerk II	59.1	733	327	5	Up
BSOBR	71.4	637	310	15	Down
1000 ft	71.3	479	269	15	Down
RNP HRY ILS 3.5°					
BSOBR	58.8	632	302	15	Down
1000 ft	72.5	443	279	15	Down
RNAV HRY GBAS 4°					
13034 "segmented"	67.1	805	317	10	Up
Fahrwerk I	57	783	315	10	Up
Fahrwerk II	63.3	741	312	10	Up
BSOBR	69.8	678	299	15	Down
1000 ft	73.7	482	253	15	Down
3.0° Fraport					
13034 "straight in"	63	789	327	5	Up
LMP Fahrwerk I	65.4	744	330	5	Up
LMP Fahrwerk II	68.1	689	326	15	Down
BSOBR	72.1	583	307	15	Down
1000 ft	73.3	387	260	15	Down
3.2° Fraport					
13034 "straight in"	62.5	846	331	5	Up
Fahrwerk I	64.1	794	334	5	Up
Fahrwerk II	68	733	337	5	Up
BSOBR	71.6	626	312	15	Down
1000 ft	73.8	417	266	15	Down
GBAS 4.5°					
13034 "straight in"	64.8	1124	264	40	Down
Fahrwerk I	65.4	1049	263	40	Down
Fahrwerk II	64.8	972	260	40	Down
BSOBR	65.5	839	259	40	Down
1000 ft	70.7	536	250	40	Down
GBAS 5.0°					
13034 "straight in"	63.1	1225	276	30	Down
Fahrwerk I	62.2	1194	268	40	Down
Fahrwerk II	65.3	1118	264	40	Down
BSOBR	65.1	923	273	40	Down
1000 ft	68.3	580	261	40	Down
GBAS 5.5°					
13034 "straight in"	62.3	1234	283	30	Down
Fahrwerk I	62	1232	268	40	Down
Fahrwerk II	63.4	1180	259	40	Down
BSOBR	64	1012	254	40	Down
1000 ft	67.4	638	267	40	Down

measurements. The maximum levels of the a-weighted sound pressure level SPL(A) are provided. Measurements indicate that RNAV and RNP procedures reduce noise levels in the sensitive area of Offenbach by 6 to 8 dB (A) compared to a straight-in approach, i.e. a clearly noticeable change in apparent loudness. The turn on final approach at the end of the RNAV and RNP procedure did not show any

Table 4. Noise measurements 2nd leg.

	LASmax (dB(A))	Altitude (m) SL	Speed (km/h)	Flaps (°)	Gear
3.0° Fraport					
13034 "straight in"	62.5	805	336	5	Up
Fahrwerk I	64.5	758	338	5	Up
Fahrwerk II	68.9	670	332	15	Down
BSOBR	70.9	599	314	15	Down
1000 ft	74.2	400	276	15	Down
3.2° Fraport					
13034 "straight in"	66.9	852	388	5	Up
Fahrwerk I	68.3	804	388	5	Up
Fahrwerk II	69.6	736	389	5	Up
BSOBR	73.8	633	369	15	Down
1000 ft	75.2	420	316	15	Down
RNAV RVL GBAS **3**°					
13034 "segmented"	67.1	791	326	5	Up
Fahrwerk I	57.6	767	324	5	Up
Fahrwerk II	61.2	729	315	5	Up
BSOBR	70.3	660	292	15	Down
1000 ft	74.1	385	286	15	Down
RNAV HRY GBAS 3°					
13034 "segmented"	69.4	747	336	15	Down
Fahrwerk I	58.3	715	326	15	Down
Fahrwerk II	60.7	648	318	15	Down
BSOBR	70.1	565	302	30	Down
1000 ft	73.6	391	277	30	Down
RNP HRY ILS 3.5°					
BSOBR	57.6	638	327	30	Down
1000 ft	72.2	432	294	30	Down

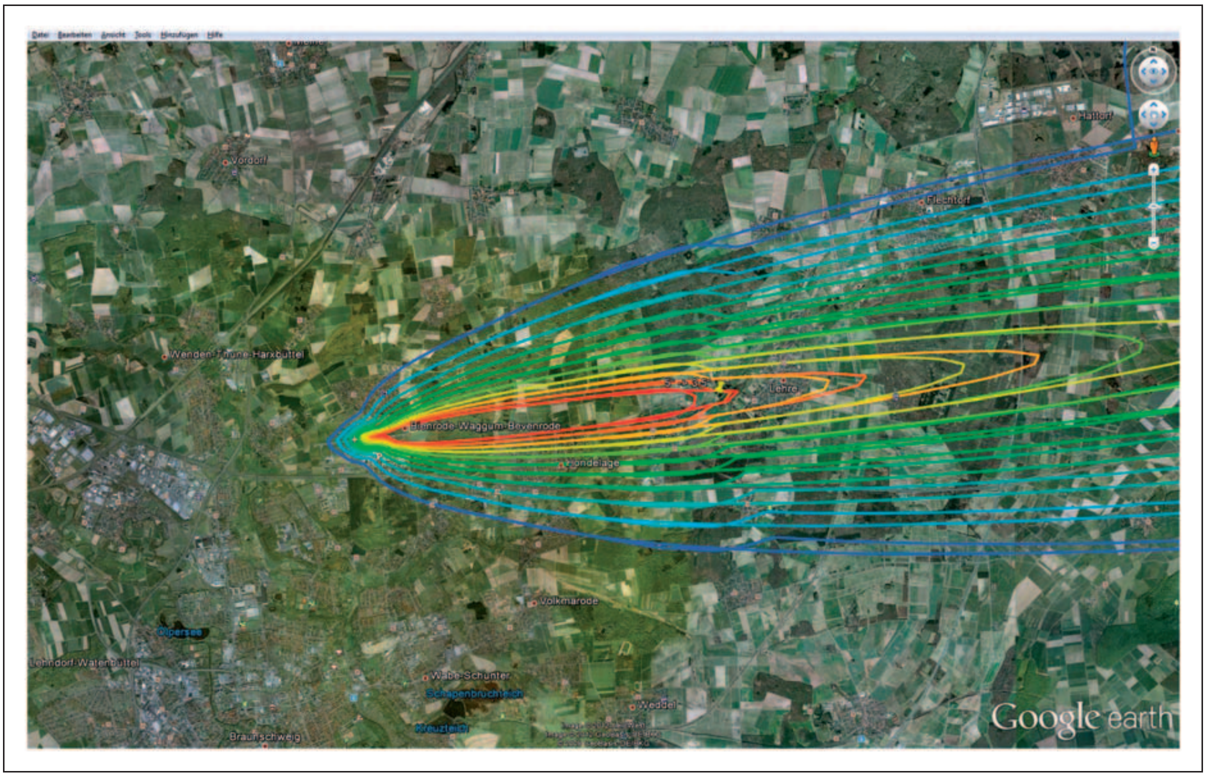

Figure 11. Comparison of two noise contours. The outer noise contour shows lines of equal noise for a 3° approach. The inner noise contour with the constriction shows lines of equal noise for a 5°, at the position of the pin needle changing to 3°.

noise level increase compared to a straight-in approach. There are minor variations between the different approaches due to different approach speeds.

The slightly steeper approaches at an angle of 3.2° are a little bit less noisy than the 3.0° approaches. A reduction of 0.4 dB (A) was measured during the first leg. During the second leg, an increase by 4.4 dB (A) was measured on the 3.2° approach. This increase can be traced back to a higher approach speed (52 km/h) due to a slightly stronger tail wind.

Much larger reductions of the noise level were achieved with the steeper approaches at angles of 4.5°, 5.0° and 5.5°. At an angle of 4.5° a reduction of 2.1 dB (A) was measured compared to a 3.0° approach. At an angle of 5.0° the reduction was 3.6 dB (A). Along the 5.5° approach it was as high as 4.6 dB (A), which is a clearly noticeable reduction of perceived ground noise levels.

These steep approach angles can be flown down to landing only by a very low number of aircraft. The vertical segmentation of steep approaches might be a compromise between noise reduction and flyability. This means the approach will start at steep approach angles (i.e. 5.0°) and during the approach the approach angle will be reduced to 3.0°. This would reduce the noise level at least in the region with the steep approach angle. Figure 11 shows a comparison of two noise contours calculated with the DLR noise prediction tool PANAM[14] for two different approach profiles. The outer noise contour shows lines of equal noise for a 3° approach. The inner noise contour with the constriction shows lines of equal noise for an approach starting at an approach angle of 5° and then (at the position of the pin needle) changing to 3°. The noise reduction in the area with steeper approach angle clearly can be seen, but there might be a very small increase around the area where the approach angle is changed.

Conclusion

The noise measurement results for the segmented RNAV and RNP approaches showed a high reduction of the noise level for the areas in the east of Frankfurt airport like Offenbach as overflys are avoided based on the segmented approach. Therefore, these routes are in operation by Frankfurt airport since 10 February 2011 in the time between 11.00 p.m. and 5.00 a.m.

At approach angles of 3.2° the tail wind might become a problem sometimes. To reduce the speed the aircraft has to put the flaps earlier which might lead to a higher noise level than sticking to the 3.0°approach.

Steeper approaches show a higher reduction in noise level direct under the flightpath but actually can be flown down to landing only by a small number of aircraft, primarily turboprops.

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Conflict of interest

None declared.

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Appendix

Acronyms and Abbreviations

ANP	Actual Navigation Performance
DLR	German Aerospace Center
FAP	Final Approach Point
GBAS	Ground Based Augmentation System
GLS	Global Positioning Landing System
GPS	Global Positioning System
ILS	Instrument Landing System
INS	Inertial Navigation System
MSL	Mean Sea Level
RDH	Reference Datum Height
RNAV	Area Navigation
RNP	Required Navigation Performance
TCH	Threshold Crossing Height
TMS	Terminal Manoeuvring Area